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BOWHEAD WHALE FEEDING IN THE EASTERN ALASKAN BEAUFORT SEA: UPDATE OF SCIENTIFIC AND TRADITIONAL INFORMATION

by

LGL LIMITED
environmental research associates

for

MMS U.S. Department of the Interior
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Edited by

W. John Richardson and Denis H. Thomson

LGL Limited, environmental research associates
22 Fisher Street, POB 280, King City, Ont. L7B 1A6, Canada

and

LGL Ecological Research Associates Inc.
1410 Cavitt St. Bryan TX 77801

for

Department of the Interior
Minerals Management Service
Alaska OCS Region, 949 East 36th Ave., Anchorage, AK 99508-4302
Procurement Operations Branch, 381 Elden Street, Herndon, VA 20170-4817

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ACRONYMS AND ABBREVIATIONS

~	Approximately
a.d.	Angular deviation
ADF&G	Alaska Department of Fish and Game
AEWC	Alaska Eskimo Whaling Commission
AIC	Akaike's Information Criterion (chapters 11, 15)
ANWR	Arctic National Wildlife Refuge
ASA	American Standards Organization (as related to film speed — see ISO)
a.s.l.	Above sea level
ASW	Arctic Surface Water
AVHRR	Advanced very high-resolution radiometer (an instrument on a satellite)
BAR-1	Komakuk Distant Early Warning (DEW) station
BCB	Bering–Chukchi–Beaufort (stock of bowhead whales)
Bf	Beaufort state—a measure of wave height (*cf.* SS)
BIA	Bureau of Indian Affairs (chapter 2)
BLM	Bureau of Land Management
BMR	Basal Metabolic Rate (chapter 22)
BOS	Behavioral observation session
B.P.	Before Present (chapter 2)
BWASP	Bowhead Whale Aerial Survey Project (MMS)
CART	Classification and Regression Tree Analysis (chapter 19)
CI	Confidence interval
CTD	Conductivity (salinity), temperature and depth.
dB	Decibels, intensity relative to the minimum target strength
DEW	Distant Early Warning
DWM	Department of Wildlife Management (NSB)
EIS	Environmental Impact Statement
$f(0)$	Correction factor for declining detectability of animals with increasing distance from the survey track line
FLIR	Forward Looking Infrared
$g_a(0)$	Correction factor to account for the probability of detecting diving animals during aerial censuses (availability bias)
$g_d(0)$	Correction factor to account for animals at the surface along the track line but not recorded (detectability or perception bias)
GC	Gas chromatograph (chapter 19)
GPS	Global Positioning System
IHLC	[Commission on] Inupiat History Language and Culture (chapter 2)
ISO	International Standards Organization (as related to film speed — see ASA)
IWC	International Whaling Commission
KWCA	Kaktovik Whaling Captains' Association

LTK	Local and Traditional Knowledge (chapter 2)
LTS	Least Trimmed Squares — a robust regression method (chapter 4)
MMPA	Marine Mammal Protection Act
MMS	Minerals Management Service
MT	Metric Tonne; equals 1000 kg or 2203 pounds
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOSC	Naval Ocean Systems Center
NSB	North Slope Borough
OPR	Office of Protected Resources (NMFS)
PDB	Pee Dee Belemnite, a standard for stable isotope work (chapter 20)
ppt	Parts per thousand; same as ‰
psu	Practical salinity unit, approximately = parts per thousand
QFASA	Quantitative Fatty Acid Signature Analysis (chapter 19)
r, R	Simple (r) and multiple (R) Correlation coefficient
r^2, R^2	Percent of variance explained
SAC	Science Advisory Committee (NSB)
s.d.	Standard deviation
s.e.	Standard error
SODA	Stop Over Duration Analysis (chapter 11)
SRB	Scientific Review Board
SRD	Surfacing, respiration and dive (chapters 13, 14)
SS	Sea State—a measure of wave height, differing slightly from the Bf scale
Sv (dB)	Volume back scattering strength of a target as recorded by an echosounder (chapter 3)
SWEPI	Shell Western Exploration and Production, Inc.
TEK	Traditional Ecological Knowledge (chapter 2, etc.)
USGS	U.S. Geological Survey
UAF	University of Alaska Fairbanks
UHF	Ultra High Frequency
VHF	Very High Frequency
VLF	Very Low Frequency (a type of navigation system formerly used)
$\delta^{13}C$	A measure of carbon isotope ratio
$\delta^{18}O$	A measure of oxygen isotope ratio
‰	Parts per thousand (ppt)

EXECUTIVE SUMMARY

Introduction and Approach

The purpose of the project, as defined by the Minerals Management Service, was to compile and integrate existing traditional and scientific knowledge about the importance of the eastern Alaskan Beaufort Sea for feeding by bowhead whales; to build consensus on the need for and approach to fieldwork to augment this knowledge; to conduct the field studies and to analyze the results; to integrate them with existing traditional and scientific knowledge; and to report on and publish the results.

The activities of bowhead whales throughout the year need to be considered when assessing the importance of feeding in the eastern Alaskan Beaufort Sea during late summer and autumn. Bowhead whales are known to feed in the Canadian Beaufort Sea in summer/early fall, and during westward migration across the Alaskan Beaufort Sea during late summer and fall (Fig. S.1). At least some of the bowheads also feed in the southwest Chukchi Sea in mid- to late fall. Bowhead activities in the Bering Sea during winter have not been studied. There is some feeding, probably quite limited, during spring migration around western Alaska. Although behavioral observations and stomach contents provide some data on feeding intensity during spring, summer, and fall, such data are lacking for late fall in the Chukchi Sea, and from winter. It is unclear, from the available data of those types, what fraction of the annual feeding occurs in any one part of the annual range.

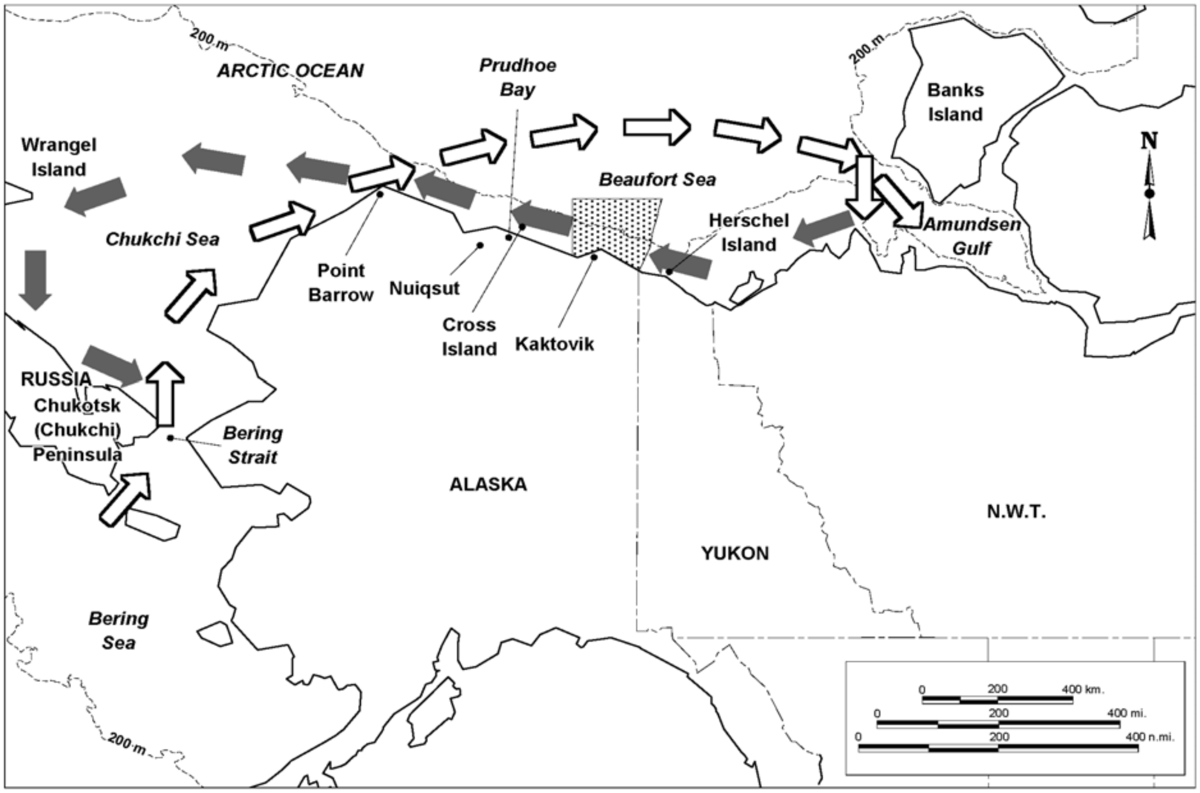

FIGURE S.1. Schematic depiction of the seasonal migration of the Bering–Chukchi–Beaufort stock of bowhead whales, and locations mentioned in text. The “eastern Alaskan Beaufort Sea” is shaded.

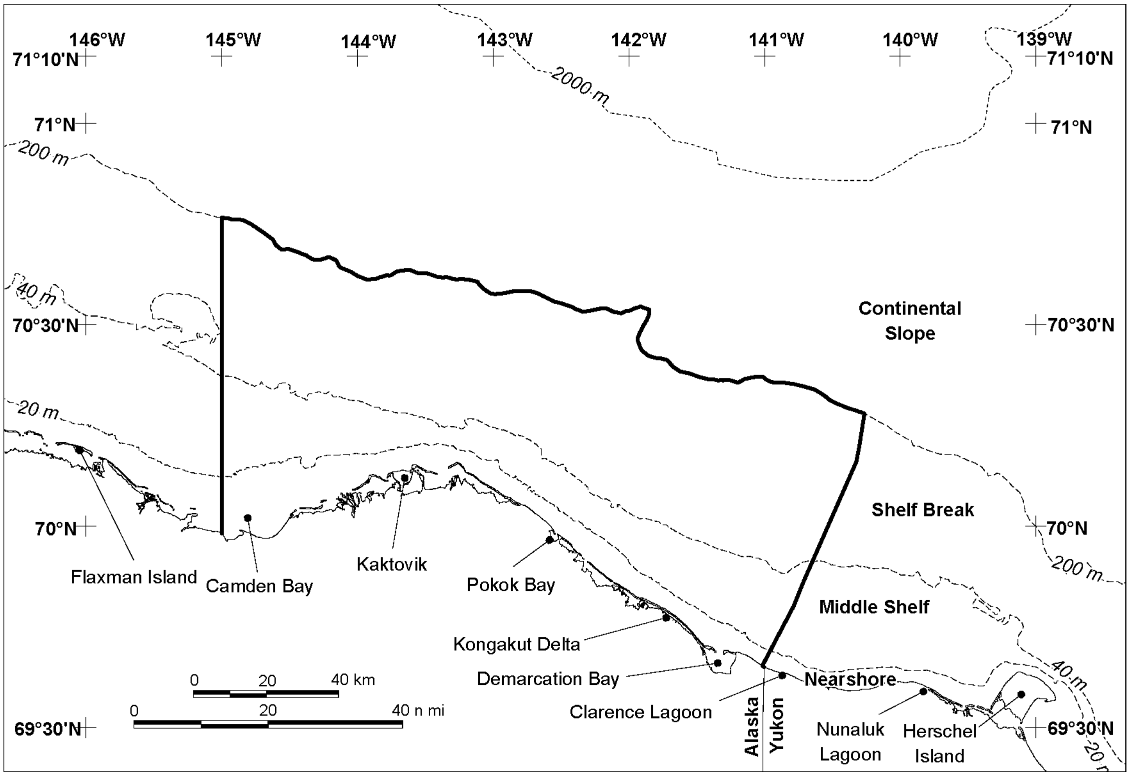

FIGURE S.2. Map of the primary study area in the eastern Alaskan Beaufort Sea. Some data collection efforts and analyses extended farther to the west, north, and east.

The specific area of concern in this project is the eastern part of the Alaskan Beaufort Sea (Fig. S.2). The community of Kaktovik is located along the coast within that area. Subsistence whaling for bowhead whales is of high importance to the people of Kaktovik. Bowhead whales occur in the Kaktovik area in late summer and autumn. Bowheads are hunted as they feed in and travel through the Kaktovik area at that time of year.

This report is an integrated account of traditional knowledge, previous scientific knowledge, and results from recent scientific studies concerning the use of the study area for feeding by bowhead whales. The new data collected during this study, mainly during September of 1998, 1999 and 2000, have been supplemented with data collected earlier in and adjacent to the study area. In particular, this project is an extension of a bowhead feeding study conducted in the same area during 1985 and 1986. The present study is intended to provide additional data from more years, and to do so in collaboration with subsistence hunters and other local stakeholders. Where appropriate and possible, methods applied during the new three-year study were consistent with methods used during the 1985–86 study. Thus, there are now consistent data from five years, supplemented by additional data (e.g., aerial surveys) from other years, with which to address the main objectives and hypotheses. Although the main fieldwork during the feeding studies in 1985–86 and 1998–2000 was during September, the project also incorporated aerial survey results and local knowledge concerning bowhead use of the study area earlier and later in summer and autumn.

Objectives of the Study.—The objectives of this study, as defined by MMS and revised based on the advice of the project's Scientific Review Board (SRB), are as follows. References to "Year 1" refer to mid-1997 through mid-1998. Years 2, 3 and 4 included the September 1998, 1999 and 2000 field seasons, respectively:

1. *Use existing data (traditional and scientific) to assess when and how feeding bowheads can be recognized and distinguished from those engaged in social/milling and other behaviors (Year 1), and distinguish those activities whenever possible during field studies (Years 2–4).*
2. *Mutually develop hypotheses that scientists and subsistence whale hunters concur can be successfully tested to determine and quantify the relative importance of the eastern Alaskan Beaufort Sea as a feeding area for bowhead whales (Year 1).*
3. *Design (Year 1) and conduct (Years 2–4) research appropriate for testing the above hypotheses and for quantifying potential feeding by bowhead whales in the same area.*
4. *Analyze previous and updated scientific information, summarize pertinent knowledge of area subsistence whale hunters, and, where possible, test the above hypotheses and quantify bowhead area feeding for previous years (Years 1 and 2–4).*
5. *Use historical satellite and aerial survey data to search for links between spatial or temporal patterns in bowhead feeding vs. ambient oceanographic conditions (Year 1). If links are evident, use all available data to characterize those links (Year 4).*
6. *Summarize (Year 1) and update (Year 4) available information, including traditional knowledge, on the effects of acoustic and visual disturbance to bowhead whales (or other planktivorous whales) engaged in apparent feeding behavior. This is considered to be a secondary objective.*
7. *Use the above information to determine and quantify the relative importance of the eastern Alaskan Beaufort Sea as a seasonal feeding habitat for bowhead whales (Year 4).*

Questions to be Answered.—Questions were developed to address the study objectives and the study design was based on these questions. These questions were worded as "hypotheses" at some stages in the project. However, a consensus developed late in the project that they should be considered to be research questions that were addressed by the project rather than formal hypotheses to be tested:

> *Question (1). In an average year, how important is the eastern Alaskan Beaufort Sea for bowhead whales; what percentage of the population's annual energetic requirements is derived from the area?*

Question (1) was the key question for the project. It was addressed by considering many different types of data acquired or assembled during the project, integrated by means of an energetic model (Chapter 22 and below).

> *Question (2). How much of its annual food requirements does the Bering–Chukchi–Beaufort (BCB) population of bowhead whales derive in the eastern and central Beaufort Sea? At least 10 percent?*

Question (2) concerns the eastern and central Beaufort Sea as a whole, not just the eastern Alaskan Beaufort Sea. This question was addressed by examining the isotopic composition of bowhead tissue in spring and fall, and of prey tissue through the range of the bowhead whale.

> *Question (3a). Of the bowheads that travel through the eastern Alaskan Beaufort Sea, how long does an <u>average</u> whale spend there? At least 7 days?*

> *Question (3b). Of the* <u>*individual*</u> *bowheads that travel through the eastern Alaskan Beaufort Sea, how long do some individuals spend there? At least 7 days?*

These two related questions were addressed through analysis of aerial photogrammetric data documenting the residence times of individually-recognizable bowhead whales. The question has been split into two because there are questions about the importance of the study area both to individual whales that linger in the area and to the population as a whole.

> *Question (4). What percentage of the bowheads that pass through the eastern Alaskan Beaufort Sea feed there? At least 10 percent?*
>
> *Question (5). What percentage of the geographic area within the study area is suitable as feeding habitat in different years? Is at least 1 % of the study area suitable in some years?*
>
> *Question (6). During migration through the eastern Alaskan Beaufort Sea, how often are bowheads observed to feed while they are traveling? Is feeding while traveling evident more than 10 % of the time while traveling?*

Question (4) was answered using stomach content data from the Kaktovik harvest, supplemented with behavioral observations of whales. Question (5) was answered using boat-based observations of the quantities and types of zooplankton at locations where bowheads feed, and the spatial extent of plankton concentrations. Question (6) was answered using aerial observations of the behavior of the whales.

The answers to these questions, as derived by the project, are summarized in the last section of this Executive Summary (below).

Approach.—In general, the project plan called for us to determine if the study area is important to feeding bowhead whales in the following way:

- determine if numbers of animals remain in the study area for an extended period of time,
- determine what proportion of these animals are feeding,
- describe the zooplankton and hydrography near feeding whales,
- attempt to locate and characterize whale feeding habitat,
- determine what the whales are eating through examination of stomach contents and fatty acid analysis, and compare stomach fullness and contents between Kaktovik and Barrow,
- determine how much feeding occurs in the eastern and central Beaufort Sea through isotopic studies, and
- estimate the annual energetic requirement of the population (based on an updated energetics model), and estimate what proportion of this is acquired in the study area.

These tasks have all been done, with the exception that the fatty acid study was limited to a pilot project. The results of the stable isotope study remain difficult to reconcile with those of other study components. However, one feeding scenario that could be consistent with all the data has been identified. This scenario is summarized in the last section of this Executive Summary.

Local Coordination.—Local cooperation and participation was considered critical to the success of the study. Including the July 1998 Scientific Review Board (SRB) meeting, we met with representatives of the Kaktovik Whaling Captains Association (KWCA), Alaska Eskimo Whaling Commission (AEWC), and North Slope Borough (NSB) on six occasions during Year 1. The purposes were to seek traditional knowledge and advice on project design, and to coordinate fieldwork with the bowhead hunt. We again met with the KWCA, AEWC and NSB during the June 1999 SRB meeting. One or more project participants also met with some of the whaling captains and other Kaktovik residents in Kaktovik during

June and early September 1999, and August 2000, to further coordinate our planned fieldwork with whaling activities during those years. One key objective of all these meetings was to develop and refine a field plan that whalers would accept as non-interfering and likely to be effective in assessing the importance of the area to feeding by individual bowheads and the population.

Key items discussed at the meetings and incorporated into the Project Plan were as follows: ***(1)*** Kaktovik residents were to be directly involved with the project through participation in the boat-based field sampling in September of 1998–2000, conduct of boat-based reconnaissance surveys during August 1998–2000, and participation on the Scientific Review Board. ***(2)*** Aircraft-based field work was permitted east of Kaktovik during the whaling season, provided that the aircraft did not fly over whaling operations and that a radio communications protocol was established for coordination. ***(3)*** Boat-based work would not be conducted east of or near Kaktovik until after whalers landed their second whale. In 2000, because whalers landed their third whale early in the season (8 Sept.), boat-based work was not conducted until after the third whale was landed. ***(4)*** An LGL representative would attend the pre-whaling-season meeting of the Kaktovik Whaling Captains' Association during each year of fieldwork (see preceding paragraph). ***(5)*** LGL's aerial survey crew would be based in Kaktovik during the 1998–2000 field seasons, facilitating local coordination. ***(6)*** Subcontractor ADF&G would station a biologist in Kaktovik during the 1998–2000 whaling seasons (as they had done in 1997) to collect stomach content and bowhead tissue samples from bowheads landed at Kaktovik.

After the draft final report on this project was completed, AEWC, KWCA and NSB representatives participated in a final Scientific Review Board meeting (January 2002) where the results were discussed. Immediately thereafter, a one-day workshop was held in Kaktovik to present the results to Kaktovik residents and to seek input on the interpretation. Discussion at the January 2002 SRB meeting and Kaktovik workshop has been taken into account in the final report. The SRB comments on the draft report are included in Annex A of the report, along with responses by the project team. The report has been considerably revised since January 2002 to allow for the comments and to make other improvements.

Kaktovikmiut Whaling: Harvest Data and Local Knowledge

The desire to characterize the degree to which the eastern part of the Alaskan Beaufort Sea is used by bowhead whales for feeding arises from a number of concerns. The importance of subsistence whaling for the Kaktovikmiut ("people of Kaktovik") ranks high among these. Chapter 2 by M.S. Galginaitis and W.R. Koski, summarized here, provides a brief description of the community of Kaktovik and Kaktovikmiut subsistence whaling, summarizes the Kaktovikmiut whale harvest, describes local coordination efforts undertaken as part of this project, and summarizes Local and Traditional Knowledge (LTK) pertinent to whale feeding behavior.

Kaktovik is a small community located on Barter Island in the extreme northeast of Alaska (Fig. S.1, S.2), within the boundaries of the Arctic National Wildlife Refuge (ANWR). The 2000 U.S. Census enumerated 293 people, most of whom (247, or 84 percent) are Native. Household economies rely upon both wage labor and subsistence activities as vital components of an integrated system. The major employers are the North Slope Borough, the City of Kaktovik, and the village Native (ANCSA) corporation. There are also a few private sector jobs and businesses separate from the Native corporations, but most employment is related to government or Native Corporations. Subsistence activities, and especially activities surrounding the bowhead whale hunt, are central to the structural organization and cultural identity of Kaktovik residents.

Definitive information on the antiquity of whaling on the North Slope east of Barrow does not really exist, but available information is consistent with whaling activity at least in the late Thule period (beginning about 900 years ago). Informants maintain that whaling took place at Barter Island in aboriginal times. It is also not altogether clear when subsistence whaling ceased at Barter Island (prior to 1964), or why whaling was suspended in the mid-Beaufort area in general. Whaling at Kaktovik resumed in 1964 and has taken place during most subsequent late summer/autumn seasons, with a high degree of success, especially since 1989. After the formation of the Alaska Eskimo Whaling Commission (AEWC) in 1977, Kaktovik received a formal quota. One to three bowheads were landed during most years in the 1980s, and two to four bowheads during most years in the 1990s and beyond.

The bowhead hunt normally begins the day after Labor Day and 83% of harvested whales have been taken in September. In recent years, whales have been taken earlier in the season than in earlier years. The core whaling area extends from the Hulahula River in the west to Tapkaurak Point in the east and offshore as far as 32 km (20 mi). Most whales have been taken within 30 km of the village and the mean distance of harvest locations from Kaktovik has not changed from the 1970s to present. Whaling captains select small whales over large whales and there has been a significant decrease in the average size of whales harvested from the 1970s to the present. The size of whales harvested does not increase with date although other data show that smaller whales become less common in the area as the season progresses. This confirms that whalers are selective in their harvest. Male and female bowheads are harvested in very similar numbers, but females make up a significantly higher proportion of whales harvested early in the season and males make up a significantly higher proportion of whales harvested late in the season.

Bowhead whales are of great cultural importance to the Inupiat and are a major source of food, and Inupiat know a great deal about whales. However, one elder noted that it is difficult to transmit local knowledge and understanding verbally if others lack the personal experience that underlies it. This study required much cooperation and direct participation from local residents in the study design and field work. All concerned wanted to ensure that Inupiat knowledge of bowhead whales would be integrated into the planning of the project and the interpretation of its findings. Local participation also insured that the study did not interfere with the hunt for bowhead whales. Assembly of LTK of bowheads, and coordination of project and local activities, were two closely intertwined tasks.

Numerous local coordination efforts were built into the project in order to encourage local participation, to respond to local desires for project modification, and to incorporate local knowledge into research design and interpretation of results. These efforts included meetings and interviews in Kaktovik in 1997–98 before the first major field season, and additional meetings in Kaktovik before subsequent field seasons. A final workshop in Kaktovik was conducted on 31 January 2002 to discuss the project findings and to provide input for use in the final report. In addition, there was local Kaktovik representation (as well as AEWC and NSB representation) on a Scientific Review Board that provided technical advice on project plans and results. As a result of recommendations by Kaktovik residents, a local boat and crew, in conjunction with the LTK researcher, searched for bowheads present in late August and early September, earlier than the main field season. While in Kaktovik for that effort, the LTK researcher served many project liaison functions. No specific LTK research was conducted during the part of September when Kaktovik residents were actively whaling. However, a local resident was employed to work as a member of the boat-based zooplankton sampling crew during the September 1998–2000 field seasons. Also, another project biologist worked closely with the whalers during September 1997–2000, obtaining measurements and samples of stomach contents and whale tissue from the harvested whales. Furthermore, the project's survey aircraft was based in Kaktovik during September 1998–2000 (and 1985–86), affording opportunities for coordination between project biologists and local people.

Kaktovik residents are very knowledgeable about the times and locations near Kaktovik where bowheads are present (including small vs. large bowheads), the places where bowheads tend to linger, and other information relevant to whaling. However, relatively little specific LTK is available about whale feeding behavior near Kaktovik. "Whale feeding behavior" is a discrete category of definable behaviors to a scientist, but is for the most part beside the point for an Inupiat subsistence whaler. Nonetheless, two feeding areas in the general area are recognized: ***(1)*** the Demarcation Point/Icy Reef area in the southeast corner of the study area, and ***(2)*** waters near Arey Island just west of Kaktovik. Some local residents mentioned that they often see whale food in the water, and know that whales tend to occur in those places. Local residents emphasized that some bowheads occur in the area in August and even July, before the start of the main westward migration, and that the project should consider these times as well as later in the season. However, they noted that bowheads are more common in Canadian waters than near Kaktovik in July–August. The main hunting period for bowheads is in September, but they are present near Kaktovik as late as mid-October in some years. LTK research activities during this project, although limited, were closely related to the broader local coordination efforts, and served to structure the local participation aspects of the research in fruitful ways.

Zooplankton: Acoustic vs. Net Biomass

There was a need for a method to estimate zooplankton biomass from echosounder data acquired along transects and at whale feeding locations in the eastern Alaskan Beaufort Sea. As described in Chapter 4 by W.B. Griffiths, this was done by comparing zooplankton biomass collected in horizontal bongo-net tows with concurrent echosounder measurements of acoustic backscatter at corresponding depths. Paired data of these types were collected during late summer/early autumn in five years: 1985–86, and 1998–2000. Linear regression techniques (robust LTS regression in 1998–2000) were used to develop equations that could predict zooplankton biomass from acoustic backscatter when only the latter is measured. In all five years, there was a positive and statistically significant ($P < 0.05$ or better) correlation between net biomass and acoustic backscatter. Predictive equations were developed for data collected in 1985, 1986, 1999, and 2000. In 1998, the relationship between backscatter and zooplankton biomass was too weak to be of use. The equations are used in Chapters 5 and 6 to convert acoustic backscatter along transects and at whale feeding stations into estimates of relative zooplankton biomass, and from this to define the nature and extent of suitable bowhead feeding habitat in the study area. The resultant echosounder-based data are useful primarily in comparing *relative* amounts of zooplankton at different locations, depths, and years.

Numerous sources of error can confound the relationship between acoustic backscatter data and zooplankton biomass measured with nets. A strong relationship between backscatter and net biomass is difficult to obtain because the acoustic data may contain echoes from other biotic as well as abiotic sources. Sources of variability include such things as the presence of fish larvae or other large swift animals that are not captured by the net, the shape and orientation of zooplankters, sediment plumes, and density discontinuities in the water. Some of these biases (e.g., backscatter from fish and density discontinuities) can be partially or completely removed. Other biases cannot be eliminated. These reduce the strength of correlation between acoustic backscatter and zooplankton biomass in concurrent net samples, and thus the accuracy with which biomass can be estimated from backscatter data. More expensive and technologically advanced zooplankton samplers, and more sophisticated acoustic systems, were not practical in this study. Also, other studies have shown that these approaches do not guarantee better or more consistent results.

Despite the limitations and biases, the method provided useful data concerning the locations and depths of high-density zooplankton patches, and the relative amounts of zooplankton at different locations, depths, and times within and among the four years when useful data were available. This approach was an important technique in assessing the characteristics and quality of feeding habitat available to bowhead whales in the eastern Alaskan Beaufort Sea during those four years.

Zooplankton: Species Composition, Biomass and Distribution

Introduction and Objectives.—Chapter 5, by W.B. Griffiths and D.H. Thomson, describes the first comprehensive study on late summer zooplankton biomass in the eastern Alaskan Beaufort Sea from shore to the 200 m depth contour. The primary objective was to gather data on the taxonomic composition, biomass, patchiness, and variability of the zooplankton available to feeding bowhead whales in that area during late summer and early autumn. Consequently, emphasis was placed on species and taxa that were major contributors to overall zooplankton biomass. The study was based on coordinated net sampling and quantitative echosounder surveys conducted over 7- to 16-day periods during early-mid or mid-late September of five years. It describes the vertical and horizontal distribution, composition, and patchiness of zooplankton biomass in relation to water mass characteristics.

Methods.—In all 5 years (1985–86; 1998–2000) sampling was conducted from a 13-m vessel during September. Zooplankton and CTD data were collected at stations along transects perpendicular to shore between central Camden Bay and Demarcation Bay, extending seaward to ~200 m depth (1985–86) or 50 m depth (1998–2000). Quantitative echosounder data were collected along the same transects. All data were used to describe the nature and variability of the zooplankton community, and its relationships to water masses in the study area.

Three types of bongo tows were used to collect zooplankton samples each year: surface tows, oblique tows, and horizontal tows at depth. A flow meter was placed in the center of one frame. The echosounder was used to help select depths for horizontal tows, to ensure sampling within and outside layers of concentrated zooplankton. Actual tow depth was measured directly.

Hydroacoustic sampling to estimate zooplankton distribution (horizontal and vertical) and relative biomass along transects was conducted in all 5 years using single- (1998) or dual-frequency (other years) echosounders. Relative biomass was determined for each 2 min (~240 m) horizontal segment by 1– or 2–m depth interval for all transects.

CTD profiles were measured at stations along each transect each year. Near-surface temperature (and, in 1985–86, salinity) were recorded continually during transits between sampling.

Results.—In all five years of the study, at least two water masses were deemed to be present: ***(1)*** a Shallow Cold Saline water mass, usually without sharp discontinuities in the vertical distribution of temperature and salinity (i.e., without pycnoclines). These waters were typically relatively cold and saline from surface to bottom. ***(2)*** A Mackenzie-Influenced more-offshore water mass with Mackenzie-influenced water at the surface, overlying water that was generally colder and more saline than that of the nearshore water mass. In 1985, 1986 and 1998, warm fresh Mackenzie plume water was transported into the study area; in 1999 and 2000 it was absent. The distribution of water masses did not appear to have a strong effect on the distribution of major zooplankton taxa. However, the highest biomass of zooplankton occurred in the presence of strong pycnoclines, in the colder and more saline bottom waters.

The annual average zooplankton biomasses collected in ***Shallow Cold Saline waters*** varied over the five years of study: 189–409 mg/m^3 for the water column as a whole, 18–205 mg/m^3 for surface waters, and 236–516 mg/m^3 for horizontal tows at depth. In all years, zooplankton biomasses in surface waters were lower than in samples taken at depth. Typically, zooplankton biomasses were higher in the cold saline bottom layer than in the fresher warm surface water. In 1985–86, the maximum biomass in individual horizontal tows at depth was 900–2000 mg/m^3, considerably higher than the 500–1000 mg/m^3 recorded in 1998–2000. Overall, zooplankton biomasses were higher in 1986 than in 1985, 1998, 1999 and 2000. The lowest biomass levels were recorded in 1999, while those in 1985, 1998 and 2000 were intermediate.

The high zooplankton biomasses in 1985–86 were due to the much higher biomasses of copepods, particularly *Limnocalanus macrurus.* In 1998–2000, *Calanus glacialis* and *C. hyperboreus* were the dominant species among all taxa. Predatory cnidarians, ctenophores and chaetognaths were abundant in the study area in 1998–2000 and not in 1985–86. These predators may have contributed to the lower biomass of copepods in 1998–2000.

In the water column as a whole, within the Shallow Cold Saline zone, five major zooplankton taxa were collected in all five years. These were copepods, gelatinous zooplankton (i.e., ctenophores + cnidarians), chaetognaths, mysids, and fish. Copepods were the dominant taxon in all years, especially in 1985 and 1986. Gelatinous zooplankton and chaetognaths, considered together, were major contributors (>10 mg/m^3) to zooplankton biomass in every year, and in 1998–2000 their biomass approached that of copepods. Euphausiids were collected in all years except 1986 and were major contributors to the zooplankton biomass in 1985 and 2000, while decapods were major contributors only in 1986.

In all five years, the copepods *Calanus hyperboreus* and *C. glacialis* were major contributors to the copepod biomass. In 1985 and 1986, biomass of the copepod *Limnocalanus macrurus* was higher than that of any other species, but it was not found in the nearshore zone at all in 1998 and 1999 and only in small quantities in 2000.

The low biomass in the surface waters was composed of copepods, gelatinous zooplankton and, to a lesser extent, chaetognaths. Below the surface, the composition of the zooplankton collected in horizontal tows was similar to that in the water column as a whole

The ***Mackenzie-Influenced more-offshore water mass*** was present in the study area during 1985, 1986 and 1998, but not in 1999 and 2000. The annual average zooplankton biomasses in this water mass were 170 to 223 mg/m^3 for the water column as a whole, and 4 to 25 mg/m^3 for surface waters. Each of these averages was lower than the corresponding value in Shallow Cold Saline zone. The warm freshened water layer above the pycnocline contained a very low biomass of zooplankton (annual averages 46–115 mg/m^3) compared to the cold saline water below (394–659 mg/m^3). Copepods and gelatinous zooplankton, with lesser contributions from amphipods, euphausiids, chaetognaths, pteropods and fish, accounted for most of the biomass. In all three years, copepods were the dominant taxon, particularly in 1985 and 1986. Overall, *C. glacialis* and *C. hyperboreus* were the major contributors to the total copepod biomass in the Mackenzie-Influenced waters in all three years. *Limnocalanus macrurus*, the dominant copepod in Shallow Cold Saline waters in 1985–86, was also a major contributor to biomass in Mackenzie-Influenced waters in 1985 but not in 1986. It was not found in this water mass in 1998.

The ***Outer Shelf Arctic water mass*** was only sampled in 1985 and 1986 when transects extended out to the 200 m contour (vs. 50 m in 1998–2000). Zooplankton biomass in this zone was, on average, less than that in nearshore and inner shelf waters. In both years, *Calanus hyperboreus* and *C. glacialis* contributed most of the copepod biomass.

Average biomasses of zooplankton collected in summer and early autumn in the eastern Alaskan and Canadian Beaufort Seas are similar. Zooplankton biomass collected by oblique (1985–2000) or vertical (1980) tows in the top 50 m of the water column have ranged from ~150 to 600 mg/m^3 with an overall average for all 218 of these tows of ~260 mg/m^3. Under some circumstances, biomass in layers of concentrated zooplankton, as measured with horizontal bongo tows, can equal or exceed 1000 or 2000 mg/m^3.

Echosounder surveys in 1985 and 1986 showed that only a small fraction of the water along the transects contained a high (>500 mg/m^3) biomass of zooplankton, although there were patches where the estimated biomass apparently exceeded 3000 mg/m^3 in 1985 and 3500 mg/m^3 in 1986. In 1999, zooplankton patches were more extensive than in 1985–86 but the estimated biomass levels were lower with the densest patches containing only an estimated maximum of 800–1000 mg/m^3. In 2000, there was a pattern of increasing zooplankton biomass from east to west, with highest values from Barter Island to eastern Camden Bay. In 2000, there were also many more patches where estimated biomass exceeded 700 or 1000 mg/m^3 along the western three transects than along the three eastern transects.

Zooplankton: Characteristics of Bowhead Feeding Areas

Introduction and Objectives.—Bowhead whales winter in the Bering Sea and annually migrate to summering areas in the Beaufort Sea (Fig. S.1). If bowheads, like other mysticete whales, feed mainly during summer, a primary reason for the annual migration would be to reach preferred summer feeding areas. This would imply that summering areas are sufficiently rich in food to justify migrating several thousand kilometers (round-trip) to feed. This component of the study, described in Chapter 6 by W.B. Griffiths, D.H. Thomson and M.S.W. Bradstreet, had three main objectives: ***(1)*** to describe the characteristics of bowhead feeding areas in the eastern Alaskan and Canadian Beaufort Seas, with emphasis on the zooplankton and water masses; ***(2)*** to determine whether bowhead whales feed in areas where zooplankton is concentrated; and ***(3)*** to determine the quantity and kinds of zooplankton associated with feeding bowheads.

Methods.—In the Eastern Alaskan Beaufort Sea, zooplankton was sampled during September of 1986, 1998 and 1999 at 21 stations where bowhead whales were either observed feeding or where whales had been observed feeding the previous day. Sampling near feeding bowheads was not possible in 1985 and 2000. For each feeding station sampled, a control station about 8 to 10 km from the feeding station was also sampled. Zooplankton near feeding bowheads was sampled at 16 additional stations in the Canadian Beaufort Sea during August and early September of 1980–81, 1985–86, and 1988. The eastern Alaskan and Canadian data are presented separately, but are also considered together to provide a broader view of bowhead feeding in the eastern Beaufort Sea. Vertical profiles of temperature and salinity were obtained at all but one systematic sampling station.

At most stations, oblique and horizontal zooplankton tows were made using a standard bongo frame fitted with two 0.5 mm mesh, 0.61 m diameter, plankton nets, and a flow meter. At most stations, at least one horizontal tow was targeted to a specific depth where an echosounder showed an apparent zooplankton concentration. The limited 1980 and 1988 sampling in Canadian waters employed vertical tows, and in 1986 the horizontal tows in Alaskan waters used an opening-and-closing bongo system. Animals from all oblique tows were identified to species, and those from horizontal tows to major taxa. Sorted animals were wet-weighed, and wet-weight biomass/m^3 was calculated using flow-meter data on volume filtered.

In the Alaskan Beaufort Sea, quantitative echosounder surveys were conducted between whale feeding and control stations during 1986, 1999 and 2000, and along other transects during all five field seasons. Regression equations were developed to relate zooplankton biomass in horizontal net tows to measured acoustic backscatter, and then used to estimate biomass where only echosounder data were available. In the Canadian Beaufort, the echosounder used in 1981, 1985 and 1986 identified depths with high (and low) apparent biomasses of zooplankton, but did not provide quantitative data on biomass.

Results.—Bowhead whales feed in areas with a higher than average concentrations of zooplankton. A high biomass of zooplankton was found in areas where feeding bowheads were observed from the sampling boat in the eastern Alaskan and Canadian Beaufort Sea. Mean wet-weight biomass in the water column near actively feeding whales was 529 mg/m^3, a value considerably higher than the mean biomass in the water column elsewhere in the eastern Alaskan and Canadian parts of the Beaufort Sea (230 mg/m^3). Mean biomass in the horizontal tows with maximum biomass at 17 stations where whales were observed within 1 km of the boat and the echosounder was functioning was 1841 ± s.d. 1226 mg/m^3. The distribution of biomass values at places with feeding bowheads indicates that the feeding threshold for bowheads may be a wet biomass of ~800 mg/m^3.

A high biomass of zooplankton near feeding whales in nearshore waters was usually associated with the presence of strong temperature and salinity gradients (pycnocline) in the water column. In these cases, concentrations of zooplankton are found in the cold saline water that underlies the warmer freshened layer. These conditions are found at varying locations in the Canadian Beaufort Sea regardless of wind direction, but occur in shallow waters of the eastern Alaskan Beaufort Sea mainly under east wind conditions. The eastern Alaskan Beaufort Sea appears to be more important to feeding whales in years when oceanographic conditions that cause zooplankton to concentrate in nearshore waters off the Yukon coast extend west into Alaska.

The small copepod *Limnocalanus macrurus* dominated the zooplankton biomass near feeding bowheads in nearshore waters along the Yukon coast and into northeast Alaska when cold saline water was overlain by warm Mackenzie water. Farther offshore, the large copepods *Calanus hyperboreus* and C. *glacialis* dominated. Stomach contents of whales landed at Kaktovik show that bowheads sometimes feed on dense swarms of euphausiids. However, euphausiids are rarely the dominant zooplankters around bowheads feeding in the present study areas. Other taxa that occasionally are dominant near feeding whales are gelatinous cnidarians and ctenophores, chaetognaths, and mysids.

We did not find places with feeding whales where euphausiids were dominant, but this has been reported previously from the Camden Bay area, and euphausiids are the dominant components of the prey in the stomachs of a minority of the bowheads landed at Kaktovik (see below and Chapter 18). Euphausiids are known to show avoidance reactions to sampling nets. As a result euphausiids are probably somewhat under-represented in our net samples. However, where euphausiids are abundant, as they are at times in the western Beaufort Sea, they are prominent in net samples. In general, euphausiids are apparently less important as prey for bowhead whales in the eastern Alaskan Beaufort Sea than farther west near Point Barrow.

Most whales observed in the areas sampled were subadults. Adult bowheads tend to feed in deeper water, where large copepods predominate. By early autumn, most large copepods have descended to their overwintering depths (>100 m).

Water masses in the areas sampled are defined by the presence or absence of the plume of freshened and warmer water influenced by Mackenzie River outflow. Wind conditions have rapid effects on the Mackenzie plume, so oceanographic conditions can change rapidly. These changes influence the biomass and composition of the zooplankton community in the eastern Beaufort Sea, and especially the portion that is in Alaska.

Bowheads: Distribution and Abundance

Previous studies plus observations by local people have shown that some bowhead whales may spend at least part of the summer feeding period off the north coast of Alaska. Many others summer in Canadian waters but continue to feed as they begin to travel west through the Alaskan Beaufort Sea during September and October. Bowhead use of the Alaskan Beaufort Sea during late summer and autumn has been documented since 1979 by systematic aerial surveys, mainly conducted or sponsored by BLM and MMS. The surveys have gathered much information that can be used to evaluate bowhead use of the eastern Alaskan Beaufort Sea during August–October, including relative utilization according to year, season, and region within the study area.

Chapter 9, by G.W. Miller and others, describes the seasonal distribution and numbers of bowheads observed in the eastern Alaskan Beaufort Sea and adjacent Canadian waters during August–October of 1979–2000, based on existing and new aerial survey data from the 139°–146°W region, south of 71°10'N. (This "Flaxman Isl.–to–Herschel Isl." area is a larger area than outlined in Figure S.2.) The 21 years of data considered here (no data were available from 1980) include ***(1)*** annual aerial surveys by MMS, ***(2)*** some of the aerial surveys conducted during industry-sponsored monitoring programs (1986 and 1993), and ***(3)*** surveys that we conducted specifically to assess the importance of the eastern Alaskan Beaufort Sea to bowheads in 1985–86 and 1998–2000. The combined dataset includes more data from the central Beaufort Sea than have been analyzed by previous authors; it involves 155,000 km of systematic aerial surveys within the "Flaxman–to–Herschel" study area. For periods where sufficient aerial survey data are available, we have estimated the numbers of bowheads present in the part of the study area inshore of the 200 m contour off Alaska ("Flaxman–to–border"). These estimates are based on line transect techniques, including correction factors for whales missed by aerial surveyors (see Chapter 15 for derivation of correction factors).

The "Flaxman–to–Herschel" area was divided into four E–W regions, and four water-depth strata —a total of 16 analysis zones. For seasonal analyses, the data were categorized into six half-month (15– or 16–day periods) from 1 Aug. to 31 Oct.

When standardized for survey effort, the overall average abundance index during systematic aerial surveys under acceptable sighting conditions (Aug.–Oct. combined) was 0.77 bowheads seen/100 km. Bowhead abundance differed significantly among the four depth strata, with highest average abundance recorded in the Shelf Break stratum (40–200 m deep), followed by the Middle Shelf stratum (20–40 m) and Nearshore stratum (<20 m); average abundance was lowest in the Continental Slope stratum (>200 m deep). Differences in bowhead abundance among the four E–W regions were marginally significant, with bowhead abundance highest in the east and declining with increasing longitude.

Local residents occasionally see bowheads in the study area during July and August; they see peak numbers in September, and some bowheads during October.

Aerial surveys showed that bowhead abundance and distribution varied significantly by half-month period during August–October of 1979–2000. Moderate numbers of bowheads were present during early August, especially in offshore waters (>200 m deep) of the three easternmost regions of the study area. Bowhead abundance was somewhat lower during the second half of August, and there was a slight shoreward shift in the distribution of bowheads from early to late August.

During the first half of September the relative abundance of bowheads in the study area increased. Also, their distribution shifted inshore and expanded westward to span the full width of the study area, coincident with increased migration into and through the study area. Peak bowhead abundance was recorded during the second half of September, when bowheads were most abundant in the Shelf Break and Middle Shelf strata (20–200 m deep).

Bowhead relative abundance in the study area was lower during early October, and the highest densities were again shoreward of the 200 m contour. By late October, the relative abundance of bowheads was very low.

The percentage of the bowhead sightings recorded as “traveling” was similar (86–100%) over the six half-month periods. For traveling whales, the headings were significantly non-uniform (and predominantly westward or northwestward) in all half-month periods except for late August. However, the variation in headings was larger up to 15 Sept. than thereafter.

Few bowheads were identified as feeding during systematic aerial surveys. The low apparent numbers of feeding bowheads reflect, in large part, the difficulty of recognizing feeding activity in the brief glimpses of whales that typically occur during systematic aerial surveys. Areas where feeding was seen most commonly included Nearshore waters close to Komakuk (Yukon); Nearshore, Middle Shelf and Shelf Break waters off Demarcation Bay; and Middle Shelf and Shelf Break waters off Camden Bay.

During the 1979–2000 period, the relative abundance of bowheads recorded during aerial surveys has varied markedly from year to year. Eight years had abundance indices higher than the overall average of 0.77 bowheads seen/100 km. The highest indices were recorded in 1995 (3.23 /100 km), 1999 (3.32 /100 km) and 1990 (4.05 /100 km). Seven of the eight years with above-average bowhead abundance were in the 1990s and most (9 of 13) of the years with below-average bowhead abundance occurred prior to 1990. The average of the annual abundance indices was 0.36 bowheads seen/100 km during the 1979–89 period vs. 1.60 bowheads/100 km for 1990–2000. The increase since 1989 was larger than can be accounted for by the previously-reported rate of increase of this population (3.2% per year).

The numbers of bowheads present in the restricted “Flaxman–to–border” area were estimated whenever survey coverage allowed, considering waters inshore of the 200 m contour. This area was similar to that outlined in Figure S.2, but extended 20 n.mi. (37 km) farther west, to longitude 146ºW. These line-transect estimates were based on 81 surveys or combinations of surveys flown during 1– or 2–day periods during 1979–2000, and include allowance for missed whales. The estimates ranged from 0 (during many surveys) to a maximum of 4505 bowheads (based on 765 km of survey coverage on 13 Sept. 1999).

Within most half-month periods, the estimated numbers of bowheads present were highly variable. All six half-month periods included some surveys for which no bowheads were estimated to be present. However, the average estimated numbers of bowheads present in the restricted study area during the six half-month periods followed the same pattern as the abundance indices described above for the overall study area: moderate in August, high in September and early October (peaking during late September), and almost none during the second half of October.

We compared the estimated numbers of bowheads present in the restricted “Flaxman–to–border” area during 1979–89 vs. 1990–2000, considering only the September and early October periods when peak numbers of bowheads were present. The estimates from the 1990–2000 period were, on average, significantly higher than those from 1979–89 even after de-trending to remove the assumed annual 3.2% population increase over the 22-year study period. Thus, the increased sighting rates in the 1990–2000 period are apparently attributable in part to an increase in the relative utilization of the present study area as compared with other areas.

Bowheads: Habitat Use by Size Class

Chapter 10, by W.R. Koski and G.W. Miller, examines year, location, water depth, and date effects on the size and status of bowhead whales occurring in and near the eastern Alaskan Beaufort Sea (water depths ≤200 m) during late summer and early autumn. It assesses the population structure of bowhead whales found in this area and evaluates whether there was habitat or seasonal segregation by whales of different sizes (ages) and status (subadult and adult), including mothers and calves. This information is relevant in evaluating the importance of the study area to the different components of the bowhead whale population, and is a factor in subsequent energetic calculations.

We used the calibrated vertical photography technique developed by LGL to obtain vertical photographs of 901 different whales during mid-August to early October of 1982–86 and 1998–2000 in the area between Flaxman and Herschel islands (longitudes 146° to 139°W). Whale images were measured directly from the film and the measured image sizes were converted to whale lengths by accounting for systematic biases introduced by the cameras and the radar altimeter.

Subadults, adults and calves made up 64.7, 29.2 and 6.2%, respectively, of the bowheads photographed in the "Flaxman–to–Herschel" area over all years of this study. We found proportionally more subadults and fewer adults within that area than are estimated to be in the overall population. Some, but not all, of this difference was a result of the fact that most of our effort was in the peak whale migration period, with little effort during the initial 20% and final 29% of the bowhead migration through our study area. The presence of a relatively high proportion of subadults in our length–frequency distribution even after allowance for the seasonal bias in sampling suggests that the parts of the eastern Alaskan Beaufort Sea ≤200 m deep are relatively more important for subadult bowheads than for adults.

There was significant variation in length–frequency distributions of whales among years, geographic subdivisions of the study area, water depth categories, and time periods. This variation was due to variable use of the study area by each age class in different years, differences in the water depths preferred by different age classes, and different migration timing by each age class. Small subadult whales (<10 m long) are the dominant group in shallow (<20 m) nearshore habitats, with progressively fewer small subadult whales and more adults as water depth increases. Small subadults start to arrive in the study area during late August, numbers peak in early September, and they have passed through the study area by early October. Large subadults start to arrive in late August but are scarce until September; moderate numbers are still present in early October. Mothers and calves start to arrive in early September and are common in the study area until early October. Other adults arrive mainly in late September and are common in early October.

In the mid-1980s, large numbers of subadult bowheads tended to occur in shallow nearshore areas in the eastern part of the study area from the Kongakut River Delta to Herschel Island, and they lingered in that area for days to a few weeks. Few whales were seen in that nearshore area during 1998–2000, and those that were seen there did not appear to linger.

Bowheads: Rates of Movement and Residence Times

To determine the importance of the eastern Alaskan Beaufort Sea to bowhead whales, we need to know how long whales remain in the area. This is one key factor in estimating how much food bowheads consume while there. We also need to know how fast they travel while feeding to estimate how much water they might filter. Chapter 11, by W.R. Koski and others, documents short-term rates of movement of bowhead whales and estimates average residence times in waters from Flaxman Island (146ºW) to

Herschel Island (139°W). Probable residence times in the smaller "Flaxman–to–border" area are discussed in Chapter 23, and are estimated to be about 76% of those in the larger "Flaxman–to–Herschel" area.

We estimated rates of movement from within-day sightings of photographed bowhead whales in the "Flaxman–to–Herschel" portion of the Beaufort Sea and compared them to similar data collected during the 1980s off the Yukon east of Herschel Island (Yukon East) and in Amundsen Gulf.

Over periods of 15 min to a few hours, bowheads gradually moved away from the location where they were initially photographed, but as the interval between the initial sighting and resighting increased, speeds declined. This suggested that some movements were local, in part associated with feeding. Within-day speeds were not significantly different between the "Flaxman–to–Herschel" zone and the more easterly Canadian zones. Within the "Flaxman–to–Herschel" zone there was a significant difference in speeds among years. The difference appeared to be due to slower speeds by feeding adults photographed in 1999 than by primarily subadult whales photographed in other years.

The primary activities recorded for bowheads during late summer and autumn were feeding and traveling. Based on the successive locations of bowheads observed during prolonged behavioral observation sessions, the average rate of movement of bowheads in the "Flaxman–to–Herschel" zone was about 1.54 km/h for feeding whales vs. 4.50 km/h for traveling whales. The mean alongshore component of the net speed, measured along the 288°–108° (True) axis, was 0.71 km/h *eastward* for feeding whales and 3.67 km/h westward for traveling whales.

We attempted to estimate residence times of bowhead whales in the "Flaxman–to–Herschel" area using four general types of data: photoidentification data, behavioral observations, aerial survey results, and telemetry data. Photoidentification data from the 1980s were also used to estimate residence times in the Yukon East and Amundsen Gulf zones. ***(1)*** *Photographic resightings* were used to determine within-day rates of movement and intervals between resightings for the "Flaxman–to–Herschel" zone and for the Yukon East and Amundsen Gulf zones in all years with sufficient data. Net speeds from within-day photographic resightings were the basis for one estimate of residence times of whales in each zone. Resighting intervals indicated minimum residence times for the specific whales resighted. A computer program (SODA, "stop-over duration analysis") was used to derive an unbiased estimate of residence time in each zone based on data on photographic effort as well as resightings. ***(2)*** *Behavioral observations* of bowhead whales were used to determine short-term rates of movement of whales, and net westward speeds of whales engaged in different activities, in the "Flaxman–to–Herschel" zone during late summer and autumn of 1985–86 and 1998–2000. ***(3)*** *Aerial survey* data were used to estimate residence times in that area based on relative densities during aerial surveys and based on numbers of whales estimated to be present during aerial surveys. ***(4)*** Data on whale locations obtained during *telemetry* studies in three years were used to estimate residence times of whales in the "Flaxman–to–Herschel" zone.

Annual residence time estimates for the "Flaxman–to–Herschel" zone were extremely variable among years and among different methods of analysis applied to the same year. We attribute the latter variability to biases in the different methods that interacted with year-to-year variability in sampling effort, whale distribution, and whale activities. For example, most behavioral data and some photographs collected in 1985 were from feeding whales off the Yukon coast ("border–to–Herschel Isl."); activities and speeds of those whales were not representative of whales in Alaskan waters in 1985. In general, estimates based on behavior data, and to a lesser extent photogrammetry data, were positively biased.

We identified six calculation methods based on photoidentification, behavioral observation, aerial survey, and telemetry data that provided residence time estimates most representative of actual residence times. However, even with these six methods, a few of the residence time estimates were recognizably biased. The annual residence time estimates for the "Flaxman–to–Herschel" area during 1985–86, 1988, 1989, 1992, and 1998–2000 based on these six methods varied from 2.1 to 8.3 d and averaged 5.1 d. A sensitivity analysis (in Appendix 23.1) indicated that the 95% confidence limit for the 5.1-d estimate of mean residence time was 4.2 to 6.1 d.

Residence times varied dramatically among years because of different levels of use of the "Flaxman–to–Herschel" zone for feeding during late summer and autumn. In 1985 and 1986, the eastern part of the area was used for feeding by subadult bowheads during late summer. In 1998, subadult whales briefly stopped to feed in central and western parts of the study area during their migration through the study area. In 1999, adult whales stopped to feed for extended periods in eastern and central parts of the study area. During 2000, most whales migrated through the study area without stopping.

The mean interval for between-day photographic resightings was 4.35 days in the "Flaxman–to–Herschel" zone and 5.91 days in Canadian zones east of there, and estimates for both areas were highly variable among years. A tendency for residence times in the "Flaxman–to–Herschel" zone to be shorter than those in the more easterly Canadian areas became more evident when the SODA model was used to estimate total residence times, including allowance for time present before the first and after the last sighting, and for whales photographed only once. SODA showed that the mean residence times for the Canadian zones were considerably longer (12.6 d) than the mean resighting intervals (5.9 d), whereas the mean residence times for the "Flaxman–to–Herschel" zone were either lower than (1985) or similar to (1986, 1999) the mean resighting intervals. The shorter residence times in the latter zone compared to the Yukon East and Amundsen Gulf zones are consistent with distributional and behavioral data in suggesting that bowhead whales spent less time feeding in the "Flaxman–to–Herschel" area than in adjacent Canadian zones in most years. Furthermore, residence time estimates for eastern Alaska would be further reduced if data from Canadian waters west of Herschel Island (the Komakuk area) were excluded from the "Flaxman–to–Herschel" zone.

Bowheads: Activities and Behavior

Chapter 12, by Dr. B. Würsig and others, describes the general activities of bowhead whales while they are off northeastern Alaska, and in adjacent Canadian waters, during late summer and early autumn (feeding, traveling, socializing, and combinations thereof). It also documents the specific behaviors associated with these activities, and determines the proportion of time engaged in each activity (time budget). During September of 1985, 1986, 1998, 1999, and 2000 (and early October in 1986), systematic behavioral observations were obtained from twin-engine aircraft circling at an altitude of 460 m (occasionally 610 m) a.s.l., with a minimum of three observers describing and videotaping behavioral events. We obtained data on the activities and behaviors of whales during 84 Behavioral Observation Sessions totaling 91.9 h of observations under presumably undisturbed conditions. Of these, 69 sessions were off northeast Alaska (Flaxman Island to border), and 15 were in Canadian waters from the Alaska-Yukon border to Herschel Island. We compared our data for this "Flaxman–to–Herschel" area in September/early October to previously reported data on activities, behaviors, and time budgets during spring and during summer, and demonstrated seasonal differences. For the late summer/early autumn period, the time-budgets also differed among years.

Feeding was the most common activity of bowhead whales in and near the eastern Alaskan Beaufort Sea in September/early October during 1985, 1986, 1998, and 1999; but not in 2000. Over the five seasons, bowheads engaged in feeding for ~47% of the total time (9% in 2000; 38–66% in other years). Overall, ~34% of the time was spent feeding in the water column, 8% on near-surface ("skim-") feeding, and 4% on near-bottom feeding. Almost all observed feeding in water >20 m deep was water-column feeding; surface and bottom feeding were proportionally more common in areas ≤20 m deep, but there too water-column feeding was the most common activity. Mothers and first-year calves were rarely sighted in waters ≤20 m deep, and the most common activity of mothers was feeding in the water column in areas >20 m deep. Most whales fed singly. Bottom feeders were usually widely spaced, but water-column and skim feeders generally were more aggregated, typically with 4+ whales within 1 km of each other. We did not see skim feeding in echelon formation during late summer–early autumn, although it has been reported previously in the Alaskan Beaufort Sea. The estimated proportion of time devoted to feeding during September/early October (47%) was intermediate between values during spring migration east of Point Barrow, Alaska (1%), and on the summer range in the Canadian Beaufort Sea (71%).

Traveling was the second-most common activity, accounting for 31% of time overall; but 74% in 2000. Travel tended to be in areas 20–49 m deep and in groups of one to two whales. Whales spent more time traveling during the latter half of September than in early September. Traveling whales were oriented mainly westward. Bowheads commonly interspersed feeding and socializing with travel during the latter half of September. The estimated proportion of time devoted to traveling (31%) was also intermediate between that during spring migration (81%) and that on the summer range (9%).

Socializing accounted for 18% of the time during September/early October, and other activities (aside from feeding, travel or socializing) accounted for 4%. Socializing tended to consist of low-level behaviors such as nudges and other touches, with the exception of apparent sexual aggregations of up to seven whales per aggregation on two days in September 1998. First-year calves stayed close to their mothers, showed little surface-active behavior, and were not observed to play. No lone calves were seen, indicating that calves had not been weaned.

Although feeding was the most common activity of bowhead whales in and near the eastern Alaskan Beaufort Sea during September/early October, there was much intra- and inter-season variability in the amount and type of feeding, other activities, and specific behaviors, and in the locations (within the study area) where these activities occurred. These variable results are generally consistent with the apparent variability in prey availability in the study area, as documented in other parts of this study. However, bowheads observed in 1999 spent a high proportion of their time feeding, and exhibited relatively long residence times, even though average zooplankton abundance (at least inshore of the 50 m contour) was relatively low that year. Overall, the importance of the study area for late-summer feeding by bowhead whales varies considerably from year to year, and is difficult to predict for any one late summer–early autumn season.

Bowheads: Surfacing, Respiration and Dive Cycles vs. Whale Activity

Data on surfacing, respiration and dive (SRD) cycles of bowhead whales during late summer and early autumn were needed to derive correction factors for whales missed during aerial surveys, and as a basis for analyses of bowhead energetics. As described in Chapter 13 by T.A. Thomas and others, bowheads were observed systematically during September and early October of 1985–86 and 1998–2000 in the Eastern Alaskan Beaufort Sea and adjacent Canadian waters (Flaxman Island to Herschel Island). Bowhead behavior was observed from an aircraft circling at an altitude of ≥457 m (≥1500 ft), high enough to avoid significant aircraft disturbance. Data collected near other human activities were excluded. We documented the durations of surfacings and dives, number of blows (respirations) per surfacing, and intervals between successive blows. These four variables were defined as in our recent studies of bowhead behavior in other seasons and regions. We first summarized the SRD variables for various categories of whale activity, year, and (for feeding whales) water depth. The main bowhead activities distinguished here are feeding, traveling, and socializing. Then we used multiple regression to assess the joint effects of these and other temporal, environmental, and whale-behavior variables on the four measures of SRD cycles.

Whales engaged in ***feeding*** showed a noticeable increase in the number of blows per surfacing and the durations of surfacings and dives across years. Some of this variability may be attributable to the water depth in which the whales were feeding. In the 1980s most of the observed surfacing–dive cycles occurred in shallow (≤20 m) water, whereas in the 1990s more of observations came from deeper water. An average SRD cycle by an undisturbed bowhead feeding in shallow (≤20 m) water, calves excluded, consisted of a 1.10 min surfacing with 4.9 blows spaced 13.1 s apart, followed by a 5.84 min dive. A corresponding average SRD cycle in water >20 m deep (average 45 m) consisted of a 1.77 min surfacing with 8.5 blows spaced 13.1 s apart, followed by a 16.09 min dive. Whale status and distance from shore had a strong effect on the SRD cycles of bowheads feeding in and near the Eastern Alaskan Beaufort Sea. During feeding, surfacings and dives were longer, with more blows per surfacing and longer intervals between blows, with increasing distance from shore, and for older, larger whales as compared with subadults.

Traveling bowheads (including those feeding while traveling) tended to have surfacing and dive cycles similar to those of bowheads feeding in water >20 m deep. Some of this similarity may be attributable to the habitat that the whales are occupying, as traveling whales tended to be in water >20 m deep. An average SRD cycle by a traveling bowhead (including bowheads that were feeding as they traveled) consisted of a 1.65 min surfacing with 6.4 blows spaced 15.76 s apart, followed by a 13.66 min dive. Whale status and group size had a strong influence on the SRD cycles of bowheads traveling in and near the Eastern Alaskan Beaufort Sea. The standard measures of these cycles were higher for mothers and for increased group sizes, and were shorter for subadults.

Socializing whales and whales feeding in shallow water tended to have similar breathing characteristics. Some of this similarity may be attributable to the habitat (shallow water) that the whales were occupying. An average SRD cycle by a socializing bowhead (including bowheads that intermixed socializing with other activities) consisted of a 1.29 min surfacing with 6.0 blows spaced 12.67 s apart, followed by a 5.54 min dive.

Bowheads: Surfacing, Respiration and Dive Cycles vs. Age

Data on age- and size-dependence of surfacing, respiration and dive (SRD) cycles of bowhead whales were needed as a basis for analyses of bowhead energetics. This type of information is also relevant in deriving correction factors for whales missed during aerial surveys, especially when there is geographic and seasonal variation in the ages and sizes of bowheads present. Chapter 14, by T.A. Thomas and others, provides this information based on several studies, including the present study.

Bowheads in the Alaskan and Canadian Beaufort Sea were observed systematically at various times in 1980–2000 during spring, summer, and fall. During each of six studies, bowhead behavior was observed from an aircraft circling at an altitude of ≥457 m (≥1500 ft), high enough to avoid significant aircraft disturbance. Data collected in the presence of other human activities were excluded. We documented the durations of surfacings and dives, number of blows (respirations) per surfacing, and intervals between successive blows. These four variables were defined as in our recent studies of bowhead behavior in various seasons and regions. We summarized the SRD variables by whale status (calf, subadult, adult other then mother, mother), various categories of whale activity (traveling, feeding, and socializing), season (spring, summer, fall), year, and nursing vs. not nursing.

Subadult whales had lower median blow intervals than adults and mothers; this was evident for bowheads engaged in all three whale activities studied (traveling, feeding, and socializing). Subadults also had lower dive durations during traveling, and marginally lower surface times during feeding, as compared with adults and mothers. Mothers and other adults had similar SRD cycles, with the exception that, during feeding, other adults had lower median blow intervals than mothers.

Subadults engaged in traveling showed no spring–fall differences in any of the SRD variables. Adult whales, in contrast, showed differences in all four variables. Mothers and calves engaged in traveling showed seasonal variability in SRD cycles. For both mothers and calves, there was a noticeable increase in the number of blows per surfacing, surface times, and dive times from spring to fall.

During travel, nursing dives by calves were much shorter than their other dives in both spring and fall. Occurrence of nursing also affected SRD cycles of traveling mothers. When nursing, traveling mothers tended to have long surfacings with long blow intervals. Dive durations by traveling mothers also tended to average slightly longer when nursing.

Bowheads: Correction Factors for Aerial Surveys

Aerial surveys have been used to estimate the number of bowheads present in the eastern Alaskan Beaufort Sea at various times during late summer and autumn for the present study. However, meaningful estimates of numbers present can only be made if the raw aerial survey data are adjusted using appropriate correction factors for missed whales. Not all whales present close to an aerial survey trackline are detected by the aerial surveyors, and raw aerial survey results underestimate the densities and numbers of whales present. ***(1)*** Sightability is often reduced directly below the aircraft and, beyond some "optimum" lateral distance, diminishes with increasing lateral distance. ***(2)*** Some whales are below the surface and undetectable as the aircraft passes; this is "availability bias". ***(3)*** Not all whales at the surface at the optimum lateral distance are detected; this is "detectability bias", sometimes called "perception bias". In theory, three correction factors, designated $f(0)$, $g_a(0)$, and $g_d(0)$, can be computed to compensate in large part for these three biases. Chapter 15, by T.A. Thomas and others, estimated these three correction factors for aerial surveys of bowhead whales, and investigated their variability.

Lateral Distance from Trackline and $\boldsymbol{f(0)}$.—Aerial survey data were used to determine the effect of lateral distance on sightability, and the influences of aircraft type, survey altitude, wave height, and ice cover. Eight aerial-survey studies in the Alaskan and Canadian Beaufort Sea during 1979–2000 provided data on distances of bowhead sightings from the trackline. Altitude and aircraft type affected the size of the zone directly below an aircraft where sightability was reduced. The higher the altitude, the wider the zone. Twin Otter aircraft had a narrower zone of reduced sightability below the aircraft than did Twin Commanders; a TurboGoose was intermediate. Wave height (expressed as Beaufort sea state, Bf) and ice cover each affected the rate at which sightability diminished with increasing distance from the trackline. Also, the effect of Bf state depended on aircraft type. With increasing Bf conditions and ice cover, the relative number of sightings at the longer lateral distances diminished. As a result, the lateral distance where sighting probability diminished to 15% of that at the optimum distance declined with increasing Bf state and ice cover, and $f(0)$ values also changed.

Availability Bias Factor g_a(0).—This factor estimates the proportion of whales at the surface and potentially visible to aerial surveyors as the aircraft passes overhead. We determined this factor for whales in the "Flaxman Isl.–to–Herschel Isl." area during September–October based on three studies of bowhead behavior in that area during 1985–86 and 1998–2000. This correction factor varied substantially with whale activities. The probability was lowest for traveling whales, slightly higher for feeding whales, and notably higher for whales engaged in socializing: $g_a(0)$ = 0.125, 0.153, and 0.234, respectively. Our overall estimate of $g_a(0)$ for an average bowhead in the eastern Alaskan Beaufort Sea during late summer and autumn is 0.144. These factors are slightly higher than the corresponding proportions of time the whales spend at the surface, as the factors assume that any whale near the trackline will be sighted if it surfaces during an (approx.) 21.6-s period while that area is in view.

Detectability Bias Factor g_d(0).—This factor estimates the proportion of whales at the surface near the trackline that are detected by observers. We estimated $g_d(0)$ based on the double independent observer method, as applied during three aerial survey projects in the Canadian (1981) and Alaskan (1985–86, 1998–2000) Beaufort Sea. This method applies an analysis of the capture–recapture type to sightings by two surveyors observing independently from the same side of the aircraft, considering sightings within a 400-m strip of where detectability is optimal. Our estimates of $g_d(0)$ for bowheads are 0.59 ± s.e. 0.160 for a single observer, and 0.84 for two observers on the same side of the aircraft. Detectability was lower in a 600-m strip just beyond the inner 400-m strip (g_d = 0.42 ± 0.129 for one observer). Other aerial survey evidence indicates that this factor very likely is affected by sea state.

The correction factors developed here are used elsewhere (Chapter 9) to convert raw aerial survey data into estimates of the actual numbers of bowheads present in the eastern Alaskan Beaufort Sea on various occasions.

Bowhead Distribution, Numbers & Activities: Conclusions

There were substantial differences in the numbers, distribution, size classes, residence times, activity budgets, and specific behaviors of bowhead whales in and near the eastern Alaskan Beaufort Sea during late summer and early autumn of the five years with feeding studies. As summarized in Chapter 16 by W.R. Koski and W.J. Richardson, bowhead use of that area during August–October is highly variable. Systematic aerial survey data from 1979–2000 suggest that the five years when the feeding studies were conducted included years with low, moderate and high use by bowheads and thus may be reasonably representative of the range of possible usage patterns. However, usage in any future year probably will differ in at least minor ways from that in any of our five years of study.

Most bowhead whales of the Bering–Chukchi–Beaufort stock migrate through the eastern Alaskan Beaufort Sea each year during late summer or early autumn en route to autumn feeding areas farther west and wintering areas in the Bering Sea. Behavioral observations (and also the stomach contents of bowheads harvested at Kaktovik—Chapter 18) show that feeding is a common activity while these whales are in the eastern Alaskan Beaufort Sea. Over the five years studied, the two most common activities of bowheads, at least during daytime when aerial observations were possible, were feeding (47%) and traveling (31%). The proportions of time engaged in these two activities during late summer and early autumn were intermediate between those observed during spring, when bowheads spend most of their time traveling and little time feeding, and during summer, when bowheads spend most of their time feeding and little time traveling. However, the estimated proportions of time spent feeding during late summer and autumn ranged from 9% to 66% in different years. The inter-annual differences in numbers estimated to have been present probably were related to how long whales stopped to feed in the study area, and thus to residence times.

The abundance and locations of zooplankton concentrations had a strong influence on bowhead feeding locations (Chapter 6), and very likely also influenced residence times in the study area. We found that different size classes of bowhead whales had different habitat preferences and different timing of migration through the study area. Small subadult whales preferred Nearshore waters. As water depth increased, small subadults became less common and the proportion of large subadults and adults increased. When prey was locally abundant in Nearshore and Middle Shelf waters, as in 1985 and 1986, some subadult whales lingered in the study area to feed, and many larger whales (which tended to be found in deeper water) traveled through the study area without stopping to feed. When prey biomass was higher in Shelf Break waters (40–200 m) than closer to shore, as in 1999, large subadult and adult whales lingered to feed there, and most small subadult whales traveled through without stopping. When prey was sparse in the eastern part of the study area, as in 2000, most if not all whales traveled through that area without stopping. Over all years of this study, subadult whales seemed to make more use of the study area than adults, but there was year-to-year variation in the use by different age classes. Possible reasons for these year-to-year differences in utilization are discussed further in Chapter 23, “Integration”.

Diet and Regional Feeding: Introduction

This component of the study sought to determine ***(1)*** what types of prey bowhead whales of the Bering–Chukchi–Beaufort (BCB) stock eat, and ***(2)*** what parts of their seasonal range provide the predominant part of this food. The principal and most direct method for determining what bowheads eat was analysis of the stomach contents of bowheads harvested by Inupiat whalers (Chapter 18). The project also included a pilot study of the fatty acid composition of bowhead blubber in relation to the fatty acid composition of potential zooplankton prey (Chapter 19). It was hoped that this approach might, when further developed, provide a method for assessing food consumption over a longer period (and larger geographic area) than can be assessed from stomach contents. To assess the proportion of the food consumed in different parts of the seasonal range, the carbon and nitrogen isotope ratios in bowhead tissues were compared with those in the prey from the eastern Beaufort Sea vs. the Bering–Chukchi area (Chapter 20). Several of the earlier chapters also provide information directly or indirectly relevant to “Diet and Regional Occurrence of Feeding”.

Diet & Regional Feeding: Stomach Contents

This component of the study, by L.F. Lowry and G. Sheffield of Alaska Department of Fish & Game (Chapter 18), documents bowhead whale feeding in the Alaskan Beaufort Sea based on stomach contents of whales harvested by Alaska Natives. They examined field records and archived data from previous studies of bowhead stomach contents, and analyzed similar samples from 85 additional bowhead whales harvested during 1986–2000 near Kaktovik, Barrow, and Cross Island. All available data from bowheads harvested near those locations were used to characterize and compare diet by harvest location and season (i.e., Kaktovik fall; Barrow fall; Barrow spring), and by whale size and sex.

Thirty-two bowheads harvested near Kaktovik during fall 1979–2000 have been examined for evidence of feeding. Of 29 whales whose feeding status could be classified as “feeding” or “not feeding”, at least 83% had been feeding prior to death. Copepods, most commonly *Calanus hyperboreus* and *C. glacialis*, were the most important prey; copepods occurred in all 21 stomachs with food and were the dominant prey by volume in 62% of the samples. Euphausiids, mainly *Thysanoessa raschii,* were also an important food item. Estimated volume of stomach contents was as much as 150 liters, and in 7 of 18 cases was greater than 20 liters.

Four of five bowheads harvested near Cross Island during 1987–2000 were recorded as having been feeding. Copepods were the main prey in the three stomach contents samples examined.

Stomachs of 106 bowheads harvested in fall near Barrow during 1976–2000 were examined. Of the 103 "non-calf" whales that could be classified as "feeding" or "not feeding", at least 75% had been feeding prior to death. Euphausiids were the most important prey; they occurred in 94% of the stomachs with food and were the dominant prey by volume in 88%. Estimated volumes of stomach contents were as much as 189 liters, and in many cases were recorded as ≥100 liters or "full".

Stomachs of 100 bowheads harvested in spring near Barrow during 1969–2000 were examined. Of the 90 whales that could be classified as "feeding" or "not feeding", at least 33% had been feeding prior to death. Euphausiids occurred in 93% of the samples and were the dominant prey in 61%. Copepods were also an important diet item, especially in samples collected before the 1990s. Estimated volumes of stomach contents were smaller than for whales taken in fall, and never exceeded 60 liters.

There was no significant difference in the proportion of bowheads that had been feeding in the fall near Kaktovik and Barrow. However, there was a significant difference in composition of the fall diet at these locations. Copepods occurred more often and were more frequently the dominant prey by volume in whales from Kaktovik. Euphausiids occurred more often and were more frequently the dominant prey by volume in whales from Barrow.

At Barrow, the frequency of feeding in harvested bowheads was significantly greater in the fall than in the spring. Copepods occurred significantly more often in whales harvested near Barrow in the spring than in the fall.

Male and female bowheads ate essentially the same food items. The data suggest the possibility of a slight difference in the prey eaten by small (<13 m) and larger (≥13 m) whales. There was no difference in the frequency of feeding of small versus large whales.

Preliminary estimates of the overall bowhead diet composition by location/season were as follows: Kaktovik fall, 61–62% copepod, 22–24% euphausiid, 15–17% other prey; Barrow fall, 5% copepod, 84–88% euphausiid, 7–11% other prey; and Barrow spring, 27–28% copepod, 61–63% euphausiid, and 10–11% other prey.

Lowry and Sheffield conclude that coastal waters of the Alaskan Beaufort Sea should be considered as part of the bowheads' normal summer–fall feeding range. During spring, feeding by bowheads near Barrow is more common than previously thought, but the frequency and apparent intensity of feeding is less in spring than in the fall.

Diet & Regional Feeding: Fatty Acids

Fatty acids, the dominant constituent of lipids, are often deposited in animal tissue with minimal modification from those in the diet. Lipids in the marine food web are exceptionally complex and diverse. Dr. S.J. Iverson et al. (Chapter 19) undertook a pilot study to assess whether analysis of fatty acid signatures in bowheads and their potential prey (zooplankton) would be a useful tool for better understanding the foraging ecology and diets of bowheads in Alaskan waters. They identified and measured the fatty acids in samples of blubber from 28 bowheads harvested at Kaktovik (fall) and Barrow (spring and fall); 33 samples of mixed zooplankton from the eastern Alaskan Beaufort Sea; and 32 samples of zooplankton that had been sorted into seven major prey groups (copepods, euphausiids, etc.).

This preliminary study indicates that fatty acid signature analysis could be a very useful tool in better understanding the foraging ecology and diets of bowheads in Alaskan waters. The inferences that can be made now are limited because of small sample sizes of whales and potential prey, and lack of data on fatty acid profiles in individual species of prey. However, there are indications that fatty acid analyses may show differences in diets of whales of different sexes and size classes; such differences have not been clearly detectable from stomach contents analyses. Iverson et al. analyzed samples of mixed zooplankton from two years, and the fatty acids of the zooplankton are consistent with them being bowhead diet items. Additionally, although there are very limited data on fatty acid patterns in potential prey, preliminary results from a QFASA (Quantitative Fatty Acid Signature Analysis) model indicate that fatty acid patterns of the inner blubber, presumably indicative of recent diet, are consistent with general diet data obtained from stomach contents analyses. The high fat content of these prey, especially copepods, also suggests high dietary intakes of fat. With further and more extensive sampling and analysis, the taxonomic composition of bowhead prey could likely be better assessed using the quantitative tools now being developed. Fatty acid signatures are expected to represent the integrated diet over weeks or possibly months, and thus over larger geographic areas, than are the stomach contents of harvested whales.

Diet & Regional Feeding: Stable Isotopes

This part of the work (Chapter 20) was done by Sang Heon Lee and Dr. D.M. Schell of University of Alaska Fairbanks, with assistance from Dr. Trent McDonald of WEST Inc. $\delta^{13}C$ and $\delta^{15}N$ ratios in muscle and baleen from harvested bowhead whales were used to estimate the relative amounts of food acquired from the eastern Beaufort Sea (summer and early autumn range) versus the Bering and Chukchi seas—the two regions previously proposed as major feeding grounds. This analysis was based on the fact that isotope ratios in the zooplankton prey of bowheads are different in the two regions. Isotope ratios in prey are reflected in the predators. When isotope ratios differ regionally, this provides a basis for determining the main area(s) where the predators feed.

Samples obtained from whales harvested in autumn of 1997–99 and spring of 1986–88 were compared. Both $\delta^{13}C$ and $\delta^{15}N$ values in the whales have decreased in recent years in response to a long term decreasing trend in isotope ratios in the Bering–Chukchi food chain. The whale samples collected ~10 yr apart were normalized to allow direct comparison.

For all whales, the $\delta^{13}C$ values in muscle sampled in fall were not significantly different from the muscle sampled in spring. Muscle $\delta^{13}C$ during both seasons closely matched the isotope ratios of zooplankton from Bering and Chukchi water, indicating that most of the annual food requirement of adults and subadults is met from that portion of their range. Isotope data from baleen showed, however, different feeding strategies by adult and subadult whales. Subadults acquired sufficient food in the eastern Beaufort Sea to alter the carbon isotope ratios in baleen deposited there relative to baleen representing feeding in Bering and Chukchi water. Baleen plates from subadults showed a wider range in isotope ratios than those from adults, suggesting active feeding by subadults over all parts of their range. A simple approximation based upon observed seasonal shifts in muscle isotope ratios indicates that between 10 and 26 percent of the muscle carbon is replaced over the summer, depending on the method of calculation. A sensitivity analysis that allowed for variability in each factor involved in the calculation indicated that the true percentage probably did not exceed 23 %. Limited data on blubber indicates an even smaller percentage. Although these specific estimates are subject to a variety of assumptions, the isotopic evidence indicates that only a minority of the feeding by either subadults or (especially) adults is in the eastern Beaufort Sea.

Diet and Regional Feeding: Conclusions

At least at first glance, there seems to be an inconsistency between isotopic evidence (Chapter 20) and other evidence concerning the importance of feeding in the eastern Beaufort Sea. The isotope record in bowhead muscle, blubber, and baleen seems to indicate that bowheads (especially adults) feed mainly on prey from the Bering and/or Chukchi Seas. However, behavioral, aerial-survey, and stomach-content data, as well as certain energetics data (see below), show that bowheads also feed widely across the eastern and central Beaufort Sea in summer and fall.

Behavioral and stomach content data do not directly show how much food is consumed in the eastern Beaufort Sea as compared with the Bering/Chukchi system. One could hypothesize that bowhead feeding in the Beaufort Sea might be frequent, as shown by behavioral and stomach-content data, but not very efficient. Behavioral and stomach content results might be reconcilable with isotopic data if prey availability to bowheads were notably better in Chukchi and/or Bering water than in the eastern Beaufort Sea. This hypothesis would be consistent with the known high productivity of the Bering Sea and of water from the Bering Sea that is transported north into the Chukchi. That possibility is discussed further under “Integration and Conclusions”, below. However, if feeding in the Beaufort Sea were not important to bowhead whales, it is difficult to understand why bowheads would spend so much time feeding there, and why they would adapt their movements and local distribution to prey concentrations. Indeed, it is difficult to understand why bowheads would migrate from the Bering–Chukchi area to the Beaufort Sea if feeding in the Beaufort Sea were unimportant.

Energetics of Bowhead Whales

An estimate of the importance of the eastern Alaskan Beaufort Sea to feeding bowheads requires that their daily and annual food requirements be estimated and then used to determine what proportion of their annual requirements could be obtained in the study area. Chapter 22, by D.H. Thomson, first describes the size, growth and reproduction of bowhead whales and the related physical attributes needed for the estimation of energetic requirements. This is followed by several approaches to the estimation of the metabolic rate of bowheads. These are compared to estimates of the amount of food consumed by bowhead whales as determined through observations of behavior, swimming speed, and amount of food found near feeding whales. The only specific data on the amount of food near feeding whales come from the Canadian and eastern Alaskan Beaufort Sea. There are numerous other data gaps where it has been necessary to make assumptions. Identification of these data gaps is useful in showing topics on which additional research would be desirable.

The sizes of bowhead whales and their blubber content can be estimated using known-scale vertical aerial photographs. The results are in agreement with blubber content as estimated from old whaling records and weights of a few whales harvested at Barrow. Baleen length was estimated as a function of whale length using data from whales harvested at Kaktovik and from data in old whaling records. Important relationships needed for energetic calculations are summarized below, where “a” and “b” are the coefficients for an equation of the form $y = a \times (\text{body length in meters})^b$, r is the correlation coefficient, and P denotes the significance level of the correlation:

Parameter/ units [a]		**a**	**b**	***r***	***P***
Whale Weight	MT[b]	0.047	2.58	0.98	< 0.001
Blubber Weight	MT	0.052	2.19	0.95	< 0.001
Total surface area	m^2	0.54	1.85	0.99	< 0.001
Surface area of fluke	m^2	0.012	1.94	0.92	< 0.001
Weight of metabolic core	MT	0.03	2.53	0.97	< 0.001
Surface area of metabolic core	m^2	0.49	1.70	0.97	< 0.001

[a] Equation form: $y = a \times \text{body length (m)}^b$. [b] 1 MT (metric tonne) = 1000 kg.

Theoretical energetic requirements were calculated for a 12.5 m whale that weighs 31 MT, taking account of the available data on whale physiology and bowhead dimensions, seasonal activities, swimming speeds, and surfacing–respiration–dive cycles. The energetic requirements of bowhead whales, as estimated using the respiration method, are higher than estimates based on calculated power output or hydrodynamic considerations plus the standard metabolism approach, which is based on heat loss.

The theoretical energy requirements of bowheads appear to be quite low and are in keeping with the adaptations that bowheads possess for living in a cold environment where food is relatively scarce compared to some other marine waters. These adaptations include

- A very slow maturation rate where males mature when 12 to 13 m long at an age of ~25 years, and females at a length of 13 to 13.5 m when ~27 years old.
- Very slow growth rates: after weaning, subadults initially show little growth and an average subadult gains only about 0.8 to 1MT/yr; adults gain 0.2–0.9 MT/yr.
- The highest blubber content on a percentage basis of any species of whale.
- The longest baleen of any species of whale.
- A long reproductive cycle which spreads the energetic cost of reproduction over about four years.

Potential feeding rates in nature were computed from the area of the mouth opening, speed while swimming, and quantity of food available to bowheads in the eastern and central Beaufort Sea. The mouth opening computed from width of the mouth at ~1/3 the distance between the tip of the rostrum and the rear corner of the mouth, as a function of body length, was estimated as

$$\text{Mouth Opening } (m^2) = -2.15 + 0.312 \times \text{Length (m)}; \quad r = 0.93, \; P < 0.001$$

Because the lower lip holds the baleen in place when the mouth is open, bowheads could feed with their mouths open very wide. The relationship between whale length in m and maximum mouth opening in m^2 was best described as

$$\text{Maximum mouth opening } (m^2) = -2.03 + 0.342 \text{ Length (m)}; \quad r = 0.94, \; P < 0.001$$

Bowheads feed on zooplankters that have a high lipid content. The small size of the bowhead stomach and observations of bowhead feces are consistent with a hypothesis that bowheads extract only the lipids from their prey, at least when feeding in areas with much zooplankton. Zooplankton concentrations near feeding subadult bowheads in the Canadian and eastern Alaskan Beaufort Sea average 1.8 g/m^3 on a wet weight basis, based on echosounder-guided net sampling. This corresponds to an energetic value of about 2069 J/g wet weight considering only the lipid content of the prey. Observations of behavior indicate that bowheads may feed an equivalent of ninety-three 24-hour-days per year. This estimate has wide uncertainty given the lack of specific time-budget data for the western Chukchi Sea and Bering Strait in fall (where we assume intensive feeding) or the central Bering Sea in winter (where we assume no feeding). Assuming 93 days of feeding per year and a swimming speed of 2.5 km/h while feeding, a 12.5 m whale feeding at locations with average prey biomass of 1.8 g/m^3 could consume 1.4 × 10^5 kJ/d, averaged over the year and adjusted for annual differences in lipid content. For comparison, the calculated value assuming a swimming speed while feeding of 5 km/h and prey density 4 g/m^3 was 6.0 × 10^5 kJ/d,

Several different methods have been used to compute the energetic requirements of an average 12.5-m bowhead whale weighing 31 MT:

	kJ/d x 10^5
Standard metabolism	2.8
Standard metabolism + swimming	3.4
Basal metabolic rate	5.8
Basal metabolic rate of core only	4.1
Power output + BMR	6.6
Cost of swimming +BMR	6.437
Core BMR + Cost of swimming	4.7
Respiration	6.4
Feeding in nature (2.5 km/h, 1.8 g plankton/m^3	1.4
Feeding in nature (5 km/h, 4 g zooplankton/m^3	6.0
Growth/Food Storage for Winter	1.4

Estimated basal metabolism is higher than standard metabolism computed through consideration of heat loss. However, estimated basal metabolism for the core weight (excluding blubber) is about the same as standard metabolism. The metabolic rate of bowhead whales may be quite low for their size. The evidence tends to support a low estimate based on BMR calculated from the core weight not including blubber, plus some small but unknown amount for maintenance of the blubber layer. The cost of locomotion derived through consideration of power output and cost of swimming were also computed, and added to standard and basal metabolism.

About 1.4 × 10^5 kJ/d needs to be added to the above estimates to account for growth and food storage, and ~1.8 × 10^5 kJ/d need to be added to adult female requirements for the cost of reproduction averaged over a 4-year reproductive cycle. When these amounts are added to the two theoretical estimates, the difference between those estimates and the lower "feeding in nature" estimate becomes even greater.

One major uncertainty affecting the energetic analysis is the unknown amount of feeding in the Chukchi Sea and Bering Strait in fall, and the Bering Sea in winter. Isotopic results suggest that most feeding by both subadult and (especially) adult bowheads occurs outside the Canadian and eastern Alaskan Beaufort Sea. However, feeding is commonly observed in those areas, most whales harvested at Kaktovik have food in their stomachs, and subadult bowheads harvested in fall are heavier and have a higher lipid content in their blubber than do spring harvested animals. Measurements of length and girth from known-scale aerial photographs confirm some loss of girth (and thus weight) in winter. Available data indicate that the net loss of weight from the time bowheads leave the Beaufort in fall until they return in spring may be on the order of 2.5 to 3.6 MT for an 11 m subadult and a 14.5 m adult. Actual weight loss in winter is probably greater, assuming there is further weight gain in the Chukchi Sea and Bering Strait in late autumn before the (presumed) period of winter fasting and weight loss begins.

Sampling of food available at places where bowheads were observed feeding has only been conducted near subadults feeding in summer and early fall. These data came from feeding sites in the Canadian and eastern Alaskan Beaufort Sea. The average prey availability at the depth of maximum prey biomass at these sites was measured as 1.8 g/m^3 on a wet weight basis. Estimated prey consumption by subadults feeding in such locations is only about half that required by even the lower of the estimates of theoretical energetic requirements if average food availability in other feeding locations is similar. Subadults and adults would need to feed in higher concentrations of zooplankton. The quantity of prey available at specific locations where adult bowheads feed is unknown. Given our assumptions about the number of days of feeding in various seasons, subadults and adult males would, over the course of the year, need to feed on average concentrations of 4 g/m^3 at an average speed of 5 km/h to meet energetic requirements. A swimming speed of 5 km/h while feeding, and zooplankton concentrations of 4 g/m^3 near feeding whales, are at the upper ends of the observed ranges of values in the Beaufort Sea, and above the average observed values for that area.

The estimate of energetic requirements derived through consideration of respiration is at the high end of the range of estimates derived here. It is based on weights of only 5 lungs and assumptions about the undocumented relationship (for bowheads) between weight of lungs and their volume. Tidal volume and oxygen consumption of bowheads are unknown, as are breathing rates in winter.

The estimate derived through consideration of heat loss and cost of motion is an intermediate estimate relative to other methods. This intermediate estimate may represent the best available estimate of the energetic requirements of bowhead whales. It is consistent with adaptation to a cold environment with relatively low food availability, and with the morphology and physiology of the animal.

Integration and Conclusions

The purpose of the project, as stated at the outset, was to compile and integrate existing traditional and scientific knowledge about the importance of the eastern Alaskan Beaufort Sea for feeding by bowhead whales; to build consensus on the need for and approach to fieldwork to augment this knowledge; to conduct the field studies and to analyze the results; to integrate them with existing traditional and scientific knowledge; and to report on and publish the results. Chapters 1–22, and the foregoing summaries of those chapters, describe the variety of studies included in the project, efforts to coordinate the work with local residents, and incorporation local knowledge of bowhead whales into the project. Chapter 23, by D.H. Thomson, W.R. Koski and W.J. Richardson, with assistance by B.F.J. Manly, draws the various lines of evidence together in order to address several key questions regarding the importance of the study area for feeding by bowhead whales. Those questions were stated in the introduction of this Executive Summary. In these final analyses, the study area is considered to extend from Flaxman Island to the Alaska/Canada border (a distance of ~205 km), and from the shore to the 200 m depth contour. This is the area outlined in Figure S.2 plus a westward extension by 20 n.mi. (37 km) to Flaxman Island.

A comparison of carbon isotope ratios in bowhead muscle and baleen with those in the main food organisms suggests that bowhead whales consume only a minority of their food in the eastern and central Beaufort Sea, including Canadian as well as eastern Alaskan waters:

- Based on stable-isotope evidence, bowhead whales likely consume only 10 to 26 % of their food in the eastern and central Beaufort Sea. Subadult bowheads appear to derive >10 % of annual food requirements there, although the 95 % confidence interval extends below 10 %. It is also probable that adults gain >10 % of their food in that area, but for adults the isotope evidence considered in isolation would support an answer of <10 %.

The isotope results are surprising in relation to several other types of evidence that show considerable feeding by bowheads in the eastern and central Beaufort Sea during summer and early autumn: • Behavioral observations show that bowheads spend much of their time feeding while in those areas. • Zooplankton sampling near bowheads feeding in those areas shows that whales concentrate their feeding at locations with much higher than average biomasses of zooplankton. • Stomach contents of bowheads harvested during late summer and autumn at three locations in the Alaskan Beaufort Sea (including Kaktovik, within the eastern Alaskan Beaufort) show that most bowheads, both subadult and adult, had been feeding shortly prior to death. • Length–girth relationships show that subadult bowheads, and possibly adults, gain weight while in the Beaufort Sea in summer, and lose weight while elsewhere. • Lipid content of blubber, at least of subadults, is higher when they leave the Beaufort in fall than when they return in spring. Although some of this evidence is preliminary and based on small sample sizes, the evidence suggests the importance of feeding in the Beaufort Sea during summer and early autumn.

A feeding scenario that might be consistent with all these data is as follows: Feeding occurs commonly in the Beaufort Sea in summer and early autumn, and bowheads gain energy stores while feeding there. However, zooplankton availability is not as high in the Beaufort Sea during summer as in the Chukchi and northern Bering seas during autumn. Also, feeding in the western Beaufort in autumn may effectively be on Chukchi prey advected to that area. Thus, bowheads might acquire more energy from Bering/Chukchi prey in autumn than from eastern and central Beaufort prey in summer/early autumn. Given this, plus an assumed low turnover rate of body components, the overall body composition of bowheads may be dominated by components from the Bering/Chukchi system even at the end of the summer when leaving the Beaufort. Energy gained in the Beaufort and Chukchi seas during summer and fall is presumably used during winter when food availability is low, resulting in reduced girth and energy stores when returning to the Beaufort Sea in spring than when leaving in autumn.

Several aspects of this scenario are speculative. Also, as noted above, it remains unclear why bowheads would migrate to the Beaufort Sea and feed there so frequently during summer and early fall if bowheads obtain little of their annual diet in that region. These uncertainties point toward topics warranting further research.

Although various types of evidence (with the exception of isotope ratios) indicate that the eastern Beaufort Sea as a whole, including the Canadian Beaufort, is important to bowhead whales for feeding, the eastern Alaskan Beaufort Sea is only a small fraction of that area. It was of interest to know how much time an average whale, and some individual whales, spend in the specific eastern Alaskan Beaufort Sea. Was there evidence of average or individual residence times of at least 7 days? Analysis of several types of data resulted in the following conclusions:

- An average bowhead spends ~3.8 days in the area from Flaxman Island to the Alaska/Canada border during the late summer/autumn period, or ~1.4 d longer than expected for a whale that swims steadily across that area. Averages in various years ranged from ~2.5 to 6.3 d. Although the average was <7 d in all years studied, it might exceed 7 days in a small minority of the years, based on the calculated upper 95 % confidence bounds.

- Of the individual bowheads that travel through the eastern Alaskan Beaufort Sea, some spend at least 7 days between the Alaska/Canada border and Flaxman Island during late summer and autumn.

What percentage of the geographic area within the eastern Alaskan study area is suitable as feeding habitat? At least 1 % in some years? At whale feeding locations in the Canadian and eastern Alaskan Beaufort Sea, zooplankton biomass at the depth of maximum biomass, where bowheads presumably fed, averaged 1.8 g/m^3 and was usually ≥ 800 mg/m^3. The latter was assumed to be the minimum biomass that was sufficient for economical feeding by bowheads.

- The percentage of the study area suitable as feeding habitat, i.e., with ≥ 800 mg/m^3 zooplankton at some depth, averaged 25 % over four years with effective echosounder sampling, and varied from 7 % to 43 % in individual years.

Two additional questions of interest concerned the proportion of bowheads that feed while in the eastern Alaskan Beaufort Sea, and the frequency with which they feed while actively traveling:

- Based on stomach content data, supplemented by behavioral evidence, far more than 10 % of the bowheads that pass through the eastern Alaskan Beaufort Sea during late summer and autumn feed there. Of the whales harvested at Kaktovik, 83 % had food in their stomachs, and 39 % had ≥20 L of stomach contents.
- Bowheads fed for an average of 47 % of their time in the eastern Alaskan Beaufort Sea during late summer and autumn. A substantial minority of the feeding occurred during travel. Among traveling whales, feeding as well as travel was occurring during a substantial percentage of the time, on the order of 43 %.

A key objective for this study was to estimate what percentage of the bowhead population's annual energetic requirements might be derived from the study area. The estimated number of whale-days in the study area during August–October averaged ~16,953 /yr across the five study years, but varied widely from year to year. Whale-days estimates were based on aerial survey data adjusted to allow for whales missed by the surveyors. Based on the whale-days estimates, and the fact that bowheads in the study area were observed to feed for 47 % of the time (9 to 67 % in different years), we estimated the number of effective feeding-days in the study area each year. Given this, the bowhead energetics model developed in the preceding chapter, and various assumptions, it was possible to estimate the fraction of the population's annual dietary requirements that might be derived from the eastern Alaskan study area:

- In an average year, the population of bowhead whales derives an estimated 2.4 % of annual energetic requirements in the eastern Alaskan Beaufort Sea. In 1 of 5 years of study, the population may have derived 7.5 % or more of annual energetic requirements from the area. Utilization of the study area varies widely in time and space depending on zooplankton availability and other factors.

In 4 of 5 study years, the bowhead population was estimated to consume <2 % of its annual requirements within the eastern Alaskan Beaufort Sea during late summer and autumn. A sensitivity analysis by Dr. B.F.J. Manly indicated that, in those four years, the upper bound of the 95 % confidence interval was below 5 %. However in 1999, when the best estimate was 7.5 %, the upper bound was 16.5 %. We suspect that the whale-days figure for 1999 was overestimated, and that the 16.5 % upper bound is unrealistically high. However, consumption in the study area during a high-utilization year might exceed 5 % of annual population requirements. Given some of the approximations that were made, these estimates are more likely to be over- than underestimates. It is implausible that the population would consume more than a few percent of its annual food requirements in the study area in an average year.

A related analysis showed that an individual whale would need to spend 10 days in the eastern Alaskan Beaufort Sea in order to consume 5 % of annual food requirements. A small (but uncertain) fraction of the individuals spend 10 days there in late summer/autumn. Few if any individuals spend 20 days in the area, which would be required to obtain 10 % of their individual annual food requirements there.

Overall, the results show that the eastern Alaskan Beaufort Sea is used for feeding to widely varying degrees depending on the year and on the individual bowhead. It is not surprising that the average contribution to the annual diet is apparently rather small: Most individual bowheads remain in that area for only a rather short period in late summer/fall, averaging ~4 days. That is too little time to allow an average bowhead to consume more than a small fraction of its annual dietary intake. Also, the eastern Alaskan study area is rather small in comparison to the overall area in the Beaufort and Chukchi seas where bowheads are known to feed. It would be unreasonable to expect that a high percentage of the annual diet would be acquired during a short stay in one small area. However, it was beyond the scope of this study to assess the importance (for feeding) of the present study area as compared to other similar-sized areas.

Bowhead whales are of great cultural importance to the Inupiat and are a major source of food. Thus, any area used by bowheads, especially when it is also a hunting area, is considered important by the local residents. No matter what percentage of the annual food requirement is derived from the eastern Alaskan Beaufort Sea, local residents will continue to view their hunting grounds as an important area for bowhead whales.

This study has devoted much effort to the integration of existing and new scientific knowledge with local and traditional knowledge. It has provided many new data concerning bowhead feeding ecology and related aspects of bowhead biology, especially in the eastern Alaskan Beaufort Sea. However, there are still numerous approximations, assumptions, data gaps, and variations of opinion regarding interpretation of data. This is inevitable in dealing with such a complex topic, especially in an environment where field studies must cope with severe logistical difficulties. The authors do not claim that the project has resolved all uncertainty about the importance of the eastern Alaskan Beaufort Sea for feeding by bowhead whales—only that much progress has been made, and that the range of uncertainty has been narrowed. One of the major outcomes of the project is to better identify the major questions that remain to be answered. A list of potential research topics is included in the "Integration and Conclusions" chapter of the final report.

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Royalty Management Program** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.

1. INTRODUCTION

W. John Richardson and Denis H. Thomson [1]

The Bowhead Whale

The bowhead whale, *Balaena mysticetus*, is a large arctic-dwelling baleen whale in the right whale family (Balaenidae). Bowheads, like other right whales, are rotund, slow-swimming whales with long and fine baleen, well adapted for filtering small prey from large volumes of water. This introductory section provides some basic information on the species. References are generally excluded, as most of this information is common knowledge, and summarized in the standard monograph on *The Bowhead Whale* (Burns et al. [eds.] 1993).

The distribution of the bowhead whale is limited to arctic and subarctic regions, rarely very far from ice. Historically there were five populations of bowhead whales distributed around the arctic. All were subject to commercial whaling before and/or during the 19th century. All five populations were greatly reduced by this whaling, and only one of the five stocks has recovered to a substantial degree. That is the Bering–Chukchi–Beaufort (BCB) population, which winters in the Bering Sea and travels north and east around Alaska to the Beaufort Sea in summer (Fig. 1.1). As of 1993, the BCB stock was estimated to contain about 8200 animals and to be increasing at about 3.2% per year. That would suggest a population of somewhat over 10,000 whales by 2000. The next census was in 2001, and preliminary results from 2001 confirm that the current BCB population is indeed near 10,000 whales and continuing to increase (George et al. 2002).

Alaskan natives conduct subsistence hunts for BCB bowheads every year. Communities in western Alaska, northeast as far as Barrow, hunt bowheads during the spring migration. Three communities along the coast of the Alaskan Beaufort Sea – Kaktovik, Nuiqsut, and Barrow – hunt bowheads during their westward migration in late summer and autumn. In recent years, the maximum allowable harvest has been about 67 bowheads struck or 56 landed per year; actual landings are generally somewhat less. The harvests have been well below the sustainable yield of the population, as confirmed by the upward trend in population size. The quota is assigned by the International Whaling Commission (IWC), and managed by the Alaska Eskimo Whaling Commission and National Marine Fisheries Service. A Special Meeting of the IWC in October 2002 provided for up to 280 bowheads to be landed in the period 2003–2006. The bowhead harvest is of great significance, both cultural and nutritional, to the communities that participate. The importance of bowheads to Alaskan natives has been a dominant factor in elevating concerns about the potential impacts on bowheads of industrial activities and other factors.

The BCB bowhead whales winter in the pack ice of the northern Bering Sea, and migrate northward into the Chukchi Sea in early spring. Most of the population travels northeastward through leads in the pack ice until they reach Point Barrow, and then travel east into the Beaufort Sea. The spring migration past Barrow is predominantly from mid-April through early June, with the subadults tending to pass first, then adults, and finally mothers with newborn calves. From the Barrow area, many bowheads

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[1] LGL Ltd., environmental research associates, 22 Fisher St., POB 280, King City, Ont. L7B 1A6. *Phone:* 905-833-1244; *e-mail:* wjr@lgl.com, dthomson@lgl.com

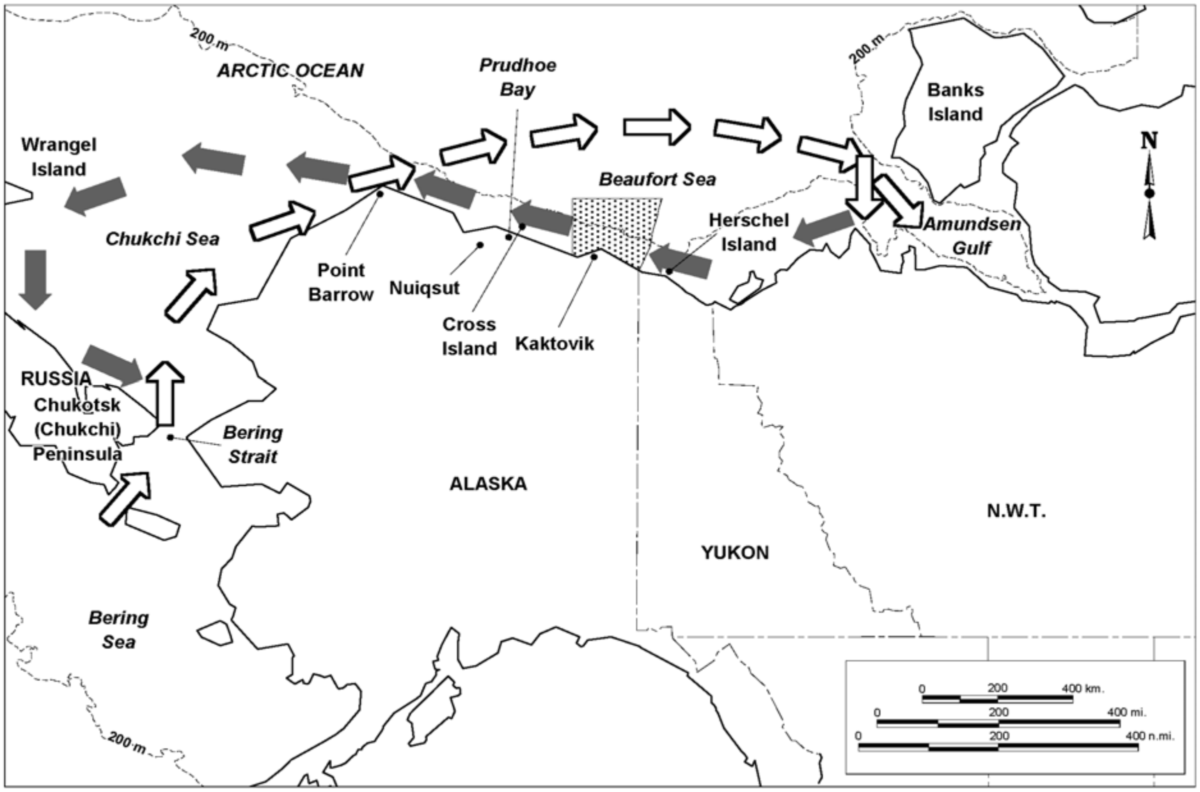

FIGURE 1.1. Seasonal migration of the Bering–Chukchi–Beaufort stock of bowhead whales, and locations mentioned in text. The "eastern Alaskan Beaufort Sea" is shaded.

travel east through cracks and leads in the pack ice until they reach more extensive lead systems in the Canadian Beaufort Sea. Little is known of their activities there until mid-summer, when the ice has usually receded and bowheads are commonly seen feeding in open waters of the southeastern Beaufort Sea and western Amundsen Gulf. In August and early September of some years, large numbers of bowheads (mainly subadults) feed in shallow waters along the north coast of the Yukon. (The adults tend to be farther offshore and east at this time.) Most summer feeding is apparently in the water column. However, bowheads are sometimes seen bringing mud to the surface, indicative of feeding near the bottom, and sometimes they are seen swimming at the surface with mouths open. In addition to feeding, summering bowheads are commonly seen to rest, socialize, or travel. They sometimes exhibit "aerial behaviors" (breaching, flipper or fluke slapping), and they occasionally play with inanimate objects such as logs.

Although most bowheads apparently move into the Canadian part of the Beaufort Sea in summer, some may not. Local residents in northern Alaska report occasional sightings of bowheads in July and August, and aerial surveys in August have found bowheads far offshore in the eastern part of the Alaskan Beaufort Sea. Also, by late August or early September, the whales that concentrate in late summer (in some years) along the Yukon coast often start to move into eastern Alaskan waters. Those whales are often seen feeding in the same ways as they feed in the Canadian Beaufort Sea. Most of the bowheads harvested in the annual subsistence hunt at Kaktovik, in the eastern Alaskan Beaufort Sea, have prey in their stomachs – predominantly copepods and to a lesser extent euphausiids and other organisms. The bulk of the westward migration from Canada into the eastern Alaskan Beaufort Sea occurs from late August until mid October.

The speed of westward travel across the Alaskan Beaufort Sea is quite variable, with some individuals traveling west rather steadily (as indicated by telemetry) but others lingering, in many cases to feed. Bowheads have often been seen to feed while traveling west, but at other times they linger in feeding aggregations, at times including tens or even hundreds of whales. In addition to the eastern Alaskan Beaufort Sea near and east of Kaktovik, concentrations of bowheads feed in waters east of Barrow in some years. Bowheads harvested at Barrow in fall frequently have much food in their stomachs, predominantly euphausiids.

From the Barrow area, many bowheads travel southwestward across the northern Chukchi Sea to the northeast coast of Russia, where feeding aggregations have sometimes been seen in autumn. There is relatively little direct information about the nature and amount of feeding along the Russian coast. Eventually these whales turn southeastward and travel through the Bering Strait toward the wintering grounds. Almost nothing is known about the activities of bowheads in winter. However, a previous study of carbon isotope ratios in bowhead prey and bowhead tissues suggested that much of the annual food intake is obtained from Chukchi or Bering Sea waters, where most BCB bowheads occur from late autumn until spring. The same study suggested that only a minority of their food comes from the eastern and central Beaufort Sea, including the eastern Alaskan Beaufort. This was surprising given the frequent observations of feeding in the Beaufort Sea, the common occurrence of food in stomachs of bowheads harvested in the Alaskan Beaufort in fall, and the fact that other baleen whales feed mainly in summer.

Bowheads are notable for their slow growth rates and long lifetimes. Calves are born in spring after a gestation period of just over one year. They remain with their mothers through the summer and autumn but most are weaned by the following spring. After weaning, their growth becomes very slow for the first few years of independent life. Bowheads do not become sexually mature for many years – much later than other baleen whales. After reaching sexual maturity, bowhead females appear to have calving intervals of 3–4 years. Recent evidence suggests that some bowheads may live to very great ages – well beyond 100 years.

Background to this Project

The purpose of the present project, as defined by the Minerals Management Service, was to compile and integrate existing traditional and scientific knowledge about the importance of the eastern Alaskan Beaufort Sea for feeding by bowhead whales; to build consensus on the need for and approach to fieldwork to augment this knowledge; to conduct the field studies and to analyze the results; to integrate them with existing traditional and scientific knowledge; and to report on and publish the results.

This feeding study was considered necessary by MMS to support environmental risk assessments, environmental impact statements (EISs), and other pre- and post-leasing decision documents for potential gas and oil leasing in the Beaufort Sea planning area.

Chapters 2 through 23 of this report are an integrated account of traditional knowledge, previous scientific knowledge, and results from recent scientific studies concerning the use of the eastern Alaskan Beaufort Sea for feeding by bowhead whales. The new data collected during this study, mainly during September of 1998, 1999 and 2000, have been supplemented with data collected earlier in and adjacent to the study area. This increases the power of analyses and provides a better basis for assessing among-year variation in the various aspects of bowhead feeding ecology.

This project is an extension of a bowhead feeding study conducted in the same area during 1985 and 1986 (Richardson [ed.] 1987). The present MMS-sponsored study is intended to provide additional data from more years, and to do so in collaboration with subsistence hunters and other local stakeholders. The 1985–86 study concluded that the eastern Alaskan Beaufort Sea did not, in those years, provide more than a small proportion of the food consumed by the Bering–Chukchi–Beaufort stock of bowheads, although the area may be important to some individual bowheads. That conclusion was controversial. The main concerns were the short duration of the previous study (two field seasons, one of which was limited by ice cover), questions about sampling designs, and difficulties in estimating food availability and consumption. Two years is too short a period in which to fully characterize use of an area by bowhead whales. Environmental conditions, and the distribution and activities of bowheads, are all known to vary widely from year to year.

The current project is similar in scope and purpose to the previous study, but includes changes and refinements to deal with concerns about the earlier study raised by the North Slope Borough's Science Advisory Committee (SAC) in 1987. The Project Plan (Thomson and Richardson 1999) was designed to take account (insofar as possible) of the main concerns about the 1985–86 work. Major differences between this study and the one done in 1985–86 are as follows:

- closer coordination with the Kaktovik Whaling Captains' Association (KWCA), North Slope Borough (NSB), Alaska Eskimo Whaling Commission (AEWC), National Marine Fisheries Service (NMFS), and industry to involve stakeholders in the project and its planning,
- use of a Scientific Review Board (SRB) including both independent scientists and representatives of the aforementioned stakeholder groups to review project plans and draft reports,
- extended use of stable isotope analyses, taking account of developments since 1985–86,
- a pilot study to investigate the potential usefulness of promising new methods of fatty acid analysis to help characterize prey types,
- use of 14 more years of bowhead distribution data, mainly based on aerial surveys conducted annually by MMS (total of 21 years now available),
- addition of 3 more years of specific feeding studies in the eastern Alaskan Beaufort Sea (total of 5 years now available), and
- most importantly, greatly increased efforts on local coordination, with the objective of ensuring that key stakeholders support the need for the project, its objectives, its methods, and the interpretation of its results.

Where appropriate and possible, methods applied during the new three-year study were consistent with methods used during the 1985–86 study. Thus, there are now consistent data from five years, supplemented by additional data (e.g., aerial surveys) from other years, with which to address the main objectives and hypotheses.

Objectives of the Study

The objectives of this study are listed below. References to "Year 1" refer to mid-1997 through mid-1998. Year 2 began in mid-1998 and included the September 1998 field season. Year 3 began in mid-1999 and included the September 1999 field season. Year 4 began in mid-2000 and included the final field season in September 2000.

1. *Use existing data (traditional and scientific) to assess when and how feeding bowheads can be recognized and distinguished from those engaged in social/milling and other behaviors (Year 1), and distinguish those activities whenever possible during field studies (Years 2–4).*

2. *Mutually develop hypotheses that scientists and subsistence whale hunters concur can be successfully tested to determine and quantify the relative importance of the eastern Alaskan Beaufort Sea as a feeding area for bowhead whales (Year 1).*

3. *Design (Year 1) and conduct (Years 2–4) research appropriate for testing the above hypotheses and for quantifying potential feeding by bowhead whales in the same area.*
4. *Analyze previous and updated scientific information, summarize pertinent knowledge of area subsistence whale hunters, and, where possible, test the above hypotheses and quantify bowhead area feeding for previous years (Years 1 and 2–4).*
5. *Use historical satellite and aerial survey data to search for links between spatial or temporal patterns in bowhead feeding vs. ambient oceanographic conditions (Year 1). If links are evident, use all available data to characterize those links (Year 4).*
6. *Summarize (Year 1) and update (Year 4) available information, including traditional knowledge, on the effects of acoustic and visual disturbance to bowhead whales (or other planktivorous whales) engaged in apparent feeding behavior. This is considered to be a secondary objective.*
7. *Use the above information to determine and quantify the relative importance of the eastern Alaskan Beaufort Sea as a seasonal feeding habitat for bowhead whales (Year 4).*

Also, although the limited available pre-1998 and 1998–2000 satellite data on sea-surface conditions were acquired, these data were not used in any detailed way. All other objectives listed above were addressed in detail.

Study Area and Periods

Why Concentrate on the Eastern Alaskan Beaufort Sea?

The eastern part of the Alaskan Beaufort Sea has been known for many years as an area where bowhead whales commonly feed during late summer and early autumn. By the early-mid 1980s, it was recognized that, in some years, considerable numbers of feeding bowheads occur in that area, especially in September (e.g., Johnson 1984). By that time it was also known that there is zooplankton – mainly copepods and euphausiids – in the stomachs of most bowheads harvested in autumn near Kaktovik (e.g., Lowry and Burns 1980; Lowry and Frost 1984). It was recognized that some feeding occurs farther west during autumn, especially in the area just east of Barrow, but feeding frequency seemed to decrease as bowheads moved west through the Alaskan Beaufort during autumn (Ljungblad et al. 1986). Whether there really is such a decrease is uncertain, as specific studies of feeding have not been done in the central and western parts of the Alaskan Beaufort Sea. In fact, feeding frequency may be as high or higher just east of Barrow than in more easterly parts of the Alaskan Beaufort (Treacy in prep.). Most bowheads harvested at Barrow in fall have been feeding shortly before death (Lowry 1993; see also Chapter 18 of this report). However, during the early-mid 1980s the eastern part of the Alaskan Beaufort Sea was judged to be of special significance to bowheads. Now-available data confirm that it is, at the least, one of the parts of the Alaskan Beaufort where feeding is common in late summer and early autumn.

Given the concern in the mid-1980s about the importance of the eastern Alaskan Beaufort Sea as a feeding area, MMS sponsored an intensive study of bowhead feeding in that area during 1985–86 (Richardson [ed.] 1987). That study concentrated on the area from eastern Camden Bay (144°W, just west of Kaktovik) to the Alaska–Canada border, and from the shore to the 200 m depth contour roughly 50–65 km offshore (Fig. 1.2). However, some attention was also given (via aerial surveys) to deeper waters north of the 200 m contour.

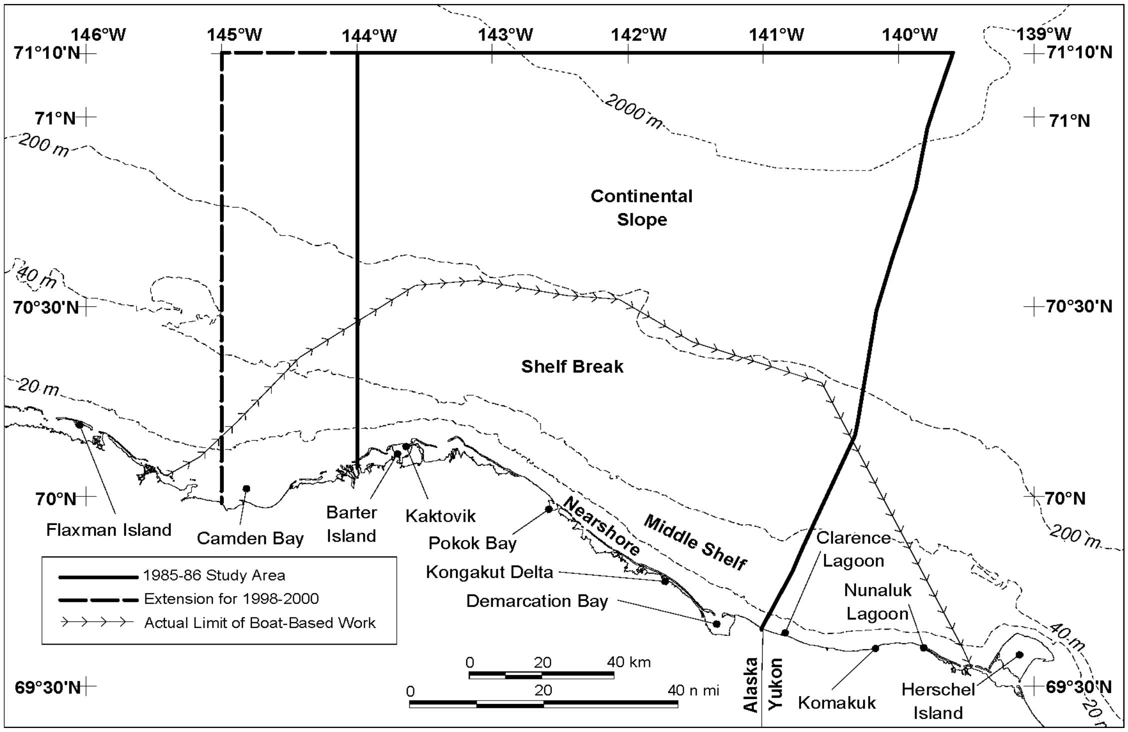

FIGURE 1.2. The eastern Alaskan Beaufort Sea and adjacent waters, showing the areas identified as the primary study areas for the 1985–86 and 1998–2000 feeding studies.

The 1985–86 study concluded that, in those years, the eastern Alaskan Beaufort Sea did not provide a very high proportion of the annual energy requirements of the bowhead population, although food from that area may have been important to some individual bowheads that fed there longer than did the average whale. That conclusion was controversial. Among other concerns, the Science Advisory Committee of the North Slope Borough concluded that the 1985–86 study did not cover a sufficient number of years to justify any general conclusion about the importance of the area. This conclusion, and subsequent expressions of concern about the adequacy of the 1985–86 study, was one of the main reasons why MMS decided to sponsor a follow-up study in the same general region, with amendments in study procedures to address the concerns about the 1985–86 study.

It is well known that much feeding by bowheads occurs elsewhere, both farther east in the Canadian Beaufort Sea during summer (e.g., Würsig et al. 1985, 1989; Bradstreet et al. 1987), and farther west in the Alaskan Beaufort Sea and the Chukchi Sea during autumn (e.g., Lowry 1993; Landino et al. 1994; Moore et al. 1995). There is also a limited amount of feeding along the spring migration route (Carroll et al. 1987; Lowry 1993; Richardson et al. 1995). Evidence from stable isotopes suggests that feeding is, in fact, predominantly in Bering and Chukchi waters (Schell and Saupe 1993). The eastern Alaskan Beaufort Sea constitutes only a small percentage of the total range of the BCB bowheads, and likewise only a small percentage of the part of that range where feeding is known to occur (Fig. 1.1). The MMS-sponsored feeding study in 1985–86 concentrated on the eastern Alaskan part of the Beaufort Sea because, of the feeding areas under MMS jurisdiction (waters off Alaska), the eastern Alaskan part of the Beaufort Sea was of particular concern in the mid-1980s. The study area for the current 1998–2000 study was similar because of continued interest in that area, and because of a desire to resolve questions that had been raised about the results of the initial 1985–86 study.

Specific Study Area Boundaries

As noted above, the study area for the 1985–86 project extended from eastern Camden Bay, just west of Kaktovik (144°W), to the Alaska–Canada border (141°W at the coast), and from the coast offshore to the 200 m contour (intensive effort) and beyond (aerial surveys only). During the planning process for the present study, we reviewed the available information available from a wider area, from Flaxman Island near the western edge of Camden Bay (146°W) to Herschel Island some 75 km into Canadian waters (139°W). Based on that review, advice from Kaktovik whalers (see Chapter 2), and advice from the project's Scientific Review Board (SRB), it was decided to extend the primary study area westward by 1° of longitude (37 km) as compared with the western edge of the 1985–86 study area. This placed the new western boundary near the middle of Camden Bay (145°; Fig. 1.2). Also, with SRB concurrence, it was decided to further de-emphasize efforts in deep offshore areas in order to concentrate available resources in the shallower areas of particular concern to Kaktovik hunters and (potentially) the oil industry. During the 1998–2000 study, boat-based zooplankton sampling was limited to areas seaward to the 50 m contour (vs. 200 m in 1985–86). However, our standard aerial survey coverage in 1998–2000 extended to the 200 m contour, and in those years less intensive aerial survey coverage was obtained farther offshore by ourselves and as part of the broad-scale aerial survey program conducted by MMS (Treacy 2000, 2002).

Although the official study areas for the 1985–86 and 1998–2000 projects were as defined above, relevant data of various types were obtained from adjacent areas to the west, north, and east. For example, the aerial surveys conducted or sponsored by MMS each year since 1979 have extended slightly east and far west of the official study areas for the 1985–86 and 1998–2000 feeding studies. Behavioral observations of bowheads, and aerial photogrammetric data on bowheads, have also been obtained from areas farther east and west during certain years. Other bowhead feeding studies, especially in Canadian waters (e.g., Bradstreet et al. 1987), provide data that are relevant in interpreting the data from the specific "eastern Alaskan" study area. The overall approach in this study was to make use of relevant data from other projects when appropriate, thereby expanding the available data and strengthening the conclusions that can be drawn. Thus, in some chapters of this report, we include data from areas bordering the official study area. For each chapter or analysis, we have described the area in which data were collected or assembled. This inclusive approach causes some complications in deriving averages and estimates specific to the official study area, as described in various chapters. However, within limits, the advantages of larger sample size and broader perspective outweigh the disadvantages.

Study Periods

Years.—The specific MMS-sponsored studies of bowhead feeding in the eastern Alaskan Beaufort Sea were in 1985–86 and 1998–2000, for a total of five late summer/early autumn seasons. However, bowhead utilization of that area was documented in at least a general way during other years in the 1979–2000 period. MMS conducted or sponsored systematic aerial surveys including the eastern Alaskan Beaufort Sea in all of those years aside from 1980. In addition to the broad-scale MMS aerial surveys and the additional surveys conducted in 1985–86 and 1998–2000 as part of the feeding studies, other industry-sponsored or Canadian-based aerial surveys covered parts of the eastern-Alaskan study area in certain years. Aerial surveys in years other than 1986–86 and 1998–2000 were used to obtain an extended (in time) perspective on utilization of the study area. Comparison of aerial survey data from the five feeding-study years vs. other years provides information as to how representative the feeding-study years were. Chapter 9 of this report summarizes the aerial survey data from 1979 to 2000.

Whalers and other local residents also provided information about certain whale activities in the eastern Alaskan study area during some years aside from the five feeding-study years. Most of the Kaktovik residents who provided us with Local and Traditional Knowledge (LTK) have lived and hunted in the study area for several decades, and are very familiar with year to year variability in use of the area by bowhead whales. The information that they provided is summarized in Chapter 2 and in Annex B (in volume 2). As with the aerial survey information, LTK provided an additional basis for judging whether the detailed results from the five feeding-study years were representative.

Samples of bowhead stomach contents from whales harvested at Kaktovik were available not only from the feeding-study years (except 1985, when no bowheads were taken at Kaktovik) but also from 1997 and various other years (see Chapter 18). Only a very small number of samples of bowhead stomach contents can be obtained at Kaktovik each year given the low number of animals harvested there per year (maximum of 3 in most recent years, not all of which contain prey when landed). However, the samples from other years broaden the perspective.

Study Dates.—Boat-based fieldwork was conducted for about 2 weeks during early-to-mid or mid-to-late September of 1985–86 and 1998–2000. Aircraft-based fieldwork specifically for the feeding study occurred for 3–4 weeks during September in each of those years. These main field periods occurred during the time of peak occurrence of bowheads in the study area. However, these periods began after bowheads first arrived in the area (especially in 1998–2000), and ended well before the end of the bowhead migration. Indeed, it is possible that some bowhead whales are in the general area throughout the summer, given the occasional sightings of bowheads in the area during July (see Chapter 2). However, the scarcity of summer (as compared with fall) sightings indicates that bowheads are present in summer only sporadically and/or in low numbers, at least in the nearshore areas that are of most concern.

The limited duration of the main field periods during the five years of the feeding studies was a result of several factors:

- limited resources that precluded intensive operations throughout the whale migration season;
- a desire (during the 1998–2000 study) to sample in three additional years rather than concentrate a fixed amount of effort into two longer field seasons;
- an agreement with the Kaktovik hunters, during each of 1998–2000, to avoid boat-based sampling east of Kaktovik until after two bowheads had been harvested; and
- a serious risk that ice would interfere with boat operations, including safe return of the boat to Prudhoe Bay, if sampling continued into October. The 1985 field season was, in fact, curtailed early because of an incursion of pack ice that threatened to trap the sampling vessel.

To help interpret the results of the September sampling, we took advantage of several supplementary sources of data that provided information about whale use of the study area during a larger fraction of the migration period. These additional sources of information included

- MMS and other aerial survey data (1979 to 2000), typically extending from about 1 September until early or mid October, and occasionally late October; from 1979 to 1986, aerial survey data were also available from the present study area during much of August (see Chapter 9);
- local knowledge, as assembled through meetings and discussions with individual residents of Kaktovik (see Chapter 2 and Annex B); and
- boat-based reconnaissance surveys near Kaktovik during late August (mainly of 2000), as suggested by Kaktovik residents (see Chapter 2).

We acknowledge that the intensive feeding study work did not extend through the full period while bowhead whales are present in the eastern Alaskan Beaufort Sea. However, it did occur during the time of peak utilization of that area by bowhead whales, as documented by aerial surveys. It would be interesting to have specific information about food availability and whale feeding during the early and late parts of the late summer/autumn season. However, we believe that the various sources of data, in combination, provide a reasonable basis for assessing the overall importance of the study area for feeding by bowhead whales.

Project and Report Title

The title of the present final report is the title that was assigned to the 1998–2000 feeding study by MMS in the "Request for Proposals" (April 1997) and in the contract:

> "*Bowhead whale feeding in the eastern Alaskan Beaufort Sea: Update of Scientific and Traditional Information*"

The Scientific Review Board suggested, at its January 2002 meeting, that the final report be given a title including more specific details concerning the study area and study period. However, the areas and periods of study depended on the type of data being collected. Any attempt to be more precise leads to a long and cumbersome title. These matters are discussed further in Annex A (in volume 2). We decided to retain the original project title as the report title; it accurately represents the overall study scope, and maintains continuity with titles used earlier in the project.

Questions to be Addressed

Questions to be addressed by the study were developed around the study objectives. The study design was, in turn, based in large part on these questions.

A set of general hypotheses was developed during Year 1 and included in the Project Plan (Thomson and Richardson 1998). An updated set of seven hypotheses was subsequently developed that included specific cutpoints such as numbers of days whales might spend in the study area and percent of time they might spend feeding. In selecting cutpoints, we took the view that small differences in food intake may have major consequences for individuals and populations. Insufficient food intake might cause reproductive failure and retardation of the age at maturity, among other effects. Thus, some of the cutpoints that we used in the revised hypotheses were relatively low values. These hypotheses were not conventional "null" and "alternate" hypotheses. Following review of the draft final report by the project's Scientific Review Board (see Annex A), it was agreed by all concerned that these hypotheses should be re-phrased as research questions that were addressed by the project.

Question (1)

The overall question addressed during this study is as follows:

> *In an average year, how important is the eastern Alaskan Beaufort Sea for bowhead whales; what percentage of the population's annual energetic requirements is derived from the area?*

This overall question is addressed by considering many different types of data acquired or assembled during the project (see Chapters 2 – 22), integrated by means of an energetic model (Chapter 22). Here, as in the more specific questions listed below, the project aims to estimate an actual value rather than simply determine whether the value is above or below some specified cutpoint. However, for Questions 2 – 6, the cutpoints included in the (former) hypotheses have been retained. We consider these cutpoints to represent levels of feeding activity that, if exceeded, would indicate substantial feeding in the area.

Question (2)

> *How much of its annual food requirements does the Bering–Chukchi–Beaufort (BCB) population of bowhead whales derive in the eastern and central Beaufort Sea? At least 10 percent?*

This question is to be addressed by examining isotopic composition of bowhead tissue in spring and fall, and of prey tissue through the range of the bowhead whale. Presently-available stable isotope techniques cannot discriminate food acquired in the Canadian vs. the eastern Alaskan Beaufort Sea. As written, this is an important and potentially answerable question *if* there is consensus about the applicability of the stable isotope method to this question. If it is established that bowheads derive little of their annual food requirements from the larger area (eastern and central Beaufort Sea), as previous isotope data suggest (Schell and Saupe 1993), then the smaller "eastern Alaskan Beaufort Sea" would necessarily provide an even smaller proportion of the population's annual energetic requirements. However, before the isotopic method could be accepted as resolving this matter one way or the other, the applicability of this method needed further consideration. Results of earlier isotopic studies (and of some of the additional isotopic work described in Chapter 20) are surprising in light of several other types of evidence documenting frequent feeding in the eastern and central Beaufort Sea during summer and early autumn. Also, a related isotope-based study (Hoekstra et al. 2002) has provided some data that differ from those of the present study. These data need to be compared and reconciled. This topic is addressed in Chapters 20–23.

Question (3a)

> *Of the bowheads that travel through the eastern Alaskan Beaufort Sea, how long does an average whale spend there? At least 7 days?*

Question (3b)

> *Of the individual bowheads that travel through the eastern Alaskan Beaufort Sea, how long do some individuals spend there? At least 7 days?*

These two related questions can be answered based on evidence concerning residence times, including aerial photogrammetric data documenting residence times of individually-recognizable bowhead whales, previously-reported telemetry data, etc. The question has been split into two because there are distinct questions about the importance of the study area to certain individual whales vs. the population as a whole. The 7-day cutpoint is substantially less than the duration of each field season. Several sources of data such as behavioral observations and stomach contents show that most if not all whales that travel through the eastern Alaskan Beaufort Sea feed there to at least a limited extent. Thus, total residence times in the area can be assumed to be closely related to the importance of the area for feeding.

Question (4)

> *What percentage of the bowheads that pass through the eastern Alaskan Beaufort Sea feed there? At least 10 percent?*

This question addresses the proportion of the whales passing through the area that feed. This can be answered with two independent types of data: stomach content data from the Kaktovik harvest, and behavioral observations.

Question (5)

> *What percentage of the geographic area within the study area is suitable as feeding habitat in different years? Is at least 1% of the study area suitable in some years?*

This question can be answered through boat-based observations of the quantities and types of zooplankton present at locations where bowheads feed, the spatial extent of such plankton concentrations, and the stomach contents of bowheads harvested near Kaktovik. Dense concentrations of zooplankton tend to occupy only a small proportion of the available space in the world's oceans. One percent of the study area would represent a large amount of feeding habitat and a large quantity of potential food.

Question (6)

> *During migration through the eastern Alaskan Beaufort Sea, how often are bowheads observed to feed while they are traveling? Is feeding while traveling evident more than 10% of the time while traveling?*

This question can be addressed based on aerial observations of the activities of whales in the study area during late summer and fall, taking account of such indications of feeding such as surface feeding, defecation, and surfacing with mud streaming from the mouth. One concern in addressing this question is the reliability with which water column feeding can be recognized, especially during travel. Failure to detect much feeding while traveling would not necessarily lead to a conclusion that feeding while traveling is rare. However, if traveling whales are seen to feed more than 10% of the time, we could conclude that feeding while traveling is fairly common. This question is important to the overall objectives of the study. If a large proportion of the population feeds while actively migrating through the area, then a large amount of food would be consumed.

In general, the project plan calls for us to determine if the study area is important to feeding bowhead whales in the following way:

- determine if numbers of animals remain in the study area for an extended period of time,
- determine what proportion of these animals are feeding,
- describe the zooplankton and hydrography near feeding whales,
- attempt to locate and characterize whale feeding habitat,
- determine what the whales are eating through examination of stomach contents and fatty acid analysis, and compare stomach fullness and contents between Kaktovik and Barrow,
- determine how much feeding occurs in the eastern and central Beaufort Sea through isotopic studies, and
- estimate the annual energetic requirement of the population (based on an updated energetics model), and estimate what proportion of this is acquired in the study area.

These tasks have all been done, with the exceptions that the fatty acid study was limited to a pilot project, and the results of the stable isotope study remain difficult to reconcile with those of other study components.

Study Components

Present Study Components

The project included

- *retrospective studies* and compilation of *local and traditional knowledge* about bowhead whales in and near the study area; this work was conducted primarily in Year 1 (1997–98) but was later updated for inclusion in this final report;
- *boat-based sampling of prey (zooplankton)* via net-sampling and echosounder methods during 1998–2000, plus use of comparable data collected during 1985–86;
- *aircraft-based surveys, behavioral observations, and photogrammetry/photoidentification of bowheads* during 1998–2000, plus use of comparable data collected during 1985–86, other aerial survey results from 1979–2000, and behavioral and photographic data from various years;
- collection and analysis of *bowhead stomach contents* in 1997–2000, plus analysis of additional

archived samples from earlier years, to document diet directly;

- *stable-isotope* and *fatty acid* analyses of tissue samples from bowheads and potential prey to document trophic relationships (fatty acid work was limited to a pilot study);
- data analysis;
- integration; and
- preparation of reports and publications.

***Retrospective Studies*.—**The retrospective analyses conducted during Year 1 (1997–98) included several different studies, the results of which were reported in a draft report to MMS and the project's Scientific Review Board during July 1998. The final reports of each of these retrospective studies were submitted in September 1999 as part of Richardson and Thomson (eds., 1999). Most of that material has been incorporated into relevant chapters of the present report, most notably

- Chapter 2, local and traditional knowledge,
- Chapters 5 and 6, zooplankton and water masses in the study area, both generally and at specific bowhead feeding locations,
- Chapter 9, bowhead distribution and abundance from aerial surveys,
- Chapter 18, bowhead stomach contents, and
- Chapter 20, regional feeding as evident from stable isotopes.

In addition, most of the other major chapters of this report, specifically Chapters 4, 10–15, and 22, also incorporate data from studies conducted previous to 1998, even though the Year 1 work did not specifically include retrospective analyses of those topics.

***Project Plans*.—**A Project Plan for the work in years 2–4 was prepared in 1998 based on the results of the retrospective and traditional knowledge studies. A draft of that plan was presented to the SRB in July 1998 for its evaluation and comments. The final Project Plan, dated 31 August 1998, was prepared taking those comments into account (Thomson and Richardson 1998). Studies conducted during year 2 (1998–99) were based on this plan. A Project Plan for years 3 and 4 (1999–2001), dated 21 May 1999, was presented at the June 1999 SRB meeting. This project plan was revised to account for comments and suggestions made by the SRB and was submitted in final form in August 1999 (Thomson and Richardson 1999).

***Project Reports*.—**A final report on the retrospective studies and on fieldwork during September 1998 (years 1 and 2 of the study) was distributed in September of 1999 (Richardson and Thomson 1999). The data collected during the second season of intensive fieldwork (September 1999) were presented in an interim report circulated in July 2000. No further substantive changes to the study plan were recommended or implemented based on the data presented then. The present final report includes the first presentation of data from the third season of intensive fieldwork (September 2000) plus all relevant data from earlier years. Much additional analysis of data from years previous to 1998 has also been done for the present final report. *The present report supersedes all previous project reports.* The organization of the present report is described later in this Introductory chapter.

***Project Participants*.—**The prime contractor for this project (and for the related 1985–86 feeding study) was LGL Ecological Research Associates Inc. and its affiliate LGL Ltd., environmental research associates. LGL was responsible for the boat-based studies of zooplankton (Chapters 3–7), the aircraft-based studies of bowheads (Chapters 8–16), the energetics and integration tasks (Chapters 22–23), and management aspects of the project. Several personnel from *BioSonics Inc.* assisted LGL with collection and analysis of echosounder data on zooplankton. Consultant *Dr. Bernd Würsig* of Texas A & M University at Galveston worked with LGL on aircraft-based studies of bowheads.

Several chapters of this report have been contributed by others. Consultant *Michael Galginaitis* of Applied Sociocultural Research, Anchorage, was responsible for working with Kaktovik residents to compile local and traditional knowledge (LTK; Chapter 2); he also undertook or assisted with various local coordination tasks. Stomach contents of bowheads landed at Kaktovik and elsewhere were determined by the Alaska Department of Fish and Game (ADF&G), principally *Lloyd Lowry* and *Gay Sheffield* (Chapter 18). The pilot study on fatty acids was done by *Dr. Sara Iverson*, Dalhousie University, in collaboration with ADF&G (Chapter 19). The stable isotopes study was done by *Dr. Don Schell* and *Sang Heon Lee*, University of Alaska Fairbanks (Chapter 20). Sensitivity analyses for some key calculations have been done by *Drs. Bryan Manly* and *Trent McDonald* of WEST Inc. (Chapters 20, 23).

Many others assisted in numerous ways, as acknowledged near the end of this chapter and (more specifically) near the ends of many of the subsequent chapters.

Other Potential Study Components

An up-to-date model concerning the energetics of bowhead whales was needed for this project. A previous energetics model, developed during the 1985–86 bowhead feeding study, was available (Thomson 1987). Also, J.C. George of the North Slope Borough Department of Wildlife Management has been conducting research in this area. We deferred updating our model until the last year of the project in order to take account of the latest available information. This updating has now been done in collaboration with J.C. George. The updated model is described in Chapter 22 of this report.

No analysis of satellite images was done. Borstad Associates, who conducted the retrospective analysis of satellite imagery, obtained and archived AVHRR satellite images during late summer and early autumn of 1998–2000 to ensure that they would be available if needed, but performed no processing of the images.

Fatty acid analysis of bowhead tissue and prey might be able to provide information on what kinds of animals are eaten. If so, this type of analysis would provide data on diet over a longer time scale (and thus over a larger area) than can be obtained from sampling of stomach contents. Samples of bowhead tissue and zooplankton suitable for fatty acid analysis were collected in 1998–2000 but were not initially analyzed. A pilot study was done and the results are reported in Chapter 19. Although the results show promise for helping to elucidate bowhead trophic relationships, this pilot study was not carried sufficiently far to provide much information relevant to the overall objectives of the present project.

MMS originally requested that the present study include some acoustic components. This work would have been peripheral to the main objectives of the project. In the interest of devoting limited resources to key tasks, the SRB indicated that acoustic modeling work, if deemed important, should be funded separately. No acoustic work was done as part of this project.

There was also some discussion of incorporating radio- or satellite-tagging into this project. All concerned have recognized the potential value of this. However, funding for a tagging component was not available. The SRB noted (most recently in 1999) that tagging should only be incorporated if it could be separately funded. No radio- or satellite-linked tags were deployed during the present project. When reviewing the draft of this report, the SRB again commented on the potential value of a separate radio- or satellite-tagging study (see Annex A in volume 2).

Integration

Integration across disciplines has occurred to some extent throughout all phases of the project, and is a central feature of the present final report. Each study component was designed so as to provide the data needed by other study components. The cross-disciplinary data needs were taken into account during planning, fieldwork, analysis, and reporting.

A primary requirement was to ensure that, by the latter stages of the project, we would have all the data necessary to test key questions and to assess the importance of the study area for feeding by bowhead whales. This integrated assessment requires the following:

- description of zooplankton distributions in terms of physical habitat,
- description of whale distributions in terms of the biophysical attributes of the study area, such as depth, water mass characteristics, and zooplankton distributions,
- description of bowhead feeding areas in terms of zooplankton, water mass characteristics, and presence of feeding and non-feeding bowhead whales,
- estimates of theoretical energetic requirements of bowheads, and a comparison with zooplankton biomasses near feeding bowheads,
- estimates of the amount of feeding in the Beaufort sea vs. other areas, and the contributions of various prey taxa to the bowhead diet,
- an estimate of the percentage of the study area with suitable feeding habitat for bowheads,
- estimates of numbers and residence times of bowheads in the study area,
- an estimate of the percentage of time that bowheads in the study area spend feeding, and
- an estimate of the relative importance of the study area for individual whales that feed there for extended periods.

A stated objective of this integration was to set bounds on the overall energetic importance of the study area to the population as a whole, as estimated from calculated feeding rates and estimated whale-days of feeding within the study area.

Data bearing on these topics are included in various chapters of this report. Figure 1.3 shows many of the main connections among the various project components. Each box in Figure 1.3 represents one of the main chapters of the present report. Some additional connections are excluded in order to avoid further complicating the Figure. The overall integration is done in Chapter 23.

Local Coordination

From the earliest phases of planning, local cooperation and participation were considered critical to the success of the study. Including the July 1998 SRB meeting, we met with representatives of the Kaktovik Whaling Captains Association (KWCA), Alaska Eskimo Whaling Commission (AEWC), and North Slope Borough (NSB) on six occasions during Year 1 to seek traditional knowledge and advice on project design, and to coordinate fieldwork with the bowhead hunt. These meetings were in Kaktovik during December 1997 and January 1998, Barrow in May, Kaktovik in July, Anchorage in July (SRB), and Kaktovik in August 1998. We again met with the KWCA, AEWC and NSB during the June 1999 SRB meeting. One or more project participants also met with some whaling captains and other Kaktovik residents in Kaktovik during June and early September 1999, and August 2000, to further coordinate planned fieldwork with whaling activities during those years. One key objective of all these meetings was to develop and refine a field plan that whalers would accept as non-interfering and likely to be effective in assessing the importance of the area to feeding by individual bowheads and the population.

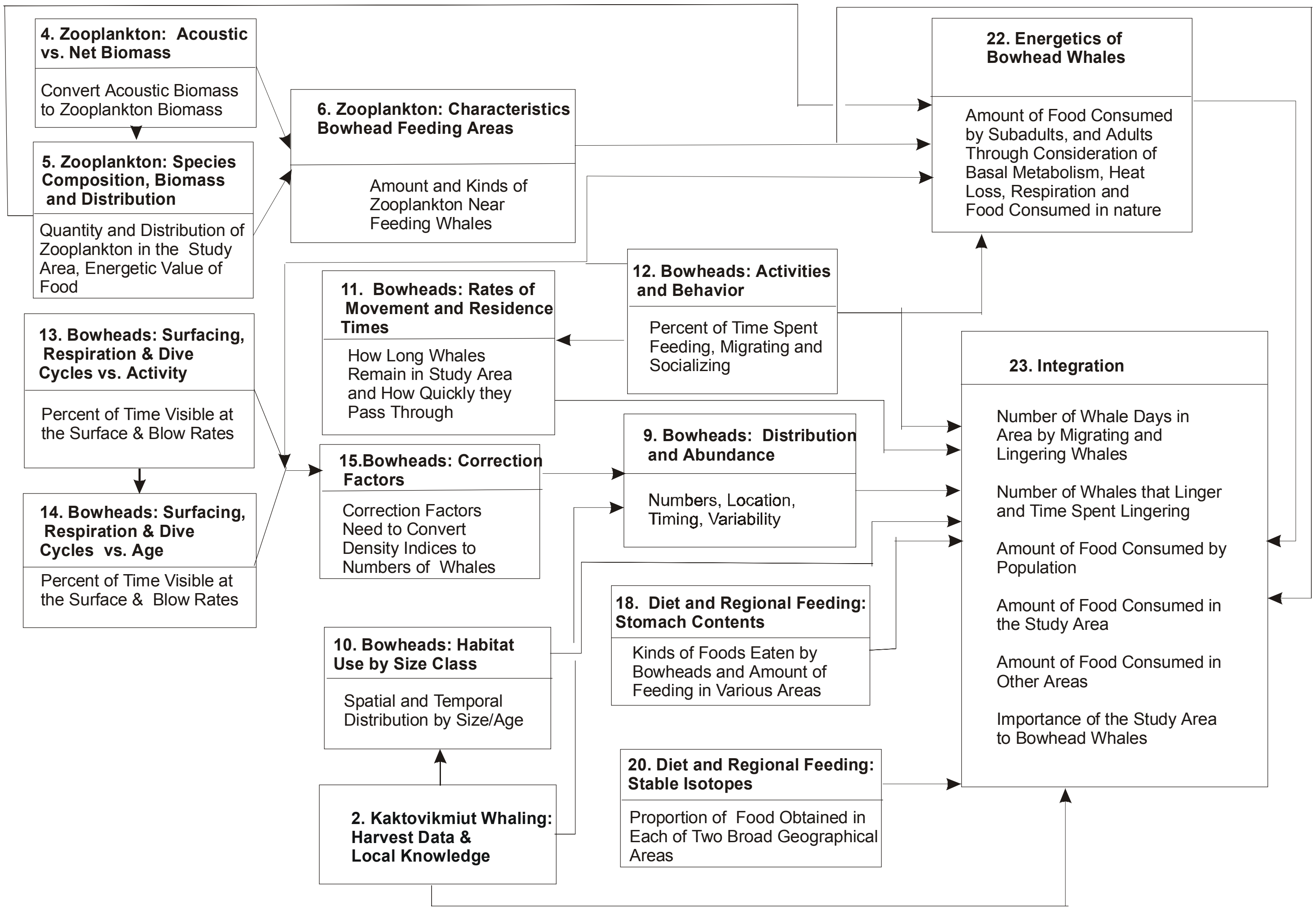

FIGURE 1.3. Major linkages among feeding study tasks and report chapters.

Key items discussed at the meetings and incorporated into the Project Plan were as follows: (1) Kaktovik residents were to be directly involved with the project through participation in the boat-based field sampling in September of 1998–2000, conduct of boat-based reconnaissance surveys during August 1998–2000, and participation on the Scientific Review Board. (2) Aircraft-based field work was permitted east of Kaktovik during the whaling season, provided that the aircraft did not fly over whaling operations and that a radio communications protocol was established for coordination. (3) Boat-based work would not be conducted east of or near Kaktovik until after whalers landed their second whale. In 2000, because whalers landed their third whale early in the season (8 Sept.), boat-based work was not conducted until after the third whale was landed. (4) An LGL representative would attend the pre-whaling-season meeting of the Kaktovik Whaling Captains' Association during each year of fieldwork (see preceding paragraph). (5) LGL's aerial survey crew would be based in Kaktovik during the 1998–2000 field seasons, facilitating local coordination. (6) Subcontractor ADF&G would station a biologist in Kaktovik during the 1998–2000 whaling seasons (as they had done in 1997) to collect stomach content and bowhead tissue samples from bowheads landed at Kaktovik.

As noted in (1), above, direct participation of Kaktovik residents in the project included three main components:

- A Kaktovik resident (Mr. Leonard Solomon) was employed to work aboard the zooplankton sampling vessel during September of 1998, 1999, and 2000. He served as a full member of the zooplankton sampling team, helped in spotting whales, and provided another line of communication with the local community.
- The Kaktovik hunters recommended that a "local boat" survey be initiated during August to determine whether the vanguard of the migrating bowheads reaches the area before aerial surveys commence in September. This was to be a cooperative effort involving locally-based boats operated by knowledgeable hunters, plus a biologist or subsistence specialist from the project team. Arrangements were made to conduct local-boat surveys during late August of 1998–2000, earlier in the season than any aerial surveys planned for those years. The "local boat" surveys were attempted by the project's sociocultural specialist, Mr. Michael S. Galginaitis, with the cooperation of several Kaktovik residents and boat-owners. Results are described in Chapter 2. These boat surveys were most successful in 2000.
- From the start of the project, the project's Scientific Review Board has included a representative of the Kaktovik Whaling Captains' Association (KWCA), Mr. Joseph Kaleak. Mr. Kaleak was President of the KWCA during the early stages of the project, and is Kaktovik's senior representative on the AEWC (Alaska Eskimo Whaling Commission). The SRB also includes representatives from the AEWC and the North Slope Borough Department of Wildlife Management (NSB–DWM).

In order to present the results of the project to Kaktovik residents and to seek input on their interpretation, a one-day workshop in Kaktovik held 31 January 2002. Representatives of the AEWC and NSB also attended, along with the chair of the project's SRB. Representatives of the project team presented the key results and our interpretation of those results. Representatives of the SRB attending the workshop were able to convey the SRB's views regarding the results and their interpretation. We sought feedback from workshop participants on all aspects of the project. This has been taken into account when revising the draft final report to produce the present final report. As requested at the 31 January 2002 workshop, we plan that project representatives will return to Kaktovik in late 2002 to describe how the SRB and local comments were taken into account in the final report.

Scientific Review Board

The purpose of the SRB was to evaluate all aspects of the study, with a view to improving study design and interpretation, and to help build consensus among stakeholders. The SRB included representatives of key stakeholders as well as independent scientists. The SRB included a representative from each of the KWCA, AEWC, NSB–DWM, oil industry (2 representatives), NMFS, and three knowledgeable independent scientists. MMS asked that the SRB meet in Anchorage three times during the project to review draft plans for the coming field season and/or the draft report for the previous year.

The first SRB meeting was held in Anchorage on 20–21 July 1998. That meeting discussed a draft Project Plan that had been circulated before the meeting, and made recommendations regarding project plans and priorities.

The second SRB meeting was held in Anchorage on 3–4 June 1999. The SRB reviewed the draft report on the fieldwork conducted in 1998, and the proposed plan for work in August–September 1999. During the June 1999 SRB meeting it was agreed that no SRB meeting would be held in 2000, but that the report on results from the 1999 field season would be circulated to SRB members for comment prior to the 2000 field season. (That report was provided to the SRB in July 2000.)

A third and final meeting of the SRB was held in Anchorage on 28–29 January 2002. The purpose was to review the draft final report circulated before that meeting, and to make recommendations that should be taken into account while the report is being finalized. We expected that the SRB would also make other comments and recommendations concerning the overall outcome of the project. The report compiled by the SRB based on their January 2002 meeting is included as Annex A near the back of the present report (in volume 2), along with responses by project participants to some SRB comments.

Scientific Research Permits

A Scientific Research Permit under the provisions of the Marine Mammal Protection Act (MMPA) and Endangered Species Act was obtained from NMFS for the 1998 and subsequent field seasons. We requested that the permit cover the project activities near Kaktovik during 1998 through 2000, and permit number 481–1463 was issued on that basis. In 1999, a permit modification was received to authorize collection of stomach contents and tissue samples from bowheads landed at other Alaskan communities, as well as extension of aircraft operations near bowheads to the Prudhoe Bay area, where a test of a Forward Looking Infrared device was planned and conducted.

We also applied for and received permits to extend some of the work into Canadian waters between the Alaska–Yukon border and Herschel Island (~40 n.mi. to the east, Fig. 1.2) if this proved to be advantageous. These permits were issued by Fisheries and Oceans Canada and by the Environmental Impact Screening Committee of the Inuvialuit Joint Secretariat. The latter permit was initially issued for 1998 and was renewed for 1999–2000. The Fisheries and Oceans Canada permit was issued for the 1998 season and was renewed for each of the 1999 and 2000 field seasons.

Report Organization

This final report is divided into several major sections and numerous smaller chapters. The sections concern whaling and local knowledge of bowheads at Kaktovik (Chapter 2), zooplankton (Chapters 3–7), bowhead distribution, numbers and activities (Chapters 8–16), diet and regional feeding dependencies (Chapters 17–21), energetics of bowheads (Chapter 22), and integration (Chapter 23). The three multi-chapter sections each contain short introductory and concluding chapters.

The major chapters are designed to be more-or-less self-contained, with their own introduction, methods, results, discussion, and summary subsections. Where necessary, detailed data are included as Appendices at the end of the chapter in question. Most major chapters have been written in a format that will facilitate the completion of scientific papers based on the corresponding topics; the MMS contract for this project encouraged this approach. Thus, some material (particularly Methods) is mentioned in more than one chapter, although with different emphasis in different chapters. This approach has the advantage that the chapters are largely self-contained, and most are reasonably compact. Many chapters are expected to be suitable for submission to journals with only minor modification (e.g., deletion of Appendices). The various short introductory and concluding chapters are not intended to become journal papers, but are included here to tie together the chapters on various specific topics.

Acknowledgements

We thank the Kaktovik whaling captains, whaling crew members, and other Kaktovik residents who participated in the several meetings and discussions that were part of the project planning process. We appreciate their willingness to work out a way in which fieldwork could be conducted during the autumn whaling seasons. Joe Kaleak, whaling captain and AEWC Commissioner for Kaktovik, has been especially helpful in all aspects of this process. Charles Brower, President of the KWCA during the latter part of the project, has also been very helpful in coordinating meetings and during the field seasons. Leonard Solomon of Kaktovik provided able and enthusiastic assistance with the boat-based sampling in 1998 and 1999. Many Kaktovik residents provided information about whale use of the area, and several participated in the “local boat” surveys (see Chapter 2).

We also thank Maggie Ahmaogak of the AEWC, Fred Kanayurak of the Barrow Whaling Captains’ Association, and Thomas Napageak of the AEWC and Nuiqsut, for participating in meetings and providing various types of assistance.

Craig George, Dr. Todd O’Hara, and Dr. Tom Albert of the North Slope Borough Dept. of Wildlife Management also participated in meetings and gave much valuable advice and assistance, including provision of stomach content and baleen samples from bowheads harvested at Barrow. Mark Major of ARCO and Phillips Petroleum kindly arranged to obtain stomach contents samples from some bowheads harvested at Cross Island in 1999 and 2000.

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2. KAKTOVIKMIUT WHALING: HISTORICAL HARVEST AND LOCAL KNOWLEDGE OF WHALE FEEDING BEHAVIOR

Michael S. Galginaitis[1] and William R. Koski[2]

Introduction

The desire to characterize the degree to which the eastern part of the Alaskan Beaufort Sea is used by bowhead whales for feeding arises from a number of concerns. Subsistence whaling is of high importance to the Kaktovikmiut, the "people of Kaktovik" (Kaktovikmiut and Francis n.d.). This chapter describes the community of Kaktovik and Kaktovikmiut subsistence whaling, summarizes the historic and recent subsistence whale harvests of the Kaktovikmiut, and presents local and traditional knowledge pertinent to whale feeding behavior near Kaktovik. None of these topics is treated exhaustively, but they are presented in the detail appropriate to the main objective of the project: understanding the importance of the eastern Alaskan part of the Beaufort Sea for feeding by bowhead whales. For present purposes, the eastern Alaskan Beaufort Sea is taken to extend from the middle of Camden Bay to the Canadian border (Fig. 2.1; see also Fig. 1.2 in Chapter 1 for a specific study area map). The complete transcripts of several interviews with Kaktovik residents are included as Annex B of this report (in Volume 2).

Kaktovik—A Brief Description [history, population, economy, infrastructure]

Kaktovik, also referred to as Barter Island, is a small community located on Barter Island in the extreme northeast of Alaska, within the boundaries of the Arctic National Wildlife Refuge (ANWR) (Fig. 2.1). The 2000 U.S. Census enumerated 293 people, most of whom (247, or 84 percent) are Native. Household economies rely upon both wage labor (and other income sources) and subsistence activities as vital components of an integrated system. The major employers are the North Slope Borough, the City of Kaktovik, and the village Native corporation. There are also a few private sector jobs and businesses separate from the Native corporations. These include retail stores, a hotel, and air carrier services. However, most employment is related to government or Native Corporations (IAI 1990a).

Subsistence activities in Kaktovik make use of a unique set of resources. Because of Kaktovik's location, hunters have access to terrestrial, riparian, and marine resources, and make substantial use of all three. Fish caught both in rivers and in the ocean are important resources. Caribou are the most important terrestrial subsistence resource, but sheep, muskox, and grizzly bears are also taken. Of the marine mammals, the bowhead whale is the primary subsistence resource, but seals and polar bears are also taken (Jacobson and Wentworth 1982; IAI 1990b). Subsistence activities, and especially activities surrounding the bowhead whale hunt, are central to the structural organization and cultural identity of Kaktovik residents.

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[1] Applied Sociocultural Research, 608 West 4th Ave, Suite 31, POB 101352, Anchorage, AK 99510-1352. *Phone:* 907-272-6811; *e-mail:* msgalginaitis@gci.net

[2] LGL Ltd., environ. res. assoc., 22 Fisher St., POB 280, King City, Ont. L7B 1A6. *Phone:* 905-833-1244; *e-mail:* bkoski@lgl.com

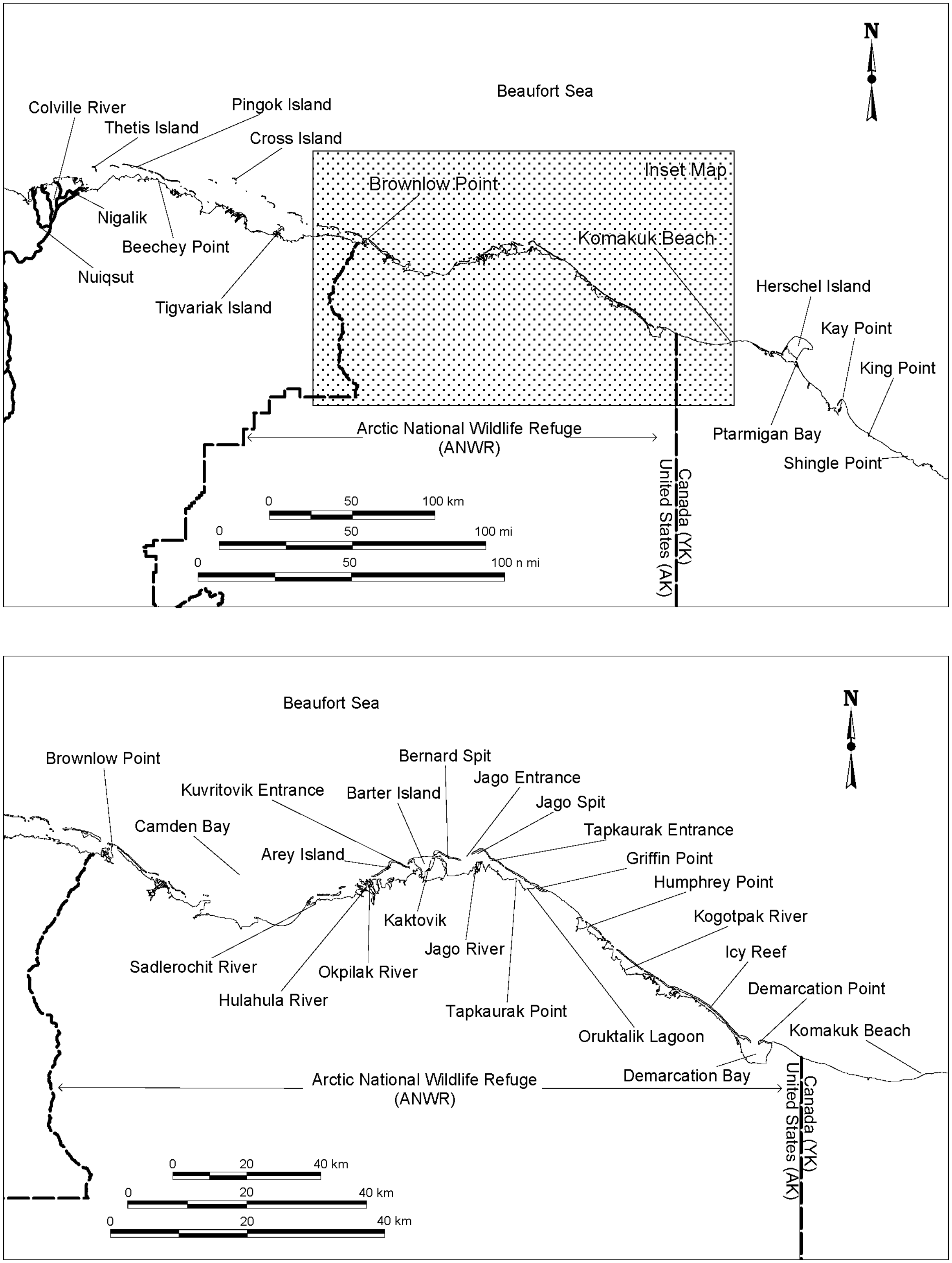

FIGURE 2.1. Kaktovik and vicinity showing place names mentioned in the text. Place names are according to USGS Geographic Names Information System (http://geonames.usgs.gov)

Before contact with Euroamericans, the site of the present community of Kaktovik was not a permanent Inupiat settlement, but had a long history as the location for seasonal gatherings for trading. Along with the surrounding area and most of the adjoining coastline, it was also used for seasonal subsistence activities of the highly mobile Inupiat people (Nielson 1977:1; Kisautaq 1981:161–173). One account of how the site came to be called "Kaktovik" (or "Qaaktugvik") also serves as an explanation for why it was not the site for a permanent village. The story relates how the Qagmaliks from the east (Canada) came to trade and decided to live in the area. They later abandoned the area after someone had killed the only son of a couple living in the area. The couple found their son's body while seining, and so the place acquired its name from that activity and became "A-Seining-Place" and those "... living in the wrong way had caused it to have no more people" (Kisautaq 1981:167–168; Libbey 1983:2).

In 1923, the Gordon family moved their store to Barter Island from Demarcation Point, where they had lived since 1917. (Prior to that time Tom Gordon had worked with Charles Brower in Barrow and other North Slope locations.) Apparently this move was made because Tom Gordon's wife had relatives who had taken up residence on Barter Island because of its location in relation to fishing spots and the mountains (Kaveolook 1977; Jacobson and Wentworth 1982:3). The nascent settlement also was a more viable location for the trading post, which in turn increased the desirability of Barter Island as a place for families to live. People still lived on the land and traveled extensively, but Kaktovik had become more of a central service center than before (Jacobson and Wentworth 1982:3–4; Libbey 1983:15).

Later in the 1920s, reindeer were brought into the Barter Island area under the sponsorship of the BIA (Bureau of Indian Affairs). It is reported that reindeer herding combined with hunting kept people out on the land for most of the time, although their residential focus was Barter Island. Reindeer herding was a family business, with each family having a defined herding area. Taakpaq, a famous whaling captain from Barrow (but sometimes referred to as a Kaktovik whaling captain), herded in the area between Beechey Point and Brownlow Point. Richmond Ologak herded from Brownlow Point east to the Sadlerochit River, while the Akootchooks and Tiglooks herded between the Sadlerochit and Jago Rivers. Gallegher Arey and Mickey Gordon herded from the Jago River to Demarcation Bay (Libbey 1983:15). Reindeer herding in the Kaktovik area ended in the late 1930s or early 1940s (by 1937 according to Kaktovik elder Isaac Akootchook, pers. comm., Jan. 2002). A number of reasons are commonly cited. However, an assessment of the relative importance of the various factors in the Kaktovik area is hardly possible as almost all studies of Alaskan reindeer have focused on the Seward Peninsula and seldom mention North Slope operations. The interested reader is referred to Andrews (1939), Grosvenor (1902), Jackson (1904), Koughan (1931), Miller (1935), Olson (1969), Stern (1980) and Ray (1983).

Trapping also supported a dispersed population, and trappers tended to focus on a supply center where furs could be traded for consumer goods of various sorts. In addition to the trading post on Barter Island run by Tom Gordon, other trading posts were operated by Jack Smith at Beechey Point, Henry Chamberlain at Brownlow Point, John Olson at Imaignauraq, Old Man Store at Demarcation Bay, and others as well (Fig. 2.1). These trading posts tended to change locations (and proprietors) depending on the productivity of the trapping territory surrounding them. The decline of the fur market in the mid-1930s caused many of these trading posts to close, and other traders died (Tom Gordon died in 1938, John Olson in 1942) or simply moved elsewhere. The result was that, by the 1930s and 1940s, there were few trading posts left and people once again dispersed—some to Canada (the Mackenzie River area, where a trading post remained open), Barrow, or other places. A core population remained in the area, maintaining a mobile subsistence lifestyle (Libbey 1983:16–18).

In the mid-1940s the U.S. Coast and Geodetic Survey began mapping the Beaufort seacoast, with their main base camp on Tigvariak Island, 137 km (85 mi) west of Kaktovik. Several relatives of present-day Kaktovik residents worked on this project and spent time at Tigvariak Island. In 1947, the Air Force began construction of the airstrip and hangar facility at Kaktovik, forcing the relocation of some Kaktovik residents and disturbing a significant prehistoric village site. In 1951, the entire area around Kaktovik was designated a military reserve, and again some Kaktovik residents had to relocate (Nielson 1977; Jacobson and Wentworth 1982). A Distant Early Warning (DEW) station was constructed there in 1952/3, as a prototype/test facility for the other proposed stations of the DEW-line system (Denfeld 1994:190–192). A BIA school was opened in Kaktovik in 1951. The combination of the school and the availability of local wage employment supported a population influx. The population stabilized at ~140 people, and remained at about this level until the late 1970s. Then the establishment of the NSB (North Slope Borough) in 1972 resulted in more local employment opportunities, and an increased and improved housing supply (Jacobson and Wentworth 1982:5).

The period of time since the establishment of the NSB has been one of increased economic stability in Kaktovik, in terms of wage employment, and a modification of the schedule of subsistence activities to accommodate steady wage employment. This is not a static system, however, and there is uncertainty whether an equilibrium has been reached or whether wage labor as a scheduling force will remain as important as it is at present. There are currently (2001) few active subsistence specialists in Kaktovik who do not also work for wages. That is, few people support themselves solely by hunting and by trading the game they procure for other goods that they cannot harvest. Most hunters participate directly in the wage economy, and some wage laborers do little or no hunting.

Historical Kaktovikmiut Whaling

Historical Subsistence Whaling East of Barrow

Definitive information on the antiquity of whaling in the regions of the Alaskan North Slope east of Barrow does not really exist, although evidence for such activity at least in the late Thule period (starting about 900 years Before Present) is generally accepted. Informants maintain that whaling took place at Barter Island in aboriginal times (Kisautaq 1981:170–173). Hall (1987) and Hall and Associates (n.d.) could possibly provide more site specific information in this regard, but access to those sources is restricted. Hall's more accessible publications do not suggest that whaling occurred there in aboriginal times. No fully documented and dated excavation at Barter Island itself has taken place, but prehistoric features with whale bone suggest a whaling tradition (Jacobson and Wentworth 1982). It is likely that the prehistoric sites excavated by Diamond Jenness in 1914 have either eroded away or were destroyed when the airstrip was built (Wescott et al. 2000), although it is possible that remnants remain (Yarborough 2001).

In a summary publication, Hall (1981:48) states that the available archaeological evidence from other sites along the Alaskan north coast east of Barrow provides only the most meager cultural history:

> "Essentially, there is no unequivocal evidence of occupation in the area previous to 4,000 years ago, precious little data on the nature of human adaptation in Arctic Small Tool tradition times, and only enough information from the more recent sites to broadly outline a picture of human occupation in the past 600 years [the late prehistoric]."

For the late prehistoric period, ~1350 to present, there are only three well documented archaeological sites east of Barrow, all within or near the Colville Delta 250 km (155 mi) west of Kaktovik: ***(1)*** Nigalik is a specialized activity site in the Colville River Delta. The lack of systematic archaeological testing at this site has resulted in an inability to establish prehistoric roots for the Native seasonal trade fair at Nigalik. Little has been recovered at this site that would address the subsistence behavior of the people using the site. ***(2)*** Thetis Island, just northeast of the Colville Delta, has prehistoric remains dated to A.D. 1350–1500. There is evidence of whaling activity, but both the nature of the tools and faunal remains found there support a subsistence pattern oriented primarily toward caribou (50 percent) and seal (25%), with the remainder representing birds, foxes, whales, and various small animals (25%, in that order). Thus, whales must have been an infrequent catch, given their large size relative to the other resources being harvested. ***(3)*** Pingok Island, near Thetis Isl., has prehistoric remains dated to A.D. 1550–1700. Land subsistence activities are well represented in this archaeological assemblage as well, but seals and whales are also common. The bearded seal and walrus are not well represented, but overall it appears that whaling was a significant activity at Pingok Island during this period. A site at Herschel Island, in the Canadian Beaufort, dates to the late Thule period, about 900 years B.P. (Stanford 1976).

However, the interpretation of this information in terms of cultural history is far from clear (Hall 1981:4–49, 71–73). Sites on Barter Island and Arey Island display whale bone, but have not been dated with any precision. Arey Island is named for Ned Arey, a commercial whaler, and the Inupiat name, Naalagiagvik, means “Where you go to listen for whales” (Libbey 1983:46–48). Arey Island is often mentioned by Kaktovik residents as a location where whales feed and linger. Diamond Jenness excavated these sites in 1914, but never published the results (Jenness 1914). Jenness did write some non-analytical accounts of this work (Jenness 1957, 1991), but for the most part these describe day-to-day activities rather than scientific findings. Edwin Hall performed an analysis of the artifacts and field notes from the Jeness excavations and concluded “… most of the features were built and utilized between 550 and 400 years ago, although a few of the recovered artifacts dated to a much earlier period and others indicated use of the sites up through the historic period. … The types of artifacts found suggest a subsistence quest that emphasized land hunting as much or more than marine hunting. Whaling was practiced by at least some of the families that occupied the sites, though when in the occupational sequence is not known. Fishing also played a role in the subsistence efforts of some families” (Hall 1987:258-259).

Time was not available to review the commercial (Yankee) whaler literature for information relevant to Kaktovik whaling. Commercial whaling ships first appeared at Barter Island in 1886, and reached the Mackenzie Delta whaling grounds in 1888. By 1894, fifteen ships were spending the winter at Herschel Island, attracting native hunters to supply them from as far away as Point Hope (Bockstoce 1986; Wilson 1991). How much time these ships spent in the eastern Alaskan Beaufort sea is not clear, but ships logs and accounts may contain observations of whale behavior in that area from that time.

Cross Island has been reported by Inupiat informants to have been the site of whaling activities for hundreds of years, and so could date back at least to the late prehistoric period. It is known that Taaqpak, a whaling captain who Spencer (1959:154) places in Barrow, whaled from Cross Island from the 1920s to 1940 or so (Carnahan 1979:25–31). Taaqpak was one of several Inupiat who bought boats from Euro-american whalers or traders in the 1920s, and a history of such transactions, especially as they affected Inupiat whaling, would be very informative. Such a history has not been written, however, and would likely require extensive research with no guarantee of ultimate success. The Commission on Inupiat History, Language, and Culture (in Barrow) has some tape-recorded oral history possibly relating to Taaqpak and Cross Island, but this information either has not as yet been translated or was unavailable for other reasons. In any event, Taaqpak also had a reindeer herd in the area and many of the men on his whaling crew worked for him, and some of those with reindeer herds to the east of him also whaled with him.

It is not known if Taaqpak ever lived in Kaktovik or had that community as his center of orientation, but many of those who served on his crew did. Many of the people now whaling in Kaktovik received their training while whaling in the Cross Island area with Taaqpak (or with someone who had learned from such a person). Thus, although whaling in the immediate Kaktovik area is not documented prior to 1964, Kaktovik people certainly have a long and continuous history and tradition of whaling (Jacobson and Wentworth 1982:52–53), directly related to that of Barrow and the mid-Beaufort Sea area.

It is not altogether clear why whaling was suspended in the mid-Beaufort area west of Kaktovik, but primary factors were probably economic and demographic dynamics (which were also important for the community history of Kaktovik). The decline of the reindeer industry may have prompted most of the people who had been in the general mid-Beaufort Sea area to relocate to Barrow or Kaktovik. The mid-Beaufort Sea and Colville River areas were experiencing depopulation at this time. Schools and wage labor jobs were serving to attract people off the land and into central communities.

Contemporary Kaktovikmiut Whaling

Whaling resumed at Kaktovik in 1964 (Kaleak 1996), and since then has been a central focus of life in Kaktovik. The immediate reasons for the resumption of whaling in 1964 are not clear, but the community had been growing, whales had been observed regularly, and some residents had experience from whaling elsewhere. Information for some years soon after 1964 is not complete, but whaling has taken place out of Kaktovik during most years since then, with a high degree of success—especially since 1989 (Braund et al. 1988: Appendix 1, page 14; see also next section). After the formation of the Alaska Eskimo Whaling Commission (AEWC) in 1977, Kaktovik received a formal quota. One to three bowheads were landed during most years in the 1980s, and two to four bowheads during most years in the 1990s. Braund and Moorehead (1995) briefly describe the institutional development of the current subsistence whaling management system. Huntington (1992) provides a similar background and treatment within the broader context of federal, state, and cooperative management programs.

People from Kaktovik hunt whales only in the fall, as the spring migration of bowheads past Kaktovik occurs far offshore beyond the landfast ice zone. The autumn whaling season starts no sooner than late August, though most commonly near Labor Day in early September, and ends later in September or sometimes October. At Kaktovik, whaling is done from powerboats. These boats can vary widely in characteristics, from an 18 foot open Lund skiff to a 24 or 25 foot cabin-cruiser type vessel. As speed is a much desired characteristic, motor size has tended to increase through time. Depending on the year, there are up to 11 whaling crews in Kaktovik. With a minimum of four or five men to a crew, most adult men are involved with whaling. Most other people in the village are involved in some support or processing capability. Whaling is truly a community-wide activity.

Whaling crews use the village as their home base, leaving from the village and returning to it every day. As described by one informant, a crew leaves Kaktovik, cruises in search of whales, and then ties up to a piece of ice. Eventually a number of boats will congregate and the crews will set out their provisions, eat, and socialize while a few of their number watch for whales. There are some years when there is little or no ice, but even when there is ice the boats spend much time cruising the water and searching for whales. Coordination between boats may be more difficult at these times, although CB and marine VHF radios plus GPS units have made this easier in recent years.

When whales are spotted, the boats are arranged to intercept them in such a way that at least one should have a good shot. There is some competition to be the first to strike a whale, as this increases the prestige of that captain and his crew, but the process as described is mainly cooperative. Once a whale is struck, all crews in the area go to help procure the whale, haul it back to Kaktovik, and process it. In recent years, heavy equipment has been used to haul the whales onto the beach for butchering, as well as to shift the whale during the process of butchering. The heavy equipment is also used for transporting the butchered muktuk and meat (which is placed directly into the equipment's buckets) and for the ultimate removal of the whale carcass. A similar method has been adopted for the butchering of fall-harvested whales in Barrow, and is one of a series of adaptations that make the butchering of a large and heavy animal on a gravel beach easier, faster, and more efficient than more "traditional" methods.

The "core" whaling area for Kaktovik is from the Okpilak and Hulahula Rivers in the west to Tapkaurak Point in the east. The core whaling area extends out as far as 20 miles (32 km) from the coast, although crews usually stay within 12 miles or so of shore. Nearly all whales harvested since 1964 have been struck within this "core" area and there is an explicit effort to stay within this range. Available information on the locations where bowheads were struck is shown in the next section.

Towing a whale is hard work and relatively slow, especially if there is a wind or rough seas to contend with. The farther away from Kaktovik a whale is killed, the longer the tow will be, and the greater the chance that at least part of the meat will spoil. The extreme limits of the "Kaktovik whaling area"—the middle of Camden Bay in the west and just north of the Kogotpak River in the east—are as far as Kaktovik whalers can conceive of trying to tow a whale back to Kaktovik. As previously stated, most whales are taken within the smaller "core" area, and within that area most of the whales are in fact struck close to the village.

Crews could function with as few as three people in the boat, but most crews have four or five, and some claim as many as eight. Not all days are equally good for whaling, and there are periods when crews do not go out because of wind, waves, or large amounts of sea ice. Because of the quota system that has applied since 1978, the season is over once the allocated number of strikes is used. Kaktovik currently has a quota of three strikes or kills, but is often in a position to request additional strikes since it is common for spring whaling communities not to use their entire quota. However, since 1997 the Kaktovik hunters have not requested that unused strikes from other communities be transferred to Kaktovik. The prevailing local opinion is that three whales are adequate to meet Kaktovik's needs.

Kaktovik has what is essentially an intercommunity agreement with Anaktuvuk Pass under which Kaktovik muktuk and whale meat is sent to Anaktuvuk Pass and caribou is sent from Anaktuvuk Pass to Kaktovik. This is not trade in the strict sense, as in years when Kaktovik does not harvest a whale they still receive caribou from Anaktuvuk Pass, and may indeed receive more caribou in those years than in years when they do harvest a whale because of the greater nutritional need. Most of the food thus exchanged is redistributed at public functions and feasts, primarily at major holidays such as Thanksgiving, Christmas, Easter, and the Fourth of July.

Whaling is a cooperative activity and as such the Kaktovik whaling area is open to all who wish to participate in the hunt, as long as each person belongs to a crew whose captain is a member of the Kaktovik Whaling Captains Association (KWCA). The AEWC administers the hunt, and has slowly assumed a greater role than merely ensuring that the quota is not exceeded. However, in most matters related to the local hunt, the AEWC will defer to the KWCA. The AEWC is very concerned with safety during the hunt and the qualifications of the crews that participate. To these ends the AEWC registers all whaling captains and collects information on crew members. This serves, to a degree, as a restricting mechanism on who can organize a whaling crew. Almost anyone who wants to participate in whaling can find a role on an existing crew, but the AEWC process serves to deter the formation of new and inexperienced whaling crews by prospective whaling captains who may be resource-rich but experience-poor.

In terms of use of the whaling area, there are no restrictions. In fact, in 1979 when conditions in the area where Nuiqsut crews normally whale made whaling there impossible, the Nuiqsut crews whaled with the Kaktovik crews.

The division of a whale harvested at Kaktovik is essentially similar to that in other villages (Daniel and Lillian Akootchook, interview). The captain of the first crew to strike the whale receives credit for taking that whale, and receives a large share of the whale. He is expected to redistribute a good deal of this, and does so, so that most whales taken are in fact treated as community property.

Recent Bowhead Harvest at Kaktovik

***Numbers Taken by Year*.—**Recent bowhead harvests at Kaktovik commenced in 1964 when two whales were harvested. National Marine Fisheries Service (NMFS) records of harvests in 1964–72 are incomplete and do not list any whales harvested at Kaktovik from 1965–72 (Marquette 1977). However, a map in Oil/Whalers Working Group (1986) indicates that single whales were harvested there in 1968 and 1969. It is unlikely that many additional whales were harvested during this period because Kaktovik residents would remember an event as rare as a bowhead harvest from that period.

There was no quota on the number of bowheads that could be harvested before 1978, but rapid increases in bowhead harvest levels throughout Alaska in the mid-1970s caused concern that harvest levels were not sustainable. The International Whaling Commission (IWC) decided to impose quotas on the number of bowheads that could be taken by Alaskan native hunters starting in 1978. The IWC quota is administered and monitored by the AEWC. From 1978 to 1991, no more than two bowhead strikes or kills were allocated per year to Kaktovik. From 1992 to 2001, Kaktovik has been allocated three strikes or kills per year. In most years when Kaktovik reached its quota, the KWCA could have applied for additional strikes because some strikes were not used by spring whaling villages. The most recent year when a 4th strike was transferred to Kaktovik was 2001 (and before that, 1997). During 1998–2000, additional strikes were available but KWCA decided not to request additional strikes because village requirements were met by the three whales landed in each of those years.

Since 1973, data on bowhead harvests have been collected by NMFS and the NSB, including information on numbers of whales landed, dates when whales were landed, the sizes and gender of those whales. Figure 2.2 summarizes harvests at Kaktovik from 1973 to 2000. From 1973 to 1988, one to two whales were generally harvested, reflecting the village quota. In 1979 and 1981, whaling crews from Nuiqsut joined the Kaktovik whalers and the higher catches of five and three, respectively, in those years reflect the quotas from both villages. From 1989 to 2000, generally 2–4 whales were harvested.

***Timing of the Harvest*.—**Each year the KWCA decides, at a meeting shortly before the start of the whaling season, the date at which the hunt will begin (weather permitting). In recent years, the bowhead hunt at Kaktovik has normally begun Labor Day weekend. The scheduled starting dates for the 1997 to 2001 hunts were 3, 4, 11, 2, and 2 September. (The starting date of the 1999 hunt was delayed by a local emergency—a fatal boating accident.) However, the hunt has started earlier in some years (e.g., by 22 Aug. in 1992). In most years, few bowhead whales are present near Kaktovik until the beginning of the westward migration of whales from the main summering areas east of Kaktovik (see Chapter 9). Also, some hunters state that the hunt is now delayed until early September because the tendency for warmer weather in August means that whale meat is more likely to deteriorate before completion of butchering if whales are taken in August. Thus, the start of the hunt is usually timed to coincide with the early part of the main westward migration in early September. The whales accessible then tend to consist primarily of the small subadult whales that are preferred by hunters (Chapter 10).

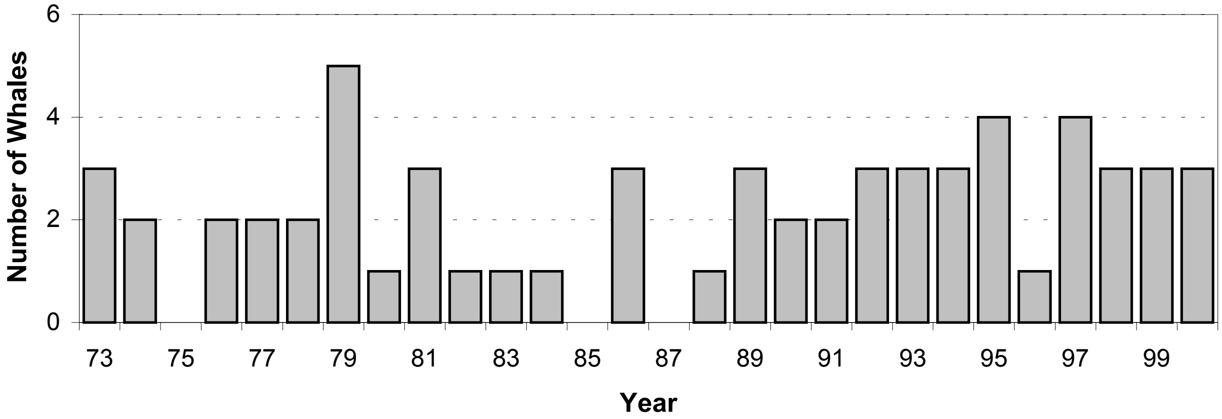

FIGURE 2.2. Numbers of bowhead whales landed at Kaktovik each year, 1973–2000. Main sources: Marquette 1977; Braham 1987; Withrow et al. 1991; J.C. George, pers. comm.; G. Sheffield, pers. comm.

The dates when whales landed at Kaktovik during 1976 to 2000 were struck are shown in Figure 2.3, organized by year (panel A) and 10-day period (panel B). (The date is unknown for 1 of the 61 whales landed in these years.) The majority (83%) of the whales landed during this period have been struck during September. Thirty-two percent of the whales were struck in each of the 1–10 and 11–20 September periods, 20% were struck 21–30 September, 10% were struck 1–10 October, and 3% were struck in each of 22–31 August and 11–20 October (Fig. 2.3B).

In recent years, the typical harvest dates have become earlier even though the quota and the number of whales taken have increased. The trend for an earlier harvest is significant ($r = -0.46$, df = 58, $P = 0.00022$). This change appears to have resulted from an increase in the efficiency of the Kaktovik hunters in harvesting whales. Another contributing factor may be that the size of this bowhead population is increasing. As a result, whales presumably are now more numerous near Kaktovik early in the hunting season than they were during the 1970s and 1980s. Changes in whale utilization of the general Kaktovik area (see Chapter 9) may also be involved. Average sighting rates during aerial surveys increased markedly in the 1990s relative to the 1980s (Chapter 9).

***Harvest Locations*.**—Since 1973, all bowheads harvested by residents of Kaktovik for which the harvest locations have been reported were struck within 43 km (27 mi) of the village. Most of these whales were struck within 30 km or 19 mi (Fig. 2.4). As mentioned above, the core area where whalers search for whales is from the Okpilak and Hulahula Rivers in the west to Tapkaurak Point in the east and offshore as far as 32 km (20 miles) (Fig. 2.1). Although a few of the most distant harvest locations were during the 1970s (Fig. 2.4), the mean distance of reported harvest locations from Kaktovik was not significantly different among the 1970s (17.0 km, $n = 16$), 1980s (17.9 km, $n = 14$) and 1990–2000 (15.2 km, $n = 21$) (Kruskal–Wallis $\chi^2 = 0.96$, df = 2, $P = 0.62$). It should be noted that the locations where 10 bowheads were struck are not known to us, and some reported locations, especially for years before GPS units were widely used, are approximate.

***Sizes of Harvested Bowheads*.**—The Kaktovik whalers attempt to harvest small whales because they are easier to handle and are considered to be better to eat. Thus, the sizes of the harvested whales are partly an indication of the sizes of the whales near Kaktovik at the dates in question, but are also strongly influenced by hunter selectivity. The frequency distribution for the lengths of whales landed at Kaktovik

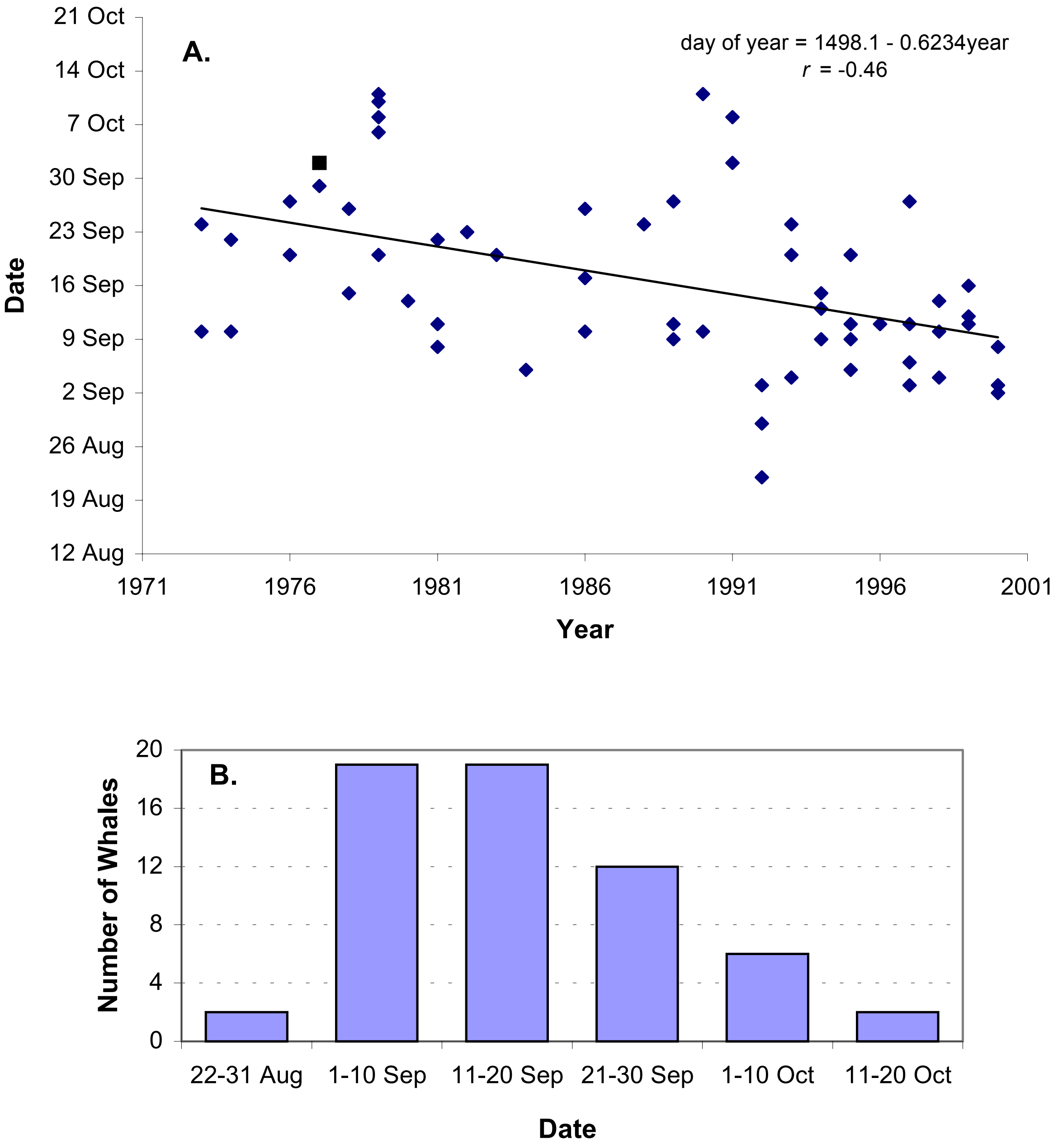

FIGURE 2.3. Dates when bowheads were struck at Kaktovik ***(A)*** by year and ***(B)*** by 10-day period, 1973-2000. The square symbol near the upper left side of panel A represents a young-of-the-year calf (approx. 5 months old). Main sources same as Fig. 2.2.

is shown in Figure 2.5B. The reported lengths in this and subsequent Figures have been reduced by 8.2% to account for the stretching that occurs when the whale is dragged onto land (see Thomson, Chapter 22). The overall size range (adjusted) of the whales landed at Kaktovik is similar to that of the living whales whose lengths have been measured in the Arey Island to Humphrey Point area during September (Fig. 2.5B vs. 2.5A). Whales as long as 16.1 m (17.4 m before adjustment for stretching) have been landed at Kaktovik (Fig. 2.5B)—approximately the same length as the longest whale (16.2 m) measured photogrammetrically near Kaktovik (see Koski and Miller, Chapter 10).

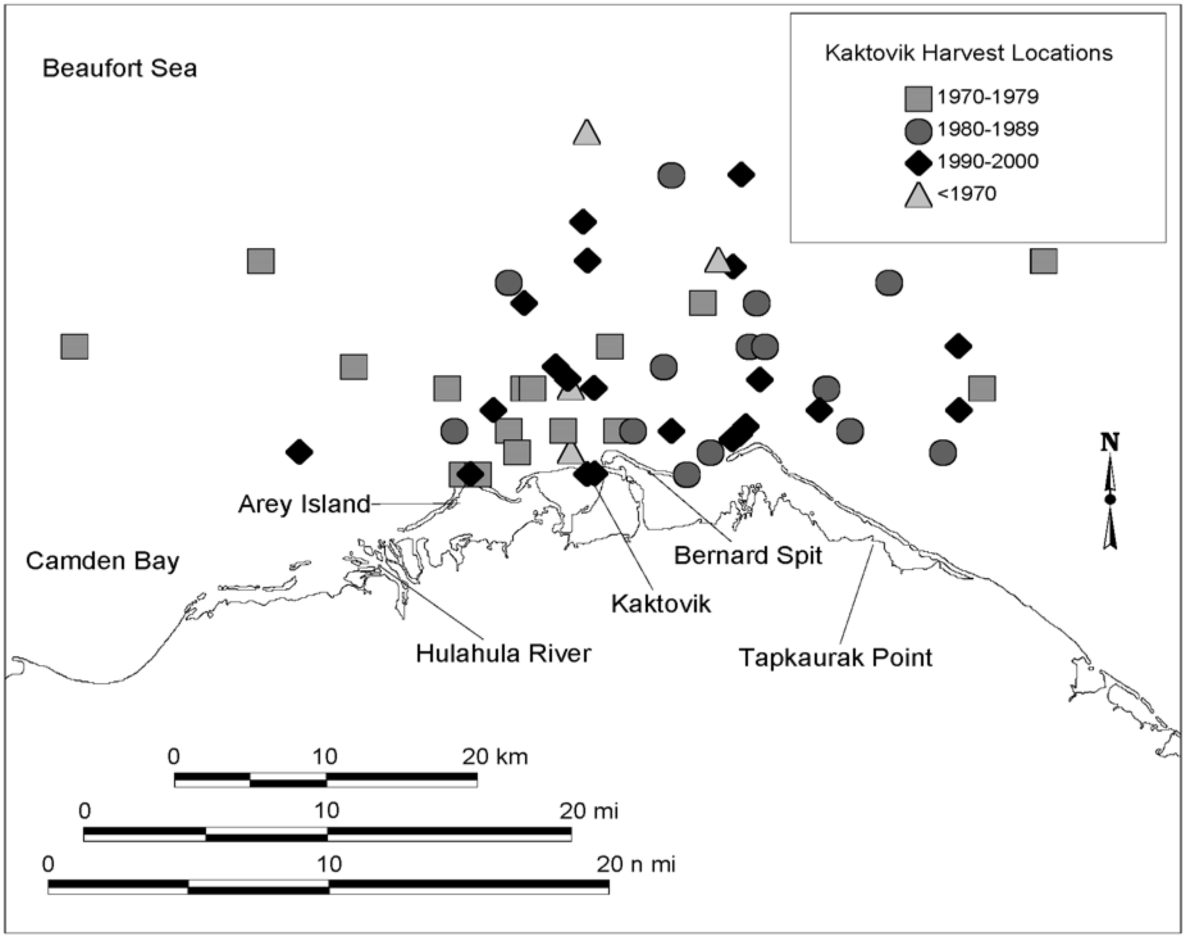

FIGURE 2.4. Locations where bowhead whales were reported to have been harvested by residents of Kaktovik, 1976–2000. Not shown are two whales taken ~170 km west of Kaktovik in 1937 and 1940. Major Sources: Oil/Whalers Working Group (1986), Kaleak (1996), G. Sheffield, pers. comm., J.C. George, pers. comm.

However, small whales constitute a higher percentage of the landed whales than of the whales photographed in the area. Of the bowheads harvested by Kaktovik whalers, 23.6% were longer than 13 m (after allowance for stretching), and therefore were considered to be adults (Koski et al. 1993). This compares to 43.4% adults in the overall bowhead population, if calves are excluded (Angliss et al. 1995), and 50% adults among whales photographed near Kaktovik (calves excluded, Koski and Miller, Chapter 10). The proportion of adults was significantly lower among the harvested whales than among the population as a whole ($\chi^2 = 8.80$, df = 1, $P = 0.0030$) or among the whales that were photographed near Kaktovik ($\chi^2 = 14.98$, df = 1, $P = 0.00011$). These data confirm that the bowheads landed by Kaktovik whalers tend to be smaller than those in the population as a whole.

The autumn bowhead migration is partially segregated according to size, with the smaller whales tending to occur earlier in the autumn (Koski and Miller, Chapter 10). However, there was no significant correlation between date and the size of a whale harvested ($r = –0.064$, df = 53, $P = 0.64$; Fig. 2.6). This indicates that whalers were able to select small whales throughout the whaling season even though the small whales become proportionally scarcer as the season progresses.

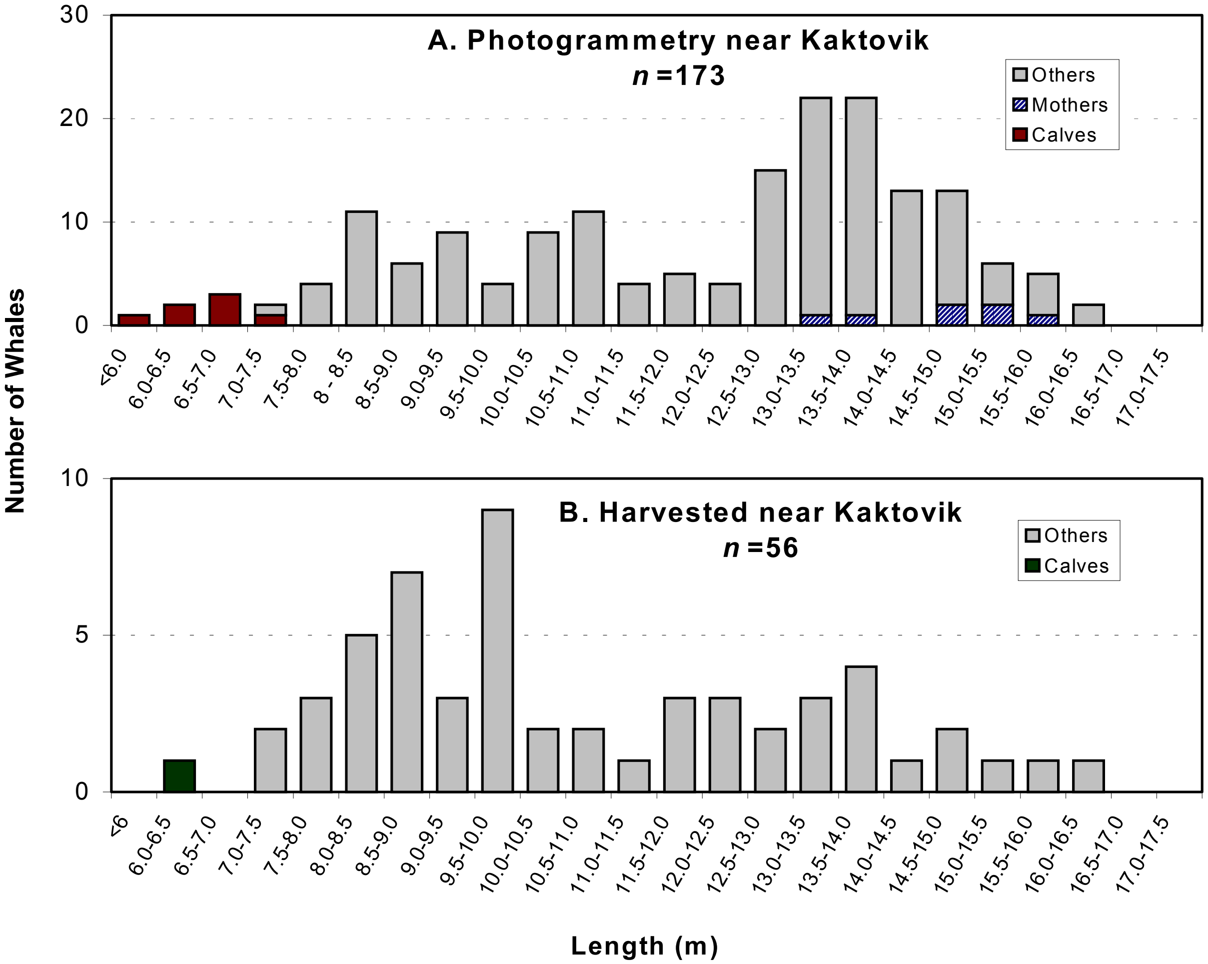

FIGURE 2.5. Length frequency distributions of bowheads ***(A)*** photographed near Kaktovik 1982–2000 (from Koski and Miller, Chapter 10) and ***(B)*** harvested near Kaktovik 1976–2000 (same sources as Fig. 2.2). In (B), lengths have been adjusted downward by 8.2% to account for stretching (see text).

Figure 2.7 shows the lengths of the harvested whales by the year harvested. There has been a significant decline in the average size of whales harvested over the 1976–2000 period ($r = -0.33$, df = 53, $P = 0.014$). This suggests that the whalers have become more selective about the sizes of whales that they have harvested in recent years. This increased selectivity has probably been possible through some combination of two factors: increased availability of whales associated with the bowhead population increase, and increased efficiency of the hunters in capturing whales (allowing them to be selective while still filling their quota).

Sex of Harvested Bowheads.—The sex of 55 bowhead whales harvested at Kaktovik has been recorded. Twenty-eight were males and 27 were females, which is not significantly different than the 50% males and 50% females that would be expected ($\chi^2 = 0.0012$, df = 1, $P = 0.91$). However, during the first half of the harvest (22 Aug.–13 Sept.), 67% of the harvested whales were female, and during the last half of the harvest (14 Sept.–11 Oct.), only 32% were female (Fig. 2.6, 2.8). This difference is significant ($\chi^2 = 6.55$, df = 1, $P = 0.010$). From 1990 to the present females have been more common among the harvested whales (18 females and 13 males), but before 1990 more males than females were harvested (15 males and 8 females). This difference is marginally significant ($\chi^2 = 2.87$, df = 1, $P = 0.090$) and is due to small females commonly being caught early in the season since 1990 (Fig. 2.6, 2.7).

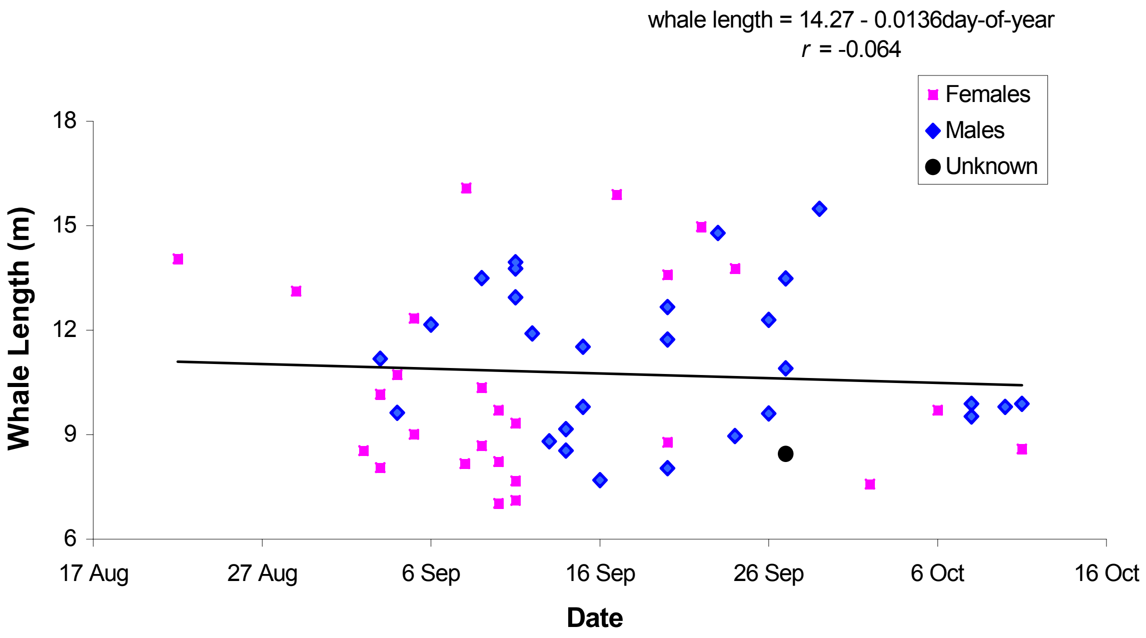

FIGURE 2.6. Whale length vs. date for bowheads harvested at Kaktovik, 1976–2000; females and males are distinguished. A 6.2-m calf harvested on 2 October 1977 is excluded. Whale lengths are adjusted downward to allow for stretching (see text).

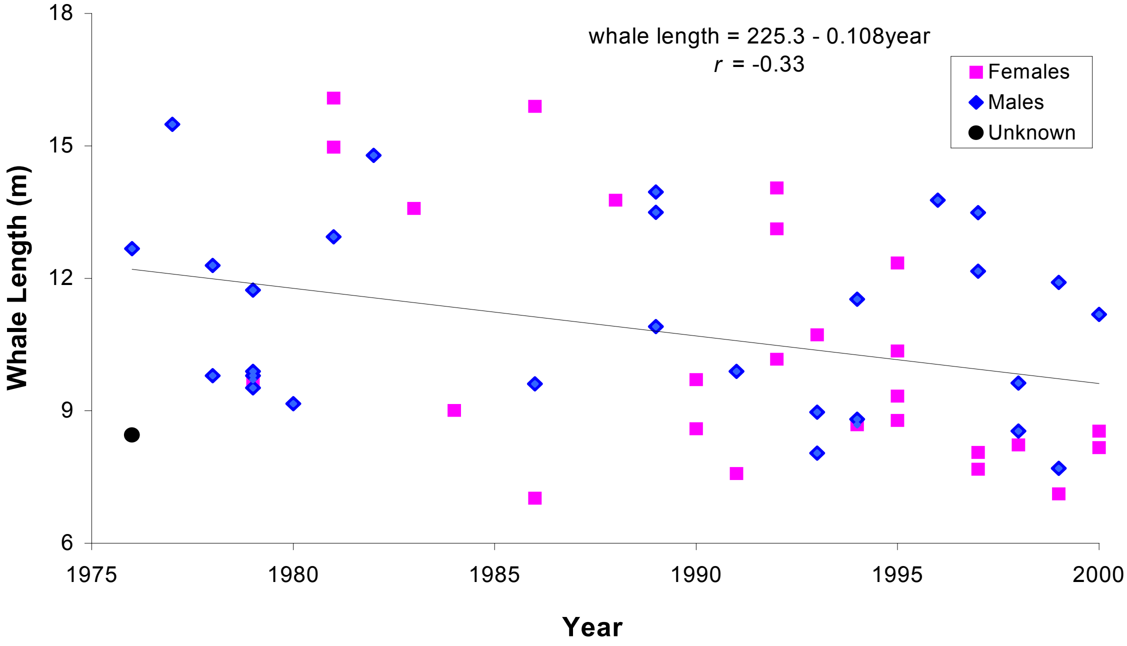

FIGURE 2.7. Whale length vs. year for bowheads harvested at Kaktovik, 1976–2000; females and males are distinguished. A 6.2-m calf harvested in 1977 is excluded. Whale lengths are adjusted downward to allow for stretching (see text).

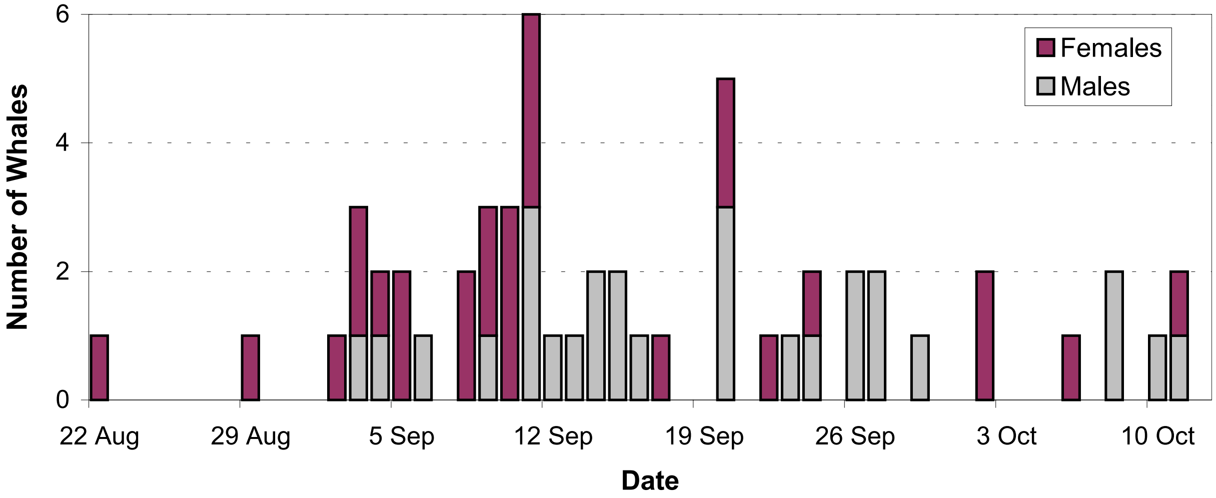

FIGURE 2.8. Sex of whales vs. date for bowheads harvested at Kaktovik, 1976-2000.

Local and Traditional Knowledge of Whale Feeding Near Kaktovik

Bowhead whales are of great cultural importance to the Inupiat and are a major source of food. Inupiat know a great deal about bowhead whales. This study required much cooperation with and direct participation from local residents in the study design and field work, for two major reasons: ***(1)*** A major objective of the project was to integrate Inupiat knowledge of bowhead whales into the planning of the project, the fieldwork, and the interpretation of the findings. The project devoted significant effort, both during the planning phase and during fieldwork, to the compilation of local and traditional knowledge concerning use of the Kaktovik area by feeding whales. Resources to document broader aspects of local and traditional knowledge related to whales and whaling were not available, given the need to concentrate on work directly bearing on use of the area by feeding whales. ***(2)*** Local coordination and participation also insured that the study did not interfere with the hunt for bowhead whales and, to the fullest extent possible, respected Inupiat cultural sensitivities. Several types of liaison functions were built into the project plan to meet these requirements.

Concept and Use of "Local and Traditional Knowledge"

Defining what is meant by "local and traditional knowledge" (LTK) or "traditional ecological knowledge" (TEK) is not a simple process, and summarizing such knowledge is even more difficult (Kinsella 1999). There have been many attempts to define TEK and its place in research and in the assessment of the effects of development or management projects (see, for example, Bielawski 1992; Freeman 1992; Hobson 1992; Johnson 1992; Sallenave 1994; Government of Canada 1996; Carter 1997; Huntington and Fernandez-Gimenez 1999). This is not the place to reprise this discussion, from which no complete consensus has as yet emerged, nor is it likely to emerge soon. Rather, we have extracted certain themes from this literature that are most pertinent in a pragmatic way for this project.

The label "traditional" often seems to serve as a barrier to the integration of such knowledge with "Western scientific" knowledge. "Tradition" is often interpreted as unchanging and of the past, and "science" with the investigation of the present in order to support some change in knowledge or thought. In fact, both "traditional" and "scientific" knowledge are evolving and changing systems of thought, based on life experiences organized in certain ways. The scientific method is an explicit set of rules for organizing and drawing conclusions from experience. Traditional knowledge does not have such an explicit method of evaluating information and drawing general conclusions, and thus in many specific cases is quite situationally or contextually bounded, with no obvious way to broaden its application. Thus, local and traditional knowledge is sometimes dismissed as "anecdotal" when in fact it is merely over-specific for the purposes at hand, and the underlying generalizations (or the methods to arrive at such generalizations) have not been perceived.

In the present project, we have used several approaches in attempts to compile LTK by Kaktovik residents concerning whale feeding in the Kaktovik area. We first conducted a literature review of selected published and unpublished sources. Then, during January 1998, we consulted local Kaktovik residents through a 1½-day whale workshop held in Kaktovik. During that meeting, LTK was compiled and local participants helped modify the research design to address local concerns and to incorporate local knowledge. In addition, we interviewed a limited number of whaling captains and other experienced whalers during the first year of the project. Complete transcripts of the interviews that were rccorded are included as Annex B in Volume 2 of this report.

Prior to each year's main field season (1998, 1999 and 2000), one team member spent two to three weeks in Kaktovik during mid-late August, meeting with local residents, coordinating logistics, and (with local residents) attempting to conduct a "local boat" survey to detect any early-arriving bowhead whales in the Kaktovik area. The local boat survey included both a visual search and use of hydrophones to listen for calling bowhead whales. This component of the research had been suggested by local participants at the Whale Workshop in January 1998. It was hoped that it would document some of the whales that might occur in the area prior to the start of whaling and of the project's more intensive aerial- and boat-based fieldwork in September. Also, the "local boat" survey provided an additional opportunity to collect LTK related to whale feeding behavior. Furthermore, during September of 1997–2000, a project participant from Alaska Dept of Fish & Game worked closely with the whalers to collect biological data and samples of the stomach contents from bowheads harvested at Kaktovik. Other opportunities for exchanges between local residents and project scientists are described in the next subsection. These included the project's three Scientific Review Board meetings, annual meetings in Kaktovik before the whaling season, employment of a local resident on the project boat, basing of the project aircraft at Kaktovik, and an additional workshop in Kaktovik in January 2002 to discuss the draft of this report.

Overall, although Kaktovik residents are very knowledgeable about bowhead whales generally, rather little LTK related specifically to whale feeding behavior was found, as summarized below. There are probably several reasons for this. One is that whale feeding behavior, in and of itself, is not of central interest to Inupiat whalers. LTK tends to emphasize the types of observations most salient for the success of whatever activity one is engaged in (or for safety or survival in general). Thus, many people remarked that they were concerned with where whales could be found, and when, but not with what they were doing there. Also, LTK is embedded in life experience and, as such, those components of it most pertinent to a specific topic such as whale feeding behavior can be difficult to isolate from this larger context. This is especially true if the research effort must take place within a short period of time. Long-term, nondirective research is more likely to be successful in compiling LTK on any specific topic than is short-term and more "direct" research—although directed research will also compile much information on other specific (and general) topics as well.

The following sections summarize the local contact activities conducted for this project, and include a summary of LTK related to whale feeding in the Kaktovik area.

Chronology of Local Coordination and LTK Activities

After initial contacts with the North Slope Borough, the Alaska Eskimo Whaling Commission, and the Kaktovik Whaling Captains Association during the late summer and autumn of 1997, a meeting to introduce the project to Kaktovik whaling captains was held in Kaktovik in December 1997. This was followed by a 1½-day workshop in Kaktovik in January 1998, at which a rough draft of possible study options was discussed with the Kaktovik whaling captains and representatives of the AEWC, NSB, federal government agencies, and the oil industry. Local advice was obtained about the timing of the study, its feasibility and compatibility with bowhead hunting activities, and options for improving the research. The formal workshop agenda included time for public statements by local residents concerning LTK of bowhead whales. There was also time for two-way discussions about bowheads between local residents and project scientists who had studied bowhead whales near Kaktovik and elsewhere in previous years. A number of informal and private discussions with whaling captains and other knowledgeable Kaktovik residents were conducted in the days following the workshop to further develop the traditional knowledge information base. A limited number of interviews with whaling captains and other experienced whalers were recorded and transcribed, or otherwise documented when recording was not possible.

The feedback received at the workshop and at a subsequent meeting on 30 May 1998 was taken into account in the Project Plan that was completed in draft during early July 1998. During July, that draft plan was further discussed at meetings with local residents in Kaktovik and with the project's Scientific Review Board (SRB) in Anchorage. The SRB includes representatives of the Kaktovik whaling captains (Mr. Joe Kaleak), the AEWC (Mr. Thomas Napageak or Mrs. Maggie Ahmaogak), and the North Slope Borough (Dr. Todd O'Hara or Mr. Craig George) as well as NMFS, industry, and independent scientists. The SRB, with local representation, also met in June 1999 to review the results of the first (1998) field season and plans for subsequent field seasons. The SRB did not meet after the second (1999) field season, but reviewed the 1999 results individually. The SRB met a final time during January 2002 to review results of the overall project as described in this draft final report.

Project scientists participated in several Kaktovik Whaling Captains Association meetings, including meetings in July and August 1998, June and August 1999, and early September 2000. The meetings in August–September, in particular, provided an opportunity for final coordination of research plans with whaling plans, for local comments, and for possible research modifications. Also, during September of 1998, 1999 and 2000, a Kaktovik resident was employed aboard the boat that was used for systematic studies of food available to bowheads near Kaktovik (see Chapters 3–7). This provided another avenue for interchange between the project and the community. As noted earlier, a project representative was in Kaktovik in late August of 1998–2000 for the local boat survey, and another worked closely with the whalers in September 1997–2000 to collect biological data and samples of the stomach contents from bowheads harvested at Kaktovik (see Chapter 18). Finally, the project's aerial survey crew was based at Kaktovik for their work during the 1998–2000 whaling seasons (see Chapters 8–16), providing further opportunities for communication.

A meeting to present and discuss the results of the study was conducted in Kaktovik on 31 January 2002, shortly after the final SRB meeting. The discussion at those two meetings has been taken into account in the final version of this report.

Whale Workshop in Kaktovik (Jan. 1998)

The workshop extended for two days (15–16 Jan. 1998), and primarily addressed specific aspects of the research design that those present believed could potentially affect the behavior of whales (and

Kaktovikmiut whaling success) during the course of the research. While these discussions reflected local and traditional knowledge and beliefs derived from life experience (for instance, how noise sources affect whales), little in the way of observations related to whale feeding was presented. Rather, the local attendees were concerned with understanding the proposed research program, and then suggesting modifications to the planned research design and schedule to minimize possible effects on subsistence whaling (noise, timing of the research). There were also concerns that the research, as designed, could base its conclusions on information that was too limited. An extensive discussion on the appropriate geographical boundaries of the study area was one example. Another example was the concern that not all years are the same, and if there were a year when whale feeding could not be documented, because of ice or other conditions, that this could skew the results. These concerns revealed a great depth of local knowledge about whale behavior in the Kaktovik area, although not specifically related to feeding behavior.

At the beginning of the second day of the workshop, one Elder briefly summarized the depth and orientation of local knowledge, and contrasted it with the approach proposed by the Whale Feeding Study methodology:

> "Since I started to know about the whales is—beautiful. My knowledge can see that, because this area, Kaktovik all the way to Demarcation-Icy Reef—since I find out about it, my parents and my uncles already know about that. They don't have any history. They never talk about much about it. When you was a little boy and your grandpa or your grandparents and your uncle tell you—beautiful. They never write it onto paper, but you have it, it's all the time in your mind, in your knowledge. That's what we have." (Isaac Akootchook, 16 Jan. 1998)

This describes an expertise derived from a lifetime of experience, as well as the transmission of such experience from one generation to the next. Such transmission is not written, and in many cases is not even verbal, but is the guidance provided by the older generation while hunting or engaged in other shared activities. Subsistence—obtaining food and the other requirements for a good life—was the unifying theme. Knowledge is inside a person's head, and is used for the pragmatic purpose of making a living.

The Elder mentioned that what he and others said in meetings such as this often had little apparent effect; it is difficult to transmit this knowledge and understanding verbally if others lack the personal experience that underlies it. He also stated that he knew the study was necessary, since it would provide a potential way for outsiders to understand about whales in the area. The study also provided the opportunity for local residents and outside scientists to work cooperatively together to better investigate and communicate how whales were using the Kaktovik area, to their potential common benefit.

The workshop concluded with the Kaktovik Whaling Captains Association giving permission for the research to proceed, with some modifications in the research design as initially proposed. Foremost was the condition that, during the first main field season (1998), the project's boat-based work would not begin until Kaktovik whalers had landed two bowheads. Some conditions were also placed on the aerial survey component of the project. A local boat component was added to the project to increase local participation, and potentially expand the temporal and geographic range of observations for the project. Lastly, to the extent possible, local and traditional knowledge would be incorporated into the project documents and fully acknowledged.

Limited Interviews (16–20 Jan. 1998)

Individual discussions were held with several Kaktovik whaling captains and other residents during and shortly after the workshop summarized in the preceding subsection. These discussions were held to seek additional information about utilization of the study area by bowheads, and particularly by feeding bowheads. Kaktovik residents know much about the occurrence of bowheads in their area, but they usually cannot determine whether the whales that they see are feeding as opposed to migrating or engaged in some other activity. Nonetheless, much local information on whale occurrence and behavior exists and can be elicited.

The following summaries are not intended as complete records of the interviews conducted following the workshop in Kaktovik. Rather, they indicate the type of information that was discussed and some of the content. Content has been confined for the most part to local and traditional knowledge concerning whale behavior and Kaktovik whaling. Unless noted, the interviews were recorded on tape cassettes. In most cases, the quality of the recording is fair to poor, in part due to the sites of the interviews. With one exception, the interviews were conducted in Kaktovik on 16–19 January 1998 by Steven MacLean, a biologist (and Inupiat) employed by LGL Alaska, and by Michael Galginaitis of Applied Sociocultural Research (Anchorage). Herman Aishanna was contacted by phone in Barrow on 20 January 1998. Copies of original tapes and draft transcripts were sent to each person interviewed, for their review. The detailed transcripts are included, largely un-edited, as Annex B to the present report (see Volume 2). MMS will distribute copies of these tapes and transcripts to the appropriate repositories (AEWC, IHLC, KWCA). The order in which the interviews appear below is the order in which they were conducted.

George Kaleak and Bert Akootchook (Steerer, Harpooner).—Both interviewees stated several times that they cannot say anything about whale feeding behavior, as whalers are not looking for such behavior when they are out whaling. They sometimes see krill in the water, but not always when they see whales, nor is krill always present when they see whales. The amount of krill they observe varies by year, and they related that they did not see much krill in 1997, although they saw many whales.

They stated that whales "hang around" the Kaktovik area in September, although they do not know why. Whales could be feeding, but whalers are not looking for that behavior, and search for whales by looking for "blows". Whales can be seen in the area as late as October, but do not seem to linger in the area at that time.

During the summer, on their trips to Canada, the interviewees commonly encounter many whales. In July, bowheads are mainly on the Canadian side, especially in the Herschel Island to Shingle Point region. However, they also reported that people hunting caribou in July near Camden Bay see whales in that area. In the past, they have whaled as early as August, but found that the weather was too warm at that time and the meat spoiled too easily.

Daniel and Lillian Akootchook (retired Whaling Captain and spouse).—This conversation took place at the interviewees' home in Kaktovik. The Akootchooks shared many stories of their experiences in Kaktovik, both whaling and more generally. Little of this related directly to the question of whale feeding in the Kaktovik area. The stories are not really suited to summation, but speak to the centrality of whaling and subsistence to Inupiat life in general, and in the lives of the Akootchooks in particular. They did not generalize broadly, but did explain that whales seem to listen to what people say, and respond to what they do. Not only are whales very sensitive to the noises people make but, according to the interviewees, whales are also very concerned with the propriety of peoples' actions and their relations with each other. That is, whales allow themselves to be taken by those who respect them and behave properly. The Akootchooks' stories thus indicate that whaling is very much about the Inupiat relationship with the whale and each other.

Isaac Akootchook (Whaling Captain, Lay Preacher).—Isaac Akootchook (IA) started with the observation that, before the Kaktovik residents started (or restarted) whaling in 1964, they saw many whales right off Arey Island, Bernard Spit, and Jago Spit. His parents told him that the whales were feeding in those areas. He does not know from his own observation, as he cannot tell when a whale is feeding. He asked, "Who can say what a whale is doing underwater?" Many other people told the researchers essentially the same thing—they cannot tell if a whale is feeding.

IA said that, when out boating, you see little things in the water wherever you travel. He related that he often looks to see what is in the water. What they see is not only whale food—ringed seals and ugrook (bearded seals) need food as well. People go seal and ugrook hunting in the spring, and (sometimes) see whales while doing that. The hunters do not bother the whales at this time. IA also used to just go out boating in the fall, just to look around, and used these trips to spot whales. IA said that the whales were communicating with one another, and that the "leader whales" of the migration should be left alone. Otherwise the main body of whales may deflect further offshore. The whale leaders establish the "trail" for the whale migrations. Once the leaders go by, the main pack will follow this trail. IA said it is like the caribou of Anaktuvuk Pass.

When asked whether whales travel in groups IA said that some years there are lots of whales, and then relatively few, and then lots again. Some whales can be early. In July, it is not uncommon to see single whales, but the hunters do not know if these are migrating from the east. The migration noticeably starts in August and lasts through October. IA said that there are more whales now in October than there used to be. "[In 1997 we] went out in a boat in October [when there was quite a bit of open water] and there were lots of whales—seemed to be smaller ones." Ice does not really affect the numbers of whales that go by or the migration, but does affect the hunt. Hunters need to find open water. When they see a whale, they need to be able to get to it, but find it difficult to do so in heavy ice years. Hence, their success rate under those conditions is low. IA reported that Kaktovik residents like to hunt other things in October, and ice cover tends to increase in October, so they try to finish whaling in September. Hunters tend to go south into the mountains to hunt caribou (or sheep) in October. They also hunt caribou in July, but more in coastal locations.

IA said that the best spots for whaling are the areas near Jago Entrance (between Bernard Spit and Jago Spit) and Kuvritovik Entrance (between Barter Island and Arey Island). Some whalers go west a little way and check Arey Island first, while some check off Jago Spit first. Tapkaurak Entrance also is a place that people check and find whales. The important waters for Kaktovik whalers are Camden Bay to Tapkaurak Entrance. When hunting whales, some boats are closer to shore and others are farther out, with spacing of maybe a mile between "adjacent" boats. Most of the time the whale to be hunted is seen by one of the middle boats. Sometimes they spot the whale in the morning, near Kaktovik; bring it in and cut it up in the afternoon; and are done by evening [and then they do it again for the rest of the quota]. They generally look for a 25 to 30 footer, as these small whales are tender and relatively easy to handle. Sometimes they do take bigger whales, as it can be difficult to be sure of the size of a whale when hunting. Some years they finish the season early.

One year off Jago Spit there were no whales. There was lots of open water, but they could not see whales for some reason. IA reported that the old people say

> "Don't talk about whales before you go out, don't say you are going to get one, whales hear you and will react to what you say, and will stay away…. The year before, there had been lots of ice and whales had been hard to see. No whales taken, maybe one. The next year, the ice was gone but they still did not get any whales. People had been talking before they went out, said that maybe they would get a whale this year. People were talking, so they did not get any whales."

IA concluded that "… you can never know about the whale, who will get one, if anyone will. Have to ask God. Animals are all here to use the earth. People are just sitting here, make plans and then break it."

During a later meeting (31 Jan. 2002), IA mentioned that in his younger days, before the DEW facilities were built, many whalebones were evident at Barter Island, including bones inside the lagoon behind the spit. These bones are buried now. IA believes that the Kaktovik area is an important feeding area for bowheads.

Thomas Agiak (Whaling Captain).—Thomas Agiak (TA) said that in early August whales can be found offshore from West Barter Island, in Kuvritovik Entrance. His brother goes to the Camden Bay area in July and August and sees whales (but generally only a few). Kaktovik whalers catch them off Bernard Spit in September. TA reported that, as late as conditions allow boating, maybe the second week of October, whales can be observed in the area—but that he is not really sure what the "ending" date for the whale migration is. When people go out to hunt caribou in October on Arey Island they see small whales (Kuvritovik Entrance).

TA indicated that in August, you can see all sizes of whales in the Kaktovik area, sometimes including some big ones, and that you can tell the difference in size by a difference in the size of the blows. Smaller whales tend to be closer to shore. TA stated that big whales will also go by early (around 1 Sept.) with smaller whales. Whalers stay away from those pairs of whales, big with small, as often it is a mother and a young one. By the end of September the larger whales, 43 to 46 footers, are present.

In his experience of travel by boat to Canada or hunting during [early] August, TA seldom has seen whales between Kaktovik's usual hunting area and Herschel Island. East of Herschel Island he has seen many whales during this period. On his way back to Kaktovik [presumably during late August] he reports seeing many whales in both areas. Regardless of other comments, he said that the migration can sometimes be early, or late.

When whales are very close to shore they are easy to spot and whalers can follow them by the "brown bubbles" they stir up from the bottom. In the shallow water, the whales disturb the bottom as they swim. However, TA also said that when whales are that close to shore (and in shallow water) that they "spook" quite easily and thus are more difficult to catch.

TA said that for the last 10 years Kaktovik whalers have not had to look beyond a limited geographical area east to west, up to 20 miles out into the ocean. When there was seismic activity in the area, he reported that Kaktovik whalers had to go farther out to sea in order to find whales—but they never struck whales out there because it was too far from Kaktovik. TA reported that when the oil companies were doing seismic work off Jago, Kaktovik whalers had to go quite a ways to find whales. He said that noise affects whales quite a lot. One year they saw many whales but they were easily spooked. When the whalers turned towards them they spooked and disappeared—the whalers could not get near the whales. The year when seismic work was being done, there was also a good amount of ice. Whalers would turn towards whales and never see them again. TA thinks it was because of too much noise in the area, as they had to go far to see whales. He said that when a drill rig was offshore, for 2 years they hardly saw any whales. When there is no noise—no [industrial] boat traffic—Kaktovik whalers can usually get their whales close to Kaktovik.

Charles Brower (Whaling Captain, President of Kaktovik Whaling Captains Association).—This interview took place at Charles Brower's (CB) house. He considered that others would be better sources, as he was a relatively young captain, and he advised us to seek out the more senior captains.

CB said that they try and stay away from big whales, as they prefer 30 to 40 footers. The earliest whales seen are in late July, and one year they saw early whales in the Jago area. The regular subsistence activity in July is to hunt for caribou. The hunters do not actually look for whales at that time, but sometimes notice them. When Kaktovik whalers can't see whales nearby during whaling (September), they look off Arey Island, near the bend. Medium-size whales tend to hang around there. CB reported that you can see smaller whales hanging around Jago Entrance in mid-August.

When he goes to Canada by boat, he starts to meet whales near BAR-1 [Komakuk]. This is in early August. He returns to Kaktovik in time for the whaling season there. During boat travel along the coast, they do not see as many whales between Komakuk and Herschel Island as they do east of Herschel Island. In July they sometimes see whales locally, or near Ptarmigan Bay if they are traveling to Canada at that time. The last whale that they see passing Kaktovik in fall tends to be seen around 8 to 12 October. Kaktovik residents know that whales are still going by in October. Big whales are seen later in the season; little whales are seen more often at the time when Kaktovik hunters normally whale (early September).

Archie Brower (Whaling Captain).—This interview took place at Mr. Brower's (AB) house in Kaktovik. It was not tape recorded as it had the elements of a social visit as well as the official one. There was also quite a bit of background noise. Mr. Brower shot the whale taken in 1964 that marked the resumption of whaling in Kaktovik; he used a .50 caliber rifle. He has passed away since the time of this interview.

Archie Brower (AB) reported that whales are most often seen off Jago Point and west of Barter Island. He spontaneously volunteered that the whales were feeding from Barter Island all the way down to Demarcation Point, but pointed out especially the areas off Jago spit and Tapkaurak Spit. AB said that whales feed in those areas. At Griffin Point, near AB's summer camp, the whales can be very close to the shore (he said 10 to 20 feet, probably meaning water depth). AB does not know what they feed on, but said that they are feeding in this area—mainly in late August and early September. AB said that there are also whales off the western end of Arey Island, but he does not know if they are feeding. They do stay in the area for a while, and again most of the whales are close to the shore. There are not many whales far from shore. Last year (1997) the whale taken the furthest from the community was 12 or 14 miles offshore—a two hour tow.

AB and his family made their summer camp at the east corner of Oruktalik Lagoon near Griffin Point. They went there in July and August, to fish and hunt for caribou and brant. Other families also have summer camps in the area, but they tend to put up tents and not stay as long as AB and his family. In their trip to the east to Griffin Point they encounter whales already traveling to the west. These whales are mostly close to shore in water 20 to 30 feet deep. AB said that they seem to be feeding. Some whales feed on the top, some dive, and some even bring up mud. The whales in this area seem to stay around for a while. They may go out further into the ocean for a while, but often come back. AB said there is little whale feeding further out from the shore, and there are not many whales out there. AB has observed whales in the Griffin Point area since September of 1955 and/or 1956, when he started to travel there.

Sometimes AB traveled to Canada (Herschel Island area) by boat in August. It takes a day in good weather to get to Shingle Point, along the coast between Herschel Isl. and Inuvik. They usually see lots of whales by the time they get to King and Shingle Point, but sometimes see only a few. The whales are not far off the point, and are going back and forth. AB did not know if they are feeding (at King Point), and said they are medium size whales. AB said that at Shingle Point the whales may be farther from the shore than at King Point.

When whales start to return westward during August, the smaller ones tend to be first. The migration goes into October. There is almost always some open water, which determines to a great extent where the whales actually are. Kaktovik whalers wait for good weather to go whaling—and the more open the water, the better the weather has to be. Winds make for rough water when there is much open water. Good weather and open water allow quick whaling trips, AB said, as was evident in 1997—whaling consisted of short trips separated by a week of waiting for good weather (waiting for the wind to die down). Winds in this area are mainly from the west or east. Those from the west tend to be the strongest ones, while those from the east are usually not too strong.

Joe Kaleak (Whaling Captain and AEWC Commissioner).—Joe Kaleak (JK) started whaling at Kaktovik in 1972, when he settled there. He thinks that the feeding study is quite important. He started by saying that the area between Demarcation Point and Icy Reef, and another area on the west side of Barter Island around Arey Island, are whale feeding areas:

> "Well, we don't really pay attention [to] feeding [by] whales—when we're out whaling, we just go look for some whales, you know. So we don't really pay attention [to] where the feeding areas are. But I know they've got feeding area at the east side of us, between Demarcation [Point] and Icy Reef. And I just find out not too long ago, there's another feeding area on the west side of us … Arey Island."

Later in the interview JK stated that, on his summer trips to Canada, he had observed whales feeding in Canadian waters, near Kay Point. He summarized his observations of feeding whales by saying "… that's the only place, right by Demarcation and this side of Herschel. And right over by the Arey Island toward Camden Bay."

JK makes a trip to Canada every year. He leaves Kaktovik in mid-July, and always meets whales east of Demarcation Point but west of Herschel Island. East of Herschel Island, Kay Point is an area where whales congregate for feeding. Whales that he meets on the way to Canada tend to be small whales, close to shore. On the way back from Canada in mid-late August, he sees whales on the east side of Herschel Isl. These whales are traveling slowly. After whales reach BAR-1 [Komakuk] on the Canadian side, it takes them 1 to 1.5 more weeks to reach Barter Island. Whales stay in certain areas for several days, but JK does not know why. He said that whales may stay in the Demarcation Point area for two weeks or more—"maybe for a whale convention".

JK has seen a whale in Camden Bay as early as July, and the Kaktovik hunters used to hunt small whales near Kaktovik during August in the early years of whaling at Kaktovik. However, JK indicated that August is too early to whale—the meat too often spoils. Whales often stay in areas around Kaktovik, especially in the Jago Spit area. That is why so many whales are taken there. After bowheads reach the Kaktovik area, there will sometimes be a two week "pause" in spotting whales. Whales can be hard to spot. Big whales come near the end of the migration—up to the middle of October.

JK stated that when Kaktovik whalers go whaling they do not bother whales in the feeding areas, e.g., Arey Island. Rather, the strategy when the water is open and weather is clear is to go north from Barter Island 10 to 12 miles out from shore, and then cruise slowly east looking for whales. If no whales are spotted within 3 days or so, they will start the same way but cruise west. They do not like to go farther than the Jago Spit–Tapkaurak Entrance area to the east, or beyond Arey Island to the west, but will go as far east as Griffin Point if they do not find whales any closer. In bad ice years, when they cannot otherwise get out very far from the village, they will make their way to Camden Bay and go north from there. Even when the ice is "tight" by the village, it tends to be "loose" off Camden Bay, and allows Kaktovik hunters to get out to the lead. They then start by first cruising east, as in the normal pattern, and often end up getting a whale off Jago or Griffin Point anyway, as they would have in a more normal ice year. In this case they usually end up farther out in the ocean, since open water is farther out. (In later discussions during January 2002, JK noted that in 2001 hunting extended well offshore because of ice to the east. He also noted that bowheads tend to remain for more than 7 days when there is no ice, and less than 7 days with ice.)

Herman Aishanna (Whaling Captain).—HA said that Kaktovik whalers know what whales eat. They often see whales milling around on the east side of Barter Island, especially the north side of Jago spit, Bernard Spit. Whale food is present when whales are, and whalers (at least HA) look for whale food when out looking for whales. It is not hard to look in the water, and when there is lots of krill and plankton there will be lots of whales. HA said that whales sometimes mill around, and he thinks this is probably related to the supply of whale food in the area. However, whales are often sufficiently accessible that there is no need to look around for whale food and such signs. In 1997, there was absolutely no ice and the first time that Kaktovik whalers went out they got a whale and towed it in. They butchered it and used all the meat with no waste. There was no ice and thus no interference with seeing and reaching the whales. Kaktovik whalers rely on calm weather for hunting bowheads, as windy weather results in large waves.

Still, sometimes when there is little or no ice there are also few whales. HA thinks that this is related to the lack of whale food—whales and whale food tend to be together in the Kaktovik area. Whalers also need to take current into account, as HA thinks that the current brings the food to the whales. The current is always shifting, in every direction, from time to time.

Local Boat Effort

At the workshop in Kaktovik during January 1998, whaling captains proposed a local boat effort as an added component of the research design. In their view, the local boat effort would contribute in several ways. ***(1)*** It furnished an additional avenue for significant local participation in the research. ***(2)*** By taking place prior to whaling and prior to the project's primary aerial- and boat-based fieldwork, it broadened the time period during which use of the area by bowheads could be documented (although of course the local boat observations were not comparable to those of the formal project survey period). ***(3)*** This effort also afforded the possibility of extending observations west of the formal survey area, into an area that Kaktovik whalers believed could also be significant for whale feeding. (In practice, the primary boat-based and aerial work in September also extended west of Kaktovik.) ***(4)*** It also afforded an opportunity for a researcher (MSG) to interact with whalers in a natural situation on the water, and perhaps gain some local information about whale feeding in an undirected way.

For both 1998 and 1999, the local boat effort was problematic due to weather. The 2000 effort was more successful:

- In ***1998***, MSG was present in Kaktovik from 24 August to 9 September. The weather did not allow small boats to go out before whaling began on 4 September, but then the weather cleared and Kaktovik whalers successfully harvested their full quota of whales
- In ***1999***, a delay in the researcher reaching Kaktovik, the involvement of many local people in a search and rescue operation once he arrived (15 Aug.), and poor weather resulted in only two trips being made before MSG left (6 Sept.). On the second of these trips (3 Sept.), whales were observed and recorded with a hydrophone. The whales were located in the Jago area, where Kaktovik whalers commonly encounter them, not far from the community. Again, Kaktovik whalers were successful in harvesting their full quota.

- The ***2000*** small boat effort was more successful. Arrangements were made with two boats (and crews), rather than only one, to take turns. Of the 19 days when the researcher was in Kaktovik in 2000 (14 Aug. to 1 Sept.), 10 days had conditions suitable for boating, i.e., good weather when the researcher was prepared to go out. Seven trips were actually made. Two days were "lost" when both local-boat crews wished to hunt for seals and/or ducks rather than look/listen for whales. One good weather day was skipped to allow the researcher to catch up on notes. There were equipment problems in 2000, so few good hydrophone recordings were made. Trips were made on 16, 17, 19, 21, 24, 25, and 31 August. A single bowhead whale was observed on 25 August, but no obvious bowhead vocalizations were noted. It was thought that whales had been heard on 31 August, but later analysis of the tape did not confirm this. Kaktovik whalers again took their full quota of whales in 2000.

In terms of extending the scope of the observations made by the project, both in time and space, the local boat effort had little success. Only in the third year were a significant number of trips made, and most were within the "regular" project area. Few whales were observed, although the 1999 and 2000 efforts did confirm that at least a few whales were in the area well before the start of more intensive feeding-study fieldwork.

However, in terms of local participation, the small boat effort succeeded admirably. During each of the three years, the researcher stayed in the community at the home of a local couple. Overall, four boat crews participated directly in the project, and provided information related to whales and whaling. Although little of this information specifically related to whale feeding behavior, all boat crews had clear ideas about where they expected that whales would most likely be found. These areas were essentially the same for all crews, and were the same as the "core" and "expanded" whaling areas described in earlier interviews by Kaktovik whaling experts. Much of the crew's conversations were about subsistence activities (location, timing, past experiences). Information on whale presence in, and migration through, the Kaktovik area was generally consistent with that provided during the earlier interviews and during public meetings. This could be expected, as the KWCA assisted in the recruitment of local boats for this research component, and ensured that the researcher only went out with experienced whalers.

Existing Documented Local and Traditional Knowledge

Previous sources of documented Inupiat local and traditional knowledge provide little or no information about whale feeding behavior in the eastern Alaskan Beaufort Sea. The Commission on Inupiat History, Language, and Culture (IHLC) has an extensive collection of unpublished tapes and transcripts, many of which contain information on whaling. However, they are only roughly indexed, and a quick survey did not uncover any which appeared to contain observations on whale feeding behavior. It is possible that some tapes, especially those of Vincent Nageak (see below), may contain such information, but this cannot be known at present. Some tapes are completely unprocessed, and others are only minimally indexed and abstracted.

The North Slope Borough periodically conducts conferences for the sharing and distribution of local and traditional knowledge. The tapes from these conferences are added to the IHLC collection. A few of these conference sessions have been processed and published. The most pertinent, Kisautaq (1981), contains much about whaling (and especially about spring whaling), but only a little about whale feeding behavior. Vincent Nageak stated that

> "Herschel Island … it is said they [whales] no longer reach Herschel Island. Many of them have now begun to stay to the surface at Herschel Island also. They never used to be like that since time

> immemorial. They used to stop a way far east of there. It is said the ones staying close to the surface are beginning to be farther and farther this way, they are becoming many. In the surrounding area of Herschel Island. The whales stop their traveling as soon as they reach Herschel Island. We learn that it takes a long time for them to get any fatter. … Once the whale begins [its migration] it doesn't stop anywhere along here. We learn that only when it reaches that place in the east on the Canadian side does it then finally stay to the surface. And so nowadays, although they say that Herschel Island has never been like this before, now it has many whales which are staying to the surface, ones whose only concern is trying to get something to eat." (Kisautaq 1981:294–295)

This session continues:

> Ernie Frankson: "So when they start returning do they do it the same way?"
>
> Waldo Bodfish, Sr.: "By leisurely by frequently going close to it, it is said they take their time returning, just barely moving at all. When they are [returning] they use a gathering-together area places which contained food, they do not worry at all."
>
> Vincent Nageak: "When the whales come this way from the east they don't travel fast, they often become fatter and their meat is even different." (Kisautaq 1981:296) This last point is relevant to Chapters 20 - 23, where the question of the relative amounts of feeding in the Beaufort Sea vs. elsewhere is addressed.

A volume in process, Hopson and Panigeo (n.d.), is similarly useful because of the information it contains on how whaling has changed from the past to 1991, but it does not address whale feeding areas. The volume of *Uiniq* devoted to Kaktovik (Hess 1993) is concerned with visually documenting whaling and other significant village activities, and so does not address whale feeding areas.

Summary

The desire to characterize the degree to which the eastern part of the Alaskan Beaufort Sea is used by bowhead whales for feeding arises from a number of concerns. The importance of subsistence whaling for the Kaktovikmiut ("people of Kaktovik") ranks high among these. This chapter provides a brief description of the community of Kaktovik and Kaktovikmiut subsistence whaling, summarizes the Kaktovikmiut whale harvest during recent years, describes the local coordination efforts undertaken as part of this project, and summarizes local and traditional knowledge (LTK) pertinent to whale feeding behavior.

Kaktovik is a small community located on Barter Island in the extreme northeast of Alaska, within the boundaries of the Arctic National Wildlife Refuge (ANWR). The 2000 U.S. Census enumerated 293 people, most of whom (247, or 84 percent) are Native. Household economies rely upon both wage labor and subsistence activities as vital components of an integrated system. The major employers are the North Slope Borough, the City of Kaktovik, and the village Native (ANCSA) corporation. There are also a few private sector jobs and businesses separate from the Native corporations, but most employment is related to government or Native Corporations. Subsistence activities, and especially activities surrounding the bowhead whale hunt, are central to the structural organization and cultural identity of Kaktovik residents.

Definitive information on the antiquity of whaling on the North Slope east of Barrow does not really exist, but available information is consistent with whaling activity at least in the late Thule period (beginning about 900 years ago). Informants maintain that whaling took place at Barter Island in aboriginal times. It is also not altogether clear when subsistence whaling ceased at Barter Island (prior to 1964), or why whaling was suspended in the mid-Beaufort area in general. Whaling has taken place out of

Kaktovik during most late summer/autumn seasons since 1964, with a high degree of success, especially since 1989. After the formation of the Alaska Eskimo Whaling Commission (AEWC) in 1977, Kaktovik received a formal quota. One to three bowheads were landed during most years in the 1980s, and two to four bowheads during most years in the 1990s and beyond.

The bowhead hunt normally begins the day after Labor Day and 83% of harvested whales have been taken in September. In recent years, whales have been taken earlier in the season than in earlier years. The core whaling area extends from the Hulahula River in the west to Tapkaurak Point in the east and offshore as far as 32 km (20 mi). Most whales have been taken within 30 km of the village and the mean distance of harvest locations from Kaktovik has not changed from the 1970s to present. Whaling captains select small whales over large whales and there has been a significant decrease in the average size of whales harvested from the 1970s to the present. The size of whales harvested does not increase with date although other data show that smaller whales become less common in the area as the season progresses. This confirms that whalers are selective in their harvest. Male and female bowheads are harvested in very similar numbers, but females make up a significantly higher proportion of whales harvested early in the season and males make up a significantly higher proportion of whales harvested late in the season.

Bowhead whales are of great cultural importance to the Inupiat and are a major source of food, and Inupiat know a great deal about whales. However, one elder noted that it is difficult to transmit local knowledge and understanding verbally if others lack the personal experience that underlies it. This study required much cooperation and direct participation from local residents in the study design and field work. All concerned wanted to ensure that Inupiat knowledge of bowhead whales would be integrated into the planning of the project and the interpretation of its findings. Local participation also insured that the study did not interfere with the hunt for bowhead whales. Assembly of LTK of bowheads, and coordination of project and local activities, were two closely intertwined tasks.

Numerous local coordination efforts were built into the project in order to encourage local participation, to respond to local desires for project modification, and to incorporate local knowledge into research design and interpretation of results. These efforts included meetings and interviews in Kaktovik in 1997–98 before the first major field season, and additional meetings in Kaktovik before subsequent field seasons. A final workshop in Kaktovik was conducted on 31 January 2002 to discuss the project findings and to provide input for use in the draft final report. In addition, there was local Kaktovik representation (as well as AEWC and NSB representation) on a Scientific Review Board that provided technical advice on project plans and results. As a result of recommendations by Kaktovik residents, a local boat and crew, in conjunction with the LTK researcher, searched for bowheads present in late August and early September, earlier than the main field season. While in Kaktovik for that effort, the LTK researcher served many project liaison functions. No specific LTK research was conducted during the part of September when Kaktovik residents were actively whaling. However, a local resident was employed to work as a member of the boat-based zooplankton sampling crew during the September 1998–2000 field seasons. Also, another project biologist worked closely with the whalers during September 1997–2000, obtaining measurements and samples of stomach contents and whale tissue from the harvested whales. Furthermore, the project's survey aircraft was based in Kaktovik during September 1998–2000 (and 1985–86), affording opportunities for coordination between project biologists and local people.

Kaktovik residents are very knowledgeable about the times and locations near Kaktovik where bowheads are present (including small vs. large bowheads), the places where bowheads tend to linger, and other information relevant to whaling. However, relatively little specific LTK is available about whale feeding behavior near Kaktovik. "Whale feeding behavior" is a discrete category of definable behaviors to a scientist, but is for the most part beside the point for an Inupiat subsistence whaler. Nonetheless, two feeding areas in the general area are recognized: the Demarcation Point/Icy Reef area, and waters near Arey Island. Some local residents mentioned that they often see whale food in the water, and know that whales tend to occur in those places. Local residents emphasized that some bowheads occur in the area in August and even July, before the start of the main westward migration, and that the project should consider these times as well as later in the season. However, they noted that bowheads are more common in Canadian waters than near Kaktovik in July–August. The main hunting period for bowheads is in September, but they are present near Kaktovik as late as mid-October in some years. LTK research activities during this project, although limited, were closely related to the broader local coordination efforts, and served to structure the local participation aspects of the research in fruitful ways.

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SPECIES COMPOSITION AND BIOMASS OF ZOOPLANKTON IN RELATION TO BOWHEAD WHALE FEEDING IN THE EASTERN ALASKAN BEAUFORT SEA

3. INTRODUCTION TO THE ZOOPLANKTON COMPONENTS OF THE STUDY

Denis H. Thomson[1] and William B. Griffiths[2]

Prior to 1998, most of the available information on the zooplankton species composition and biomass near feeding bowheads came from studies conducted between 1980 and 1988 in the eastern Alaskan Beaufort Sea and various parts of the Canadian Beaufort Sea: along the Yukon Coast, off the Mackenzie Delta, and off the Tuktoyaktuk Peninsula (Bradstreet and Fissel 1986; Bradstreet et al. 1987; Griffiths et al. 1987). Copepods were the dominant zooplankters at all whale feeding stations, with *Limnocalanus macrurus* dominating at nearshore stations in the eastern Alaskan Beaufort Sea and along the Yukon Coast, and *Calanus hyperboreus* and *C. glacialis* dominating at stations off the Mackenzie Delta and off the Tuktoyaktuk Peninsula.

The mean biomass recorded in horizontal net tows taken within layers of concentrated zooplankton located by echosounder near feeding whales was 1639 mg/m^3 in the eastern Alaskan Beaufort Sea and 1400 mg/m^3 along the Yukon Coast in 1986. At the one feeding station at Shingle Point off the Yukon coast in 1988, the mean biomass was 3762 mg/m^3. Comparable values are not available for the deeper offshore areas because of the lack of echosounder data from those situations (which meant that nets could not be guided to depths of maximum zooplankton biomass). The values from the whale feeding stations were much higher than the mean biomass of zooplankton taken within layers of concentrated zooplankton evident on the echosounder at stations where no bowheads were seen (324 mg/m^3).

Biomass in oblique tows, which integrate biomass over the water column, was higher at stations sampled near bowheads than at stations without bowheads: 499 mg/m^3 (n = 15) vs. 158 mg/m^3 (n = 111). These average biomasses were based on 1985 and 1986 data from the eastern Alaskan and Canadian Beaufort Sea (Bradstreet and Fissel 1986; Bradstreet et al. 1987; Griffiths et al. 1987).

There is a discrepancy between the species composition of zooplankton found near feeding whales prior to 1998 and the stomach contents of whales landed at Kaktovik, Alaska (Lowry 1993; see also Chapter 18 in this report). Euphausiids and the large copepods *Calanus* spp. were very much over-represented in the stomach contents relative to plankton samples taken near feeding whales, and the small copepod *Limnocalanus macrurus* was under-represented in stomach contents. Four factors may account for much or all of this difference: ***(1)*** The easternmost site where bowhead whales are harvested and

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[1] LGL Ltd., environmental research associates, 22 Fisher St., POB 280, King City, Ont. L7B 1A6. *Phone:* 905-833-1244; *e-mail:* dthomson@lgl.com

[2] LGL Ltd., environmental research associates, 9768 Second St., Sidney, B.C. V8L 3Y8. *Phone:* 250-656-0127; *e-mail:* bgriff@lgl.com

stomach contents are available for analysis is Kaktovik, ~200 km west of most stations where (prior to 1998) zooplankton was sampled by nets near feeding whales. Food eaten 200+ km east of the harvest sites would no longer be present in the stomachs at the time of harvest. ***(2)*** Before 1998, the composition of stomach contents at Kaktovik had been reported for only 12 whales (Lowry 1993)—possibly not a representative sample. ***(3)*** Some of the potential bowhead feeding habitats in the eastern Alaskan Beaufort Sea had not been sampled prior to 1998. ***(4)*** Some components of the zooplankton in areas where bowheads were feeding may not have been sampled effectively.

The main difficulty in sampling zooplankton availability for bowhead feeding is that it is very difficult to find suitable feeding habitat in the absence of whales, even using sophisticated hydroacoustic techniques. The best predictor of a high biomass of zooplankton in concentrated layers is the presence of feeding bowhead whales. It was recognized, at the start of the 1998–2000 study, that it would be useful to place more emphasis on sampling the diversity of feeding habitats used by bowhead whales. A systematic survey of zooplankton throughout the study area was beyond the logistic and funding scope of the 1998–2000 study. However, sampling during 1998–2000 has expanded the number of locations and the number of years in which food availability has been studied in the eastern part of the Alaskan Beaufort Sea generally, and more specifically near feeding whales.

The zooplankton chapters of this report describe work done in and near the eastern Alaskan Beaufort Sea during both 1985–86 and 1998–2000. The 1985–86 phase of this study was conducted by Griffiths et al. (1987) in the eastern Alaskan Beaufort Sea and adjacent Canadian waters west of Herschel Island. The 1985–86 portion of the study was of relatively short duration (two late summer/early autumn seasons), and zooplankton sampling was possible near feeding bowheads during only one of those years (1986). The second phase of the study was conducted in 1998, 1999, and 2000, with similar objectives and methods to those of the first phase. The combined effort was designed to provide more information on annual variability than had been available based on 1985–86 work. The additional efforts during 1998–2000 evaluated bowhead feeding and zooplankton availability during September of three years (1998–2000). Those data, in addition to the 1985–86 data, yield five years of data on zooplankton and bowhead feeding in the eastern Alaskan Beaufort Sea during September.

In each of the five years of study, zooplankton sampling was limited to a duration of about 2 weeks during early-mid or mid-late September. September is the month of peak bowhead migration through the study area (see Chapters 2, 9). However, aerial surveys and local knowledge show that bowheads are occasionally present in July and early August, and are commonly present in late August and in October (Chapters 2, 9). Although the zooplankton sampling encompassed the period of peak bowhead abundance in the eastern Alaskan Beaufort Sea, it did not include the entire period when bowheads are present. Zooplankters have seasonal patterns of growth, energy accumulation, and vertical migration, and oceanographic conditions vary from August to October. Average food availability in August and October (especially late August and early October) is expected to be generally similar, but not identical, to that measured in September.

The five years of zooplankton data now available, in conjunction with physical oceanographic data collected as part of the 1985–86 and 1998–2000 studies, provide a more comprehensive and defensible determination of the availability of zooplankton to bowheads in the eastern Alaskan Beaufort Sea, especially during September, than was possible based on studies up to 1986 (*cf.* Richardson [ed.] 1987). The following four Chapters describe and compare the zooplankton community and physical oceanography of the study area during all five years of the overall study. Chapters 4–6, collectively, address the primary objectives of the zooplankton sampling program, and are expected to form the basis of three journal publications. Those three Chapters are on the following topics:

- Chapter 4. Relationship between acoustic biomass and net biomass of zooplankton,
- Chapter 5. Species composition and biomass of zooplankton in relation to water masses in the eastern Alaskan Beaufort Sea, and
- Chapter 6. Characteristics of areas where bowhead whales feed in the eastern Alaskan Beaufort Sea.

In Chapter 4, relationships are established that allow data recorded with echosounders during four of the five years of the study ("acoustic biomass") to be converted to wet weight biomass of zooplankton. Using these relationships, acoustic biomass recorded along transects and near whale feeding stations is shown as zooplankton biomass in Chapters 5 and 6. Chapter 5 describes the horizontal and vertical distribution, biomass, and species composition of zooplankton in the study area in relation to physical properties. In Chapter 6, results described in Chapter 5 are compared with results of zooplankton sampling, echosounder surveys, and physical oceanographic measurements near feeding whales in an effort to characterize bowhead whale feeding habitat. Chapter 6 also estimates the quantities of zooplankton available to feeding whales, on a wet-weight biomass/m^3 basis. In later chapters, these data are used to help determine the annual variability in the amount of food available to and consumed by bowhead whales in the study area. Chapter 7 is a summary of the zooplankton components of the work.

All marine sampling during the five field seasons was conducted from a 13-m boat, the *Annika Marie.* The intent was to arrive in the Barter Island (Kaktovik) area in early September, which is the approximate start of the period of peak use of that area by bowheads. In 1998–2000, our arrival in that area was timed to avoid the first few days of the whaling season. In those years, the Kaktovik whalers requested that boat-based work not extend east of Kaktovik until after they had landed the second whale from their quota of three whales per year. After the second whale was landed, we were free to sample east of Barter Island provided that we did not interfere with ongoing whaling activities.

Our top priority in 1998–2000 was to sample zooplankton near feeding bowheads and near bowheads that were not feeding. In conjunction with this sampling, we sampled along transects to determine the sizes of the zooplankton patches near the feeding or non-feeding bowheads. When no bowheads were present in the study area, we sampled sites where bowheads had been observed feeding in previous studies, in order to determine if these areas have attributes that are associated with high concentrations of zooplankton. We also sampled at stations along routine transects oriented perpendicular to shore in order to determine the distribution and abundance of zooplankton in the study area as a whole. Priorities in 1985–86 had been similar, but in those years the sampling along routine transects was also a high priority. Routine transects extended farther offshore in 1985–86 (generally to the 200-m depth contour) than in 1998–2000 (to the 50-m contour). In addition, zooplankton samples were collected in certain years for laboratory analysis of fatty acid, stable-isotope, and caloric content of selected groups and species of zooplankton. Those results are included in Chapters 19, 20, and 22, respectively.

Few bowhead whales were present in the study region during September of 1985 or 2000, and consequently we were not able to sample near feeding bowhead whales during those years. Instead, zooplankton sampling in those seasons was conducted along transects and in some other locations where bowheads had been observed feeding in previous years.

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4. RELATIONSHIPS BETWEEN ACOUSTIC BIOMASS AND NET BIOMASS OF ZOOPLANKTON IN THE EASTERN ALASKAN BEAUFORT SEA

William B. Griffiths[1]

Introduction

During late summer and autumn, bowhead whales of the Bering–Chukchi–Beaufort stock migrate westward across the Beaufort Sea, often either stopping to feed or feeding while traveling (Lowry 1993; Moore and Reeves 1993). The overall study of which the present work is a part was designed to determine the importance of the eastern Alaskan portion of the Beaufort Sea to feeding bowhead whales. This required collection of information on the distribution of zooplankton biomass from eastern Camden Bay to the Canadian border, and from nearshore waters out to the 50 m contour, during September (Fig. 4.1).

Traditionally, studies of zooplankton have relied on sampling with nets to provide information on species composition, distribution and biomass. However, net sampling can produce only limited amounts of data because of the time and expense of collecting and processing the samples. Consequently, these studies provide limited information on the distribution of biomass over large areas. Bowhead whales tend to feed in areas with a high biomass of zooplankton (Bradstreet et al. 1987; Griffiths et al. 1987). Areas with a very high biomass of zooplankton are relatively rare. In addition, the high biomass in these areas tends to be concentrated in layers, some of which are very thin. These areas would likely remain undetected if only net sampling were used. Furthermore, with net-sampling alone, there is no way to know whether the locations and depths with maximum zooplankton biomass have been sampled. These problems can, to a large degree, be solved through the use of a quantitative echosounder in combination with net sampling.

Over the past few decades, sophisticated sonar systems have been used to find and quantitatively sample marine fish and zooplankton (Sameoto 1976; Stanton et al. 1994a,b; Macaulay et al. 1995; Coyle 2000; Hewitt and Demer 2000; Kirsch et al. 2000). Hydroacoustic systems that include digital acquisition and processing can be used to estimate biomass and numbers of fish, and biomass of zooplankton. These systems measure the strength of the echo, called back scattering, that is returned from a biological (or other) target. Generally, a strong echo returned from a target means that the target is large and/or that there are many targets. Hydroacoustic surveys can provide continuous information on the horizontal and vertical distributions of zooplankton biomass if the relationship between acoustic back scattering and actual biomass of zooplankton, as estimated by net sampling at selected stations, can be established.

A strong relationship between acoustic back scattering and biomass of zooplankton as determined by net sampling can be difficult to establish. Acoustic data may contain echoes from fish, from large fast-swimming or very small zooplankters that are not captured in nets, and from sediment or water density discontinuities (Johnson and Griffiths 1990). In addition, the intensity of the back scattering can vary with the size and shape of the animals, their orientation relative to the sonar beam, and species

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[1] LGL Ltd., environmental research associates, 9768 Second St., Sidney, B.C. V8L 3Y8. *Phone:* 250-656-0127; *e-mail:* bgriff@lgl.com

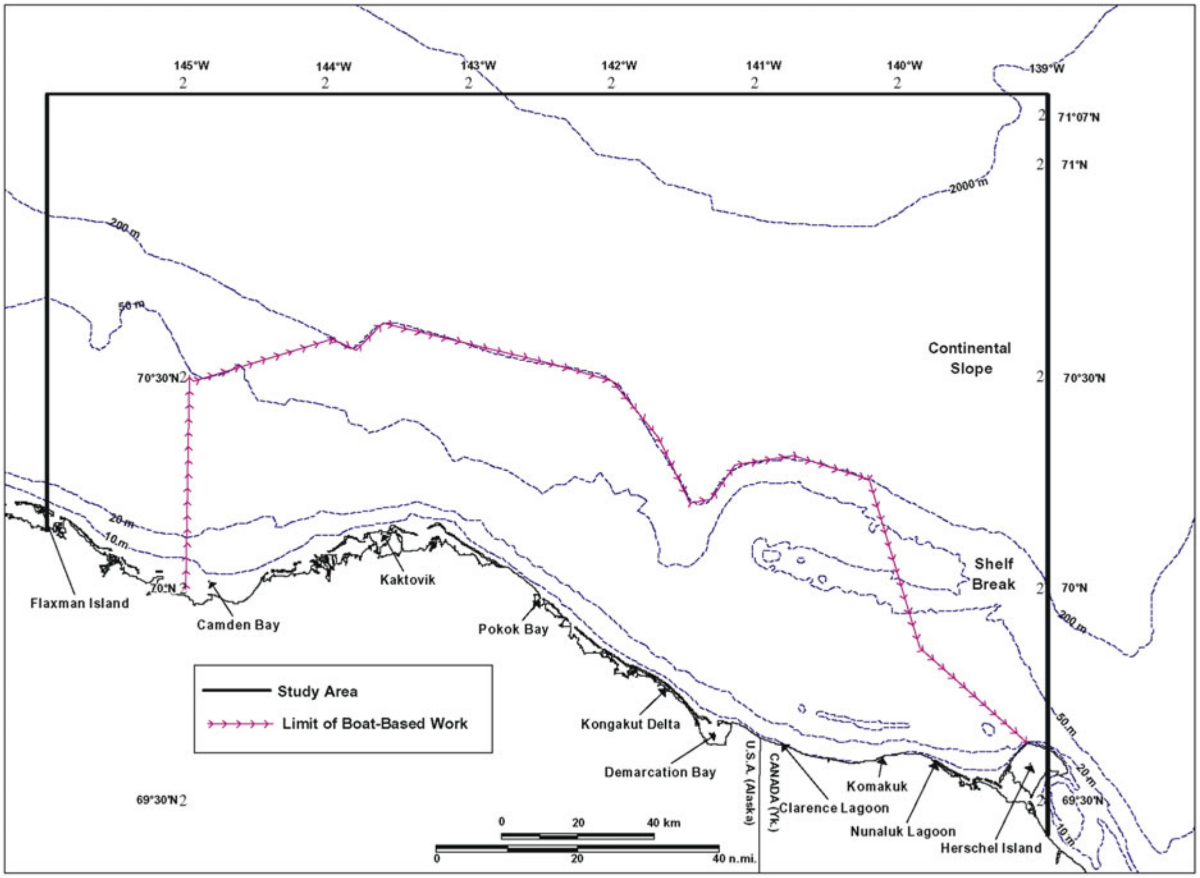

FIGURE 4.1. Map of the study area for the zooplankton components of the 1985–86 and 1998–2000 studies of bowhead whale feeding in and near the eastern Alaskan Beaufort Sea. The solid line outlines the area where zooplankton sampling might potentially have been done. The smaller area within which boat-based sampling was actually conducted is also outlined.

composition (Stanton et al. 1994a; Coyle 2000). In these cases, there may be no relationship between the back scattering from the targets and the quantity of zooplankton in the water. A further complication is that net sampling provides only an estimate, and often a biased estimate, of the actual biomass of zooplankton present. Complicating factors can include net avoidance by zooplankton, uncertainties in the volume of water filtered, uncertainty in the exact depth(s) that were sampled by the net, and passage of small zooplankters through the mesh (Hamner 1984; Wiese 1996; Wong 1996). It is important to minimize these problems when the objective is to use the relationship between net samples and acoustic data in order to calibrate other acoustic data collected in the absence of net sampling.

The present results are based on data collected during studies designed to determine the importance of the eastern Beaufort Sea to feeding bowhead whales. The first part of the study was conducted in September of 1985 and 1986, and the second in September of 1998 through 2000. In 1985 and 1986, a 120 and 200 kHz dual-frequency echosounder system was used with variable success (Griffiths et al. 1987; Johnson and Griffiths 1990). In 1998, a split-beam single-frequency 430 kHz transducer system was used to collect digital hydroacoustic data during all zooplankton tows and along transects. In 1999 and 2000, a split-beam dual-frequency system operating at 208 and 430 kHz was used. We also used bongo nets of two types to collect zooplankton samples at certain stations and depths. Many modern hydroacoustic and zooplankton sampling methods are more sophisticated and complex than the ones used here (e.g., Wiebe et al. 1996; Coyle 2000). Other sophisticated zooplankton sampling devices, e.g., video systems, can also be used (e.g., Davis et al. 1996). However, we required small and lightweight equipment that could be quickly deployed and retrieved from a 13-m boat in a remote area.

Methods

During all five years of the study, boat-based sampling was conducted during September from the 13-m *Annika Marie* based at Prudhoe Bay, Alaska. In 1985–86, locations of zooplankton sampling stations and of hydroacoustic transects were established using a VLF satellite navigation system, while in 1998–2000 a global positioning system (GPS) was used. Zooplankton, hydroacoustic, and physical oceanographic sampling were conducted at individual stations and along extended transects perpendicular to shore within the study area. The number of stations and the number and length of transects varied among the five years (see below).

Data Sources

In all five years of the study, concurrent acoustic backscattering data, zooplankton samples, and physical measurements were collected at stations along transects. In years when it was possible to approach feeding whales, the same types of data were collected at whale feeding and control stations (Table 4.1). Figures 5.1 and 6.1A in Chapters 5 and 6 show the locations of sampling stations along routine transects and near feeding whales, respectively.

1985–1986.—Acoustic backscattering data were acquired using a dual-frequency system with 120 and 200 kHz transducers. Instrument settings for each frequency and year are listed in Table 4.2. For a detailed description of the hydroacoustic methods in 1985–86, see Johnson and Griffiths (1990).

1998–2000.—In 1998, hydroacoustic data were collected using a split-beam single-frequency 430 kHz transducer. In 1999–2000, a split-beam dual-frequency system with 208 and 430 kHz transducers was used. The numbers of transects and stations sampled in these three years are listed in Table 4.1. The instrument settings for all frequencies used in the study from 1998–2000 are listed in Table 4.2.

Hydroacoustic Sampling of Zooplankton

Echosounder procedures varied among years. The equipment and procedures used in 1985–86 were described by Johnson and Griffiths (1990) and summarized in Table 4.1. Here we describe the 1998–2000 procedures.

In 1999 and 2000, the dual frequency system consisted of a Dell Inspiron 3200 Pentium-based laptop computer, a BioSonics surface unit, transducer cables, and two BioSonics DT 6000 Split Beam digital transducers operating at 208 and 430 kHz. The system used in 1998 was similar, but employed a single 430 kHz transducer.

The downward-facing transducers were mounted in a BioFin sled and were towed via armored cable from the side of the boat, away from the wake and ~1 m below the water surface. Tow speed was ~7.2 km/h (2 m/s) during surveys between stations, and ~3.6 km/h (1 m/s) during zooplankton tows.

When triggered, the 430 and 208 kHz echosounders both transmitted sound pulses into the water. Returning echoes were amplified and digitized within the transducers. Real-time acoustic data and positions were collected with the BioSonics Visual Acquisition Program and were stored to the computer's hard drive. Real-time data for both transducers were also simultaneously displayed on the computer screen. At the end of each day, two copies of the data were made and stored on removable Iomega disks.

TABLE 4.1. Number of broad-scale transects, transect stations, and whale feeding and control stations sampled during 1985–86 and 1998–2000.

Year	No. of Transects	No. of Transect St.	No. of Feeding St.	No. of Control St.
1985	3	12	0	0
1986	4	18	6	5
1998[a]	4	18	10	8
1999[b]	4	17	5	3
2000	7	27	0	0

[a] Three whale feeding stations and 1 control station were also Transect stations.

[b] Two whale feeding stations and 1 control station were also Transect Stations.

TABLE 4.2. Echosounder parameters used during whale feeding studies in the eastern Alaskan Beaufort Sea, 1985–86 and 1998–2000.

	1985		1986	
Parameters	120 kHz	200 kHz	120 kHz	200 kHz
Peak to peak source level (dB re 1 µPa)	217.4	225.0	217.8	224.4
Receiver sensitivity (dBV)	-153.5	-123.6	-135.2	-134.0
Pulse Width (ms)	-	-	-	-
Receiver gain (dB)	18.0	-18.0	6.0	0.0
Pulses per second (pps)	1.0	1.0	1.0	1.0
Beam pattern factor	0.005	0.002	0.002	0.002
Beam width	10°	7°	10°	7°
TVG (Time varied gain)	Analog	Analog	Analog	Analog

	1998	1999		2000	
Parameters	430 kHz	430 kHz	208 kHz	430 kHz	208 kHz
Peak to peak source level (dB re 1 µPa)	219.3	219.3	222.9	219.3	222.9
Receiver sensitivity (dBV)	-129.7	-129.7	-126.0	-129.7	-126.0
Pulse Width (ms)	0.5	0.5	0.4	0.5	0.4
Receiver gain (dB)	-	-	-	-	-
Pulses per second (pps)	5.0	2.0	2.0	2.0	2.0
Beam pattern factor	0.001	0.001	0.001	0.001	0.001
Beam width	7°	7°	6°	7°	6°
TVG (Time varied gain)	Digital	Digital	Digital	Digital	Digital

The acoustic data were collected at a threshold level of –90 dB relative to the minimum target strength with 40 Log R time varied gain. Signals below this threshold were not saved to the data file. The –90 dB threshold was used to maximize the ability of the acoustic system to pick up small zooplankters that had been common in and near the study area during the first part of the study in 1985 and 1986 (Johnson and Griffiths 1990). One option would have been to save only time- and depth-integrated backscatter data. However, this would have precluded re-processing of the data with different parameters. Post-processing of raw hydroacoustic data in 1985 and 1986 showed that re-processing was necessary. Hence, in all five years, all the digital raw hydroacoustic data were saved.

In all five years, the echosounder transducers were towed ~1 m below the surface. Typically, wave turbulence and air-bubbles in surface waters prevented obtaining meaningful acoustic results from the upper 2–3 m of the water column.

Net Sampling Methods

All zooplankton tows were made using a bongo assembly towed behind the boat. The bongo frame was fitted with two 0.5 mm mesh, 0.61 m diameter, plankton nets. A General Oceanics Inc. model 2030 flow meter was placed in the mouth of one of the nets. Standard bongo nets were used in 1985, 1998, 1999, and 2000. A Tareq opening and closing bongo assembly was used in 1986 to collect all horizontal tows at depth. In 1985 and 1986, the depth of all horizontal tows was recorded in real time using an Apelco Ranger model 1650 depth sounder. The transducer was attached to the bongo frame so that it measured distance to the water surface. In 1998, 1999 and 2000, the depth of the net during the tow was calculated using wire angle and the amount of wire out. The actual depth profile of each tow was determined later from data recorded with a Wildlife Computers dive recorder (Model Mk7-S) attached to the bongo frame.

Horizontal Bongo Tows.—All horizontal tows were of five minutes duration with the start time being the time when the net reached the desired depth. At most stations, we did from 1 to 3 horizontal tows. Sampling depths were selected based on real-time hydroacoustic data, and ranged from ~3 to 50 m depth. At all stations where this was feasible, separate horizontal tows were taken both within and outside (above or below) concentrations of zooplankton apparent on the echosounder. Except in 1986, the bongo assembly sampled during both descent to and ascent from the desired sampling depth. Letting the net free-fall to the desired depth while the boat was moving very slowly minimized the collection of zooplankton during descent. Slowing the speed of the boat also minimized sampling of zooplankton during ascent.

Sample Treatment.—After each tow, the entire sample from the side of the bongo net fitted with the flow meter was preserved in 10% formalin for analyses of zooplankton biomass and numbers. Subsamples from the other net were frozen on the boat and later sent to other project participants (University of Alaska; Alaska Department of Fish & Game) for caloric, isotopic, and fatty acid analyses.

CTD Profiles.—In both 1985 and 1986, temperature and salinity profiles were taken from the surface to the bottom at all zooplankton sampling stations. An Applied Microsystems CTD-12 was used (accuracy: temperature, ± 0.2 C°; conductivity, ± 2.0 mmho/cm). All data were recorded on a self-contained tape recording unit and were processed by Arctic Sciences Ltd on their PDP 11/24 computer. In 1998, 1999 and 2000, temperature and salinity profiles were taken at all stations with a digital Sea-Bird SBE 19 conductivity, temperature, depth (CTD) recorder (accuracy: temperature, ± 0.01 C°; conductivity, ± 0.01 mmho/cm). All data were downloaded from the CTD to a computer using Sea-Bird software and were processed using the Sea-Bird Analyzer software. In all five years, the CTD was allowed to equilibrate at the surface for several minutes before each cast, and was then lowered and raised at ~1 m/s.

The recorder collected data during both descent and ascent; however, only the descent data were analyzed. The data for all five years were transferred to Microsoft Excel for analysis.

Laboratory Analyses of Zooplankton

All samples collected during the five years of this study were analyzed by the same person (Nell Stallard). Each sample was sieved through a 163-µm mesh Nitex sieve, carefully rinsed with tap water to remove the preservative, and then examined under a low-power binocular microscope. Only data from horizontal zooplankton tows at depth were used in developing the linear relationships between acoustic backscatter data vs. zooplankton biomass from net samples. Individual organisms from all horizontal tows at depth were identified to major group (e.g., copepods, amphipods, and fish larvae, etc.), and wet-weighed to the nearest mg using an Acculab electronic balance. Before weighing, each sample was blotted dry on damp filter paper in a consistent manner.

If large numbers of individuals were present, the sample was first scanned for large or rare organisms, and small animals were then sub-sampled with a Folsom Plankton Splitter or a Hensen-Stempel pipette. In these cases, the zooplankters in the subsample were counted, weighed to the nearest mg, and identified to major group. The subsample data were then applied to the whole sample to estimate total numbers and wet weight for each major group in the sample.

Data Processing and Analysis

Zooplankton Data.—Results from the laboratory analyses of zooplankton were entered into a Microsoft Excel spreadsheet. For each sample, the flow meter reading recorded during the tow was used to calculate the volume of water filtered. This information, in conjunction with wet weights for the individual groups, was used to determine the total biomass in mg/m^3.

In 1986, the sampling efficiencies of the regular bongo assembly vs. the opening and closing bongo nets were compared based on five paired double-oblique tows at a single station. This showed that the biomasses of most major zooplankton groups, and the total biomass, were significantly higher for samples collected with the regular bongo assembly. The mean biomass of major taxa in the standard bongo nets was 1.23 to 5.82 times higher than that in samples taken in opening and closing bongo nets at the same place and depth, and nearly the same time. Therefore, all 1986 biomass estimates based on horizontal tows with opening and closing nets were scaled up using correction factors appropriate to each major taxonomic group and to total biomass. These factors were 2.53 for copepods and 1.32 for euphausiids (the predominant taxa), and 2.05 for total biomass.

Hydroacoustic Data.—Methods used to process the hydroacoustic data collected in 1985 and 1986 are presented in Johnson and Griffiths (1990). Briefly, in both years, acoustic volume-scattering data were obtained by processing digitized voltages with a BioSonics digital echo integrator. In 1985, strata were 2 m thick between 4 and 52 m depth, and 10 m thick between 52 and 102 m depth. In 1986, the strata were 1 m thick between 3 and 55 m depth, and 5 m thick from 55 to 100 m depth. In both years, mean squared voltage for each stratum was calculated for every two minute interval during continuous transects and for the duration of each horizontal net tow. In 1985 and 1986, acoustic data were collected with a threshold of −100 dB.

Methods for 1998–2000 were generally similar to those for 1985–86. In 1998, acoustic data from the 430 kHz transducer were analyzed using BioSonics Visual Analyzer 3.1.1. In 1999 and 2000, hydroacoustic data files for the 430 and 208 kHz transducers were processed separately using BioSonics Visual

Analyzer 4.0 (1999) or 4.0.2 (2000). The results were the intensity of acoustic return (volume back scattering) by location and depth. In 1998–2000, acoustic data were collected with threshold –90 dB.

The acoustic data collected during each horizontal tow were processed to estimate the average volume backscatter at tow depth during the duration of that tow. Horizontal tow depth varied somewhat during each tow so the time-depth plot taken from the depth recorder on the net during that tow was used to determine actual depths sampled. The volume backscattering data from all 1-m depth strata within the depth range sampled by the net were averaged. For example, for a tow with a mean depth of 10 m, a maximum depth of 12 m and a minimum depth of 8 m, the average volume backscattering data from the four 1 m strata between 8 and 12 m over the distance of the tow was used.

***Acoustic vs. Net Biomass*.—**The mean backscattering cross section (σ) of individual zooplankters encountered during the study was not known, and the value was set to one in the analyses. To convert the resulting "relative" estimates of zooplankton biomass to estimates of absolute biomass, separate regression analyses were performed on each year's data. These analyses determined the relationship between volume back scattering and net biomass (in mg/m^3), based on the concurrent horizontal zooplankton tows and matched acoustic samples described above.

For 1998–2000, the least trimmed squares (LTS) robust regression program in S-Plus (version 6) was used to calculate the relationship between acoustic back scattering and net biomass of zooplankton. This method was chosen because robust regression techniques provide a better fit for a linear regression model when the data contain outliers, as was the case here (Fig. 4.2). The LTS technique is a highly robust method for fitting a linear regression model, and achieves this by ordering the residuals from a least squares fit, trimming the observations that correspond to the largest residuals, and then computing a least squares model for the remaining observations (S-Plus 2001). This resulted in 6, 4 and 5 data points being eliminated from the 1998, 1999 and 2000 analyses, respectively. The method provides a more robust fit then the ordinary least squares regression because it reduces the influence of outliers. For 1985–86, the regression relationships are presented as previously derived by Johnson and Griffiths (1990), based on geometric mean regression for 1985 and least-squares multiple regression for 1986.

***Application to Echosounder Surveys*.—**For routine transects and transects between whale feeding and control stations, volume backscatter data for each depth stratum (1 m thick in 1998-2000) were averaged over 2-min time periods. A 2-min period corresponded to ~240 m distance at typical tow speed. To estimate wet-weight biomass for each depth stratum and 2-min time interval, the regression relationship described above was applied to the measured volume backscatter. The resulting biomass estimates were the basis for much of the analysis (in later chapters) of zooplankton availability to bowhead whales.

Results

The best-fit regressions for each of the five years and for 1999–2000 combined are listed in Table 4.3 and illustrated in Figure 4.2. In all years except 1998, dual frequency systems were used to collect acoustic data. In 1985 and 1986, 120 and 200 kHz transducers were used; in 1999 and 2000, 208 and 430 kHz transducers were employed. Only the results from the higher frequency transducer used in any given year are presented. In all four years with dual-frequency data, the correlation between net and acoustic data was higher for acoustic data from the higher-frequency transducer

In the 1985–86 study, some pairs of concurrent net and acoustic data were excluded from the analyses because of the presence of sharp horizontal density gradients (pycnoclines). Pycnoclines can produce a strong acoustic return in the absence of zooplankton concentrations (Johnson and Griffiths 1990).

TABLE 4.3. Regression equations for zooplankton net catch vs. echosounder volume back scattering for 1985–86 and 1998–2000.

Independent Variable	Coefficient	Std Error	t-value	P value
1985 mg/m^3 vs. 200 kHz[a]				
Constant	27.9	-	-	<0.001
(Sv dB 200 kHz)	346.4	-	-	0.011
Correlation Coefficient r =	0.810	n = 17		
r^2 (% variation explained) =	0.631	df = 15		
1986 Log mg/m^3 vs. 200 kHz[a,b]				
Constant	11.589	1.51	7.680	<0.001
Log (Sv dB 200 kHz)	1.079	0.182	5.920	<0.001
Sta. Depth (m)	-0.007	0.003	-2.19	0.033
Multiple Correlation Coefficient R =	0.660	n = 56		
R^2 (% variation explained) =	0.440	df = 53		
R^2 adjusted for df =	0.420			
1998 Log mg/m^3 vs. 430 kHz (-90 dB-60 dB)[b]				
Constant	3.6487			<0.05
10 x Sv dB 430 kHz	0.015			<0.05
Correlation Coefficient r =	0.274	n = 53		
r^2 (% variation explained) =	0.070	df = 51		
1999 Log mg/m^3 vs. 430 kHz (-90 dB-60 dB)[b]				
Constant	12.112			<0.001
10 x Sv dB 430 kHz	0.126			<0.001
Correlation Coefficient r =	0.897	n = 33		
r^2 (% variation explained) =	0.804	df = 31		
2000 Log mg/m^3 vs. 430 kHz (-90 dB-60 dB)[b]				
Constant	6.625			<0.001
10 x Sv dB 430 kHz	0.057			<0.001
Correlation Coefficient r =	0.570	n = 39		
r^2 (% variation explained) =	0.325	df = 37		

[a] From Johnson and Griffiths (1990).
[b] 1986 and 1998-2000 data reprocessed to minimize contributions by fish (see text).

Net samples taken near pycnoclines found little zooplankton. In 1998, pycnoclines were not a major problem as distinct pycnoclines were not common at shallow depths (10-25 m) when matched net and acoustic data were collected. In deeper waters (>25 m), pycnoclines were present during 1998 but very little zooplankton was evident in the water above them. None of the horizontal tows used in the 1998 analysis of net vs. hydroacoustic data were taken above or in obvious pycnoclines. In 1999 and 2000 all sampling was done in areas inside the 50 m contour, and no obvious pycnoclines were observed at any stations there.

In 1985, the best-fit equation was a linear regression between zooplankton biomass and the acoustic backscatter data from the 200 kHz transducer (Table 4.3; Fig. 4.2A—from Johnson and Griffiths 1990). This regression was derived via the geometric mean method (Ricker 1973, 1984). It "explained" 63% of the variation in zooplankton biomass after exclusion of eight problematic data points. In 1985, strong temperature–salinity gradients (pycnoclines) were present in the top 10 m of the water column. When these discontinuities were present, acoustic echoes from zooplankton could not be separated from

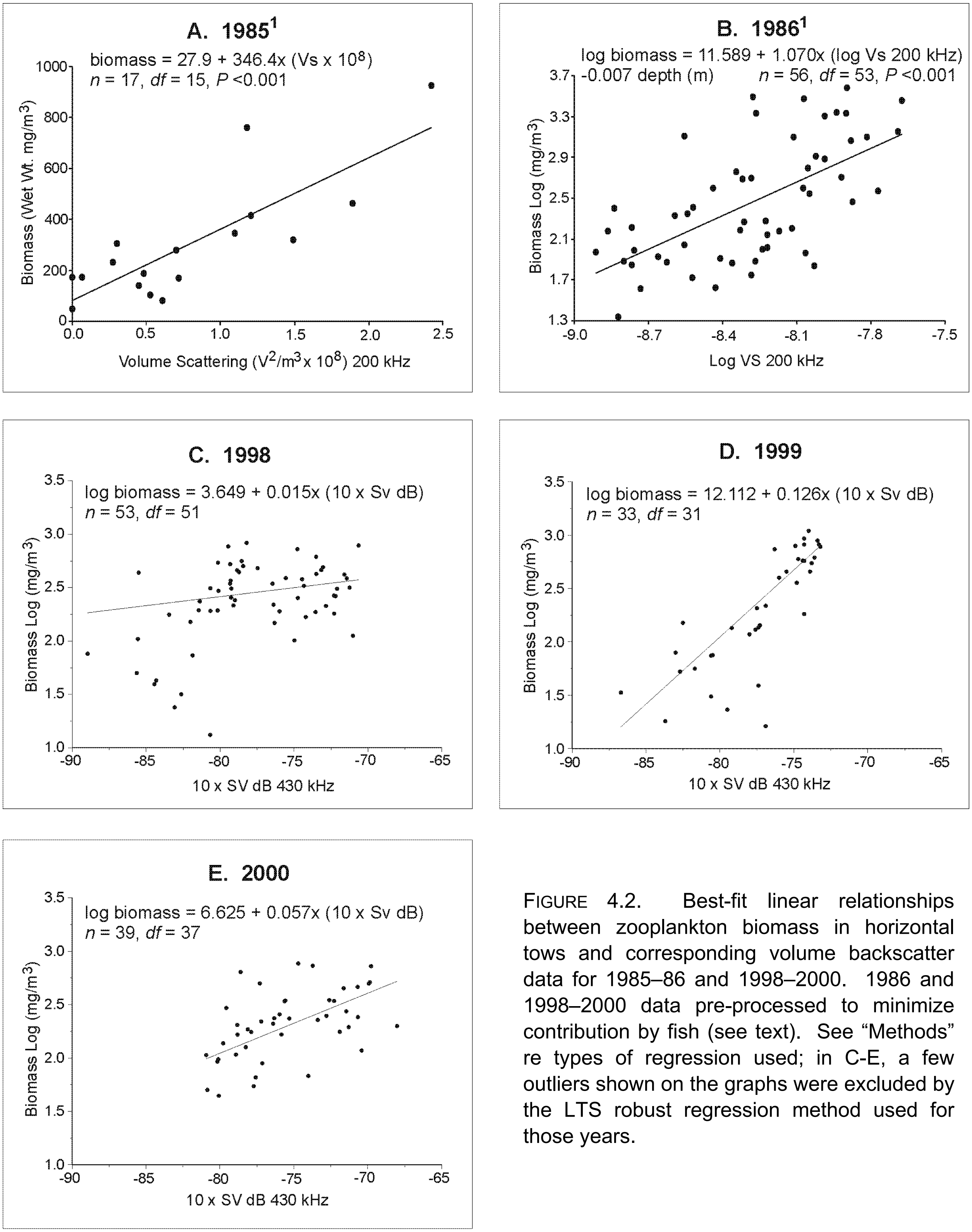

FIGURE 4.2. Best-fit linear relationships between zooplankton biomass in horizontal tows and corresponding volume backscatter data for 1985–86 and 1998–2000. 1986 and 1998–2000 data pre-processed to minimize contribution by fish (see text). See "Methods" re types of regression used; in C-E, a few outliers shown on the graphs were excluded by the LTS robust regression method used for those years.

those attributable to the pycnocline, biasing the backscatter data. To avoid this problem, eight net tows collected from depths near pycnoclines, and the corresponding acoustic data, were excluded from the analysis. This resulting regression relationship (Fig. 4.2A) was used to estimate zooplankton biomass from echosounder data obtained along 1985 transects, and to investigate the vertical and horizontal patchiness of zooplankton.

In 1986, the best-fit equation was a multiple regression equation predicting zooplankton biomass from the 200 kHz backscatter data and station depth (m). That relationship accounted for 42% of the variation in zooplankton biomass (Table 4.3; Fig. 4.2B—from Johnson and Griffiths 1990). Some preliminary data selection and special processing was necessary before the regression analysis was done. Ten pairs of concurrent net and hydroacoustic data were excluded because of problems with sharp pycnoclines, similar to those in 1985. In addition, the presence of large numbers of small fish that were not effectively captured by the bongo nets was a serious bias in 1986. To remove them from the analysis, the acoustic data were re-processed at a higher threshold to estimate acoustic backscatter attributable to fish. The "fish" backscatter was then subtracted from the overall backscatter to estimate the backscatter attributable to zooplankton (Johnson and Griffiths 1990). The volume scattering data were already in log format and the net biomass was log transformed to stabilize the variation across the range of the two variables. The resulting multiple regression equation (Fig. 4.2B) was used to estimate zooplankton biomass from echosounder data obtained in 1986 along routine transects and between whale feeding and control stations, and to investigate the vertical and horizontal patchiness of zooplankton.

In 1998, the best-fit equation was a robust LTS linear regression between net biomass and the 430 kHz back scatter, pre-processed as described below. This regression explained only 7% of the variation in net biomass (Table 4.3; Fig. 4.2C). Although there were some strong pycnoclines in the study area in 1998, no samples were collected near any of the discontinuities and no pairs of data required deletion. However, as in 1986, small fish, primarily Arctic cod (*Boreogadus saida*), produced strong acoustic signals but were not effectively caught in the nets. Before the regression analysis was done, the acoustic data were re-analyzed using –60 dB as a threshold in order to estimate the backscatter attributable to fish. These values were subtracted from the overall –90 dB data to estimate backscatter attributable to zooplankton. The Sv dB (volume backscattering) values are already on a logarithmic scale. Analysis of scatter plots of the original data and residuals indicated that the log of zooplankton net biomass (mg/m^3) produced the best relationship between net and acoustic biomass. Although the correlation between net and acoustic biomass was statistically significant ($P < 0.05$), this relationship was too weak to be useful in estimating zooplankton biomass along the 1998 echosounder transects ($r^2 = 0.07$).

In 1999, the best-fit equation was a robust LTS linear relationship between net biomass and 430 kHz back scatter (pre-processed to eliminate fish as in 1998). Pycnoclines were not observed in the study area in 1999 and did not present a problem in the analysis. This regression explained 80% of the variation in net biomass (Table 4.3; Fig. 4.2D). This value was sufficiently high to allow use of the 1999 regression in estimating zooplankton biomass along the echosounder transects.

In 2000, the best-fit equation was a robust LTS linear relationship between net biomass and 430 kHz back scatter (pre-processed to eliminate fish as in 1998–99). As in 1999, no pycnoclines were observed in the study area in 2000. This regression explained 33% of the variation in net biomass (Table 4.3, Fig. 4.2E). The correlation was statistically significant ($P < 0.001$), and the relationship was used to obtain approximate estimates of zooplankton biomass along the 2000 transects.

Discussion

The absence of strong linear relationships between zooplankton net biomass and acoustic backscatter data in some years of the study is not surprising. Several types of problems can bias the results. The sources of error include biases in estimating actual zooplankton biomass with nets, imprecise coordination of acoustic and net sampling, back scatter from organisms not sampled by the nets, and/or back scatter by physical properties of the water. In some cases, these biases can be reduced or removed during analysis. In other instances they cannot be eliminated, thus leaving residual variation, and sometimes bias, in acoustic estimates of zooplankton biomass.

Net Sampling Biases

Different groups or species of zooplankton are not equally susceptible to capture in zooplankton nets. Some zooplankters are larger and swifter than others, and some fraction of these animals are able to avoid capture by a relatively slow moving net (Hamner 1984; Wiese 1996; Wong 1996). Consequently, those taxa will be under-represented in the zooplankton samples. This can cause underestimation of zooplankton biomass. Because of the patchy nature of zooplankton, this error varies with time and location. If large swift zooplankters represent a significant portion of the zooplankton community at a given station, the zooplankton biomass estimated with nets will substantially underestimate actual biomass, and the relationship of these net-based estimates with acoustic back scatter (which theoretically represents all animals) will be weak.

It is also possible, given the relatively large mesh size used (0.5 mm), that some very small zooplankters or some of the smaller life stages of the more common zooplankters may have passed through the net and were thus under-sampled. The biomass of these smaller organisms would then have been under-represented in the zooplankton sample, leading to a similar problem as that described above for the larger swift zooplankters.

To establish the relationship of net biomass to acoustic back scatter, a high degree of coordination is required in obtaining matched samples by the two methods. A primary assumption of this technique is that the acoustic system is recording backscatter data from the same zooplankton that is being sampled by the zooplankton net. However, the acoustic system is in fact towed beside the boat while the zooplankton net is towed some distance off the stern of the boat. It is assumed that the zooplankton is evenly distributed both vertically and horizontally over these relatively short distances, but this may not always be the case. If the zooplankton biomass sampled by the two methods is different in the horizontal plane, then a non-correctable error would be introduced into the data.

In 1985 and 1986, the position of the zooplankton nets in the water column was determined by attaching an upward looking depth sounder to the bongo net frame and reading the output directly from a deck unit in real time. In addition, in 1986, a set of opening and closing bongo nets was used in order to collect zooplankton samples only from the desired depth and eliminate the collection of zooplankton during both the ascent and descent of the net. Despite the assumed advantage of using the opening and closing nets in 1986, a stronger relationship between net and acoustic data was obtained for 1985 using the standard bongo assembly than for 1986 using the opening and closing net (r^2 = 0.63 vs. 0.42). Furthermore, the r^2 = 0.42 value for 1986 was achieved only by applying a multiple regression approach using station depth as an additional predictor variable. Part of the problem in 1986 may have been with the opening and closing bongo net itself, which underestimated the biomass of most major zooplankton groups in the water column compared to the standard bongo assembly (see Methods). Correction factors derived from paired double-oblique tows with standard bongo nets vs. opening/closing bongo nets were applied to all data from the opening and closing nets. However, uncertainty in estimating those correction factors was another source of measurement error.

From 1998 to 2000, the position of the standard bongo net in the water column was determined after the net had been retrieved based on a time–depth recorder attached to the net frame. These data were then used to determine the depth range from which acoustic data should be selected for correlation with the net data. Again, the results over the three years were variable, with the strongest relationship from 1999 ($r^2 = 0.80$) and the weakest from 1998 ($r^2 = 0.07$). Other studies have used larger and more expensive multiple sampling nets that simultaneously recorded sampling depth, net angle, and a variety of physical measurements. Analyses of those net data relative to simultaneously collected echosounder data have resulted in r^2 values in the same range ($r^2 = 0.23$ to 0.93) as those from this study (Simard and Mackas 1989; Coyle 2000). The net sampling gear used in those studies could not have been handled from the small research vessel available in the present study, and it is not clear that the more complex gear, if used, would have provided better results.

It is undoubtedly important, in a study such as this, to coordinate the collection of acoustic and net data accurately in time and space. However, this alone does not guarantee that the relationships between the two sets of data will be strong. There are other factors that can influence the strength of the relationship.

Physical Biases

Physical discontinuities can take several forms, e.g., temperature–salinity density gradients, surface wave turbulence, and air bubbles dispersed deep into the water column by strong wave action. In the present study area, strong temperature–salinity gradients or pycnoclines are common oceanographic features. The causes include ice melt and warm freshwater river run-off during the open-water season (Coachman and Aagaard 1974; Melling et al. 1984). Pycnoclines were common in 1985 and 1986, but were much less so in 1998 and were absent in 1999 and 2000. When present, the strong acoustic echoes attributable to the pycnocline could not be separated from those of the zooplankton, so backscattering data from those places and water depths were biased. If CTD data are not available, it may be difficult to determine whether an area of strong back scatter evident during a hydroacoustic survey is attributable to zooplankton or to a pycnocline. In the present analysis, this problem was easily remedied by eliminating data collected in or near pycnoclines since CTD data were available from all net sampling stations used in the analyses. However, CTD data were not available from all locations along the transects where echosounder data were collected for purposes of estimating zooplankton biomass (Chapters 5, 6). Thus, zooplankton biomass as estimated from echosounder surveys may have been overestimated at some locations and depths where a strong pycnocline was present. This problem was most likely to have occurred in 1985–86, when strong pycnoclines were present, and less likely in 1998–2000 when they were infrequent or absent.

Surface wave turbulence mixes air into the surface water. The echosounder transducers were towed one meter below the surface and the upper meter was not sampled. Severe and prolonged wave-action produces air bubbles in the upper 2–3 m of the water column. These are clearly visible in the echograms and can easily be removed from the data. However, small air bubbles cannot be discerned on the echogram display or in the acoustic data but can be found at greater depths (Stanton et al. 1994a; J. Dawson, BioSonics Inc., Seattle, WA, pers. comm.). The backscatter signal from these small bubbles cannot be separated from that of the zooplankton and, consequently, the acoustic data can be biased upwards. This source of error would be eliminated if all sampling could be conducted during extended periods of calm weather. However, with limited time available to collect samples, most studies (including this one) necessarily sample in marginal as well as ideal weather conditions. This source of error could not be recognized or removed during analyses.

There was a weak relationship between acoustic biomass and net biomass in 1998 and a stronger one in 1999. Large amounts of sediment were evident in the water in 1998. No direct measurements of turbidity were made in 1998, but turbidity plumes were visible near the bottom at several stations where a video system was being tested for possible use in detecting zooplankton layers. The 430 kHz transducer system used in 1998 was capable of detecting and recording signals from sediment plumes in the water column (Brock Staple, BioSonics Inc., Sumas, WA, pers. comm.). In other applications, high frequency (500 kHz) echosounders have been used to profile the concentrations and transportation of fine sediments, 5.5 to 7.4 µm in size (Shi et al. 1999). Bradstreet et al. (1987), using a Ross 200 kHz acoustic system, reported that high turbidity levels and strong pycnoclines were factors in causing a low correlation between acoustic and zooplankton data during a whale feeding study along the Yukon coast of the Beaufort Sea—an area where very turbid water is common. The turbidity plumes present during the 1998 phase of the present study may at times have caused high backscattering values regardless of zooplankton biomass present. This may partially account for the lack of a clear relationship between acoustic and net biomass in 1998 (Fig. 4.2C). To help address this source of error in future studies conducted in shallow seas where suspended sediments can bias the acoustic results, it would be useful to measure turbidity vs. depth profiles as well as standard temperature–salinity profiles. This should be done as often as possible along the echosounder transects. In this way, data collected at locations and depths with high turbidity and/or a pycnocline could be removed from the analysis to help improve the relationship between the acoustic signal and net biomass, and to allow more reliable estimates of biomass from acoustic data. Alternatively, turbidity and density gradient might be used as covariates in equations predicting zooplankton biomass from acoustic back scatter.

Biological Biases

A common problem during all years of the studies was the presence of large swift organisms, such as juvenile fish, that produced strong backscatter signals but were not effectively captured by the zooplankton net. This caused acoustic biomass to be relatively higher than net biomass. This bias was partially addressed by removing the back scatter from large animals. This was done by re-analyzing the acoustic data at a higher threshold level to estimate back scatter attributable to large animals and then subtracting these results from the lower threshold values representing all back scatter. The results were an estimate of the acoustic back scatter from the smaller zooplankton, which were more effectively sampled by the zooplankton nets (and more representative of the prey of bowhead whales). This process does not entirely eliminate the problem associated with fish, because fish oriented so as to produce little back scatter, or at the edge of the beam, could produce an echo below the upper threshold value but above the lower threshold (i.e., indistinguishable from zooplankton). This is a source of error, and could reduce the correlation between acoustic and net biomass (Johnson and Griffiths 1990). However, during this study, application of the dual-threshold procedure to data collected in the four years when fish were a problem improved the correlation between net and acoustic data.

Echosounders have been widely and successfully used to estimate the number and biomass of fish in a school. This success has depended on the assumption that the schools are composed primarily of a single size and species with similar scattering characteristics (Stanton et al. 1994b). The structure of zooplankton communities, on the other hand, is more complex. Although there can be a dominant species or group, the Beaufort Sea zooplankton community is inevitably composed of a variety of species and groups (Bradstreet and Fissel 1986; Bradstreet et al. 1987; Griffiths et al. 1987; see also Chapter 5). The gross anatomical shape of individual organisms can vary widely across species and sometimes within species, resulting in great variations in the acoustic reflective or scattering properties (Stanton et al. 1994b, 1996). The orientation of individual zooplankters in the water column can also dramatically affect their acoustic scattering properties (Coyle 2000).

Thus, organisms of the same size but different species, or of the same species but oriented differently in the water column, can produce widely different backscatter properties. Because the species structure of the zooplankton community varies both spatially and temporally, the average backscattering cross section (σ) of the animals will vary accordingly (Stanton et al. 1994b). This potential source of error probably goes a long way toward explaining the wide variation in percent of variance (7% to 80%) "explained" by our regression relationships between net and acoustic data. Coyle (2000), in summarizing the results of several studies that used linear regressions to determine the relationship between net-caught and acoustic estimates of biomass, found that the explained variance ranged widely, from 23% to 93%. The "percent of variance explained" values can range widely within the same season and area. Simard and Mackas (1989) used a 104 kHz transducer to detect dense scattering layers and an instrumented multiple opening and closing net sampler to sample within these layers. They found that large euphausiids (>12 mm long) and copepods comprised ~70% and ~25%, respectively, of the dry weight biomass in both June and August. Based on a stepwise linear analysis, they found an r^2 value of 0.85 for large euphausiids in June and 0.42 in August. They found that the addition of copepod biomass as a covariate did not significantly improve the relationship in either month.

Although other types of techniques and analyses have been used to address these problems, the results have also been mixed. Coyle (2000) used multifrequency acoustic data to estimate wet weight biomass in concurrently collected zooplankton samples. He used canonical correlation between the seven acoustic variables (volume backscatter at 43, 120, 200 and 420 kHz; mean σ at 43, 120, and 200 kHz) and the wet weights of individual taxonomic groups to identify significant correlations between acoustic and biological variables. The technique identified significant correlations of acoustic data with euphausiids and fish larvae, but not with copepods and chaetognaths—the two main contributors to the zooplankton biomass (as sampled by nets) in the eastern Alaskan Beaufort Sea.

Despite these limitations and biases, the concurrent acoustic and zooplankton net data collected during 1985, 1986, 1999 and (less adequately) 2000 provided a basis for estimating, from echosounder data alone, the relative zooplankton biomass vs. depth, location, and year. Although the technique did not provide a "perfect" representation of zooplankton biomass, it did provide a useful measure of relative biomass at different places, depths, and times. A major objective of the overall study was to assess the characteristics and quality of bowhead whale feeding habitat in the eastern Alaskan Beaufort Sea. This required zooplankton surveys that could not be conducted with adequate resolution by net-sampling alone. The relationships developed here provide the basis for converting echosounder data into contour plots depicting zooplankton biomass vs. depth and location along transects (see Chapters 5 and 6). These plots show the locations of zooplankton concentrations ("patches") within the study area in a given year, the relative biomasses of zooplankton available to whales at different places and times, and year-to-year differences among the years when useable data were available (see Chapters 5 and 6).[3]

Summary

There was a need for a method to estimate zooplankton biomass from echosounder data acquired along transects and at whale feeding locations in the eastern Alaskan Beaufort Sea. This was done by comparing zooplankton biomass collected in horizontal bongo-net tows with concurrent echosounder

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[3] Acknowledgements applicable to all zooplankton chapters are included near the end of Chapter 3.

measurements of acoustic back scatter at corresponding depths. Paired data of these types were collected during late summer/early autumn in five years: 1985–86, and 1998–2000. Linear regression techniques (robust LTS regression in 1998-2000) were used to develop equations that could predict zooplankton biomass from acoustic back scatter when only the latter is measured. In all five years, there was a positive and statistically significant ($P < 0.05$ or better) correlation between net biomass and acoustic back scatter. Predictive equations were developed for data collected in 1985, 1986, 1999, and 2000. In 1998, the relationship between back scatter and zooplankton biomass was too weak to be of use. The equations are used in Chapters 5 and 6 to convert acoustic back scattering along transects and at whale feeding stations into estimates of relative zooplankton biomass, and from this to define the nature and extent of suitable bowhead feeding habitat in the study area. The resultant echosounder-based data are useful primarily in comparing *relative* amounts of zooplankton at different locations, depths, and years.

Numerous sources of error can confound the relationship between acoustic backscatter data and zooplankton biomass measured with nets. A strong relationship between backscattering data and net biomass is difficult to obtain because the acoustic data may contain echoes from other biotic as well as abiotic sources. Sources of variability include such things as the presence of fish larvae or other large swift animals that are not captured by the net, the shape and orientation of zooplankters, sediment plumes, and density discontinuities in the water. Some of these biases (e.g., backscatter from fish and density discontinuities) can be partially or completely removed. Other biases cannot be eliminated. These reduce the strength of correlation between acoustic back scatter and zooplankton biomass in concurrent net samples, and thus the accuracy with which biomass can be estimated from backscatter data. More expensive and technologically advanced zooplankton samplers, and more sophisticated acoustic systems, were not practical in this study. Also, other studies have shown that these approaches do not guarantee better or more consistent results.

Despite the limitations and biases, the method provided useful data concerning the locations and depths of high-density zooplankton patches, and the relative amounts of zooplankton at different locations, depths, and times within and among the four years when useful data were available. This approach was an important technique in assessing the characteristics and quality of feeding habitat available to bowhead whales in the eastern Alaskan Beaufort Sea during those four years.

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5. SPECIES COMPOSITION, BIOMASS, AND LOCAL DISTRIBUTION OF ZOOPLANKTON RELATIVE TO WATER MASSES IN THE EASTERN ALASKAN BEAUFORT SEA

William B. Griffiths [1] and Denis H. Thomson [2]

Introduction

There have been several published studies of the species composition and numerical standing crop of zooplankton in the Beaufort Sea (Johnson 1956, 1958, 1963; Grainger 1965, 1975; Horner 1978, 1979, 1981; Horner and Murphy 1985; Shih and Laubitz 1978; Sutherland 1982). In waters of the Beaufort Sea <100 m in depth, Grainger (1965) described two major groups of zooplankton based on horizontal and vertical distribution patterns and physical characteristics of the water. One group, characteristic of the upper 100 m of Arctic Surface Water (ASW), is tolerant of temperatures of –1° to ~5–10°C and salinities of 12 to 34 practical salinity units (psu). This group includes the hydrozoans *Aglantha digitale* and *Aeginopsis laurentii,* the ctenophore *Beroe cucumis*, and several species of copepods including *Calanus hyperboreus*, *C. glacialis*, *Pseudocalanus minutus*, *Metridia longa,* and *Oithona similis*. A second group is characteristic of shallow nearshore brackish waters along the coastlines of the Beaufort and Chukchi seas and includes the hydrozoans *Euphysa flammea, Halitholus cirratus,* and *Sarsia princeps*, the ctenophore *Obelia* spp., and the copepods *Limnocalanus macrurus*, *Acartia clausi*, *Eurytemora herdmani,* and *Derjuginia tolli*. During the open water season these nearshore brackish waters have relatively high temperatures of 1 to 12°C and low salinities of 8 to 25 psu (Grainger 1965; Shih et al. 1971). These and most other studies in the Beaufort Sea have presented results as numbers of individuals, not biomass.

Zooplankton is typically concentrated in patches or layers that can vary widely in both horizontal extent and thickness. The occurrence of these patches can be affected by temperature and salinity, food availability, and light intensity (Mackas et al. 1985). At times, the plume of warm, brackish, turbid water associated with the Mackenzie River outflow can be advected into the eastern Alaskan Beaufort Sea by the wind. The presence, in the same area, of water masses with different properties in the vertical and/or horizontal dimension can influence the distribution and abundance of zooplankton (Simard et al. 1986; Castel and Veiga 1990).

This chapter presents the results of 5-year study of the distribution and biomass of zooplankton in continental shelf waters of the eastern Alaskan Beaufort Sea (central Camden Bay to the Canada/Alaska border) during September. In September, some bowhead whales are still present on their summer range in the Canadian Beaufort Sea, but others are migrating westward across the Alaskan Beaufort Sea, frequently stopping to feed or feeding while traveling (see Chapters 9, 12). The study was based on coordinated net sampling and quantitative echosounder surveys. It and similar summer studies in the Canadian Beaufort Sea (Bradstreet and Fissel 1986; Bradstreet et al. 1987) were components of broader studies of the feeding ecology of the planktivorous bowhead whale. These projects in the Canadian and eastern

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[1] LGL Ltd., environmental research associates, 9768 Second St., Sidney, B.C. V8L 3Y8. *Phone:* 250-656-0127; *e-mail:* bgriff@lgl.com

[2] LGL Ltd., environmental research associates, 22 Fisher St., POB 280, King City, Ont. L7B 1A6. *Phone:* 905-833-1244. *E-mail:* dthomson@lgl.com

Alaskan parts of the Beaufort Sea were the first comprehensive studies on late summer biomass of zooplankton in these areas.

The primary purpose of the present study was to gather data on the taxonomic composition, biomass, patchiness, and variability of the zooplankton available to feeding bowhead whales in the eastern Alaskan Beaufort Sea. This study emphasized only those species and taxa that were major contributors to the overall zooplankton biomass. We describe their vertical and horizontal distribution and patchiness in relation to water masses in the eastern Alaskan Beaufort Sea. Chapter 6 (by Griffiths et al.) compares average zooplankton biomass and species composition as documented here with those found near feeding bowheads.

Methods

In all five years of the study (1985–86; 1998–2000), sampling was conducted from a 13-m vessel, *Annika Marie*, during September. Zooplankton and physical oceanographic sampling were conducted at stations along transects perpendicular to shore from central Camden Bay to Demarcation Bay near the Alaska/Canada border (Fig. 5.1). In 1998, 1999 and 2000, transects were ~25 km in length and sampled areas from near the shore seaward to the 50 m depth contour. In 1985 and 1986, transects were ~45 km in length and sampled areas seaward to the 100–200 m contour. In 1985–86, locations of sampling stations and of hydroacoustic transects were established using a VLF satellite navigation system, whereas in 1998–2000 a global positioning system (GPS) was used. Hydroacoustic and surface-temperature data were also collected continuously along those transects. At selected stations along the transects, zooplankton tows and vertical profiles of temperature and salinity were taken (Table 5.1). The resulting data were used to describe the nature of the zooplankton community and to investigate its relationships to the physical oceanographic characteristics in the study area. Unless otherwise noted, the methods described below were used in all five years.

Temperature and Salinity Measurements

CTD Profiles.—In *1985 and 1986*, temperature and salinity profiles were taken from the surface to bottom at all zooplankton sampling stations. An Applied Microsystems CTD-12 (accuracy: temperature, ± 0.2 C°; conductivity, ± 2.0 mmho/cm) was used. All data were recorded on a self-contained tape recording unit and were processed by Arctic Sciences Ltd on their PDP 11/24 computer. In *1998–2000*, the temperature and salinity profiles were taken at all stations with a digital Sea-Bird SBE 19 conductivity, temperature, depth (CTD) recorder (accuracy: temperature, ± 0.01 C°; conductivity, ± 0.01 mmho/cm). All data were downloaded from the CTD to a computer using Sea-Bird software and were processed using the Sea-Bird Analyzer software. In *all five years*, the CTD was allowed to equilibrate at the surface for several minutes before each cast, and was then lowered and raised at ~1 m/s. The recorder collected data during both descent and ascent; however, only the descent data were analyzed. Data for all five years were transferred to Microsoft Excel for analysis.

Continuous Surface Measurements.—In *1985 and 1986*, near-surface temperature and salinity were recorded every 15 min during transits between sampling stations. The data were collected using a Hydrolab System 4000 CTD meter in 1985, and a Hydrolab TC-2 (TCOSL) meter in 1986 (accuracy for both meters: temperature ± 0.2 C°; conductivity, ± 2.0 mmho/cm). In *1998–2000*, a continuous record of near-surface temperatures was made during transits between stations. Temperatures were recorded every 15 s using an Onset Computer Corp. HOBO data recorder that had a remote uncovered thermistor (accuracy: ± 0.5 C°). The thermistor probe was attached to a piece of pipe and positioned ~0.5 m below the surface to ensure that it did not come out of the water when the boat was under way.

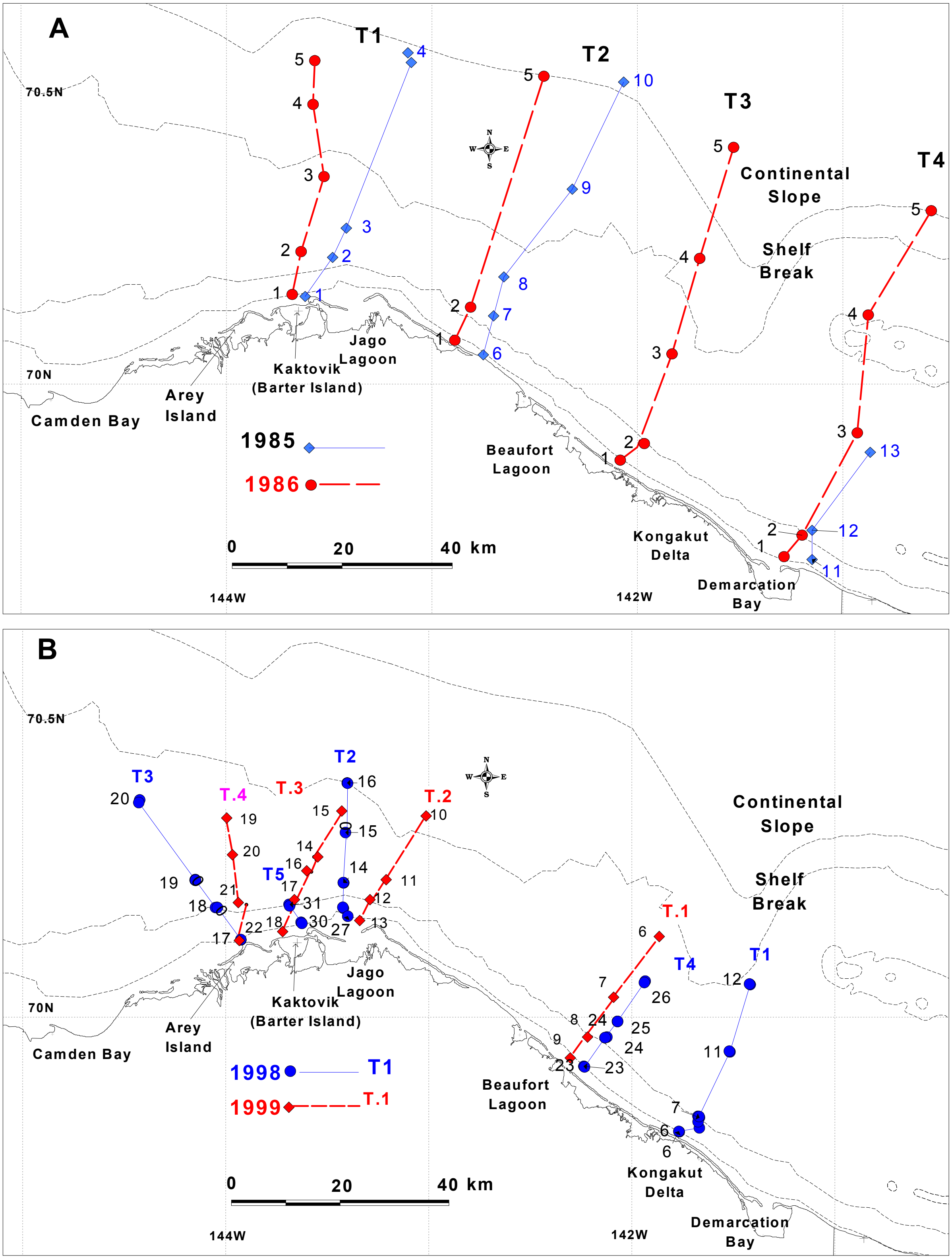


FIGURE 5.1. Locations of transects and zooplankton stations sampled in the eastern Alaskan Beaufort Sea during September of ***(A)*** 1985–86, ***(B)*** 1998–99, and ***(C)*** 2000.

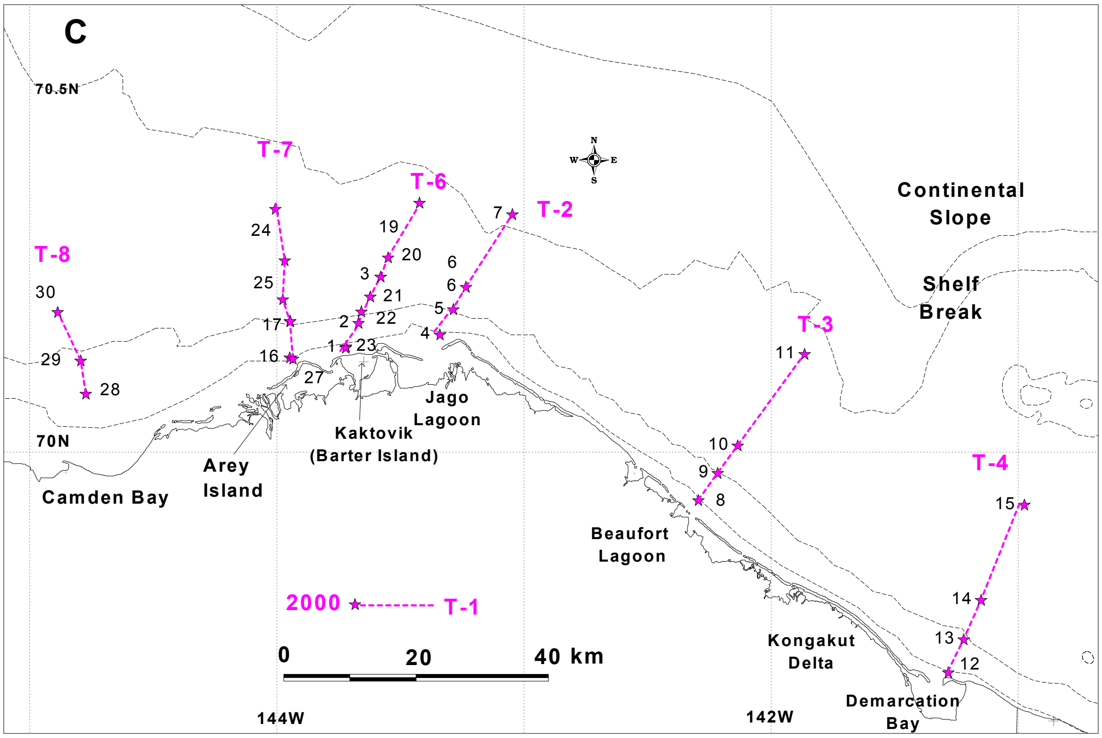


FIGURE 5.1. Concluded.

TABLE 5.1. Number of transects, zooplankton stations and tows, and CTD samples collected in the eastern Alaskan Beaufort Sea during September 1985–86 and 1998–2000. Details are provided in Appendices 5.1 to 5.5 at the end of this chapter.

Year	Sampling Date	No. of Transects	No. of Plankton Stations	No. of Oblique Tows	No. of Horizontal Tows	No. of Surface Tows	No. of CTD Samples
1985	4-18 Sept	3	8	8	19	3	12
1986	4-19 Sept	4	11	11	24	6	17
1998	11-22 Sept	5	19	18	31	13	18
1999	16-22 Sept	4	17	17	27	17	17
2000	9-20 Sept	8[a]	30	30	55	30	30

[a] Two of eight 2000 transects were short transects that duplicated the shoreward ends of two of the other six transects.

Net Sampling of Zooplankton

All oblique and surface tows, and most horizontal tows, were made with a bongo assembly of paired 0.5-mm mesh, 0.61-m diameter, plankton nets. A General Oceanics Inc. model 2030 flow meter was placed in the center of one frame. In 1986, a Tareq opening and closing bongo assembly was used to take all horizontal tows at depth.

***Horizontal Tows at Depth*.—**At most stations, we did from 1 to 3 horizontal tows. In *1985 and 1986*, the depth of each horizontal tow was recorded in real time using an upward-looking depth sounder transducer. In *1998–2000*, approximate net depth during horizontal tows was calculated in real-time using wire angle and wire out, and the actual depth was recorded with a Wildlife Computers dive recorder (Model Mk7-S) attached to the bongo frame. The latter provided more accurate after-the-fact data on tow depth, which was important in matching net samples with echosounder data from the corresponding depths. In *all years*, sampling depths were selected based on real-time echosounder data, and ranged from ~3 to 110 m depth in 1985–86 and 3 to 50 m in 1998–2000. At all stations where this was feasible, separate horizontal tows were taken both within and outside zooplankton layers that were apparent on the echosounder. Except in 1986, the bongo assembly sampled during both descent to and ascent from the desired sampling depth. Letting the net free-fall to the desired depth while the boat was moving very slowly minimized the collection of zooplankton during descent. Slowing the speed of the boat minimized sampling of zooplankton during ascent. Each horizontal tow was five minutes in duration, with the start time being the time when the net reached the desired depth, and tow speed was ~1 m/s. The opening and closing bongo net used for horizontal tows in Alaska during 1986 underestimated biomass, as shown by matched tows with that net and a standard bongo net. Therefore, results from 1986 horizontal tows with the opening and closing net were corrected, i.e., scaled up, as described in Chapter 4.

***Horizontal Surface Tows*.—**The bongo assembly was also used to take a near-surface tow at each station, at ~1 m depth. Tow speed was again ~1 m/s for 5 min.

***Oblique Tows*.—**Oblique tows were made at ~1 m/s and sampled the water column during two sequential descent–ascent cycles. The maximum depth sampled at each station was determined with real-time hydroacoustic data to ensure that all zooplankton concentrations were included. In *1985–86*, the net was dropped to near the bottom in shallow water, and to a maximum of 100-m in deep water. All oblique tows during *1998–2000*, when most transects did not extend seaward of the 50-m contour, were to depths <50 m.

Additional sampling details are provided in Chapter 4. Station locations are listed in Appendices 5.1 to 5.5 (at the end of this chapter).

***Sample Treatment*.**—After each tow, the entire sample from one of the bongo nets was preserved in 10% formalin for analyses of zooplankton biomass and numbers. Sub-samples from the other net were frozen on the boat and later sent to University of Alaska and Alaska Department of Fish & Game for analyses of caloric, isotopic, and fatty acid content.

Hydroacoustic Sampling of Zooplankton

Hydroacoustic sampling to estimate the distribution and relative biomass of zooplankton along transects was conducted in all 5 years. Equipment and procedures were described by Johnson and Griffiths (1990) and in Chapter 4.

A single frequency (1998) or dual frequency (other years) Biosonics echosounder was used. The downward-facing transducers were mounted in a BioFin sled and were towed via armored cable from the side of the boat, away from the wake and ~1 m below the water surface. Typically, wave turbulence and air-bubbles in surface waters prevented obtaining meaningful acoustic results from the upper 2–3 m of the water column. Tow speed was ~7.2 km/h (2 m/s) during surveys between stations, and ~3.6 km/h (1 m/s) during zooplankton tows.

Hydroacoustic and position data were collected in real-time and all data were stored for later analysis. Post-processing of raw hydroacoustic data in 1985 and 1986 showed that reprocessing was necessary (Johnson and Griffiths 1990). Hence, in all five years, all raw hydroacoustic data were saved in digital form.

Regression equations were developed to relate zooplankton biomass as determined from horizontal net tows to matched data on measured acoustic back scatter (Johnson and Griffiths 1990; Griffiths, Chapter 4). These equations were then used to estimate zooplankton biomass at other places and depths where echosounder but no net-tow data were available. Chapter 4 describes regression equations applicable to our 200 kHz echosounder data from the Alaskan Beaufort Sea in 1985–86, and to our 430 kHz echosounder data in 1999–2000. For 1998, the correlation between matched net-tow and echosounder (430 kHz) data was too weak to allow confident use of other 1998 echosounder data in estimating zooplankton biomass (Chapter 4). Along each transect, zooplankton biomass was integrated for each 2-m (1985–86) or 1-m (1999–2000) depth interval within each 2-min (~240 m) horizontal interval.

Sample Analysis

Zooplankton.—All samples collected in the five years were analyzed by the same person (Nell Stallard). Each sample was sieved through a 163-µm mesh Nitex sieve, carefully rinsed with tap water to remove the preservative, and then examined under a low-power binocular microscope. Individual organisms from all oblique tows, and from selected horizontal and surface tows, were identified to species where possible, counted, and wet-weighed by species to the nearest mg using an Acculab electronic balance. Other samples were counted and weighed at the major taxonomic group level.

If large numbers of individuals were present, the sample was first scanned for large or rare organisms, which were processed for the sample as a whole. Small animals were then sub-sampled with a Folsom Plankton Splitter or a Hensen–Stempel pipette. The flowmeter reading was used to calculate the volume of water filtered and used to determine the biomass in mg/m^3. Additional details are provided in Chapter 4.

Hydroacoustic Data.—The raw hydroacoustic data collected along transects consisted of volume backscattering. Because the mean backscattering cross section (σ) of individual zooplankters encountered during the study was not known, regression analyses were used to determined the relationship between volume back scatter and net biomass (in mg/m^3). Regression equations derived from each year were applied to the corresponding integrated volume backscattering data collected along transects to derive an estimate of relative zooplankton biomass. In some cases, large returns from fish larvae that had air bladders obfuscated returns from zooplankton. Because the raw data were preserved, they could be reanalyzed to remove these large returns (see Johnson and Griffiths 1990 and Chapter 4). Especially in 1985 and 1986, strong pycnoclines produced large backscattering values in the absence of correspondingly large biomasses zooplankton in the nets. Returns from these pycnoclines, as evident from CTD profiles taken at the stations, were excluded from the data. There was only a weak relationship between volume backscatter and zooplankton biomass in 1998 (Chapter 4), so the 1998 echosounder data were not considered further.

Relative biomass for each 2-min period by 1- or 2-m depth interval was entered into MapInfo Professional with the Vertical Mapper add-on to produce biomass contour plots for each transect.

Results

Physical Oceanography

Temperature–salinity characteristics of stations sampled during 1985–86 and 1998–2000, and the surface temperatures along transects between those stations, are shown in Appendices 5.6–5.10 and 5.11–5.12. Analysis of these data indicated that two water masses were present during all years of the study: (1) A Shallow Cold Saline water mass at station depths 10 m to as much as 50 m. (2) A generally more-offshore water mass strongly influenced by the Mackenzie River at station depths from as little as 25 m to 50 m (Fig. 5.2; Table 5.2). (3) Also, in 1985–86, an outer shelf water mass characterized by Arctic

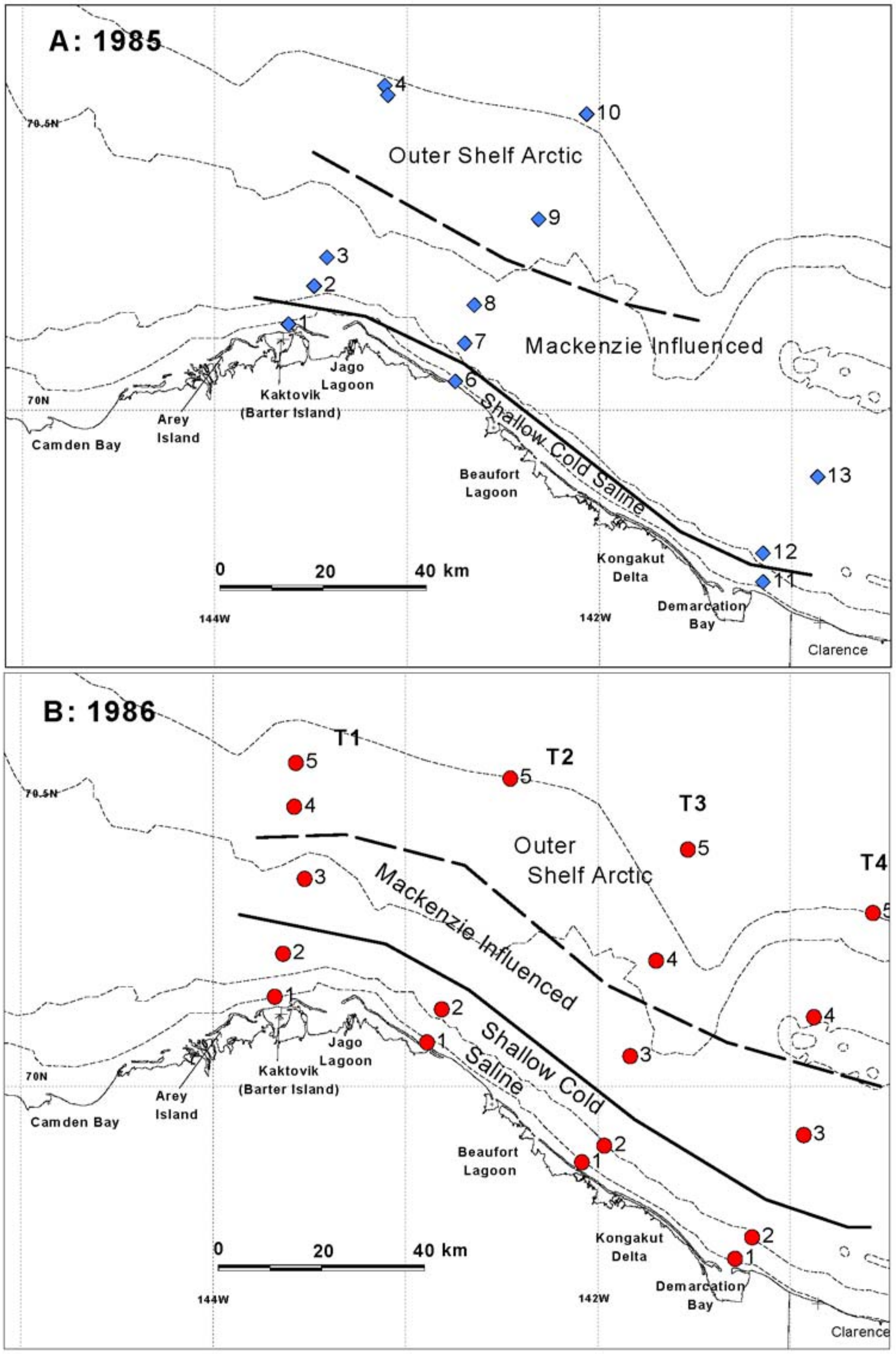


FIGURE 5.2. General locations of water masses in the study area in 1985, 1986 and 1998. In 1999 and 2000, the Shallow Cold Saline water mass covered the entire study area.

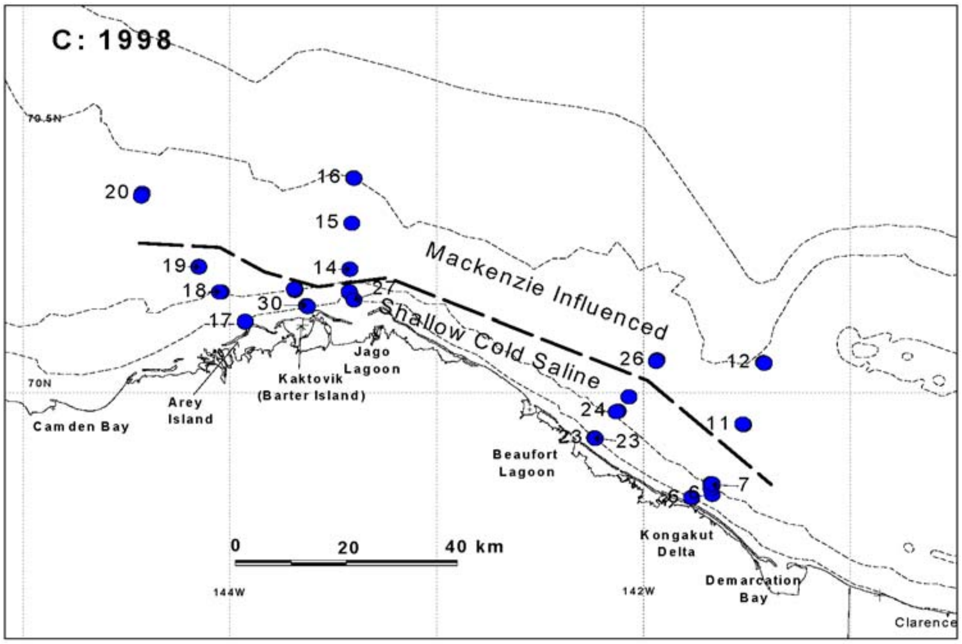


FIGURE 5.2. Concluded

Surface Water (ASW) was also sampled. Transects in those years extended to the 200-m contour, whereas in 1998–2000 they extended only to the 50-m contour and offshore waters were not sampled.

Shallow Cold Saline Water Mass.—The main characteristics of this water mass were the absence of a strong influence of Mackenzie River water and, usually, the absence of sharp discontinuities in the vertical distribution of temperature and salinity (pycnoclines). The relatively cold temperatures and high salinities were fairly uniform from surface to bottom (Table 5.2). This water mass typically occurred in shallow depths during 1985, 1986 and 1998. In 1986 and 1998 it extend out to depths of 28 to 34 m but in 1985 it was found only very close to shore in water depths of 10 and 15 m (Fig. 5.2; Table 5.2). In 1999 and 2000, this water mass occupied all of the areas sampled out to water depths of 50 m. In 1998 and 1999, and at most stations in 2000, temperatures and salinities in this water mass were fairly uniform from surface to bottom (Table 5.2).

In some cases, pycnoclines were found in this water mass: In 1986, there were strong pycnolines at most stations. In 1998, there were some weak to moderate pycnoclines along the three most easterly transects (Appendices 5.7, 5.8). In 2000, there was some evidence of weak pycnoclines at the deeper offshore stations and at all stations along the two most easterly transects (Appendix 5.10). In 2000, there was also some evidence of a weak Mackenzie River influence near the surface at six stations, as surface salinities there were lower than those in shallower nearshore water. This Mackenzie influence was more pronounced in the east where surface temperatures were warmer than those in the west by ~1 to 1.5°C and salinities lower by 2 psu (Appendix 5.10).

In 1986, surface temperatures were ~2°C higher and salinities ~2 psu lower than those recorded during the other 4 years. The presence of this relatively warm fresh surface layer caused pycnoclines in the nearshore zone. Strong pycnoclines were not present during 1985, 1998, 1999, or 2000. Bottom water at 1986 stations classified as being in the Shallow Cold Saline water mass was warmer and fresher than that in the more-offshore water mass strongly influenced by the Mackenzie River (Table 5.2).

TABLE 5.2. General physical characteristics of the Shallow Cold Saline and Mackenzie-Influenced water masses in September of 1985–86 and 1998–2000. Details are provided in Appendices 5.6 to 5.10.

Year	Shallow Cold Saline	Mackenzie-Influenced			
1985	2 Stations, depth 13 to 14 m	6 Stations, depth 25 to 45 m			
	No pycnocline	Strong pycnoclines		Temperature	Salinity
	Temperature and salinity uniform surface to bottom		Above	0.5 to 1.2	28 to 29 psu
			Below	<-1.0 °C	>31 psu
	Temperature 0.1 to 0.2 °C				
	Salinity 31 psu				
1986	8 Stations, depth 10 to 34 m	3 Stations, depth 41 to 47 m			
	Strong pycnocline	Strong pycnoclines		Temperature	Salinity
	Surface temperatures 0.0 to 5 °C		Above	2.2 to 3.3 °C	25 to 27 psu
	Surface salinities 24 to 27 psu		Below	<-1.0 °C	>31 psu
	Bottom temeperatures -0.35 to 0.7°C				
	Bottom Salinities 29 to 31 psu				
1998	11 Stations, depth 10 to 28 m	8 Stations, depth 27 to 40 m			
	No strong pycnoclines	Strong pycnoclines		Temperature	Salinity
	Surface Temperatures: <0.1 to 4.1°C		Above	3.5 to 6.4 °C	28 to 31 psu
	Surface Salinities: 27.7 to 32 psu		Below	<-1.0 to 0.8 °C	31.6 to 32.7 psu
	Bottom Temperatures: -0.9 to 1.6 °C				
	Bottom Salinities: 31.3 to 32.4 psu				
1999	17 Stations, depth 10 to 45 m	No stations showed strong pycnoclines in 1999			
	No strong pycnoclines				
	Surface Temperatures: 0.5 to 3.1 °C				
	Surface Salinities: 26.9 to 31.5 psu				
	Bottom Temperatures: -1.1 to 1.8 °C				
	Bottom Salinities: 31.0 to 32.1 psu				
2000	30 Transect Stations, depth 10 to 50 m	No stations showed strong pycnoclines in 2000			
	No strong pycnoclines				
	Surface Temperatures: -1.0 to 1.0 °C				
	Surface Salinities: 25.6 to 31.0 psu				
	Bottom Temperatures: -1.6 to -0.2 °C				
	Bottom Salinities: 30.5 to 32.3 psu				

Surface temperature patterns varied among years. In 1986, surface temperatures were considerably higher (3.4 to 4.5°C) than at the two 1985 stations (0.4 to 0.2°C). In 1998, the surface temperatures along transects increased from ~1°C nearshore to over 6°C offshore (Appendix 5.10). In 1999, surface temperatures did not show this pattern and, overall, were lower across the entire study area (1.5–3.5°C). In 2000, surface temperatures were uniformly cold across the study area, usually <0.0°C and only rarely approaching 1.0°C (Appendix 5.11). Overall, the surface waters of the entire study area were colder in 2000 than during any of the other four years of the study.

Mackenzie-Influenced More-Offshore Water Mass.—This water mass was characterized by the presence of a strong Mackenzie River influence at the surface, overlying water that was generally colder and more saline. There were sharp discontinuities between the relatively warm, freshened water near the surface and the cold saline water below. These sharp pycnoclines were characteristic of this water mass (Table 5.2). When the two water masses were present, the Mackenzie-Influenced water mass was generally found offshore of the Shallow Cold Saline water mass at station depths of 25+ m.

Some stations sampled in 1985, 1986, and 1998 were located in this water mass, but it was absent from the areas sampled in 1999 and 2000 (Fig. 5.2; Table 5.2). Attributes of the surface water varied from year to year. In 1998, the surface water temperatures were much warmer and the salinities were generally higher than those recorded in 1985 and 1986. The bottom water was cold and saline in all three years (Table 5.2).

Outer Shelf Arctic Water Mass.—The Outer Shelf Arctic water mass was characterized by Arctic Surface Water (temperatures <1.5°C and salinity >31 psu) overlaid by a thick (5–7 m) surface layer of Mackenzie Bay water with temperatures of 1.5 to 2.5°C and salinities of 23 to 26 psu. The ASW was typically colder and more saline than either of the two water-masses described above.

A few stations sampled in 1985 and 1986, when transects extended to the 200 m contour or beyond, were located in the Outer Shelf water mass (Fig. 5.2; Appendices 5.6, 5.7). The influence of Mackenzie River water was stronger in 1985 than in 1986.

The geographical extent and depth ranges of the water masses described above varied within and among the five years. This was particularly true for the surface waters. As shown below, the among-year variations in these water masses appear not to have had a strong effect on the distribution of major taxa comprising the zooplankton community. This is probably a reflection of their tolerance of a wide range of temperatures and salinities (–1° to ~5–10°C; 20 to 30 psu). However, there were major among-year differences in the species composition and biomass of the zooplankton, particularly copepods, in relation to water masses.

Vertical and Horizontal Species Composition and Biomass Distribution of Zooplankton

The following paragraphs describe the distribution and biomass of zooplankton in relation to water masses (1) in the water column as a whole, (2) near the surface, (3) in all horizontal tows at depth, and (4) distinguishing horizontal tows above and below pycnoclines, when present. The species composition of the zooplankton is described for the Shallow Cold Saline water mass and the more-offshore Mackenzie-Influenced water mass (for additional details, see Appendices 5.13–5.29).

Shallow Cold Saline Water Mass.—This water mass was present within the area sampled during all five years of the study.

Biomass: The annual average wet-weight biomasses collected in Shallow Cold Saline waters over the five years of study ranged from 189 to 409 mg/m^3 for the water column as a whole, from 18 to 205 mg/m^3 for surface waters, and from 236 to 516 mg/m^3 for the horizontal tows at depth (Table 5.3). The average biomass in the water column as a whole, as sampled by oblique bongo tows, was lowest in 2000 (189 mg/m^3) and substantially higher in the other four years (268–409 mg/m^3; Table 5.3). The average zooplankton biomass in surface water was much lower in 1999 and 2000 (18 and 25 mg/m^3) than in any of the other three years (70–205 mg/m^3; Table 5.3). In all years, the mean zooplankton biomasses in surface waters were lower than in samples taken at depth, although the difference was not large in 1998.

In all years, we conducted horizontal tows at depth both within and outside what appeared to be layers of zooplankton evident on the echosounder. In 1998, however, because of the weak correlation between acoustic vs. net data (see Chapter 4), we were not able to confirm that the layers where some horizontal tows were taken actually represented concentrations of zooplankton. For example, strong acoustic backscatter was associated with both high and low zooplankton biomass (e.g., –70.63 dB with 785 mg/m^3 and –70.01 dB with 112 mg/m^3). Conversely, weak acoustic signals were also associated with a wide range of biomasses (e.g., –85.51 dB with 438 mg/m^3 and –85.56 dB with 194 mg/m^3). Consequently, to compare the results among the five years, we calculated the average zooplankton biomass in all horizontal tows at depth taken for each year, whether or not they were specifically taken within a layer evident on the echosounder. The average biomass of 516 mg/m^3 in horizontal tows at depth in the nearshore zone was highest in 1986 and lowest in 2000 (Table 5.3). The maximum biomass in individual tows was 1000 and 2200 mg/m^3 in 1985–86, considerably higher than the 500–1000 mg/m^3 maxima recorded in 1998–2000.

TABLE 5.3. Comparison of mean total zooplankton biomass (mg/m^3) collected by various types of tows on transects in the eastern Alaskan Beaufort Sea, September 1985–86 and 1998–2000.

	Water		1985			1986			1998			1999			2000		
	Mass		mg/m^3	s.d.	n	mg/m^3	s.d.	n	mg/m^3	s.d.	n	mg/m^3	s.d.	n	mg/m^3	s.d.	n
Water Column as a Whole																	
	Shallow Cold Saline[a]		409	110	2	296	389	8	268	151	11	383	260	17	189	92	30
	Mackenzie-Influenced[b]		189	84	6	170	128	3	223	131	7	-	-	-	-	-	-
	Outer Shelf Arctic		133	55	4	46	22	8	-	-	-	-	-	-	-	-	-
Surface Waters																	
	Shallow Cold Saline[c]		87	61	2	70	73	3	205	180	8	18	36	17	25	29	30
	Mackenzie-Influenced[d]		4[g]	-	1	13	19	3	25	30	5	-	-	-	-	-	-
	Outer Shelf Arctic		-[h]	-	-	43	71	7	-	-	-	-	-	-	-	-	-
Horizontal Tows at Depth																	
	Shallow Cold Saline[e]		398	79	3	516	755	18	353	191	14	390	324	27	236	179	55
	Mackenzie-Influenced[f]	Above Pycnocline	46	22	5	109	74	2	115	121	6	-	-	-	-	-	-
		Below Pycnocline	440	335	11	659	510	4	394	252	11	-	-	-	-	-	-
	Outer Shelf Arctic	Above Pycnocline	14	4	2	91	21	2	-	-	-	-	-	-	-	-	-
		Below Pycnocline	153	78	6	312	339	5	-	-	-	-	-	-	-	-	-

[a] Data plotted in Figure 5.3.

[b] Data plotted in Figure 5.7.

[c] Data plotted in Figure 5.5.

[d] Data plotted in Figure 5.7.

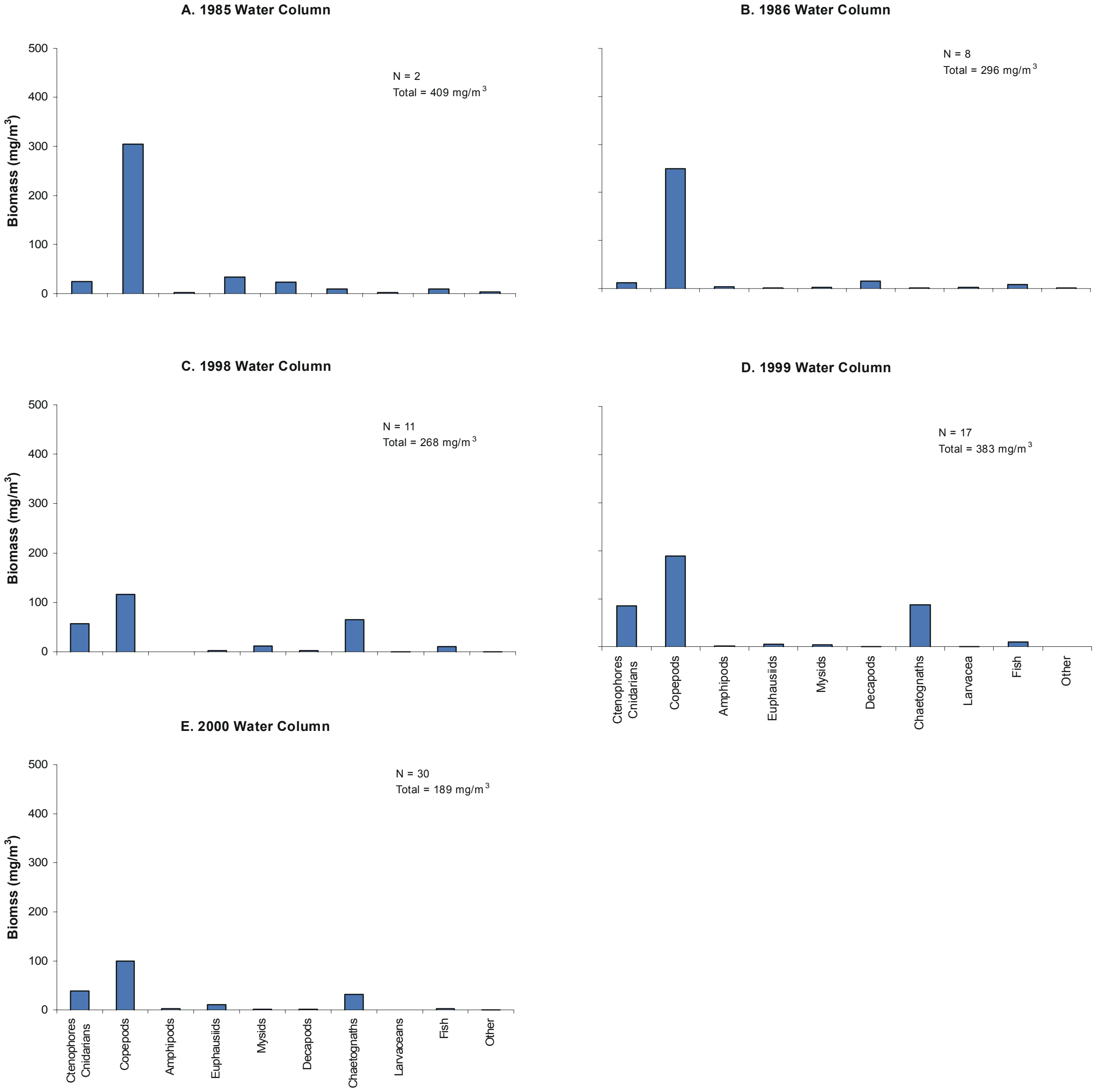
[e] Data plotted in Figure 5.6.

[f] Data plotted in Figure 5.8.

[g] 1985 data based on single sample.

[h] No surface tows in 1985 because of heavy ice conditions.

Composition of Zooplankton: Major taxa were defined as those that contributed more than 10 mg/m^3 to total biomass in at least one year. In the water column as a whole, within the Shallow Cold Saline zone, five major zooplankton taxa were collected in one or more of the five years. These were copepods, gelatinous zooplankton (i.e., ctenophores + cnidarians), chaetognaths, mysids, and fish larvae (Fig. 5.3A–E). Copepods were the dominant taxon in all years, and were especially dominant in 1985 and 1986. Gelatinous zooplankton and chaetognaths, considered together, were major contributors to zooplankton biomass in every year, and in 1998 to 2000 their biomass approached that of copepods (Fig. 5.3C,E). Other groups were major contributors in some years but not others. Euphausiids were collected in oblique tows in all years except 1986 and were major contributors to the zooplankton biomass in 1985 and 2000; decapods were major contributors only in 1986 (Fig. 5.3A–E).


A. 1985 Water Column

B. 1986 Water Column

C. 1998 Water Column

D. 1999 Water Column

E. 2000 Water Column

FIGURE 5.3. Mean biomasses (mg/m^3) of major zooplankton taxa in the **Shallow Cold Saline** water mass as evident from **oblique tows** through the water column in the eastern Alaskan Beaufort Sea, September 1985–86 and 1998–2000.

In all five years, only a small number of species accounted for most of the biomass of each of the major taxa. The copepods *Calanus hyperboreus* and *C. glacialis* were each major contributors (>10 mg/m^3) to the copepod biomass in all years (Fig. 5.4A–E). In 1985 and 1986, the biomass of *Limnocalanus macrurus* was higher than that of any other species in samples taken in Shallow Cold Saline waters, but this species was not found in these waters at all in 1998 and 1999, and only in small quantities in 2000 (Fig. 5.4A–E). The copepod *Pseudocalanus minutus* was the dominant copepod at a single shallow-water station on Transect T-3 in 1999. *Derjuginia tolli* was a major contributor to the copepod biomass only in 1985.

Similarly, few species accounted for most or all of the biomass of other major zooplankton taxa in the Shallow Cold Saline zone in any of the five years. These were the chaetognath *Sagitta elegans*; the cnidarians *Aglantha digitale*, *Halitholus cirratus*, and *Cyanea capillata*; the ctenophore *Mertensia ovum*; the mysid *Mysis litoralis*; the euphausiid *Thysanoessa raschii*; the amphipod *Parathemisto libellula*; and larvae of the arctic cod *Boreogadus saida* (Fig. 5.4A–E). The species composition of these major taxa of zooplankton was quite similar among years, with the exception of minor differences for gelatinous zooplankton (Fig 5.4A–E).

The low biomass in the surface waters was composed of copepods, gelatinous zooplankton and, to a lesser extent, chaetognaths (Fig 5.5A–E). Below the surface, the composition of the zooplankton collected in horizontal tows was similar to that in the water column as a whole (Fig. 5.6A–E; *cf.* Fig. 5.3A–E).

Mackenzie-Influenced More-Offshore Zone.—This water mass was present in the area sampled during 1985, 1986 and 1998, but not in 1999 and 2000.

Biomass: The annual average wet-weight biomasses collected in this zone during 1985, 1986 and 1998 ranged from 170 to 223 mg/m^3 for the water column as a whole, and from 4 to 25 mg/m^3 for surface waters (Table 5.3). For each year, each of these averages was lower than the corresponding value in the Shallow Cold Saline zone. Average biomass in the water column was slightly higher in 1998 (223 mg/m^3) than in either 1985 or 1986 (189 and 170 mg/m^3, respectively; Table 5.3). In all three years, the warm freshened water layer above the pycnocline contained a very low biomass of zooplankton (mean 46 to 115 mg/m^3) compared to the cold saline water below (mean 394 to 659 mg/m^3; Table 5.3).

Composition of Zooplankton: In the Mackenzie-Influenced more-offshore zone, zooplankton taxa that accounted for most of the biomass varied among years in the water column as a whole (Fig. 5.7A–C) and in surface tows (Fig. 5.7D–F). In the water column as a whole, copepods and gelatinous zooplankton, with lesser contributions from amphipods, euphausiids, chaetognaths, pteropods, and fish, accounted for most of the biomass (Fig. 5.7A–C). In all three years, copepods were the dominant taxon, particularly in 1985 and 1986. In 1998, the biomass of gelatinous zooplankton and chaetognaths (combined) almost equaled that of copepods (Fig. 5.7A–C). In surface tows, copepods were major contributors in all years, while gelatinous zooplankton, decapods, larvaceans, chaetognaths and fish were major contributors in some years but not others (Fig. 5.7D–F).

Above the pycnocline, copepods were (by a small margin) the dominant taxon in 1985 and 1998, but pteropods and gelatinous zooplankton dominated in 1986 (Fig. 5.8A–C). Below the pycnocline, copepods accounted for more of the biomass than any other group during all three years, although in 1998 the biomasses of gelatinous zooplankton and chaetognaths (combined) exceeded copepod biomass (Fig. 5.8D–F). No horizontal tows were taken near the bottom, so any zooplankton concentrated there may be underrepresented.

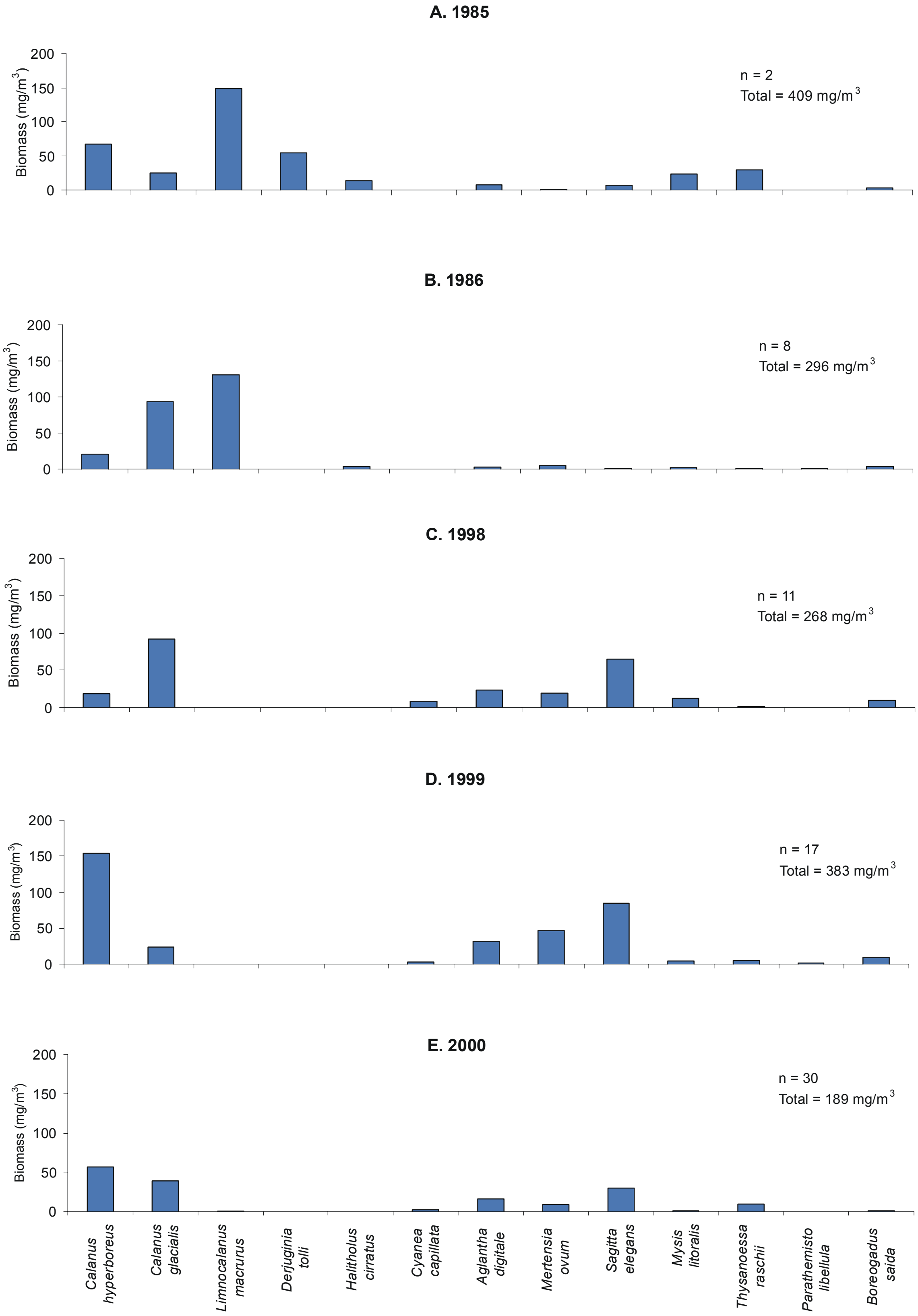


FIGURE 5.4. Mean biomasses (mg/m^3) of major zooplankton species in the S**hallow Cold Saline** water mass, **water column** as a whole, in the eastern Alaskan Beaufort Sea, September 1985–86 and 1998–2000.

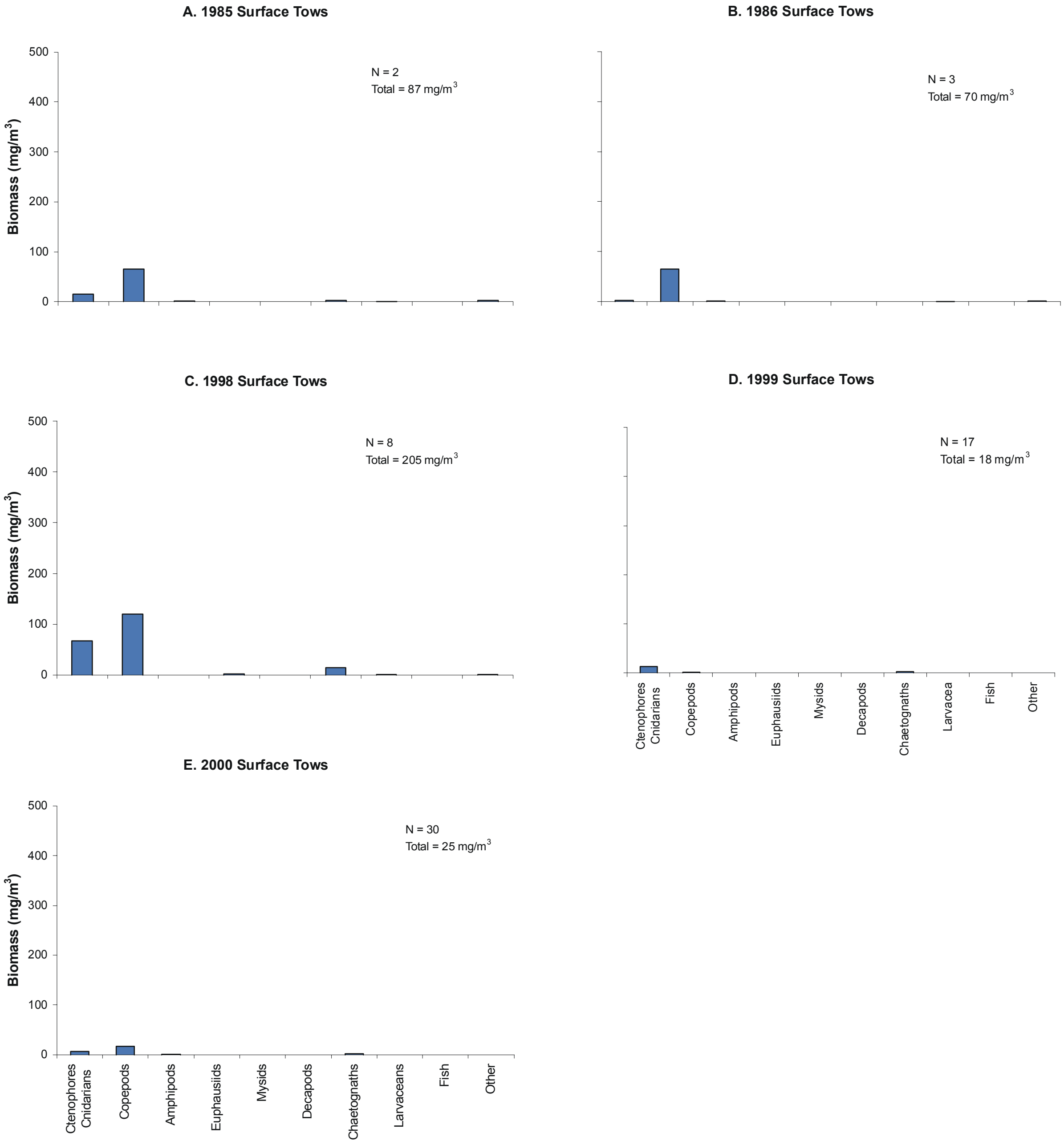


FIGURE 5.5. Mean biomasses (mg/m^3) of major zooplankton taxa in **surface waters** of the **Shallow Cold Saline** water mass, eastern Alaskan Beaufort Sea, September 1985–86 and 1998–2000.

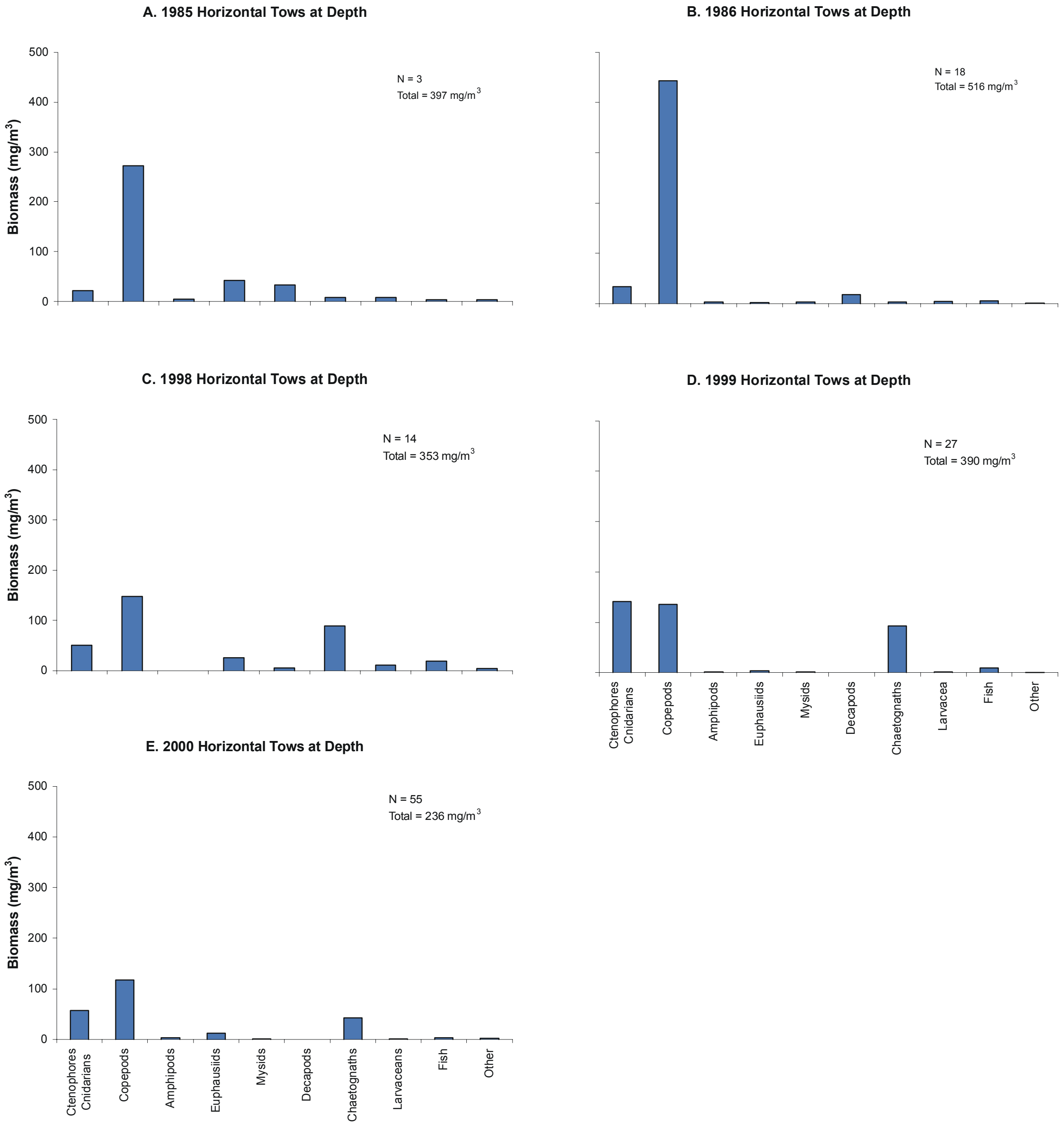


FIGURE 5.6. Mean biomasses (mg/m^3) of major zooplankton taxa in the **Shallow Cold Saline** water mass as evident from **horizontal tows at depth**, eastern Alaskan Beaufort Sea, September 1985–86 and 1998–2000.

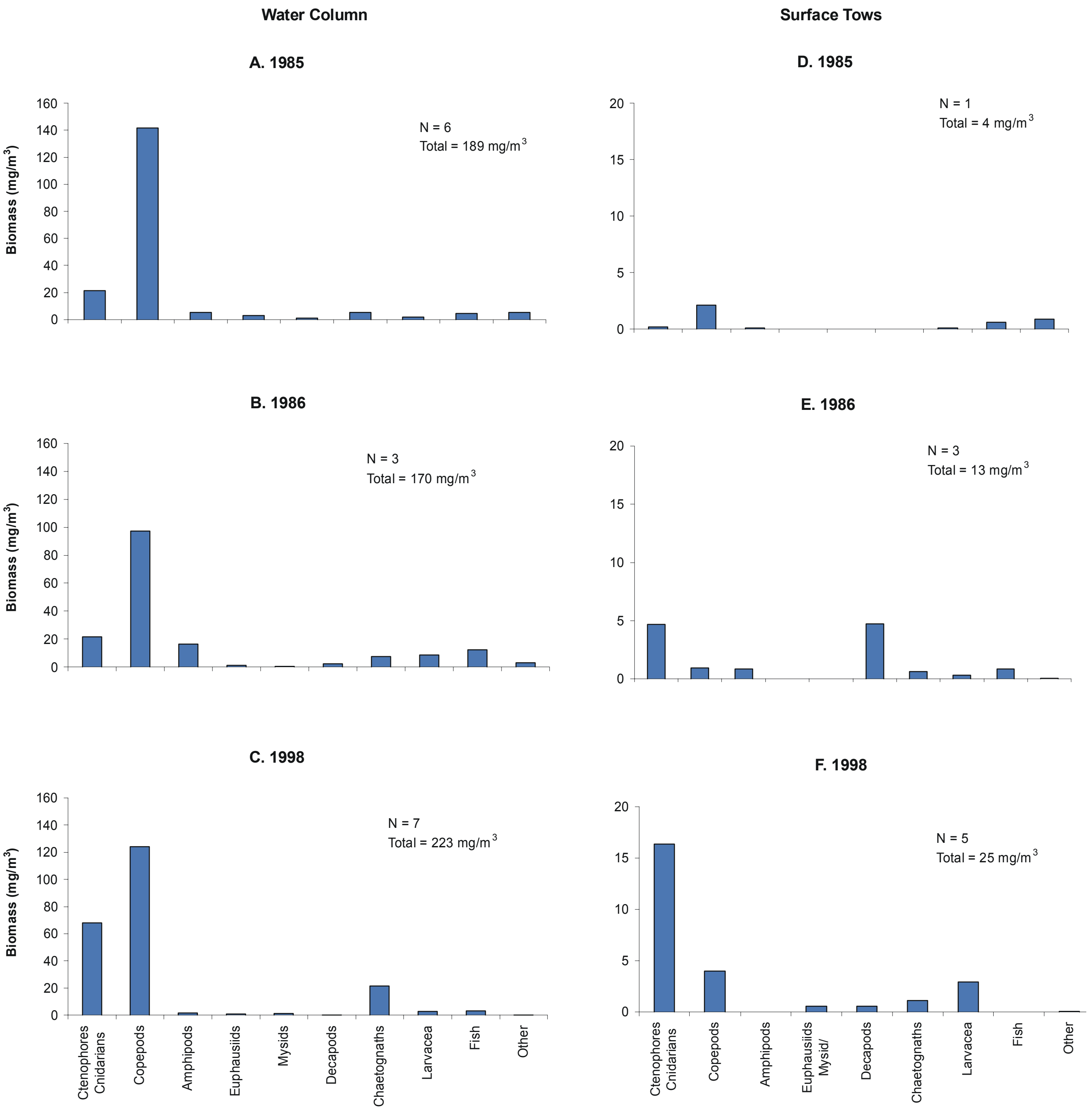


FIGURE 5.7. Mean biomasses (mg/m^3) of major zooplankton taxa from the **Mackenzie-Influenced** water mass as evident from **oblique tows (left)** and **horizontal surface tows (right)**, eastern Alaskan Beaufort Sea, September 1985, 1986 and 1998. Note the different scales on the vertical axes for water column and surface tows.

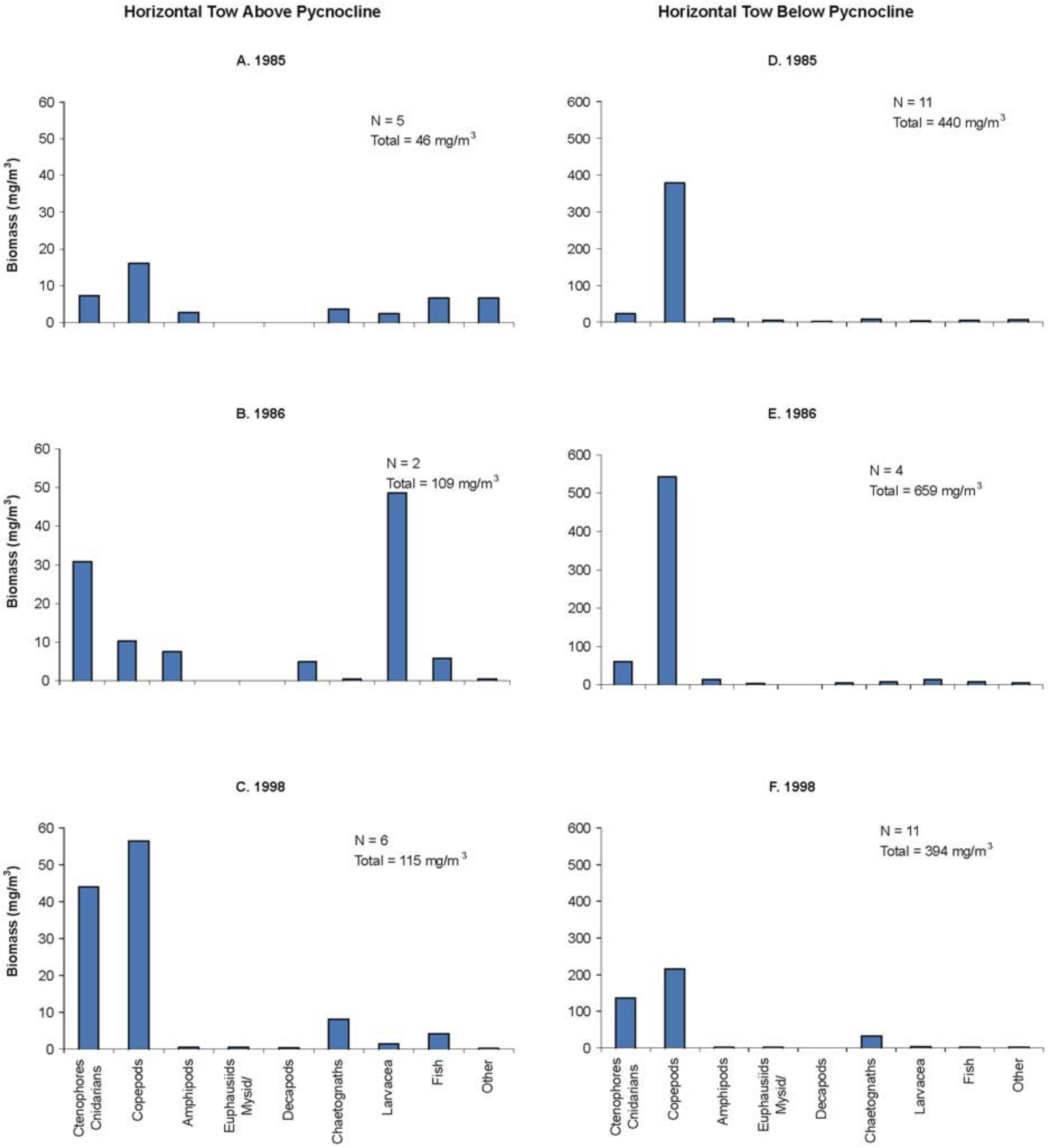


FIGURE 5.8. Mean biomasses (mg/m^3) of major zooplankton taxa in the **Mackenzie-Influenced** water mass as evident from **horizontal tows** above (left) and below (right) pycnoclines in the eastern Alaskan Beaufort Sea, September 1985, 1986 and 1998. Note the different scales on the vertical axes for tows above and below pycnoclines.

In the Mackenzie-Influenced more-offshore water mass, as was the case in the Shallow Cold Saline zone, only a few species accounted for most zooplankton biomass in the water column as a whole (Fig. 5.9A–C). *Calanus hyperboreus* and *C. glacialis* were major contributors to the copepod biomass in all three years, with *C. glacialis* being the dominant contributor in 1986 and 1998, and *C. hyperboreus* in 1985 (Fig. 5.9A–C). *Limnocalanus macrurus*, the dominant copepod in the Shallow Cold Saline zone in 1985 and 1986, was a major contributor to the zooplankton biomass in Mackenzie-Influenced waters in 1985, a minor contributor in 1986, and was not found in 1998.

Other dominant species were the chaetognath *Sagitta elegans*; the cnidarians *Aglantha digitale* and *Cyanea capillata*; the amphipod *Parathemisto libellula*; and arctic cod larvae *Boreogadus saida* (Fig. 5.9 A–C). Except for some minor differences in gelatinous zooplankton, the species composition of these major taxa of zooplankton was similar in all three years when this water mass was sampled (Fig. 5.9A–C).

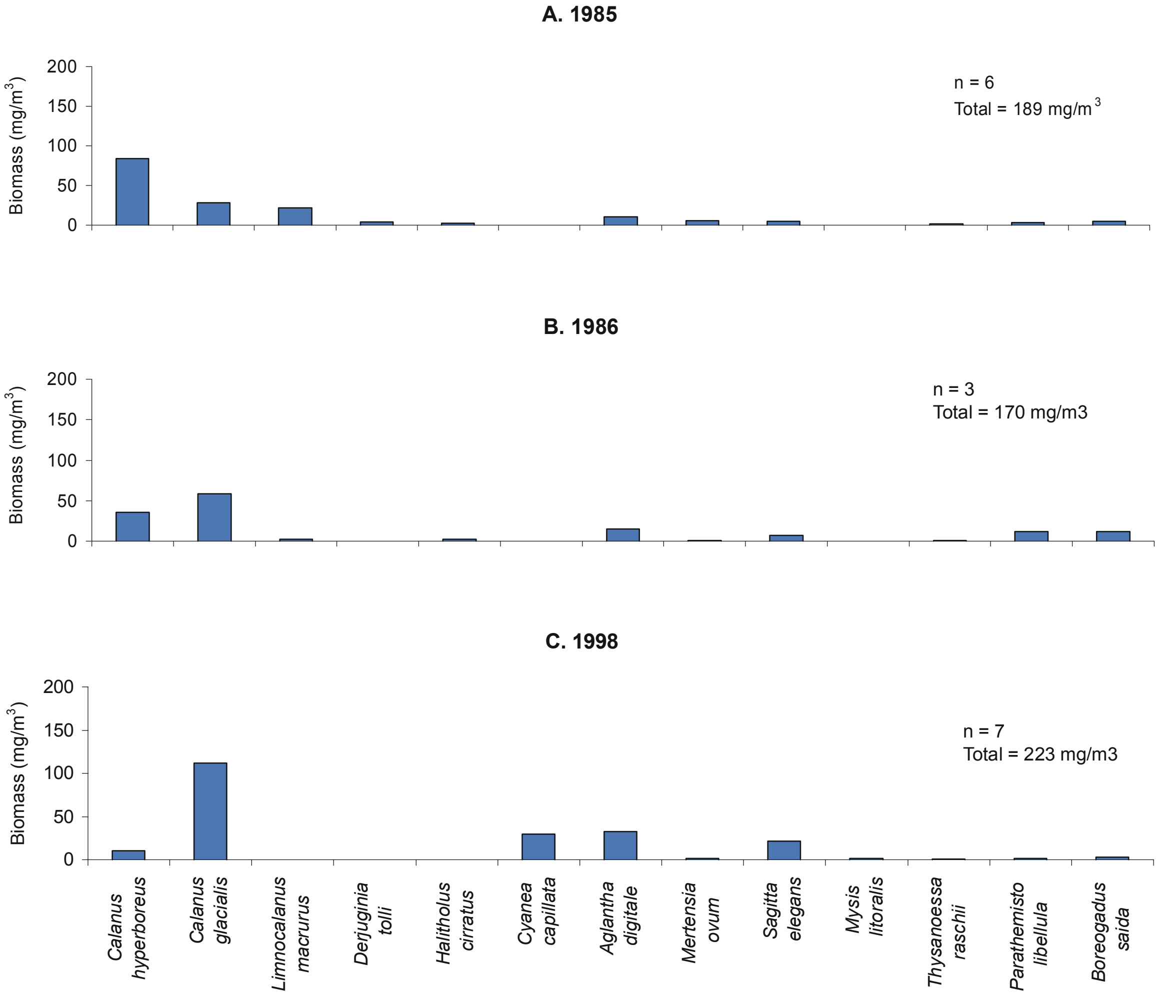


FIGURE 5.9. Mean biomasses (mg/m^3) of major zooplankton species in the **Mackenzie-Influenced** water mass, **water column as a whole**, eastern Alaskan Beaufort Sea, September 1985, 1986 and 1998.

Overall, *C. glacialis* and *C. hyperboreus* were the major contributors to the total copepod biomass in this water mass in all three years. *Limnocalanus macrurus*, the dominant copepod in Shallow Cold Saline waters in 1985–86, was also a major contributor to biomass in more-offshore Mackenzie-Influenced waters in 1985 but not in 1986. It was not found in this water mass in 1998.

Outer Shelf Arctic Zone.—This water mass was only sampled in 1985 and 1986 when transects extended out to the 200-m contour (vs. 50 m in 1998–2000). Zooplankton biomass in the Outer Shelf Arctic zone was, on average, less than that in either of the other two water masses (Table 5.3). This was true for the water column as a whole and for horizontal tows, particularly those taken below the pycnocline.

In the water column as a whole, gelatinous zooplankton was the predominant group in the Outer Shelf water mass during 1986, but they contributed only 16 mg/m^3. In 1985, copepods were the dominant taxon, followed by gelatinous zooplankton. Dominant species were the copepods *Calanus hyperboreus* and *C. glacialis*, the chaetognath *Sagitta elegans*, the hydrozoan *Aglantha digitale*, and the ctenophore *Mertensia ovum*. The predatory copepod *Euchaeta glacialis* was a major contributor to biomass only in 1985 (Griffiths et al. 1987).

In surface waters within this zone, total zooplankton biomass was very low in 1986. Biomass above the pycnocline in 1986 was low, but twice that in surface waters (91 vs. 43 mg/m^3; Table 5.3). Below the pycnocline in Arctic Surface Water, copepods, gelatinous zooplankton, and chaetognaths accounted for most of the biomass in both 1985 and 1986. In both years, total biomasses were much higher below the pycnocline than above it (Table 5.3). In both years, *Calanus hyperboreus* and *C. glacialis* contributed most of the copepod biomass. No horizontal tows were taken near the bottom, so any zooplankton concentrated there may be underrepresented.

Echosounder Surveys of Zooplankton Biomass

The volume backscatter data collected along the transects in 1985–86 and 1999–2000 were converted to estimates of total biomass using the regression relationships calculated from horizontal tows at depth and corresponding backscatter data (Chapter 4). The results were used to describe (1) the vertical distribution of zooplankton biomass at individual stations, (2) the average biomass of zooplankton along transects, and (3) the patchiness of zooplankton along transects. Similar data are not available for 1998 when the relationship between acoustic back scatter and zooplankton biomass was weak and unusable for predictive purposes.

***Horizontal and Vertical Distribution*.—**The vertical distributions of zooplankton biomass differed among the four years. In 1985–86 there were 1–3 layers of zooplankton in the upper 45 m, each 5 to 8 m thick, at individual stations (Fig. 5.10, 5.11). In 1999, there was usually only a single layer of zooplankton, 5–25 m thick, that extended from depth 10 m to near the bottom (Fig. 5.12). The year 2000 was different from all other years in that there was a marked spatial difference in zooplankton distribution (Fig. 5.13). Few layers were evident on the three eastern transects, and there were 1–3 layers on the western transects.

1985–1986: In these years, one to three layers of zooplankton were found at individual stations (Fig. 5.10, 5.11). Throughout the study area, most of these zooplankton layers were 5 to 8 m thick and (in deeper parts of the study area) most were in the upper 45 m of the water column. At some stations in <30 m water depth, patches of high biomass occurred throughout most of the water column, extending all the way to the bottom. In 1985, the estimated biomasses within layers were typically 300 to >1000 mg/m^3, while between the dense layers the values were 100–300 mg/m^3. In 1986, estimated biomasses within layers were 250–1500 mg/m^3, while between layers they were 150–350 mg/m^3 (Fig. 5.10, 5.11).

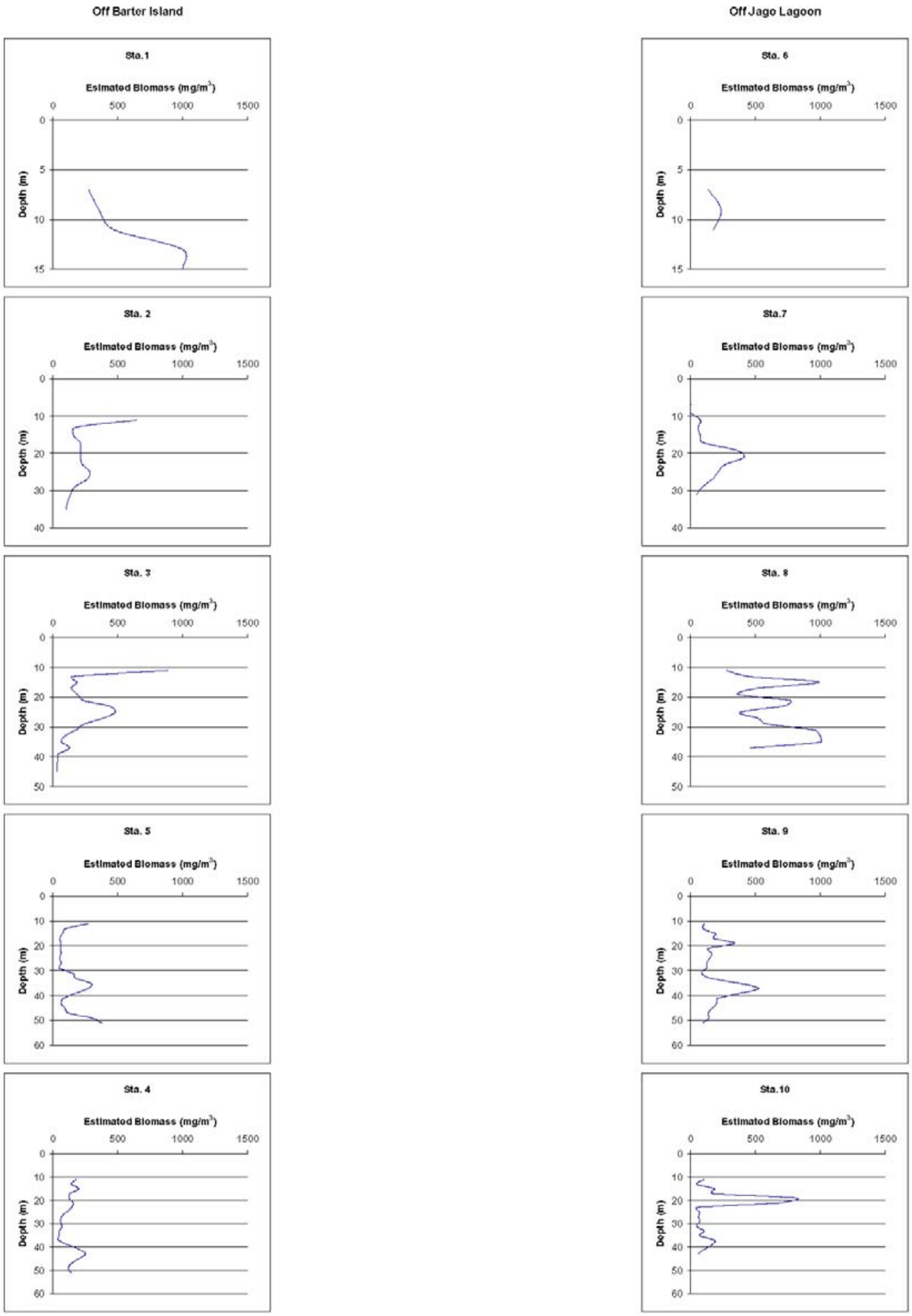


FIGURE 5.10. Vertical distribution of zooplankton biomass estimated with the 200 kHz echosounder at stations along transects in the eastern Alaskan Beaufort Sea, September 1985. See Figure 5.1A for station locations.

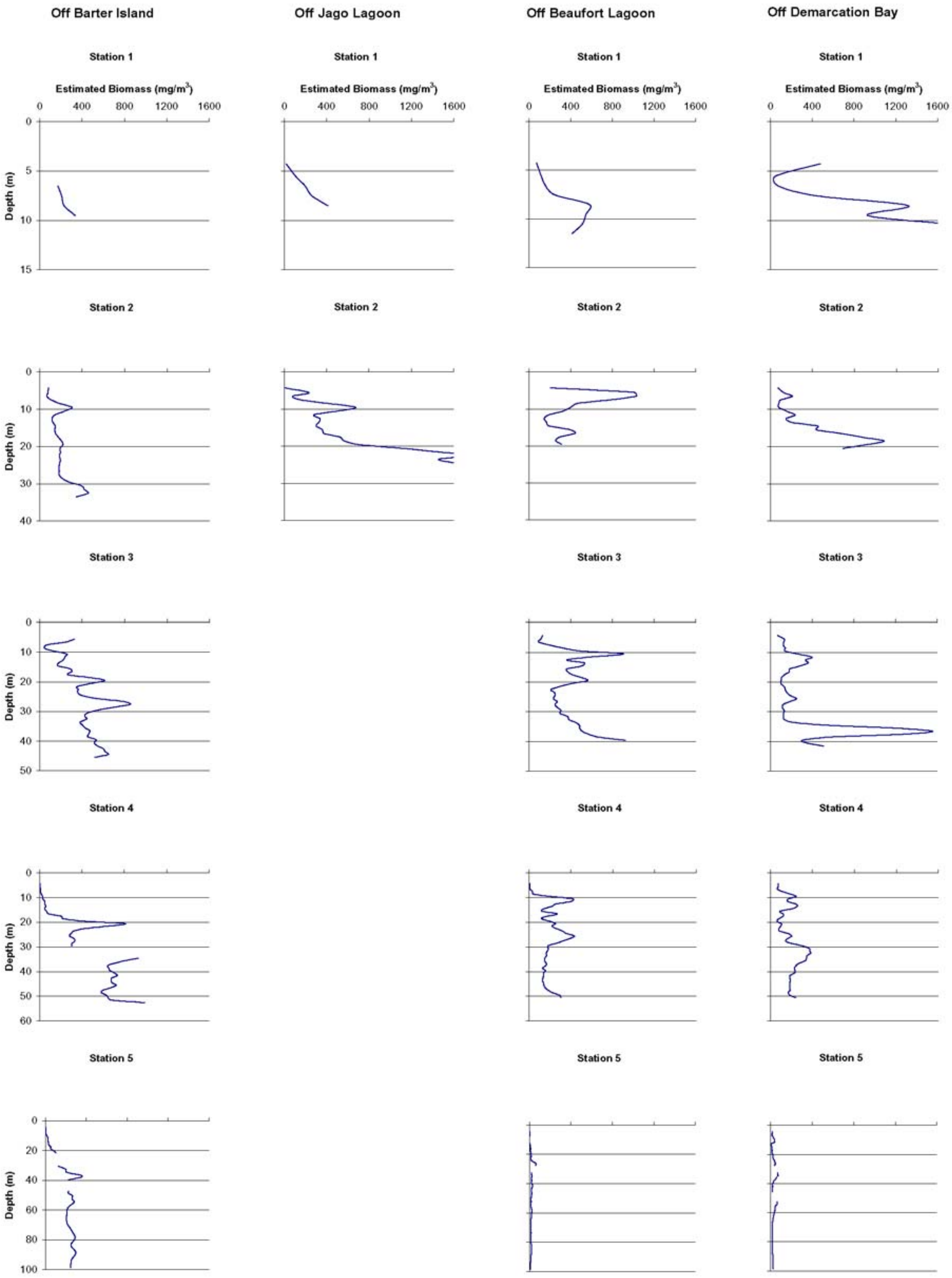


FIGURE 5.11. Vertical distribution of zooplankton biomass estimated with the 200 kHz echosounder at stations along transects in the eastern Alaskan Beaufort Sea, September 1986. Transects arranged from west to east; see Figure 5.1A for station locations.

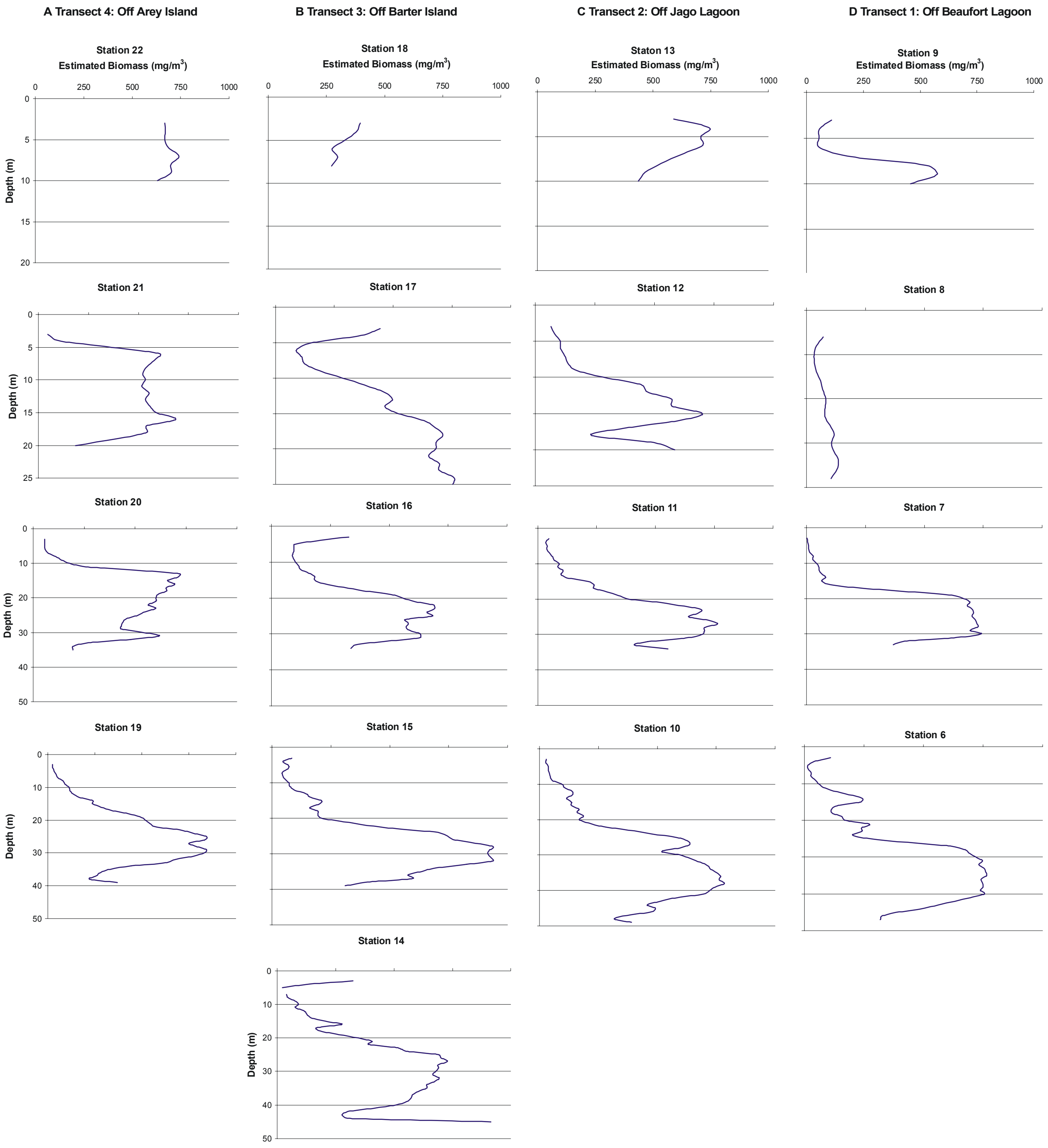


FIGURE 5.12. Vertical distribution of zooplankton biomass estimated with the 430 kHz echosounder at stations along transects in the eastern Alaskan Beaufort Sea, September 1999. Transects arranged from west to east; see Figure 5.1B for station locations.

FIGURE 5.13. Vertical distribution of zooplankton biomass estimated with the 430 kHz echosounder at stations along transects in the eastern Alaskan Beaufort Sea, September 2000. Transects arranged from west to east; see Figure 5.1C for station locations.

In 1985, average estimated biomass in the overall water column appeared to decrease with increasing water depth and distance from shore along Transect 1 but not Transect 2 (Fig. 5.14). Average biomasses were uniform from about the mid-portion out to the end of the two transects (Fig. 5.14A,B). Maximum estimated biomasses were near or above 1000 mg/m^3 along extended segments of both transects, and reached ~3000 to ~4000 mg/m^3 at several locations along each transect.[3]

Along all 1985 and subsequent-year transects, there are places where peaks in maximum zooplankton biomass occurred without noticeable increases in the mean water column biomass. This can occur where the dense zooplankton layer that produces the high maximum value is relatively thin, usually only 1–2 m thick. When averaged with estimated zooplankton biomasses from other depths through the water column, these maxima have little effect on the overall average.

In 1986, the average estimated zooplankton biomass along the four transects varied widely (Fig. 5.14C–F). Biomass increased with increasing depth along transect 1, decreased with increasing depth along transect 2, and reached a maximum over the middle portion of Transect 3. High biomasses were found at many locations along Transect 4 (Fig. 5.14F). Maximum estimated biomasses were 1500 to over 2000 mg/m^3 along Transect 1, and 1500 to >3000 mg/m^3 on Transects 2, 3 and 4, with the highest values typically persisting for only short segments of transect (Fig. 5.14C–F).

1999 and 2000: In 1999, only a single layer was evident at most stations, varying in thickness from 5 to 25 m (Fig. 5.12). In most places, the layer was found below 10 m and extended nearly to the bottom. At some nearshore stations the concentrated layer extended throughout the water column. Estimated biomasses within layers were typically 500–750 mg/m^3, while outside the layers biomass was ~200 mg/m^3. The average estimated biomass was more variable along Transect 1 off Beaufort Lagoon than along the three more westerly 1999 transects (Fig. 5.15). Generally, mean biomass along Transect 1 increased with distance from shore, reaching an estimated 400 mg/m^3 at the seaward end. Estimated peak biomasses were 500 to 750 mg/m^3 along this transect (Fig. 5.15). Along Transects 2 off Jago Lagoon and 3 off Barter Island, a nearly continuous band of zooplankton with biomass 400–500 mg/m^3 extended from the shallow to the offshore station (Fig. 5.12, 5.15). The average and maximum estimated biomasses were relatively uniform over the entire length of each of these transects (Fig. 5.15). On Transect 4 off Arey Island, the band of high-density zooplankton extended throughout much of the water column and was generally closer to the surface than were similar patches along the other three transects (Fig. 5.12A). Several peaks of zooplankton with densities in the 800 to >1000 mg/m^3 range were evident along this transect (Fig. 5.15A).

The year 2000 was different from the other three years in that there were large spatial differences in zooplankton distribution. There were few layers at stations along the three easternmost transects (Fig. 5.13D–F). The estimated biomass was usually 200–300 mg/m^3 within layers and <150 mg/m^3 outside layers along the three easternmost transects (Transects 2, 3 and 4; Fig. 5.13D–F). In contrast, biomass was typically 300–800 mg/m^3 in the one to three layers found on the western transects (Transects 6, 7 and 8; Fig. 5.13A–C). The layers with the highest biomass (600–800 mg/m^3) were only 1–3 m thick and were at depths <15 m. Other thicker (5 to 15 m) layers contained an estimated biomass of 300–350 mg/m^3. Between the dense layers, the biomass was 200–250 mg/m^3 (Fig. 5.13A–C). Average estimated zooplankton biomass along the three eastern transects was 150–300 mg/m^3, with the highest average levels in shallow waters close to shore (Fig. 5.16D–F). Maximum biomass levels showed peaks of 400–600 mg/m^3, but typically

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[3] Note that the highest estimates, e.g., 1500+ mg/m^3, are especially uncertain. They are based on applying regression equations for net biomass vs. acoustic backscatter (from Chapter 4) to backscatter values higher than those at most stations with paired net and backscatter data, i.e., higher than most data used in deriving the regressions.

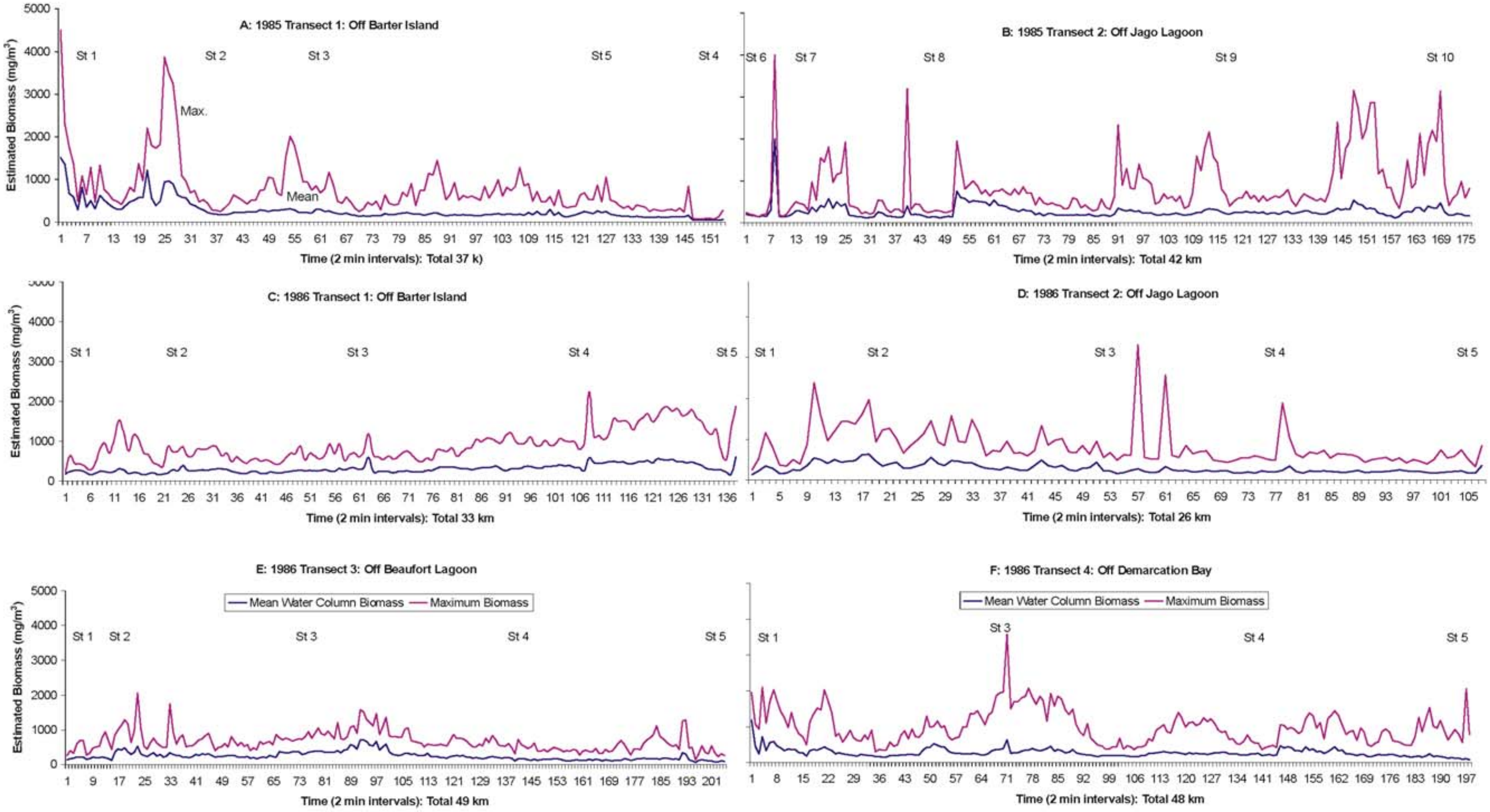

FIGURE 5.14. Average biomass in the water column (lower line), and maximum biomass of zooplankton within any 2 m thick layer (upper line). Estimated from 200 kHz echosounder data for the top 50 m of the water column along transects in the eastern Alaskan Beaufort Sea, September 1985 and 1986. Note that the horizontal axes are much compressed relative to the vertical axes.

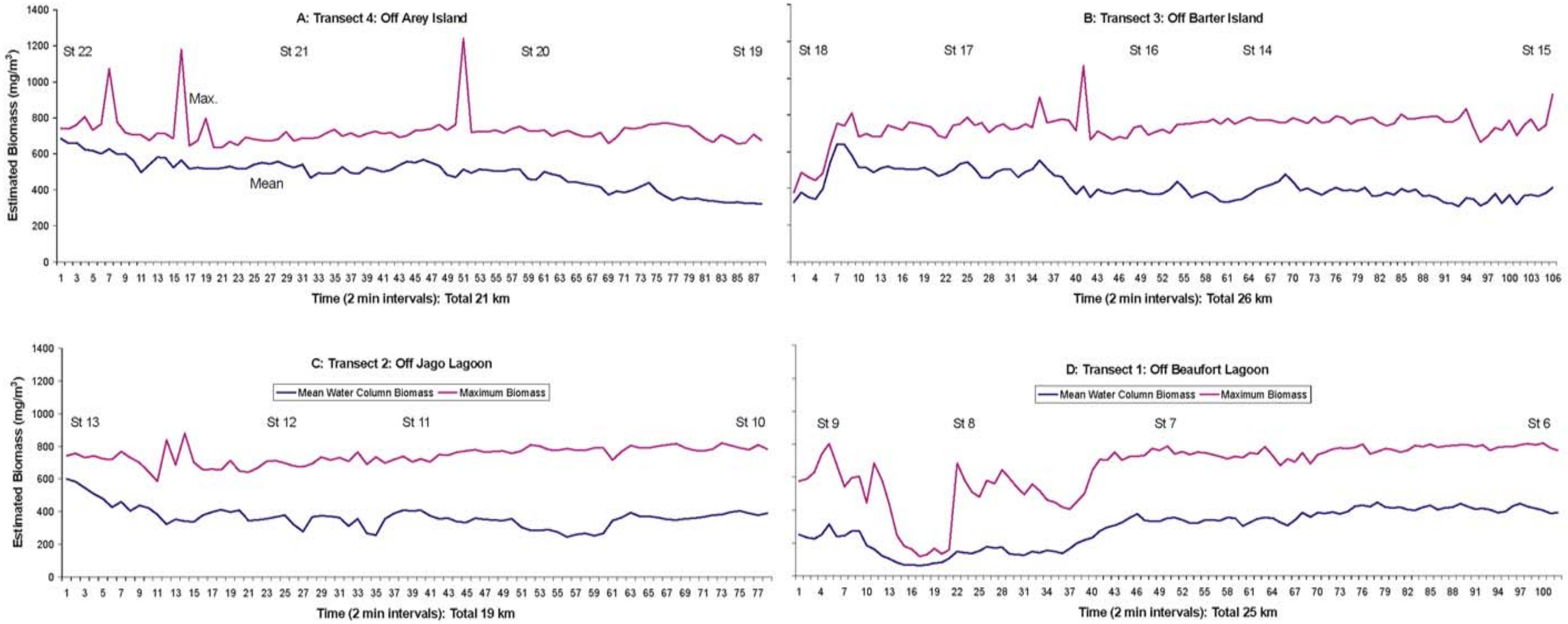

FIGURE 5.15. Average biomass in the water column (lower line), and maximum biomass of zooplankton within any 1 m thick layer (upper line). Estimated from 430 kHz echosounder data from four transects in the eastern Alaskan Beaufort Sea, September 1999. Note that the horizontal axes are much compressed relative to the vertical axes.

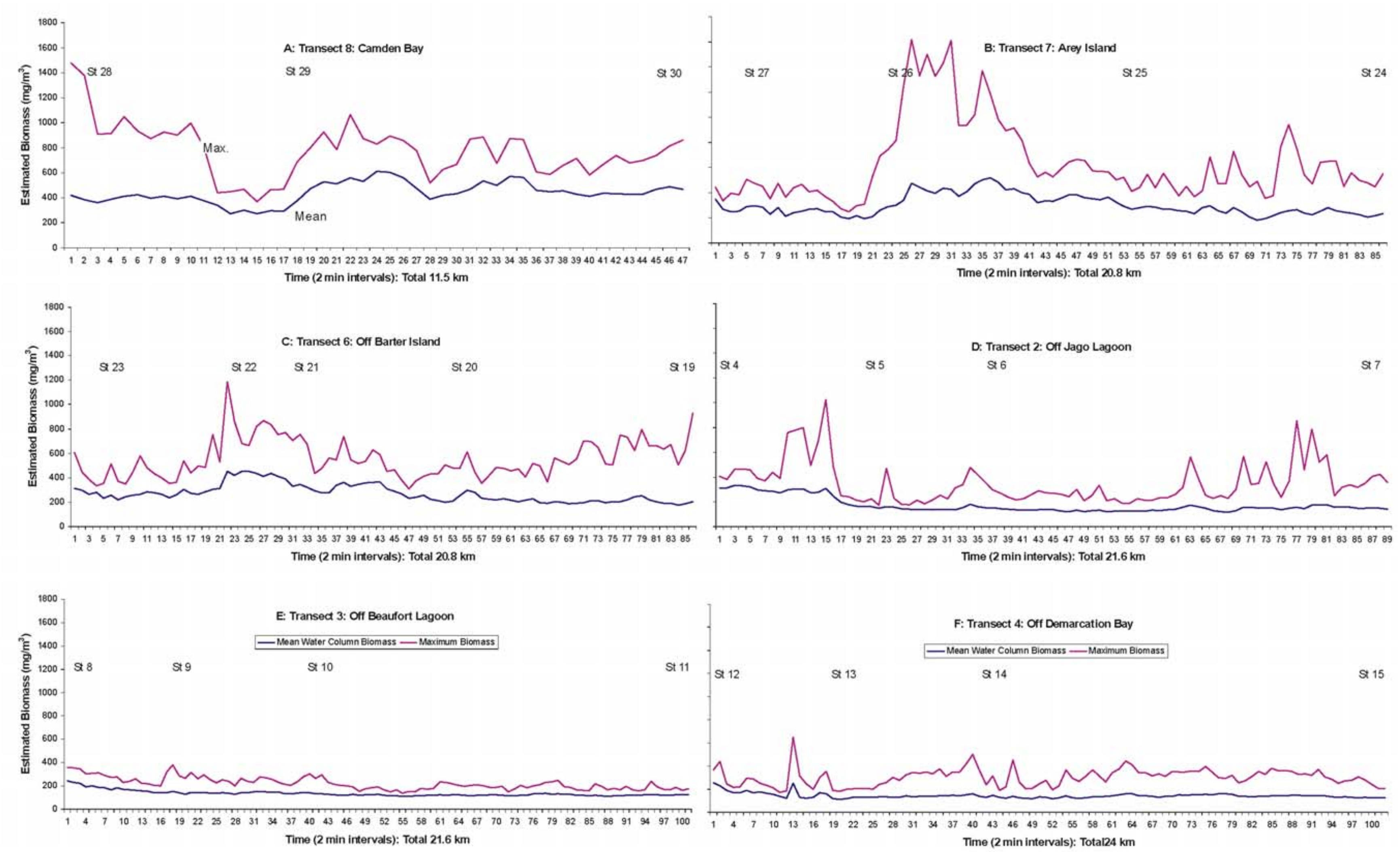

FIGURE 5.16. Average biomass in the water column (lower line), and maximum biomass of zooplankton within any 1 m thick layer (upper line). Estimated from 430 kHz echosounder data from six transects in the eastern Alaskan Beaufort Sea, September 2000. Note that the horizontal axes are much compressed relative to the vertical axes.

these areas were relatively small in horizontal extent. Between them biomasses were 200–300 mg/m^3 (Fig. 5.16D–F). Along the western transects, average estimated zooplankton biomasses were 300–400 mg/m^3, while maximum biomass showed numerous peaks with 400–1600 mg/m^3 (Fig. 5.16A–C). High maximum levels of estimated zooplankton biomass extended for much greater horizontal distances along the western transects than along the eastern ones.

During all years, most concentrated layers of zooplankton were within 45 m of the surface, even where water depth was over 100 m. Thus, most zooplankton concentrations would be easily accessible to feeding bowhead whales. The echosounder did not measure zooplankton biomass in surface waters in any year. However, net tows showed little zooplankton in surface waters in any year (with the exception of shallow waters in 1998). When pycnoclines were present (mainly 1985 and 1986), zooplankton biomass was low above the pycnocline.

Zooplankton Patchiness. Zooplankton patchiness was determined along each of the transects surveyed in 1985–86 and 1999–2000; contour plots of estimated zooplankton biomass are shown in Figures 5.17 to 5.20.

With the exceptions of 1985 Transect T2 off Pokok Bay and 1986 Transect T1 off Barter Island, zooplankton patches were more abundant in the nearshore and middle regions than at the seaward ends of the transects (Fig. 5.17, 5.18). In 1985, zooplankton patches were generally smaller in both length and depth than in 1986, and the highest biomasses were generally just below the pycnocline (6 to 10 m depth). In contrast, during 1986 the highest biomasses were usually deeper in the water column, typically just above the bottom, particularly in shallow nearshore waters and at mid-depths along the transects. Echosounder surveys in 1986 were consistent with net samples in showing that surface waters contained low biomasses of zooplankton (Fig. 5.18). In both these years only a small fraction of the water along the transects contained a high (>500 mg/m^3) biomass of zooplankton, although there were patches where the estimated biomass exceeded 1000 mg/m^3 in 1985 and 3500 mg/m^3 in 1986. (See preceding footnote regarding the extrapolation involved in deriving these high estimates.)

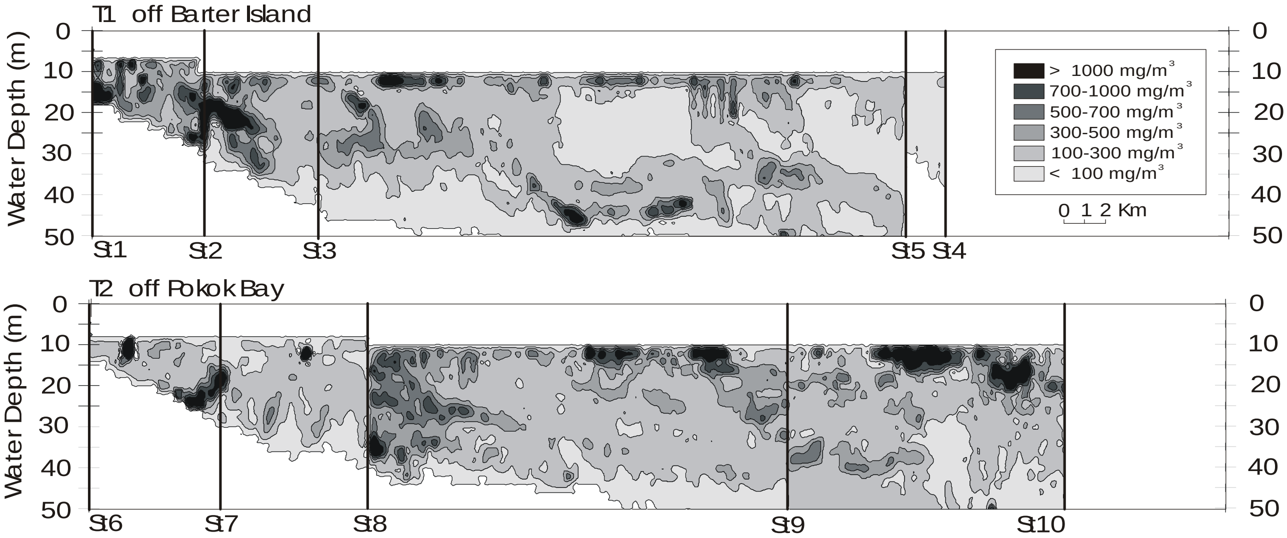

FIGURE 5.17. Zooplankton patchiness estimated from continuous hydroacoustic sampling along 1985 Transects T1 and T2. Data recorded within and above pycnoclines are excluded. The horizontal axes are much compressed relative to the vertical axes. See Fig. 5.1A for transect locations.

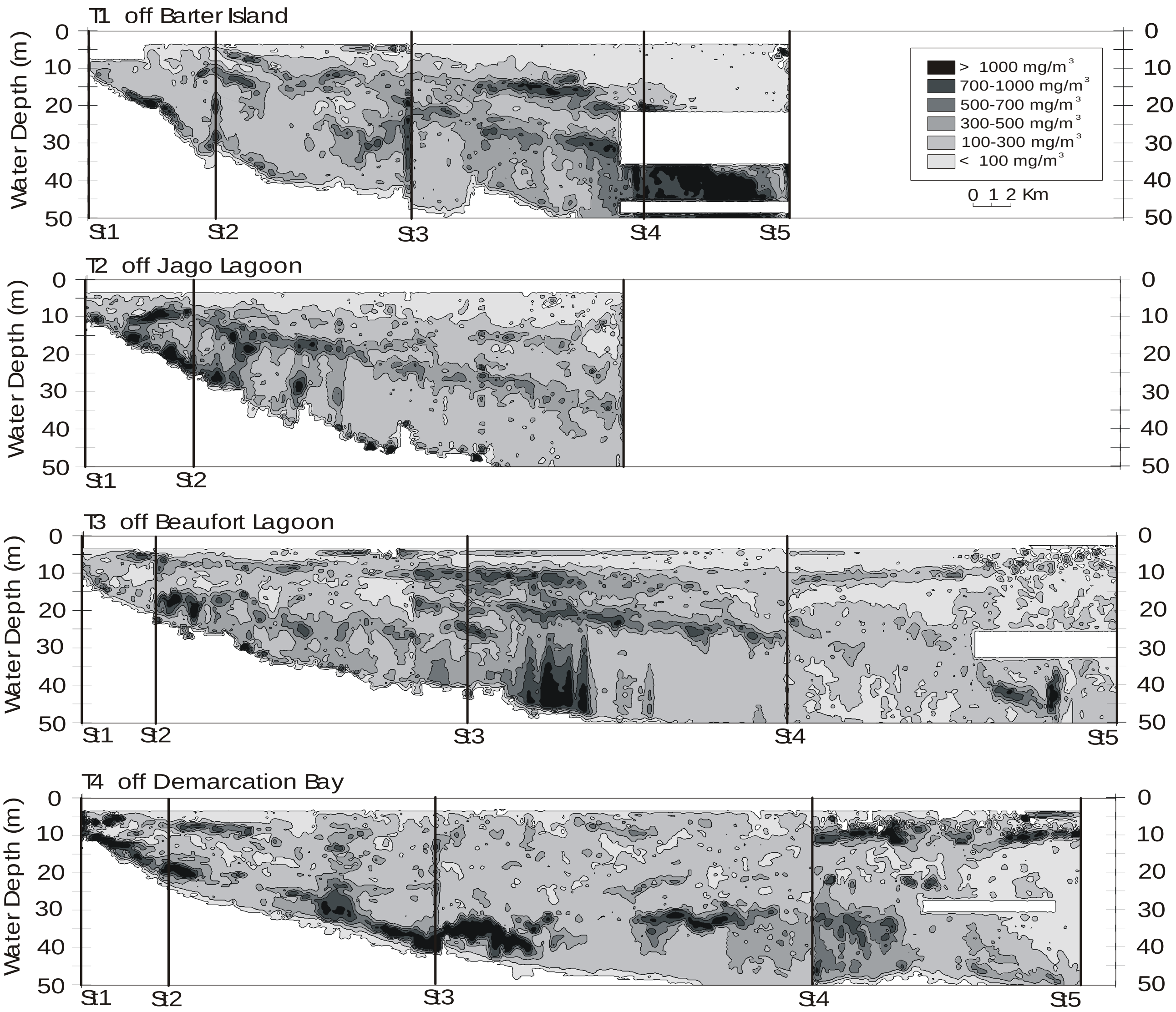

FIGURE 5.18. Zooplankton patchiness estimated from continuous hydroacoustic sampling along 1986 Transects T1, T2, T3 and T4. Data recorded within and above pycnoclines are excluded. The horizontal axes are much compressed relative to the vertical axes. See Fig. 5.1A for transect locations.

In 1999, there were nearly continuous bands of zooplankton of at least 300 to 500 mg/m^3 that extended from nearshore to offshore stations along all transects except Transect T1, off Beaufort Lagoon. In the latter area, most of the zooplankton was along the outer portion of the transect (Fig. 5.20). The bands along all transects were relatively thick (10–20 m) and were usually at depths >25 m. The main exception was along Transect T4, off Arey Island, where there was a band much closer to the surface. Zooplankton biomass was low near the surface along all transects (Fig. 5.19). Although zooplankton patches were more extensive in 1999 than in 1985–86, the estimated biomass levels were lower in 1999; the densest patches contained an estimated maximum of 200 to 1000 mg/m^3.

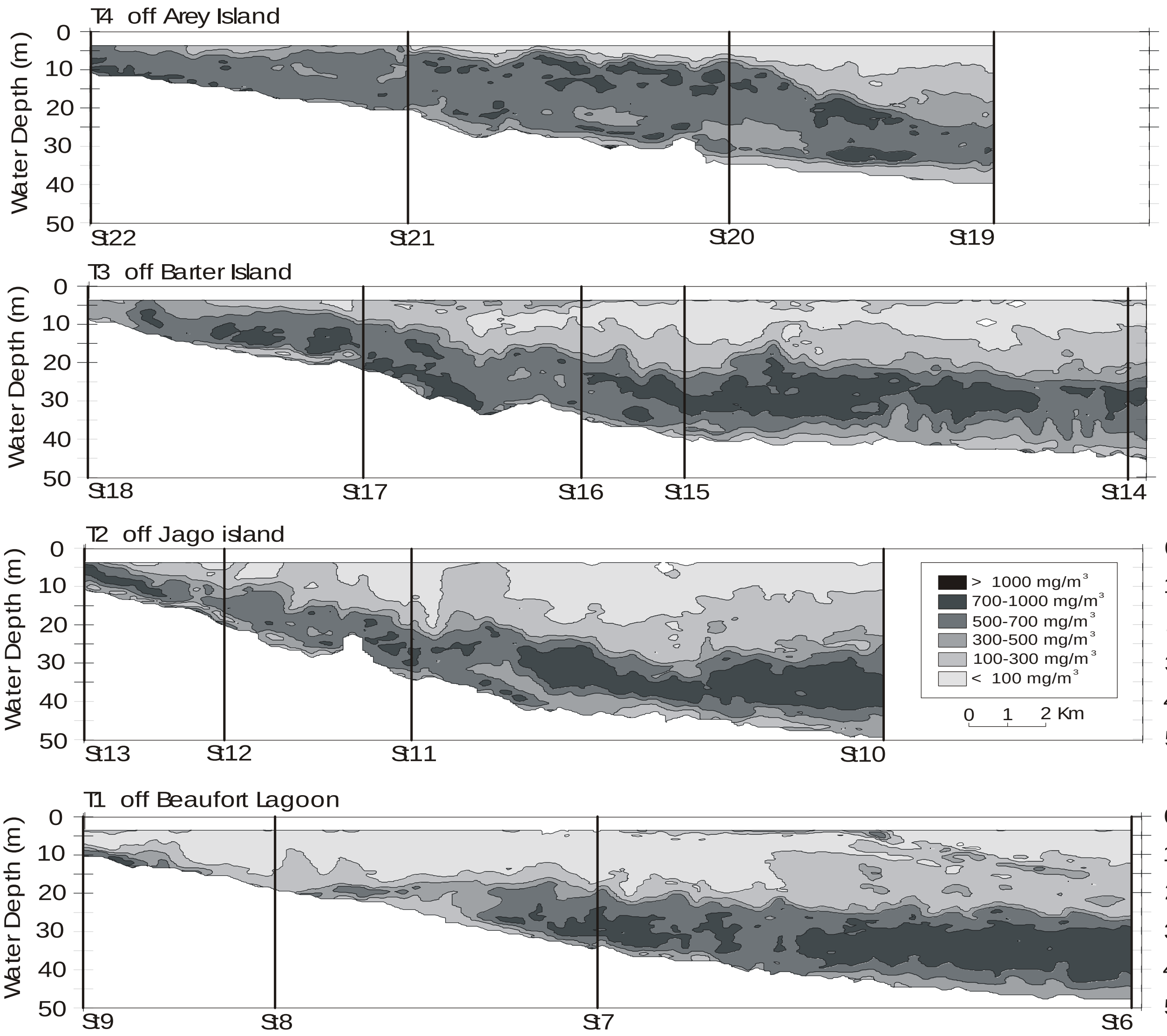

FIGURE 5.19. Zooplankton patchiness estimated from continuous hydroacoustic sampling along 1999 Transects T1, T2, T3 and T4. Data recorded in top 3 m of the water are excluded. The horizontal axes are much compressed relative to the vertical axes. See Fig. 5.1B for transect locations.

In 2000, the six transects between Demarcation Bay in the east and Camden Bay in the west show a pattern of increasing zooplankton biomass from east to west, particularly from Barter Island to Camden Bay (Fig. 5.20). The three most easterly transects, between Demarcation Bay and Jago Lagoon, contained extensive patches of zooplankton, kilometers in length and 10s of meters thick, with biomasses 100 to 300 mg/m^3. However, there were very few patches where estimated biomass exceeded 700 or especially 1000 mg/m^3 (Fig. 5.20). In contrast, the westernmost transects from Barter Island to Camden Bay contained several patches where zooplankton biomasses exceeded 1000 mg/m^3, with the frequency and extent of the high density patches increasing from east to west (Fig. 5.20). Patches with the maximum estimated zooplankton biomasses tended to be in the mid-water to near-surface depths along all transects except for Transect 8 in Camden Bay. There, patches of maximum biomass occurred both at mid-depth and near the bottom (Fig. 5.20).

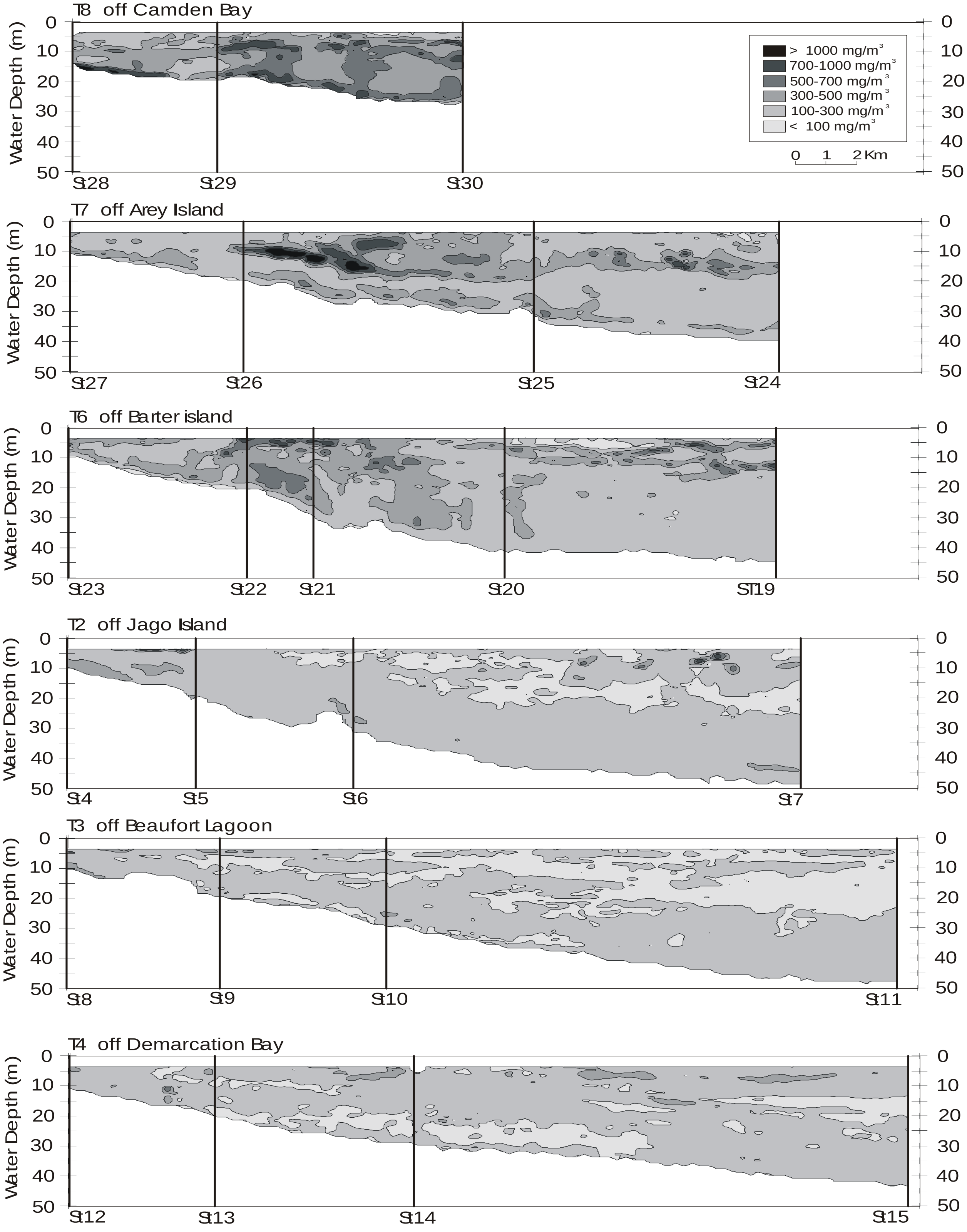

FIGURE 5.20. Zooplankton patchiness estimated from continuous hydroacoustic sampling along 2000 Transects T2, T3, T4, T6, T7 and T8. Data recorded in the top 3 m of the water are excluded. The horizontal axes are much compressed relative to the vertical axes. See Fig. 5.1C for transect locations.

Overall, the zooplankton biomasses estimated from echosounder data were higher in 1986 than in 1985, 1999, and 2000. This was true for peak biomasses along all transects and at individual stations where estimated biomass levels reached 1600 mg/m^3. The lowest biomass levels were recorded in 1999, while those in 1985 and 2000 were intermediate.

Discussion

Physical Oceanographic Features

Physical oceanographic properties of the study area, as in most other areas, vary considerably from year to year, and they can also change rapidly within the same year and within a particular study area. However, the present study area can show more variability than many other marine areas because of its proximity to massive sources of ice and freshwater that can be advected into the study area by the wind. Under persistent east winds, cold saline bottom water upwells into shallow water. This upwelling can cause areas along the coast that are otherwise brackish and warm to become much colder and saltier (Mangarella et al. 1982; Savoie and Wilson 1983, 1986). In this case, nearshore waters are mixed rather than stratified. East winds can also transport the relatively warm and fresh Mackenzie River plume into eastern and offshore portions of the study area (Bradstreet et al. 1987; Fissel et al. 1987). Its presence causes strong temperature and salinity discontinuities in these waters. If a west wind occurs when there is no Mackenzie plume water offshore, then only cold saline offshore water is moved inshore. However, if west winds occur when the Mackenzie plume is offshore, then it will be blown onshore

Wind direction is from the northeast 35% of the time and from the northwest 23% of the time (Fissel et al. 1987). Water masses in the Beaufort Sea can respond to changes in wind patterns in as little as 12 h (Aagaard 1984; Niedoroda and Colonell 1990).

Two kinds of oceanographic regime were evident during the five years of this study. (1) In September of 1985, 1986 and 1998, warm fresh Mackenzie River water was transported into the study area (Bradstreet et al. 1987; Fissel et al. 1987; this study). (2) In 1999 and 2000, all water in the study area (out to the 50 m contour) was characterized as Shallow Cold Saline with little or no Mackenzie influence. The first regime was most readily characterized by the presence of strong pycnoclines and the second by their absence.

Zooplankton Biomass and Composition

Species composition and biomass of the zooplankton did not correspond in any simple way to the oceanographic regimes described above. The most obvious differences in the zooplankton occurred between 1985–86 and 1998–2000. In the region as a whole, the total zooplankton biomass was higher in 1985 and especially in 1986 than in 1998, 1999 and 2000.

The higher zooplankton biomasses in 1985–86 were due to the much higher biomasses of copepods, particularly *Limnocalanus macrurus* in the Shallow Cold Saline zone. *Calanus glacialis* and *C. hyperboreus* were also major contributors to the copepod biomass in all years. In 1986 and 1998, *Calanus glacialis* was the dominant of the two species, while in 1985, 1999 and 2000 the dominant species was *C. hyperboreus*. Predatory cnidarians, ctenophores, and chaetognaths were abundant in the study area in 1998–2000 and not in 1985–86. These predators may have contributed to the lower biomass of copepods in 1998–2000.

Grainger (1965) described two major groups of Beaufort Sea zooplankton in waters <100 m in depth. The species characteristic of the upper 100 m of Arctic surface waters are found both offshore and inshore and are typically tolerant of a wide range of temperatures (–1° to ~5–10°C) and salinities (12 to 34 psu). Organisms in this group include the hydrozoans *Aglantha digitale* and *Aeginopsis laurentii,* the ctenophore *Beroe cucumis*, and several species of copepods: *Calanus hyperboreus*, *C. glacialis*, *Pseudocalanus minutus*, *Metridia longa,* and *Oithona similis*. A second group is characteristic of shallow nearshore brackish waters along the coastlines of the Beaufort and Chukchi seas. It includes the hydrozoans *Euphysa flammea, Halitholus cirratus* and *Sarsia princeps*, the ctenophore *Obelia* spp., and the copepods *Limnocalanus macrurus*, *Acartia clausi*, *Eurytemora herdmani*, and *Derjuginia tolli*. These species are typically found in waters with relatively high temperatures (1 to 12°C) and low salinities (8 to 25 psu), characteristic of nearshore brackish waters during the open water season (Grainger 1965; Shih et al. 1971). Overall, 77 of the 83 stations sampled in this study were in the first group, as defined by species composition, and only 6 in the second. Species characteristic of the second group were often found in cold saline water as well as in nearshore brackish waters.

In all five years, net sampling showed zooplankton biomass to be low in surface and near-surface waters above pycnoclines. Zooplankton biomass was always higher in the colder saline water at depth >10 m. This was true even for the brackish-water copepod *L. macrurus*. Maximum abundances of this copepod were recorded in cold saline water rather than in the estuarine water influenced by the Mackenzie River. This was true in 1985 and 1986 both in this study and in a similar study along the Yukon coast (Bradstreet and Fissel 1986; Bradstreet et al. 1987). However, *L. macrurus* was only abundant in the study region when the influence of Mackenzie River water extended along the coast of the Yukon and into the eastern Alaskan Beaufort Sea. It may be that the brackish Mackenzie water brings this copepod into eastern Alaskan waters but, once there, it is able to thrive in the colder and more saline water typically found in the region.

Copepods represented 80 to 90% of zooplankton biomass over deep ice-covered waters of the Arctic Ocean, including those north of the Beaufort Sea (Hopkins 1969). In the eastern Canadian high arctic, copepods constituted 80% of the total zooplankton biomass in the upper 150 m of Lancaster Sound and northwestern Baffin Bay (Buchanan and Sekerak 1982). Calanoid copepods were the major component of the zooplankton in the present study area and other parts of the Beaufort Sea (Grainger and Grohe 1975; Horner 1979, 1981; Griffiths and Buchanan 1982; Bradstreet and Fissel 1986; Bradstreet et al. 1987)

Average biomasses of zooplankton collected in summer and early autumn in the eastern Alaskan and Canadian Beaufort Seas are similar. Depending on year and sampling area, mean wet-weight biomasses collected by oblique samples in the top 50 m of the water column in various areas have ranged from ~150 to over 380 mg/m^3 with an overall average for all 218 oblique and (1980 only) vertical tows taken in these areas of ~260 mg/m^3 (Table 5.4). Under some circumstances, biomass in layers of concentrated zooplankton, as measured with horizontal bongo tows, can equal or exceed 1000 or 2000 mg/m^3.

Zooplankton biomass is considerably higher over the continental shelf of the Beaufort Sea than over deeper offshore waters of the Arctic Ocean. In the latter area, Hopkins (1969) found an average biomass of only 5 mg/m^3 wet-weight in the upper 200 m, based on 39 tows.

Abundance of zooplankton in the southeastern Chukchi Sea is higher south of Cape Lisburne than north of it (Wing 1974). Average summer zooplankton biomass in 145 samples taken in the southeastern Chukchi Sea between Cape Lisburne and the Bering Strait was ~1700 mg/m^3 wet-weight (English 1966). However, primary and secondary productivity in the Chukchi Sea may be highest in the southern and southwestern part (Truett 1984). Bowhead whales are known to feed in that general area during autumn (Moore et al. 1995).

TABLE 5.4. Wet-weight biomass of dominant zooplankton taxa taken in oblique tows (1985–2000) and vertical tows (1980) through the upper 50 m of the water column on transects in the Canadian and Alaskan Beaufort seas during summer and early autumn. The percent of total biomass represented by each taxon is also shown.

	Yukon Coast						Mackenzie Delta				Tuktoyaktuk Peninsula		Eastern Alaskan Beaufort Sea[d]									
	1980[a]		1985[b]		1986[c]		1986[c]		1980[a]		1986[c]		1985		1986		1998		1999		2000	
	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%
Copepods	125	39	181	86	121	70	99	65	140	22	126	60	168	75	130	73	119	48	189	49	99	52
Limnocalanus macrurus	38	12	141	68	67	39	<1	<1	0	0	<1	<1	43	19	59	33	<1	<1	<1	<1	<1	<1
Calanus hyperboreus	62	19	15	7	27	16	74	48	128	21	97	46	80	36	17	10	16	6	154	40	56	30
Calanus glacialis	0	<1	13	6	23	13	21	14	11	2	26	12	25	11	52	29	100	40	24	6	40	21
Mysids	44	14	8	4	7	4	7	4	6	1	5	2	5	2	1	1	8	3	4	1	1	1
Euphausiids	0	0	2	1	11	6	2	1	0	0	0	0	8	4	<1	<1	2	1	5	1	11	6
Cnidarians/Ctenophores	108	34	7	3	11	10	24	15	441	71	35	17	22	10	15	8	61	24	85	22	39	21
Chaetognaths	6	2	4	2	6	3	5	3	8	1	17	8	6	3	4	2	48	19	87	23	32	17
Total	319		211		173		153		632		210		207		170		250		383		189	
Standard Deviation	180		245		195		84		516		139		121		273		141		260		92	
Number of Tows	12		16		15		21		48		10		12		19		18		17		30	
Max. Sample Depth (m)			10-25		10-50		9-50				9-50		10-50		8-50		7-46		7-42		8-47	
Station Depths (m)	7-17		12-171		14 -167		10-68		10-26		12-52		13-80		10-205		9-48		10-50		10-50	

a Griffiths and Buchanan (1982). Note that all tows in 1980 were vertical tows.
b Bradstreet and Fissel (1986).
c Bradstreet et al. (1987).
d This study.

During May and June, when bowheads leave the Bering Sea, average biomass in the upper 100 m can reach 1500 to 2000 mg/m^3 over large areas (Coyle et al. 1996). [All values in this paragraph are wet-weights.] In spring, the greatest zooplankton biomass (1000 to 2000 mg/m^3) is found in the Gulf of Anadyr, Norton Sound, and Bering Strait (Coyle et al. 1996). Average biomass of zooplankton in the upper 50 to 100 m of the deep basin of the Bering Sea during spring ranges from 500 to over 1000 mg/m^3 (Ikeda and Motoda 1978; Coyle et al. 1996). Biomass is lower in summer, but the distribution pattern is similar. Summer biomass in the deep basin is about the same as that found in the Beaufort Sea in fall (200–500 mg/m^3). Biomass is 500 to 1000 mg/m^3 over the shelf and >1000 mg/m^3 in the Gulf of Anadyr. In fall when bowheads return to the Bering Sea, zooplankton biomass in the upper 100 m of the deep basin is 300–400 mg/m^3 (Coyle et al. 1996), again about the same as that in the Beaufort Sea. Biomass over the shelf is lower and ~100–200 mg/m^3. During winter, when bowheads are present, biomass in the upper 200 m is ~50 mg/m^3, but is >200 mg/m^3 below 200 m (Coyle et al. 1996).

It is acknowledged that all of these data on zooplankton biomass and species composition are subject to a variety of potential limitations and biases. Many of these were discussed in Chapter 4. The faster swimming taxa, e.g., euphausiids, are known to show a net-avoidance effect, resulting in underestimation of their biomass. Some individuals of the smallest species, or the smaller life-stages of somewhat larger species, will pass through the mesh of standard sampling nets (here 0.5 mm), and also be undersampled. A further complication is that net tows of 5-min or similar duration produce an estimate of average zooplankton biomass across a range of horizontal distances, and are likely to underestimate the maximum biomass present. The latter is of particular relevance in studies of feeding by zooplankton predators (such as bowhead whales) that feed preferentially in areas of maximum prey abundance. Also, even a horizontal tow that is guided to the depth of a thin zooplankton "layer" by an echosounder, as in this study, provides an average biomass estimate applicable to some (narrow) range of depths, not just to the precise depth of maximum biomass. All of these problems result in a tendency for standard net-samples of zooplankton to underestimate the average and maximum biomasses of zooplankton present.

Nonetheless, biomass data obtained from this type of sampling do provide, at the least, minimum estimates of zooplankton biomass, and approximate data on the proportions contributed by different species and species-groups. Also, these types of data are quite suitable for comparing the relative zooplankton availability in different years, water masses, locations, depths, etc.

The likely under-sampling of fast-moving euphausiids is of particular concern in this study, as bowhead whales are known to feed on euphausiids at times. Euphausiids dominate the stomach contents of a minority (24%) of the bowhead whales harvested in late summer/early autumn at Kaktovik, within the present study area. Euphausiids dominate in a majority (88%) of the bowheads harvested in autumn at Barrow, farther west (Lowry 1993; Lowry and Sheffield, Chapter 18). Although euphausiids, mainly *Thysanoessa raschii*, were caught in our net samples, euphausiids rarely contributed a large proportion of the biomass. During a broad-scale zooplankton survey across the Alaskan Beaufort Sea during the autumn of 1986, Griffiths et al. (1987) found considerably higher absolute and proportional biomasses of euphausiids in the western Alaskan Beaufort (near Barrow) than in the eastern Alaskan Beaufort. Based on these and other results, we conclude that euphausiids are very likely underrepresented in our net samples but, when they are abundant, they are prominent components of the net samples. We interpret the infrequent occurrence of substantial biomasses of euphausiids in zooplankton samples from the eastern Alaskan (and Canadian) Beaufort Sea as a meaningful indication of their lower abundance there than in the western Alaskan Beaufort Sea.

In this study, all zooplankton sampling was done during daylight hours in September. At this latitude (70°N), there is 24-hour daylight from spring until early August, a few hours of darkness each night in early September, and rapidly increasing hours of darkness as September and October progress. In most areas, zooplankton tend to migrate toward the surface at night and to deeper depths by day. The extent of diel vertical migration of zooplankton in the present study area has not been studied. It is possible that the vertical distribution of zooplankton in this area during September is different at night than in the daytime. However, most of our sampling (and all of that in 1998–2000) was in places where we were able to document the zooplankton throughout almost all of the water column via a combination of nets and echosounding. Although the measured biomass might have a different vertical distribution at night, the overall average biomass would not be expected to differ appreciably at night.

Echosounder Surveys

This study has provided the first quantitative echosounder data on zooplankton in the Alaskan Beaufort Sea. Much information about the vertical and horizontal distribution of zooplankton has been obtained during September of four years. This information is complementary to the net-sampling data. The echosounder data provide greatly increased resolution, both horizontal and vertical, as compared with net sampling, but they depend on the net-sampling for calibration purposes, and (unlike the net-sampling) they do not provide information about species composition.

The limitations and biases of the echosounder data were discussed in Chapter 4. Physical features in the water column such as density gradients, turbidity, and air bubbles can produce acoustic backscatter, and at times this is difficult to distinguish from zooplankton. Biological factors that can cause complications are the presence of fish, and variability in the sizes and orientations of the zooplankters themselves. Some of these confounding factors have been alleviated in this study through exclusion of data from locations and depths with known density gradients (pycnoclines) and special processing of the data to minimize the contribution by fish (see "Methods" and Chapter 4). However, there is residual variability in the echosounder data. Furthermore, our calibrations of the echosounder data to allow estimation of zooplankton biomass from acoustic backscatter alone are based on net samples and echosounder data from matched locations and depths. Difficulties in obtaining precise matching of the two types of samples, and the inherent limitations and biases of the net-sample data (see preceding subsection), result in imprecise calibration of the echosounder data (see Chapter 4).

Thus, the echosounder surveys provide only approximate estimates of absolute zooplankton biomass, along with extensive data on relative biomass at different places, depths, and times. A major objective of the overall study of which this Chapter is one part was to assess the characteristics and quality of bowhead whale feeding habitat in the eastern Alaskan Beaufort Sea. This required zooplankton surveys that could not be conducted with adequate resolution by net-sampling alone. Our contour plots depicting zooplankton biomass vs. depth and location along transects show locations of zooplankton concentrations ("patches") within the study area in a given year, the relative biomasses of zooplankton available to whales at different places and times, and year-to-year differences. These data provide a valuable basis for comparisons of food availability in the eastern Alaskan Beaufort Sea as a whole (this chapter) with that at the specific locations where bowhead whales have been observed to feed (Chapter 6).[4]

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[4] Acknowledgements applicable to all zooplankton chapters are included near the end of Chapter 3.

Summary

Introduction and Objectives

This chapter describes the first comprehensive study on late summer zooplankton biomass in the eastern Alaskan Beaufort Sea from shore to ~200 m deep. The primary objective was to gather data on the taxonomic composition, biomass, patchiness, and variability of the zooplankton available to feeding bowhead whales in that area during late summer and early autumn. Consequently, emphasis was placed on species and taxa that were major contributors to overall zooplankton biomass. The study was based on coordinated net sampling and quantitative echosounder surveys conducted over 7- to 16-day periods during early-mid or mid-late September of five years. It describes the vertical and horizontal distribution, composition, and patchiness of zooplankton biomass in relation to water mass characteristics.

Methods

In all 5 years (1985–86; 1998–2000) sampling was conducted from a 13-m vessel during September. Zooplankton and CTD data were collected at stations along transects perpendicular to shore between central Camden Bay and Demarcation Bay, extending seaward to ~200 m depth (1985–86) or 50 m depth (1998–2000). Quantitative echosounder data were collected along the same transects. All data were used to describe the nature and variability of the zooplankton community, and its relationships to water masses in the study area.

Three types of bongo tows were used to collect zooplankton samples each year: surface tows, oblique tows, and horizontal tows at depth. A flow meter was placed in the center of one frame. The echosounder was used to help select depths for horizontal tows, to ensure sampling within and outside layers of concentrated zooplankton. Actual tow depth was measured directly.

Hydroacoustic sampling to estimate zooplankton distribution (horizontal and vertical) and relative biomass along transects was conducted in all 5 years using single- (1998) or dual-frequency (other years) echosounders. Relative biomass was determined for each 2 min (~240 m) horizontal segment by 1- or 2-m depth interval for all transects.

CTD profiles were measured at stations along each transect each year. Near-surface temperature (and, in 1985–86, salinity) were recorded continually during transits between sampling.

Results

In all five years of the study, at least two water masses were deemed to be present: (1) a Shallow Cold Saline water mass, usually without sharp discontinuities in the vertical distribution of temperature and salinity (i.e., without pycnoclines). These waters were typically relatively cold and saline from surface to bottom. (2) A Mackenzie-Influenced more-offshore water mass with Mackenzie-influenced water at the surface, overlying water that was generally colder and more saline than that of the nearshore water mass. In 1985, 1986 and 1998, warm fresh Mackenzie plume water was transported into the study area; in 1999 and 2000 it was absent. The distribution of water masses did not appear to have a strong effect on the distribution of major zooplankton taxa. However, the highest biomass of zooplankton occurred in the presence of strong pycnoclines, in the colder and more saline bottom waters.

The annual average zooplankton biomasses collected in ***Shallow Cold Saline*** waters varied over the five years of study: 189–409 mg/m^3 for the water column as a whole, 18–205 mg/m^3 for surface waters, and 236–516 mg/m^3 for horizontal tows at depth. In all years, zooplankton biomasses in surface waters were lower than in samples taken at depth. Typically, zooplankton biomasses were higher in the cold saline bottom layer than in the fresher warm surface water. In 1985–86, the maximum biomass in individual horizontal tows at depth was 900–2000 mg/m^3, considerably higher than the 500–1000 mg/m^3 recorded in 1998–2000. Overall, zooplankton biomasses were higher in 1986 than in 1985, 1998, 1999 and 2000. The lowest biomass levels were recorded in 1999, while those in 1985, 1998 and 2000 were intermediate.

The high zooplankton biomasses in 1985–86 were due to the much higher biomasses of copepods, particularly *Limnocalanus macrurus.* In 1998–2000, *Calanus glacialis* and *C. hyperboreus* were the dominant species among all taxa. Predatory cnidarians, ctenophores and chaetognaths were abundant in the study area in 1998–2000 and not in 1985–86. These predators may have contributed to the lower biomass of copepods in 1998–2000.

In the water column as a whole, within the Shallow Cold Saline zone, five major zooplankton taxa were collected in all five years. These were copepods, gelatinous zooplankton (i.e., ctenophores + cnidarians), chaetognaths, mysids, and fish. Copepods were the dominant taxon in all years, especially in 1985 and 1986. Gelatinous zooplankton and chaetognaths, considered together, were major contributors (>10 mg/m^3) to zooplankton biomass in every year, and in 1998–2000 their biomass approached that of copepods. Euphausiids were collected in all years except 1986 and were major contributors to the zooplankton biomass in 1985 and 2000, while decapods were major contributors only in 1986.

In all five years, the copepods *Calanus hyperboreus* and *C. glacialis* were major contributors to the copepod biomass. In 1985 and 1986, biomass of the copepod *Limnocalanus macrurus* was higher than that of any other species, but it was not found in the nearshore zone at all in 1998 and 1999 and only in small quantities in 2000.

The low biomass in the surface waters was composed of copepods, gelatinous zooplankton and, to a lesser extent, chaetognaths. Below the surface, the composition of the zooplankton collected in horizontal tows was similar to that in the water column as a whole

The ***Mackenzie-Influenced more-offshore water mass*** was present in the study area during 1985, 1986 and 1998, but not in 1999 and 2000. The annual average zooplankton biomasses in this water mass were 170 to 223 mg/m^3 for the water column as a whole, and 4 to 25 mg/m^3 for surface waters. Each of these averages was lower than the corresponding value in Shallow Cold Saline zone. The warm freshened water layer above the pycnocline contained a very low biomass of zooplankton (annual averages 46–115 mg/m^3) compared to the cold saline water below (394–659 mg/m^3). Copepods and gelatinous zooplankton, with lesser contributions from amphipods, euphausiids, chaetognaths, pteropods and fish, accounted for most of the biomass. In all three years, copepods were the dominant taxon, particularly in 1985 and 1986. Overall, *C. glacialis* and *C. hyperboreus* were the major contributors to the total copepod biomass in the Mackenzie-Influenced waters in all three years. *Limnocalanus macrurus*, the dominant copepod in Shallow Cold Saline waters in 1985–86, was also a major contributor to biomass in Mackenzie-Influenced waters in 1985 but not in 1986. It was not found in this water mass in 1998.

The ***Outer Shelf Arctic water mass*** was only sampled in 1985 and 1986 when transects extended out to the 200 m contour (vs. 50 m in 1998–2000). Zooplankton biomass in this zone was, on average, less than that in nearshore and inner shelf waters. In both years, *Calanus hyperboreus* and *C. glacialis* contributed most of the copepod biomass.

Average biomasses of zooplankton collected in summer and early autumn in the eastern Alaskan and Canadian Beaufort Seas are similar. Zooplankton biomass collected by oblique (1985–2000) or vertical (1980) tows in the top 50 m of the water column have ranged from ~150 to 600 mg/m^3 with an overall average for all 218 of these tows of ~260 mg/m^3. Under some circumstances, biomass in layers of concentrated zooplankton, as measured with horizontal bongo tows, can equal or exceed 1000 or 2000 mg/m^3.

Echosounder surveys in 1985 and 1986 showed that only a small fraction of the water along the transects contained a high (>500 mg/m^3) biomass of zooplankton, although there were patches where the estimated biomass apparently exceeded 3000 mg/m^3 in 1985 and 3500 mg/m^3 in 1986. In 1999, zooplankton patches were more extensive than in 1985–86 but the estimated biomass levels were lower with the densest patches containing only an estimated maximum of 800–1000 mg/m^3. In 2000, there was a pattern of increasing zooplankton biomass from east to west, with highest values from Barter Island to eastern Camden Bay. In 2000, there were also many more patches where estimated biomass exceeded 700 or 1000 mg/m^3 along the western three transects than along the three eastern transects.

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APPENDIX 5.1. Locations of sampling stations along transects in the eastern Alaskan Beaufort Sea, 4-18 Sept 1985.

Station	Date	Transect No	Water Depth (m)	Time ADT	Station Latitude	Station Longitude
1	4/9/1985	T-1	13	1000	70° 09' N	143° 37' W
2	5/9/1985	T-1	28	2024	70° 13' N	143° 29' W
3	5/9/1985	T-1	45	1947	70° 16' N	143° 25' W
4	6/9/1985	T-1	125	1208	70° 34' N	143° 07' W
5	6/9/1985	T-1	80	1749	70° 33' N	143° 06' W
6[a]	9/9/1985	T-2	10	1836	70° 03' N	142° 45' W
7	7/9/1985	T-2	25	1334	70° 07' N	142° 42' W
8	7/9/1985	T-2	42	1712	70° 11' N	142° 39' W
9	8/9/1985	T-2	56	1325	70° 20' N	142° 19' W
10	10/9/1985	T-2	185	1205	70° 31' N	142° 04' W
11	18/09/85	T-4	14	924	69° 42' N	141° 09' W
12	18/09/85	T-4	25	1323	69° 45' N	141° 09' W
13	18/09/85	T-4	40	1523	69° 53' N	140° 52' W

ADT = Alaska day light time.

[a] No zooplankton tows at this station due to ice conditions.

APPENDIX 5.2. Locations of sampling stations along transects in the eastern Alaskan Beaufort Sea, 4-19 Sept 1986.

Station	Date	Transect No.	Water Depth (m)	Time (ADT)	Station Latitude	Station Longitude
T4-1	9/9/1986	T4	12	1430	69°42.3'N	141°17.2'W
T4-2	10/9/1986	T4	21	800	69°44.5'N	141°11.9'W
T4-3	10/9/1986	T4	43	1151	69°55.0'N	140°55.8'W
T4-4	10/9/1986	T4	53	1604	70°07.1'N	140°52.6'W
T4-5	11/9/1986	T4	180	1245	70°17.8'N	140°34.2'W
T3-1	12/9/1986	T3	13	835	69°52.2'N	142°05.0'W
T3-2	12/9/1986	T3	21	1030	69°53.9'N	141°58.0'W
T3-3	13/09/86	T3	41	1000	70°03.1'N	141°49.9'W
T3-4	13/09/86	T3	53	1400	70°12.9'N	141°41.8'W
T3-5	14/09/86	T3	205	1234	70°24.3'N	141°31.9'W
T1-1	16/09/86	T1	10	810	70°09.2'N	143°40.8'W
T1-2	16/09/86	T1	34	1030	70°13.6'N	143°38.2'W
T1-3	16/09/86	T1	47	1345	70°21.3'N	143°31.5'W
T1-4	17/09/86	T1	54	1100	70°28.7'N	143°34.7'W
T1-5	17/09/86	T1	118	1410	70°33.2'N	143°34.2'W
T2-1	18/09/86	T2	10	855	70°04.5'N	142°53.3'W
T2-2	18/09/86	T2	26	1145	70°07.9'N	142°48.7'W
T2-5	19/09/86	T2	150	1245	70°31.6'N	142°27.3'W

ADT = Alaska daylight time.

APPENDIX 5.3. Locations of sampling stations along transects in the eastern Alaskan Beaufort Sea, 11-22 Sept 1998.

Station	Date	Transect No.	Water Depth (m)	Time ADT	Station	
					Latitude	Longitude
6	14/09/98	T-1	9	937	69° 48.50' N	141° 46.00' W
7	14/09/98	T-1	18	1031	69° 49.92' N	141° 40.04' W
10	15/09/98	T 1	20	952	69° 50.05' N	141° 40.46' W
11	15/09/98	T-1	36	1153	69° 56.52' N	141° 31.03' W
12[a]	15/09/98	T-1	48	1423	70° 03.34' N	141° 25.23' W
13	16/09/98	T-2	10	857	70° 10.94' N	143° 25.25' W
14	16/09/98	T-2	27	945	70° 13.50' N	143° 25.23' W
15	16/09/98	T-2	40	1330	70° 18.72' N	143° 25.81' W
16	16/09/98	T-2	46	1535	70° 23.52' N	143° 24.12' W
17	17/09/98	T-3	9.5	849	70° 07.76' N	143° 55.53' W
18	17/09/98	T-3	19	952	70° 11.03' N	144° 02.58' W
19	17/09/98	T-3	28	1219	70° 13.82' N	144° 09.00' W
20	17/09/98	T-3	38	1600	70° 21.82' N	144° 25.42' W
23	19/09/98	T-4	10	845	69° 55.07' N	142° 14.20' W
24	19/09/98	T-4	20	1107	69° 58.01' N	142° 07.37' W
25	19/09/98	T-4	30	1159	69° 59.56' N	142° 04.20' W
26	19/09/98	T-4	40	1501	70° 03.62' N	141° 56.07' W
30	22/09/98	T-5	12	926	70° 09.53' N	143° 37.75' W
31	22/09/98	T-5	19	1011	70° 11.31' N	143° 41.06' W

ADT = Alaska daylight time.

[a] Only a CTD taken at this station.

APPENDIX 5.4. Locations of sampling stations along transects in the eastern Alaskan Beaufort Sea, 16-22 Sept 1999.

Station	Date	Transect No.	Water Depth(m)	Time ADT	Station Latitude	Station Longitude
6	18/9/99	T1	48	1047	70° 08.13' N	141° 51.98' W
7	18/9/99	T1	35	1254	70° 02.01' N	142° 05.47' W
8	18/9/99	T1	20	1537	69° 58.04' N	142° 13.13' W
9	18/9/99	T1	10	1629	69° 55.97' N	142° 18.29' W
10	19/9/99	T-2	50	1147	70° 20.22' N	143° 00.85' W
11	19/9/99	T-2	34	1339	70° 13.89' N	143° 12.65' W
12	19/9/99	T-2	20	1606	70° 11.81' N	143° 17.45' W
13	19/9/99	T-2	10	1646	70° 09.74' N	143° 20.45' W
14	20/9/99	T-3	40	1004	70° 16.12' N	143° 32.87' W
15	20/9/99	T-3	45	1200	70° 20.75' N	143° 25.70' W
16	20/9/99	T-3	35	1507	70° 14.76' N	143° 36.15' W
17	20/9/99	T-3	20	1626	70° 11.80' N	143° 39.75' W
18	21/09/99	T-3	10	921	70° 08.64' N	143° 43.27' W
19	21/09/99	T-4	40	1159	70° 20.09' N	143° 59.78' W
20	21/09/99	T-4	35	1523	70° 16.37' N	143° 58.09' W
21	21/09/99	T-4	21	1643	70° 11.58' N	143° 56.31' W
22	22/09/99	T-4	10	903	70° 07.76' N	143° 56.05' W

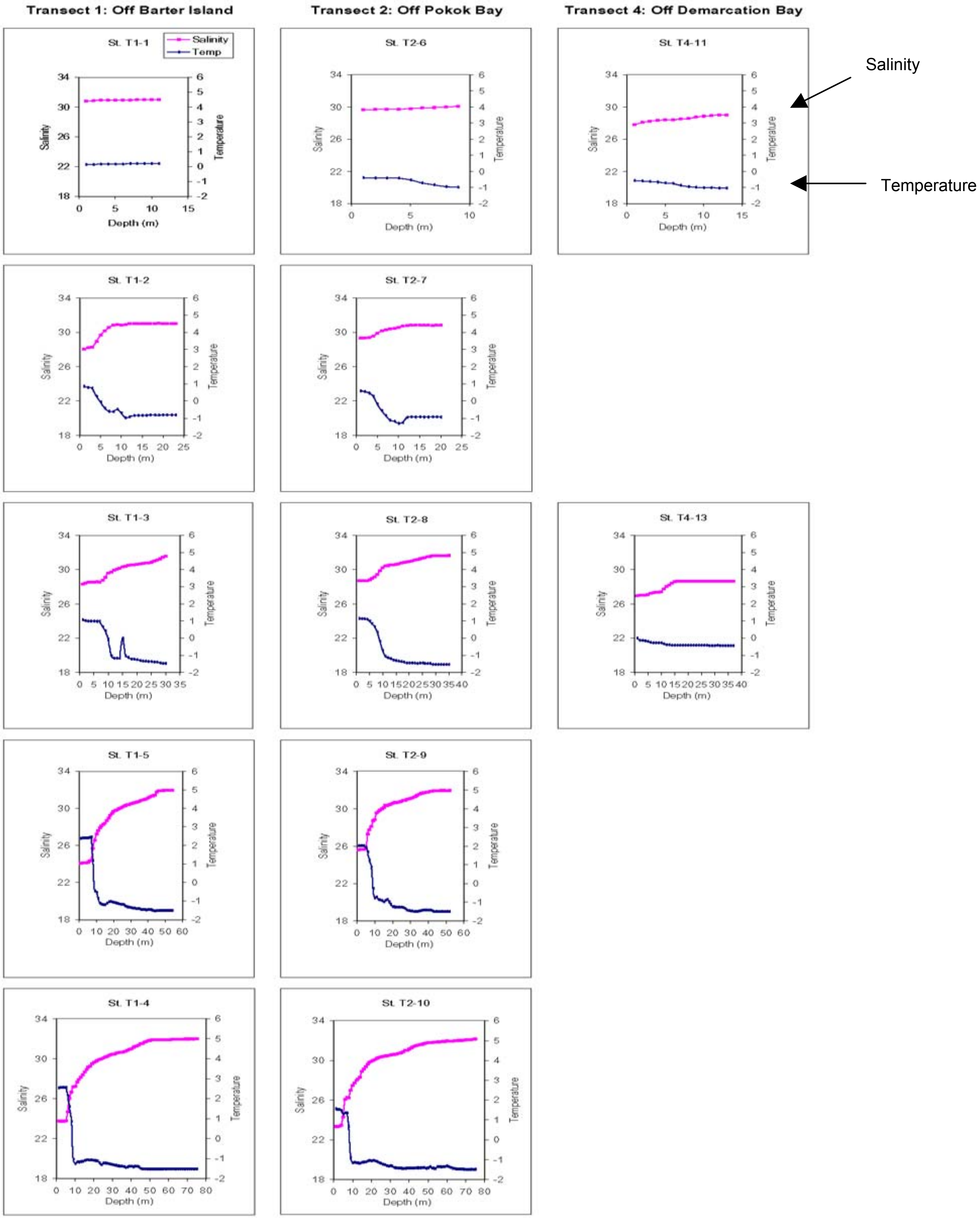
ADT = Alaska daylight time.

APPENDIX 5.5. Locations of sampling stations along transects in the eastern Alaskan Beaufort Sea, 2-20 Sept 2000.

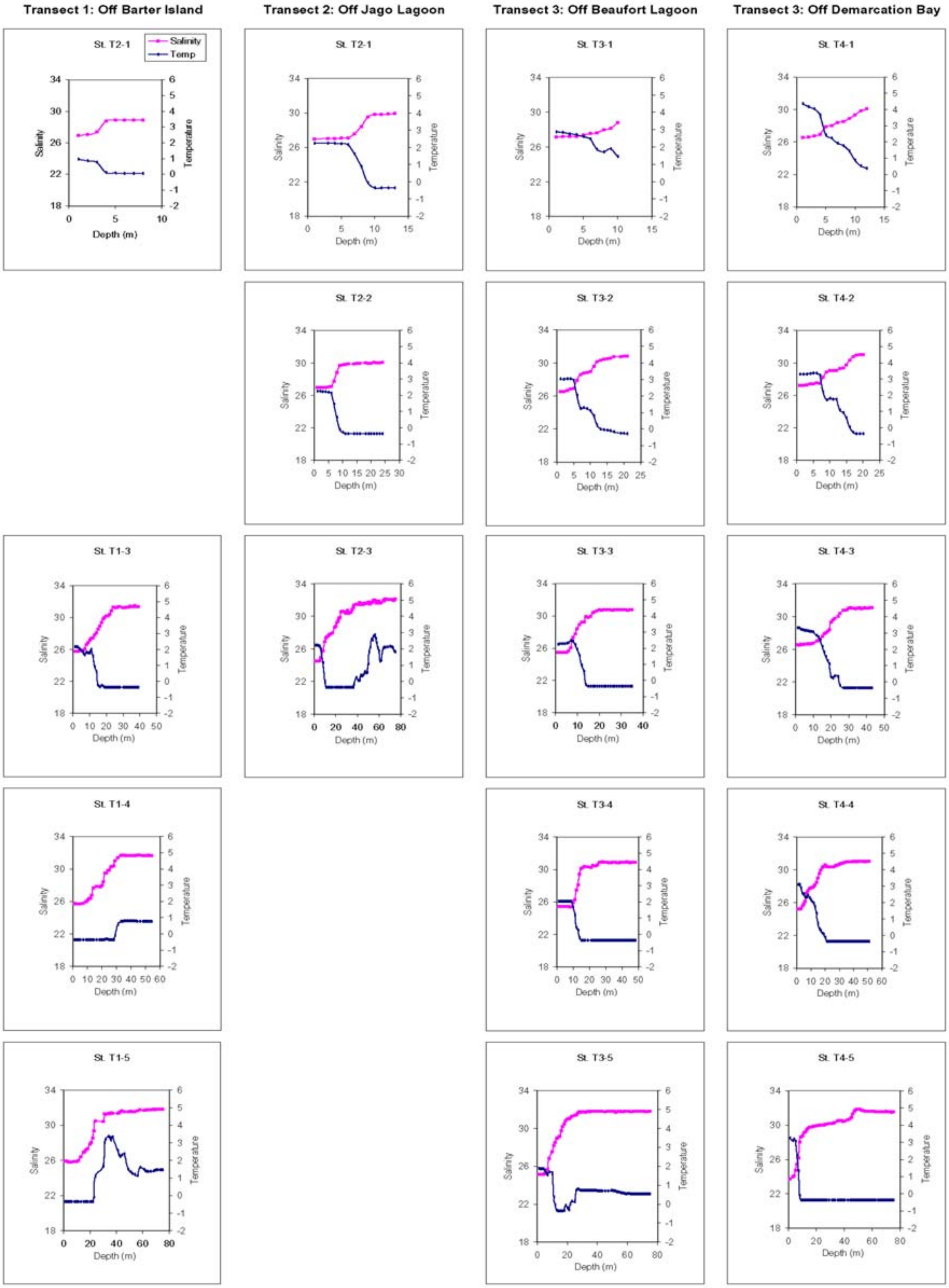
Station	Date	Transect No	Water Depth (m)	Time ADT	Station	
					Latitude	Longitude
1	9-Sep-00	T-1	10	1207	70° 08.65' N	143° 43.32' W
2	9-Sep-00	T-1	20	1337	70° 10.69' N	143° 40.18' W
3	9-Sep-00	T-1	35	1438	70° 14.52' N	143° 34.80' W
4	10-Sep-00	T-2	10	837	70° 09.74' N	143° 20.41' W
5	10-Sep-00	T-2	20	1005	70° 11.82" N	143° 17.15' W
6	11-Sep-00	T-2	30	1027	70° 13.67' N	143° 14.10' W
7	11-Sep-00	T-2	50	1236	70° 19.67" N	143° 02.82' W
8	12-Sep-00	T-3	10	802	69° 56.05' N	142° 17.68' W
9	12-Sep-00	T-3	20	845	69° 58.29' N	142° 12.98' W
10	12-Sep-00	T-3	30	1107	70° 00.57' N	142° 08.10' W
11	12-Sep-00	T-3	48	1317	70° 08.13' N	141° 51.87' W
12	13-Sep-00	T-4	10	810	69° 41.82' N	141° 16.99' W
13	13-Sep-00	T-4	20	853	69° 44.55' N	141° 13.24' W
14	13-Sep-00	T-4	30	1123	69° 47.80' N	141° 09.01' W
15	13-Sep-00	T-4	43	1331	69° 55.67' N	140° 58.50' W
16	16-Sep-00	T-5	10	855	70° 07.84' N	143° 56.88' W
17	16-Sep-00	T-5	20	947	70° 10.82' N	143° 56.82' W
18	16-Sep-00	T-5	27	1241	70° 12.64' N	143° 58.54' W
19	17-Sep-00	T-6	45	1026	70° 20.62' N	143° 25.37' W
20	17-Sep-00	T-6	40	1137	70° 16.10' N	143° 32.99' W
21	17-Sep-00	T-6	29	1407	70° 12.87' N	143° 37.31' W
22	17-Sep-00	T-6	20	1429	70° 11.64' N	143° 39.48' W
23	17-Sep-00	T-6	10	1634	70° 08.76' N	143° 43.20' W
24	18-Sep-00	T-7	40	911	70° 20.11' N	144° 00.39' W
25	18-Sep-00	T-7	30	1159	70° 15.87' N	143° 58.10' W
26	18-Sep-00	T-7	20	1315	70° 10.86' N	143° 56.75' W
27	18-Sep-00	T-7	10	1518	70° 07.74' N	143° 56.10' W
28	20-Sep-00	T-8	15	901	70° 04.84' N	144° 46.39' W
29	20-Sep-00	T-8	20	943	70° 07.58' N	144° 47.63' W
30	20-Sep-00	T-8	27	1230	70° 11.59' N	144° 53.22' W

ADT = Alaska daylight time.

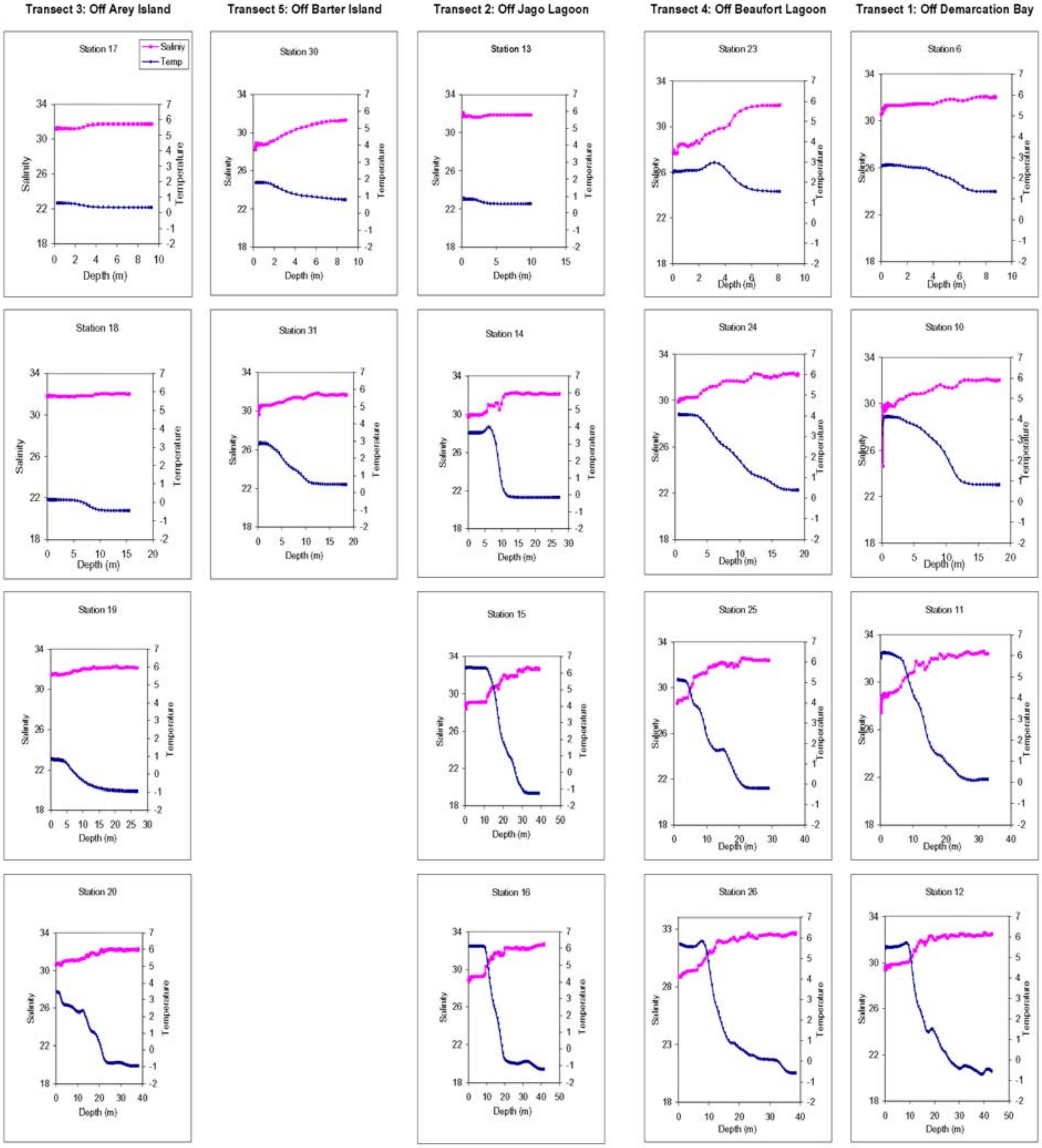
APPENDIX 5.6. Temperature and salinity profiles (CTD) in the water column at stations on transects in the eastern Alaskan Beaufort Sea, Sept 1985. See APPENDIX 5.1 and Fig. 5.1A for station locations. Transects are arranged from west to east. At the right of all profiles, salinity is the top line and temperature is the bottom line.



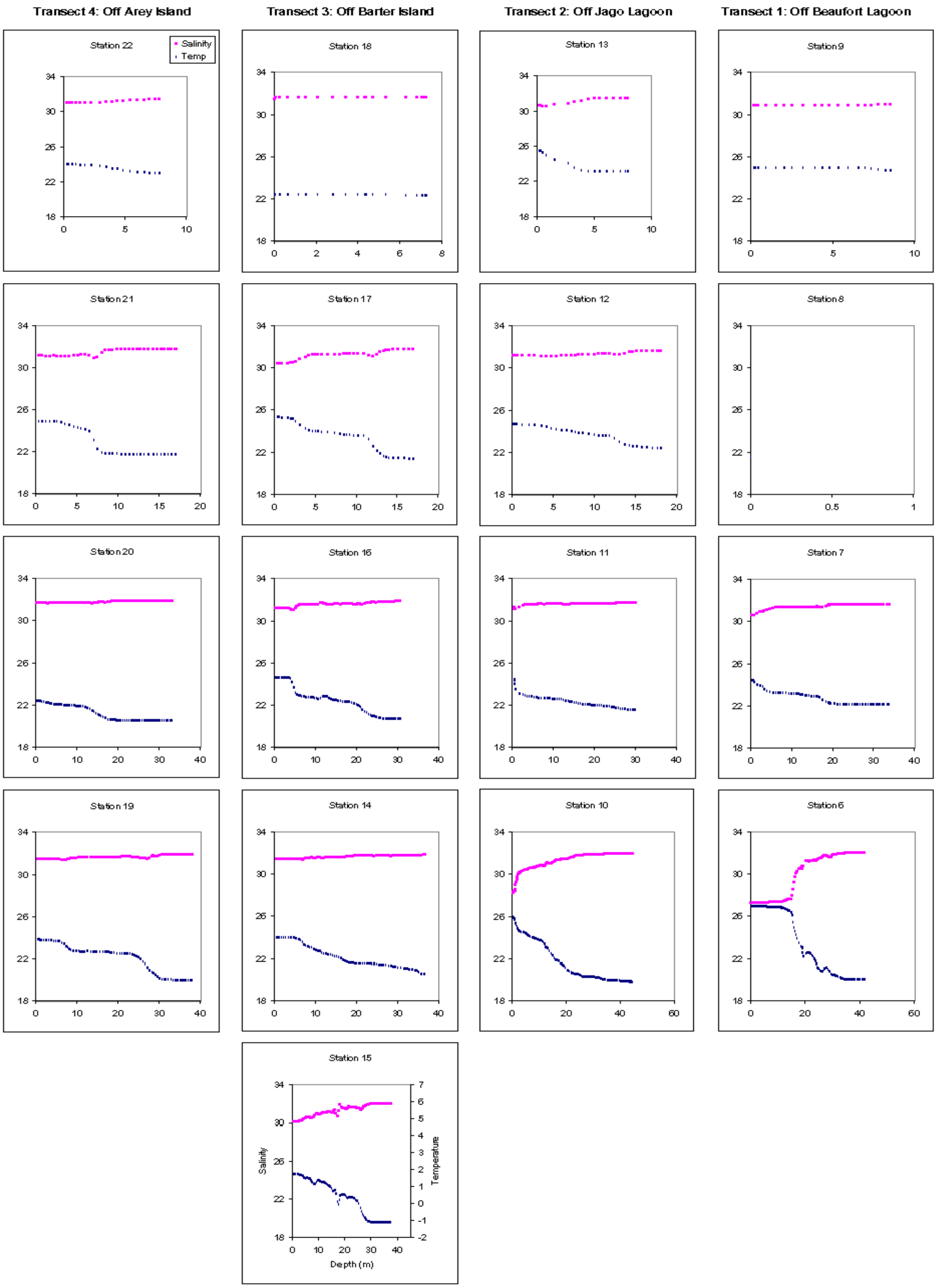
APPENDIX 5.7. Temperature and salinity profiles (CTD) in the water column at stations on transects in the eastern Alaskan Beaufort Sea, Sept 1986. See APPENDIX 5.2 and Fig. 5.1A for station locations. Transects are arranged from west to east. At the right of all profiles, salinity is the top line and temperature is the bottom line.



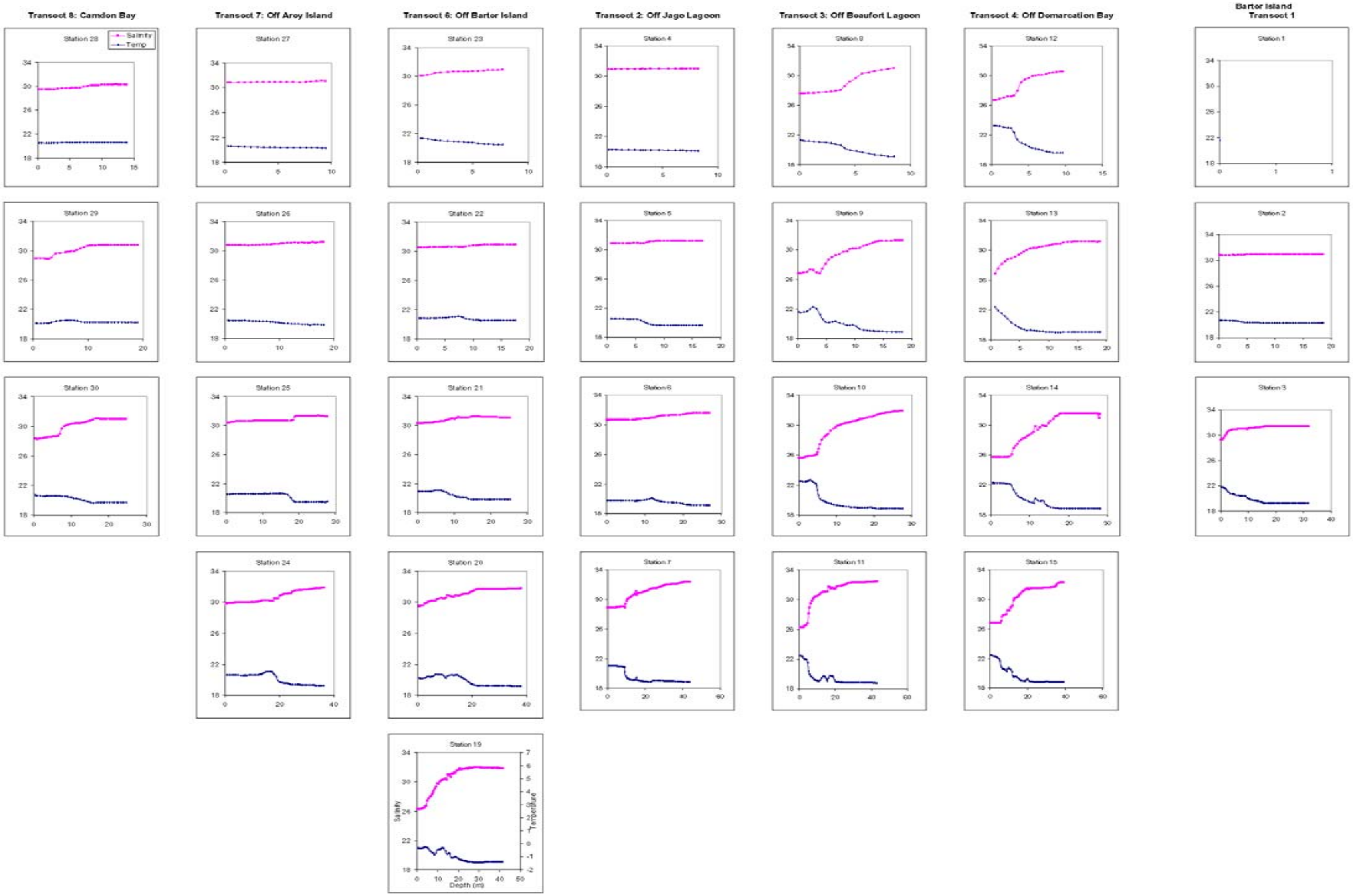
APPENDIX 5.8. Temperature and salinity profiles (CTD) in the water column at stations on transects in the eastern Alaskan Beaufort Sea, Sept 1998. See APPENDIX 5.3 and Fig. 5.1B for station locations. Transects are arranged from west to east. At the right of all profiles, salinity is the top line and temperature is the bottom line.



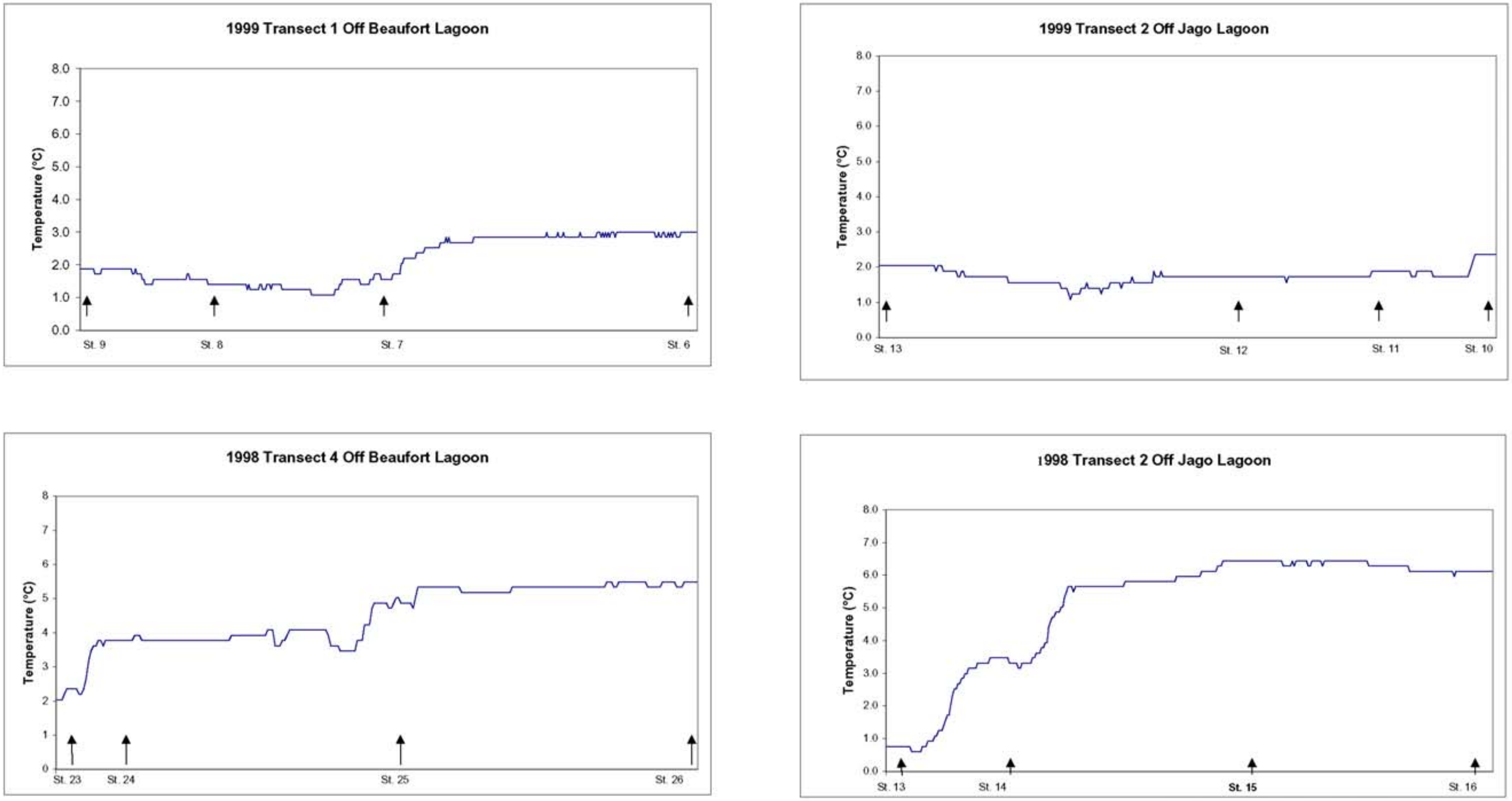
APPENDIX 5.9. Temperature and salinity profiles (CTD) in the water column at stations on transects in the eastern Alaskan Beaufort Sea, Sept 1999. See APPENDIX 5.4 and Fig. 5.1B for station locations. Transects are arranged from west to east. Top line: salinity; bottom line temperature.



APPENDIX 5.10. Temperature and salinity profiles (CTD) in the water column at stations on transects in the eastern Alaskan Beaufort Sea, Sept 2000. See APPENDIX 5.5 and Fig. 5.1C for station locations. Transects arranged from west to east. Top line: salinity; bottom line: temperature.



APPENDIX 5.11. Sea surface temperature (°C) recorded along two of the transects in the eastern Alaskan Beaufort Sea, Sept 1998 and 1999.

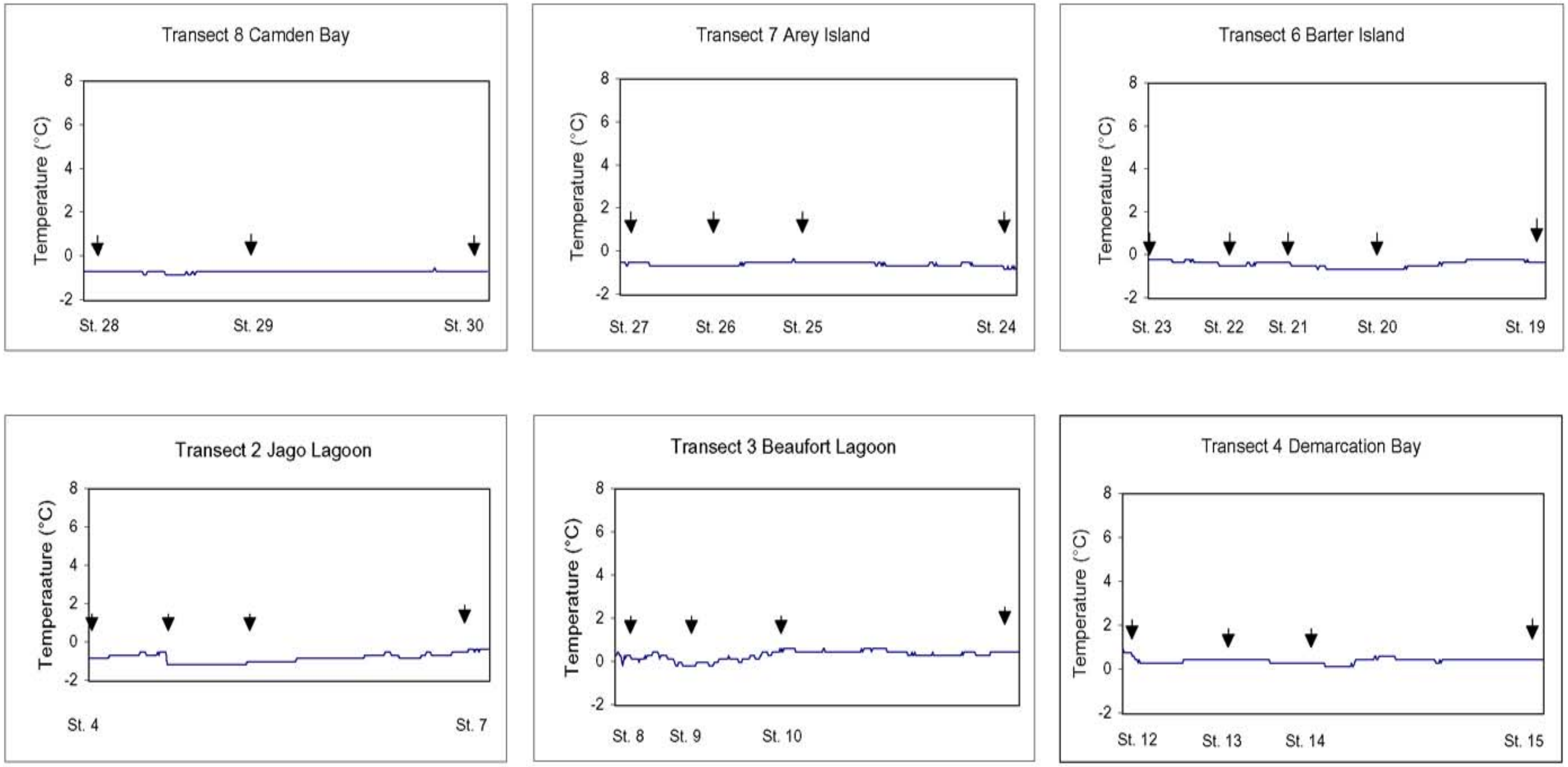

1999 Transect 1 Off Beaufort Lagoon

1999 Transect 2 Off Jago Lagoon

1998 Transect 4 Off Beaufort Lagoon

1998 Transect 2 Off Jago Lagoon

APPENDIX 5.12. Sea surface temperature (°C) recorded along the six transects in the eastern Alaskan Beaufort Sea, Sept 2000. Panels are from west to east.



APPENDIX 5.13. Biomass (mg/m^3) of the dominant zooplankton groups in horizontal (HB) and oblique (OB) bongo tows in the eastern Alaskan Beaufort Sea, Sept 1985.

Trans	Sta. No.	Samp. No.	Tow Depth (m)	Sta. Depth (m)	Tow Type	Water Mass Horizontal[a]	Water Mass Vertical[b]	Copepods	Cnidarians Ctenophores	Mysids	Euphausiids	Amphipods	Pteropods	Chaetognaths	Other	Fish	Total
TRN-1	1	2	10	13	HB	1	3	344.5	34.3	7.2	58.4	4.7	0.7	8.4	4.4	0.8	463.4
TRN-1	1	3	1	13	HB	1	1	116.8	7.3	0.0	0.2	1.9	0.1	0.2	4.1	0.0	130.6
TRN-1	2	6	14	28	HB	2	3	290.7	15.6	6.8	4.0	9.4	2.1	9.5	5.6	1.3	345.0
TRN-1	3	7	25	45	HB	2	3	932.6	72.3	0.0	14.9	23.6	15.6	16.8	21.5	1.4	1098.7
TRN-1	3	8	22	45	HB	2	3	124.1	25.5	0.0	2.1	7.3	2.4	4.6	3.5	1.1	170.6
TRN-1	3	9	8	45	HB	2	3	886.2	6.7	0.0	0.0	10.1	2.3	2.9	11.0	5.7	924.9
TRN-1	3	10	15	45	HB	2	3	145.2	20.9	0.0	0.0	4.6	4.1	6.3	6.3	1.7	189.1
TRN-1	3	11	0.5	45	HB	2	1	2.1	0.2	0.0	0.0	0.1	0.1	0.0	0.9	0.6	4.0
TRN-1	4	15	5	125	HB	3	2	7.3	1.0	0.0	0.0	1.1	0.2	1.5	0.3	0.1	11.5
TRN-1	4	16	30	125	HB	3	3	144.2	15.2	0.0	0.0	2.7	0.4	6.6	4.4	0.5	174.0
TRN-1	5	17	5	80	HB	3	2	4.9	6.9	0.0	0.0	1.2	0.6	1.2	1.6	0.3	16.7
TRN-1	5	18	55	80	HB	3	3	122.6	32.5	0.0	0.8	1.9	0.2	8.7	5.2	0.1	172.0
TRN-2	7	22	5	25	HB	2	2	45.3	12.5	0.0	0.0	3.9	1.4	1.1	2.5	8.2	74.9
TRN-2	7	23	16	25	HB	2	3	254.0	5.1	0.0	19.2	18.5	1.4	8.9	11.6	1.5	320.2
TRN-2	8	24	18	42	HB	2	3	173.2	34.8	0.0	0.1	7.9	1.5	7.7	5.0	0.2	230.4
TRN-2	8	25	12	42	HB	2	3	250.0	23.9	0.0	0.1	4.1	2.7	20.0	2.8	2.6	306.2
TRN-2	8	26	6	42	HB	2	2	5.8	7.1	0.0	0.0	5.9	5.2	11.2	18.2	5.3	58.7
TRN-2	9	30	19	56	HB	3	3	201.7	32.6	0.0	0.0	10.7	17.1	11.1	3.0	2.4	278.6
TRN-2	9	31	32	56	HB	3	3	62.9	21.9	0.0	0.0	4.9	6.4	6.4	1.4	0.7	104.6
TRN-2	9	32	9	56	HB	3	2	0.2	20.6	0.0	0.0	9.5	1.5	0.6	0.2	5.4	38.0
TRN-2	10	35	90	185	HB	3	3	33.6	5.9	0.0	0.1	1.3	0.2	3.9	0.4	0.6	46.0
TRN-2	10	36	18	185	HB	3	3	99.3	22.3	0.0	0.0	2.6	1.0	10.0	2.3	2.5	140.0
TRN-4	11	38	0.5	14	HB	1	1	14.4	22.9	0.0	0.0	0.9	1.0	4.0	1.0	0.0	44.2
TRN-4	11	39	8	14	HB	1	3	208.6	13.6	5.9	52.1	5.1	7.7	6.9	5.8	4.1	309.8
TRN-4	11	40	10.5	14	HB	1	3	262.0	18.2	86.8	15.2	3.5	14.7	9.1	2.5	7.4	419.4
TRN-4	12	43	12	25	HB	2	3	376.4	10.4	0.5	0.5	3.0	1.7	5.8	3.4	12.4	414.1
TRN-4	12	44	20	25	HB	2	3	681.6	37.3	10.1	5.4	5.0	3.7	7.8	3.3	6.4	760.6
TRN-4	12	45	5	25	HB	2	2	11.9	3.5	0.0	0.0	0.6	3.3	2.5	2.3	9.1	33.2
TRN-4	13	48	12	40	HB	2	2	2.1	6.1	0.0	0.0	8.8	10.5	0.1	10.6	6.2	44.4
TRN-4	13	49	30	40	HB	2	3	48.9	4.2	0.1	2.6	5.2	2.4	1.6	4.7	12.4	82.1
TRN-4	13	50	5	40	HB	2	2	1.7	6.5	0.0	0.0	0.4	0.0	0.0	3.8	4.5	16.9
TRN-1	1	1	10	13	OB	1	-	403.6	25.4	17.7	21.3	1.5	0.3	9.5	2.3	4.9	486.5
TRN-1	2	5	25	28	OB	2	-	153.3	1.9	0.5	0.0	2.7	0.3	1.2	2.3	0.1	162.3
TRN-1	3	12	35	45	OB	2	-	199.6	53.9	0.0	5.8	6.9	3.2	8.4	5.1	1.9	284.8
TRN-1	4	14	80	125	OB	3	-	98.4	13.4	0.0	0.0	1.8	0.2	7.0	2.7	0.0	123.5
TRN-1	5	19	50	80	OB	3	-	51.3	14.9	0.0	0.0	2.1	2.0	4.2	5.1	0.0	79.6
TRN-2	7	21	22	25	OB	2	-	134.7	22.7	0.0	6.6	4.5	2.4	6.0	5.3	1.4	183.6
TRN-2	8	27	39	42	OB	2	-	144.3	32.6	0.0	3.2	7.1	0.7	13.0	3.4	0.6	204.9
TRN-2	9	29	50	56	OB	3	-	166.5	28.7	0.0	0.1	5.6	2.7	4.7	1.1	0.3	209.7
TRN-2	10	34	100	185	OB	3	-	94.2	14.7	0.0	0.9	1.1	0.0	6.0	0.9	1.4	119.2
TRN-4	11	37	10	14	OB	1	-	204.6	22.8	27.7	45.1	2.2	4.9	7.8	3.8	12.1	331.0
TRN-4	12	46	20	25	OB	2	-	214.5	13.6	6.0	1.5	2.7	2.1	2.5	2.9	8.2	254.0
TRN-4	13	47	35	40	OB	2	-	4.2	2.8	0.0	0.0	8.0	3.2	0.1	11.7	15.9	45.9

[a] 1 = Shallow Cold Saline, 2 = Mackenzie Influenced, 3 = Outer Shelf Arctic

[b] 1 = surface layer; 2 = tow made within pycnocline; 3 = arctic water.

APPENDIX 5.14. Biomass (mg/m^3) of the dominant zooplankton species in horizontal (HB) and oblique (OB) bongo tows in the eastern Alaskan Beaufort Sea, Sept 1985.

							Copepods					Cnidarians and Ctenophores			Chaetognaths	Mysids	Euphausiids	Pteropods	Amphipods	Fish	
Trans	Sta. No.	Tow Type	Sta. Depth	Sample Depth	Water Mass Horizontal[a]	Water Mass Vertical[b]	*Calanus hyperboreas*	*Calanus glacialis*	*Limnocalanus macrurus*	*Derjuginia tolli*	*Eucheata glacialis*	*Halitholus cirratus*	*Aglantha digitale*	*Mertensia ovum*	*Sagitta elegans*	*Mysis litoralis*	*Thysanoessa raschii*	*Spiratella helicina*	*Parathemisto libellula*	*Boreogadus saida*	Total
TRN-1	1	HB	13	1	1	3	19.80	7.50	82.90	3.00	1.40	0.00	0.20	0.00	0.20	0.00	0.20	0.20	0.00	0.00	130.60
TRN-1	1	HB	13	10	1	1	148.40	42.70	66.40	83.60	0.00	1.80	9.60	22.90	7.20	7.20	55.80	0.70	0.10	0.30	463.40
TRN-1	2	HB	28	14	2	3	170.30	81.40	32.20	4.30	1.00	3.40	4.30	7.50	8.70	6.80	3.50	2.10	1.00	0.10	345.00
TRN-1	3	HB	45	25	2	3	689.30	223.10	2.40	0.00	17.80	2.10	33.30	35.90	15.80	0.00	5.70	15.60	15.10	1.40	1098.70
TRN-1	3	HB	45	8	2	3	863.80	20.80	1.60	0.00	0.00	0.00	3.30	0.90	2.90	0.00	0.00	2.30	6.80	3.70	924.90
TRN-1	3	HB	45	22	2	3	84.70	30.90	0.50	0.00	7.90	5.40	8.70	2.30	4.20	0.00	0.40	2.40	2.80	0.50	170.60
TRN-1	3	HB	45	15	2	3	95.90	41.90	0.10	0.00	6.90	1.60	3.60	15.40	5.10	0.00	0.00	4.10	2.50	1.10	189.10
TRN-1	3	HB	45	0.5	2	1	0.40	0.80	0.70	0.00	0.10	0.00	0.20	0.00	0.00	0.00	0.00	0.10	0.00	0.60	4.00
TRN-1	4	HB	125	30	3	3	119.10	14.20	0.00	0.00	10.40	0.00	2.30	9.90	4.50	0.00	0.00	0.40	2.30	0.00	174.00
TRN-1	4	HB	125	5	3	2	0.70	6.50	0.00	0.00	0.10	0.00	0.00	0.00	1.40	0.00	0.00	0.20	1.10	0.10	11.50
TRN-1	5	HB	80	5	3	2	1.90	2.30	0.00	0.00	0.70	0.00	0.00	0.40	0.20	0.00	0.00	0.60	1.20	0.30	16.70
TRN-1	5	HB	80	55	3	3	77.30	17.40	0.00	0.00	21.20	0.00	19.80	12.20	3.80	0.00	0.20	0.20	1.20	0.10	172.00
TRN-2	7	HB	25	5	2	2	8.70	7.40	28.60	0.00	0.60	0.00	12.50	0.00	1.10	0.00	0.00	1.40	1.00	8.20	74.90
TRN-2	7	HB	25	16	2	3	182.10	55.80	3.30	0.00	12.70	0.00	1.80	2.70	8.90	0.00	14.10	1.40	14.80	1.50	320.20
TRN-2	8	HB	42	18	2	3	81.90	75.10	4.00	0.00	12.20	0.00	25.50	0.60	7.70	0.00	0.00	1.50	3.90	0.20	230.40
TRN-2	8	HB	42	6	2	2	1.80	1.50	2.50	0.00	0.00	0.80	1.90	4.00	11.20	0.00	0.00	5.20	5.00	5.30	58.70
TRN-2	8	HB	42	12	2	3	122.60	123.20	3.70	0.00	0.40	0.30	18.30	1.80	20.00	0.00	0.00	2.70	0.40	2.60	306.20
TRN-2	9	HB	56	9	3	2	0.20	0.00	0.00	0.00	0.00	0.00	11.20	0.80	0.60	0.00	0.00	1.50	9.20	3.90	38.00
TRN-2	9	HB	56	19	3	3	160.50	25.20	3.90	0.00	12.10	0.00	30.90	0.00	10.70	0.00	0.00	17.10	9.50	2.40	278.60
TRN-2	9	HB	56	32	3	3	43.70	9.10	0.80	0.00	9.20	0.00	19.90	0.00	6.20	0.00	0.00	6.40	3.50	0.30	104.60
TRN-2	10	HB	185	18	3	3	71.80	12.70	0.10	0.00	13.50	0.00	15.20	2.10	5.80	0.00	0.00	1.00	1.60	2.50	140.00
TRN-2	10	HB	185	90	3	3	18.90	9.20	0.00	0.00	5.50	0.00	4.20	1.50	3.20	0.00	0.00	0.20	1.00	0.50	46.00
TRN-4	11	HB	14	10.5	1	3	67.90	13.90	160.70	8.50	8.10	0.00	13.00	0.80	8.20	86.80	12.40	14.70	0.10	0.60	419.40
TRN-4	11	HB	14	0.5	1	1	13.10	0.50	0.70	0.00	0.00	4.90	1.90	0.00	1.20	0.00	0.00	1.00	0.00	0.00	44.20
TRN-4	11	HB	14	8	1	3	56.70	71.10	75.70	3.90	0.00	0.00	8.30	0.00	6.20	5.90	49.20	7.70	0.50	0.90	309.80
TRN-4	12	HB	25	5	2	2	5.70	2.60	0.50	2.80	0.00	0.30	0.70	0.00	0.00	0.00	0.00	3.30	0.00	4.20	33.20
TRN-4	12	HB	25	20	2	3	365.60	125.40	163.70	15.10	0.00	21.40	5.00	1.00	7.60	9.20	0.10	3.70	1.70	3.80	760.60
TRN-4	12	HB	25	12	2	3	45.60	9.70	286.20	34.20	0.00	3.10	0.00	2.20	5.40	0.50	0.50	1.70	0.20	8.50	414.10
TRN-4	13	HB	40	30	2	3	26.80	19.40	0.50	0.00	2.10	0.80	1.40	0.00	1.60	0.00	1.50	2.40	4.70	9.90	82.10
TRN-4	13	HB	40	5	2	2	1.10	0.00	1.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	4.50	16.90
TRN-4	13	HB	40	12	2	2	1.10	0.10	0.00	0.00	0.70	5.10	0.00	0.00	0.00	0.00	0.00	10.50	8.40	6.20	44.40
TRN-1	1	OB	13	10	1	-	83.40	11.80	195.30	100.00	0.00	11.90	10.40	1.20	8.80	17.70	19.80	0.30	0.00	3.30	486.50
TRN-1	2	OB	28	25	2	-	93.50	28.10	27.10	0.60	3.70	0.00	0.20	1.50	0.90	0.50	0.00	0.30	0.40	0.10	162.30
TRN-1	3	OB	45	35	2	-	134.80	54.40	0.40	0.00	9.20	7.60	30.30	15.60	6.60	0.00	2.30	3.20	3.80	1.90	284.80
TRN-1	4	OB	125	80	3	-	65.50	14.40	0.00	0.00	15.70	0.00	4.20	8.90	4.40	0.00	0.00	0.20	0.90	0.00	123.50
TRN-1	5	OB	80	50	3	-	28.30	14.60	0.10	0.00	8.20	1.10	7.70	0.10	2.10	0.00	0.00	2.00	1.50	0.00	79.60
TRN-2	7	OB	25	22	2	-	81.40	28.60	9.90	12.50	1.10	0.00	9.60	5.00	5.90	0.00	5.70	2.40	2.50	1.40	183.60
TRN-2	8	OB	42	39	2	-	102.50	40.20	0.90	0.20	0.20	0.00	18.80	13.70	11.60	0.00	1.10	0.70	2.80	0.40	204.90
TRN-2	9	OB	56	50	3	-	136.10	19.10	0.70	0.00	6.80	0.50	27.10	1.00	4.30	0.00	0.10	2.70	3.50	0.30	209.70
TRN-2	10	OB	185	100	3	-	61.00	18.80	0.00	0.00	12.80	0.00	4.50	10.20	2.10	0.00	0.10	0.00	0.80	1.40	119.20
TRN-4	11	OB	14	10	1	-	51.80	37.50	102.70	8.30	2.30	14.70	4.30	0.10	4.30	27.70	39.20	4.90	0.30	1.00	331.00
TRN-4	12	OB	25	20	2	-	87.90	17.90	94.20	9.60	0.00	8.20	2.40	0.10	2.30	0.00	0.10	2.10	0.00	7.70	254.00
TRN-4	13	OB	40	35	2	-	2.70	0.30	0.50	0.00	0.50	0.00	1.00	0.00	0.10	0.00	0.00	3.20	7.60	15.90	45.90

[a] 1 = Shallow Cold Saline, 2 = Mackenzie Influenced, 3 = Outer Shelf Arctic

[b] 1 = surface layer; 2 = tow made within pycnocline; 3 = arctic water.

APPENDIX 5.15. Biomass (mg/m^3) of the dominant zooplankton groups in oblique (OB) and surface (SB) bongo tows in the eastern Alaskan Beaufort Sea, Sept 1986.

Station Type	Depth (m)	Tow Type	Sta. No.	Samp. No.	Water Mass[a]	Copepods	Cnidarians Ctenophores	Mysids	Euphausiids	Amphipods	Pteropods	Chaetognaths	Decapod	Fish	Other	Total-
TRN-1	9	OB	1	120	1	70.86	2.41	0.05	0.00	1.37	0.73	0.21	0.38	1.14	1.27	78.41
TRN-1	30	OB	2	124	1	144.16	45.54	0.00	4.85	2.63	0.19	2.16	9.74	12.87	0.82	222.95
TRN-1	40	OB	3	129	2	236.49	23.33	1.50	0.89	20.59	4.66	20.51	2.26	2.65	4.18	317.06
TRN-1	50	OB	4	133	3	4.93	4.76	0.00	0.00	6.01	2.26	1.02	0.33	2.20	3.22	24.73
TRN-1	50	OB	5	138	3	0.72	48.98	0.00	0.00	3.76	0.18	0.54	0.02	3.02	0.19	57.41
TRN-2	8	OB	1	142	1	46.00	0.69	0.00	0.00	4.53	0.11	0.11	0.00	3.54	0.55	55.53
TRN-2	22	OB	2	146	1	717.89	8.13	0.95	0.13	10.90	6.72	5.94	13.08	9.26	3.86	776.85
TRN-2	50	OB	5	150	3	1.24	21.78	0.00	0.00	7.92	0.03	2.36	0.00	0.00	10.59	43.92
TRN-2	100	OB	5	151	3	11.68	23.55	0.00	0.00	3.81	0.05	8.27	0.00	18.73	0.20	66.29
TRN-3	9	OB	1	79	1	12.88	21.04	0.00	0.00	2.09	2.99	0.03	6.99	2.77	1.47	50.27
TRN-3	18	OB	2	83	1	2.81	14.25	0.76	0.90	7.15	7.47	0.07	93.23	17.42	2.81	146.86
TRN-3	35	OB	3	87	2	48.59	12.95	0.00	1.98	22.35	2.61	0.99	3.23	15.77	4.18	112.65
TRN-3	50	OB	4	91	3	33.04	6.63	0.00	0.00	10.43	2.88	2.89	0.00	9.69	2.55	68.11
TRN-3	50	OB	5	95	3	1.36	4.38	0.00	0.00	4.27	1.34	0.15	0.30	1.42	4.96	18.19
TRN-4	10	OB	1	57	1	1001.20	3.35	14.80	0.00	0.32	0.66	0.50	0.45	14.53	0.00	1035.81
TRN-4	18	OB	2	62	1	0.47	0.16	0.00	0.00	0.51	0.05	0.98	1.68	0.00	0.12	3.99
TRN-4	40	OB	3	66	2	6.92	28.10	0.00	0.78	5.82	18.37	0.88	1.44	18.21	0.73	81.24
TRN-4	50	OB	4	71	3	0.41	9.70	0.00	0.00	5.54	2.73	0.19	0.36	1.94	0.38	21.26
TRN-4	50	OB	5	75	3	18.70	13.95	0.00	0.01	1.38	1.42	28.50	0.00	0.51	0.66	65.13
WF[b]	16	OB	1	2	1	13.97	36.74	5.66	0.17	12.54	5.00	2.93	13.37	2.77	3.20	96.36
WF	12	OB	5	19	1	1179.07	30.59	2.09	0.31	1.85	0.58	2.73	3.35	7.58	0.00	1228.16
WF	8	OB	7	27	1	777.10	6.72	53.38	0.15	4.04	0.09	0.22	0.55	0.51	10.61	853.38
WF	5	OB	9	36	1	165.83	13.49	127.43	0.00	6.26	0.24	0.13	0.00	4.87	0.28	318.54
WF	9	OB	10	39	1	35.44	43.81	4.85	0.00	2.01	3.01	0.12	6.33	7.91	1.53	105.01
WF	18	OB	12	48	1	869.90	10.61	2.17	0.00	5.80	1.04	6.94	0.71	11.02	4.21	912.39
CTL	12	OB	11	44	1	114.01	53.23	0.38	1.84	3.82	0.48	6.80	7.74	6.39	3.83	198.53
CTL	20	OB	2	7	1	40.68	2.89	0.00	0.00	0.61	0.26	0.73	2.49	3.04	1.10	51.79
CTL	22	OB	6	23	2	14.05	30.94	0.00	0.00	3.24	11.36	1.02	5.86	12.74	2.00	81.19
CTL	18	OB	8	32	2	12.83	4.96	0.00	0.00	15.39	0.96	1.33	1.72	0.00	3.32	40.51
CTL	21	OB	13	53	2	0.65	9.74	0.00	0.00	0.69	5.76	0.03	14.54	19.79	7.47	58.67
TRN-1	0	SB	1	119	1	49.41	2.17	0.00	0.00	2.54	0.04	0.11	0.39	0.00	1.69	56.35
TRN-1	0	SB	3	128	2	1.02	0.13	0.00	0.00	0.03	0.01	0.13	0.01	0.09	0.05	1.48
TRN-1	0	SB	5	137	3	0.37	0.12	0.00	0.00	0.09	0.03	0.05	0.07	0.00	0.27	1.01
TRN-2	0	SB	5	149	3	0.60	0.19	0.00	0.00	0.27	0.01	0.01	0.00	4.89	0.05	6.01
TRN-3	0	SB	1	78	1	1.10	2.02	0.00	0.00	0.59	0.28	0.24	0.00	0.00	0.72	4.96
TRN-3	0	SB	3	86	2	0.55	0.42	0.00	0.00	0.01	0.07	0.01	0.09	0.93	0.07	2.14
TRN-3	0	SB	5	94	3	0.04	0.00	0.00	0.00	0.14	0.01	0.01	0.01	0.00	0.04	0.24
TRN-4	0	SB	1	56	1	144.04	3.30	0.42	0.00	0.14	0.55	0.00	0.00	0.66	0.19	149.30
TRN-4	0	SB	3	65	2	1.24	13.53	0.00	0.00	2.48	0.87	1.74	14.07	1.47	0.01	35.42
TRN-4	0	SB	5	74	3	0.09	0.07	0.00	0.00	0.29	0.00	0.01	0.07	0.11	0.40	1.03
WF	0	SB	1	1	1	0.05	0.36	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.67
WF	0	SB	5	18	1	0.47	0.54	0.00	0.00	0.58	1.94	0.00	0.02	0.00	0.30	3.84
WF	0	SB	7	26	1	7.62	9.06	0.00	0.00	1.93	0.08	0.02	0.00	0.26	0.09	19.06
WF	0	SB	9	35	1	67.39	4.99	0.15	0.00	1.29	0.00	0.10	0.00	0.22	0.10	74.24
WF	0	SB	10	38	1	8.36	3.88	0.13	0.00	0.09	1.09	0.03	3.86	0.94	0.57	18.95
WF	0	SB	12	47	1	2.37	1.26	0.00	0.00	0.02	0.03	0.01	0.00	0.07	0.14	3.90
CTL	0	SB	11	43	1	0.41	13.72	0.00	0.00	0.05	1.76	0.00	9.42	4.57	0.17	30.11
CTL	0	SB	2	6	1	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.10	0.29
CTL	0	SB	6	22	2	0.21	1.72	0.00	0.00	0.28	6.35	0.00	0.12	0.00	0.02	8.70
CTL	0	SB	8	31	2	0.47	1.37	0.01	0.00	0.04	0.00	0.00	0.00	0.00	0.01	1.90
CTL	0	SB	13	52	2	4.33	0.03	0.00	0.00	0.00	0.06	0.00	0.01	0.00	0.11	4.54

[a] 1 = Shallow Cold Saline, 2 = Mackenzie Influenced, 3 = Outer Shelf Arctic

[b] WF = Whale feeding station, CTL = Control Station (see Chapter 6).

APPENDIX 5.16. Biomass (mg/m^3) of the dominant zooplankton groups in horizontal (HB) tows in the eastern Alaskan Beaufort Sea, Sept 1986. The samples were collected with an opening and closing bongo net and the data needed to be scaled to match corresponding data collected with a standard bongo net assembly. (See Griffiths et al. 1987 for scaling factors).

Station Type	Depth (m)	Tow Type	Sta. No.	Samp. No.	Water Mass[a]	Copepods	Cnidarians Ctenophores	Mysids	Euphausiids	Pteropods	Amphipods	Chaetognaths	Decapod	Other	Fish	Total
TRN-1	10	HB	1	121	1	139.6	3.1	1.7	0.0	0.0	3.5	1.3	1.8	1.4	0.2	152.6
TRN-1	5	HB	1	122	1	141.8	4.7	0.0	0.0	4.3	1.4	0.3	1.9	0.6	0.0	155.0
TRN-1	10	HB	2	125	2	358.8	105.4	0.0	1.9	0.0	2.5	1.9	10.1	0.3	4.3	485.3
TRN-1	21	HB	2	126	3	308.6	51.3	1.1	2.7	0.0	3.7	13.9	3.4	3.6	5.1	393.4
TRN-1	5	HB	2	127	2	3.4	24.8	0.0	0.0	0.0	0.3	0.0	39.9	0.5	1.4	70.4
TRN-1	11	HB	3	131	2	15.0	23.4	0.0	0.0	8.5	2.6	0.4	3.7	0.7	2.1	56.4
TRN-1	27	HB	3	130	3	1298.9	29.4	0.0	7.7	13.7	30.4	23.1	2.2	3.0	9.2	1417.5
TRN-1	19	HB	4	135	1	8.0	133.9	0.0	0.0	38.2	4.4	0.9	0.8	3.9	0.0	190.0
TRN-1	11	HB	4	136	1	7.1	8.0	0.0	0.0	0.9	1.1	0.1	0.2	1.6	2.8	21.7
TRN-1	15	HB	5	139	1	0.5	74.7	0.0	0.0	0.0	2.6	0.0	0.0	0.1	5.9	83.9
TRN-1	34	HB	4	134	3	139.9	84.7	0.0	1.5	2.2	30.7	33.5	5.6	3.9	8.9	310.7
TRN-1	47	HB	5	140	3	0.2	66.4	0.0	0.0	0.2	0.5	0.1	0.0	0.0	0.9	68.3
TRN-2	5	HB	1	144	1	56.2	8.6	1.2	0.0	1.4	2.3	0.0	20.9	0.5	3.1	94.3
TRN-2	6	HB	2	148	1	12.6	3.6	0.0	0.0	1.5	0.1	0.0	12.3	0.2	10.6	41.0
TRN-2	8	HB	1	143	2	56.3	14.3	13.3	0.3	3.2	2.6	0.0	81.0	0.6	12.6	184.2
TRN-2	15	HB	2	147	3	2095.0	17.6	10.1	2.5	3.0	3.0	8.3	7.7	0.6	1.1	2148.9
TRN-2	10	HB	5	153	2	0.8	86.2	0.0	0.0	0.0	8.1	0.2	0.0	10.4	0.4	106.3
TRN-2	50	HB	5	152	3	6.2	25.8	0.0	0.0	0.1	1.4	3.3	0.6	0.3	6.8	44.4
TRN-3	6	HB	1	81	1	3.2	29.8	0.0	0.0	5.3	0.0	0.0	8.8	0.7	4.4	52.4
TRN-3	10	HB	1	80	2	26.5	15.6	1.4	0.4	36.6	3.0	0.2	60.1	2.4	5.2	151.4
TRN-3	18	HB	2	84	2	167.2	32.8	1.9	3.5	0.5	3.1	1.3	2.7	2.3	7.6	222.8
TRN-3	10	HB	2	85	2	5.2	18.0	0.4	0.6	13.8	6.5	0.4	25.0	3.3	25.6	98.6
TRN-3	26	HB	3	88	3	368.3	101.0	0.1	2.2	1.3	3.2	5.9	3.3	0.5	7.6	493.4
TRN-3	17	HB	3	89	3	161.1	92.2	0.0	0.4	40.6	20.7	0.7	9.7	12.7	13.0	351.2
TRN-3	26	HB	4	92	3	354.7	54.0	0.0	3.4	1.8	37.7	44.2	0.0	7.8	5.5	509.1
TRN-3	17	HB	4	93	3	8.7	93.6	0.0	0.0	8.5	10.7	1.1	0.2	2.8	14.0	139.6
TRN-3	27	HB	5	97	3	0.8	658.2	0.0	0.0	0.7	4.5	0.1	0.1	0.8	4.1	669.2
TRN-3	30	HB	5	98	3	1.1	17.2	0.0	0.0	0.9	8.6	0.6	0.9	4.3	0.0	33.6
TRN-4	4	HB	1	58	1	1943.5	28.0	9.3	0.0	1.3	0.0	0.0	23.0	0.3	1.7	2007.0
TRN-4	10	HB	1	60	2	426.2	106.4	5.9	0.2	1.2	5.6	7.7	7.3	1.5	12.4	574.4
TRN-4	8	HB	1	59	2	34.1	35.5	0.7	0.0	0.2	1.0	1.1	3.1	0.8	0.0	76.6
TRN-4	10	HB	2	64	2	93.3	49.7	0.0	0.0	11.2	1.4	3.2	5.0	0.8	0.0	164.8
TRN-4	19	HB	2	63	3	2111.3	53.2	4.2	15.3	0.6	12.2	9.2	4.7	0.5	2.5	2213.6
TRN-4	7	HB	3	69	1	5.3	7.1	0.0	0.0	25.7	0.8	0.0	1.1	0.1	1.7	41.8
TRN-4	14	HB	3	67	2	5.4	38.2	0.0	0.0	88.7	12.4	0.3	6.2	0.2	9.4	160.9
TRN-4	36	HB	3	68	3	343.9	17.1	0.0	0.9	1.0	2.1	3.4	3.3	0.3	0.0	372.1
TRN-4	12	HB	4	73	2	21.4	31.7	0.0	0.0	2.1	8.8	0.1	1.3	0.3	10.9	76.6
TRN-4	34	HB	4	72	3	782.7	15.2	0.0	4.5	0.4	5.5	2.2	0.5	0.8	1.9	813.8
TRN-4	51	HB	5	76	3	3.1	15.1	0.0	0.0	0.1	0.5	5.8	0.2	0.1	0.0	24.8
TRN-4	30	HB	5	77	3	9.3	33.7	0.0	0.0	0.3	1.8	28.3	0.0	0.2	1.0	74.7

APPENDIX 5.16. Concluded.

Station Type	Depth (m)	Tow Type	Sta. No.	Samp. No.	Water Mass[a]	Copepods	Cnidarians Ctenophores	Mysids	Euphausiids	Pteropods	Amphipods	Chaetognaths	Decapod	Other	Fish	Total
WF[b]	4	HB	1	5	1	0.2	12.1	0.0	0.0	2.1	0.2	0.0	11.6	0.0	0.0	26.3
WF	13	HB	1	3	2	20.0	21.2	0.0	0.0	2.3	7.0	2.4	18.5	0.6	1.8	73.9
WF	10	HB	5	20	2	2920.1	63.0	2.5	0.2	0.0	1.4	2.0	7.5	2.2	23.8	3022.6
WF	6	HB	5	21	2	1206.1	19.0	0.0	0.0	1.0	2.3	2.9	9.7	1.3	26.5	1268.8
WF	7	HB	7	28	2	1069.8	38.6	118.83	0.0	0.2	4.7	1.0	4.7	0.0	14.2	1252.0
WF	8	HB	7	29	2	2386.1	29.6	452.75	0.0	0.0	4.5	0.0	0.9	0.0	12.4	2886.1
WF	11	HB	10	41	2	2926.1	62.5	63.6	6.0	0.0	5.4	7.2	29.3	1.5	17.5	3119.1
WF	8	HB	10	42	2	3734.3	58.2	0.1	7.4	0.0	2.7	5.3	24.2	2.8	11.6	3846.7
WF	13	HB	12	49	2	642.9	68.8	11.7	0.0	1.3	19.3	7.3	8.0	2.7	0.0	762.1
WF	6	HB	12	50	2	598.3	4.2	8.3	0.0	1.3	1.6	1.0	0.8	0.5	2.6	618.8
WF	15	HB	12	51	2	2075.2	13.6	30.7	0.3	0.0	13.5	2.7	0.0	0.9	0.0	2137.0
WF	8	HB	1	4	2	2.0	36.7	0.0	0.0	10.6	8.5	0.0	12.6	1.2	3.1	74.7
WF	7	HB	10	40	2	34.1	29.2	0.4	0.0	1.6	0.2	0.3	1.8	0.9	0.0	68.5
WF	3	HB	7	30	2	64.5	25.4	1.1	0.0	0.0	3.0	0.0	0.0	0.8	0.0	94.9
CTL	17	HB	8	33	2	1128.1	90.5	11.6	2.8	0.8	11.9	23.7	7.7	1.4	1.4	1280.0
CTL	12	HB	11	45	2	867.3	127.3	94.8	4.8	0.0	2.5	14.7	12.6	1.2	23.9	1149.1
CTL	17	HB	13	54	2	5.9	59.0	0.0	0.0	1.5	1.2	0.7	28.3	1.2	6.6	104.6
CTL	8	HB	6	25	2	0.5	9.8	0.0	0.0	17.0	1.0	0.1	51.7	1.0	16.6	97.7
CTL	7	HB	8	34	2	16.6	49.0	0.0	0.0	10.3	7.7	0.3	14.6	2.2	10.0	110.7
CTL	6	HB	11	46	2	84.9	82.8	0.2	0.0	7.5	1.4	1.3	63.4	3.1	15.3	259.9
CTL	8	HB	13	55	2	5.0	20.0	0.0	0.0	1.9	1.7	0.1	74.2	1.1	3.4	107.5
CTL	22	HB	2	8	3	129.8	59.6	0.0	0.2	0.2	2.6	9.8	0.5	3.4	7.1	213.1
CTL	21	HB	6	24	3	14.7	28.7	0.3	0.3	8.0	7.9	3.8	19.4	1.9	7.3	92.2
CTL	10	HB	2	9	3	187.8	41.7	0.0	0.0	0.5	2.7	0.7	4.8	0.8	15.6	254.6

[a] 1 = Shallow Cold Saline, 2 = Mackenzie Influenced, 3 = Outer Shelf Arctic

[b] WF = Whale feeding station, CTL = Control Station (see Chapter 6).

APPENDIX 5.17. Biomass (mg/m^3) of the dominant zooplankton species in oblique (OB) and horizontal (HB) bongo tows and vertical (VT) tows in the eastern Alaskan Beaufort Sea, Sept 1986.

						Copepods						Cnidarians Ctenophores				Pteropods	Mysids		Euphausiids	Chaetognaths	Amphipods	Fish	
Transect	Depth (m)	Tow Type	Sta. No.	Samp. No.	Water Mass[a]	*Calanus Hyperboreus*	*Calanus glacialis*	*Pseudocalanus minutus*	*Euchaeta glacialis*	*Metridia longa*	*Limnocalanus macrurus*	*Halitholus cirratus*	*Aglantha digitale*	*Staurophora mertensi*	*Mertensia ovum*	*Spiratella hellicina*	*Mysis litoralis*	*Mysis litoralis*	*Thysansoessa raschii*	*Sagitta elegans*	*Parathemisto libellula*	*Boreogadus saisa*	Total
CTL[b]	0	HB	11	43	1	0.0	0.0	0.0	0.0	0.0	0.3	6.2	7.3	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	30.1
CTL	0	HB	2	6	1	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
CTL	0	HB	6	22	2	0.0	0.0	0.0	0.0	0.0	0.2	1.6	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0	8.7
CTL	0	HB	8	31	2	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9
CTL	0	HB	13	52	2	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	4.5
WF	0	HB	1	1	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.7
WF	0	HB	5	18	1	0.0	0.1	0.1	0.0	0.0	0.3	0.0	0.1	0.0	0.3	1.9	0.0	0.0	0.0	0.0	0.0	0.0	3.8
WF	0	HB	7	26	1	0.5	1.0	4.0	0.0	0.0	2.1	7.2	0.5	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	19.1
WF	0	HB	9	35	1	0.0	0.3	3.1	0.0	0.0	63.7	0.0	3.8	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	74.2
WF	0	HB	10	38	1	0.0	0.3	0.2	0.0	0.0	7.7	0.0	2.1	0.0	1.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	19.0
WF	0	HB	12	47	1	0.2	0.0	0.1	0.0	0.0	1.8	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.9
WF	13	HB	12	49	1	7.3	24.4	3.2	1.8	0.0	283.0	11.4	0.8	0.0	3.8	0.1	0.0	10.4	0.0	5.6	0.3	0.0	392.8
WF	6	HB	12	50	1	0.0	1.2	1.6	0.0	0.0	299.9	0.0	1.2	0.0	0.0	0.4	0.0	0.0	0.0	0.7	0.0	0.0	319.0
WF	15	HB	12	51	1	5.7	11.2	4.0	0.0	1.0	1018.6	0.0	0.0	0.0	4.2	0.0	0.0	22.0	0.0	1.8	0.0	0.0	1101.5
WF	16	OB	1	2	1	2.2	2.4	1.3	0.3	0.1	7.4	3.5	25.2	0.0	2.1	5.0	0.0	3.0	0.2	2.9	10.0	2.3	96.4
WF	12	OB	5	19	1	0.9	3.0	6.1	3.5	0.0	1162.1	22.8	0.0	0.0	6.9	0.6	0.0	1.5	0.3	2.7	0.0	2.1	1228.2
WF	8	OB	7	27	1	3.1	6.6	11.1	0.0	0.0	754.1	3.3	1.1	0.0	1.6	0.1	49.9	3.5	0.2	0.2	0.2	0.5	853.4
WF	5	OB	9	36	1	0.5	0.5	1.8	0.0	0.0	162.6	6.5	6.2	0.0	0.0	0.2	127.1	0.0	0.0	0.1	0.5	0.0	318.5
WF	9	OB	10	39	1	0.3	0.8	0.4	0.2	0.1	33.6	17.6	21.3	0.0	1.3	2.6	0.0	0.0	0.0	0.0	0.1	5.5	105.0
WF	18	OB	12	48	1	1.3	5.2	4.3	1.3	1.3	855.6	0.0	4.2	0.0	4.7	1.0	1.2	0.4	0.0	3.0	0.4	4.4	912.4
CTL	20	OB	2	7	1	9.2	6.1	0.8	1.2	1.0	22.3	0.0	2.4	0.0	0.2	0.3	0.0	0.0	0.0	0.1	0.4	3.0	51.8
CTL	22	OB	6	23	2	1.2	8.8	0.4	0.0	0.0	3.4	9.0	15.1	0.0	3.1	11.1	0.0	0.0	0.0	0.7	1.9	10.4	81.2
CTL	18	OB	8	32	2	1.1	1.9	0.4	1.4	0.5	7.5	0.0	2.8	0.0	0.0	1.0	0.0	0.0	0.0	1.2	14.7	0.0	40.5
CTL	12	OB	11	44	1	4.3	13.6	2.5	0.7	0.2	92.7	0.0	50.1	0.0	0.8	0.3	0.0	0.0	0.0	6.4	0.2	0.0	198.5
CTL	21	OB	13	53	2	0.0	0.0	0.0	0.0	0.0	0.6	0.0	8.5	0.0	0.8	5.6	0.0	0.0	0.0	0.0	0.4	11.5	58.7
TRN-1	9	OB	T1-1	120	1	1.8	10.8	14.3	0.0	0.0	39.2	0.9	0.4	0.0	0.0	0.5	0.1	0.0	0.0	0.1	0.0	0.0	78.4
TRN-1	30	OB	T1-2	124	1	23.7	118.5	1.4	0.0	0.1	0.1	6.2	2.9	0.0	34.8	0.0	0.0	0.0	4.9	1.9	0.0	11.4	223.0
TRN-1	40	OB	T1-3	129	2	63.5	170.5	0.2	1.9	0.2	0.0	0.0	17.7	0.0	0.0	4.7	0.0	0.0	0.9	20.2	13.6	2.7	317.1
TRN-1	50	OB	T1-4	133	3	1.0	3.5	0.1	0.1	0.0	0.0	0.0	2.9	0.0	0.9	2.3	0.0	0.0	0.0	0.0	4.5	2.2	24.7
TRN-1	50	OB	T1-5	138	3	0.1	0.4	0.0	0.0	0.0	0.1	0.0	0.4	0.0	6.8	0.0	0.0	0.0	0.0	0.2	3.6	3.0	57.4
TRN-2	8	OB	T2-1	142	1	0.2	39.8	3.2	1.1	0.3	0.9	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	55.5
TRN-2	22	OB	T2-2	146	1	139.4	578.1	0.4	0.0	0.0	0.0	0.8	5.4	0.0	1.3	6.6	0.0	0.1	0.0	5.2	1.1	2.2	776.9
TRN-2	50	OB	T2-5	150	3	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.4	0.0	0.0	0.0	0.0	2.3	7.6	0.0	43.9
TRN-2	100	OB	T2-5	151	3	0.2	11.2	0.1	0.0	0.0	0.1	0.0	3.9	0.0	18.5	0.1	0.0	0.0	0.0	8.2	0.0	18.7	66.3
TRN-3	9	OB	T3-1	79	1	0.0	0.4	0.6	0.0	0.0	11.8	11.2	7.8	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	50.3
TRN-3	18	OB	T3-2	83	1	0.2	0.2	0.0	0.8	0.0	1.5	8.2	5.5	0.0	0.5	7.5	0.0	0.0	0.9	0.0	2.7	12.9	146.9
TRN-3	35	OB	T3-3	87	2	43.1	4.6	0.5	0.0	0.2	0.2	4.8	3.5	0.0	1.0	2.6	0.0	0.0	1.4	0.5	17.6	15.8	112.7
TRN-3	50	OB	T3-4	91	3	31.2	1.4	0.1	0.0	0.1	0.3	0.0	4.1	0.0	0.2	2.9	0.0	0.0	0.0	2.5	6.5	9.7	68.1
TRN-3	50	OB	T3-5	95	3	0.4	0.9	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.1	1.2	0.0	0.0	0.0	0.0	3.5	1.4	18.2
TRN-4	10	OB	T4-1	57	1	1.7	4.6	1.3	0.0	0.0	993.6	0.0	1.8	0.0	1.5	0.6	14.8	0.0	0.0	0.0	0.0	0.0	1035.8
TRN-4	18	OB	T4-2	62	1	0.0	0.0	0.1	0.0	0.0	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	1.0	0.5	0.0	4.0
TRN-4	40	OB	T4-3	66	2	0.5	0.2	0.0	0.0	0.0	6.2	1.3	24.6	0.0	1.2	17.6	0.0	0.0	0.8	0.0	5.0	18.2	81.2
TRN-4	50	OB	T4-4	71	3	0.0	0.0	0.0	0.0	0.0	0.4	1.9	4.8	0.0	0.2	2.6	0.0	0.0	0.0	0.0	3.8	1.9	21.3
TRN-4	50	OB	T4-5	75	3	3.2	14.3	0.3	0.1	0.3	0.2	0.0	6.8	0.0	6.7	1.4	0.0	0.0	0.0	28.3	1.1	0.5	65.1
C	50	VT	5	272		0.1	6.4	0.1	0.9	0.3	0.0	0.0	0.4	0.0	2.0	0.0	0.0	0.0	0.2	1.7	0.0	0.0	15.0
C	50	VT	10	239		0.2	18.9	0.2	1.7	0.4	0.0	0.0	2.8	0.0	50.1	0.0	0.0	0.0	0.0	22.5	0.0	0.0	97.2
D	50	VT	10	246		0.0	15.9	0.1	0.2	12.9	0.0	0.0	0.1	269.1	1.8	0.0	0.0	0.0	1.6	19.7	0.0	0.0	328.2
D	50	VT	10	255		9.1	38.3	0.1	0.1	0.2	0.0	0.0	6.7	0.0	0.0	4.6	0.0	0.0	2.5	9.6	0.0	8.6	85.7
D	50	VT	12	261		6.5	51.3	0.2	0.0	0.1	0.0	0.0	2.2	0.0	1.5	0.1	0.0	0.0	0.4	6.7	0.5	0.0	164.8

[a] 1 = Shallow Cold Saline, 2 = Mackenzie Influenced, 3 = Outer Shelf Arctic

[b] WF = Whale feeding station, CTL = Control Station (see Chapter 6).

APPENDIX 5.18. Biomass (mg/m^3) of the dominant zooplankton species in oblique (OB) and selected surface (SB) and horizontal (HB) bongo tows in the eastern Alaskan Beaufort Sea, Sept 1998.

						Cnidarians/Ctenophores				Copepods				Amphipods		Euphausiids	Mysids	Decapods	Chaetognaths	Larvaceans	Fish	
Transect	Depth (m)	Tow Type	Sta. No.	Samp. No.	Water Mass[a]	*Aglantha digitale*	*Bouganvillea principis*	*Cyanea capillata*	*Mertensia ovum*	*Calanus glacialis*	*Calanus hyperboreus*	*Merteidia longa*	*Pseudocalanus minutus*	*Parathemisto abyssorum*	*Parathemisto libellula*	*Thysanoessa raschii*	*Mysis litoralis*	*Eualus fabricii*	*Sagitta elegans*	*Oikopleura vanhoeffeni*	*Boreogadus saida*	Total
CTL[b]	14.0	HB	5	15	1	1.27	3.45	0.00	20.38	134.18	71.35	0.00	10.17	0.02	0.00	0.00	0.18	0.00	116.38	0.00	0.00	367.17
CTL	3.7	HB	14	41	2	20.10	0.00	0.00	2.27	38.38	1.17	0.03	0.34	0.00	0.00	0.00	0.00	0.00	9.30	2.70	0.00	76.21
TRN	17.2	HB	10	30	1	32.78	0.00	0.00	2.29	297.59	1.17	0.63	5.06	0.00	0.00	4.89	36.96	0.00	77.97	0.13	0.00	462.69
TRN/WF	35.8	HB	15	43	2	7.94	0.00	0.00	9.13	346.05	11.61	0.00	1.99	0.06	0.91	0.00	0.00	0.00	41.69	3.97	0.00	425.61
WF	15.0	HB	3	7	1	18.29	8.64	0.00	0.00	234.01	22.86	1.52	5.66	0.84	0.00	0.00	6.56	0.00	303.89	0.11	0.00	615.71
WF	19.6	HB	4	10	1	53.40	2.99	0.00	13.47	191.06	35.64	4.26	8.51	1.22	0.00	0.47	0.80	0.00	138.09	0.00	0.00	460.27
WF	6.0	HB	8	23	2	10.61	0.00	8.43	0.00	0.43	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.75	0.43	0.00	23.99
WF	23.5	HB	8	24	2	44.52	0.00	0.00	0.00	376.32	22.91	0.06	2.36	0.00	0.00	0.61	0.75	0.00	48.77	0.35	0.00	504.47
WF	13.4	HB	28	96	1	0.21	2.14	0.00	13.47	10.35	2.59	0.02	6.86	0.00	1.36	0.00	26.50	0.00	37.79	0.00	10.13	112.60
WF	14.1	HB	32	111	1	12.23	21.17	0.00	31.05	19.72	4.68	0.25	8.76	0.02	0.00	12.07	16.16	0.00	104.96	0.00	69.93	328.73
CTL	6.5	OB	2	4	1	1.29	0.00	0.00	0.65	5.14	0.44	0.00	1.81	0.00	0.00	0.00	5.56	0.00	37.78	0.00	164.08	233.79
CTL	19.5	OB	5	13	1	3.72	0.00	0.00	93.51	150.73	69.69	0.00	6.53	0.16	0.00	0.00	0.16	0.00	87.57	0.00	0.00	418.12
CTL	12.5	OB	22	71	1	24.66	0.00	0.00	18.07	12.23	41.10	0.00	4.61	0.00	0.00	0.00	3.06	0.00	193.68	0.00	0.00	298.44
CTL	29.5	OB	29	99	1	4.96	0.00	0.00	54.60	83.55	65.70	0.09	8.84	0.07	0.00	0.00	5.87	0.00	204.03	0.52	0.00	429.23
TRN	7.0	OB	9	26	1	29.82	0.00	41.17	0.00	0.78	0.07	0.04	0.07	0.00	0.00	0.00	0.00	0.00	3.56	1.21	0.00	77.19
TRN	10.0	OB	6	16	1	57.64	0.00	0.00	0.65	8.15	0.51	0.03	0.34	0.00	0.00	0.00	15.96	0.00	73.97	0.00	0.00	163.90
TRN	14.0	OB	10	29	1	87.65	0.00	86.16	1.97	77.98	2.88	0.08	0.25	0.00	0.00	2.31	0.00	0.00	30.76	0.50	0.00	292.59
TRN	31.0	OB	11	32	2	18.37	0.00	10.86	3.32	73.01	10.22	0.23	0.46	0.00	1.28	0.00	0.00	0.00	32.11	0.46	0.00	151.46
TRN	9.5	OB	13	35	2	7.97	0.00	0.00	41.39	27.07	23.28	0.29	1.45	0.00	0.00	0.00	0.81	0.00	33.54	0.03	0.00	136.70
TRN	24.5	OB	14	38	2	42.23	0.00	1.89	1.37	237.08	32.37	0.00	5.61	0.01	0.00	0.00	7.85	0.00	40.17	5.61	0.00	374.73
TRN	7.5	OB	17	51	1	0.36	23.82	0.00	0.00	11.27	9.92	0.00	15.54	0.00	0.00	0.00	14.02	0.00	49.00	0.00	0.00	158.65
TRN	19.5	OB	18	54	1	40.47	0.00	0.00	19.86	60.23	41.56	0.00	4.36	0.00	0.00	0.00	4.88	0.00	183.66	0.00	0.00	361.63
TRN	24.5	OB	19	57	1	16.90	2.70	0.00	89.60	274.79	98.33	1.10	13.17	0.00	2.36	0.00	1.10	0.00	101.62	0.00	0.00	611.27
TRN	37.5	OB	20	60	2	31.94	5.73	0.00	0.08	157.36	0.76	0.00	1.39	0.00	0.94	0.95	0.00	0.00	15.56	4.17	0.00	219.90
TRN	8.0	OB	23	75	1	8.19	0.00	0.00	12.46	88.11	5.37	0.18	1.42	0.00	0.00	3.59	11.10	0.00	44.48	0.04	0.00	180.86
TRN	14.5	OB	24	78	1	8.05	0.00	0.00	0.00	163.29	3.14	0.03	2.68	0.00	0.00	0.00	0.00	0.00	50.20	3.49	0.00	231.45
TRN	21.5	OB	25	82	2	74.37	0.00	183.84	0.00	142.91	6.84	0.00	0.01	0.00	0.00	0.00	0.00	0.00	19.21	1.66	0.00	429.13
TRN	33.0	OB	26	86	2	25.12	0.00	11.41	5.57	74.19	16.34	0.35	0.12	0.02	2.58	1.71	0.00	0.00	25.47	3.49	0.00	167.52
TRN/CTL	46.0	OB	16	47	2	14.32	1.39	0.00	0.00	21.81	3.71	0.58	0.44	0.00	4.15	0.00	0.00	0.00	6.14	0.44	12.34	71.49
TRN/CTL	16.0	OB	7	19	1	28.02	0.00	0.00	0.00	40.04	1.82	0.22	0.22	0.00	0.00	2.64	1.93	0.00	18.04	0.46	0.00	93.74
TRN/CTL	8.5	OB	30	103	1	3.64	0.00	0.00	15.33	33.35	2.41	0.00	4.70	0.06	0.00	2.38	61.79	0.00	83.70	0.00	102.95	311.69
TRN/CTL	19.0	OB	31	106	1	4.09	0.00	0.00	32.28	231.05	19.94	0.00	5.11	0.00	0.00	2.52	25.24	25.81	44.98	0.51	0.00	406.88
TRN/WF	32.5	OB	15	42	2	22.56	13.54	0.00	0.43	77.05	3.93	0.19	0.97	0.00	3.20	0.00	0.00	0.00	10.29	4.08	9.21	148.23
WF	10.5	OB	1	3	1	12.34	0.00	0.00	0.47	101.75	10.67	0.00	1.46	0.15	7.75	0.00	0.00	0.00	7.43	0.09	0.00	143.95
WF	10.0	OB	3	6	1	34.32	21.45	0.00	0.00	482.51	43.37	0.07	8.58	0.43	0.00	0.00	0.00	0.00	83.17	0.03	0.00	678.35
WF	19.0	OB	4	9	1	38.95	11.31	0.00	3.04	227.85	57.94	0.28	0.84	0.21	0.00	0.94	0.00	0.00	125.10	0.02	0.00	468.44
WF	24.0	OB	8	22	1	26.87	0.00	163.96	0.00	88.01	15.42	0.61	0.91	0.00	0.00	3.60	0.00	0.00	25.81	1.21	0.00	330.96
WF	24.5	OB	21	66	1	6.42	0.00	0.00	12.25	155.33	68.43	0.00	9.72	0.00	0.00	0.00	6.44	0.00	63.38	1.17	0.00	327.05
WF	7.5	OB	27	90	1	5.08	0.00	3.49	31.23	11.36	15.48	0.00	4.32	0.00	11.40	0.00	69.93	0.00	52.82	0.00	0.00	207.61
WF	13.5	OB	28	94	1	0.59	24.93	0.00	45.28	11.17	8.01	0.02	4.40	0.00	0.00	0.00	74.32	0.00	101.47	0.00	0.00	270.51
WF	13.0	OB	32	110	1	1.52	22.56	0.00	38.21	45.17	4.40	0.05	5.57	0.00	0.00	6.22	15.87	0.00	77.21	0.00	0.00	239.03
WF	15.5	OB	33	115	2	5.58	0.65	0.00	10.22	50.88	8.72	0.00	8.16	0.00	0.00	7.33	24.05	0.00	107.48	0.14	0.00	224.45
CTL	1.6	SB	7	21	1	10.89	0.00	2.57	0.00	0.99	0.07	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.65	0.26	0.00	15.47
CTL	0.6	SB	22	74	1	2.12	0.00	0.00	5.53	2.59	1.32	0.00	4.61	0.00	0.00	0.00	0.00	0.00	1.32	0.00	0.00	17.49
TRN	1.2	SB	16	50	2	0.18	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.03	0.00	1.74

[a] 1 = Shallow Cold Saline, 2 = Mackenzie Influenced, 3 = Outer Shelf Arctic

[b] WF = Whale feeding station, CTL = Control Station (see Chapter 6).

APPENDIX 5.19. Biomass (mg/m^3) of the dominant zooplankton groups in oblique (OB) bongo tows in the eastern Alaskan Beaufort Sea, Sept 1998.

Transect	Depth (m)	Tow Type	Sta. No.	Samp. No.	Water Mass[a]	Cnidarians Ctenophores	Copepods	Amphipods	Euphausiids	Mysids	Decapods	Misc. Crustaceans	Misc. Non-Crustaceans	Chaetognaths	Larvaceans	Fish	Total
CTL[b]	6.5	OB	2	4	1	2.35	7.58	0.67	0.00	20.54	0.72	0.00	0.05	37.78	0.00	164.08	233.79
CTL	19.5	OB	5	13	1	101.83	228.16	0.16	0.02	0.16	0.21	0.00	0.01	87.57	0.00	0.00	418.12
CTL	12.5	OB	22	71	1	42.73	58.97	0.00	0.00	3.06	0.00	0.00	0.00	193.68	0.00	0.00	298.44
CTL	29.5	OB	29	99	1	59.57	158.88	0.28	0.01	5.87	0.07	0.00	0.00	204.03	0.52	0.00	429.23
TRN	7.0	OB	9	26	1	71.42	0.96	0.00	0.04	0.00	0.00	0.00	0.00	3.56	1.21	0.00	77.19
TRN	10.0	OB	6	16	1	63.49	9.08	0.00	0.65	15.96	0.00	0.00	0.00	73.97	0.00	0.00	163.15
TRN	14.0	OB	10	29	1	175.78	81.20	0.00	3.99	0.00	0.36	0.00	0.01	30.76	0.50	0.00	292.59
TRN	31.0	OB	11	32	2	33.16	83.98	1.28	0.38	0.00	0.09	0.00	0.00	32.12	0.46	0.00	151.46
TRN	9.5	OB	13	35	1	49.74	52.52	0.00	0.03	0.81	0.03	0.00	0.00	33.54	0.03	0.00	136.70
TRN	24.5	OB	14	38	2	45.50	275.06	0.01	0.25	7.85	0.01	0.00	0.25	40.17	5.61	0.00	374.73
TRN	7.5	OB	17	51	1	56.18	39.12	0.00	0.08	14.02	0.20	0.04	0.00	49.00	0.00	0.00	158.65
TRN	19.5	OB	18	54	1	60.33	106.77	0.16	0.08	4.88	0.04	0.00	0.31	183.66	0.00	5.41	361.63
TRN	24.5	OB	19	57	1	109.20	387.96	2.36	0.01	1.10	0.16	0.00	4.35	101.62	0.00	4.51	611.27
TRN	37.5	OB	20	60	2	38.06	159.51	0.94	1.09	0.00	0.02	0.00	0.56	15.56	4.17	0.00	219.90
TRN	8.0	OB	23	75	1	20.64	95.27	0.00	9.29	11.10	0.00	0.04	0.00	44.48	0.04	0.00	180.86
TRN	14.5	OB	24	78	1	8.08	169.27	0.00	0.40	0.00	0.00	0.00	0.00	50.20	3.49	0.00	231.45
TRN	21.5	OB	25	82	2	258.20	149.76	0.03	0.11	0.00	0.09	0.00	0.02	19.24	1.66	0.00	429.13
TRN	33.0	OB	26	86	2	42.11	91.10	2.60	2.06	0.00	0.10	0.00	0.12	25.93	3.49	0.00	167.52
TRN/CTL	46.0	OB	16	47	2	20.38	26.64	4.16	0.58	0.00	0.69	0.01	0.10	6.14	0.44	12.34	71.49
TRN/CTL	16.0	OB	7	19	1	28.04	42.31	0.00	2.90	1.93	0.04	0.00	0.00	18.04	0.46	0.00	93.74
TRN/CTL	8.5	OB	30	103	1	18.97	41.63	0.09	2.41	61.79	0.06	0.09	0.00	83.70	0.00	102.95	311.69
TRN/CTL	19.0	OB	31	106	1	38.34	256.49	0.00	2.59	25.24	26.01	1.49	0.28	44.98	0.51	10.96	406.88
TRN/WF	32.5	OB	15	42	2	37.64	82.38	3.66	0.23	0.00	0.47	0.06	0.06	10.45	4.08	9.21	148.23
WF	10.5	OB	1	3	1	13.63	113.89	7.89	0.26	0.00	0.70	0.01	0.06	7.43	0.09	0.00	143.95
WF	10.0	OB	3	6	1	56.50	534.79	0.43	0.10	0.00	1.95	0.07	1.32	83.17	0.03	0.00	678.35
WF	19.0	OB	4	9	1	53.66	287.03	0.21	1.19	0.00	0.51	0.00	0.73	125.10	0.02	0.00	468.44
WF	24.0	OB	8	22	2	190.83	105.10	0.00	4.32	0.00	0.27	0.06	0.00	25.81	1.21	3.34	330.96
WF	24.5	OB	21	66	1	18.97	233.58	0.00	0.00	6.44	0.00	0.00	0.00	63.38	1.17	3.51	327.05
WF	7.5	OB	27	90	1	42.06	31.33	11.40	0.07	69.93	0.00	0.00	0.00	52.82	0.00	0.00	207.61
WF	13.5	OB	28	94	1	70.80	23.62	0.00	0.04	74.32	0.27	0.00	0.00	101.47	0.00	0.00	270.51
WF	13.0	OB	32	110	1	83.28	55.27	0.10	6.57	15.87	0.72	0.00	0.00	77.21	0.00	0.00	239.03
WF	15.5	OB	33	115	2	16.53	68.00	0.00	7.77	24.05	0.48	0.00	0.00	107.48	0.14	0.00	224.45

[a] 1 = Shallow Cold Saline, 2 = Mackenzie Influenced, 3 = Outer Shelf Arctic

[b] WF = Whale feeding station, CTL = Control Station (see Chapter 6).

APPENDIX 5.20. Biomass (mg/m^3) of the dominant zooplankton groups in surface (SB) bongo tows in the eastern Alaskan Beaufort Sea, Sept 1998.

Transect	Depth (m)	Tow Type	Sta. No.	Samp. No.	Water Mass[a]	Cnidarians Ctenophores	Copepods	Amphipods	Mysids Euphausiids	Decapods	Misc. Crustaceans	Misc. Non-Crustaceans	Chaetognaths	Larvaceans	Fish	Total
CTL[b]	1.2	SB	5	14	1	3.40	3.18	0.00	0.00	0.00	0.00	0.01	0.78	0.00	0.00	7.37
CTL	1.6	SB	7	21	1	13.46	1.08	0.00	0.01	0.00	0.01	0.00	0.65	0.26	0.00	15.47
CTL	0.6	SB	22	74	1	7.64	8.53	0.00	0.00	0.00	0.00	0.00	1.32	0.00	0.00	17.49
CTL	0.9	SB	29	102	1	0.96	1.40	0.00	0.01	0.00	0.00	0.00	0.30	0.73	0.00	3.40
TRN	0.9	SB	9	28	1	38.54	0.14	0.00	0.01	0.01	0.00	0.00	0.24	0.03	0.00	38.97
TRN	1.2	SB	6	17	1	9.70	0.10	0.00	0.00	0.00	0.00	0.00	0.37	0.00	0.00	10.16
TRN	0.9	SB	13	37	1	186.38	37.48	0.00	0.01	0.00	0.01	0.56	2.55	0.06	0.00	227.05
TRN	0.7	SB	17	53	1	27.50	17.06	0.00	9.97	0.01	0.00	0.01	52.38	0.00	0.00	106.94
TRN	0.6	SB	18	56	1	2.20	12.09	0.00	0.00	0.00	0.00	0.00	0.82	0.00	0.00	15.11
TRN	1.0	SB	19	59	1	9.64	111.20	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	120.87
TRN	1.0	SB	20	65	2	7.14	6.82	0.00	0.00	0.00	0.08	0.02	0.97	9.42	0.00	24.45
TRN	1.5	SB	24	81	1	0.70	272.34	0.00	0.03	0.04	0.00	0.00	1.64	4.70	0.00	279.46
TRN	1.0	SB	25	85	2	59.82	12.13	0.00	0.01	0.02	0.00	0.00	2.99	1.46	0.00	76.42
TRN	1.0	SB	26	89	2	13.58	0.67	0.00	0.03	1.27	0.00	0.00	1.23	1.57	0.00	18.36
TRN/CTL	1.2	SB	16	50	2	0.29	0.12	0.00	0.02	1.08	0.00	0.00	0.20	0.03	0.00	1.74
TRN/CTL	1.2	SB	30	105	1	289.78	2.73	0.06	4.60	0.28	0.01	5.04	37.27	0.22	0.00	340.00
TRN/CTL	2.0	SB	31	109	1	12.82	504.27	0.00	0.57	0.60	0.00	0.00	19.31	0.27	0.00	537.85
TRN/WF	1.3	SB	15	46	2	0.95	0.16	0.00	0.00	0.31	0.01	0.00	0.06	2.23	0.00	3.72
WF	1.0	SB	4	11	1	4.05	3.94	0.00	0.00	0.00	0.03	0.01	0.57	0.02	0.00	8.62
WF	0.9	SB	21	70	1	0.28	4.82	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	5.30
WF	0.8	SB	27	93	1	1.62	2.10	0.00	0.00	0.00	0.00	0.00	0.85	0.00	0.00	4.58
WF	1.0	SB	28	98	1	5.72	1.64	0.00	0.00	0.00	0.00	0.00	0.56	0.00	0.00	7.92
WF	1.0	SB	32	114	1	32.13	3.32	0.00	0.92	0.40	0.02	0.01	11.37	0.03	0.09	48.29
WF	1.5	SB	33	118	2	5.67	93.29	0.00	0.00	0.03	0.00	0.07	2.19	0.14	0.00	101.39

[a] 1 = Shallow Cold Saline, 2 = Mackenzie Influenced, 3 = Outer Shelf Arctic

[b] WF = Whale feeding station, CTL = Control Station (see Chapter 6).

APPENDIX 5.21. Biomass (mg/m^3) of the dominant zooplankton groups in horizontal (HB) bongo tows in the eastern Alaskan Beaufort Sea, Sept, 1998.

Transect	Depth (m)	Tow Type	Sta. No.	Samp. No.	Water Mass[a]	Cnidarians Ctenophores	Copepods	Amphipods	Mysids Euphausiids	Decapods	Misc. Crustaceans	Misc. Non-Crustaceans	Chaetognaths	Larvaceans	Fish	Total
CTL[b]	5.6	HB	2	5	1	12.60	27.09	0.00	49.58	0.00	0.00	0.21	138.27	0.00	13.57	241.32
CTL	14.0	HB	5	15	1	32.94	216.76	0.18	0.22	0.00	0.00	0.69	116.38	0.00	0.00	367.17
CTL	3.7	HB	14	41	2	23.17	40.60	0.00	0.01	0.07	0.36	0.00	9.30	2.70	0.01	76.21
CTL	6.6	HB	22	73	1	38.21	112.53	0.01	0.00	0.01	0.00	1.65	288.89	0.00	0.00	441.29
CTL	25.7	HB	29	100	1	124.21	54.38	0.00	31.83	0.54	0.00	0.00	509.34	0.00	6.27	726.56
CTL	11.3	HB	29	101	1	25.08	99.29	2.16	0.06	0.56	0.00	0.45	49.31	0.01	0.00	176.93
TRN	5.4	HB	9	27	1	50.61	7.27	0.00	1.71	0.00	0.02	0.05	12.83	0.96	0.00	73.46
TRN	8.8	HB	6	18	1	18.65	12.37	0.00	16.84	0.31	0.00	0.02	0.00	132.63	0.00	180.82
TRN	16.7	HB	7	20	1	35.95	176.42	0.00	59.37	0.34	0.68	0.17	93.91	0.14	12.15	379.12
TRN	12.2	HB	10	31	1	116.74	177.32	0.01	1.62	0.26	0.00	0.54	48.48	0.55	0.00	345.52
TRN	17.2	HB	10	30	1	35.07	304.72	0.00	42.74	0.27	0.00	0.23	77.97	0.13	1.57	462.69
TRN	25.3	HB	11	33	2	50.33	211.40	0.00	1.24	0.28	0.01	0.10	44.35	0.21	2.47	310.41
TRN	12.4	HB	11	34	2	30.43	8.68	0.00	0.02	0.27	0.00	0.00	2.63	0.76	0.02	42.82
TRN	7.6	HB	13	36	1	135.72	60.29	0.00	4.92	0.15	0.02	0.00	50.79	0.00	1.80	253.70
TRN	21.9	HB	14	39	2	10.51	303.08	0.00	0.10	0.09	0.02	0.00	27.49	2.11	1.64	345.06
TRN	13.1	HB	14	40	2	63.66	143.55	0.03	0.14	0.17	0.00	0.00	7.62	0.77	0.00	215.94
TRN	8.6	HB	17	52	1	31.36	21.84	0.00	35.47	0.00	42.50	0.00	36.85	0.00	0.00	168.01
TRN	13.0	HB	18	55	1	34.51	142.65	0.06	0.03	0.03	0.00	0.71	347.41	0.00	0.00	525.41
TRN	14.5	HB	19	58	1	21.18	502.89	0.00	0.05	0.01	0.00	0.01	18.17	0.00	0.00	542.31
TRN	28.9	HB	20	61	2	54.80	399.51	0.00	0.30	0.02	0.02	0.20	24.52	1.19	1.02	481.58
TRN	18.4	HB	20	62	2	131.58	5.68	1.43	0.13	0.73	0.05	0.01	2.47	8.68	0.12	150.88
TRN	30.9	HB	20	63	2	31.22	197.56	1.01	0.07	0.12	0.10	0.41	19.36	2.93	2.81	255.60
TRN	6.2	HB	23	76	1	95.86	22.81	0.68	2.71	0.01	0.00	0.73	67.51	0.00	0.01	190.33
TRN	11.3	HB	24	79	1	62.10	98.77	0.00	0.90	0.12	0.00	0.01	20.00	3.70	8.43	194.03
TRN	8.8	HB	24	80	1	10.17	47.17	0.00	0.97	0.11	0.01	0.77	32.24	12.98	0.00	104.43
TRN	21.5	HB	25	83	2	44.83	441.67	0.00	0.03	0.00	0.00	0.05	72.20	2.55	0.00	561.33
TRN	17.5	HB	25	84	2	126.70	145.22	0.00	2.05	0.00	0.00	0.04	26.62	1.27	10.93	312.85
TRN	31.5	HB	26	87	2	321.67	416.68	1.71	1.78	0.00	0.03	0.41	83.75	0.82	3.93	830.76
TRN	22.0	HB	26	88	2	44.49	1.86	0.52	0.27	0.05	0.00	0.00	0.86	2.12	0.00	50.18
TRN/CTL	34.7	HB	16	48	2	42.44	37.96	0.54	10.05	1.69	0.60	3.69	43.97	0.94	6.00	147.87
TRN/CTL	19.2	HB	16	49	2	3.69	0.39	2.07	0.07	1.02	0.16	0.03	1.45	0.20	4.09	13.17
TRN/CTL	8.2	HB	30	104	1	59.39	68.91	0.23	111.15	0.14	2.78	0.06	133.96	0.00	116.04	492.65
TRN/CTL	19.2	HB	31	107	1	26.54	262.17	1.45	18.96	77.87	0.00	0.01	270.39	0.00	127.90	785.29
TRN/CTL	12.6	HB	31	108	1	21.60	172.84	0.00	70.49	0.22	0.00	3.90	42.10	0.49	4.47	316.12
TRN/WF	22.4	HB	15	44	2	763.82	3.24	0.01	0.03	0.15	0.07	0.00	0.74	2.65	0.00	770.71
TRN/WF	13.8	HB	15	45	2	16.94	0.07	0.06	0.03	0.20	0.05	0.00	1.23	2.94	10.28	31.80
TRN/WF	35.8	HB	15	43	2	17.15	359.65	1.02	0.14	0.94	0.00	1.05	41.69	3.97	0.00	425.61
WF	9.6	HB	1	2	1	42.16	210.44	0.55	0.00	0.07	0.00	0.21	38.78	0.00	2.66	294.86
WF	11.4	HB	3	8	1	28.77	237.22	0.35	0.41	0.60	0.00	0.19	165.17	0.03	5.17	437.91
WF	15.0	HB	3	7	1	33.50	264.65	0.84	6.65	0.65	0.02	0.17	303.89	0.11	5.20	615.71
WF	13.5	HB	4	12	1	52.28	41.54	0.11	0.46	0.35	0.01	0.12	98.86	0.00	0.00	193.74
WF	19.6	HB	4	10	1	72.16	239.62	1.34	1.36	0.23	0.00	1.65	138.09	0.00	5.83	460.27
WF	13.5	HB	8	25	1	29.63	3.66	0.00	0.47	0.16	0.06	0.00	1.64	1.89	2.00	39.51
WF	6.0	HB	8	23	1	21.46	0.73	0.01	0.06	0.26	0.28	0.01	0.75	0.43	0.00	23.99
WF	23.5	HB	8	24	1	44.61	401.65	0.00	1.74	0.93	0.01	0.18	48.77	0.35	6.24	504.47
WF	23.0	HB	21	67	1	56.43	143.86	0.02	4.46	0.01	1.06	1.21	177.42	0.00	4.50	388.96
WF	18.8	HB	21	68	1	27.50	117.07	0.07	0.00	0.07	0.00	0.06	45.71	0.00	1.48	191.96
WF	9.9	HB	21	69	1	36.31	174.09	0.00	0.43	0.11	0.00	0.19	24.17	0.00	0.21	235.50
WF	12.1	HB	21	72	1	17.48	30.37	0.08	1.28	0.00	0.00	0.65	168.68	0.00	0.00	218.53
WF	6.8	HB	27	91	1	40.79	34.69	0.00	86.60	0.06	0.00	0.72	77.17	0.00	27.26	267.29
WF	5.2	HB	27	92	1	54.74	72.28	0.00	1.75	0.12	0.00	4.48	74.92	0.00	4.88	213.17
WF	10.8	HB	28	95	1	158.41	24.94	0.00	100.14	0.00	0.02	0.00	121.34	0.00	15.88	420.73
WF	8.4	HB	28	97	1	47.52	25.60	0.00	58.42	0.00	0.03	0.00	131.81	0.00	0.00	263.38
WF	13.4	HB	28	96	1	16.39	20.05	1.45	26.50	0.05	0.23	0.00	37.79	0.00	10.13	112.60
WF	8.8	HB	32	112	1	171.25	24.41	0.24	31.57	0.16	0.00	0.22	82.17	0.13	0.00	310.14
WF	4.9	HB	32	113	1	39.84	6.49	0.78	79.44	0.22	0.01	0.01	48.09	0.00	12.41	187.29
WF	14.1	HB	32	111	1	64.45	35.03	0.73	28.47	0.16	0.34	0.11	104.96	0.00	94.49	328.73
WF	13.7	HB	33	116	2	38.07	37.80	0.43	72.70	0.17	0.00	2.44	195.01	0.32	39.31	386.25
WF	10.5	HB	33	117	2	49.04	61.45	0.00	0.35	0.12	0.00	0.01	143.77	0.17	0.00	254.90

[a] 1 = Shallow Cold Saline, 2 = Mackenzie Influenced, 3 = Outer Shelf Arctic

[b] WF = Whale feeding station, CTL = Control Station (see Chapter 6).

APPENDIX 5.22. Biomass (mg/m^3) of the dominant zooplankton species in oblique (OB) bongo tows in the eastern Alaskan Beaufort Sea, Sept 1999.

						Cnidarians/Ctenophores						Copepods						Amphipods		Euphausiids	Mysids	Chaetognaths		Fish	Total
Transect	Depth (m)	Tow Type	Sta. No.	Samp. No.	Water Mass[a]	*Aeginopsis laurentii*	*Aglantha digitale*	*Eumedusa birulai*	*Cyanea capillata*	*Mertensia ovum*	*Pleurobrachia pileus*	*Calanus glacialis*	*Calanus hyperboreus*	*Limnocalanus macrurus*	*Euchaeta glacialis*	*Metridia longa*	*Pseudocalanus minutus*	*Parathemisto abyssorum*	*Parathemisto libellula*	*Thysanoessa raschii*	*Mysis litoralis*	*Eukrohnia hamata*	*Sagitta elegans*	*Boreogadus saida*	Biomass
CTL[b]	30	OB	5	19	1	0.00	5.13	0.00	18.32	6.74	13.71	4.69	134.65	0.00	2.51	0.05	0.03	0.01	0.07	4.14	0.00	1.94	9.11	13.92	215.44
CTL	40	OB	2	6	1	69.27	0.00	0.00	12.76	5.89	0.00	15.50	215.85	0.00	1.67	5.67	0.07	0.19	8.27	0.00	0.00	3.25	38.13	3.99	384.34
TRN	7	OB	9	34	1	0.00	0.53	0.00	0.00	1.74	0.00	1.21	0.00	0.01	0.00	0.03	2.65	0.00	0.00	0.00	0.00	0.00	3.60	0.00	9.79
TRN	7	OB	13	49	1	0.00	20.92	14.06	0.00	58.65	0.00	7.56	11.25	0.00	0.00	0.07	1.16	0.00	0.00	0.00	0.00	0.00	77.03	0.00	190.99
TRN	8	OB	18	67	1	0.00	41.49	0.00	0.00	0.00	0.00	6.51	8.26	0.04	0.00	0.00	81.33	0.00	1.83	0.00	63.94	0.17	64.90	39.21	308.67
TRN	8	OB	22	83	1	0.00	94.36	0.00	31.21	4.80	0.00	5.16	44.80	0.00	2.05	0.11	0.62	0.00	0.00	0.00	0.00	0.48	95.90	0.00	288.79
TRN	15	OB	8	31	1	0.00	1.88	0.00	0.00	2.35	0.00	0.51	0.40	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	3.34	0.00	8.64
TRN	17	OB	12	45	1	0.00	11.55	2.56	0.00	77.23	0.00	5.54	18.04	0.00	0.15	0.30	0.18	0.00	0.00	21.38	1.56	0.07	200.00	27.35	366.26
TRN	18	OB	21	79	1	0.00	28.54	0.00	0.00	253.26	0.00	16.58	317.55	0.00	0.00	1.44	0.07	0.02	4.31	0.00	0.00	1.37	111.14	17.82	756.52
TRN	29	OB	11	41	1	0.00	0.94	0.00	0.00	15.14	29.41	15.68	67.18	0.00	3.82	1.06	0.08	0.04	2.43	1.42	0.00	0.60	26.62	12.08	178.00
TRN	30	OB	7	27	1	0.00	10.42	0.43	0.00	16.13	0.85	9.14	101.08	0.00	0.93	0.00	0.24	0.00	1.14	20.09	0.00	1.76	155.99	8.74	327.13
TRN	30	OB	16	60	1	0.00	10.50	2.01	0.00	60.05	13.59	61.54	271.13	0.00	2.27	9.05	0.36	0.42	1.21	3.05	0.00	1.45	179.37	7.57	627.79
TRN	30	OB	20	74	1	0.00	60.59	0.00	0.00	58.87	0.00	58.31	603.59	0.00	0.53	19.34	0.85	0.03	0.28	0.00	0.00	11.95	199.68	12.22	1029.45
TRN	35	OB	19	70	1	0.00	120.45	2.38	0.00	8.78	0.00	22.53	65.66	0.00	8.38	1.09	0.00	0.06	2.14	0.29	0.00	15.30	13.06	1.90	270.49
TRN	40	OB	6	23	1	0.00	46.18	0.21	20.54	12.77	0.00	30.85	278.04	0.00	1.22	3.97	0.12	0.14	3.65	0.00	0.00	8.69	48.53	10.18	466.08
TRN	42	OB	10	37	1	0.00	11.54	1.25	0.00	13.28	0.00	12.55	147.90	0.00	2.56	0.00	0.02	0.13	3.33	0.00	0.00	3.31	12.44	3.12	212.57
TRN/CTL	18	OB	17	64	1	0.00	12.38	0.00	0.00	111.79	0.00	28.38	54.04	0.00	1.85	0.30	0.15	0.11	2.04	40.26	4.06	0.57	173.74	6.75	437.96
TRN/WF	32	OB	14	52	1	0.00	42.40	0.00	0.00	44.64	0.00	35.01	271.54	0.00	5.04	5.32	0.30	0.04	0.00	0.54	0.00	7.24	30.88	5.36	449.52
TRN/WF	40	OB	15	56	1	0.00	21.32	1.74	0.00	46.00	0.00	87.58	356.47	0.00	11.48	11.56	0.26	1.80	0.46	1.10	0.00	5.33	31.33	4.04	582.76
WF	40	OB	1	2	1	1.09	17.66	0.20	0.00	13.82	0.00	43.60	242.72	0.00	1.31	10.32	0.14	0.22	4.31	2.11	0.00	14.80	67.30	13.79	442.72
WF	40	OB	3	11	1	11.10	0.00	1.56	0.00	1.53	0.00	18.69	127.52	0.00	4.27	1.10	0.03	0.03	5.78	3.67	0.00	3.90	15.45	6.80	207.41
WF	41	OB	4	15	1	0.42	26.08	0.00	0.00	6.03	0.00	16.19	137.25	0.00	1.97	0.53	0.03	0.00	3.23	0.40	0.00	6.77	14.55	4.44	221.16

[a] 1 = Shallow Cold Saline, 2 = Mackenzie Influenced, 3 = Outer Shelf Arctic

[b] WF = Whale feeding station, CTL = Control Station (see Chapter 6).

APPENDIX 5.23. Biomass (mg/m^3) of the dominant zooplankton groups in oblique (OB) bongo tows in the eastern Alaskan Beaufort Sea, Sept 1999.

Transect	Depth (m)	Tow Type	Sta. No.	Samp. No.	Water Mass[a]	Ctenophores Cnidarians	Copepods	Amphipods	Euphausiids	Mysids	Chaetognaths	Larvacea	Fish	Miscellaneous	Total
CTL[b]	30	OB	5	19	1	43.90	141.93	0.08	4.25	0.00	11.05	0.07	13.92	0.00	215.44
CTL	40	OB	2	6	1	89.78	238.76	9.37	0.00	0.00	41.38	0.69	3.99	0.27	384.34
TRN	7	OB	9	34	1	2.28	3.91	0.00	0.00	0.00	3.60	0.01	0.00	0.00	9.79
TRN	7	OB	13	49	1	93.89	20.07	0.00	0.00	0.00	77.03	0.00	0.00	0.00	190.99
TRN	8	OB	18	67	1	41.49	96.68	1.83	0.00	63.94	65.06	0.04	39.21	0.41	308.67
TRN	8	OB	22	83	1	130.37	52.78	0.00	0.00	0.00	96.37	0.00	9.23	0.00	288.79
TRN	15	OB	8	31	1	4.23	0.98	0.00	0.00	0.00	3.34	0.01	0.00	0.00	8.64
TRN	17	OB	12	45	1	91.34	24.21	0.00	21.38	1.56	200.07	0.00	27.35	0.01	366.26
TRN	18	OB	21	79	1	281.80	335.64	4.32	0.00	0.00	112.50	0.04	21.64	0.00	756.52
TRN	29	OB	11	41	1	45.60	87.81	2.68	1.42	0.00	27.22	0.45	12.08	0.00	178.00
TRN	30	OB	7	27	1	27.84	111.39	1.14	20.09	0.00	157.76	0.00	8.74	0.00	327.13
TRN	30	OB	16	60	1	86.14	344.36	2.21	3.05	0.00	180.81	0.90	9.55	0.00	627.79
TRN	30	OB	20	74	1	120.32	682.63	0.60	0.00	0.00	211.63	1.42	12.36	0.00	1029.45
TRN	35	OB	19	70	1	134.70	97.66	2.19	0.29	0.00	28.35	0.90	4.85	0.00	270.49
TRN	40	OB	6	23	1	79.70	314.20	3.79	0.00	0.00	57.22	0.99	10.18	0.00	466.08
TRN	42	OB	10	37	1	26.07	163.03	3.47	0.00	0.00	15.74	1.12	3.12	0.01	212.57
TRN/CTL	18	OB	17	64	1	124.17	84.72	2.15	40.26	4.06	174.30	0.00	8.11	0.00	437.96
TRN/WF	32	OB	14	52	1	87.04	317.21	0.05	0.54	0.00	38.12	0.07	5.36	0.03	449.52
TRN/WF	40	OB	15	56	1	69.06	467.34	2.26	1.10	0.00	36.66	1.80	4.53	0.02	582.76
WF	40	OB	1	2	1	32.76	298.08	6.32	2.11	0.00	82.11	0.14	13.79	7.43	442.72
WF	40	OB	3	11	1	14.20	151.61	5.95	3.67	0.00	19.34	0.97	11.47	0.01	207.41
WF	41	OB	4	15	1	33.03	155.97	3.43	0.40	0.00	21.32	0.79	5.62	0.48	221.16

[a] 1 = Shallow Cold Saline, 2 = Mackenzie Influenced, 3 = Outer Shelf Arctic

[b] WF = Whale feeding station, CTL = Control Station (see Chapter 6).

APPENDIX 5.24. Biomass (mg/m^3) of the dominant zooplankton groups in horizontal (HB) bongo tows in the eastern Alaskan Beaufort Sea, Sept 1999.

Transect	Depth (m)	Tow Type	Sta. No.	Samp. No.	Water Mass[a]	Ctenophores Cnidarians	Copepods	Amphipods	Euphausiids	Mysids	Chaetognaths	Larvacea	Fish	Miscellaneous	Total
TRN[b]	31	HB	6	24	1	142.81	39.41	4.46	0.00	0.00	18.61	1.70	9.64	0.00	216.63
TRN	41	HB	6	25	1	171.89	541.14	5.03	3.38	0.00	75.65	2.06	14.22	0.00	813.36
TRN	17	HB	7	28	1	163.19	73.22	0.89	8.35	0.00	86.91	23.75	1.16	0.00	357.47
TRN	8	HB	7	29	1	34.84	1.16	3.43	0.00	0.00	3.19	0.02	8.86	0.02	51.52
TRN	8	HB	8	32	1	143.33	0.12	0.00	0.00	0.00	0.46	0.00	5.84	0.00	149.75
TRN	6	HB	9	35	1	0.30	0.51	1.10	0.81	0.00	1.57	0.01	8.98	0.00	13.28
TRN	26	HB	10	38	1	85.95	339.49	0.88	0.00	0.00	19.73	3.99	2.88	0.16	453.09
TRN	8	HB	10	39	1	9.79	0.55	2.20	0.00	0.00	0.49	1.63	2.40	0.00	17.06
TRN	27	HB	11	42	1	86.73	9.92	0.94	2.45	0.00	20.55	0.24	7.03	0.90	128.75
TRN	11	HB	11	43	1	64.60	2.68	1.60	0.00	0.00	3.94	1.01	4.05	0.12	78.00
TRN	11	HB	12	46	1	132.90	8.75	0.00	1.42	0.00	54.15	0.00	7.84	0.48	205.53
TRN	15	HB	12	47	1	493.77	38.14	0.78	57.26	0.00	335.13	0.00	2.73	0.00	927.81
TRN	7	HB	13	50	1	93.12	17.81	1.16	0.00	0.00	40.86	0.00	27.76	0.05	180.76
TRN	23	HB	16	61	1	114.27	587.21	0.07	0.45	0.77	365.40	0.22	26.37	1.44	1096.21
TRN	10	HB	16	62	1	83.89	7.78	3.66	0.00	0.00	35.34	0.15	2.58	0.35	133.76
TRN	5	HB	18	68	1	103.37	66.42	0.00	0.00	25.12	248.27	0.00	10.32	0.00	453.49
TRN	26	HB	19	71	1	317.60	149.29	0.31	1.79	0.00	92.62	0.53	5.78	6.51	574.43
TRN	10	HB	19	72	1	61.14	0.82	7.37	0.00	0.00	0.38	0.30	2.84	0.41	73.26
TRN	9	HB	20	77	1	166.45	430.93	0.18	0.00	0.00	125.32	1.62	11.37	0.05	735.93
TRN	12	HB	21	80	1	137.85	406.25	0.02	2.46	0.00	237.40	0.00	8.01	0.05	792.03
TRN	6	HB	21	81	1	199.17	102.38	0.57	0.00	0.77	72.12	0.03	21.64	0.43	397.11
TRN	8	HB	22	84	1	166.08	121.66	1.35	0.00	7.37	305.29	0.00	11.98	0.00	613.73
TRN/CTL	17	HB	17	65	1	287.44	243.68	0.29	12.73	4.07	263.99	0.00	1.24	0.84	814.28
CTL	21	HB	2	8	1	88.04	2.70	12.81	0.00	0.00	8.04	0.53	4.07	0.30	116.49
CTL	8	HB	2	7	1	56.81	1.76	11.50	0.00	0.00	0.91	0.28	2.39	0.46	74.10
CTL	15	HB	5	20	1	32.24	69.90	0.22	0.00	0.00	29.72	0.12	2.75	0.12	135.07
CTL	6	HB	5	21	1	16.33	0.55	4.67	0.00	0.00	0.01	0.02	10.91	0.00	32.49
TRN/WF	31	HB	14	53	1	261.53	242.52	4.72	0.52	0.00	76.60	0.00	7.93	1.09	594.91
TRN/WF	13	HB	14	54	1	45.20	1.58	1.54	0.00	0.00	0.61	0.10	6.03	0.00	55.07
TRN/WF	24	HB	15	57	1	247.10	239.94	7.58	0.00	0.00	34.66	4.70	36.82	0.71	571.51
TRN/WF	13	HB	15	58	1	9.68	1.25	0.35	0.00	0.00	1.27	4.83	2.81	1.99	22.18
WF	37	HB	1	3	1	82.71	391.88	1.89	0.20	0.00	61.06	0.65	6.39	0.11	544.88
WF	19	HB	1	4	1	135.10	0.59	1.29	0.00	0.00	0.36	0.58	3.22	0.53	141.66
WF	10	HB	1	5	1	28.37	0.09	0.81	0.00	0.00	0.39	0.12	0.00	0.00	29.78
WF	19	HB	3	12	1	13.42	1.45	2.43	0.00	0.00	3.44	3.44	13.44	1.26	38.89
WF	34	HB	3	13	1	146.49	593.92	6.24	21.31	0.00	102.96	1.59	13.80	0.12	886.43
WF	40	HB	4	16	1	59.48	607.98	5.73	2.80	0.00	89.31	0.17	12.19	0.04	777.71
WF	14	HB	4	17	1	3.18	0.16	5.04	0.00	0.00	0.38	0.36	6.12	0.01	15.25

[a] 1 = Shallow Cold Saline, 2 = Mackenzie Influenced, 3 = Outer Shelf Arctic

[b] WF = Whale feeding station, CTL = Control Station (see Chapter 6).

APPENDIX 5.25 Biomass (mg/m^3) of the dominant zooplankton groups in surface (SB) bongo tows in the eastern Alaskan Beaufort Sea, Sept 1999.

Transect	Depth (m)	Tow Type	Sta. No.	Samp. No.	Water Mass[a]	Ctenophores Cnidarians	Copepods	Amphipods	Euphausiids	Mysids	Chaetognaths	Larvacea	Fish	Miscellaneous	Total
TRN[b]	1	SB	6	22	1	0.36	0.06	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.42
TRN	1	SB	7	26	1	0.80	0.05	0.00	0.00	0.00	0.15	0.03	0.00	0.00	1.02
TRN	1	SB	8	30	1	11.35	0.93	0.00	0.15	0.00	0.35	0.02	0.00	0.00	12.79
TRN	1	SB	9	33	1	0.46	0.25	0.00	0.00	0.00	0.45	0.01	0.00	0.00	1.17
TRN	1	SB	10	36	1	0.21	0.11	0.08	0.00	0.00	0.00	0.01	0.00	0.00	0.41
TRN	1	SB	11	40	1	9.13	1.59	0.04	0.00	0.00	0.23	0.03	0.00	0.00	11.01
TRN	1	SB	12	44	1	0.96	0.30	0.51	0.00	0.00	0.08	0.03	0.00	0.00	1.88
TRN	1	SB	13	48	1	10.37	0.20	0.31	0.00	0.00	0.51	0.00	0.00	0.00	11.39
TRN	1	SB	16	59	1	1.00	0.01	0.08	0.00	0.00	0.05	0.17	0.00	0.00	1.31
TRN	1	SB	18	66	1	88.68	18.98	0.00	0.00	0.00	10.81	0.01	0.00	0.00	118.48
TRN	1	SB	19	69	1	0.07	0.25	0.00	0.00	0.15	0.03	0.00	0.00	0.00	0.50
TRN	1	SB	20	73	1	1.89	3.27	0.00	0.00	0.00	0.02	0.03	0.00	0.00	5.20
TRN	1	SB	21	78	1	2.31	0.20	0.06	0.00	0.00	0.01	0.01	0.00	0.00	2.58
TRN	1	SB	22	82	1	72.60	3.67	1.41	0.00	0.70	23.92	0.00	0.05	0.01	102.35
CTL	1	SB	2	7	1	15.99	0.04	0.00	0.00	0.00	0.01	0.17	0.00	0.00	16.22
CTL	1	SB	5	18	1	1.55	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.56
TRN/CTL	1	SB	17	63	1	24.23	0.42	0.83	0.00	0.00	0.12	0.01	0.20	0.00	25.81
TRN/WF	1	SB	14	51	1	0.01	0.65	0.00	0.00	0.00	0.08	0.01	0.00	0.01	0.76
TRN/WF	1	SB	15	55	1	0.25	0.37	0.00	0.00	0.00	0.10	0.07	0.00	0.00	0.80
WF	1	SB	1	1	1	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
WF	1	SB	3	10	1	3.35	0.10	0.04	0.00	0.00	0.00	0.00	0.00	0.00	3.49
WF	1	SB	4	14	1	0.19	0.25	0.00	0.00	0.00	0.05	0.03	0.00	0.00	0.52

[a] 1 = Shallow Cold Saline, 2 = Mackenzie Influenced, 3 = Outer Shelf Arctic

[b] WF = Whale feeding station, CTL = Control Station (see Chapter 6).

APPENDIX 5.26. Biomass (mg/m^3) of the dominant zooplankton species in oblique (OB) bongo tows in the eastern Alaskan Beaufort Sea, Sept 2000.

						Cnidarians/Ctenophores								Copepods				Amphipods		Euphausiids		Mysids	Chaetognaths		Larvaceans	Fish	
Transect	Depth (m)	Tow Type	Sta. No.	Samp. No.	Water Mass[a]	*Aeginopsis laurentii*	*Aglantha digitale*	*Eumedusa birulai*	*Euphysa flammea*	*Halitholus cirratus*	*Sarsia princeps*	*Cyanea capillata*	*Mertensia ovum*	*Calanus glacialis*	*Calanus hyperboreus*	*Limnocalanus macrurus*	*Metridia longa*	*Parathemisto abyssorum*	*Parathemisto libellula*	*Thysanoessa raschii*	*Thysanoessa longipes*	*Mysis litoralis*	*Eukrohnia hamata*	*Sagitta elegans*	*Oikopleura vanhoeffeni*	*Boreogadus saida*	Total Biomass
TRN-1	10	OB	1	1	1	0.07	0.66	16.13	0.00	10.50	0.00	0.00	8.92	26.65	1.51	1.26	0.02	0.00	0.00	1.49	0.00	0.00	0.16	0.69	0.14	0.00	70.60
TRN-1	18	OB	2	4	1	0.09	3.36	0.00	0.00	19.24	0.00	8.39	46.69	31.41	7.34	0.20	0.27	0.08	0.00	0.85	0.00	0.00	0.11	37.81	0.33	1.21	157.81
TRN-1	30	OB	3	9	1	0.03	3.98	1.10	0.04	7.62	0.00	60.57	19.27	29.73	118.14	0.00	0.64	3.87	0.00	3.46	0.00	0.02	3.53	30.64	0.49	0.36	285.08
TRN-2	8	OB	4	12	1	0.02	1.34	2.10	0.00	10.03	0.00	0.00	0.92	15.73	0.61	0.69	0.00	0.00	0.00	0.00	0.50	12.13	0.23	6.89	0.00	1.95	56.30
TRN-2	19	OB	5	15	1	0.00	1.10	0.00	0.00	0.00	8.41	0.00	16.24	44.38	4.41	0.02	0.14	0.38	0.00	9.59	0.00	1.73	0.02	24.13	0.02	0.00	111.66
TRN-2	28	OB	6	19	1	0.43	3.29	0.00	0.00	3.43	0.17	0.00	2.50	26.48	40.62	0.09	0.64	1.63	0.11	3.32	0.00	0.00	0.57	40.57	0.08	0.30	126.84
TRN-2	47	OB	7	23	1	0.20	17.74	0.00	0.00	4.65	0.00	0.00	15.64	26.46	52.08	0.16	7.93	3.81	0.52	3.14	0.00	0.00	20.20	10.65	0.31	0.38	184.17
TRN-3	9	OB	8	27	1	0.25	4.45	0.00	0.00	0.00	0.00	0.00	0.90	38.62	43.52	2.10	0.03	0.56	5.29	0.00	0.00	3.19	1.60	38.79	0.14	0.98	153.34
TRN-3	18	OB	9	30	1	0.55	8.43	2.05	0.00	0.00	0.00	0.00	0.97	32.43	25.27	0.05	0.63	0.23	1.82	0.45	0.00	0.00	0.36	11.77	0.27	0.61	91.66
TRN-3	28	OB	10	34	1	0.04	15.73	1.70	0.00	0.00	0.00	0.00	0.00	30.49	64.35	0.05	2.00	0.64	2.36	2.05	0.00	0.00	0.97	6.12	0.13	0.00	129.15
TRN-3	45	OB	11	38	1	0.00	13.57	0.00	0.00	0.00	0.00	0.00	25.51	19.02	45.49	0.11	9.26	1.85	0.52	0.35	0.00	0.00	5.53	2.26	0.25	0.00	127.40
TRN-4	8	OB	12	42	1	0.03	3.90	6.75	0.00	0.00	0.00	0.00	0.00	25.60	62.54	4.65	0.17	0.29	0.00	0.00	0.00	3.81	0.12	4.48	0.06	0.00	114.02
TRN-4	18	OB	13	45	1	0.06	33.52	0.30	0.86	0.00	0.00	0.00	7.03	33.63	152.39	0.58	1.16	1.33	1.12	2.51	0.00	0.09	1.77	48.36	0.64	0.00	288.75
TRN-4	28	OB	14	49	1	0.28	18.32	1.74	0.38	0.00	0.35	0.00	0.39	29.69	38.53	0.03	0.79	0.75	4.69	2.17	0.00	0.00	1.27	18.48	0.14	0.00	120.23
TRN-4	40	OB	15	53	1	1.15	15.45	0.00	0.00	0.00	0.00	1.84	3.22	20.69	40.71	0.02	4.24	0.66	0.00	0.52	0.00	0.00	2.97	9.90	0.39	0.47	108.01
TRN-5	9	OB	16	58	1	0.15	0.00	7.01	0.03	36.94	0.00	0.00	0.53	27.00	1.38	6.60	0.00	0.00	0.00	0.00	0.00	2.41	0.21	1.58	0.03	0.00	92.25
TRN-5	18	OB	17	61	1	0.00	6.81	0.94	0.00	0.00	4.16	0.00	38.60	47.52	13.61	0.05	6.00	1.44	1.49	1.98	0.00	0.11	1.84	82.74	0.02	0.31	210.91
TRN-5	20	OB	18	66	1	0.61	15.06	0.00	0.00	3.50	0.00	0.00	0.61	61.47	19.28	0.02	0.18	0.27	0.14	12.88	0.00	0.00	0.10	30.84	0.03	9.13	158.02
TRN-6	40	OB	19	70	1	0.27	16.30	0.00	0.00	0.23	0.00	2.69	4.98	55.56	92.66	0.01	2.81	4.18	1.52	4.26	0.00	0.00	2.19	27.13	0.19	0.88	217.15
TRN-6	39	OB	20	74	1	0.21	12.33	2.59	0.00	0.00	0.00	0.53	6.09	26.27	63.60	0.25	1.40	2.50	0.00	19.95	0.00	0.00	0.75	28.73	0.07	1.83	171.27
TRN-6	26	OB	21	78	1	0.67	49.89	2.11	0.04	0.00	0.63	0.00	2.51	27.46	121.83	0.57	0.81	1.60	0.82	0.00	16.77	0.00	1.83	43.72	0.38	8.70	286.20
TRN-6	18	OB	22	82	1	0.66	27.88	0.41	0.00	0.00	0.00	0.00	1.05	34.83	71.11	0.25	0.16	0.30	0.69	26.22	0.00	0.00	0.54	62.62	0.13	8.86	244.44
TRN-6	8	OB	23	86	1	0.15	5.70	0.46	0.00	0.00	2.01	0.00	4.58	24.38	7.22	0.03	0.06	0.77	0.00	12.02	0.00	0.34	0.00	33.09	0.00	1.36	97.30
TRN-7	38	OB	24	89	1	0.32	15.93	5.64	0.00	0.65	0.00	0.00	4.70	128.36	86.20	0.94	2.54	1.43	6.14	15.67	0.00	0.00	3.88	57.22	0.27	2.23	342.96
TRN-7	26	OB	25	93	1	0.42	11.24	0.22	0.00	0.00	0.00	0.00	1.86	28.65	160.00	0.00	0.63	0.31	0.68	14.64	0.00	0.00	0.16	46.07	0.13	2.80	276.39
TRN-7	18	OB	26	97	1	0.26	119.10	2.45	0.00	0.00	0.00	0.00	17.69	52.74	170.81	0.04	2.20	0.82	0.00	6.45	0.00	1.61	0.75	42.26	0.18	1.25	421.20
TRN-7	10	OB	27	101	1	0.46	5.28	5.83	0.40	123.82	0.06	0.00	20.81	24.45	9.16	6.03	0.23	0.00	0.00	0.34	0.00	14.04	0.77	6.63	0.03	0.00	218.89
TRN-8	14	OB	28	104	1	1.58	7.47	0.98	7.97	0.00	0.00	0.00	2.61	105.75	53.85	0.42	0.03	1.35	5.78	17.73	0.00	0.42	0.00	50.74	0.00	0.00	265.80
TRN-8	18	OB	29	108	1	0.38	5.40	0.72	0.00	0.00	0.00	2.81	7.06	77.04	29.99	0.00	0.05	0.26	3.84	28.63	0.00	1.18	0.05	37.77	0.05	1.85	203.12
TRN-8	25	OB	30	112	1	0.65	41.56	0.09	0.03	2.36	0.00	0.24	0.70	32.38	92.29	0.06	0.38	2.37	0.00	107.62	0.00	0.00	0.66	55.30	0.25	1.98	341.92

[a] 1 = Shallow Cold Saline, 2 = Mackenzie Influenced, 3 = Outer Shelf Arctic

APPENDIX 5.27. Biomass (mg/m^3) of the dominant zooplankton groups in oblique (OB) bongo tows in the eastern Alaskan Beaufort Sea, Sept 2000.

Transect	Depth (m)	Tow Type	Sta. No.	Samp. No.	Water Mass[a]	Ctenophores Cnidarians	Copepods	Amphipods	Euphausiids	Mysids	Decapods	Chaetognath	Larvaceans	Fish	Other	Total
TRN-1	10	OB	1	1	1	36.28	31.85	0.00	1.49	0.00	0.00	0.85	0.14	0.00	0.00	70.60
TRN-1	18	OB	2	4	1	77.89	39.35	0.08	0.85	0.00	0.12	37.92	0.33	1.21	0.05	157.81
TRN-1	30	OB	3	9	1	92.61	149.48	3.93	3.46	0.02	0.05	34.16	0.49	0.86	0.00	285.08
TRN-2	8	OB	4	12	1	14.41	17.07	0.04	0.50	12.13	0.33	7.12	0.00	4.67	0.04	56.30
TRN-2	19	OB	5	15	1	25.75	49.35	0.83	9.59	1.73	0.24	24.14	0.02	0.00	0.00	111.66
TRN-2	28	OB	6	19	1	9.82	68.66	2.14	3.32	0.00	0.52	41.14	0.08	1.15	0.00	126.84
TRN-2	47	OB	7	23	1	54.98	89.54	4.59	3.14	0.00	0.03	30.84	0.31	0.38	0.34	184.17
TRN-3	9	OB	8	27	1	10.83	84.31	9.18	0.00	3.19	0.11	40.39	0.14	5.18	0.01	153.34
TRN-3	18	OB	9	30	1	16.30	58.87	2.86	0.45	0.00	0.08	12.13	0.27	0.61	0.08	91.66
TRN-3	28	OB	10	34	1	18.22	98.59	3.00	2.05	0.00	0.06	7.09	0.13	0.00	0.02	129.15
TRN-3	45	OB	11	38	1	39.08	77.40	2.37	0.35	0.00	0.15	7.79	0.25	0.00	0.01	127.40
TRN-4	8	OB	12	42	1	10.67	93.14	1.37	0.00	3.81	0.38	4.60	0.06	0.00	0.00	114.02
TRN-4	18	OB	13	45	1	41.77	189.56	2.65	2.51	0.09	1.20	50.13	0.64	0.06	0.14	288.75
TRN-4	28	OB	14	49	1	21.47	69.38	5.60	2.17	0.00	0.72	19.75	0.14	0.00	1.00	120.23
TRN-4	40	OB	15	53	1	25.10	66.89	0.80	0.52	0.00	0.45	12.87	0.39	0.47	0.52	108.01
TRN-5	9	OB	16	58	1	45.13	35.36	0.26	0.00	2.41	0.00	1.79	0.03	7.28	0.00	92.25
TRN-5	18	OB	17	61	1	50.52	67.26	3.23	1.98	0.11	2.07	84.57	0.02	1.14	0.00	210.91
TRN-5	20	OB	18	66	1	19.78	80.94	0.58	12.88	0.00	3.44	30.94	0.03	9.13	0.31	158.02
TRN-6	40	OB	19	70	1	24.53	151.33	5.92	4.26	0.00	0.68	29.32	0.19	0.88	0.04	217.15
TRN-6	39	OB	20	74	1	21.76	92.35	2.69	19.95	0.00	2.49	29.48	0.07	2.25	0.25	171.27
TRN-6	26	OB	21	78	1	55.84	150.75	3.11	16.77	0.00	2.41	45.55	0.38	9.82	1.56	286.20
TRN-6	18	OB	22	82	1	30.02	107.73	1.14	26.22	0.00	4.82	63.16	0.13	8.86	2.35	244.44
TRN-6	8	OB	23	86	1	12.92	31.88	1.02	12.02	0.34	0.12	33.09	0.00	5.92	0.00	97.30
TRN-7	38	OB	24	89	1	27.25	218.75	8.06	15.67	0.00	0.67	61.10	0.27	10.42	0.76	342.96
TRN-7	26	OB	25	93	1	13.74	190.97	1.25	14.64	0.00	4.25	46.22	0.13	4.67	0.52	276.39
TRN-7	18	OB	26	97	1	139.50	227.55	1.05	6.45	1.61	0.31	43.01	0.18	1.25	0.29	421.20
TRN-7	10	OB	27	101	1	156.66	40.36	0.00	0.34	14.04	0.06	7.41	0.03	0.00	0.00	218.89
TRN-8	14	OB	28	104	1	22.16	160.21	7.57	17.73	0.42	0.21	50.74	0.00	6.68	0.08	265.80
TRN-8	18	OB	29	108	1	16.38	107.97	4.55	28.63	1.18	1.25	37.81	0.05	1.85	3.46	203.12
TRN-8	25	OB	30	112	1	45.62	125.12	2.80	107.62	0.00	2.55	55.96	0.25	1.98	0.01	341.92

[a] 1 = Shallow Cold Saline, 2 = Mackenzie Influenced, 3 = Outer Shelf Arctic

APPENDIX 5.28. Biomass (mg/m^3) of the dominant zooplankton groups in horizontal (HB) bongo tows in the eastern Alaskan Beaufort Sea, Sept 2000.

Transect	Depth (m)	Tow Type	Sta. No.	Samp. No.	Water Mass[a]	Ctenophores Hydrozoans	Copepods	Amphipods	Euphausiids	Mysids	Chaetognaths	Larvaceans	Fish	Other	Total
TRN-1	8	HB	1	3	1	61.38	78.51	0.89	0.43	0.68	0.52	0.09	2.48	0.47	145.46
TRN-1	6	HB	2	6	1	34.07	45.88	1.16	0.65	1.25	37.12	0.30	0.79	0.10	121.33
TRN-1	6	HB	2	7	1	22.88	58.10	0.32	0.11	0.00	39.33	0.13	0.07	0.14	121.09
TRN-1	28	HB	3	10	1	25.98	102.90	9.69	5.46	0.00	28.70	0.22	0.48	0.07	173.51
TRN-1	10	HB	3	11	1	8.68	31.29	0.46	0.00	0.00	1.64	0.03	2.89	0.01	45.01
TRN-2	7	HB	4	14	1	39.20	42.03	0.64	1.33	14.23	16.74	0.41	1.73	0.13	116.45
TRN-2	17	HB	5	17	1	51.01	46.63	2.30	14.45	4.76	109.90	1.21	2.88	0.78	233.92
TRN-2	11	HB	5	18	1	25.04	68.35	0.14	0.03	0.06	12.89	0.07	0.77	0.12	107.47
TRN-2	27	HB	6	21	1	14.90	168.73	1.78	11.36	0.00	20.75	0.20	1.24	0.45	219.41
TRN-2	10	HB	6	22	1	7.79	38.93	0.66	0.00	0.00	1.69	0.01	0.72	0.50	50.30
TRN-2	45	HB	7	25	1	14.60	79.71	1.62	0.77	0.00	66.30	2.16	0.37	0.21	165.74
TRN-2	15	HB	7	26	1	189.24	79.44	1.24	0.00	0.00	5.58	0.25	0.00	0.76	276.51
TRN-3	9	HB	8	29	1	47.94	188.10	5.85	0.49	0.87	100.57	0.18	0.20	1.60	345.80
TRN-3	15	HB	9	32	1	80.53	105.09	0.97	0.53	0.00	48.38	0.17	0.12	0.15	235.92
TRN-3	7	HB	9	33	1	2.70	61.68	2.09	0.00	0.00	3.55	0.49	2.19	0.33	73.03
TRN-3	25	HB	10	36	1	48.02	95.15	4.78	4.58	0.00	22.54	0.06	0.00	0.03	175.17
TRN-3	7	HB	10	37	1	25.30	66.35	10.88	0.00	0.05	3.06	0.01	0.54	0.20	106.40
TRN-3	43	HB	11	40	1	10.08	150.15	4.64	2.00	0.00	16.97	1.76	0.00	0.06	185.66
TRN-3	15	HB	11	41	1	33.16	46.39	8.82	0.00	0.00	3.68	0.03	0.00	0.53	92.61
TRN-4	8	HB	12	44	1	15.29	303.21	1.08	1.01	11.81	5.94	0.02	0.55	0.03	338.95
TRN-4	16	HB	13	47	1	81.98	153.15	2.48	3.12	0.00	52.15	0.49	0.00	0.60	293.97
TRN-4	6	HB	13	48	1	59.37	135.03	5.73	1.90	0.00	48.34	0.32	0.23	5.10	256.01
TRN-4	22	HB	14	51	1	23.90	81.44	4.55	0.00	0.00	26.48	0.28	0.00	0.53	137.17
TRN-4	8	HB	14	52	1	15.48	41.64	8.38	0.00	0.00	1.49	0.83	0.00	3.47	71.28
TRN-4	35	HB	15	55	1	11.51	72.99	2.84	0.00	0.00	9.76	0.08	0.00	0.13	97.30
TRN-4	15	HB	15	56	1	72.85	109.12	3.99	0.00	0.00	12.61	0.16	3.64	1.59	203.96
TRN-4	7	HB	15	57	1	5.55	68.13	2.13	0.00	0.00	10.17	0.29	2.62	0.28	89.17
TRN-5	9	HB	16	60	1	36.53	76.69	0.53	0.09	1.85	7.11	0.03	2.86	0.11	125.80
TRN-5	18	HB	17	63	1	48.88	49.49	4.39	3.16	3.63	336.56	0.06	3.73	0.76	450.65
TRN-5	9	HB	17	64	1	20.34	98.67	1.33	0.00	0.52	101.78	0.03	2.20	2.01	226.88
TRN-5	5	HB	17	65	1	15.47	136.23	0.42	0.00	0.00	56.22	0.03	0.42	0.62	209.42
TRN-5	15	HB	18	68	1	52.31	41.79	1.68	34.37	1.91	32.10	0.07	8.74	2.83	175.78
TRN-5	6	HB	18	69	1	12.90	33.50	1.21	0.00	0.00	3.09	0.03	4.94	1.93	57.60
TRN-6	30	HB	19	72	1	110.62	322.51	6.82	2.23	0.00	53.08	0.38	2.99	0.86	499.50
TRN-6	5	HB	19	73	1	11.08	36.65	0.21	0.00	0.00	0.49	2.33	3.05	0.54	54.37
TRN-6	28	HB	20	76	1	14.66	212.57	2.59	71.98	0.00	39.62	0.09	0.00	0.64	342.16
TRN-6	10	HB	20	77	1	2.73	36.39	0.66	0.70	0.00	9.42	0.33	13.10	2.48	65.81
TRN-6	22	HB	21	80	1	32.65	71.49	3.47	63.03	0.00	59.46	0.26	8.25	3.10	241.71
TRN-6	8	HB	21	81	1	183.99	113.30	3.26	1.06	0.00	25.15	0.15	6.30	15.37	348.58
TRN-6	17	HB	22	84	1	21.44	87.69	3.82	90.59	0.98	287.83	0.16	4.83	14.49	511.84
TRN-6	6	HB	22	85	1	36.94	112.47	0.88	0.55	0.00	17.80	0.35	26.53	4.13	199.65
TRN-6	8	HB	23	88	1	19.05	71.60	0.64	46.83	0.07	46.73	0.00	9.51	0.21	194.64
TRN-7	34	HB	24	91	1	452.42	209.85	5.51	13.55	0.00	55.61	0.79	1.13	11.19	750.04
TRN-7	8	HB	24	92	1	2.98	36.32	1.66	0.00	0.00	2.19	0.38	0.00	0.78	44.32
TRN-7	24	HB	25	95	1	82.99	413.43	3.11	62.20	0.00	156.81	0.38	11.41	1.05	731.39
TRN-7	8	HB	25	96	1	21.44	203.53	1.09	0.00	0.00	16.83	0.43	4.07	0.51	247.91
TRN-7	10	HB	26	99	1	311.36	323.05	0.60	2.19	0.00	76.87	0.06	4.13	5.73	723.99
TRN-7	5	HB	26	100	1	115.49	514.09	0.94	0.00	0.00	7.55	0.40	0.30	0.30	639.06
TRN-7	9	HB	27	103	1	213.11	203.96	1.32	0.61	2.66	34.62	0.00	4.42	1.63	462.31
TRN-8	5	HB	28	107	1	6.52	148.58	7.95	0.75	0.00	1.27	0.09	0.27	0.68	166.10
TRN-8	11	HB	28	106	1	135.13	61.75	10.94	3.57	2.48	56.95	0.01	1.49	1.05	273.35
TRN-8	6	HB	29	111	1	8.03	110.68	0.96	0.82	0.00	3.29	0.32	1.52	0.55	126.17
TRN-8	13	HB	29	110	1	21.27	53.74	5.49	15.95	1.17	13.11	0.20	3.86	2.50	117.28
TRN-8	6	HB	30	115	1	2.28	47.60	0.44	0.00	0.00	0.16	0.12	17.08	0.12	67.80
TRN-8	18	HB	30	114	1	89.83	107.19	4.02	189.00	2.53	99.20	0.49	2.30	3.38	497.95

[a] 1 = Shallow Cold Saline, 2 = Mackenzie Influenced, 3 = Outer Shelf Arctic

APPENDIX 5.29. Biomass (mg/m^3) of the dominant zooplankton groups in surface (SB) bongo tows in the eastern Alaskan Beaufort Sea, Sept 2000.

Transect	Depth (m)	Tow Type	Sta. No.	Samp. No.	Water Mass[a]	Ctenophores Cnidarians	Copepods	Amphipods	Euphausiids	Mysids	Chaetognaths	Larvaceans	Fish	Other	Total
TRN-1	1	SB	1	2	1	9.34	5.07	0.04	0.00	0.00	0.01	0.02	0.21	0.00	14.68
TRN-1	1	SB	2	5	1	0.16	1.34	0.04	0.00	0.00	0.00	0.01	0.00	0.00	1.54
TRN-1	1	SB	3	8	1	4.62	1.74	0.52	0.00	0.00	0.17	0.02	0.03	0.02	7.12
TRN-2	1	SB	4	13	1	19.04	6.58	0.12	0.00	0.42	12.42	0.02	0.00	0.17	38.77
TRN-2	1	SB	5	16	1	3.52	2.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	5.52
TRN-2	1	SB	6	20	1	16.01	8.33	0.45	0.00	0.00	0.01	0.00	0.00	0.01	24.79
TRN-2	1	SB	7	24	1	4.64	3.65	0.85	0.00	0.00	0.23	0.00	0.00	0.00	9.37
TRN-3	1	SB	8	28	1	9.06	23.21	3.58	0.00	0.03	0.29	0.02	0.00	0.11	36.30
TRN-3	1	SB	9	31	1	0.48	0.73	0.48	0.00	0.00	0.05	0.05	0.00	0.00	1.79
TRN-3	1	SB	10	35	1	2.65	2.23	0.09	0.00	0.00	0.01	0.01	0.00	0.00	5.00
TRN-3	1	SB	11	39	1	0.11	0.94	0.04	0.00	0.00	0.02	0.01	0.00	0.00	1.12
TRN-4	1	SB	12	43	1	1.75	43.67	0.55	0.00	0.32	0.17	0.03	0.00	0.14	46.62
TRN-4	1	SB	13	46	1	2.28	39.66	0.72	0.00	0.02	0.66	0.27	0.00	0.03	43.63
TRN-4	1	SB	14	50	1	0.01	1.48	0.00	0.00	0.00	0.01	0.01	0.00	0.01	1.52
TRN-4	1	SB	15	54	1	0.89	1.06	0.06	0.00	0.00	0.00	0.00	0.00	0.00	2.01
TRN-5	1	SB	16	59	1	24.49	23.17	0.00	0.00	0.00	1.93	0.00	0.00	0.01	49.59
TRN-5	1	SB	17	62	1	9.35	26.39	0.06	0.00	0.00	4.35	0.01	0.00	0.03	40.19
TRN-5	1	SB	18	67	1	14.87	30.31	0.34	0.00	0.00	0.36	0.01	0.00	0.01	45.90
TRN-6	1	SB	19	71	1	6.43	31.04	0.16	0.00	0.00	0.01	0.04	0.00	0.00	37.68
TRN-6	1	SB	20	75	1	7.50	9.86	0.33	0.00	0.00	0.06	0.26	0.00	0.04	18.04
TRN-6	1	SB	21	79	1	2.88	4.26	0.00	0.40	0.00	0.06	0.09	0.00	0.00	7.70
TRN-6	1	SB	22	83	1	1.01	10.34	0.12	0.00	0.00	0.31	0.01	0.00	0.26	12.06
TRN-6	1	SB	23	87	1	29.66	51.17	0.21	0.24	0.00	28.35	0.00	0.82	0.04	110.49
TRN-7	1	SB	24	90	1	0.79	22.75	0.14	0.00	0.00	0.05	0.01	0.00	0.01	23.75
TRN-7	1	SB	25	94	1	1.10	9.80	0.22	0.00	0.00	0.13	0.01	0.00	0.00	11.26
TRN-7	1	SB	26	98	1	5.72	30.68	0.11	0.00	0.00	0.11	0.05	0.00	0.00	36.67
TRN-7	1	SB	27	102	1	3.65	0.89	0.00	0.00	0.00	0.05	0.00	0.29	0.12	4.99
TRN-8	1	SB	28	105	1	6.26	105.85	0.36	0.00	0.00	0.08	0.00	0.00	0.06	112.61
TRN-8	1	SB	29	109	1	0.12	4.91	0.07	0.00	0.00	0.01	0.00	0.00	1.25	6.35
TRN-8	1	SB	30	113	1	0.95	0.45	0.36	0.60	0.00	0.03	0.00	0.00	0.00	2.38

[a] 1 = Shallow Cold Saline, 2 = Mackenzie Influenced, 3 = Outer Shelf Arctic

6. ZOOPLANKTON AND WATER MASSES AT BOWHEAD WHALE FEEDING LOCATIONS IN THE EASTERN BEAUFORT SEA

William B. Griffiths[1], Denis H. Thomson [2] and Michael S.W. Bradstreet [2,3]

Introduction

Bowhead whales of the Bering–Chukchi–Beaufort (BCB) stock winter in the Bering Sea and annually migrate to summering areas in the Beaufort Sea and Amundsen Gulf (Moore and Reeves 1993). It has traditionally been assumed that bowheads, like other mysticete whales, feed primarily during summer and autumn (Lowry 1993). If so, a primary reason for the annual migration to the Beaufort Sea would be to reach preferred feeding areas. This would imply that summering areas are rich in food, and important to the whales that travel a round-trip distance of several thousand kilometers to feed in those areas.

Many BCB bowhead whales arrive in Canadian waters in June. At that time at least part of the population is present in the extreme eastern Beaufort Sea and Amundsen Gulf area, having traveled from Point Barrow, Alaska, to Banks Island through offshore waters where there are cracks and leads in the ice (Braham et al. 1984; Moore and Reeves 1993). By early to mid August, bowheads are present in inshore waters of the Canadian Beaufort Sea, near the Bathurst and Tuktoyaktuk Peninsulas, Mackenzie Delta, and/or Yukon coast. In some years, many bowheads remain in those areas until well into September (Richardson et al. 1987; Moore and Reeves 1993). Behavioral observations indicate that they spend a considerable amount of time feeding in the Canadian Beaufort Sea (Würsig et al. 1985, 1989; Dorsey at al. 1989; see also Chapter 12).

The eastern part of the Alaskan Beaufort Sea may represent a western extension of the late-summer feeding range for bowhead whales. The westward migration of bowhead whales along the Beaufort Sea coast starts in August, when many bowheads in the Canadian Beaufort Sea begin to move gradually west, and when bowheads start to appear along the Alaskan coast. Feeding whales have been observed in the eastern Alaskan Beaufort Sea during the late summer/early autumn period in each of the five years of this study, though with widely varying frequencies in different years (Chapters 9, 12). The overall sighting rates of bowheads in the eastern Alaskan Beaufort Sea during late summer and early autumn were substantially higher in 1990–2000 than in the 1980s, although widely variable among years (Chapter 9).

Bowhead whales and the closely related right whales are filter feeders. Their feeding apparatus allows them to feed while moving through the water (Pivorunas 1979). They feed on zooplankton. Copepods were the dominant food items (by volume) in 13 of 21 stomach samples from bowhead whales harvested in the eastern Alaskan Beaufort Sea in autumn, while euphausiids were dominant in 5 of 21 stomachs; mysids and amphipods occasionally were important (Lowry and Sheffield, Chapter 18). In contrast, stomachs of bowheads harvested in autumn some 500 km farther west, near Barrow, Alaska, were dominated by euphausiids (Chapter 18).

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[1] LGL Ltd., environmental research associates, 9768 Second St., Sidney, B.C. V8L 3Y8. *Phone:* 250-656-0127; *e-mail:* bgriff@lgl.com

[2] LGL Ltd., environmental research associates, 22 Fisher St., POB 280, King City, Ont. L7B 1A6. *Phone:* 905-833-1244. *e-mail:* dthomson@lgl.com

[3] Present address of MSWB: Bird Studies Canada, P.O. Box 160, Port Rowan, Ont. N0E 1M0. *Phone:* 519-586-3531; *e-mail:* mbradstreet@bsc-eoc.org

The purposes of this study were (1) to describe the characteristics of bowhead feeding areas in the eastern Alaskan Beaufort Sea, with emphasis on the zooplankton and water masses found there; (2) to determine whether bowhead whales feed in areas where zooplankton is concentrated; and (3) to determine the quantity and kinds of zooplankton associated with feeding bowhead whales. This study was one part of a broader investigation of the importance of the eastern part of the Alaskan Beaufort Sea for feeding by bowhead whales. The study included field sampling during September of five years, 1985–86 and 1998–2000 (Table 6.1). In addition, similar studies were conducted during 1980, 1981, 1985 and 1986 farther east in the Canadian part of the Beaufort Sea, where most BCB bowhead whales summer. In this analysis, we use results from both of these areas to document characteristics of bowhead feeding areas.

Methods

In the Eastern Alaskan Beaufort Sea, zooplankton was sampled at 21 stations where bowhead whales were either observed feeding or where whales had been observed feeding the previous day (Table 6.1; Fig. 6.1A; Appendix 6.1).[4] Feeding bowheads were not encountered during zooplankton sampling in that area in September 1985 and 2000. Zooplankton was sampled at other stations along systematic transects during all five years (see Griffiths and Thomson, Chapter 5). Aircraft-based observers guided the sampling boat to feeding whales seen during aerial reconnaissance, systematic aerial surveys, or systematic aerial observations of whale behavior, as described in Chapters 9–12. On 7 occasions, whales were still present when the boat arrived on site, in which case sampling was conducted near bowheads observed from the boat. In other cases, the whales had departed by the time the boat arrived and sampling was conducted at locations transmitted to the boat by aerial observers. For each feeding station sampled, a "control" station was also sampled about 8 to 10 km from the feeding station.

In the Canadian Beaufort Sea, zooplankton near feeding bowheads was sampled at a total of 16 stations (Table 6.1; Fig. 6.1B). Sampling in late August and early September of 1980, and August 1981, was conducted during an BLM-sponsored study of the behavior of bowhead whales. The project aircraft directed the boat to areas where whales were observed to be feeding. In 1985 and 1986, the boat sampled in areas where bowhead whales were seen from the boat. In addition, in 1986, samples taken along systematic transects at places where no whales were seen from the boat were later classified as being in (or not in) one of two large areas—diameter 40 and 100 km—where whales were often observed during concurrent aerial surveys by Ford et al. (1987). In 1988, zooplankton was sampled opportunistically at a single whale feeding station off Shingle Point, along the Yukon coast, during a zooplankton study.

Temperature and Salinity Measurements

Vertical profiles of temperature and salinity were obtained at all systematic sampling stations, except for the single station off Shingle Point in 1988. In the Canadian Beaufort, we used a Hydrolab System 8000 in 1980–81 and a System 4021 in 1985, and an Applied Microsystems CTD-12 (CTD = Conductivity–Temperature–Depth) in 1986. The CTD-12 was also used in the Alaskan Beaufort Sea in

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[4] In 1986, the vessel that sampled in the eastern Alaskan Beaufort Sea also sampled near bowheads feeding off the Yukon coast west of Herschel Island on two dates (4 and 7 Sept.; Fig. 6.1A). Sampling at these two stations 50 and 5 km into Canada employed the same methods as in Alaska, not the methods used farther east in the Canadian Beaufort Sea in 1986. Subsequent references to sampling in the eastern Alaskan Beaufort during 1986 include these two stations. However, whales were seen from the boat at only 1 of these 2 stations—the one 5 km into Canada. Thus, analyses of zooplankton at stations where whales were seen from the boat use data from Alaskan waters plus one station ~5 km into Canada. All sampling described as being in the Canadian Beaufort was east of Herschel Island.

TABLE 6.1. Summary of sampling effort in the Canadian and Eastern Alaskan Beaufort Sea, showing the dates of sampling, vessels used, and kind of guidance received by the vessels. "# Stations" refers to stations near bowhead whales; many additional stations without whales were also sampled.

Year	Dates	# Stations	Vessel (LOA)[1]	Positioning	Aerial guidance	References
Canadian Beaufort Sea (east of Herschel Isl.)						
1980	14-26 Aug	1	*Ungaluk* (14 m), zodiac *Imperial Sarpik* (21 m)	NavSat, theodolite radar	Search and direction	Griffiths and Buchanan 1982
1981	31Jul-25 Aug	3	*Sequel* (12.5 m)	Radar, NavSat	Search and direction	Griffiths and Buchanan 1982
1985	23-30 Aug	4	*Sequel* (12.5 m)	Radar, NavSat	Surveys in area	Bradstreet and Fissel 1986
1986	28 Aug-8 Sep	7	*Arctic Ivik* (67 m)	NavSat	Surveys in area	Bradstreet et al. 1987
1988	12 Sep	1	Boston whaler (7 m)	Dead reckoning	None	LGL Limited, Unpublished Data
Eastern Alaskan Beaufort Sea (and east to Herschel Isl.)[2]						
1985	1-20 Sep	0	*Annika Marie* (13 m)	NavSat	Search and direction	Griffiths et al. 1987; Johnson and Griffiths 1990; Chapter 5
1986	4-19 Sep	6	*Annika Marie* (13 m)	NavSat	Search and direction	Griffiths et al. 1987; Johnson and Griffiths 1990; Chapter 5
1998	11-22 Sep	10	*Annika Marie* (13 m)	GPS	Search and direction	Chapter 5
1999	16-22 Sep	5	*Annika Marie* (13 m)	GPS	Search and direction	Chapter 5
2000	10-21 Sep	0	*Annika Marie* (13 m)	GPS	Search and direction	Chapter 5

[1] Length overall

[2] Locations are shown in Appendix 6.1

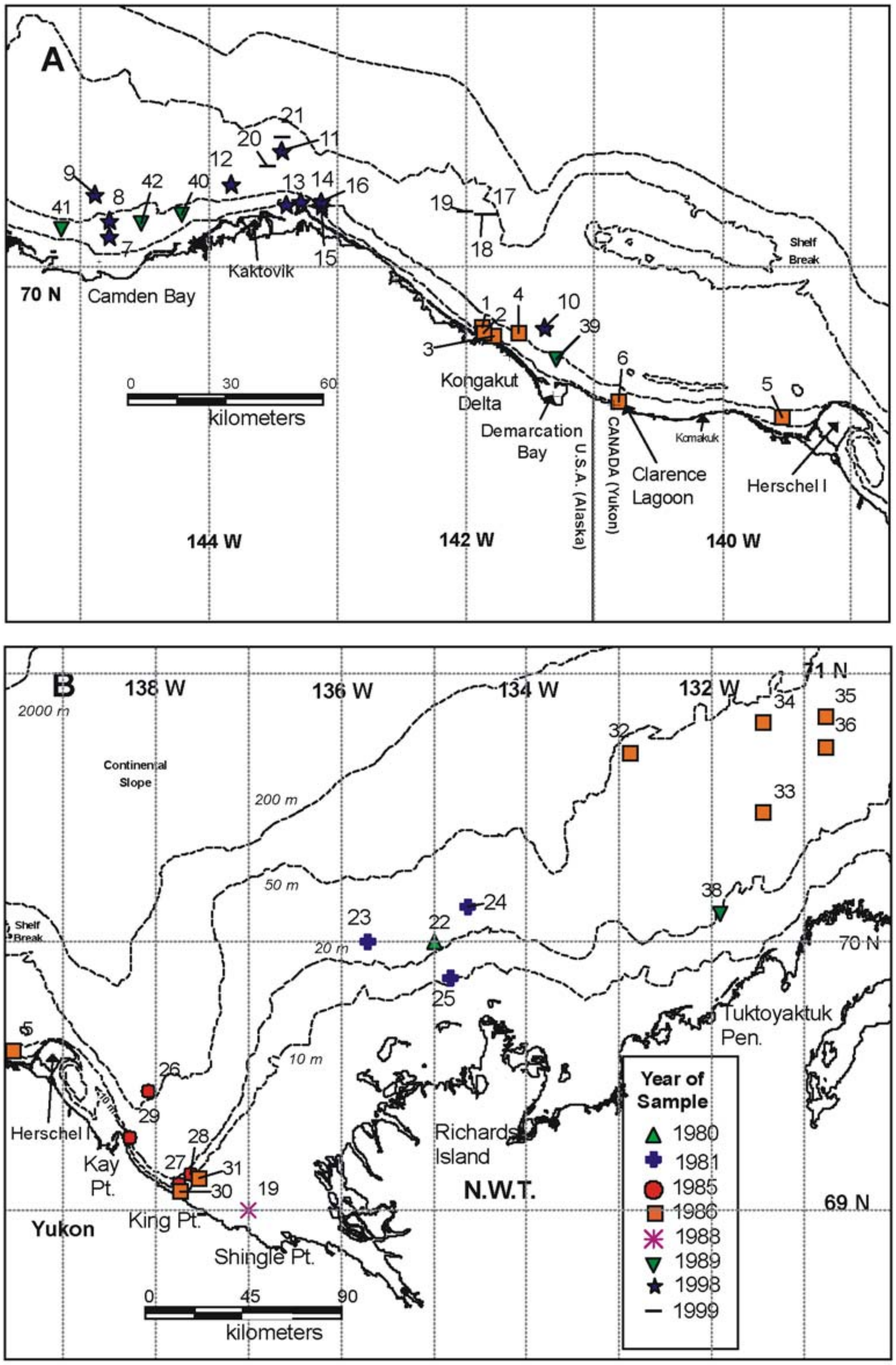

FIGURE 6.1. Locations of sampling near feeding bowhead whales ***(A)*** in and near Alaskan Beaufort Sea, and ***(B)*** in Canadian Beaufort Sea from Herschel Island eastward. Details about each station are shown in Appendices 6.1 and 6.3.

1985–86, and a digital Sea-Bird SBE 19 was used in 1998–2000. Methods for deploying the instruments and for retrieving and analyzing the data are described by Griffiths (Chapter 4) and Griffiths and Thomson (Chapter 5). They also describe the accuracy of the meters.

Zooplankton Sampling

***1981–86 and 1998–2000*.—**In 1981, 1985, and 1998–2000, oblique and horizontal zooplankton tows were made using a standard bongo assembly towed behind the boat. In 1986, standard bongo nets were used in the Canadian Beaufort and for oblique and surface tows in the eastern Alaskan Beaufort. However, horizontal tows in Alaska in 1986 were taken with a Tareq opening and closing bongo assembly. In all cases, the bongo frame was fitted with two 0.5 mm mesh, 0.61 m diameter, plankton nets and a General Oceanics Inc. model 2030 flow meter. The horizontal tows were targeted to specific depths where an echosounder showed an apparent zooplankton concentration. We used a 200 kHz Ross Fine Line 250-M echosounder in the Canadian Beaufort Sea in 1981, 1985 and 1986, and Biosonics 200–430 kHz units (described later) in the eastern Alaskan Beaufort Sea in 1985–86 and 1998–2000. In 1985 and 1986, the depth of each horizontal tow in both the Alaskan and Canadian studies was recorded in real time using an upward-looking depth sounder (Apelco Ranger model 1650) attached to the bongo frame. In 1998–2000, the depth of the net during the tow was calculated using wire angle and the amount of wire out. The actual depth profile of each 1998–2000 tow was determined later from data recorded with a Wildlife Computers dive recorder (Model Mk7-S) attached to the bongo frame. In 1981, net sampling depth was determined by measuring wire angle and the amount wire out.

In 1981, 1985–86 and 1998–2000, in all areas, horizontal tows lasted five minutes from the time the net reached the desired depth. The net was lowered and retrieved slowly while the boat was moving slowly to minimize sampling during ascent and descent. During the 1986 horizontal sampling in the eastern Alaskan Beaufort, the net was open only when at the target depth.

Oblique tows were made by lowering the net to a depth near the bottom, raising it, and repeating the process a second time, while the boat was moving. In areas deeper than 100 m, oblique tows were to a maximum depth of 100 m.

The entire sample from one of the paired bongo nets was preserved in 10% formalin for analyses of zooplankton biomass and numbers. Sub-samples from the other net were frozen and later sent to other researchers for analyses of caloric, isotopic, and/or fatty acid content.

***1980 and 1988*.—**Sampling in these two years was less systematic. In 1980, vertical tows were taken using a 60 cm diameter plankton net with 0.5 mm mesh and an Inter Ocean model 313 flowmeter. In 1988, a 0.5-mm mesh, 0.25-m diameter zooplankton net equipped with a General Oceanics Inc. model 2030 flow meter was used. Only shallow vertical tows and shallow horizontal tows were done in 1988, given that the whales observed at this station were feeding at the surface.

Hydroacoustic Sampling

***Eastern Alaskan Study Area*.—**Quantitative echosounder surveys were conducted between whale feeding and control stations during September of 1986, 1999 and 2000, and along other transects in that area during all five field seasons. Methods are described in Johnson and Griffiths (1990), Griffiths (Chapter 4), and Griffiths and Thomson (Chapter 5). A single frequency (1998) or dual frequency (other years) Biosonics echosounder was used.

Regression equations were developed to relate measured acoustic back scatter to matched data on zooplankton biomass as determined from horizontal net tows (Johnson and Griffiths 1990; Griffiths, Chapter 4). These equations were then used to estimate zooplankton biomass at other places and depths where echosounder but no net-tow data were available. Chapter 4 describes regression equations applicable to the 200 kHz echosounder data from the Alaskan Beaufort Sea in 1985–86, and to the 430 kHz echosounder data in 1999–2000. For 1998, the correlation between matched echosounder (430 kHz) and net-tow data was too weak to allow confident use of echosounder data in estimating zooplankton biomass (Chapter 4). Along each transect, zooplankton biomass was integrated for each 2-m (1985–86) or 1-m (1999–2000) depth interval within each 2-min (~240 m) horizontal interval.

***Canadian Beaufort Sea*.—**The echosounder used in this area in 1981, 1985 and 1986 was useful in selecting depths for horizontal tows through water with high (and low) apparent biomasses of zooplankton. However, it did not provide quantitative estimates of zooplankton biomass.

Analyses of Zooplankton

The same person analyzed all samples from both regions. Samples were sieved through 163-μm mesh Nitex and examined under a low-power binocular microscope. Animals from all oblique tows were identified to species, and those from horizontal tows to major taxa. After blotting on dry filter paper, the sorted animals were wet-weighed to the nearest mg on an Acculab electronic balance.

For large samples, large or rare organisms were removed, identified and weighed, and then the small animals were sub-sampled with a Folsom Plankton Splitter or a Hensen–Stempel pipette and treated as above.

For each sample, the flow meter reading recorded during the tow was used to calculate the volume of water filtered. This information, in conjunction with wet-weights for the individual species or groups, was used to determine the wet-weight biomass in mg/m^3. The opening and closing bongo net used for horizontal tows in Alaska during 1986 underestimated biomass, as shown by matched tows with that net and a standard bongo net. Therefore, results from 1986 horizontal tows with the opening and closing net were corrected, i.e., scaled up, as described in Griffiths (Chapter 4).

Wet-weight data from oblique tows were used to calculate the average biomass of zooplankton in the water column. Data from the horizontal tows were used to calculate wet-weight biomass at particular depths at each station.

Results

Zooplankton Near Bowhead Whales in the Eastern Alaskan Beaufort Sea

***Total Biomass*.—**Feeding whales were not observed in the eastern Alaskan Beaufort Sea in 1985 and 2000. Table 6.2 shows zooplankton biomass data from whale feeding locations in that area during 1986, 1998 and 1999. Average biomass in oblique tows, in the horizontal tow with highest biomass, and in all horizontal tows were all higher in areas where bowheads were actively feeding, or where they had been observed feeding but departed prior to arrival of the boat, than at nearby control stations.

Average biomass of zooplankton in 94 oblique tows taken at other locations in the eastern Alaskan Beaufort Sea not shown in Fig. 6.1 or Table 6.2, and where whales were not observed, was 237 mg/m^3 for the years 1985–86 and 1998–2000 (Chapter 5). This value from sampling along systematic transects was very similar to the average at control stations (233 mg/m^3; Table 6.2).

TABLE 6.2. Mean wet-weight biomass (mg/m^3) of zooplankton at whale feeding vs. matched control stations in the eastern Alaskan Beaufort Sea during September of 1986, 1998 and 1999. Shown separately are data from the horizontal tow at the depth with maximum biomass, from all horizontal tows, and from oblique tows at those stations. Also shown are results from the subset of these stations where whales were actually observed while sampling was being conducted.

		Feeding Stations			Control		
		Mean	± s.d.	*n*	Mean	± s.d.	*n*
Horizontal Tows – Max. Biomass							
All Feeding Stations	1986	2393	1431	5	578	586	5
	1998	443	154	10	446	220	8
	1999	675	149	5	355	398	3
	All	989	1072	20	512	385	14
Whales Seen While Sampling	1986	2973	701	4	659	644	4
	1998	771		1	144		1
	1999	661	165	2	126	13	2
	All	2006	1307	7	433	536	7
All Horizontal Tows							
All Feeding Stations	1986	1375	1366	14	367	453	10
	1998	302	178	25	370	236	11
	1999	334	341	11	234	327	5
	All	610	876	50	343	340	26
Whales Seen While Sampling	1986	2101	1170	9	400	507	8
	1998	409	370	3	78	92	2
	1999	302	342	5	90	46	4
	All	1273	1246	17	265	407	14
Oblique Tows							
All Feeding Stations	1986	586	476	6	86	65	5
	1998	304	163	10	283	141	8
	1999	381	162	5	346	116	3
	All	403	298	21	233	152	16
Whales Seen While Sampling	1986	684	460	5	95	71	4
	1998	234		1	71		1
	1999	332	157	2	300	119	2
	All	529	416	8	150	124	7

There were two kinds of whale feeding stations: (1) those where whales were observed from the boat during or immediately before sampling was conducted, and (2) those where aerial observers had seen feeding whales within the previous day, but the whales had departed before the boat arrived and began sampling. Mean biomass in oblique tows and in the horizontal tow with the highest biomass at stations where whales were observed during sampling were significantly higher than those at paired control stations (Table 6.3). Mean biomass in the same kinds of tows taken at stations where whales were observed from the aircraft but not the boat were similar to those taken at paired control stations. Thus, only stations at which bowheads were observed from the boat during or just before sampling can be considered to be representative of feeding locations.

TABLE 6.3. Comparison of the mean biomass of zooplankton at paired whale feeding and control stations in the Eastern Alaskan Beaufort Sea in 1986, 1998 and 1999. Values shown are mean ± s.d. (*n*). In the 3 cases where two feeding stations were paired to one control, the average of the two feeding-station biomasses was used. Data were log transformed prior to analysis with a *t*-test.

	Mean Biomass (mg/m^3)			
	Feeding Station	Control Station	*t* statistic	*P* (one-tail)
Whales observed from boat				
Oblique Tows	543 ± s.d. 417 (7)	150 ± s.d. 124 (7)	2.14	0.038
Horizontal Tows	2006 ± s.d. 1307 (7)	433 ± s.d. 536 (7)	5.39	0.001
Whales not observed from boat				
Oblique Tows	299 ± s.d. 159 (10)	305 ± s.d. 154 (10)	0.20	0.424
Horizontal Tows	382 ± s.d. 152 (9)	500 ± s.d. 222 (9)	–1.66	0.068

Differences in zooplankton biomass among years were mainly due to the abundance of copepods. Copepods accounted for 715 of the 775 mg/m^3 of total zooplankton biomass in oblique tows at feeding stations where whales were observed during or just before sampling in 1986 ($n = 4$), but only 82 of 104 mg/m^3 in 1998 ($n = 1$), and 226 of 328 mg/m^3 in 1999 ($n = 2$) (Fig. 6.2). Likewise, in the horizontal tows at the depth of maximum biomass, copepods constituted most of the biomass in 1986 but not to the same extent in 1998 or 1999 (Fig. 6.3).

***Species Composition*.—**The species composition of copepods at whale feeding stations was quite different in each of the three years (Fig. 6.4; Table 6.4; see also Appendix 6.2 and 6.3). In 1986, the small copepod *Limnocalanus macrurus* was by far the dominant zooplankter at whale feeding and control stations, as it was in inshore areas generally (Chapter 5). It was not found at the few 1998 or 1999 whale feeding or control stations (Fig. 6.4; Table 6.4), or elsewhere in the study area in 1998–99 (Chapter 5).

In 1986, the large copepods *Calanus glacialis* and *C. hyperboreus* were uncommon at feeding and control stations (Table 6.4). In 1998 and 1999, *C. glacialis* and *C. hyperboreus* were the major contributors to the average biomass in the water column and in horizontal tows at depth at both whale feeding and control stations (Fig. 6.4; Table 6.4; Appendix 6.2).

Predatory cnidarians, ctenophores, and chaetognaths were major contributors to zooplankton biomass at both feeding and control stations in 1998 and 1999, but not in 1986 (Table 6.4).

In surface waters, although copepods, gelatinous zooplankters, and chaetognaths were typically present each year, no one zooplankton group was the major contributor to the biomass in surface waters in all years.

***Nature and Extent of Feeding Areas as Shown by Echosounder Surveys*.—**In 1986 and 1999, echosounder surveys were conducted at and between feeding and control stations. Acoustic backscatter data were converted to estimates of biomass. No similar estimates were possible for 1998 (see "Methods" and Chapter 4). Results are presented for situations where whales were actually observed feeding just before or during zooplankton sampling. In 1986, there were three such cases, all located in shallow water off the Kongakut Delta in the eastern portion of the study area. In 1999, three feeding stations and two control stations were located in somewhat deeper water off Beaufort Lagoon in the central portion of the study area (Fig. 6.1A).

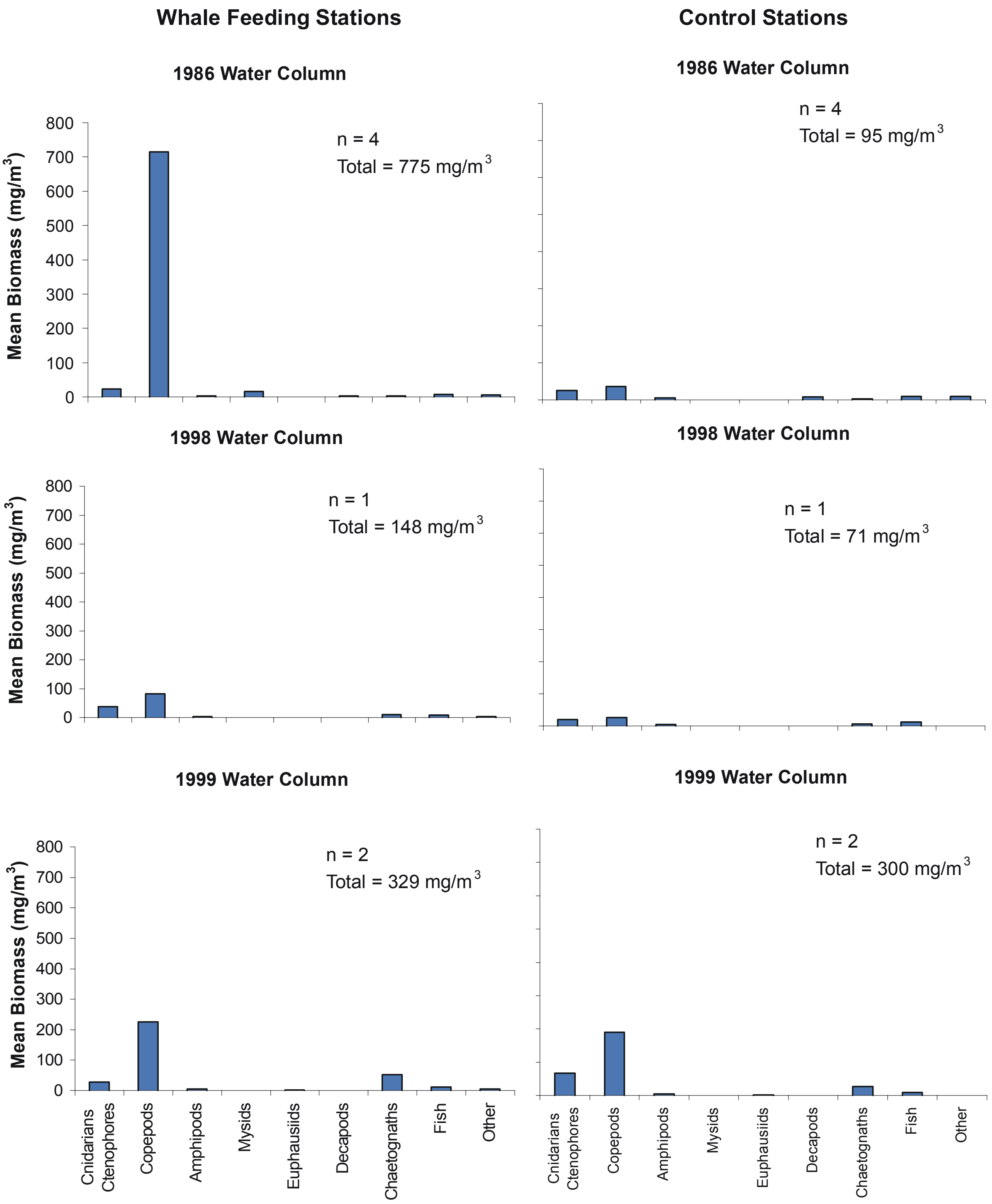

FIGURE 6.2. Mean biomass (mg/m^3) of major zooplankton groups in oblique tows taken at all whale feeding and control stations in the eastern Alaskan Beaufort Sea during Sept 1986, 1998 and 1999. Includes stations where whales were seen during zooplankton sampling.

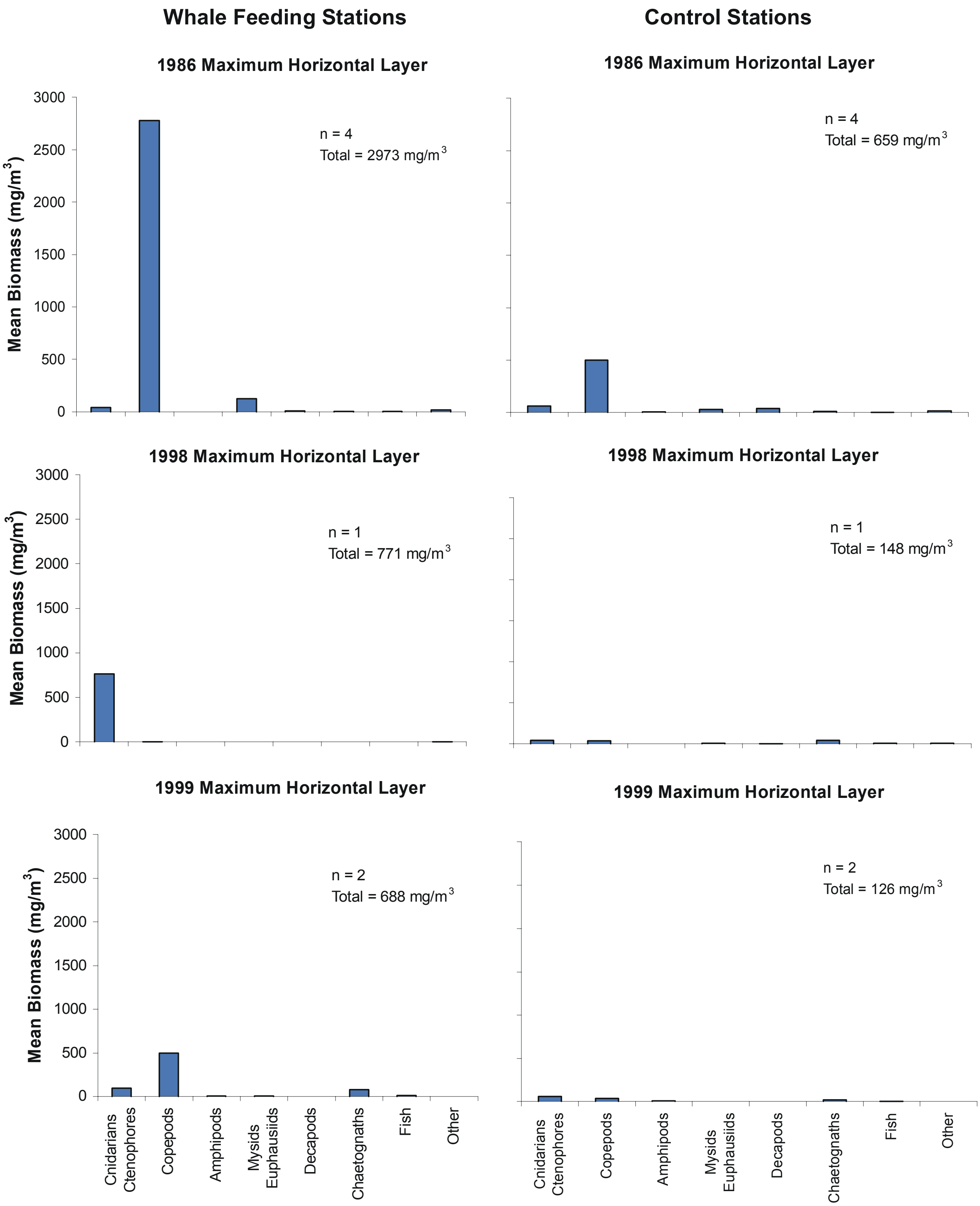

FIGURE 6.3. Mean biomass (mg/m^3) of major zooplankton groups in layer of maximum biomass at all whale feeding and control stations in the eastern Alaskan Beaufort Sea during Sept 1986, 1998 and 1999.

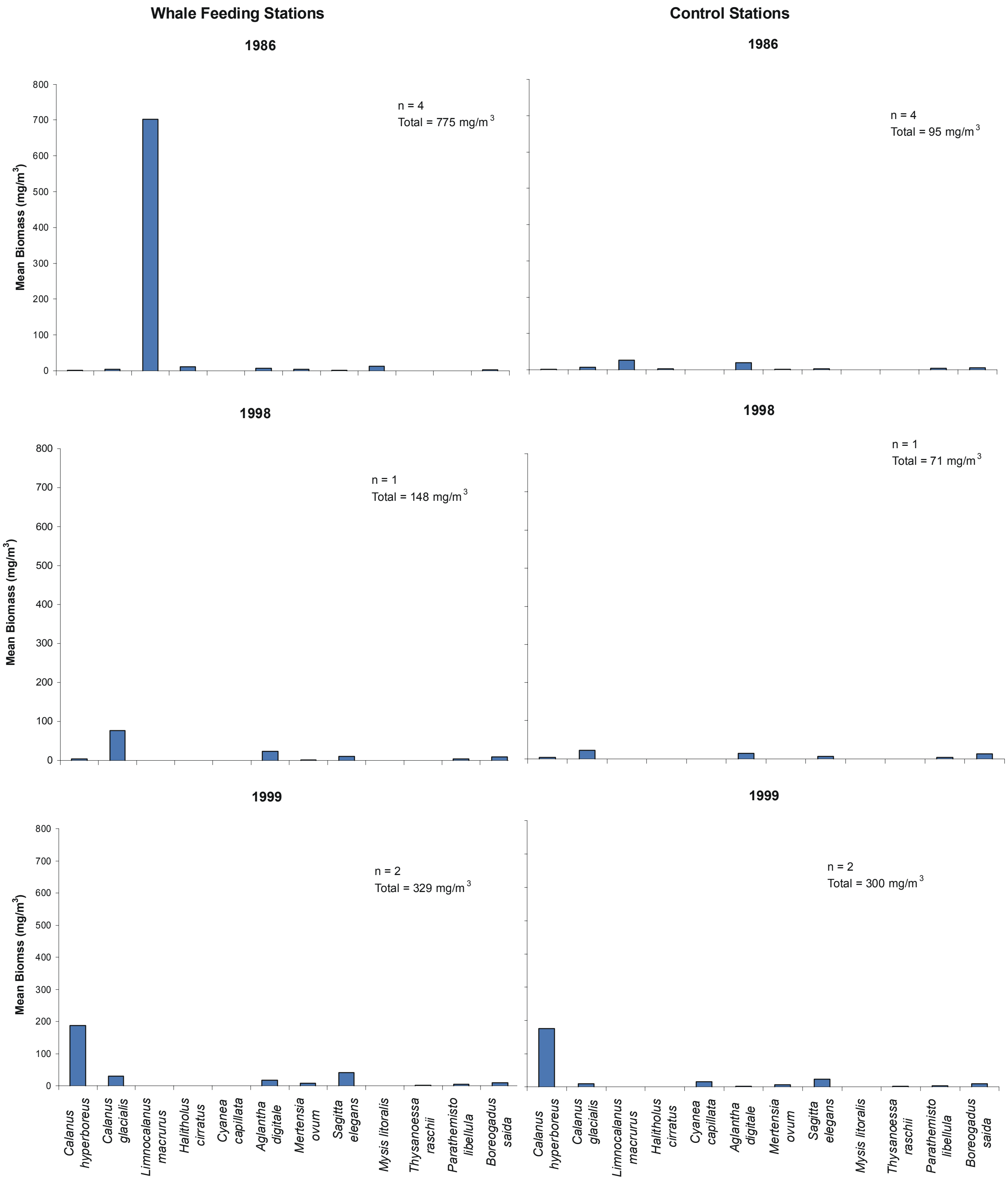

FIGURE 6.4. Mean biomass (mg/m^3) of zooplankton species in oblique tows representing the water column as a whole at all whale feeding and control stations in the eastern Alaskan Beaufort Sea, 1986, 1998 and 1999.

TABLE 6.4. Species composition of mean zooplankton biomass (mg/m^3) in oblique and horizontal tows at whale feeding and control stations in the eastern Alaskan Beaufort Sea and adjacent Yukon Coast. Samples from all horizontal tows taken in 1999, and from those taken at control stations in 1986, were not identified to species (see also Appendix 6.2).

	Whale Feeding Stations										**Control Stations**							
	Water Column as a Whole						Horizontal Tows at Depth				Water Column as a Whole						Horizontal Tows at Depth	
Species	1986 mg/m^3	% of Total	1998 mg/m^3	% of Total	1999 mg/m^3	% of Total	1986[a] mg/m^3	% of Total	1998 mg/m^3	% of Total	1986 mg/m^3	% of Total	1998 mg/m^3	% of Total	1999 mg/m^3	% of Total	1998 mg/m^3	% of Total
Copepods																		
Calanus glacialis	3	0.5	125	41.0	40	10.5	12	2.1	168	48.0	6	7.0	72	26.0	16	4.7	78	36.0
Calanus hyperboreus	1	0.2	24	8.0	227	54.6	4	0.7	14	4.0	3	3.7	26	9.0	134	40.0	38	17.0
Pseudocalanus minutus	4	0.7	4	1.0	<1	<1	3	0.5	5	1.0	1	0.9	4	1.0	<1	<1	5	2.0
Limnocalanus macrurus	496	84.7	0	0.0	0	0.0	534	90.2	0	0.0	25	29.4	0	0.0	0	0.0	0	0.0
Cnidarians/ Ctenophores																		
Aglantha digitale	10	1.7	15	5.0	21	5.5	1	0.1	21	6.0	16	18.3	11	4.0	6	1.7	3	1.0
Aeginopis laurentii	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	23	6.6		
Bougainvillea principis	0	0.0	9	3.0	0	0.0	0	0.0	5	1.0	0	0.0	0	0.0	0	0.0	9	4.0
Cyanea capillata	0	0.0	17	6.0	0	0.0	0	0.0	1	0.0	0	0.0	0	0.0	10	3.0	0	0.0
Mertensia ovum	3	0.5	14	5.0	22	5.7	3	0.2	10	3.0	1	1.1	27	9.0	41	12.0	10	5.0
Halitholus cirratus	9	1.5	0	0.0	0	0.0	4	0.3	0	0.0	2	2.1	0	0.0	0	0.0	0	0.0
Amphipods																		
Parathemisto libellula	2	0.3	2	1.0	3	0.8	<1	<1	0	0.0	4	4.1	1	0.2	3	0.9	2	1.0
Pteropods																		
Spiratella helicina	2	0.3	0	0.0	0	0.0	<1	<1	0	0.0	4	4.3	0	0.0	0	0.0	0	0.0
Mysids																		
Mysis litoralis	31	5.3	19	6.0	0	0.0	11	0.9	7	2.0	0	0.0	13	5.0	1	0.4	0	0.0
Euphausiids																		
Thysanoessa rachii	0	0.0	2	0.7	2	0.5	<1	<1	2	0.6	0	0.0	1	0.3	14	4.2	<1	<1
Chaetognaths																		
Sagitta elegans	2	0.3	65	22.0	32	8.4	3	0.2	97	27.0	2	2.0	84	30.0	74	21.4	61	28.0
Eukrohnia hamata	0	0.0	0	0.0	8	2.1	0	0.0	0	0.0	0	0.0	0	0.0	2	0.6	0	0.0
Fish Larvae																		
Boreogadus saida	3	0.4	1	0.5	7	1.8	0	0.0	11	3.0	5	5.8	35	12.0	8	2.4	6	2.0
Other Species	20	3.4	7	2.3	19	4.9	32	5.2	12	3.4	17	19.9	9	3.2	14	4.0	9	4.1
Total Biomass	586		304		381		607		353		86		283		346		221	
Number of tows	6		10		5		3		7		5		8		3		2	

[a] For 1986, horizontal tow data have been corrected to allow for underestimation by the opening and closing net.

In 1986, estimated zooplankton biomass along all three transects decreased between the whale feeding and control stations. At all three whale feeding stations, a thick layer of zooplankton with an estimated ("acoustic") biomass of 500–2200 mg/m^3 extended from depth 4–8 m to the bottom (Fig. 6.5, 6.6, 6.7). At control stations there was only a thin layer with estimated biomass about 400 to 600 mg/m^3 at depths 17–20 m. There was good correspondence between acoustic and net biomass at both the feeding and control stations (Fig. 6.5–6.7). Layers of concentrated zooplankton extended at least 2–6 km from the whale feeding stations in the direction of the control stations.

In 1999, a single layer of concentrated zooplankton, about 10 to 20 m thick, extended from depths of 25 to 30 m most or all of the way to the bottom at both feeding and control stations (Fig. 6.8, 6.9). Net sampling showed that zooplankton biomass within this layer was 350-700 mg/m^3 (Table 6.2; Fig. 6.8, 6.9). In 1999, there was little change in zooplankton biomass, as estimated from echosounder data, along transects between feeding and control stations. The depth-averaged horizontal distribution of biomass was generally uniform, and biomass within the layer of maximum biomass was also fairly consistent along the transects.

Zooplankton Near Bowhead Whales in the Canadian Beaufort Sea

In the Canadian Beaufort Sea east of Herschel Island, there were five years when sampling was conducted where bowhead whales were observed prior to or during sampling (Fig. 6.1B; Appendix 6.3). Such sampling occurred off the Tuktoyaktuk Peninsula and Mackenzie Delta in 1980, 1981 and 1986, and along the Yukon coast in 1985, 1986 and, in a limited way, 1988.

In 1980, mean biomass in 24 vertical tows in a general area off the Mackenzie Delta where aerial observers had seen whales feeding was 632 ± s.d. 491 mg/m^3. This is about the same as the biomass of 542 ± 221 mg/m^3 found in 6 oblique tows at stations where whales were observed within 1 km of the boat in 1985 and 1986 (see below). For 1980, no comparable data were obtained from locations without bowheads. However, in 1985–86, mean biomass in 49 oblique tows at locations in the Canadian Beaufort Sea where whales were not observed from the sampling vessel was 138 ± 116 mg/m^3. If 1980 "no whale" values were similar to those in 1985–86, average biomass in the water column near feeding bowheads in 1980 was ~4 times higher than at stations where bowheads were not observed to be feeding.

In 1981, aerial observers saw 30 bowheads surface-feeding near the boat at a location off Richard's Island on 18 August. The whales were feeding intensively an estimated 2–3 m below the surface, frequently in echelon formation (Würsig et al. 1985). The echosounder showed a concentration of zooplankton in a band at depths 1–4 m. Biomass in three surface tows was 216 ± s.d. 86 mg/m^3, and was predominantly *Calanus hyperboreus*. This was a relatively high biomass for surface waters; in 1981, biomass in 33 surface tows at 11 stations where no whales were observed did not exceed 21 mg/m^3. However, at the 18 August location, biomass was notably higher, 885 ± 268 mg/m^3 in 3 tows at 15 m depth, than in the near-surface waters where the bowheads fed intensively. The zooplankton at 15 m depth was also predominantly *Calanus hyperboreus*. The maximum biomass in horizontal tows at depth at two other stations where whales were observed to be feeding either below the surface or near the bottom was 1405 ± 937 (n = 3 tows) and 807 mg/m^3 (Appendix 6.3). Average maximum biomass in horizontal tows at each of 10 stations where no bowheads were observed was 298 ± 254 mg/m^3.

In 1985, average maximum biomass of zooplankton at four stations where whales were observed from the boat off the Yukon Coast was 1684 ± s.d. 621 mg/m^3. The biomass in 17 horizontal tows taken within layers of zooplankton at 10 stations where bowheads were not observed was 213 ± 232 mg/m^3.

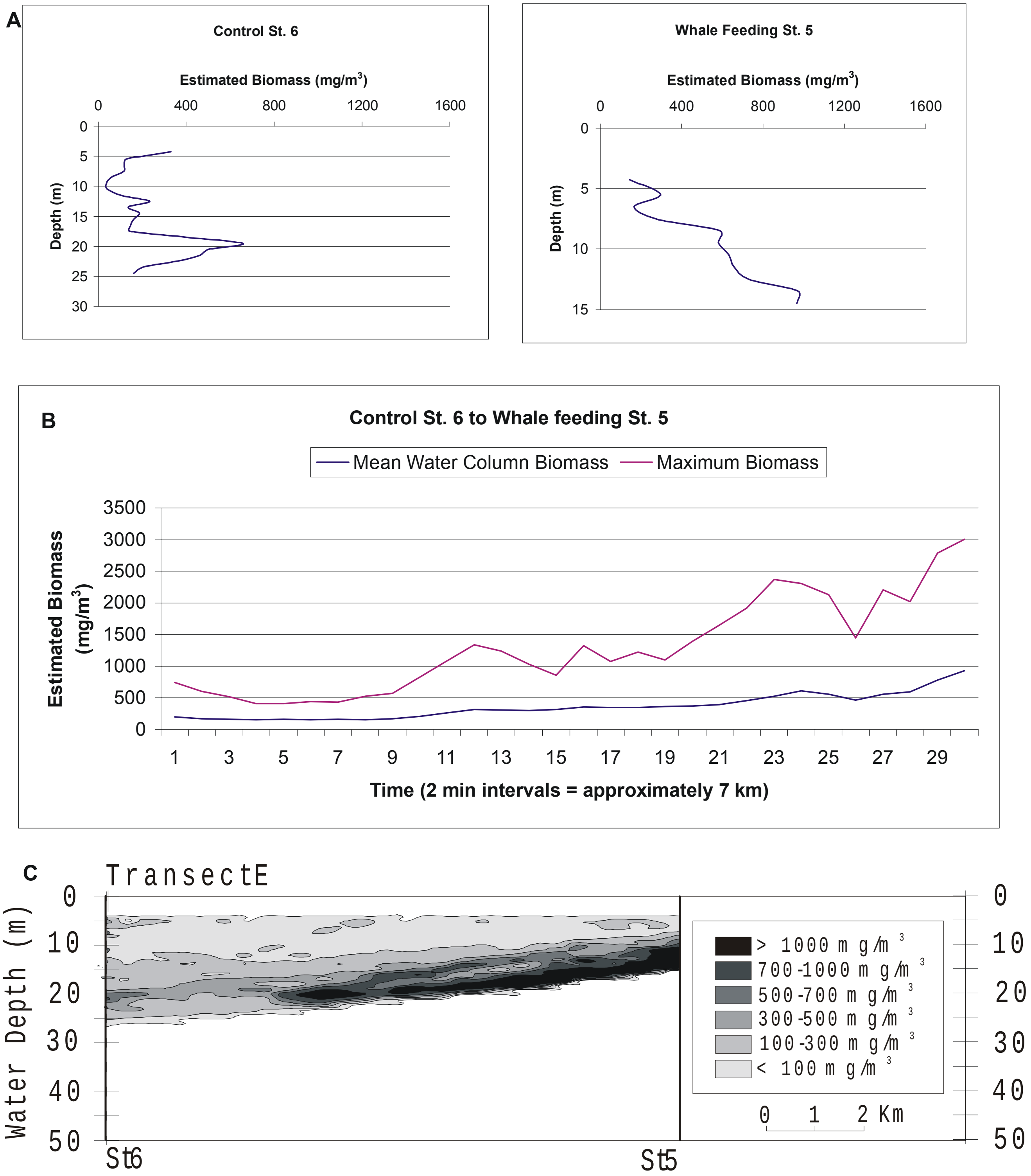

FIGURE 6.5. Echosounder-based estimates of zooplankton biomass off the Kongakut Delta, Alaska, at whale feeding station 86-5, at control station 86-6, and along Transect E between them. ***(A)*** Vertical distribution at stations, ***(B)*** depth-averaged (below) and maximum (above) biomass along transect between stations, and ***(C)*** patchiness between stations. Based on 200 kHz echosounder data, 5 Sept 1986.

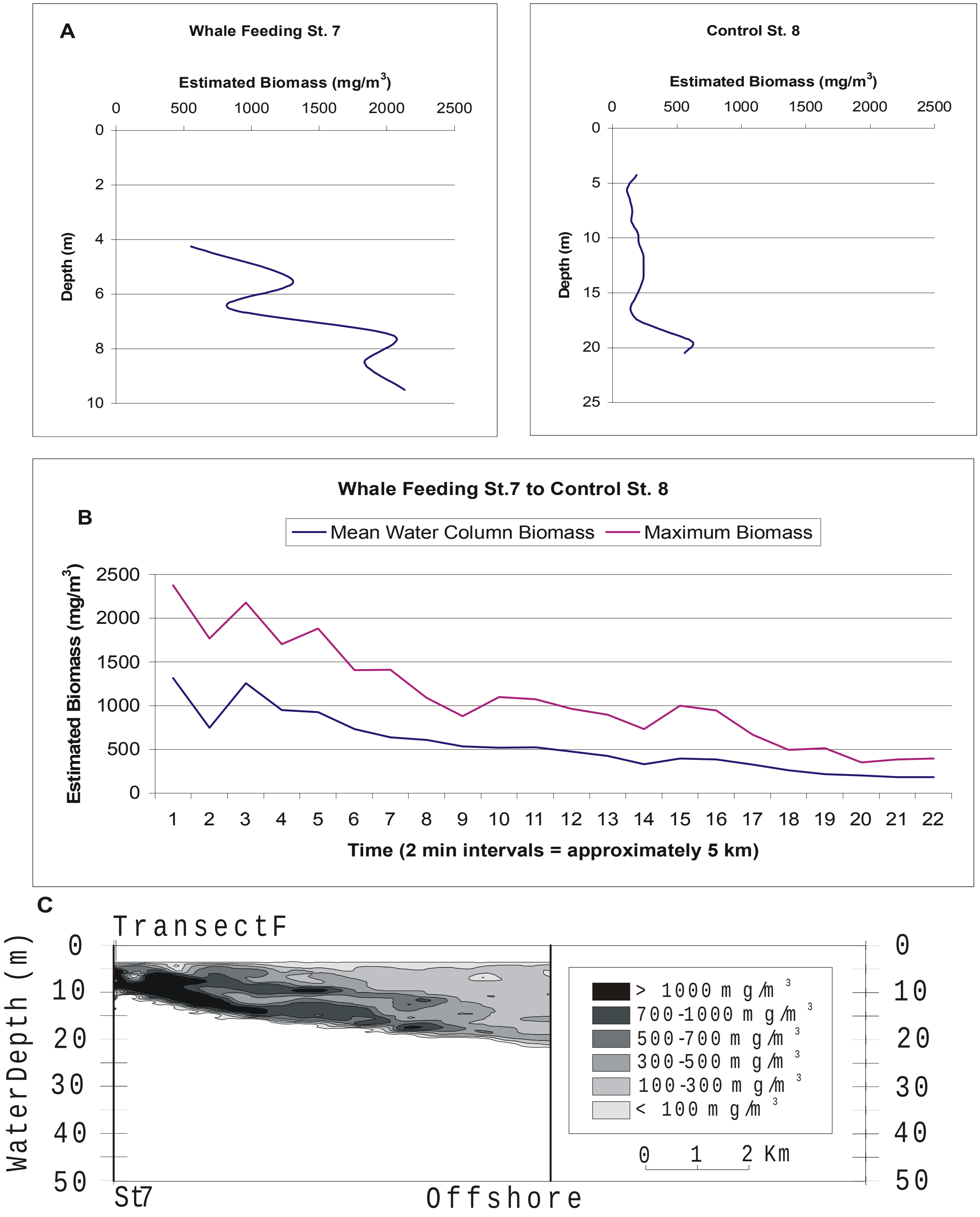

FIGURE 6.6. Echosounder-based estimates of zooplankton biomass off the Kongakut Delta, Alaska, at whale feeding station 86-7, at control station 86-8, and along Transect F between them. Otherwise as in Figure 6.5. Based on 200 kHz echosounder data, 6 Sept 1986.

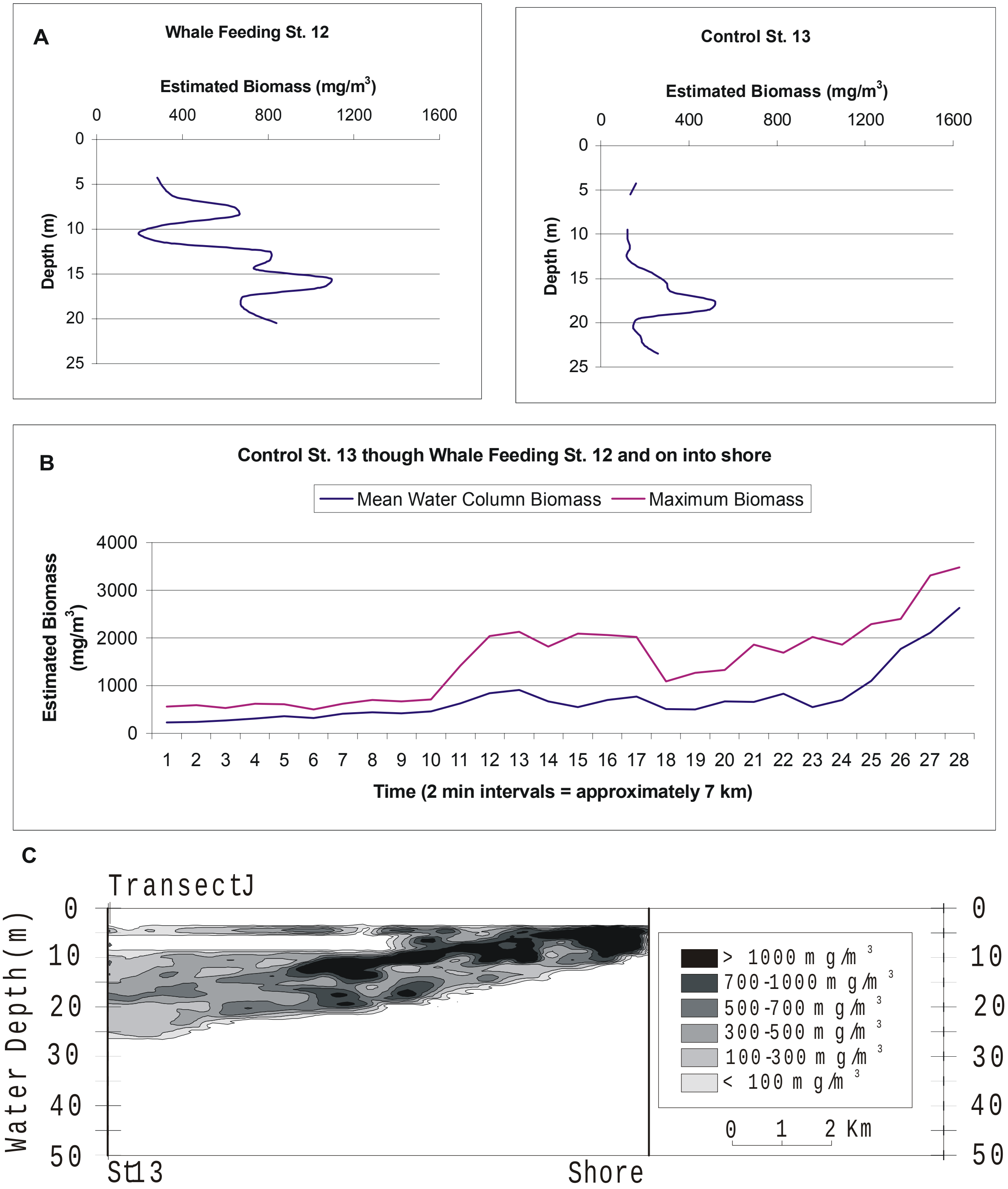

FIGURE 6.7. Echosounder-based estimates of zooplankton biomass off the Kongakut Delta, Alaska, at whale feeding station 86-12, at control station 86-13, and along Transect J between them. Otherwise as in Figure 6.5. Based on 200 kHz echosounder data, 7 Sept 1986.

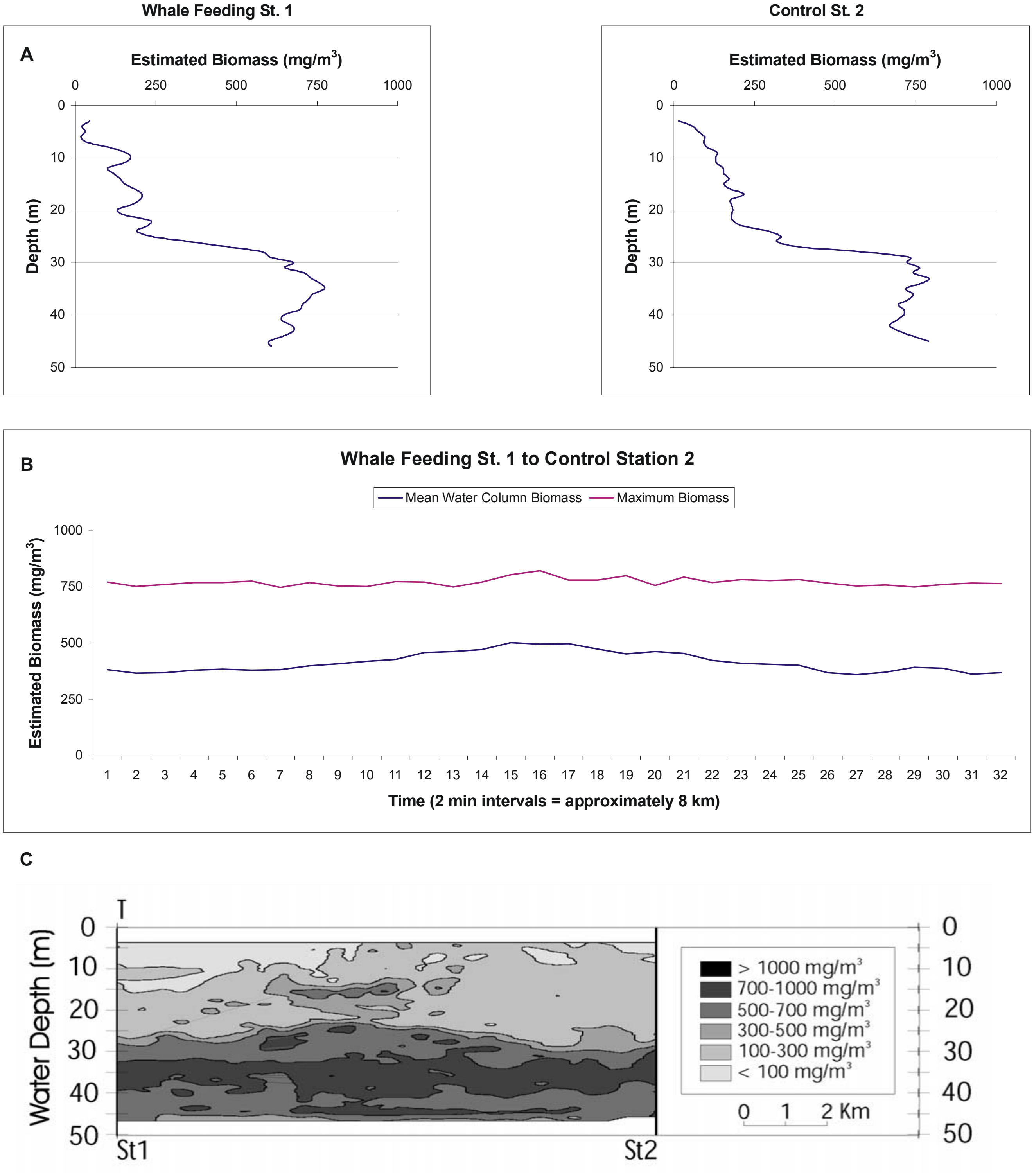

FIGURE 6.8. Echosounder-based estimates of zooplankton biomass off Beaufort Lagoon, Alaska, at whale feeding Station 1, at control Station 2, and along the transect between them. Otherwise as in Figure 6.5. Based on 430 kHz echosounder data, 16 Sept 1999.

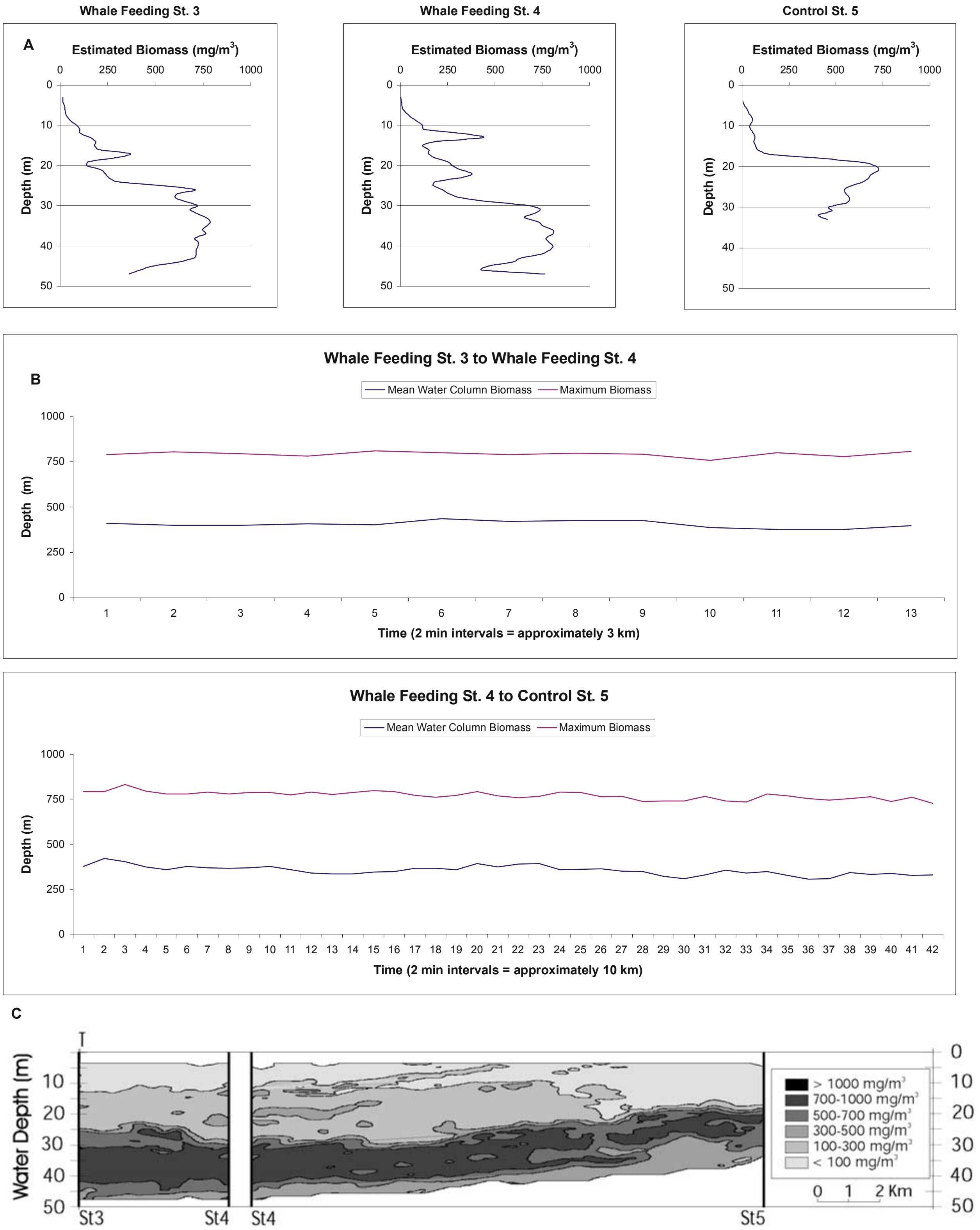

FIGURE 6.9. Echosounder-based estimates of zooplankton biomass off Beaufort Lagoon, Alaska, at whale feeding Stations 3 and 4, control Station 5, and along the transects between them. Otherwise as in Figure 6.5. Based on 430 kHz echosounder data, 17 Sept 1999.

Corresponding results from oblique tows were 562 ± 388 mg/m^3 with whales (n = 2 tows) and 161 ± 189 mg/m^3 without whales (n = 14 tows).

In 1986, mean zooplankton biomasses in oblique tows, horizontal tows at depth, and surface tows were all much higher at stations sampled near whales than at stations where the closest whales sighted from the ship were >1 km away or where no whales were observed from the ship (Table 6.5). Mean biomass in the horizontal tow with the highest biomass for that station was over 6 times greater within 1 km of whales than at stations where no whales were seen. These samples were taken off the Tuktoyaktuk Peninsula and off the Yukon coast (Fig. 6.1B). During sampling, the echosounder provided guidance to the depth of maximum biomass at only two stations with whales <1 km away. Therefore, the average for horizontal tows may underestimate the biomass available to whales in 1986. Maximum biomasses at the locations where echosounder guidance was available were 1543 and 770 mg/m^3 (mean 1157 mg/m^3).

In 1988, sampling near bowheads feeding at the surface off the Yukon coast revealed the highest biomass of zooplankton recorded during all the sampling summarized here (Appendix 6.3). Biomass was close to 5 g/m^3, and dominated by *Limnocalanus macrurus.*

There were some difference in species composition in samples taken at whale feeding stations in the Canadian Beaufort Sea among locations and years (Table 6.6, Appendix 6.3):

- Off the ***Tuktoyaktuk Peninsula***, the copepod *Calanus hyperboreus* was the dominant contributor to zooplankton biomass in samples taken at 4 of 5 stations. At the other station in that area, the hydrozoan *Aglantha digitale* was the dominant contributor.
- Off ***Richards Island***, the cnidarians *Halitholus cirratus* and *Euphysa flammea* were the dominant contributors to total zooplankton biomass at all 5 whale feeding stations in 1980. In 1981, the copepod *C. hyperboreus* dominated at all three whale feeding stations. Mysids (*Mysis litoralis*) were also a dominant contributor (18% of total biomass) at one 1981 station where bowheads were observed to be bottom feeding.
- Off the ***Yukon coast***, most of the high biomass collected in both 1985 and 1986 was attributable to the high biomass of the copepod *Limnocalanus macrurus.* At one 1986 station, euphausiids (*Thysanoessa raschii* and *T. inermis*) were also major contributors (20% of total biomass).

TABLE 6.5. Mean biomass (mg/m^3) of zooplankton in tows taken at stations in the Canadian Beaufort Sea east of Herschel Isl. during 1986, distinguishing stations where whales were seen from the ship <1 km away (4 stations) and >1 km away (2 stations), and stations where no whales were seen from the ship.[a] The "no whales seen from ship" stations are categorized as being within or outside two large areas where whales were observed from the air (Ford et al. 1987) at some time during the 11-day study (5 and 35 stations, respectively).

	Whales <1 km			Whales >1 km			Seen from air			No whales		
	Mean	± s.d.	*n*	Mean	± s.d.	*n*	Mean	± s.d.	*n*	Mean	± s.d.	*n*
Surface tows	100	167	4	6	6	3	11	25	12	6	7	33
Horizontal tows[b]	672	489	7	53	-	1	123	89	12	101	112	28
Oblique tows	532	175	4	219	90	3	144	36	4	130	70	35

[a] Excludes feeding stations in Canadian waters west of Herschel Island (*n* = 2) that were sampled during the 1986 eastern Alaska study.

[b] Considering, for each station, the horizontal tow with the highest biomass; echosounder guidance to the depth of maximum biomass was available for 2 of 4 stations <1 km from whales and for most of the other stations.

TABLE 6.6. Dominant zooplankton groups and species at whale feeding stations in the Canadian Beaufort Sea by area and year.

Location	Year	No. of Feeding Stations	Dominant Group	No. Stns Where Dominant	% of Total Biomass	Dominant Species	% of Total Biomass
Tuktoyaktuk Peninsula	1986	5	Copepods	4	71 to 87	*Calanus hyperboreus*	55 to 76
			Cnidarians	1	39	*Aglantha digitale*	34
Richards Island off Mackenzie Delta	1980	5	Cnidarians	5	46 to 94	*Halitholus cirratus*	13 to 39
						Euphysa flammea	7 to 55
	1981	3	Copepods	3	64 to 92	*Calanus hyperboreus*	39 to 82
Yukon Coast	1985	4	Copepods	4	92 to 99	*Limnocalanus macrurus*	77 to 97
	1986	2	Copepods	2	61 to 91	*Limnocalanus macrurus*	26 to 86

Physical Oceanography

Example CTD data collected at whale-feeding and control stations in the eastern Alaskan and Canadian Beaufort Sea are shown in Figure 6.10. (Station numbers in this Figure are as assigned in the original reports; they appear in parentheses to the right of the corresponding station descriptions in Appendix Table 6.3.) Appendices 6.4 and 6.5 show additional Alaskan data.

***Eastern Alaskan Beaufort Sea*.—**Griffiths and Thomson (Chapter 5) described two water masses (in depths <50 m) that were present in the eastern Alaskan Beaufort Sea during the five years of the study. The two water masses were a Shallow Cold Saline water mass and a generally more offshore water mass influenced by the Mackenzie River. The presence or absence of Mackenzie River water defined the properties of these two water masses. Its influence differed among years (Chapter 5). The main characteristic of the Shallow Cold Saline water mass was the absence of a strong influence of Mackenzie River water and the absence of sharp discontinuities in the vertical distribution of temperature and salinity (pycnoclines). The relatively cold temperatures and high salinities were fairly uniform from surface to bottom. The Mackenzie-Influenced water mass, farther offshore, was characterized by the strong presence of Mackenzie River water at the surface, overlying water that was generally colder and more saline than that of the Shallow Cold Saline water mass.

Water mass characteristics varied among the three years when feeding whales were observed in the study area and did not always correspond directly to the water masses described above. In 1986, all six whale-feeding stations were in shallow water with depths of 7 to 22 m and the five control stations in slightly deeper depths of 15 to 27 m (Fig. 6.10A,B; Appendix 6.4). The water was cooler and more saline at the whale-feeding stations than at control stations, and was characterized by a relatively warm brackish surface layer of varying thickness, overlaying cooler more saline water. All stations had sharp temperature and salinity discontinuities with differences in temperatures and salinities between surface and bottom water of ~4°C and about 5 to 6 psu. This water mass was similar to the generally offshore Mackenzie-Influenced water mass described above. However, it was only present in the shallow nearshore region in the southeastern corner of the study area when feeding bowheads were observed, and appeared to have moved in from along the nearshore area of the Yukon Coast.

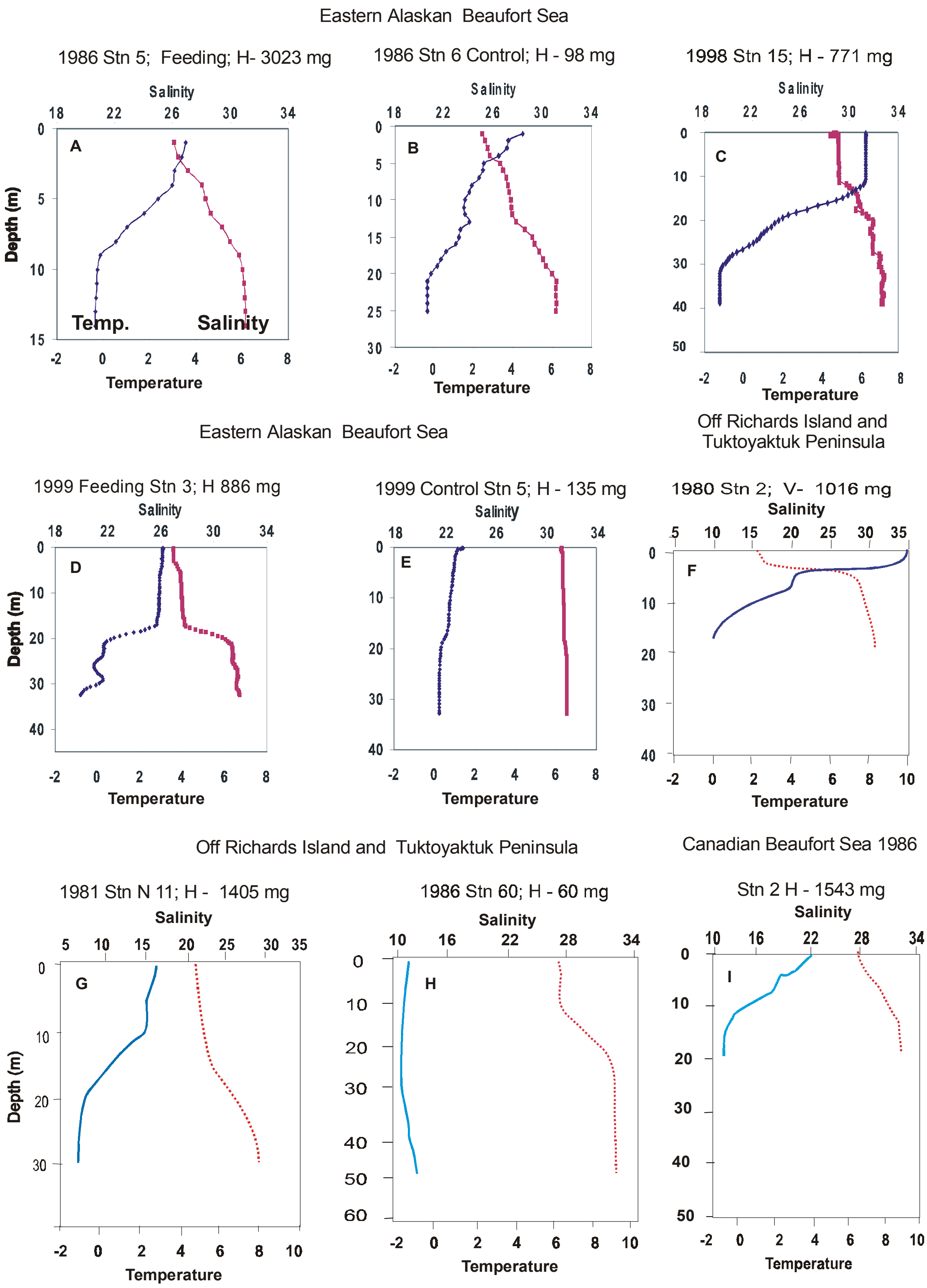

FIGURE 6.10. Examples of temperature–salinity profiles in Canadian and eastern Alaskan Beaufort Seas in various years and circumstances. Also shown is biomass in mg/m^3 at each station based on H, horizontal tow, or O, oblique tow. In each case, temperature (left line in lower part of each plot, blue) decreases with increasing depth; salinity (right line, red) increases or (in E) remains nearly constant.

In 1998, the whale-feeding and control stations varied widely in depth (10 to 40 m) and were located in both the shallow cold saline and the more offshore Mackenzie-influenced water masses described above. Seven of 10 feeding and 6 of 8 control stations were in the Shallow Cold Saline water mass, while 3 feeding and 2 control stations were in the Mackenzie-Influenced water mass (Fig. 6.10G; Appendix 6.5). Strong pycnoclines were found at 3 of 10 whale feeding and 2 of 8 control stations in 1998 (Fig. 6.10G; Appendix 6.5). Vertical temperature and salinity discontinuities were not sharp at the other 1998 feeding stations or at most (6 of 8) 1998 control stations.

In 1999, only the Shallow Cold Saline water mass was present within the area studied; it extended offshore to at least the 50 m contour. All 1999 whale-feeding and control stations were located in the deeper waters (depths 40 to 48 m) of this water mass (Fig. 6.10D,E; Appendix 6.5). Temperature and salinity discontinuities were present at 3 of 5 whale feeding stations but they were not as sharp as those seen in 1986 and 1998. There were no temperature and salinity discontinuities at 2 of the feeding or any of the control stations.

Canadian Beaufort Sea.—In 1985 and 1986, waters in nearshore areas along the Yukon coast were overlain by relatively warm freshened water of Mackenzie River origin (e.g., Fig. 6.10I). Very high biomasses of zooplankton were found in this area (Appendix 6.3). In 1986, sampling was also conducted of the Tuktoyaktuk Peninsula where strong pycnoclines were not evident (e.g., Fig. 6.10H). Biomass of zooplankton was low in this area.

In 1980 and 1981, there were vertical temperature and salinity discontinuities in areas sampled near feeding bowheads (e.g., Fig. 6.10F,G). Zooplankton biomass was high in these areas (Appendix 6.3).

At all whale-feeding stations in both the Canadian and Alaskan Beaufort seas, the highest biomass of zooplankton was taken in the cold saline water under a warm freshened layer. High biomasses of zooplankton were never taken in the warm freshened layer.

Discussion

Local and Traditional Knowledge of Bowhead Feeding

Whale hunters and other residents of Kaktovik, within the present eastern Alaskan study area, know much about the seasonal and geographic patterns in bowhead use of that area and adjacent Canadian waters, and of the general activities of the whales (see Chapter 2 and Annex B). They also know that the stomachs of most bowheads harvested near Kaktovik contain zooplankton, and believe that the area near Kaktovik is important for feeding. In one case, many large shrimp-like organisms were released from the mouth when a harvested bowhead was pulled up onto shore. A few local residents mentioned that they sometimes see concentrations of “krill” in or on the water near bowheads, with amounts of krill varying from year to year. Some residents commented that, when they see food concentrations and bowhead whales, these tend to be near water-mass boundaries or off river mouths. However, the majority of the local residents report that they rarely can distinguish feeding from other activities when they see whales at sea. This is not surprising, given the low vantage points available from small boats, ice, and shore, and the fact that bowheads seen from a moving boat are likely to be avoiding the boat even if they were originally feeding before the boat approached.

Zooplankton Biomass Available to Whales

Bowhead whales feed in concentrations of zooplankton in the both the eastern Alaskan and Canadian Beaufort Sea. As expected, zooplankton biomass in both regions was higher at stations where bowhead whales were present than at routine sampling stations where whales were not present (Tables 6.2, 6.5). Furthermore, zooplankton biomass was higher when whales were present during sampling than at stations where whales had been sighted from the aircraft recently, but were no longer present when the boat began sampling (Tables 6.2, 6.3, 6.5, 6.7). The sea is a dynamic environment where conditions change rapidly, and it appears that concentrations of zooplankton used by bowhead whales can be ephemeral and difficult to find without direct observation of the whales.

To characterize zooplankton availability at places where bowheads choose to feed, we considered horizontal plankton tows taken at the depth of maximum biomass at locations where bowheads were observed feeding. There were 17 locations where such tows were guided to layers of concentrated zooplankton by an echosounder (or taken near the surface in concentrations of zooplankton) and where bowheads were observed <1 km from the sampling boat. These locations were in the Canadian Beaufort Sea in 1981, 1985, 1986 and 1988 (*n* = 10), and in the eastern Alaskan Beaufort Sea in 1986, 1998 and 1999 (*n* = 7). These are the stations designated "whales observed from boat" in the last column of Appendix 6.3. Other samples were not included because there was no certainty that conditions during sampling were similar to those occurring earlier when bowheads had been present, or were similar to those at locations of whales visible >1 km from the boat. In addition, it was obvious that, in order to document the maximum biomass available to whales, reliable echosounder data were needed to guide the net to layers of zooplankton that were sometimes quite thin.

TABLE 6.7. Mean biomass in all horizontal tows, horizontal tows with highest biomass at each station, and oblique tows, distinguishing routine stations, stations where bowheads were observed from aircraft and/or sampling boat, and stations where whales were observed from boat immediately before and/or during sampling. Includes samples collected in 1980 (vertical tow only), 1981 (horizontal only), and 1985, 1986, 1998 and 1999 in Eastern Alaskan and Canadian Beaufort Sea. Routine sampling was conducted at stations along broad-scale transects in the same manner as that at whale feeding stations; for details, see Chapter 5 (for Alaska) and references listed in Table 6.1.

	Biomass mg/m^3		
	Mean	± s.d.	*n*
All Horizontal Tows			
All Stations - No Whales	242	315	313
All Feeding Stations	589	829	68
Whales Seen While Sampling	891	1058	35
Horizontal Tows – Maximum Biomass			
All Stations - No Whales	360	380	165
All Feeding Stations	975	1000	23
Whales Seen While Sampling	1841	1226	17
Oblique Tows[a]			
All Stations - No Whales	230	173	173
All Feeding Stations	467	356	36
Whales Seen While Sampling	529	416	8

[a] includes vertical tows made in 1980.

At these 17 whale-feeding stations, mean biomass in the horizontal tows and one vertical tow with the highest biomass was 1841 ± s.d. 1226 mg/m^3 (n = 17). The frequency distribution of biomass at these stations was

mg/m^3:	500-1000	1000-2000	2000-3000	3000-4000	4000-5000
No. samples:	5	5	4	2	1

The 1980 vertical tow with a biomass of 1153 mg/m^3 was included because no horizontal tows were taken at this whale-feeding station. Vertical tows would tend to underestimate the zooplankton biomass available to whales so the 1153 mg/m^3 value can be viewed as conservative. The lowest biomass in any of these tows was 545 mg/m^3. For 4 of 17 stations, the highest biomass measured was 771–807 mg/m^3, and for 12 of 17 stations the highest value was ≥1000 mg/m^3. Biomasses of ~800 mg/m^3, as determined by our horizontal tow method, may represent the feeding threshold for bowhead whales, i.e., the minimum biomass for economical feeding.

Although echosounders were used to guide the net to layers of zooplankton at these 17 whale feeding stations, at only 6 stations (4 from 1986 and 2 from 1999), all in the eastern Alaskan study area, were both net zooplankton samples and acoustic estimates of zooplankton biomass available:

	Kongakut Delta 1986	Kongakut Delta 1986	Kongakut Delta 1986	Clarence Lagoon 1986	Beaufort Lagoon 1999	Beaufort Lagoon 1999
Max. net tow biomass	3023	2887	2137	3847	545	778
Max. acoustic biomass	970	2131	1090	1365	650	774

A comparison of the maximum net tow biomass with the maximum estimate of acoustic biomass at the corresponding stations suggests that the net did sample within the layer of highest zooplankton biomass at each station. At 4 of 6 stations, the net detected an appreciably higher biomass than that estimated via the echosounder for the depth of maximum biomass. This suggests that, at locations of high biomass, the echosounder-based estimates may have tended to underestimate the actual maximum zooplankton biomass available, at least in 1986. As discussed in Chapters 4 and 5, even with guidance by an echosounder to the depth of maximum biomass, the net sampling is also expected to underestimate the actual maximum biomass some of the time.

Zooplankton biomass at the surface is generally lower than biomass in the water below (Chapter 5). However, bowheads are sometimes seen swimming at or near the surface with their mouths open and with water streaming from the corners of their mouths (Würsig et al. 1985; also Chapter 12). The very high ratio of the surface area of the baleen to the cross-sectional area of the mouth opening (Thomson, Chapter 22) may reduce drag and enable bowheads to feed while swimming at the surface on the typically low biomass of zooplankton in near-surface waters of the Beaufort Sea. During the unusually intensive near-surface feeding observed off Richard's Island in the Canadian Beaufort Sea in 1981, the near-surface zooplankton biomass was 216 ± s.d. 86 mg/m^3 (n = 3). At a whale feeding location off King Point (Yukon) in 1988, a vertical tow near the surface contained almost 5000 mg/m^3, mainly *Limnocalanus.*

Several studies of the anatomically similar North Atlantic right whale (*Eubalaena glacialis*) have reported data on zooplankton numbers or biomass collected at whale feeding stations (Wishner et al. 1988, 1995; Mayo and Marx 1990; Murison and Gaskin 1989; Kann and Wishner 1995; Beardsley et al. 1996; Woodley and Gaskin 1996). All of those studies have identified the copepod *Calanus finmarchicus*, particularly the larger copepodite IV and V stages, as the main food item for the right whales near the eastern Canadian and northeastern U.S. coasts. Some of the studies reported their results as number of organisms/m^3, while others reported the results as both numbers and biomass.

In the Bay of Fundy, mean biomass of zooplankton in vertical tows in grids where right whales were observed was 3566 ± s.e. 449 mg/m^3 (wet weight) in 1983, and 2639 ± s.e. 295 mg/m^3 in 1984 (Murison and Gaskin 1989). They estimated that the right whale feeding threshold was ~170 mg/m^3 dry weight (≈1133 mg/m^3 wet weight). In the same area, average density of zooplankton in the water column (160 to 197 m deep) in areas where right whales were sighted from a sampling boat was 1139 organisms/m^3 (Woodley and Gaskin 1996), which may have translated to ~680 mg/m^3 wet weight. [Most were *Calanus finmarchicus* (97%) and most of these were 2–4 mm in length. Average biomass of single copepods of this size in Wishner et al.'s (1995) samples was ~0.6 mg.] All of these values are averages for the water column, and probably underestimate the amount of food available to feeding whales; as evident in our results for bowhead feeding sites in the Beaufort Sea, densities and biomasses in layers of concentrated zooplankton may have been much higher.

More specific estimates of the amount of food potentially available to right whales have been reported from two occasions:

(1) In Cape Cod Bay, right whales were observed to be surface feeding in zooplankton densities of 6540 organisms/m^3 (Mayo and Marx 1990; ~3924 mg/m^3 based on data in Wishner et al. 1995). Biomass in surface tows where no whales were observed was 870 organisms/m^3 (~522 mg/m^3). Surface feeding began at a threshold value of ~1000 organisms/m^3 or ~600 mg/m^3 (Mayo and Marx 1990).

(2) Beardsley et al. (1996) followed two feeding right whales and sampled zooplankton with an echosounder and a MOCNESS plankton sampler. Highest biomass in horizontal tows was in the upper 10 to 20 m in a patch with mean biomass of 6000 mg/m^3 and a maximum biomass of 28,000 mg/m^3. The whale reversed direction and swam back into this dense patch when maximum biomass in the water dropped to 1000 to 3000 mg/m^3. One whale was observed to be skim feeding at the surface in a zooplankton concentration of 256,000 mg/m^3!

Kann and Wishner (1995) and Wishner et al. (1995) did not find any difference in biomass in vertically-stratified oblique tows in areas where whales were observed from the air within 24 h of sampling vs. areas where whales were not seen. When mean biomass in the water column was compared using a more rigorous definition of a whale feeding area (whales seen <1 km from sampling boat), biomass was significantly higher than average in one year, but not another.

The results obtained in the present study and in the right whale studies described above indicate that an area can only be described as a feeding area when feeding whales are in the immediate vicinity. To estimate the amount of food available to whales, sampling must be conducted close to feeding whales, and an echosounder is needed to guide the net to the layers of maximum biomass in the water column and/or to estimate biomass via quantitative echosounding methods.

Feeding thresholds of bowhead whales appear to be lower than those of the closely-related right whale. Plankton production and biomass is lower in the Beaufort Sea than in temperate waters (MacDonald et al. 1987). Bowhead whales may have lower energetic requirements than those of other whales. They grow very slowly and reach maturity later than other baleen whales, including right whales (Koski et al. 1993; George et al. 1999). In addition to having lower requirements for growth than do other species, the metabolic rate of bowheads may be lower than that of other species (George et al. 1999; Thomson, Chapter 22). Bowheads have apparently adapted their energetic requirements, physical adaptations for feeding, and feeding threshold to food availability in their habitat.

Characteristics of Feeding Areas

Copepods were the dominant taxa at the majority of the whale feeding stations, and also at the majority of the routine zooplankton sampling stations without whales, in both the eastern Alaskan and Canadian Beaufort Sea. In eastern Alaskan waters, copepods dominated at 14 of 21 (67%) stations where feeding whales were observed during sampling or on adjacent days, and at 24 of 47 (51%) routine transect stations that were not feeding or control stations.

During the 1986 eastern Alaska study, sampling sites near feeding bowhead whales were mainly in the Kongakut Delta area, in the extreme southeast part of the eastern Alaskan Beaufort Sea (Fig. 6.1). This area was under the influence of warm turbid surface water, probably influenced by the Mackenzie River, during the period when sampling was conducted. However, the biomass of copepods, especially *Limnocalanus macrurus,* was highest in the cold saline bottom layer that lay under the warmer freshened layer of Mackenzie River water. *Limnocalanus* accounted for most of the zooplankton biomass at these Alaskan whale-feeding stations (Appendix 6.3). Here the difference in temperature and salinity between surface water and the water below was ~4ºC and about 5 to 6 psu.

Similar high biomasses of *Limnocalanus macrurus* were found in cold saline bottom water that lay under warmer freshened surface water at whale feeding stations in the nearshore zone along the Yukon Coast in 1985 and 1986 (Appendix 6.3). High biomasses of *L. macrurus* were associated with strong temperature/salinity gradients in nearshore waters along the Yukon coast in 1985, 1986 and 1988. The difference in temperature and salinity between surface water and the water below at whale feeding stations along the Yukon coast was up to 5 or 6ºC and about 8 to 12 psu, i.e., somewhat more than in eastern Alaska. Of the five years with sampling in the eastern Alaskan Beaufort Sea, these physical and biological oceanographic characteristics extended into Alaska only in 1986.

In some years, bowhead whales do not concentrate along the Yukon coast, west of the mouth of the Mackenzie River, during August and early September. This was so in 1980 and 1981 (Richardson et al. 1987; Moore and Reeves 1993). There is some evidence showing that in 1980 and 1981 the Mackenzie River plume was blown to the north and east, rather than west, by the winds (Thomson et al. 1986). Conversely, in 1985 and 1986 the Mackenzie River plume had a strong influence on the oceanographic regime off the Yukon Coast and feeding bowheads were commonly observed there.

In September of 1998 and 1999, feeding bowheads were not as concentrated in the eastern Alaskan Beaufort Sea as they had been in 1986, and they were seen more often in offshore waters and/or the western part of the eastern Alaskan study area (Chapter 12). In 1998 and 1999, warm fresh Mackenzie water was not found in nearshore areas, *L. macrurus* was absent, and average zooplankton biomass at whale feeding stations was lower than in 1986. Strong temperature/salinity gradients were not found in nearshore waters in either 1998 or 1999.

Calanus hyperboreus and *C. glacialis* were the dominant copepod species at whale feeding and control stations in the eastern Alaskan Beaufort Sea in 1998 and 1999, but their biomass was typically lower than that of the *Limnocalanus macrurus* present at whale feeding stations in 1986. Predatory cnidarians, ctenophores, and chaetognaths were much more abundant at whale feeding and control stations in 1998–99 than in 1986. These animals feed on copepods and other zooplankters. The absence of *L. macrurus* in 1998–99 was largely responsible for the lower biomass observed at feeding stations in those years as compared with 1986. The absence of *L. macrurus* was possibly attributable to the reduced temperature and salinity gradients in 1998–99 and/or the presence of numerous predators. The predatory species that were abundant in 1998–99 are of much lower nutritive value than are copepods (Thomson, Chapter 22).

Calanus glacialis and (especially) *C. hyperboreus* were also the dominant copepod species at whale feeding stations off Richard's Island, N.W.T., in 1980 and 1981. Warm fresh water was found at the surface in both years, and vertical temperature and salinity gradients were present. In 1981, the echo-sounder showed layers of zooplankton below the pycnocline, and maximum biomass of zooplankton in horizontal tows was found in those layers. Whales were seen at distances >1 km from the ship, and average biomass at these stations was not particularly high. At these stations, the difference in temperature and salinity between surface water and the water below was ~1ºC and 4 to 6 psu.

Euphausiids did not dominate the zooplankton at any of our 37 zooplankton sampling sites where whales were observed from the boat and/or from an aircraft either during sampling or on an adjacent day (entries 1–37 in Appendix 6.3). Euphausiids did comprise 20% of the biomass at one whale-feeding site off the Yukon coast in 1986. They were not abundant during routine sampling in the eastern Alaskan Beaufort Sea in 1985–86 or 1998–2000. Euphausiids comprised 30% of biomass in one oblique tow in 2000, and their biomass of 189 mg/m^3 accounted for 38% of total biomass in a horizontal tow taken at the same station (see Appendix 5.28 following Chapter 5). Otherwise, euphausiids accounted for up to about 10 or 12% of biomass in a few other tows. Euphausiids also were not abundant in any samples taken during routine sampling or during sampling near bowhead whales in the Canadian Beaufort Sea in 1980, 1981, or 1985, and were abundant at only 1 station in 1986, a whale-feeding station (station 31 in Appendix 6.3).

However, euphausiids did dominate the zooplankton at 2 of 4 bowhead feeding sites in the eastern Alaskan Beaufort Sea sampled in 1989 by Wartzok et al. (1990). They found these feeding sites by tracking radio-tagged whales, and sampled around whales that were observed to be feeding. Biomass in vertical tows was 854, 1619 and 3287 mg/m^3 at three feeding sites in Camden Bay, and 730 mg/m^3 at a feeding site near Demarcation Bay. The 3287 and 730 mg/m^3 values came from locations where euphausiids represented 85% and 50% of the biomass (see last subsection of Appendix 6.3). Copepods and chaetognaths accounted for most of the biomass of zooplankters at the other two stations. Only vertical tows were taken so no data were available on layering of zooplankton at these stations; biomass at some depths was probably higher than that documented by vertical tows.

Thysanoessa inermis and *T. raschii* are the two species of euphausiids found in the study area and in bowhead stomachs (Chapter 5; see also Lowry and Sheffield, Chapter 18). As in most species of euphausiids, *T. raschii* is known to exhibit vertical migration, to form large concentrations, and (at times) to swarm at the surface (Nicol 1984; Simard et al. 1986; Watkins et al. 1986). In the St. Lawrence estuary, a layer of euphausiids dominated by *T. raschii* and with a biomass >1000 mg/m^3 was 1 to 7 km in width and over 100 km in length (Simard et al. 1986). In the Barents Sea, the highest biomass of *T. inermis* and *T. raschii* was found at depths of 400–500 m, and maximum biomass was over 3000 mg/m^3 (Dalpadado and Skjoldal 1996). When they occur, euphausiids can form large dense concentrations.

Other taxa that occasionally were dominant components of the zooplankton at whale feeding stations, aside from copepods and (less commonly) euphausiids and chaetognaths, were gelatinous groups (cnidarians and ctenophores) and mysids. Gelatinous groups were the dominant taxa at whale-feeding stations north of Tuktoyaktuk, west of Herschel Island, and off Clarence Lagoon (YT) in 1986; and east of Barter Island in 1998. As described in Chapter 22, the energy content of the gelatinous groups is low and it is doubtful that they would be a preferred food of whales. Mysids occasionally are found in bowhead stomachs (Chapter 18), and are known to swarm near the bottom at some locations (off the Kongakut Delta in 1986 and off Jago Spit in 1998).

In the shallow areas sampled close to shore, whale feeding stations contained a relatively high biomass of zooplankton as compared with other stations, and were usually characterized by strong temperature and salinity discontinuities caused by the presence of warm brackish Mackenzie River water over cold saline water below. In these areas, the zooplankton is almost always concentrated below the pycnocline. Most of the bowhead feeding is apparently below the surface (Chapter 12), and presumably at or near the depth of maximum zooplankton biomass. In nearshore waters, the small copepod *Limnocalanus macrurus* is often the dominant species. In water farther offshore, *Calanus hyperboreus* and *C. glacialis* are the dominant species. In some cases, bowheads direct their feeding to dense concentrations of euphausiids.

Most of the bowheads that fed in the shallow-water areas sampled in the Canadian and eastern Alaskan Beaufort Sea, as described above, were subadult whales (Koski et al. 1988; Chapter 10). Adult bowheads tend to occur farther offshore (and east) in the Canadian Beaufort Sea during summer, and farther offshore in the eastern Alaskan Beaufort Sea during late summer and autumn. In both areas, bowheads in deep water (>50 m) have sometimes been observed feeding in the water column (Richardson et al. 1995; Chapter 12). Some bowheads feeding in areas of the eastern Alaskan Beaufort Sea >20 m deep during September have specifically been confirmed to be adults (Chapter 12).

The zooplankton available at times and locations in the Beaufort Sea where adult bowheads were feeding has not been documented. By late summer and autumn, the large copepods *Calanus hyperboreus* and *C. glacialis* have begun to descend to their overwintering depths, which range from 200–300 m to over 1000 m in other regions (Hirche 1991). Copepods in deep water have large oil sacks and a high lipid content (Hirche 1983; Head and Harris 1985). The timing of the autumn descent by copepods depends on timing of ice breakup (Longhurst et al. 1984). The depth of the descent depends on the species, structure of the water column, and water depth (Longhurst et al. 1984; Sameoto 1984). Subadult bowheads can dive to depths >300 m (Krutzikowsky and Mate 2000). It can be assumed that adult bowheads can dive to these depths and probably greater. At Isabella Bay, Baffin Island, bowhead behavior and the vertical distribution of zooplankton biomass were indicative of feeding in waters >100 m deep (Finley et al. 1994; Richardson et al. 1995). Zooplankton biomass in a trough where bowheads were feeding was significantly higher in waters >100 m deep than in the upper 100 m of the water column. Most of the whales at Isabella Bay are large subadults and adults (Finley 1990).

Our net sampling and echosounder surveys were done during daylight. During September, there are several hours of darkness each night in this area. The extent of diel vertical migration by zooplankton in this area and season is unknown (see Chapter 5). Especially in deep areas, vertical migration of prey could cause day–night differences in food availability. However, most areas where we sampled were sufficiently shallow that any zooplankton concentrations present should have been detected (and accessible to bowheads) regardless of their depth. Krutzikowsky and Mate (2000) found no notable day–night differences in depths of dives or surface–dive cycles of bowheads during September–October.

We did not sample near feeding whales in 1985 and 2000. Concentrations of feeding whales were scarce in the eastern Alaskan study area in 1985 and especially 2000, and the sampling vessel was not able to reach any feeding concentration in those years. The estimated number of bowhead feeding days in the study area was very low in 2000, and also relatively low in 1985 (Table 6.8 and Chapter 23). Use of the study area by feeding bowheads appears to be quite variable from year to year. Likewise, right whale distribution appears to be related to the presence or absence of their preferred prey (Kenney 2001); in one case, right whales did not appear in their usual summering area because of a scarcity of copepods. In our study area, biomass of zooplankton was lower in 2000 than in the other four years, and very few bowheads fed in the study area in 2000.

TABLE 6.8. Estimated numbers of whale–days of use of the eastern-Alaskan study area by bowheads during late summer and autumn (Chapter 9), proportion of time spent feeding (Chapter 12), and feeding days of use per year (from Chapter 23).

	1985	1986	1998	1999	2000	Per Year
Number of whale–days of use	11,937	17,899	31,507	101,850	18,727	36,384
Proportion of time feeding	0.39	0.57	0.38	0.67	0.09	0.47
Feeding Days of Use	4,643	10,228	11,915	67,900	1,702	16,953

Prey in Whale Stomachs vs. Zooplankton Sampled Near Feeding Whales

Stomachs from 32 bowhead whales harvested by hunters from Kaktovik in 1979–2000 were examined by Lowry and Sheffield (Chapter 18). Twenty-four of the 32 whales were considered to have been feeding, and 21 of these contained a sufficient sample for analysis. Copepods and euphausiids were the main prey items in stomachs. Copepods were present in every stomach sample, were the dominant prey in 60% of stomachs, and were the only prey in 12 of the 21 stomachs that contained food. Euphausiids were also important as prey, and were the dominant prey in 5 whale stomachs. Other crustaceans and fishes also were eaten, but they generally were minor components (Chapter 18).

Copepods and (to a lesser degree) euphausiids, cnidarians, ctenophores, chaetognaths and mysids were, on a biomass basis, the dominant taxa collected near feeding whales in the Canadian and eastern Alaskan Beaufort Sea during all years. With the exception of euphausiids, these groups were also the dominant components of the zooplankton collected by net sampling in the eastern Alaskan Beaufort Sea as a whole (Griffiths and Thomson, Chapter 5). Euphausiids were the predominant zooplankton collected by nets at two stations near feeding whales (Wartzok et al. 1990), but were not major components of the zooplankton collected by nets in either the eastern Alaskan or Canadian Beaufort Sea (Bradstreet and Fissel 1986; Bradstreet et al. 1987; Chapter 5; Appendix 6.3). Euphausiids are fast swimmers and are often able to detect and avoid nets (Wiebe et al. 1982; Hovekamp 1989), which suggests that zooplankton sampling in the Beaufort Sea may have underrepresented euphausiids. However, we have collected large quantities of euphausiids in bongo tows at locations in the Western Alaskan Beaufort Sea (Griffiths et al. 1987), and Wartzok et al. (1990) caught large biomasses of euphausiids in vertical tows with standard nets. If euphausiids had been present in large quantities at other whale feeding stations, we believe that they would have been caught in bongo tows more often, even if underrepresented.

The dominant prey items found in whale stomachs at Kaktovik have fairly well represented the zooplankton present at whale feeding stations. The main differences between prey in bowhead stomachs and zooplankton found near feeding whales is the relatively higher importance of euphausiids and lower importance of the small copepod *Limnocalanus macrurus* in the stomachs relative to the net samples. There are several potential reasons for the differences that were observed: • Not all potential feeding habitats were sampled during this study. • Many whale-feeding stations in the eastern Alaskan Beaufort Sea were well outside the area near Kaktovik where whales were harvested (*cf.* Chapter 2). • Thomson (Chapter 22) argues that food passes through the bowhead gut very rapidly when whales are feeding, with the result that stomach contents of whales harvested near Kaktovik most likely represented prey availability close to the harvest locations. • Stomach contents of harvested whales may be affected by differential digestion rates of different prey taxa, which are quite variable in size and composition.

These factors may account for the differences between prey collected near feeding whales and prey found in whale stomachs. *Limnocalanus macrurus* is small compared to *Calanus* spp.; however, *L. macrurus* has many spines which cause the animals to become entangled with each other and form a ball in a plankton net, or presumably in a bowhead's mouth. Thus, they may be easily eaten by bowhead whales. In any event, during some years large numbers of feeding bowheads occur at nearshore locations where *Limnocalanus* is the only abundant zooplankton taxon. This provides very strong evidence that these small copepods are an important prey item in some years and locations.

Summary

Introduction and Objectives

Bowhead whales winter in the Bering Sea and annually migrate to summering areas in the Beaufort Sea. If bowheads, like other mysticete whales, feed mainly during summer, a primary reason for the annual migration would be to reach preferred summer feeding areas. This would imply that summering areas are sufficiently rich in food to justify migrating several thousand kilometers (round-trip) to feed. This component of the study had three main objectives: (1) to describe the characteristics of bowhead feeding areas in the eastern Alaskan and Canadian Beaufort Seas, with emphasis on the zooplankton and water masses; (2) to determine whether bowhead whales feed in areas where zooplankton is concentrated; and (3) to determine the quantity and kinds of zooplankton associated with feeding bowheads.

Methods

In the Eastern Alaskan Beaufort Sea, zooplankton was sampled during September of 1986, 1998 and 1999 at 21 stations where bowhead whales were either observed feeding or where whales had been observed feeding the previous day. Sampling near feeding bowheads was not possible in 1985 and 2000. For each feeding station sampled, a control station about 8 to 10 km from the feeding station was also sampled. Zooplankton near feeding bowheads was sampled at 16 additional stations in the Canadian Beaufort Sea during August and early September of 1980–81, 1985–86, and 1988. The eastern Alaskan and Canadian data are presented separately, but are also considered together to provide a broader view of bowhead feeding in the eastern Beaufort Sea. Vertical profiles of temperature and salinity were obtained at all but one systematic sampling station.

At most stations, oblique and horizontal zooplankton tows were made using a standard bongo frame fitted with two 0.5 mm mesh, 0.61 m diameter, plankton nets, and a flow meter. At most stations, at least one horizontal tow was targeted to a specific depth where an echosounder showed an apparent zooplankton concentration. The limited 1980 and 1988 sampling in Canadian waters employed vertical tows, and in 1986 the horizontal tows in Alaskan waters used an opening-and-closing bongo system. Animals from all oblique tows were identified to species, and those from horizontal tows to major taxa. Sorted animals were wet-weighed, and wet-weight biomass/m^3 was calculated using flow-meter data on volume filtered.

In the Alaskan Beaufort Sea, quantitative echosounder surveys were conducted between whale feeding and control stations during 1986, 1999 and 2000, and along other transects during all five field seasons. Regression equations were developed to relate zooplankton biomass in horizontal net tows to measured acoustic back scatter, and then used to estimate biomass where only echosounder data were available. In the Canadian Beaufort, the echosounder used in 1981, 1985 and 1986 identified depths with high (and low) apparent biomasses of zooplankton, but did not provide quantitative data on biomass.

Results

Bowhead whales feed in areas with a higher than average concentrations of zooplankton. A high biomass of zooplankton was found in areas where feeding bowheads were observed from the sampling boat in the eastern Alaskan and Canadian Beaufort Sea. Mean wet-weight biomass in the water column near actively feeding whales was 529 mg/m^3, a value considerably higher than the mean biomass in the water column elsewhere in the eastern Alaskan and Canadian parts of the Beaufort Sea (230 mg/m^3). Mean biomass in the horizontal tows with maximum biomass at 17 stations where whales were observed within 1 km of the boat and the echosounder was functioning was 1841 ± s.d. 1226 mg/m^3. The distribution of biomass values at places with feeding bowheads indicates that the feeding threshold for bowheads may be a wet biomass of ~800 mg/m^3.

A high biomass of zooplankton near feeding whales in nearshore waters was usually associated with the presence of strong temperature and salinity gradients (pycnocline) in the water column. In these cases, concentrations of zooplankton are found in the cold saline water that underlies the warmer freshened layer. These conditions are found at varying locations in the Canadian Beaufort Sea regardless of wind direction, but occur in shallow waters of the eastern Alaskan Beaufort Sea mainly under east wind conditions. The eastern Alaskan Beaufort Sea appears to be more important to feeding whales in years when oceanographic conditions that cause zooplankton to concentrate in nearshore waters off the Yukon coast extend west into Alaska.

The small copepod *Limnocalanus macrurus* dominated the zooplankton biomass near feeding bowheads in nearshore waters along the Yukon coast and into northeast Alaska when cold saline water was overlain by warm Mackenzie water. Farther offshore, the large copepods *Calanus hyperboreus* and C. *glacialis* dominated. Stomach contents of whales landed at Kaktovik show that bowheads sometimes feed on dense swarms of euphausiids. However, euphausiids are rarely the dominant zooplankters around bowheads feeding in the present study areas. Other taxa that occasionally are dominant near feeding whales are gelatinous cnidarians and ctenophores, chaetognaths, and mysids.

We did not find places with feeding whales where euphausiids were dominant, but this has been reported previously from the Camden Bay area, and euphausiids are the dominant components of the prey in the stomachs of a minority of the bowheads landed at Kaktovik (see Chapter 18). Euphausiids are known to show avoidance reactions to sampling nets. As a result euphausiids are probably somewhat under-represented in our net samples. However, where euphausiids are abundant, as they are at times in the western Beaufort Sea, they are prominent in net samples. In general, euphausiids are apparently less important as prey for bowhead whales in the eastern Alaskan Beaufort Sea than farther west near Point Barrow.

Most whales observed in the areas sampled were subadults. Adult bowheads tend to feed in deeper water, where large copepods predominate. By early autumn, most large copepods have descended to their overwintering depths (>100 m).

Water masses in the areas sampled are defined by the presence or absence of the plume of freshened and warmer water influenced by Mackenzie River outflow. Wind conditions have rapid effects on the Mackenzie plume, so oceanographic conditions can change rapidly. These changes influence the biomass and composition of the zooplankton community in the eastern Beaufort Sea, and especially the portion that is in Alaska.

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APPENDIX 6.1. Locations of whale feeding and control stations in the eastern Alaskan Beaufort Sea, September 1986, 1998 and 1999a.

Station	Reference Number[a]	Date	Whale Feeding	Water Depth (m)	Time (ADT)	Station	
						Latitude	Longitude
1986							
86-1	5	4/9/1986	Yes	17	9:20	69°35.7'N	139°31.6'W[b]
86-2		4/9/1986	Control	25	14:00	69°40.3'N	139°28.4'W[b]
86-5	1	5/9/1986	Yes	14	15:00	69°50.1'N	141°51.9'W
86-6		5/9/1986	Control	27	18:16	69°53.8'N	141°45.6'W
86-7	2	6/9/1986	Yes	11	11:03	69°48.9'N	141°47.8'W
86-8		6/9/1986	Control	23	13:28	69°52.6'N	141°48.3'W
86-9	3	6/9/1986	Yes	7	1704	69°48.6'N	141°46.8'W
86-10	6	7/9/1986	Yes	12	9:10	69°38.1'N	140°49.4'W[b]
86-11		7/9/1986	Control	15	11:47	69°38.7'N	140°52.4'W[b]
86-12	4	7/9/1986	Yes	22	14:51	69°49.2'N	141°35.3'W
86-13		7/9/1986	Control	25	16:25	69°51.1'N	141°33.8'W
1998							
1	7	11/09/98	Yes	15	14:11	70° 04.80' N	144° 46.45' W
2		11/09/98	Control	8	17:42	69° 59.74' N	144° 47.98' W
3	8	12/09/98	Yes	17	8:47	70° 07.55' N	144° 46.76' W
4	9	12/09/98	Yes	25	13:17	70° 11.57' N	144° 53.17' W
5		12/09/98	Control	22	15:22	70° 10.68' N	144° 32.06' W
7		14/09/98	Control	18	10:31	69° 49.92' N	141° 40.04' W
8	10	14/09/98	Yes	27	14:08	69° 50.18' N	141° 23.43' W
15	11	16/09/98	Yes	40	13:30	70° 18.72' N	143° 25.81' W
16		16/09/98	Control	46	15:35	70° 23.52' N	143° 24.12' W
21	12	18/09/98	Yes	27	12:54	70° 13.33' N	143° 49.68' W
22		18/09/98	Control	14.5	14:59	70° 09.67' N	143° 47.97' W
27	13	20/09/98	Yes	10	11:09	70° 10.14' N	143° 24.00' W
28	14	20/09/98	Yes	14.5	11:46	70° 10.44' N	143° 16.80' W
29		20/09/98	Control	34	15:14	70° 14.47' N	143° 09.71' W
30		22/09/98	Control	12	9:26	70° 09.53' N	143° 37.75' W
32	15	22/09/98	Yes	16	14:52	70° 09.92' N	143° 07.96' W
31		22/09/98	Control	19	10:11	70° 11.31' N	143° 41.06' W
33	16	22/09/98	Yes	19	15:08	70° 10.55' N	143° 07.77' W
1999							
1	17	16/9/99	Yes	48	14:31	70° 08.58' N	141° 49.29' W
2		16/9/99	Control	46	16:06	70° 08.34' N	142° 05.04' W
3	18	17/9/99	Yes	48	11:24	70° 08.33' N	141° 52.50' W
4	19	17/9/99	Yes	48	13:14	70° 08.85' N	142° 00.59' W
5		17/9/99	Control	35	16:00	70° 03.36' N	142° 08.31' W
15	21	20/9/99	Yes	45	12:00	70° 20.75' N	143° 25.70' W
14	20	20/9/99	Yes	35	15:07	70° 16.12' N	143° 32.87' W
17		20/9/99	Control	20	16:26	70° 11.80' N	143° 39.75' W

ADT = Alaska daylight time.

[a] Corresponding to whale feeding stations in Figure 6.1 and Appendix 6.3.

[b] Stations in the Canadian Beaufort Sea near Alaska that were sampled during the Alaskan project.

APPENDIX 6.2. Major zooplankton taxa and species collected in oblique tows at apparent feeding and corresponding control stations 1986, 1998, 1999. Sample depth is the maximum water depth of the oblique tow, which was near the bottom (see Appendix 6.1 for station depths).

Location	Sample Depth (m)	Zooplankton Biomass mg/m^3	Copepods Comprising >1% of Biomass	%	Other Taxa Comprising >1% of Biomass	%	No. of Whales	Whale Sightings
1986								
A. 4 Sept 1986, West of Herschel Island								
Sta. 86-1	16	96.4	Copepods	14.5	Cnidarians & Ctenophores	38.1	10	Whales feeding
(Whales)			*Limnocalanus macrurus*	7.7	Amphipods	13.0		on Sept 3
Ref 5[a]			*Calanus hyperboreus*	2.3	Mysids	5.9		
			Calanus glacialis	2.5	Fish Larvae	2.9		
			Pseudocalanus minutus	1.4	Chaetognaths	3.0		
					Decapod larvae	13.9		
					Pteropods	5.2		
Sta. 86-2	20	51.8	Copepods	78.5	Fish Larvae	5.9		
(Control)			*Limnocalanus macrurus*	43.1	Cnidarians & Ctenophores	5.6		
			Calanus hyperboreus	17.8	Decapod larvae	4.8		
			Calanus glacialis	11.8	Chaetognaths	1.4		
			Euchaeta glacialis	2.3	Amphipods	1.2		
			Metridia longa	1.9				
B. 5 Sept 1986, Kongakut Delta								
Sta. 86-5	12	1228.1	Copepods	96.0	Cnidarians & Ctenophores	2.5	Many	Numerous whales seen
(Whales)			*Limnocalanus macrurus*	95.0				from boat
Ref 1								
Sta. 86-6	22	81.2	Copepods	17.3	Cnidarians & Ctenophores	38.1		
(Control)			*Calanus glacialis*	10.8	Fish larvae	15.7		
			Limnocalanus macrurus	4.2	Decapod larvae	7.2		
			Calanus hyperboreus	1.5	Amphipods	4.0		
					Chaetognaths	1.3		
					Pteropods	14.0		
C. 6 Sept 1986, Kongakut Delta								
Sta. 86-7	8	853.4	Copepods	91.1	Mysids	6.3	Many	Numerous whales seen
(Whales)			*Limnocalanus macrurus*	88.4				from boat
Ref 2			*Pseudocalanus minutus*	1.3				
Sta. 86-8	23	40.5	Copepods	31.7	Amphipods	38.0		
(Control)			*Limnocalanus macrurus*	18.5	Cnidarians & Ctenophores	12.3		
			Calanus glacialis	4.7	Decapod larvae	4.3		
			Euchaeta glacialis	3.5	Chaetognaths	3.3		
			Calanus hyperboreus	2.7	Pteropods	2.4		
D. 7 Sept 1986, Clarence Lagoon								
Sta. 86-10	12	105.0	Copepods	33.8	Cnidarians & Ctenophores	41.7	8	Whales feeding
(Whales)			*Limnocalanus macrurus*	32.0	Fish larvae	7.5		on Sept 7
Ref 6					Decapod larvae	6.0		
					Mysids	4.6		
					Pteropods	2.9		
					Amphipods	1.9		
Sta. 86-11	12	198.5	Copepods	57.4	Cnidarians & Ctenophores	26.8		
(Control)			*Limnocalanus macrurus*	46.7	Fish larvae	3.2		
			Calanus glacialis	6.9	Chaetognaths	3.4		
			Calanus hyperboreus	2.2	Decapod larvae	3.9		
			Pseudocalanus minutus	1.3	Amphipods	1.9		
E. 7 Sept 1986, Kongakut Delta								
Sta. 86-12	18	912.4	Copepods	95.3	Fish larvae	1.2	12	Whales feeding
(Whales)			*Limnocalanus macrurus*	93.8	Cnidarians & Ctenophores	1.2		
Ref 4								
Sta. 86-13	21	58.7	Copepods	1.1	Fish larvae	33.7		
(Control)			*Limnocalanus macrurus*	1.0	Decapod larvae	24.8		
					Cnidarians & Ctenophores	16.6		
					Pteropods	9.8		
					Amphipods	1.2		
					Other	12.7		

APPENDIX 6.2. (continued)

Location	Sample Depth (m)	Zooplankton Biomass mg/m^3	Copepods Comprising >1% of Biomass	%	Other Taxa Comprising >1% of Biomass	%	No. of Whales	Whale Sightings
1998								
A. 11 Sept. 1998, East Camden Bay								
Sta. 98-1	10.5	144.0	Copepods	79.1	Cnidarians & Ctenophores	9.5	4+	Water-column
(Whales)			*Calanus glacialis*	70.7	Amphipods	5.5		feeding
Ref 7			*Calanus hyperboreus*	7.4	Chaetognaths	5.2		
			Pseudocalanus minutus	1.0				
Sta. 98-2	6.5	233.8	Copepods	3.2	Fish Larvae	70.2		
(Control)			*Calanus glacialis*	2.2	Chaetognaths	16.2		
			Calanus hyperboreus	0.2	Mysids	8.8		
			Pseudocalanus minutus	0.8				
B. 12 Sept. 1998, East Camden Bay								
Sta. 98-3	10.0	678.4	Copepods	78.8	Chaetognaths	12.3	10+	Seen Day
(Whales)			*Calanus glacialis*	71.1	Cnidarians & Ctenophores	8.3		Before
Ref 8			*Calanus hyperboreus*	6.4				
			Pseudocalanus minutus	1.3				
Sta. 98-4, 4 nmiles North Sta. 98-3			Copepods	61.3	Chaetognaths	26.7	3+	Water-column
(Whales)	19.6	468.4	*Calanus glacialis*	48.6	Cnidarians & Ctenophores	11.5		Feeding
Ref 9			*Calanus hyperboreus*	12.4				
			Pseudocalanus minutus	0.2				
Sta. 98-5	19.5	418.1	Copepods	54.6	Cnidarians & Ctenophores	24.4		
(Control)			*Calanus glacialis*	36.1	Chaetognaths	20.9		
			Calanus hyperboreus	16.7				
			Pseudocalanus minutus	1.6				
C. 14 Sept. 1998, Icy Reef								
Sta. 98-8	24.0	331.0	Copepods	31.8	Cnidarians & Ctenophores	57.7	6+	Water-column
(Whales)			*Calanus glacialis*	26.6	Chaetognaths	7.8		Feeding
Ref 10			*Calanus hyperboreus*	4.7	Euphausiids	1.3		
			Pseudocalanus minutus	0.3				
Sta. 98-7	16.0	93.7	Copepods	45.1	Cnidarians & Ctenophores	29.9		
(Control)			*Calanus glacialis*	42.7	Chaetognaths	19.2		
			Calanus hyperboreus	2.0	Euphausiids	3.1		
			Pseudocalanus minutus	0.2	Mysids	2.1		
D. 16 Sept. 1998, North of Bernard Spit Barter Island								
Sta. 98-15								
(Whales?)	32.5	148.2	Copepods	55.6	Cnidarians & Ctenophores	25.4	3+	Seen from the
Ref 11			*Calanus glacialis*	52.0	Chaetognaths	7.0		Boat, stayed in
			Calanus hyperboreus	2.7	Fish Larvae	6.2		area during
			Pseudocalanus minutus	0.7	Larvaceans	2.8		sampling
					Amphipods	2.5		
Sta. 98-16	46.0	71.5	Copepods	37.3	Cnidarians & Ctenophores	28.5		
(Control)			*Calanus glacialis*	30.5	Fish Larvae	17.3		
			Calanus hyperboreus	5.2	Chaetognaths	8.6		
			Pseudocalanus minutus	0.6				
E. 18 Sept. 1998, East Camden Bay								
Sta. 98-21	24.5	327.1	Copepods	71.4	Chaetognaths	19.4	14+	Water-column
(Whales)			*Calanus glacialis*	47.5	Cnidarians & Ctenophores	5.8		Feeding
Ref 12			*Calanus hyperboreus*	20.9	Mysids	2.0		
			Pseudocalanus minutus	3.0	Fish Larvae	1.1		
Sta. 98-22	12.5	298.4	Copepods	19.8	Chaetognaths	64.9		
(Control)			*Calanus glacialis*	4.1	Cnidarians & Ctenophores	14.3		
			Calanus hyperboreus	13.8	Mysids	1.0		
			Pseudocalanus minutus	1.6				

APPENDIX 6.2. (continued)

Location	Sample Depth (m)	Zooplankton Biomass mg/m^3	Copepods Comprising >1% of Biomass	%	Other Taxa Comprising >1% of Biomass	%	No. of Whales	Whale Sightings
F. 20 Sept. 1998, Off Jago Spit								
Sta. 98-27	7.5	207.6	Copepods	15.1	Mysids	33.7	4+	Water-column
(Whales)			*Calanus glacialis*	5.5	Chaetognaths	25.4		feeding
Ref 13			*Calanus hyperboreus*	7.5	Cnidarians/Ctenophores	20.3		
			Pseudocalanus minutus	2.1				
Sta. 98-28	orth of Sta. 98-27							
(Whales)	13.5	270.5	Copepods	8.7	Chaetognaths	37.5	4+	Water-column
Ref 14			*Calanus glacialis*	4.1	Mysids	27.5		feeding
			Calanus hyperboreus	3.0	Hydrozoans & Ctenophores	26.2		
			Pseudocalanus minutus	1.6				
Sta. 98-29	29.5	429.2	Copepods	37.0	Chaetognaths	47.5		
(Control)			*Calanus glacialis*	19.5	Cnidarians/Ctenophores	13.9		
			Calanus hyperboreus	15.3	Mysids	1.4		
			Pseudocalanus minutus	2.0				
G. 22 Sept. 1998, Off Barter Island								
Sta. 98-32	13.0	239.0	Copepods	23.1	Cnidarians/Ctenophores	34.8	4+	Bottom
(Whales)			*Calanus glacialis*	18.9	Chaetognaths	32.2		feeding
Ref 15			*Calanus hyperboreus*	1.8	Mysids	6.6		
			Pseudocalanus minutus	2.3	Euphausiids	2.8		
Sta. 98-30	8.5	311.7	Copepods	13.4	Fish Larvae	33.0		
(Control)			*Calanus glacialis*	10.7	Chaetognaths	26.9		
			Calanus hyperboreus	1.0	Mysids	19.8		
			Pseudocalanus minutus	1.5	Cnidarians/Ctenophores	6.1		
Sta. 98-33	15.5	224.5	Copepods	30.3	Chaetognaths	47.9	4+	Bottom
(Whales)			*Calanus glacialis*	22.7	Mysids	10.7		feeding
Ref 16			*Calanus hyperboreus*	3.9	Cnidarians/Ctenophores	7.4		
			Pseudocalanus minutus	3.6	Euphausiids	3.5		
Sta. 98-31	19.0	406.9	Copepods	63.0	Chaetognaths	11.1		
(Control)			*Calanus glacialis*	56.8	Cnidarians/Ctenophores	9.4		
			Calanus hyperboreus	4.9	Mysids	6.2		
			Pseudocalanus minutus	1.3	Decapods	6.4		
					Fish Larvae	2.7		
1999								
A. 16 Sept. 1999, Off Nug Lagoon								
Sta. 99-1	40.0	442.7	Copepods	67.3	Chaetognaths	18.5	18	Water-column
(Whales)			*Calanus glacialis*	9.8	Cnidarians/Ctenophores	7.4		feeding
Ref 17			*Calanus hyperboreus*	54.8	Fish Larvae	3.1		
			Pseudocalanus minutus	<1.0				
Sta. 99-2	40.0	384.3	Copepods	62.1	Cnidarians/Ctenophores	24.4		
(Control)			*Calanus glacialis*	4.0	Chaetognaths	10.8		
			Calanus hyperboreus	56.2	Fish Larvae	3.6		
			Pseudocalanus minutus	<1.0				
B. 17 Sept. 1999, Off Nug Lagoon								
Sta. 99-3	40.0	207.4	Copepods	73.1	Chaetognaths	9.3	15	Water-column
(Whales)			*Calanus glacialis*	9.0	Cnidarians/Ctenophores	6.8		feeding
Ref 18			*Calanus hyperboreus*	61.5	Fish Larvae	5.5		
			Pseudocalanus minutus	<1.0				
Sta. 99-4	41.0	221.2	Copepods	70.5	Cnidarians/Ctenophores	14.9	13	Water-column
(Whales)			*Calanus glacialis*	7.3	Chaetognaths	9.6		feeding
Ref 19			*Calanus hyperboreus*	62.0	Fish Larvae	2.5		
			Pseudocalanus minutus	<1.0				
Sta. 99-5	30.0	215.4	Copepods	65.6	Cnidarians/Ctenophores	20.4		
(Control)			*Calanus glacialis*	2.2	Fish Larvae	6.5		
			Calanus hyperboreus	62.4	Chaetognaths	5.1		
			Pseudocalanus minutus	>1.0				

APPENDIX 6.2. (concluded)

Location	Sample Depth (m)	Zooplankton Biomass mg/m^3	Copepods Comprising >1% of Biomass	%	Other Taxa Comprising >1% of Biomass	%	No. of Whales	Whale Sightings
C. 20 Sept. 1999, Off Barter Island								
Sta. 99-14	40.0	449.50	Copepods	70.6	Cnidarians/Ctenophores	19.4	15	Water-column
(Whales)			*Calanus glacialis*	7.8	Chaetognaths	8.5		feeding between
Ref 20			*Calanus hyperboreus*	60.4	Fish Larvae	1.2		St. 14 and 15
			Pseudocalanus minutus	<1.0				
Sta. 99-15	45.0	582.80	Copepods	80.2	Cnidarians/Ctenophores	11.8	15	Water-column
(Whales)			*Calanus glacialis*	15.0	Chaetognaths	8.5		feeding between
Ref 20			*Calanus hyperboreus*	61.2	Fish Larvae	<1.0		St. 14 and 15
			Pseudocalanus minutus	<1.0				
Sta. 99-17	18.0	438.00	Copepods	19.3	Chaetognaths	39.8		
(Control)			*Calanus glacialis*	6.5	Cnidarians/Ctenophores	28.3		
			Calanus hyperboreus	12.3	Euphausiids	9.2		
			Pseudocalanus minutus	<1.0	Fish Larvae	1.9		
					Mysids	0.9		

[a] Corresponding to whale feeding stations in Figure 6.1 and Appendix 6.3.

APPENDIX 6.3. Attributes of the 42 whale feeding stations sampled in eastern Alaskan Beaufort Sea, along Yukon coast and off Tuktoyaktuk Peninsula, 1981–99. Locations are shown on Figure 6.1 (from Griffiths and Buchanan 1982; Griffiths et al. 1987; Bradstreet and Fissel 1986; Bradstreet et al. 1987; Wartzok et al. 1990; and present study). Mean biomass and dominant taxa are from oblique bongo tows; maximum biomass from horizontal bongo tows. **Note:** The station numbers in parentheses are the station numbers that appear in the original reports.

	Date	Water Depth (m)	Biomass (mg/m^3)		Depth of Max Biomass	Dominant Taxa		Bowheads Observed
			Mean	Maximum		Taxa (%)	Species (%)	
Eastern Alaskan Beaufort Sea 1986								
1 Off Kongakut Delta 69°50.1'N 141°51.9'W (St 5)	5-Sep 86	14	1228	3023	10	Copepods (95%)	*Limnocalanus macrurus* (93%)	Feeding whales observed from boat and aircraft
2 69°48.9'N 141°47.8'W (St 7)	6-Sep 86	11	853	2887	8	Copepods (91%)	*Limnocalanus macrurus* (91%)	Feeding whales observed from boat and aircraft
3 69°48.6'N 141°46.8'W (St 9)	6-Sep 86	7	319	-b	-b	Copepods (90%)	*Limnocalanus macrurus* (85%)	Feeding whales observed earlier in day from aircraft
4 69°49.2'N 141°35.3'W (St 12)	7-Sep 86	22	912	2137	15	Copepods (95%)	*Limnocalanus macrurus* (94%)	Feeding whales observed from boat and aircraft
5 West of Herschel Is. (St 1) 69°35.7'N 139°31.6'W	4-Sep 86	17	96	75	8	Cnidarians + Ctenophores (38%)	*Aglantha digitale* (26%)	None seen from boat; feeding previous day
6 Off Clarence Lagoon (St 10) 69°38'N 140°49'W	7-Sep 86	12	105	3847	8	Cnidarians + Ctenophores (42%)	*Limnocalanus macrurus* (32%)	1 whale observed from boat; several feeding previous day
Eastern Alaskan Beaufort Sea 1998								
7 Eastern Camden Bay (St. 1) 70° 04.80'N 144° 46.45'W	11-Sep 98	15	144	295	10.5	Copepods (79%)	*Calanus glacialis* (71%)	4+ whales observed from aircraft surface feeding
8 Eastern Camden Bay (St. 3) 70° 07.55'N 144° 47.76'W	12-Sep 98	17	678	615	15	Copepods (79%)	*Calanus glacialis* (71%)	10+ whale seen from aircraft on the previous day
9 Eastern Camden Bay (St. 4) 70° 11.57'N 144° 53.17'W	12-Sep 98	25	468	460	10.6	Copepods (61%)	*Calanus glacialis* (49%)	3+ whale observed from aircraft feeding in water-column
10 Off Icy Cape (St. 8) 69° 50.18'N 141° 23.43'W	14-Sep 98	27	331	504	23.5	Cnidarians + Ctenophores (58%)	*Cyanea capillata* (49%)	6+ whale observed from aircraft feeding in water-column
11 Off Jago Spit (St. 15) 70° 18.72'N 143° 25.81'W	16-Sep 98	40	148	771	22.4	Copepods (56%)	*Calanus glacialis* (52%)	Several whales observed from boat during sampling
12 Eastern Camden Bay (St. 21) 70° 13.33'N 143 49.68'W	18-Sep 98	27	327	389	23	Copepods (71%)	*Calanus glacialis* (48%)	14+ whales observed from aircraft feeding in water-column
13 Off Jago Spit (St. 27) 70° 10.14'N 143° 24.00'W	20-Sep 98	10	208	267	6.8	Mysids (34%)	*Mysis litoralis* (34%)	4+ whales observed from aircraft feeding in water-column
14 Off Jago Spit (St. 28) 70° 10.44'N 143° 16.80'W	20-Sep 98	14.5	271	421	10.8	Chaetognaths (38%	*Sagitta elegans* (38%)	4+ whales observed from aircraft feeding in water-column
15 East of Barter Island (St. 32) 70° 09.92'N 143° 07.96'W	22-Sep 98	16	239	329	14.1	Cnidarians + Ctenophores (35%)	*Mertensia ovum* (16%)	4+ whales observed from aircraft bottom feeding

APPENDIX 6.3. (continued)

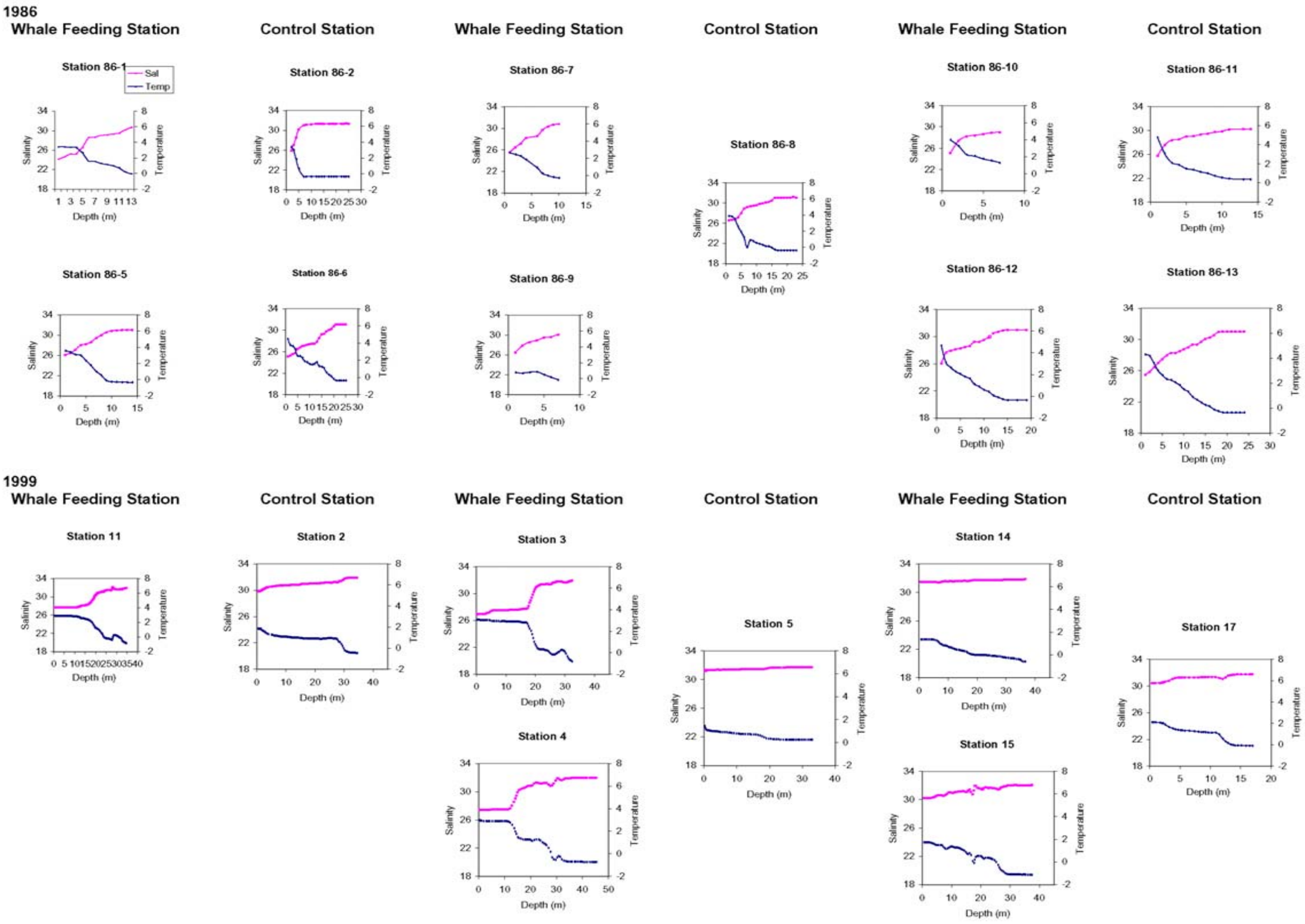
	Date		Water Depth (m)	Biomass (mg/m^3) Mean	Biomass (mg/m^3) Maximum	Depth of Max Biomass	Dominant Taxa Taxa (%)	Dominant Taxa Species (%)	Bowheads Observed
16 East of Barter Island (St. 33) 70° 10.55'N 143° 07.77W	22-Sep	98	19	225	386	13.7	Chaetognaths (48%)	*Sagitta elegans* (48%)	4+ whales observed from aircraft bottom feeding
Eastern Alaskan Beaufort Sea 1999									
17 Off Beaufort Lagoon (St. 1) 70° 08.58' N 141° 49.29' W	16-Sep	99	48	443	545	31	Copepods (67%)	*Calanus hyperboreus* (55%	18 whales observed from boat aircraft feeding in water-column
18 Off Beaufort Lagoon (St. 3) 70° 08.33' N 141° 52.50' W	17-Sep	99	48	207	886	40	Copepods (73%)	*Calanus hyperboreus* (62%	15 whales observed from aircraft feeding in water-column
19 Off Beaufort Lagoon (St. 4) 70° 08.85' N 142° 00.59' W	17-Sep	99	48	221	778	40	Copepods (71%)	*Calanus hyperboreus* (62%	13 whales observed from boat & aircraft feeding in water-column
20 East of Barter Island (St. 14) 70° 16.12' N 143° 32.87' W	20-Sep	99	40	450	595	31	Copepods (71%)	*Calanus hyperboreus* (60%	15 Whales observed between St. 14 and St. 15 from aircraft feeding in water-column
21 East of Barter Island (St. 15) 70° 20.75' N 143° 25.70' W	20-Sep	99	45	583	571	24	Copepods (80%)	*Calanus hyperboreus* (61%	15 Whales observed between St. 14 and 15 from aircraft feeding in water column
Canadian Beaufort Sea 1980									
22 Off Richard's Island Mackenzie Delta 70°00'N 134°30'W	14-26 Aug	80	26	558 1017	mean max	-b	Hydrozoans (71%)	*Halitholus cirratus (25%)* *Euphysa flammea (38%)*	Whales observed in general are by aircraft
Canadian Beaufort Sea 1981									
23 Off Richards Island., Mackenzie Delta 70°00'N 135°43'W	18-19 Aug	81	26	-c	885	15	Copepods (79%)	*Calanus hyperboreus* (70%	30 whales observed surface feeding (aircraft and boat observations)
					216	0	Copepods (92%)	*Calanus hyperboreus* (69%)	
24 Off Richards Island., Mackenzie Delta 70°08'N 134°38'W	24-Aug	81	30	-c	1405	15	Copepods (64%)	*Calanus hyperboreus* (52% *C. glacialis*	Whales observed to be feeding by boat
					552	0	Copepods (83%)	*Calanus hyperboreus* (82%) *C. glacialis*	
25 Off Richards Island., Mackenzie Delta 69°52'N 134°49'W	25-Aug	81	11	-c	807	10	Copepods (61%) Mysids (18%)	*Calanus hyperboreus* (39% *Mysis littoralis* (18%)	Whales observed to be feeding near the bottom by boat
Canadian Beaufort Sea 1985									
26 Off Kay Pt., Yukon Coast (St 69°27'N 138°04'W	27-Aug	85	64	288	1098	8	Copepods (92%)	*Limnocalanus macrurus* (77%)	Observed from boat
27 Off King Pt., Yukon Coast (St 69°05'N 137°47'W	28-Aug	85	12	-c	2142	1	Copepods (99%)	*Limnocalanus macrurus* (97%)	Observed from boat, 1 was surface feeding

APPENDIX 6.3. (concluded)

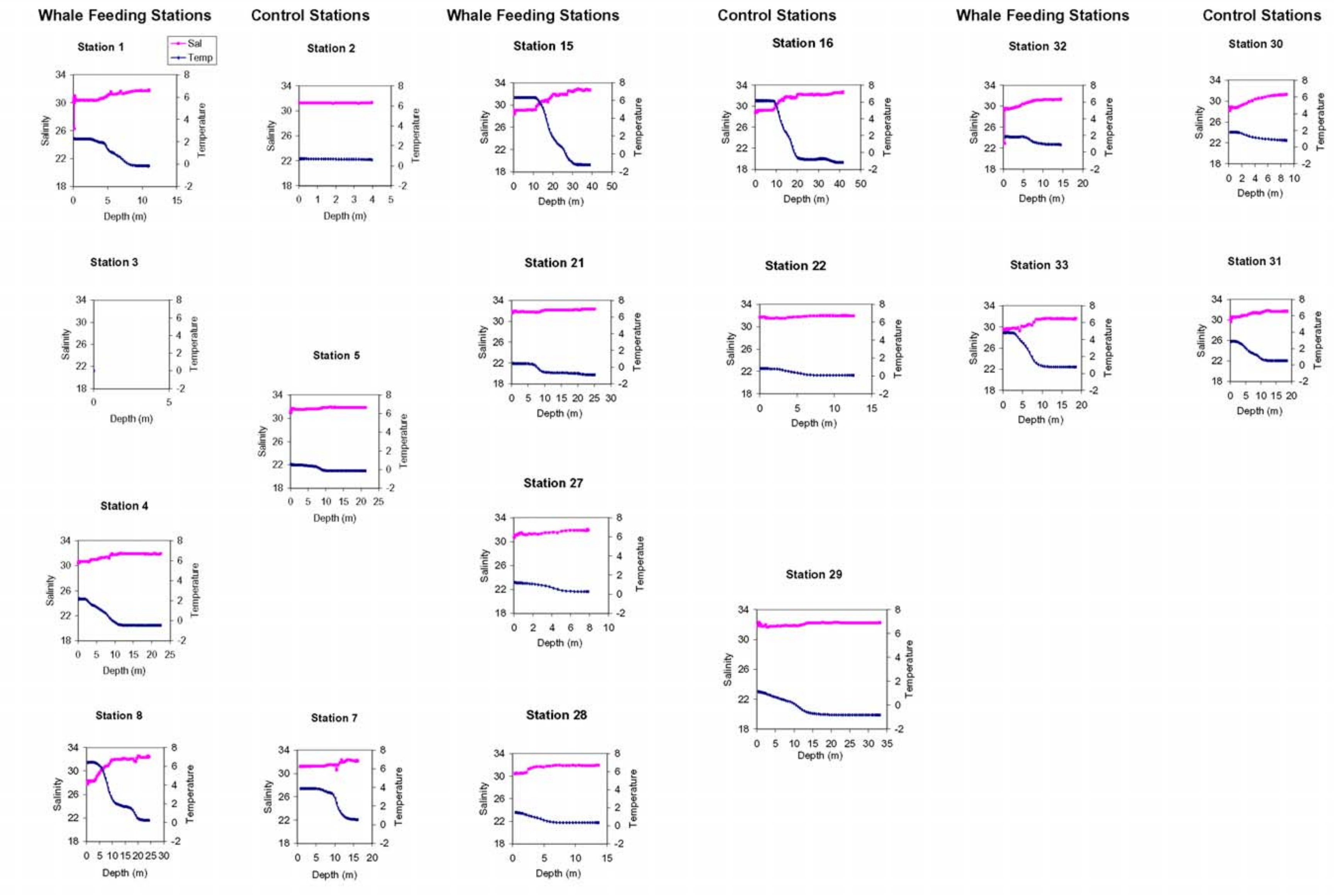
	Date		Water Depth (m)	Biomass (mg/m^3) Mean	Biomass (mg/m^3) Maximum	Depth of Max Biomass	Dominant Taxa: Taxa (%)	Dominant Taxa: Species (%)	Bowheads Observed
28 Off King Pt., Yukon Coast (St 3) 69°08'N 138°00'W	29-Aug	85	21	836	1203	9	Copepods (94%)	*Limnocalanus macrurus* (88%)	Observed water-column feeding from boat
29 Off Kay Pt., Yukon Coast (St 26) 69°16'N 138°16'W	29-Aug	85	25	-c	2294 693	8 1	Copepods (98%)	*Limnocalanus macrurus* (84%)	Observed some water-column feeding and some surface
Canadian Beaufort Sea 1986									
30 King Point, Yukon Coast (St 2) 69°05'N 137°47'W	5-Sep	86	14	776	1543	3	Copepods (91%)	*Limnocalanus macrurus* (86%)	About 12 whales observed from ship
31 King Point, Yukon Coast (St 3) 69°08'N 137°38'W	5-Sep	86	21	455	771	14	Copepods (61%) Euphausiids (20%)	*Limnocalanus macrurus* (26%) *Calanus hyperboreus* (18%)	3 whales observed from ship possibly feeding
32 North of Tuktoyaktuk (St 60) 70°42'N 132°53'W	30-Aug	86	49	369	-a	-a	Copepods (85%)	*Calanus hyperboreus* (76%)	Whales observed within 50 m of ship
33 North of Tuktoyaktuk (St 54) 70°29'N 131°27'W	30-Aug	86	38	260	-a	-a	Cnidarians + Ctenophores (39%)	*Aglantha digitale* (34%)	Whales >1 km from ship
34 North of Tuktoyaktuk (St 55) 70°49'N 131°27'W	30-Aug	86	52	282	139	20	Copepods (70%)	*Calanus hyperboreus* (68%)	Whales >1 km from ship
35 Off E. Tuk. Penin. (St 79.3) 70°51'N 130°46'W	3-Sep	86	43	116	93	33	Copepods (71%)	*Calanus hyperboreus* (55%)	Whales >1 km from ship
36 Off E. Tuk. Penin. (St 79) 70°44'N 130°46'W	3-Sep	86	36	527	-a	-a	Copepods (87%)	*Calanus hyperboreus* (68%)	3 whales observed within 500 m of ship
Canadian Beaufort Sea 1988									
37 Off Shingle Point[d] 69°00'N 137°28'W	11-Sep	88	0 to 1 0 to 2	1732 736	4889 2635		Copepods	*Limnocalanus macrurus*	5 whales observed surface feeding (boat observations)
Other Studies in the Canadian and Alaskan Beaufort Sea (Wartzok et al. 1990)									
38 Off Tuktoyaktuk Peninsula	Sep	89	about 20	426	-b	-b	Copepods (67%)		8 whales observed from boat water column feeding
39 Off Demarcation Bay	Sep	89	about 20	730	-b	-b	Euphausiids (50%)	*Thysanoessa raschii (100%)*	12 whales observed from boat skim and water colum feeding
40 Camden Bay	Sep	89	about 20	1619	-b	-b	Copepods (97%)		12 whales observed from boat water column feeding
41 Camden Bay	Sep	89	about 20	854	-b	-b	Chaetognaths (58%)		3 whales observed from boat water column feeding
42 Camden Bay	Sep	89	about 20	3287	-b	-b	Euphausiids (85%)	*Thysanoessa raschii (100%)*	20 whales observed from boat skim feeding near surface

a Echosounder not functioning.
b No horizontal taken at depth
c No oblique tows taken.
d Only numbers and calculated biomass for *Limnocalanus macrurus* known for this station.

APPENDIX 6.4. Temperature and salinity profiles (CTD) in the water column at whale feeding and control stations in the eastern Alaskan Beaufort Sea, Sept 1986 and 1999. See Figure 6.1A,B and Appendix 6.1 for station locations. At the right of all profiles, top line (red) is salinity and bottom line (blue) is temperature.



APPENDIX 6.5. Temperature and salinity profiles (CTD) in the water column at whale feeding and control stations in the eastern Alaskan Beaufort Sea, Sept. 2000. See Figure 61.1C and Appendix 6.1 for station locations. At the right of all profiles, top line (red) is salinity; bottom line (blue) is temperature.



7. ZOOPLANKTON: SUMMARY AND CONCLUSIONS

William B. Griffiths[1] and Denis H. Thomson[2]

The main purpose of the zooplankton components of the study was to characterize, in a quantitative way, the zooplankton available to feeding bowhead whales over the continental shelf from the Canadian border to central Camden Bay (141° to 145°W) during late summer and early autumn. That is the season when much of the Bering–Chukchi–Beaufort stock of bowhead whales travels west through that area, often feeding on zooplankton either while traveling west or while lingering in certain parts of the area. To characterize the zooplankton, we needed to document the general distribution (horizontal and vertical) of the zooplankton biomass and species composition in the study area, and their variability from year to year. Also required was an understanding of the distribution, biomass, and species composition of zooplankton at the specific locations and times where bowhead whales chose to feed.

We addressed these requirements via a program of boat-based sampling near feeding whales and in the study area generally during varying date ranges in September of five years, 1985–86 and 1998–2000, as documented in Chapters 4–6. Weather, oceanographic, and ice conditions varied among these years, and the frequency and locations of conspicuous feeding by bowhead whales also varied. Coordinated net sampling and quantitative echosounder surveys, both near feeding whales and along broader-scale transects, provided the needed data (in conjunction with limited physical oceanographic sampling). During all five seasons, aerial surveyors searched for bowheads in the same study area, observed whether they were feeding, and guided the boat-based crew to feeding bowheads when possible.

Acoustic vs. Net Biomass

There was a need for a method to estimate zooplankton biomass from echosounder data acquired along transects and at whale feeding locations in the eastern Alaskan Beaufort Sea. This was done by comparing zooplankton biomass collected in horizontal bongo-net tows with concurrent echosounder measurements of acoustic back scatter at corresponding depths. Paired data of these types were collected during September in all five years of the study. Linear regression techniques (robust LTS regressions in 1998–2000) were used to develop equations that could predict zooplankton biomass from acoustic back scatter when only the latter is measured. In all five years, there was a positive and statistically significant ($P < 0.05$ or better) correlation between net biomass and acoustic back scatter. Predictive equations were developed for data collected in 1985, 1986, 1999, and 2000. In all cases, the best-fit equations were developed using the highest frequency transducer, 200 kHz in 1985–86 and 430 kHz in 1999–2000. In 1998, the relationship between back scatter and zooplankton biomass was too weak to be of use. A strong relationship between backscattering data and net zooplankton biomass is difficult to obtain because the acoustic data may contain echoes not only from zooplankton but also from other biotic as well as abiotic

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[1] LGL Ltd., environmental research associates, 9768 Second St., Sidney, B.C. V8L 3Y8. *Phone:* 250-656-0127; *e-mail:* bgriff@lgl.com

[2] LGL Ltd., environmental research associates, 22 Fisher St., POB 280, King City, Ont. L7B 1A6. *Phone:* 905-833-1244. *e-mail:* dthomson@lgl.com

sources. Sources of variability include such things as fish larvae, other large swift or very small zooplankters not captured by nets, the shape and orientation of the zooplankton, sediment plumes, and density discontinuities. (In any future related work, additional attention should be given at the planning stage to possible ways of reducing these problems.) Despite the limitations and biases, the method provided useful data concerning the locations and depths of high-density zooplankton patches, and the relative amounts of zooplankton at different locations, depths, and times within and among the four years when useful data were available. This approach was an important technique in assessing the characteristics and quality of bowhead whale feeding habitat available in the eastern Alaskan Beaufort Sea during those four years.

Species Composition, Biomass, and Distribution

There have been notable differences in zooplankton biomass and species composition of zooplankton, particularly copepods, sampled in September of 1985–86 and 1998–2000. In the eastern Alaskan study area as a whole, total zooplankton biomass appeared to be higher in 1985 and especially 1986 than in 1998–2000. Predatory cnidarians, ctenophores, and chaetognaths were much more abundant in samples collected in 1998–2000 than in either 1985 or 1986. Predation may have contributed to the lower total zooplankton biomass observed in 1998 through 2000. Another major difference was a change in the dominant nearshore copepod species in the region. In 1985 and 1986, the brackish-water species *Limnocalanus macrurus* was by far the dominant copepod (on a biomass basis) in nearshore waters. This species was not found in the study area in 1998 and 1999 and was found only rarely in 2000, perhaps due to the absence of a relatively warm, freshened surface water mass in these years. Copepods of the genus *Calanus* were present in all samples from all five years, and were the dominant species in 1998–2000.

The vertical distribution of zooplankton biomass evident on the echosounders differed among the four years with useful echosounder data. The 1985 and 1986 results were similar in that one to three layers of zooplankton were observed at individual stations. Throughout the study area, most of these zooplankton layers were 5 to 8 m thick, and most were in the upper 45 m of the water column. At some of the 1985–86 shallow water stations (<25 m depth), the zooplankton layers occurred throughout most of the water column, extending all the way to the bottom. During sampling in 1999, there was usually only a single layer of zooplankton at each station, which varied in thickness from 5 to 25 m. Most of the layers were found in water depths >10 m and extended to the bottom. The year 2000 was different from all other years in that there was a marked difference in zooplankton between eastern and western stations, i.e., from the Canadian border to Jago Lagoon vs. Barter Island to Camden Bay. In the eastern portion of the study area, few zooplankton layers were evident at any stations, while to the west there were 1–3 dominant zooplankton layers.

In 1985 and 1986, the echosounder surveys and net samples showed that zooplankton biomass was generally highest in the nearshore zone and tended to decrease with increasing distance from shore and increasing depth. In 1999 and 2000, zooplankton was more evenly distributed along the transects. However, in 2000 the zooplankton biomasses were much higher in the western area (Barter Island to Camden Bay) than farther east. Another major difference in zooplankton distribution was that the biomass of zooplankton estimated to be in the concentrated layers was higher in 1985 and 1986 than in 1999 or (for most locations) 2000. Maximum zooplankton biomass in layers exceeded 1200 mg/m^3 (wet weight) in both 1985 and 1986, and 750 mg/m^3 on the three westernmost transects in 2000, but was only ~700 mg/m^3 in 1999 and 500 mg/m^3 on most other 2000 transects.

In 1985 and 1986, along each transect, numerous zooplankton patches ~1 km in length and a few meters in thickness contained densities ranging from an estimated 1400 to 2000 mg/m^3. In 1999, biomass in similar-sized zooplankton patches did not exceed 500 mg/m^3, while in 2000 large patches of zooplankton biomass that ranged from 1000 to 1400 mg/m^3 were typically found only along the western three transects.

Characteristics of Bowhead Feeding Areas

Zooplankton biomass near feeding whales was studied in September of 1986, 1998, and 1999. (In September of 1985 and 2000, few if any bowheads lingered in the eastern Alaskan area to feed, and we were not able to sample near whales feeding in that area.) Zooplankton biomass was much lower at the whale feeding locations sampled in 1998 and 1999 than in 1986. In 1986, zooplankton biomass at whale feeding stations averaged 586 mg/m^3 (maximum 1228 mg/m^3) for the water column as a whole, and averaged 1375 mg/m^3 (maximum 3847 mg/m^3) in horizontal tows at depth. During 1986, some individual whales lingered to feed for several days, particularly in the nearshore zone in the southeastern corner of the study area (Chapter 11). The small copepod *Limnocalanus macrurus* dominated there, as has often been the case at whale feeding locations in nearshore waters along the Yukon coast. In 1998 and 1999, zooplankton biomass at whale feeding stations was below 400 mg/m^3 (maximum 678 mg/m^3) in the water column as a whole, and below 400 mg/m^3 (maximum 886 mg/m^3) in horizontal tows at depth. In 1998, bowhead whales moved quickly through the area and did not appear to stop and feed for any length of time (Chapter 11). In 1999, some bowhead whales stopped to feed in the study area for a few days, but these were located in the deeper offshore waters (40 to 150 m depth; Chapter 11). Bowhead whale feeding habitat in the eastern Alaskan Beaufort Sea appears to have been of better quality in 1986 than in either 1998 or 1999.

Bowhead whales feed in concentrations of zooplankton in the both the eastern Alaskan and Canadian Beaufort Sea. There was no obvious difference in average zooplankton biomass in the water column as a whole as measured in oblique tows in those two regions. Zooplankton biomass was higher at stations where bowhead whales were present than at routine sampling stations where whales were not present. Furthermore, zooplankton biomass was higher when whales were present during boat-based sampling than at stations where whales had been sighted from the aircraft during the preceding day, but were no longer present when the boat began sampling.

Horizontal plankton tows guided to layers of concentrated zooplankton by an echosounder have been done at 17 stations where bowheads were observed <1 km from the sampling boat in the eastern Alaskan and Canadian Beaufort seas. At these stations, mean biomass in the horizontal tows with the highest biomass was 1841 ± s.d. 1226 mg/m^3 ($n = 17$; includes one vertical tow). The lowest biomass in these tows was 545 mg/m^3. For 4 of 17 stations, the highest biomass measured was 771–807 mg/m^3, and for 12 of 17 stations the highest value was ≥1000 mg/m^3. Biomasses of ~800 mg/m^3, as determined by horizontal bongo-net tows guided by echosounder, may represent the feeding threshold for bowhead whales, i.e., the minimum biomass for economical feeding.

In 1998 and 1999, *Calanus hyperboreus* and *C. glacialis* were the dominant copepod species at whale feeding stations in the eastern Alaskan Beaufort Sea, but their biomass was typically lower than that of the *Limnocalanus macrurus* present at whale feeding stations in 1986. Predatory cnidarians, ctenophores, and chaetognaths were much more abundant at whale feeding and control station in 1998 and 1999 than in 1986. These animals feed on copepods and other zooplankters. The absence of *L. macrurus* in 1998–99 was largely responsible for the lower biomass observed at feeding stations in those years as compared with 1986. The absence of *L. macrurus* was possibly attributable to the reduced temperature and salinity gradients in 1998–99 and/or the presence of numerous predators. The predatory species that were abundant in 1998–99 are of much lower nutritive value than are copepods (Thomson, Chapter 22).

Calanus hyperboreus and *C. glacialis* were also the dominant copepod species at whale feeding stations off Richard's Island in the Canadian Beaufort Sea during 1980 and 1981. *Calanus hyperboreus* was again the dominant copepod species at whale feeding stations off Richard's Island in 1986. Whales were seen at distances >1 km from the ship, and average biomass at these stations was not particularly high.

Other taxa that occasionally were dominant components of the zooplankton at whale feeding stations, aside from copepods and (less commonly) euphausiids and chaetognaths, were gelatinous groups (cnidarians and ctenophores) and mysids. We did not find places with feeding whales where euphausiids were dominant, but this has been reported previously by Wartzok et al., and euphausiids are the dominant components of the prey in the stomachs of a minority of the bowheads landed at Kaktovik (Chapter 18). Euphausiids are known to show avoidance reactions to sampling nets, and as a result euphausiids are probably somewhat under-represented in our net samples. However, where euphausiids are abundant, as they are at times in the western Beaufort Sea, they are prominent in net samples. In general, euphausiids are apparently less important as prey for bowhead whales in the eastern Alaskan Beaufort Sea than farther west near Point Barrow.

Recommended Research

The present study involved zooplankton sampling and echosounder surveys at a variety of dates during September. September is known, from aerial surveys, to be the month of peak utilization of the eastern Alaskan Beaufort Sea by westward-migrating bowheads. However, information from aerial surveys and from local residents indicates that bowheads can be present in appreciable numbers from August to October, with occasional sightings in July (Chapters 2 and 9). Zooplankton biomass and energy content are expected to vary seasonally, and there could also be seasonal trends in relative importance of different species or groups. *More precise estimates of food availability to bowheads in the eastern Alaskan Beaufort Sea would be possible if zooplankton sampling there could be extended to include the full period when bowheads use the area, or at least the main period of use from mid-August to mid-October.* However, sampling in October would be complicated by deteriorating weather conditions and the fact that ice would likely be present at this time.

The present zooplankton study was conducted in the eastern Alaskan part of the Beaufort Sea, for reasons explained in Chapter 1. Similar studies have been done on parts of the summer feeding grounds in the Canadian Beaufort Sea. However, there has been no similar zooplankton study at autumn feeding locations farther west in the Alaskan Beaufort Sea, or along the northeast coast of the Chukotsk Peninsula in the western Chukchi Sea. In the western Beaufort Sea (Barrow to Smith Bay) during autumn, euphausiids apparently are a predominant part of the bowhead diet (Chapter 18). *To understand the relative importance of autumn feeding areas west of the present eastern-Alaskan area, studies of zooplankton availability in the more westerly areas during autumn would be useful.* Insofar as possible, zooplankton availability in these areas should be studied throughout the seasonal period when bowheads occur in these areas, as evident from previous scientific studies and the experience of local residents.

Given the documented year-to-year variability in zooplankton within the eastern Alaskan study area, *any follow-up study of zooplankton availability in different months or in different areas should be planned for a duration of at least 3 years if at all possible.*

This study has shown that it is necessary to sample quite close to feeding bowhead whales in order to obtain meaningful data on the food available to the whales (Chapter 6). This limits the number of sampling opportunities, and makes it important for the zooplankton sampling team to be guided to feeding whales by aerial surveyors who have a broader and more synoptic perspective on whale use of the area. *Any future bowhead feeding study needs to include guidance by aerial observers (or some other means, e.g., telemetry) to locations of feeding whales.* Such guidance was available during the present 5-season study, but has not always been available during previous studies.

There is partial segregation of size (and age) classes of bowheads when they are passing through the eastern Alaskan Beaufort Sea during late summer and autumn, with larger (older) whales tending to be farther offshore (see Chapter 10). To date, opportunities to sample near feeding bowheads in this area have been largely limited to bowheads in nearshore and inner-shelf waters, where subadult whales predominate. *Within the eastern Alaskan Beaufort Sea, it would be desirable to obtain additional data on food availability and associated aspects of bowhead feeding in deeper waters.* In the deeper areas, a higher proportion of the bowheads are larger, older individuals, and in those areas zooplankton may concentrate at deeper depths, especially in the later parts of the season.

A combination of net sampling and echosounder surveys has been shown to be necessary in studies of food availability for bowhead whales. These methods have different strengths and limitations, and are complementary. However, the correlation between results from the two methods, as applied in the Alaskan and Canadian Beaufort Sea, has been weaker and more variable than desired. Several probable or possible reasons for the weaker-than-desired correlation have been identified (Chapter 4). *It will be desirable, in any similar future study of zooplankton availability to bowhead whales, to develop and use improved field and analysis methods that will provide more reliable and better-correlated net-sampling and echosounder results.* Possible improvements include expanded efforts to identify and measure confounding factors (e.g., density gradients and turbidity) and to treat them as covariates, and use of multi-frequency echosounder data to help deal with the problems created by different types and sizes zooplankton. *It would also be desirable to consider the suitability of improved or new types of zooplankton sampling gear that might be available (and practical) by the time a future study is being planned, e.g., opening-and-closing nets; video plankton recorder; specialized echosounder gear.* It would be useful to conduct preliminary fieldwork to develop and test any such improvement or new methods prior to applying them during an extensive sampling effort.

Data on day–night differences, if any, in the vertical distribution of zooplankton in areas and seasons where bowheads feed would be helpful in assessing food availability to bowheads. The extent of diel vertical migration by zooplankton has not been documented for the Beaufort Sea during summer or autumn. Seasonal variability in the occurrence of diel vertical migration is to be expected, given the continuous daylight from spring to mid-summer, and increasing darkness from mid-August onward. Foraging behavior of bowhead whales is likely to be affected by any pronounced vertical migration by concentrations of prey.

BOWHEAD WHALE DISTRIBUTION, NUMBERS AND ACTIVITIES

8. INTRODUCTION TO BOWHEAD WHALE COMPONENTS OF STUDY

W. John Richardson and William R. Koski[1]

Studies of the distribution, numbers, and activities of bowhead whales within and near the eastern Alaskan Beaufort Sea, primarily via aircraft-based techniques, are described in Chapters 8–16 of this report. This work was done as an integrated part of a broader study of the importance of that area to feeding bowheads. Other major study components included compilation of local and traditional knowledge (Chapter 2), studies of zooplankton near feeding whales and in the study area generally (Chapters 3–7), studies of bowhead diet (Chapters 17–21), an energetic analysis (Chapter 22), and integration (Chapter 23). As stated by MMS,

> *'The goal of this study is, collaboratively with key stakeholders, to summarize available scientific and traditional knowledge and to plan and implement a multi-year study of bowhead whale feeding in the eastern Alaska Beaufort Sea (between Kaktovik and the Canadian border, south of 71° N latitude) in order to determine its importance as a feeding area for bowhead whales.'*

The initial phase of this work was conducted during Year 1 of the project (September 1997 through August 1998). During that time, we compiled the then-available information, both traditional and scientific, concerning the use of the study area and adjacent waters for feeding by bowhead whales and other related topics (Appendices A through D in Richardson and Thomson 1999). We also worked with the subsistence hunters, other stakeholders, and the project's Scientific Review Board to define the key questions and hypotheses, and to develop a study plan for Years 2–4, which were to include fieldwork in August–September of 1998 to 2000 (Thomson and Richardson 1998, 1999).

During Year 1 of the project (1997–98), considerable effort was spent in documenting local knowledge about use of the eastern Alaskan Beaufort Sea by bowheads, feeding and otherwise. Information was assembled at a meeting and a workshop convened in Kaktovik, and from individual discussions with whaling captains and other local people interested in bowhead whales. The results were summarized by subcontractor M.S. Galginaitis and presented as Appendix D in Richardson and Thomson (1999). An updated version of that document appears as Chapter 2 of the present report.

At the meetings and via individual discussions during the planning stage, local people described the timing of occurrence of bowheads in the eastern Alaskan Beaufort Sea and the places where bowheads are most often seen. One significant point was that, although the main autumn migration does not begin near Kaktovik until early September, small numbers of bowheads occur in the area during August and occas-

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[1] LGL Ltd., environmental research associates, 22 Fisher St., POB 280, King City, Ont. L7B 1A6. *Phone:* 905-833-1244; *e-mail:* wjr@lgl.com, bkoski@lgl.com

ionally July. The hunters also noted that bowheads often are seen in Camden Bay just to the west of Kaktovik as well as in the waters near and to the east of Kaktovik. Some local people suggested that the study should extend west into Camden Bay, and this was done during fieldwork in 1998, 1999, and 2000. Relatively little of the traditional information was explicitly about whale feeding behavior, as the hunters generally do not distinguish feeding whales from other whales when they encounter them at sea. However, the information provided at the meetings and during individual discussions was helpful in formulating a study plan that (1) would focus on the key questions and (2) could be implemented without interfering with the bowhead hunt. That information, and additional information obtained during further discussions with local people during 1998–2000, has been summarized in Chapter 2 (see also Annex B in Volume 2). Relevant local and traditional knowledge has been integrated with the scientific data collected during this and previous studies in the area, e.g., in Chapters 9, 10 and 12, to provide a more complete picture of bowhead use of the eastern Alaskan Beaufort Sea.

The original study plan called for additional field research in Years 2–4 (1998–2000) on bowhead distribution, numbers, and activities in the study area. The data collected during the first year of intensive fieldwork (1998) were presented in draft in May 1999. This report was reviewed at the June 1999 Scientific Review Board (SRB) meeting. The SRB made some specific recommendations about field work and analyses to be conducted in following years. The revised study plan that considered comments made by the SRB and MMS was distributed in August 1999 (Thomson and Richardson 1999) and the final report on activities conducted during Years 1 and 2 was distributed in September of 1999 (Richardson and Thomson 1999). The data collected during the second year of intensive fieldwork (1999) were presented in a draft report circulated in July 2000. No further substantive changes to the study plan were recommended based on the data presented then, and the third season of fieldwork (2000) proceeded much as in 1999.

The project plan (Thomson and Richardson 1998, 1999) called for the use of aerial surveys, aerial observations of behavior, and aerial photographic methods to document the distribution, abundance, behavior, sizes, and residence times of bowheads in the study area. More specifically, the purposes of the aircraft-based fieldwork were to

- determine distributions and raw numbers of bowheads within the study area during late summer/early-autumn feeding periods in that area,
- determine correction factors for sightability during aerial surveys,
- use the above data to estimate whale-days of utilization of the study area,
- document the proportion of time spent feeding,
- characterize feeding behavior (near-surface/water-column/bottom), and
- determine residence times of individual bowheads.

The aerial survey crew had the additional critical task of providing the boat-based crew with information about locations of bowhead whales (especially feeding whales) on a real-time basis. This was necessary to allow the boat-based crew to locate bowheads for the purpose of sampling the zooplankton around feeding whales (described in Chapter 6).

Aerial work of these types was conducted during 1998, 1999 and 2000. Similar data were already available from a closely-related project in the same region during September 1985–86 (Richardson [ed.] 1987). Thus, comparable data are available from five different years, providing a basis for dealing with the year-to-year variability issue. Aircraft-based work during the previous study extended from 4 September to 3 October in 1985, and from 2 to 27 September in 1986.

The 1998, 1999 and 2000 field seasons for aircraft-based work were initially anticipated to be from approximately 1 to 21 September. However, the Kaktovik whaling captains requested that, in 1998–2000, boat-based work east of Kaktovik not commence until after two whales had been landed at Kaktovik. Because of the need for coordination between aerial and boat-based work, the start of both aerial and boat work in 1998 and 1999 was delayed until 10 September, when the 2nd whale was landed. In 2000, Kaktovik whalers landed their third whale on 8 September, and both aircraft-based and boat-based work started on 8 September. The aircraft and crew were based at Kaktovik for quick access to the study area and to optimize opportunities for local liaison. In 1998, 1999 and 2000, our aerial work was limited to about 2.5–3 weeks each year for budgetary reasons. However, MMS was able to modify their aerial survey effort (Treacy 2000, 2002) to provide additional coverage of our study area, particularly just before our field season started (1998, 1999 and 2000) and after our field season ended (1998). MMS provided those data to us for use in this project (see Chapters 9 and 15).

Many of the chapters of this report have been organized and written to facilitate production of scientific papers, which MMS has encouraged. Thus, some of the material (particularly Methods) is repeated in more than one chapter. For purposes of this report, one advantage of this approach is that the individual chapters are largely self-contained and reasonably compact.

Chapter 9 describes the distribution and numbers of bowheads observed in and near the eastern Alaskan Beaufort Sea during aerial surveys conducted during the late summer and autumn of 1979–2000. The data used here include not only those from the 1985–86 and 1998–2000 phases of the present study, but also the results from the surveys conducted or sponsored by MMS each autumn since 1979 (and some industry-sponsored projects as well). Raw densities of bowheads (numbers seen per 100 km of systematic surveying) are examined relative to four water-depth strata, four east–west strata, and half-month periods from 1 August to 31 October. Year-to-year and seasonal variation in use of the study area are examined. The numbers of bowheads present in the study area are calculated for specific days during each year based on the aerial survey data and correction factors for whales missed during aerial surveys, as developed in Chapter 15. Numbers of whale-days of use of the study area are calculated for the five years of the feeding study. The results contribute to the assessment of the importance of autumn feeding areas in the eastern Alaskan Beaufort Sea.

Chapter 10 describes the length–frequency distribution of bowheads in and near the eastern Alaskan Beaufort Sea relative to that of the population as a whole, and describes habitat segregation by different age classes of the bowhead whale population. It assesses variation in the sizes of whales relative to year, half-month intervals from 16 August to 15 October, geographic subdivisions, and water depth. This chapter assesses habitat use by different age classes of bowhead whale, which is important in energetics calculations (Chapter 22) and to assess the importance of the study area to the overall Bering–Chukchi–Beaufort bowhead population (Chapter 23).

Chapter 11 describes rates of movements and residence times of bowhead whales in and near the eastern Alaskan Beaufort Sea and compares them to those of bowheads in summering areas off the eastern Yukon coast and in Amundsen Gulf. Both types of data, plus activity budgets from Chapter 12, are required to estimate the proportion of the annual energy requirements of bowhead whales that are obtained in the eastern Alaskan Beaufort Sea (Chapter 22).

Chapter 12 documents the observed activities and specific behaviors of bowhead whales in and near the eastern Alaskan Beaufort Sea during late summer and autumn, and compares them with bowhead activities during other seasons. An understanding of activities and behaviors in the area, especially feeding activity, are important in understanding bowhead use of the study area. Activity budgets presented in this chapter are used in calculations of residence times (Chapter 11) and energy budgets (Chapter 22).

Chapter 13 discusses bowhead surfacing, respiration and dive (SRD) cycles in and near the study area in relation to whale activity. The patterns in which whales surface, respire and dive vary with whale activity. These patterns can be used to quantify whale activity. Data on SRD cycles are also one of the critical components in the correction factors needed to estimate absolute numbers of whales present based on the relative information provided by aerial surveys (Chapter 15). Data on SRD cycles are also needed for whale energetics calculations (Chapter 22).

Data on surfacing, respiration and dive cycles by age category of bowhead whale are given in Chapter 14. These age-specific characteristics of behavior are important in the calculations done in Chapter 22 concerning energy requirements and potential water filtering capacity while feeding. In this chapter, we include data on SRD cycles during spring migration around northwestern Alaska and on the summering grounds in the Canadian Beaufort Sea as well as data from the present study area during September.

Chapter 15 derives the correction factors needed to estimate the numbers of whales present in the study area from the results of aerial surveys (Chapter 9). The surfacing, respiration and dive cycle data presented in Chapter 13 are used in the derivation of the factor that corrects for whales missed because they are below the surface ("availability bias"). Auxiliary data acquired during aerial surveys in the present study area and elsewhere in the Beaufort Sea are used to develop other necessary correction factors, and to assess their dependence on survey conditions.

Chapter 16 summarizes the data presented in Chapters 9 through 15, and comments on what is known about the responsiveness of feeding bowheads to disturbance. Chapter 16 also outlines some recommendations for future research on the topics covered in Chapters 9 to 15.

To determine the importance of the eastern Alaskan Beaufort Sea to the annual energetic requirements of bowhead whales we need to know (1) how many bowheads occur in the study area (Chapters 9 and 15), (2) the population structure of the bowheads using the study area (Chapter 10), (3) how long individual whales remain in the area from Kaktovik to Demarcation Bay (Chapter 11), (4) what proportion of that time is spent feeding, and what feeding modes are used (Chapter 12), and (5) how much food they consume while feeding. The last of these determinations is especially difficult, but data provided in Chapters 4 through 7 (zooplankton chapters), plus 11, 13 and 14 are all relevant, along with subsequent chapters 18, 20, and 22 on diet and energetics. That topic is addressed in Chapter 23, "Integration".

During their meeting on 3–4 June 1999, the project's Scientific Review Board (SRB) recommended that statistical power analyses be done before subsequent field seasons to evaluate the optimum allocation of aerial effort among the various possible aircraft-based tasks (Appendix A in Thomson and Richardson 1999). This was done in a limited way, in conjunction with SRB member Dr. J. Zeh, as part of the planning for 1999 (Thomson and Richardson 1999). The power analyses resulted in three recommendations concerning allocation of field efforts.

First, the power analyses indicated that aerial surveys could not provide statistically rigorous estimates of bowhead numbers present in the study area throughout the autumn migration period (and hence estimates of residence time). Therefore, it was recommended that less effort be expended on aerial surveys in 1999 and 2000 than had been expended in 1998. The SRB requested that the MMS/BWASP aerial survey crew put extra effort into obtaining survey coverage of the feeding study area to augment the reduced survey effort by LGL.

Second, the number of independent samples available for assessing whale activity within the study area needed to be increased to have the power to distinguish possible differences between areas and years. Thus, the strategy for conducting behavior observations of whales was changed so that more observation sessions of shorter duration would be conducted in 1999 and 2000. It was recommended that the field time previously used to conduct aerial surveys be divided between additional behavior observation sessions and additional bowhead photography (see below).

Third, a method of estimating residence times of bowheads in the study area needed to be developed. Data from repeated photographic coverage of the study area appeared to have the potential to estimate residence times but in 1998 the duration of coverage was too short. Therefore, the SRB recommended that in 1999 and 2000 photography begin on the first day of the field program and continue to the end of the season to maximize the period covered. It was also recommended that some of the time previously spent conducting aerial surveys be used to conduct additional photography.

The recommendations of the SRB were implemented in 1999 and 2000. This resulted in more reliance on the MMS/BWASP surveys for information on bowhead distribution and numbers in the study area (Chapter 9) but increased the amount of information obtained for the other components of the study over what would have been collected if the 1998 strategy had been continued.

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9. DISTRIBUTION AND NUMBERS OF BOWHEAD WHALES IN THE EASTERN ALASKAN BEAUFORT SEA DURING LATE SUMMER AND AUTUMN, 1979–2000

Gary W. Miller, Robert E. Elliott, Tannis A. Thomas, Valerie D. Moulton, and W.R. Koski[1]

Introduction

From mid-June through October, many bowhead whales of the Bering–Chukchi–Beaufort (BCB) stock inhabit the Canadian Beaufort Sea and Amundsen Gulf. Bowheads have often been observed feeding in Canadian waters during summer (e.g., Würsig et al. 1985, 1989). That region has generally been assumed to be the primary feeding grounds of the BCB stock of bowhead whales, despite the evidence from isotopic studies that bowheads feed extensively during late autumn, winter, or both in Chukchi and Bering Sea waters (Schell and Saupe 1993; see also Chapter 20). Although the Canadian Beaufort Sea is apparently the primary summering grounds, some bowhead whales occur off the north coast of Alaska for at least part of the summer (Moore and Clarke 1991; Chapter 2), and may feed while there. Residents of Kaktovik, adjacent to the eastern Alaskan Beaufort Sea, report that they occasionally see bowheads near Kaktovik as early as July (Chapter 2 and Annex B). Bowhead sightings in the Alaskan Beaufort become more common in August, and peak sighting rates near Kaktovik occur in September. At least some of the bowhead whales that summer and feed in Canadian waters continue to feed as they migrate westward through the Alaskan Beaufort Sea during September and October. This is evident from stomach contents of harvested whales (Lowry 1993; see also Chapter 18), and from direct visual observations of feeding activities in Alaskan waters during late summer and early autumn (Ljungblad et al. 1986a; Richardson et al. 1987; Landino et al. 1994; see also Chapters 2, 12). Those data show that feeding is common in the Alaskan Beaufort Sea during September and October, but the overall importance of summer and autumn feeding in that area to bowhead whales is not well understood.

Bowhead use of the eastern Alaskan Beaufort Sea study area during late summer and autumn has been documented for many years by systematic aerial surveys, mainly conducted or sponsored by BLM and MMS (e.g., Ljungblad et al. 1987; Moore et al. 1989; Treacy 2000, 2002). These surveys have gathered much information about bowhead use of the study area, including information about relative utilization according to year, season, and region within the study area. Results for all years from 1979 through 2000 have been described in a lengthy series of annual reports. Results for various combinations of years have been summarized by Ljungblad et al. (1986b), Clarke et al. (1987), Moore et al. (1989, 2000), and Moore (2000). However, none of those papers uses the survey data collected by MMS after 1991. In addition to the 1979–2000 MMS data, additional survey data have been obtained in parts of the eastern Alaskan Beaufort Sea during late summer and autumn of certain years during industry-sponsored monitoring projects and during the present study of bowhead feeding ecology.

Richardson et al. (1987) found that in some years (e.g., 1985) very few bowheads occur in the eastern Alaskan Beaufort until the main period of westward migration from Canadian waters begins in mid-

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[1] LGL Ltd., environmental research associates, 22 Fisher St., POB 280, King City, Ont. L7B 1A6. *Phone:* 905-833-1244; *e-mail:* gmiller@lgl.com

September. In other years (e.g., 1986), the western edge of the main summer feeding range extends into the eastern Alaskan Beaufort Sea before the start of active westward autumn migration. Small numbers of bowheads often occur in eastern Alaskan waters during August, usually well offshore. Moore et al. (1989) described the late summer and early autumn (1 Aug.–15 Sept.) distribution of bowheads in the eastern Alaskan Beaufort region based on surveys conducted from 1979–86. They found that bowheads consistently occurred along the coast near the U.S./Canada border and north and northeast of Kaktovik, and that sighting rates (number of whales seen/survey hour) during late August were less than half those calculated for early August and early September. Bowheads were primarily in deep (>200 m) offshore waters in early August, with relatively more bowheads occupying shallower nearshore waters in late August and early September. Although mean headings of swimming bowheads were northwesterly throughout August, the variability was high, and headings did not become significantly clustered about that direction until early September.

Recently published studies of bowhead distribution and habitat selection, based on BLM/MMS data from the ten years 1982–91, found that in summer, bowheads in the eastern Alaskan Beaufort Sea selected outer continental shelf and slope depth habitats without regard to ice conditions. In autumn bowheads selected shallow inner-shelf waters during years with moderate and light ice cover, and deeper continental slope habitat during years with heavy ice conditions (Moore 2000; Moore et al. 2000).

Estimates of bowhead numbers in the eastern Alaskan Beaufort Sea during various periods in late summer and early autumn have included estimates of 0 (1983), <100 (1985), between 100 and 500 (1982, 1983, 1984, and 1986), and as many as 1200–3000 in early August 1982 (Richardson et al. 1987; Moore and Clarke 1991). These estimates were calculated based on strip transect techniques, with adjustments for missed whales.

This report describes the seasonal distribution and numbers of bowheads observed in the eastern Alaskan Beaufort Sea and adjacent Canadian waters during aerial surveys conducted during the late summer and autumn of 1979–2000. The 21 years of data considered here include • all systematic aerial surveys conducted by or for MMS from 1979 to 2000 (no data were available from 1980 for our study area), • some surveys conducted during industry-funded monitoring programs (1986, 1993), and • surveys conducted by us as part of the MMS-funded studies to assess the importance of the eastern Alaskan Beaufort Sea to feeding bowheads (1985–86, 1998–2000). This data set includes considerably more data from the present study area than were available to previous authors. For periods when sufficient aerial survey coverage was obtained, we have estimated the numbers of bowheads present in the Alaskan portions of the study area inshore of the 200 m depth contour, with allowance for the numbers of whales present but missed by the aerial observers. A companion chapter (Chapter 15) describes the correction factors for missed whales.

Methods

The general approach to this analysis was to examine the distribution and numbers of bowheads in various geographic regions and depth strata based on aerial survey data collected over a 22-year period. The study area for this analysis (139°–146°W, south of 71°10'N; see Fig. 9.1) extended slightly farther east and west than the area considered in most other parts of the feeding study (*cf.* Fig. 1.2 in Chapter 1). Although described as the "eastern Alaskan" study area, it included Canadian waters between the Alaska–Yukon border and Herschel Island. This extended study area was divided into four E–W regions, and four depth strata defined by the 20, 40 and 200 m contours (Fig. 9.1). Considering both the E–W regions and depth strata, the study area was divided into 16 analysis zones. For seasonal analyses, the data were categorized into six half-month (15- or 16-day periods) from 1 Aug. to 31 Oct.

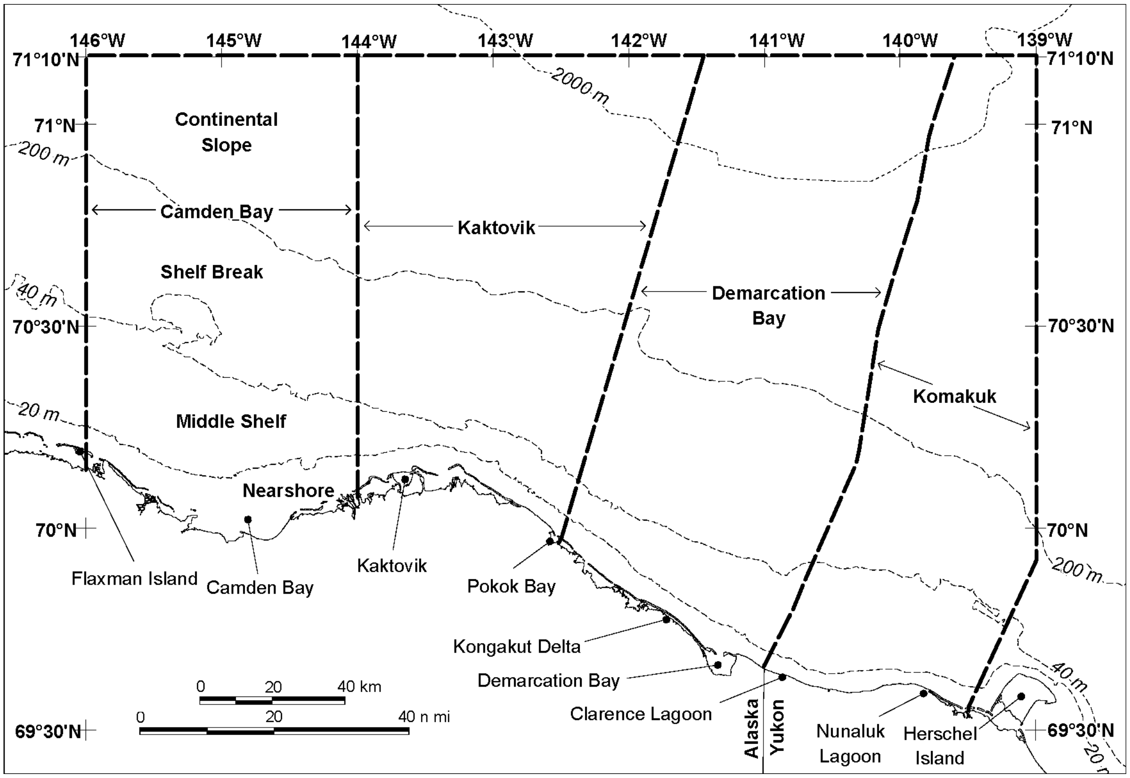

FIGURE 9.1. The study area, showing E–W regions, depth strata, and analysis zones used in analyses of bowhead distribution in the 139°–146°W region of the Beaufort Sea, August to October of 1979–2000.

Data were assembled from numerous studies conducted from 1979 to 2000. Priority was placed on obtaining data that were available in digital format. In addition, data from several important studies that were not available in digital format were converted to digital format and validated. Studies that provided few data and that were not available in digital form were not included in this analysis. Most, but not all, of the systematic surveys conducted in the eastern Alaskan Beaufort Sea during the 22-year period from 1979 through 2000 were included in the following analyses.

We examined several specific measures of bowhead use of the study area, including the following:

- distribution,
- relative abundance among zones within seasons,
- relative abundance within zones among years, and
- estimated numbers of bowheads present in the study area.

Data Sources

The data from a large number of studies conducted in late summer/autumn were compiled. These studies included aerial surveys flown by or on behalf of • the U.S. Minerals Management Service, and • various industry groups including Shell Western Exploration & Production Inc. (SWEPI) and ARCO Alaska Inc. Table 9.1 summarizes the amount of aerial survey effort by year during each study included in this analysis.

TABLE 9.1. Linear kilometers of systematic transects flown in the 139°-146°W portion of the Beaufort Sea during 1979-2000 and included in the present analysis. Excludes survey effort during poor sighting conditions.

Year	Range of Survey Dates	NOSC/ MMS for MMS	LGL for MMS Feeding	LGL for SWEPI	COPAC for ARCO	Total
1979	02 Aug - 27 Oct	4960				4960
1980	-	0				0
1981	05 Sep - 11 Oct	1396				1396
1982	02 Aug - 13 Oct	9873				9873
1983	02 Aug - 12 Oct	7692				7692
1984	01 Aug - 10 Oct	8526				8526
1985	01 Aug - 20 Oct	13391	4119			17,509
1986	15 Aug - 17 Oct	8568	3968	8494		21,031
1987	02 Sep - 31 Oct	8182				8182
1988	03 Sep - 18 Oct	7895				7895
1989	04 Sep - 11 Oct	4412				4412
1990	02 Sep - 17 Oct	2444				2444
1991	31 Aug - 12 Oct	2360				2360
1992	31 Aug - 14 Oct	6023				6023
1993	17 Aug - 28 Oct	5490			15581	21,070
1994	31 Aug - 12 Oct	2666				2666
1995	31 Aug - 19 Oct	3158				3158
1996	02 Sep - 06 Oct	3554				3554
1997	01 Sep - 19 Oct	3497				3497
1998	31 Aug - 27 Oct	6099	2852			8951
1999	03 Sep - 26 Sep	3195	1593			4789
2000	01 Sep - 12 Oct	4413	956			5369
Total		117,793	13,488	8494	15,581	155,357

1979–2000 Autumn Aerial Surveys for or by MMS.—The most extensive and consistent source of data concerning bowhead distribution in the study area is the series of aerial surveys conducted each year from 1979 to 2000 for or by MMS (Bureau of Land Management prior to 1982). This MMS dataset has been documented in a series of annual reports by Naval Oceans Systems Center (NOSC) for 1979–86 (e.g., Ljungblad et al.1987; Moore et al. 1989) and by MMS for 1987–99 (e.g., Treacy 2000). From the combined 1979–2000 dataset, we selected sighting and survey effort records pertaining to longitudes 139°–146°W. MMS/NOSC data for that region exist for all years in the 1979–2000 period except 1980, i.e., 21 years. During many early years, survey coverage of the study area began during the late summer period, typically around 2 Aug. (Table 9.1). In most later years, the MMS/NOSC surveys began in late August or early September, around the time when the autumn westward bowhead migration could be expected to start. Survey coverage ended in mid-to-late October in most years. Within those date ranges, the present study area typically was sampled on about 1 day within each 5–7 day period. During 1998–2000, MMS surveyors modified their survey effort to provide somewhat increased coverage of the eastern Alaskan Beaufort Sea study area in support of the present study.

1985–86 Aerial Surveys During Feeding Study for MMS.—LGL conducted systematic aerial surveys for MMS as part of a bowhead feeding study in the eastern Alaskan Beaufort Sea during 1985–86 (Richardson et al. 1987). The surveys were conducted weekly (approx.) from 5 to 27 Sept. in 1985 and from 4 to 26 Sept. in 1986. We digitized the data into a format similar to that used by MMS in the above studies.

1986 Aerial Surveys for SWEPI.—LGL conducted systematic aerial surveys from 2 Sept. to 9 Oct. 1986 on behalf of Shell Western Exploration & Production Inc. as part of a study to investigate the responses of migrating bowhead whales to an exploratory offshore drilling operation. These surveys were conducted near the Hammerhead and Corona drillsites in Camden Bay on a daily basis, weather permitting (Evans et al. 1987). We digitized the data into a format similar to that used by MMS.

1993 Monitoring Surveys for ARCO.—Coastal and Offshore Pacific Corp. (COPAC) conducted systematic aerial surveys in 1993 for ARCO Alaska Inc. (Anchorage). These surveys were conducted to study the distribution and relative abundance of bowheads and other marine mammals in relation to the Kuvlum (2 and 3) and Wild Weasel drilling projects in the Camden Bay area (Hall et al. 1994). The surveys were flown from 17 Aug. to 28 Oct. 1993 on a daily basis, weather permitting. Digital data were provided by Jeremy Davies (then with the National Marine Mammal Laboratory, Seattle, WA). We converted those data into a format similar to that used by MMS.

1998–2000 LGL Aerial Surveys During Feeding Study for MMS.—Systematic aerial surveys were conducted during September of 1998–2000 as part of the present study to assess the importance of the eastern Alaskan Beaufort Sea to bowhead whales. Surveys were conducted every 7–10 days (approx.) from 11 to 24 Sept. in 1998, from 12 to 26 Sept. in 1999, and on 12 Sept. 2000. Again, we digitized the data into a format similar to that used by MMS.

Aerial Survey Methods

MMS Aerial Surveys, 1979–2000.—Overall, 21 of 28 aerial survey programs considered in this analysis were the annual programs conducted or sponsored by MMS from 1979 to 2000. During these years, late summer and autumn aerial surveys were flown over broad portions of the Alaskan Beaufort Sea from 140°–157° W longitude, south of 72° N latitude. The surveys were flown in a modified Grumman Goose (1980–87) or a deHavilland Twin Otter (1979 and 1986–2000) at air speeds of 185–300 km/h (100–160 knots). In recent years, surveys were conducted at an altitude of 457 m a.s.l. (1500 ft), but some earlier surveys were as low as 100 m (330 ft) when cloud ceilings were low. The three observers used inclinometers to measure the angle (relative to horizontal) to each cetacean sighting when the initial sighting location was abeam of the aircraft. Observers and pilots were linked by a common communication system, and conversations and comments could be recorded onto audiotape (1979–82). Seating and window arrangements varied, and are summarized in Chapter 15.

The aircraft were equipped with radar altimeters and either a VLF navigation system or, in recent years, a Global Positioning System (GPS). Starting in 1982, an onboard computer interfaced with the navigation system stored flight data (time and position) automatically for later analysis. Since 1983, the on-board computer has also been linked to a radar altimeter or GPS for automatic input of altitudes. Marine mammal sightings, environmental conditions (e.g., weather, sea state, ice cover), and start and end points of transects and other survey segments, were entered manually into the computer. More details concerning the survey aircraft and other equipment used during MMS/NOSC surveys are provided in the reports summarizing each year's data (e.g., Ljungblad et al. 1987; Treacy 2002) and in previously-cited papers by S.E. Moore et al.

Daily flight patterns were derived by dividing each MMS/NOSC survey block into north–south strips 30 minutes of longitude wide; 30' is ~18.5 km or 10 n.mi. at this latitude. One of the minute marks along the northern edge of each 30' section was selected at random to designate one end of a transect. The other transect endpoint was determined using a separate randomly generated number along the southern edge of the same 30' section. A straight line, representing one transect, was drawn between the two points. The same procedure was followed for all 30' sections of the survey block. The transect to be flown within each 30' section was determined separately each time that area was surveyed. The selection of survey blocks to be flown on a given day was non-random, based on weather conditions, where survey coverage had been obtained during recent days, etc. The MMS/NOSC study area was very large, extending west from 140ºW (near the east edge of our study area) to 157ºW (near Barrow). MMS/NOSC coverage in our study area typically occurred during one day within each 5–7 d (approx.) period.

Non-transect flight segments were identified as "Connect" and "Search" segments. "Connect" segments were the east–west (or similar) flights from the end of one transect to the start of another. "Search" segments were flights to or from the survey block where transects were flown, or non-random flights to find whales. Sightings during "Connect" and "Search" segments are plotted (as open symbols) on our maps, but were not used in quantitative analyses.

LGL and COPAC Systematic Surveys.—The 7 additional aerial survey programs considered here were conducted by LGL Ltd (1985–86 and 1998–2000) and COPAC (1993).

Transects flown by LGL during the MMS-sponsored feeding studies (1985–86, 1998–2000) were randomized and oriented roughly perpendicular to the coast and depth contours. The same set of randomly-selected transects was flown repeatedly, typically about once per week in 1985–86 and every 7–10 days in 1998–99, but only once in 2000. In 1985–86, the 140°–144°W region was sampled by 13 continental shelf (0–200 m contour) transects and 8 continental slope (200–2000 m contour) transects totaling 1260 km. During 1998–2000, the study area was extended west to 145°, and 4 continental shelf and two continental slope transects in this new region were added to the transects flown in 1985–86. All 27 transects were flown in 1998, but in 1999–2000 only the 17 continental shelf transects were flown.

Surveys flown by LGL for SWEPI in 1986 and by COPAC for ARCO in 1993 consisted of repeated daily (weather permitting) surveys of N–S survey grids roughly centered on drillsites. • *SWEPI surveys in 1986* included "intensive" grids (12 transects spaced 4 km apart; total 475 km) and "area" grids (8 transects spaced 10 km apart; total 608 km when at Corona and 531 km when at Hammerhead). The intensive grid was usually flown every day that weather permitted. If no whales were seen on that grid, then portions of the "area" grid were flown. The surveys near the Corona drillsite (2–17 Sept. 1986) were wholly within the present study area. However about half of the survey grid around Hammerhead (19 Sept.–9 Oct. 1986) was west of our study area. • *COPAC surveys in 1993* were flown on a "proximal" grid (6 transects spaced 12.9 km apart) and a "distant" grid (6 transects spaced 12.9 km apart and located east of the "proximal" grid). The westernmost of the 6 proximal transects was west of our study area. Typical daily survey coverage by COPAC within our study area was ~700 km.

The aerial survey methods used during the LGL and COPAC studies were generally similar to those during surveys for MMS with the following exceptions. Survey altitude was usually 305 m a.s.l. (1000 ft), but some surveys were conducted at 152 m (500 ft) when ceilings were low. Survey speed varied from 185 to 220 km/h (100 to 120 knots). During all LGL surveys, data on whale sightings and survey conditions were recorded onto tape recorders and later entered into computer files. Aircraft position data were dictated onto audiotape in 1985–86 (LGL) but were logged automatically during 1993 (COPAC) and 1998–2000 (LGL). Surveys in 1985–86 were flown in a Twin Otter. Surveys in 1993 and

1998–2000 were flown in a Twin Commander 500 (1993 only) or 680FL (1993 and 1998–2000) piston-engined aircraft. Seating and window arrangements varied, and are summarized in Chapter 15. Details concerning the aerial survey methods used in these studies can be found in Richardson et al. (1987), Evans et al. (1987), and Hall et al. (1994).

Data Analyses

Mapping.—Bowhead sightings during the 1979–2000 study period are depicted on standard base maps. These maps show the 139°–146°W (approx.) region, from the coast north to ~71°10'N. MMS/NOSC survey coverage north of this boundary, although much reduced, extended as far north as 72°N. The industry-funded studies were more localized and did not extend north of 71°10'N. Bathymetric contours shown on maps were developed based on all publicly available point soundings. Sounding data from U.S. waters were obtained on CD-ROMs from NOAA, including Hydrographic Survey Data, Vol. 1, vers. 3.1; and Marine Geophysical Data/Bathymetry, Magnetics, Gravity, vers. 3.2. Point soundings and gridded bathymetry data were contoured using a triangulated irregular network (TIN) algorithm in the Vertical Mapper add-on module for MapInfo Professional.

Each sighting symbol on these maps represents a sighting of one or more individual bowhead whales. "Non-transect" sightings are those seen during "search or connect" segments (generally before the start or after the end of a transect). "Excluded" sightings are those seen during portions of transects with poor sightability (Beaufort scale >4 or visibility <1 km). "Transect" sightings include all other sightings along systematic transects, regardless of distance from the trackline.

The maps and analyses do not include all bowhead sightings from aircraft during the years of study. The LGL studies during 1985–86 and 1998–2000 included aerial components other than systematic aerial surveys (behavior observations, aerial photography of bowheads, reconnaissance—see Chapters 10 and 12) that also resulted in many sightings of bowheads from aircraft. Those sightings are not plotted on these maps. Similarly, the 1981–84 studies by NOSC for MMS included additional site-specific surveys, reconnaissance flights, and behavioral studies conducted from a separate aircraft; those data are also excluded.

The maps (and analyses) exclude aerial survey sightings coded as "duplicates" or "repeats" of previous sightings, i.e., the same animal(s) seen by more than one observer or more than once at the same location. Direction indicators (in degrees True) attached to the symbols indicate the headings of whales classified as "traveling".

Bowheads Per Unit Effort (Relative Abundance).—The maps described above provide much of the distributional information. However, they are difficult to interpret because survey effort varied considerably within the study area, both within and among years. To account for this variability we computed bowheads per unit effort within various zones. The study area was divided into four E–W regions and four depth strata: *Nearshore* (<20 m), *Middle Shelf* (20 m to 40 m), *Shelf Break* (40 m to 200 m) and *Continental Slope* (>200 m). This resulted in 16 "analysis zones" (Fig. 9.1).

We used MapInfo, supplemented by specially-written MapBASIC computer code, to determine the number of individual bowheads sighted and the number of kilometers of "transect" survey coverage within each analysis zone during the 1979–2000 period. These analyses excluded "non-transect" and "excluded" survey effort and sightings, as defined above. An index of bowhead abundance (individuals seen/100 km) was determined for the various analysis zones by dividing the number of "transect" individuals seen in each area of interest by the number of kilometers of transect coverage within that area. For any period where "transect" survey coverage within a particular region, stratum or zone was <200 km, those data are not plotted on Figures showing numbers of individuals seen/100 km.

Seasonal Occurrence.—We examined the distribution and abundance of bowheads in the study area by half-month periods from 1 Aug. to 31 Oct. in order to examine seasonal changes in these parameters. These analyses were restricted to "transect" sightings in order to allow meaningful calculations of individuals per unit effort during different periods. Thus, zero individuals in a particular data range means no sightings of bowheads during "transect" surveys, not necessarily that no individuals were sighted on those dates.

Estimated Numbers of Bowheads Present.—Two general approaches have been used to estimate densities and numbers of animals present in an area based on aerial transect surveys. "Line transect" methodology (Buckland et al. 1993) is now the most commonly used approach for surveys of cetaceans. It provides more precise estimates when adequate numbers of sightings are made during the survey. However, the line transect method requires a minimum number of sightings to estimate some needed parameters. "Strip-transect" methods (Eberhardt et al. 1979) have been used during most past surveys of bowhead whales (e.g., Davis et al. 1982; Richardson et al. 1987; Moore and Clarke 1991), sometimes because too few sightings were made for effective use of the line transect method.

Not all animals are seen during transect surveys. Further, the proportion of animals that are detected is affected by altitude, air speed, glare, sea state, behavior of the target species, and nominal transect width. In theory, two parameters, $f(0)$ and $g(0)$, can be computed from the raw survey data and from other observations of the species of interest to minimize most of the biases that lead to inaccurate estimates of the actual numbers of mammals present at the time of the survey. The $f(0)$ factor accounts for the reduced probability of detecting an animal at the surface of the water as its distance from the trackline increases. The $g(0)$ factor accounts for animals that are (1) on or near the trackline and at the surface but not detected during the survey, and (2) animals that are below the surface and not visible at all. The derivation of these parameters for the present surveys is discussed in Chapter 15, "Correction Factors to Calculate Bowhead Whale Numbers from Aerial Surveys of the Beaufort Sea".

We used $f(0)$ and $g(0)$ factors derived in Chapter 15 to calculate line transect estimates of the numbers of bowheads present for each day (or two-day period) when sufficient survey effort was available to justify the use of this methodology (Buckland et al. 1993). The $f(0)$ factors are specific to a given aircraft type, and altitude, sea condition and ice-cover categories (see Table 15.2 in Chapter 15 for details). The "DISTANCE" program (Thomas 1999, version 3.5, release 5) was used to calculate the numerical estimates. The area considered encompassed the Camden Bay, Kaktovik, and Demarcation zones from the shore to the 200 m depth contour (Fig. 9.1). This area included 9 of the 16 analysis zones (3 E–W zones × 3 depth zones); we excluded the Komakuk region and the Continental Slope depth stratum. This reduced 9-zone area corresponds (approximately) to the area where systematic zooplankton sampling was conducted (Chapter 5), and to the primary study area for various other parts of the project.

The number of bowheads present in the 9-zone area was estimated for each day when transect survey coverage met two minimum criteria: (1) ≥400 linear km of coverage within the 9 zones, and (2) some survey coverage within at least 6 of the 9 analysis zones. Estimates were also derived for combined surveys that together represented ≥400 linear km of survey coverage. These combinations were limited to same-day surveys by different agencies (e.g., MMS/NOSC and LGL) or surveys on two consecutive days by the same or different agencies. Consecutive days of surveys were only combined if the survey coverage on the second day was east of the coverage on the first day, thereby avoiding double sampling of whales that may have been migrating in the typical autumn E→W migratory direction. Most estimates for single days or adjacent days were based on very small numbers of sightings (see Table 9.2, later). Buckland et al. (2001, page 88) note that it is legitimate to apply line transect procedures to small samples of sightings when the *f*(0) and *g*(0) factors were derived from larger samples combined across days, as was done here (*cf.* Chapter 15).

"Whale-Days".**—**In order to assess the importance of the eastern Alaskan Beaufort Sea to bowhead whales during the specific years of the bowhead feeding studies (1985–86 and 1998–2000), we estimated the numbers of whales in the 9-zone "restricted" study area on each day (7 Aug.–27 Oct.) during each year. There were 5 to 11 days in each year with sufficient survey coverage for a direct estimate of total numbers present on the survey day (or an adjacent pair of days) using the transect methodology described above and in Chapter 15. We estimated numbers present on other days by extrapolation based on the 10-d moving-average density in the study area for that date, and an "expansion factor" (described below) for that year.

Because bowhead numbers in the study area vary seasonally, with peak numbers occurring during late September, it was not possible to average the raw numbers present on survey days and extrapolate to days without surveys. To account for seasonal trends in abundance we computed mean densities in the 9-zone restricted study area for each day (1 Aug.–31 Oct.) based on combined transect data from 1979–2000. To smooth the data for irregular sampling, we computed a 10-d moving average density for each day during the 7 Aug.–27 Oct. period (see Fig. 9.12, later).

The "expansion factor" was included in order to adjust the estimate of bowhead numbers for a given survey for the seasonal pattern in bowhead abundance depicted later in Figure 9.12. Computation of the expansion factor resulted in a date-adjusted index of bowhead abundance for each survey. Averaging the expansion factors for selected years provided a means of comparing date-adjusted annual differences in the relative abundance of bowheads in the study area. An expansion factor for each survey date was computed by dividing each of the daily "direct estimates" of the number of bowheads present in the study area by the 10-d moving average density for that date. The expansion factors for each survey date in each year were averaged to give an average expansion factor for that year. That expansion factor was multiplied times the sum of the daily moving averages of bowhead abundance for the dates in the 7 Aug.–27 Oct. period (54.341 in all years; see Appendix 9.1) to derive an estimate of the number of bowhead "whale-days" of use of the restricted 9-zone study area during selected years. The calculations are explained in more detail near the end of the "Results", and the resulting estimates are used in Chapters 11 and 23.

Statistics**.**—For all statistical tests, results were considered statistically significant based on the $\alpha = 0.05$ criterion, and marginally significant for $0.10 > \alpha > 0.05$. The Friedman test was used to compare the observed sighting rates of bowheads (individuals/100 km of survey effort) in various geographic zones or time periods. The blocking variable in each analysis was year. We conducted three analyses that compared densities across the (1) four depth strata, (2) four E–W zones, and (3) three half-month periods. Only years that had >200 km of survey effort in each of these situations were included in the analyses. This resulted in the inclusion of 17, 18, and 17 years of data for tests involving the depth strata, E–W zones, and half-month time periods, respectively.

We summarized the headings, in degrees True, of bowhead sightings in the study area and recorded as traveling. Heading data were summarized and plotted for each of the six half-month periods. The vector mean ± angular deviation were calculated (Batschelet 1981), and the Rayleigh test of uniformity was used to test the null hypothesis that bowhead headings were distributed uniformly (H_a: headings were concentrated around some particular direction). We included only "transect" sightings of "traveling" whales seen during periods of acceptable sighting conditions (Beaufort scale ≤4 and visibility ≥1 km).

Results

Survey Coverage and Effort

This analysis is based on 155,000 km of "transect" aerial surveys (Table 9.1). The combined 1979–2000 effort in the 139°–146°W region is plotted by month in Figure 9.2. Available survey coverage east of 140°W was very limited south of 70°30'N and almost non-existent north of that latitude during all months. August survey coverage elsewhere was fairly uniform (Fig. 9.2A). During September and October, coverage was most intense between the shoreline and 70°30'N (Fig. 9.2B,C). The sparse MMS/NOSC coverage north of 71°10'N is not mapped or considered in this study. The MMS/NOSC transects flown during the late summers and autumns of 1979–2000 (except 1980) dominate the flightlines mapped in Figure 9.2. The transect selection procedure used by MMS/NOSC (see "Methods") resulted in wheatsheaf-shaped bands of heavy survey coverage alternating with narrower bands of relatively sparse coverage.

Geographic Variation

The distribution of bowheads recorded during the systematic aerial surveys considered here is shown in Figure 9.3. The 891 "transect" sightings of 1199 individual bowheads are the basis of most analyses discussed below. When numbers of individuals were adjusted for survey effort, the overall abundance for the study period was 0.77 bowheads sighted per 100 km (Fig. 9.4G). This figure, and subsequent "/100 km" values, are actual sighting rates, without allowance for whales either at or below the surface that were missed by the observers. All ice conditions are included, and the only allowance for sighting conditions is that survey coverage and sightings along portions of transects with Beaufort state >4 or visibility <1 km are excluded.

***Depth Strata*.—**Considering August–October as a whole, bowhead abundance differed significantly amongst the four depth strata when data were blocked by survey year (Friedman $\chi^2 = 12.85$, df = 3, $P = 0.005$). The highest average sighting rate was in the Shelf Break zone (40–200 m) at 1.07 bowheads seen per 100 km (Fig. 9.4G). Bowheads were moderately abundant in the Middle Shelf (0.78 /100 km) and Nearshore (0.73 /100 km) strata. Average abundance for the combined August–October period was lower in the Continental Slope stratum (0.30 /100 km).

***E–W Strata*.—**Considering August–October as a whole, bowhead abundance in the four E–W regions differed by a marginally significant amount (Friedman $\chi^2 = 6.42$, df = 3, $P = 0.093$). Overall, bowhead abundance was highest in the east (1.16 bowheads seen per 100 km in the Komakuk region; Fig. 9.4G) and declined with increasing longitude to 0.54 /100 km in the Camden Bay region. In the Shelf Break stratum, bowhead abundance was highest in the Demarcation Bay region (1.50 /100 km) and lowest in the Camden Bay region (0.64 /100 km). In all other depth strata, bowhead abundance was higher in the Komakuk and Kaktovik regions than in the Camden and Demarcation Bay regions (Fig. 9.4G).

Seasonal Variation

Overall bowhead abundance differed significantly among the 1–15 Sept., 16–30 Sept., and 1–15 Oct. periods (Friedman $\chi^2 = 10.32$, df = 2, $P = 0.006$). During that 1½-mo period, bowhead abundance was highest during 16–30 Sept. (1.03 bowheads seen/100 km), slightly lower during the first half of September (0.96 /100 km), and lowest during 1–15 Oct. (0.55 /100 km; Fig. 9.5). The paucity of surveys in August and late October during certain years prevented their inclusion in this statistical analysis. However, the available data from early and late in the season showed similar sighting rates in August as in early October, and a very low sighting rate in late October (Fig. 9.5; details below).

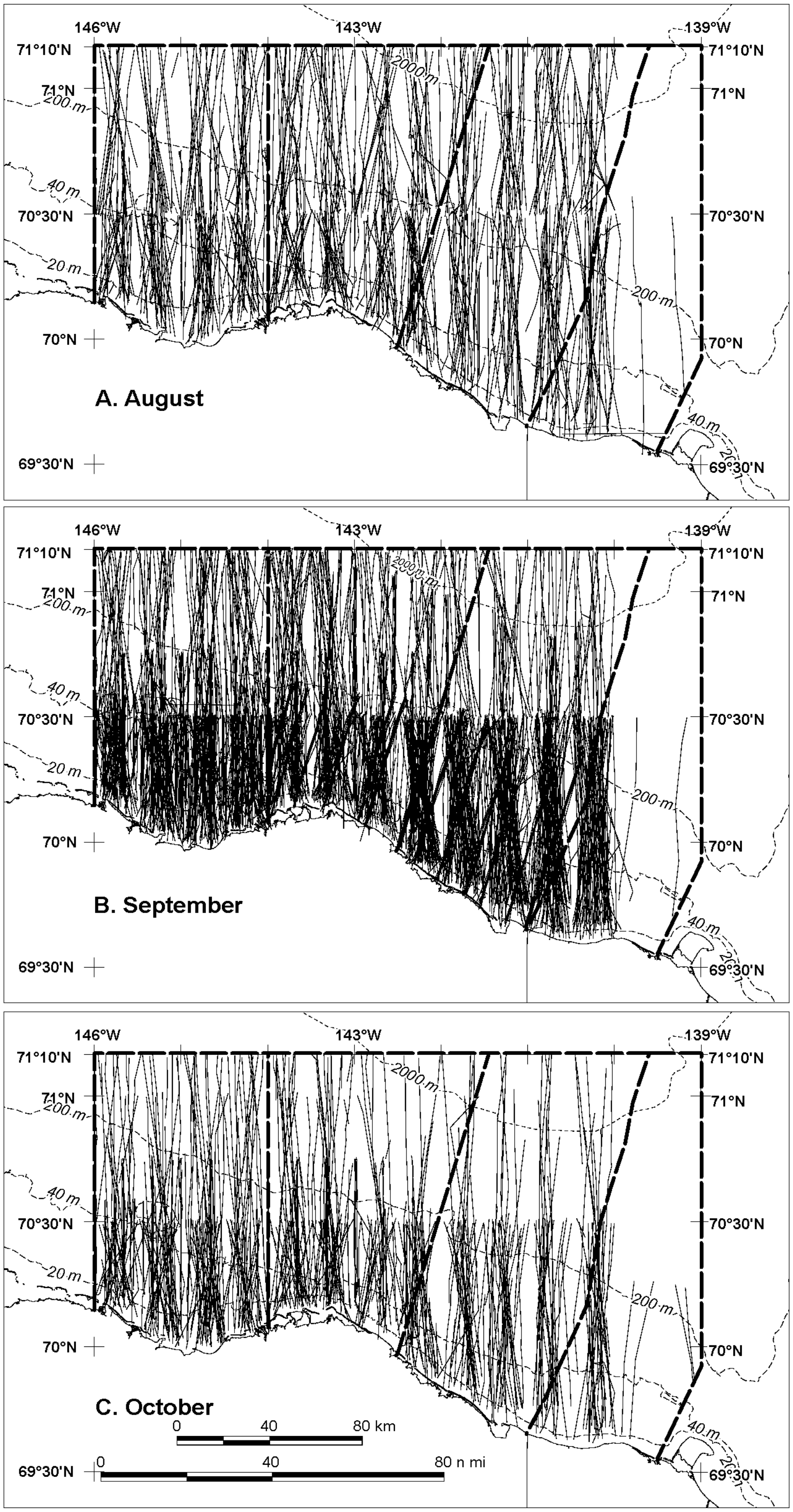

FIGURE 9.2. Aerial survey transects flown in the 139°–146°W region of the Beaufort Sea during ***(A)*** August, ***(B)*** September, and ***(C)*** October, 1979–2000. Excludes "non-transect" segments and "excluded" segments with poor sighting conditions. See Methods for description of data sources.

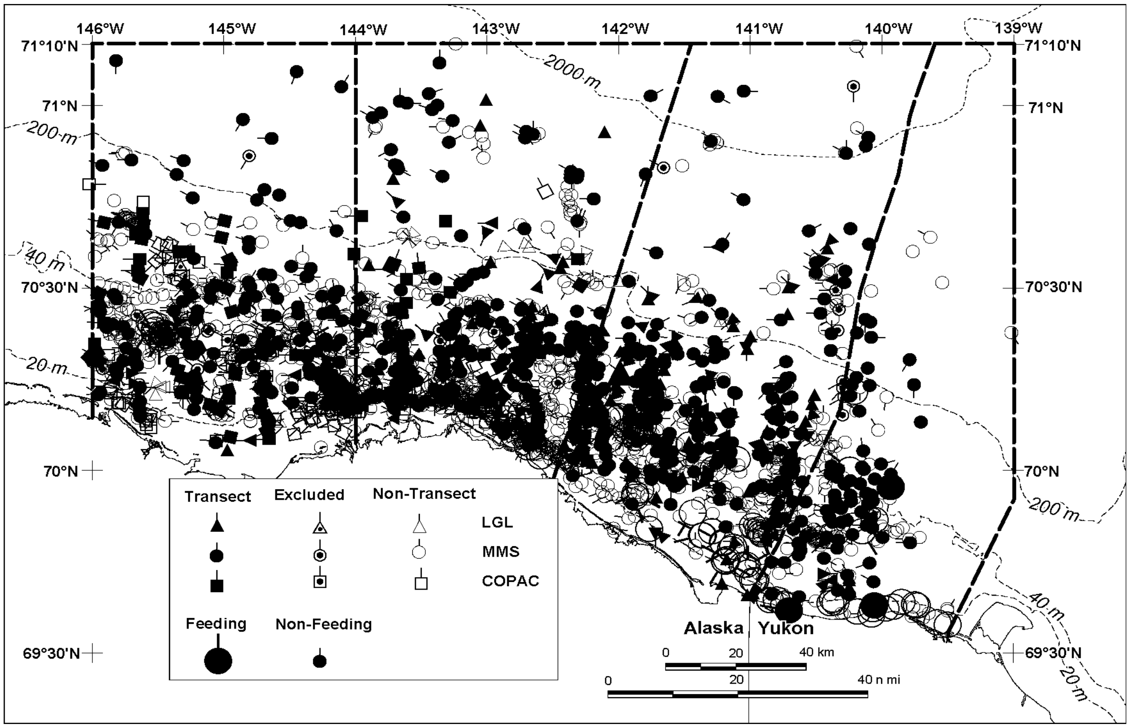

FIGURE 9.3. Locations of bowhead sightings during aerial surveys in the 139°–146°W region of the Beaufort Sea during August–October of 1979–2000.

1–15 August.—Most of the early-August survey effort was restricted to the early survey years (1979, 1982–86). These data show that, in early August, there were numerous bowhead sightings in offshore portions of the study area (Fig. 9.6A). When the data were standardized for survey effort, the overall abundance index for early August was 0.57 bowheads seen/100 km (Fig. 9.4A). Considering the four depth strata, the highest index was in the Continental Slope stratum (0.96 /100 km; Fig. 9.5A). The abundance index in the Shelf Break stratum was substantially lower (0.37 /100 km), and no transect sightings of bowheads were recorded in the Middle Shelf or Nearshore strata. Considering E–W regions (Figs. 9.4A, 9.5B), moderately high abundance was recorded in the Kaktovik and Komakuk regions (1.11 and 0.90 /100 km, respectively). Abundance was moderate in the Demarcation region (0.48 /100 km) and very low in the Camden Bay region (0.06 /100 km). All sightings with known headings were recorded as "traveling", and their headings were non-uniform (Rayleigh test, $P = 0.04$), with a mean heading toward the northwest (326°T ± a.d. 66.8°; Fig. 9.7A).

16–31 August.—Most late-August survey effort was also restricted to the early years (1979, 1982–86), although MMS autumn coverage of this area sometimes started on 31 Aug. in later years, and there was also some late August effort in 1993 by COPAC. In late August, bowheads were widely distributed throughout the study area (Fig. 9.6B). The overall sighting rate was relatively low at 0.38 bowheads seen/100 km (Fig. 9.4B)—lower than in early August. Within the various depth strata, the highest bowhead abundance again occurred in the Continental Slope stratum (0.54 /100 km)(Fig. 9.5A). Bowhead abundance was moderate in the Shelf Break stratum (0.37 /100 km) and low in the Middle Shelf and Nearshore strata (0.18 and 0.20 /100 km, respectively). Abundance declined from east to west (Figs. 9.4B, 9.5B). This is consistent with the observations of Kaktovik residents that in August bowheads tend to be more common along the Canadian coastline than in Alaskan waters (Chapter 2). Bowheads were most abundant in the Komakuk region (1.20 /100 km), and moderately abundant in the Demarcation (0.43 /100 km) and Kaktovik (0.42 /100 km) regions. As in early

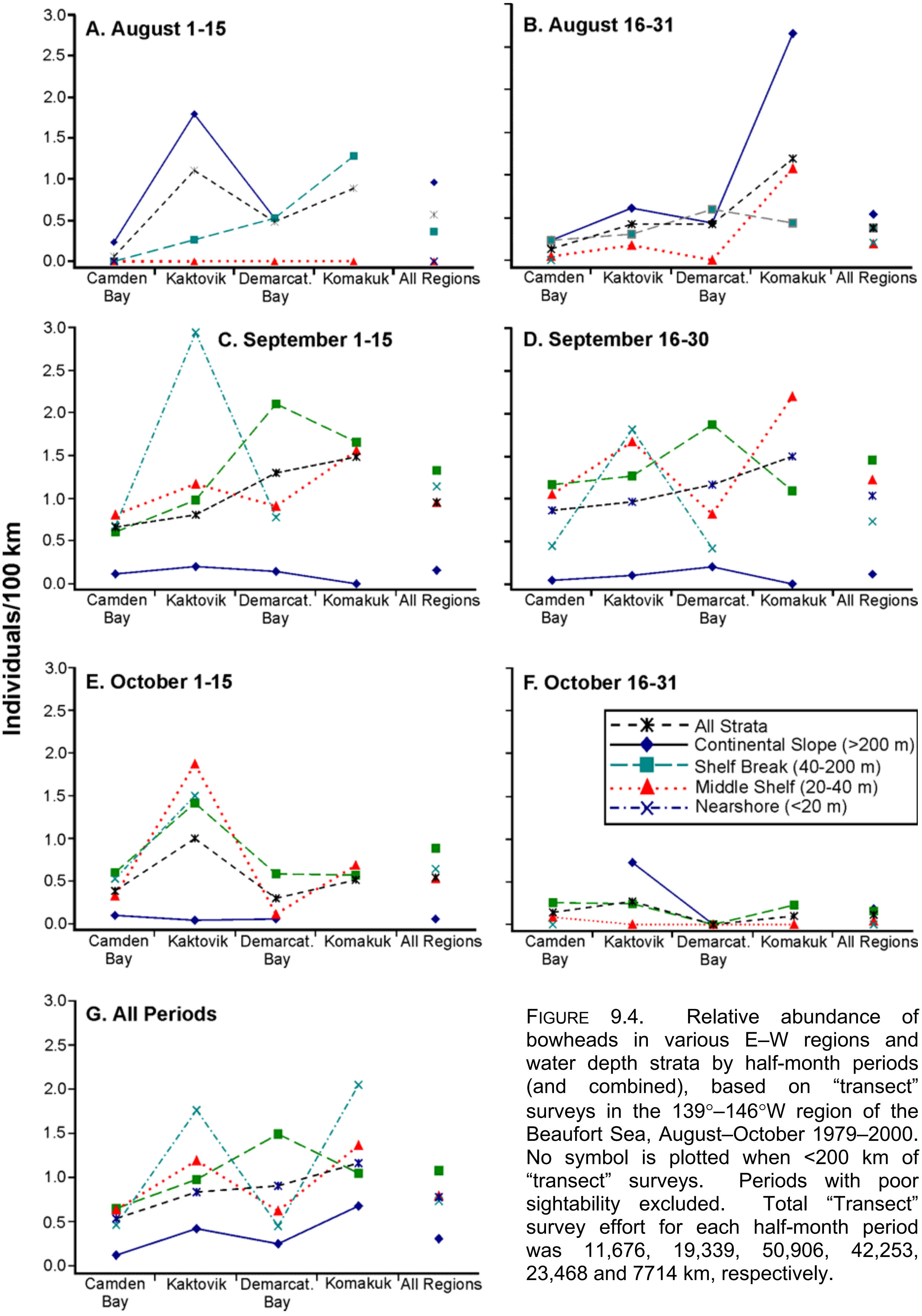

FIGURE 9.4. Relative abundance of bowheads in various E–W regions and water depth strata by half-month periods (and combined), based on "transect" surveys in the 139°–146°W region of the Beaufort Sea, August–October 1979–2000. No symbol is plotted when <200 km of "transect" surveys. Periods with poor sightability excluded. Total "Transect" survey effort for each half-month period was 11,676, 19,339, 50,906, 42,253, 23,468 and 7714 km, respectively.

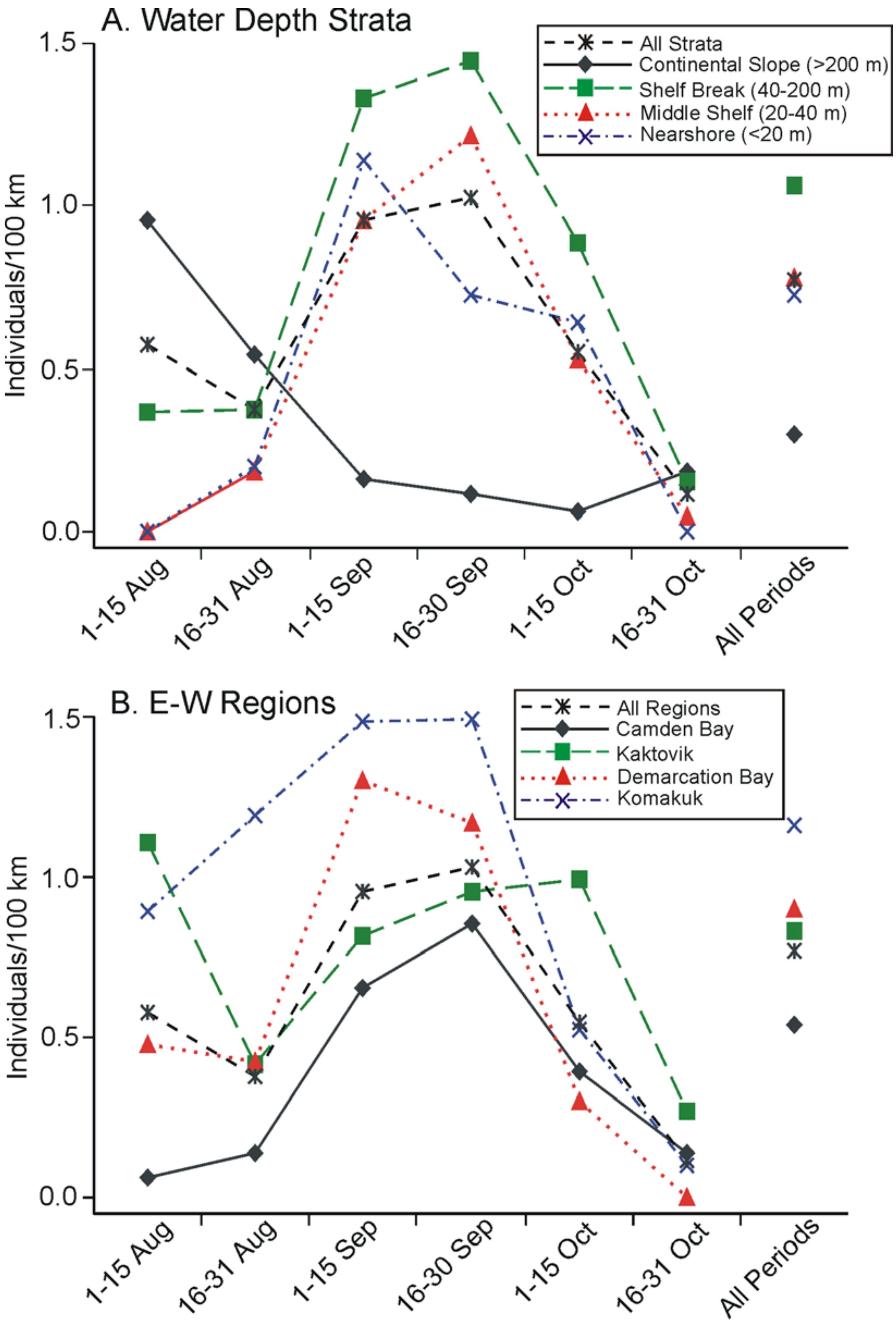

FIGURE 9.5. Relative abundance of bowheads during half-month periods by ***(A)*** water depth stratum or ***(B)*** E–W zone, based on “transect” surveys in the 139°–146°W region of the Beaufort Sea, 1979–2000. Otherwise as in Figure 9.4.

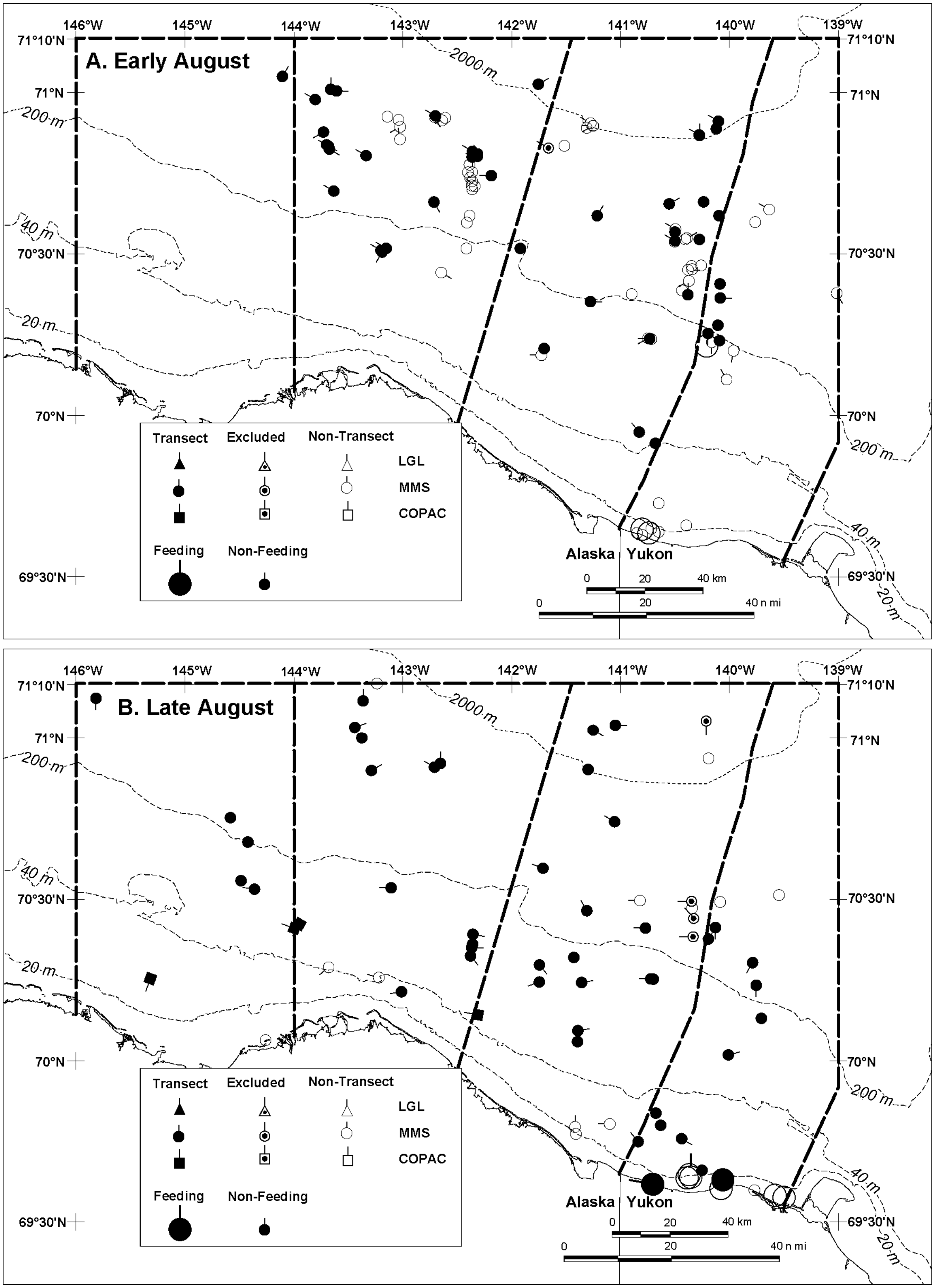

FIGURE 9.6. Locations of bowhead sightings during aerial surveys in the 139°–146°W region of the Beaufort Sea during ***(A)*** 1–15 Aug. and ***(B)*** 16–31 Aug., 1979–2000.

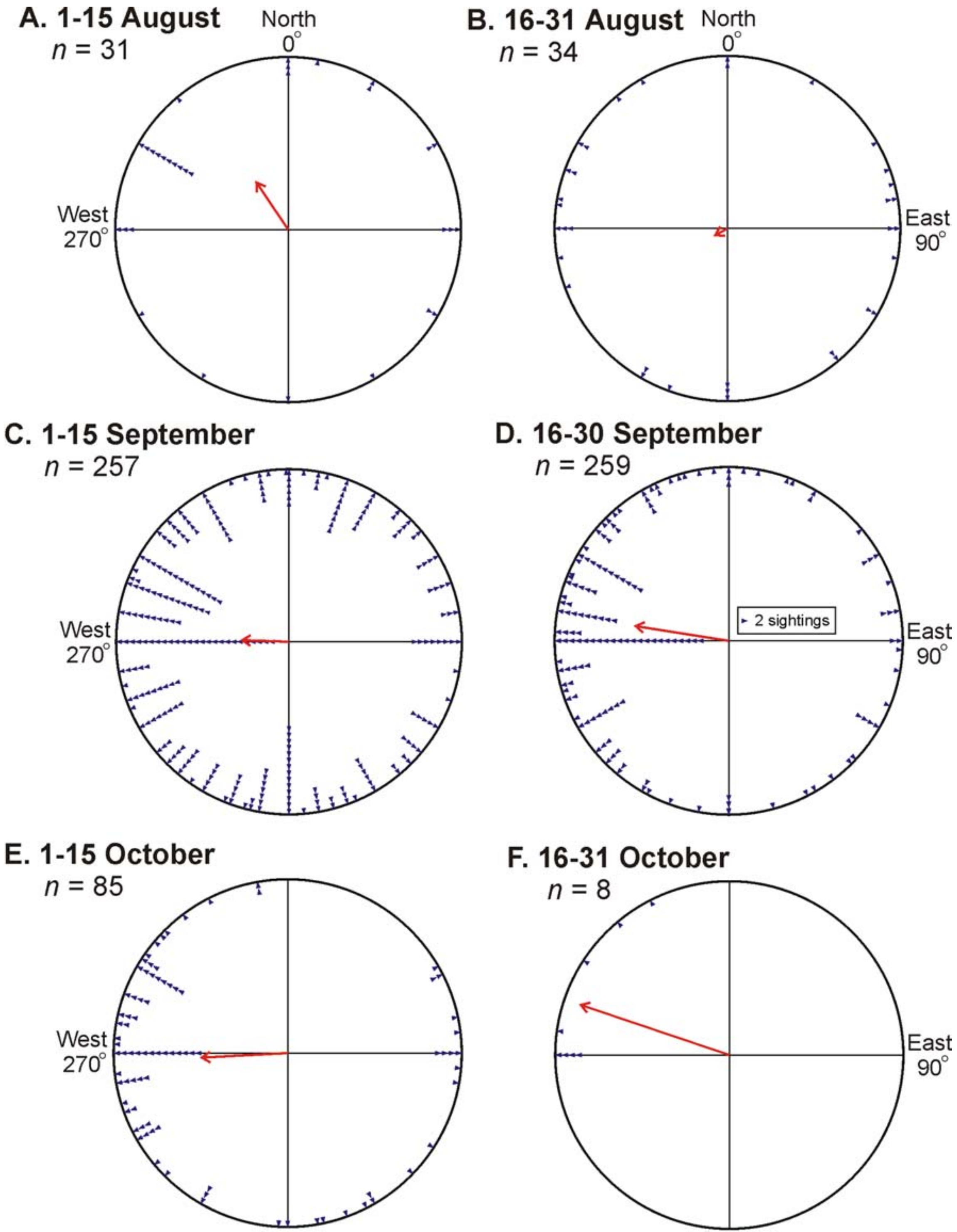

FIGURE 9.7. Headings (degrees True) of bowhead whales classified as "traveling" during aerial surveys in the 139°–146°W region of the Beaufort Sea by half-month period during August–October 1979–2000. Based on "transect" surveys, excluding periods of poor sightability. Each sighting was counted once regardless of number of whales in the group. The arrow represents mean vector and mean vector length (plotted relative to circle radius = 1.0). Except in "D", each triangular symbol represents one sighting.

August, bowhead abundance was very low in the Camden Bay region (0.14 /100 km). For the 87% of the sightings with known headings that were recorded as "traveling", the headings were highly variable and not significantly concentrated (Fig. 9.7B; a.d. = 78.6° and Rayleigh test, $P = 0.89$).

1–15 September.—In the first half of September, sightings of bowheads were concentrated inside the 200 m contour (Fig. 9.8A). The overall sighting rate was relatively high at 0.96 bowheads seen/100 km (Figs. 9.4C). The highest indices of abundance were in the Shelf Break stratum (1.33 /100 km), followed by the Nearshore and Middle Shelf strata at 1.14 and 0.95 /100 km, respectively (Fig. 9.5A). In contrast to the situation in August, the sighting rate in the Continental Slope stratum during early September was much lower than for other depth strata, at only 0.16 /100 km. Bowheads were widely distributed across all E–W regions of the study area (Fig. 9.8A). However, overall abundance was highest in the east (Komakuk, 1.49 /100 km) and declined progressively with increasing longitude to 0.66 /100 km in the Camden Bay region (Figs. 9.4C, 9.5B). During the first half of September, 86.2% of the sightings with known headings were recorded as "traveling", and the mean heading of those bowheads was 271°T ± a.d. 69.2° (Fig. 9.7C). These headings were significantly non-uniform (Rayleigh test, $P < 0.01$), but many bowheads were oriented in directions other than westward.

16–30 September.—In the last half of September, bowhead sightings were again concentrated inside the 200 m contour (Fig. 9.8B). Overall bowhead abundance (1.03 bowheads seen/100 km) was higher than for any other half-month period in August–October (Fig. 9.4D). Bowheads were most abundant in the Shelf Break and Middle Shelf strata (1.45 and 1.22 /100 km, respectively), followed by the Nearshore and Continental Slope strata at 0.73 and 0.12 /100 km, respectively (Fig 9.5A). Bowheads were distributed across all four E–W regions of the study area (Fig. 9.8B). However, bowhead abundance declined slightly from east to west, i.e., from 1.49 /100 km in the Komakuk region to 0.86 /100 km in the Camden Bay region (Figs. 9.4D, 9.5B). During the 16–30 Sept. period, 90.2% of the sightings with known headings were recorded as "traveling", and the mean heading of those bowheads was 279°T ± a.d. 55.0° (Fig. 9.7D). These headings were significantly non-uniform (Rayleigh test, $P < 0.01$), with a stronger westward tendency than in early September.

1–15 October.—In early October, bowheads were sighted in all depth strata, but appeared to concentrate within the 200 m contour (Fig. 9.9A). Overall bowhead abundance was moderate at 0.55 bowheads/100 km (Fig. 9.4E). Bowheads were most abundant in the Shelf Break, Nearshore, and Middle Shelf strata (0.88, 0.64, and 0.53 bowheads seen/100 km, respectively), and very scarce farther offshore in the Continental Slope stratum (0.06 /100 km)(Fig. 9.5A). Bowheads were distributed across all four E–W regions of the study area (Fig. 9.9A), but were most abundant in the Kaktovik region (0.99 /100 km). Bowhead abundance was lower in the Komakuk, Camden Bay, and Demarcation regions (0.52, 0.39, and 0.30 /100 km, respectively)(Figs. 9.4E, 9.5B). During the first half of October, 88.5% of the sightings with known headings were recorded as "traveling", and the mean heading of those bowheads was 267°T ± a.d. 58.4° (Fig. 9.7E). These headings were significantly non-uniform (Rayleigh test, $P < 0.01$)

16–31 October.—Survey effort in late October (7714 km) was lower than in any other half-month period, as by this time the area is usually ice-covered and most bowheads have migrated to the west. There were 8 years with >200 km of survey coverage during late October. The few bowheads seen during transect surveys (eight sightings of nine individuals) were outside the 20 m depth contour and predominantly in the western half of the study area (Fig. 9.9B). Overall bowhead abundance (0.12 bowheads seen/100 km) was lower than for any of the other five half-month periods considered (Fig. 9.4F). The few bowheads seen during transect surveys were primarily in the Continental Slope and Shelf Break strata, but there were non-transect sightings in shallower water (Fig. 9.9B). During late October, all 8 "transect" sightings were recorded as "traveling", and the mean heading of those bowheads was 289°T ± a.d. 24.3° (Fig. 9.7F). These headings were non-uniform (Rayleigh test, $P < 0.01$), with less variation than in earlier half-month periods.

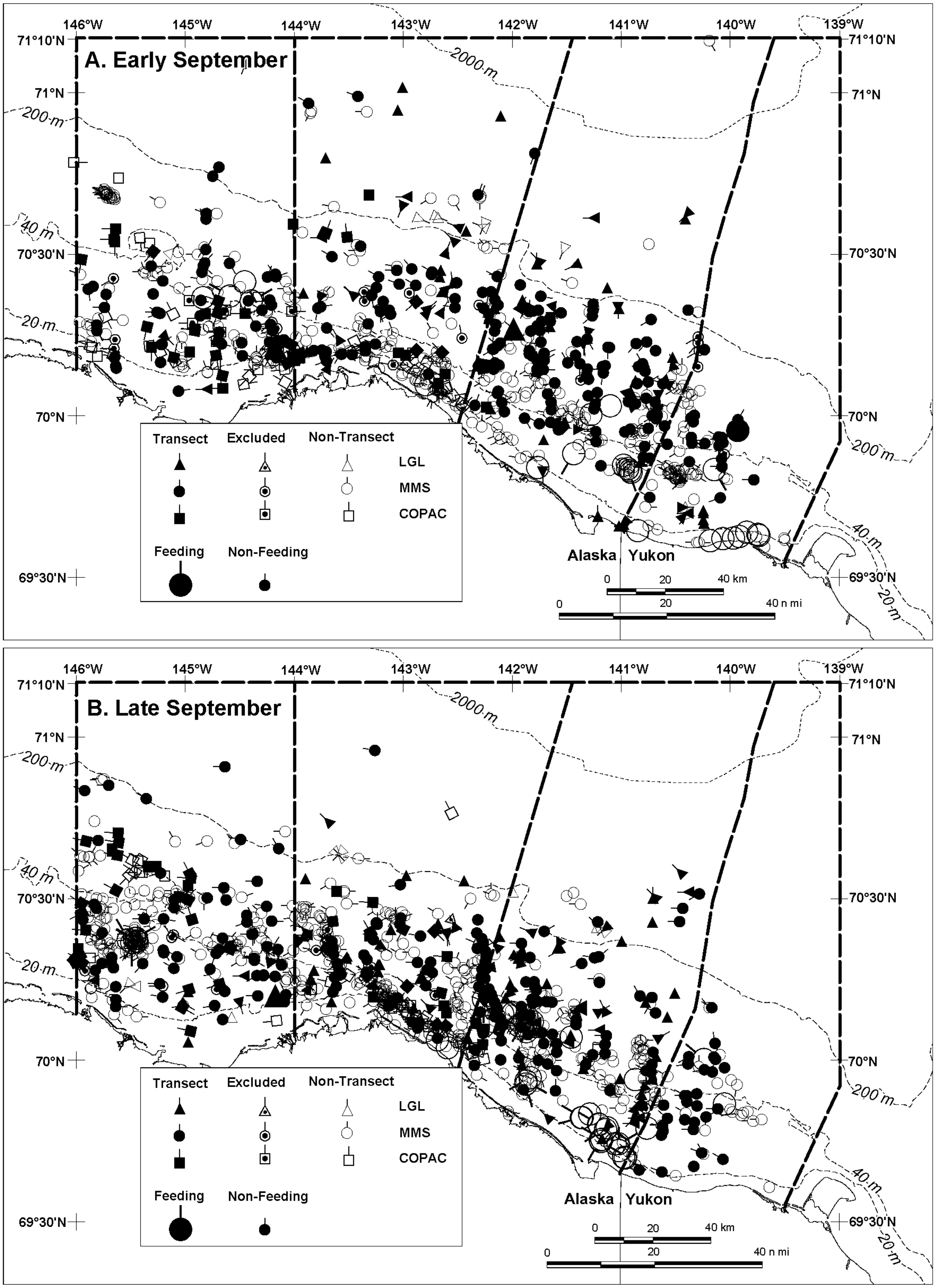

FIGURE 9.8. Locations of bowhead sightings during aerial surveys in the 139°–146°W region of the Beaufort Sea during ***(A)*** 1–15 Sept. and ***(B)*** 16–30 Sept., 1979–2000.

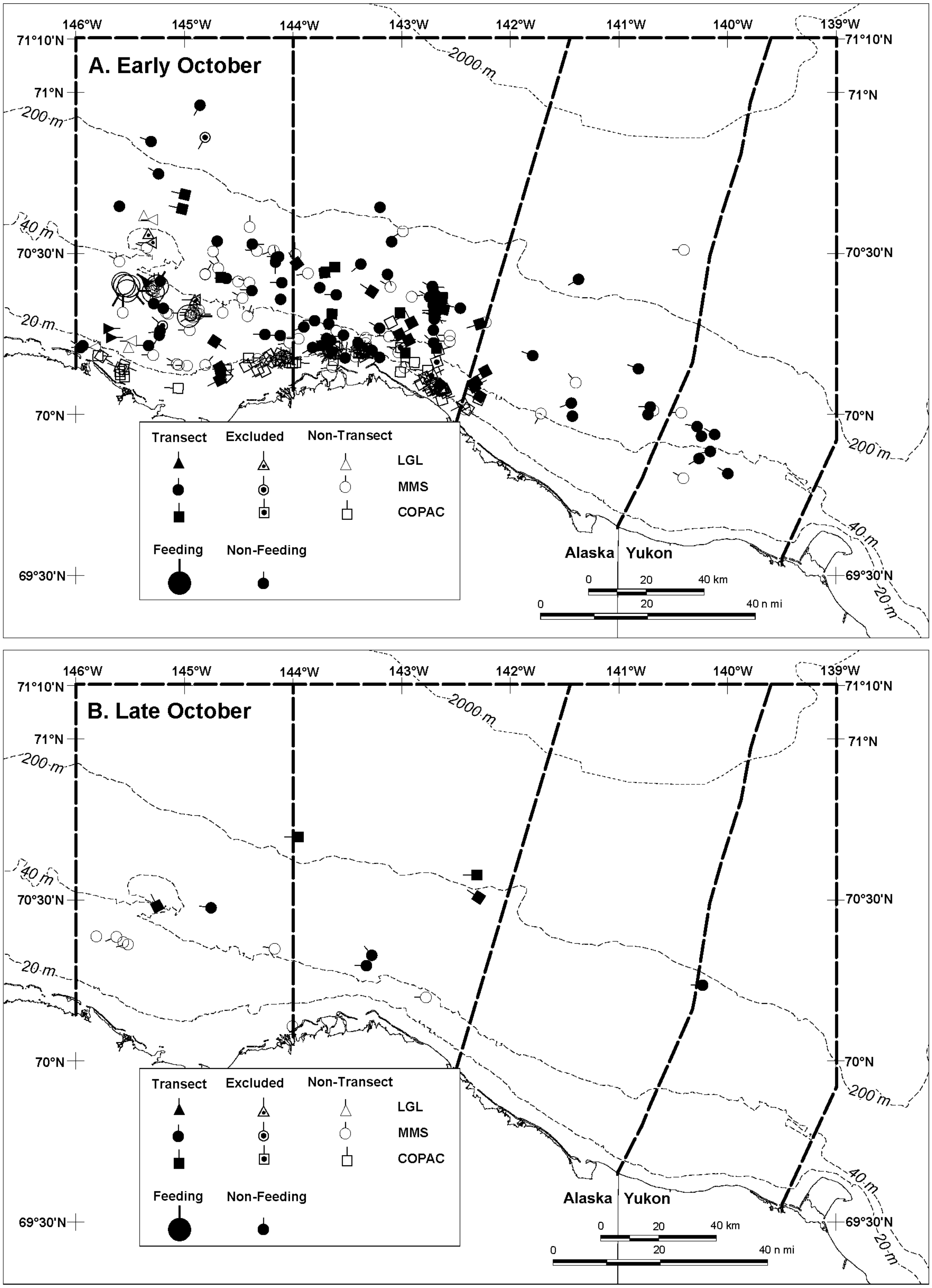

FIGURE 9.9. Locations of bowhead sightings during aerial surveys in the 139°–146°W region of the Beaufort Sea during ***(A)*** 1–15 Oct. and ***(B)*** 16–31 Oct., 1979–2000.

***Summary of Seasonal Variation*.**—Moderate numbers of bowheads were present during early August, especially in offshore waters (>200 m deep) of the three easternmost regions of the study area (Fig. 9.5). Bowhead abundance was somewhat lower during the second half of August, and there was a slight shoreward shift in the distribution of bowheads. However, bowheads remained most abundant in areas >40 m deep and in the three easternmost regions of the study area.

During the first half of September the relative abundance of bowheads in the study area increased. Also, their distribution shifted inshore and expanded westward to span the full width of the study area, coincident with increased migration into and through the study area. Peak bowhead abundance was recorded during the second half of September, when bowheads were most abundant in the Shelf Break and Middle Shelf strata (20–200 m deep).

Bowhead relative abundance in the study area declined in early October and, as in September, highest densities were shoreward of the 200 m contour. By late October, the relative abundance of bowheads was very low.

The percentage of the bowhead sightings recorded as "traveling" was similar (86–100%) over the six half-month periods. For traveling whales, headings were significantly non-uniform (and predominantly westward or northwestward) in all half-month periods except for late August. However, the variation in the headings of "traveling" bowheads was larger in the three periods up to 15 Sept. than in the three periods thereafter.

Feeding Whales

The locations of bowhead whales recorded as feeding when sighted during aerial surveys are mapped as large symbols, by half-month periods, in Figures 9.6, 9.8, and 9.9. Only 6 of 891 "transect" sightings (0.7%) in the study area, and 11 of 1199 individual bowheads (0.9%), were categorized as feeding. These low numbers contrast with other evidence that (at least in September) bowheads in this area spend a substantial part of their time feeding (see Chapters 12, 18). This contrast shows the difficulty of recognizing feeding behavior in the brief glimpses of whales that typically occur during systematic aerial surveys. About 83% of the feeding in the study area is well below the surface, and extended observations are usually needed to obtain indirect evidence of feeding below the surface (Chapter 12).

Within the 139°–146°W area, the aerial survey crews obtained additional "non-transect" sightings of feeding bowheads. Considering all feeding whales (large symbols) mapped in Figures 9.6 and 9.8–9.9, it is evident that Canadian waters in the nearshore Komakuk region have been an important feeding area in August and early September. Bowheads were recorded feeding there in 1984, 1985, and 1986. In eastern Alaskan waters, feeding bowheads were seen in the southeast part of the Demarcation region during September of 1979–82, 1986, and 1999. In the Camden Bay region, feeding whales were observed during September and early October in Middle Shelf and Shelf Break waters. These sightings occurred during 1981–82 and 1998. There were also a few sightings of feeding bowheads in nearshore Kaktovik waters during September 1980. Aerial surveyors obtained no records of feeding bowheads west of Komakuk in August, and none in waters beyond the 200 m depth contour at any time. However, as noted above, it difficult to recognize feeding activity during systematic aerial surveys, especially when whales are feeding well below the surface. Data of other types show that feeding occurs commonly within the eastern Alaska area, at least during some years (see Chapters 2, 6, 12, 18).

Annual Variation

Bowhead abundance in the study area has varied markedly from year to year (Fig. 9.10). There were eight years when observed abundance was higher than the overall average of 0.77 bowheads

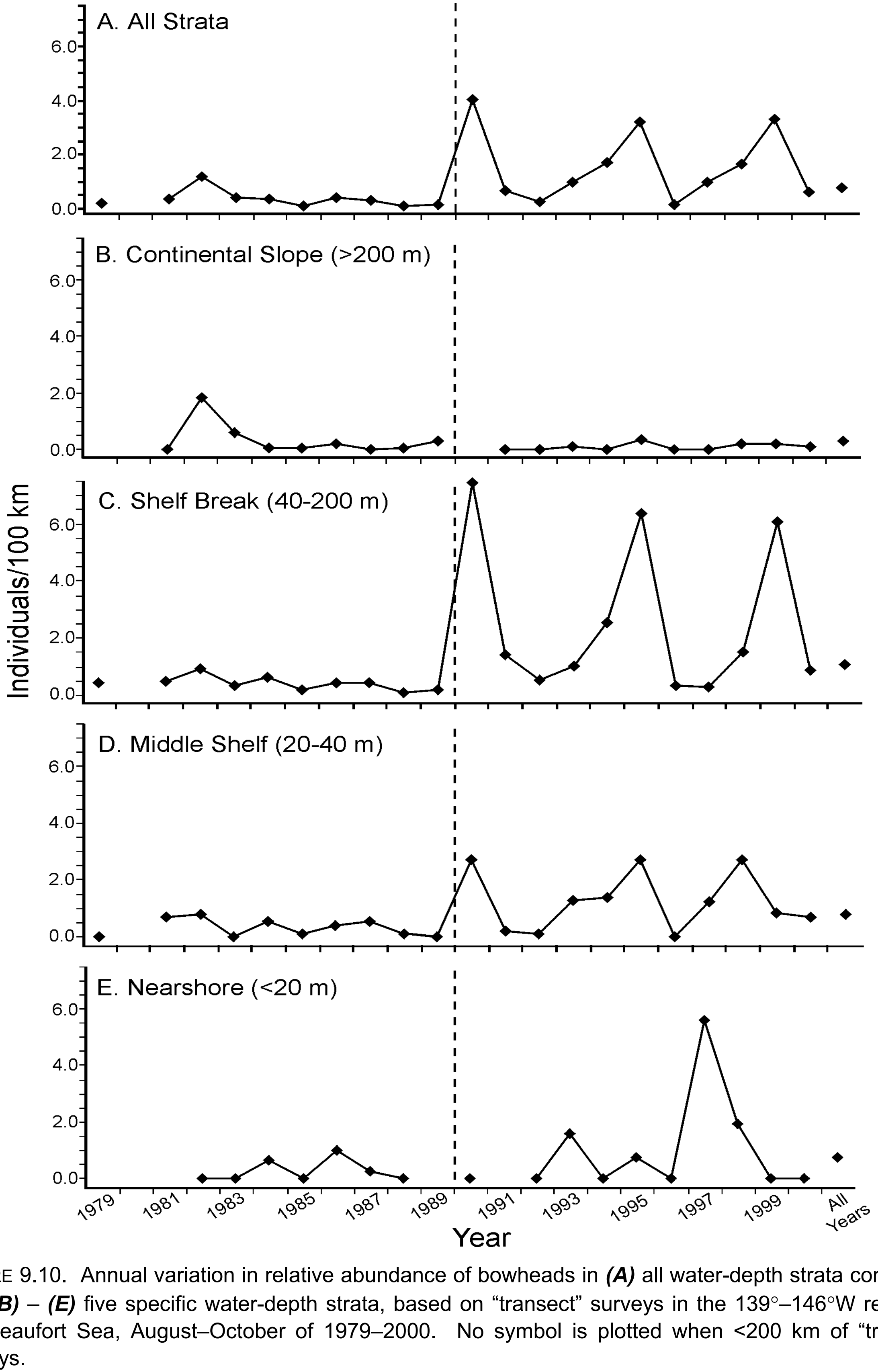

FIGURE 9.10. Annual variation in relative abundance of bowheads in ***(A)*** all water-depth strata combined, and ***(B)*** – ***(E)*** five specific water-depth strata, based on "transect" surveys in the 139°–146°W region of the Beaufort Sea, August–October of 1979–2000. No symbol is plotted when <200 km of "transect" surveys.

seen/100 km: 1982[2], 1990, 1993–95, and 1997–99 (Fig. 9.10A). The highest indices of abundance were recorded in 1995 (3.23 /100 km), 1999 (3.32 /100 km) and 1990 (4.05 /100 km). These indices were 4 to 5 times higher than the overall 1979–2000 average. During the 13 years with below-average indices, abundance ranged from 0.09 (1988) to 0.68 (1991) bowheads seen/100 km (Appendix 9.2). Seven of the eight years with above-average bowhead abundance were in the 1990s and most (9 of 13) years with below-average abundance occurred prior to 1990. The average of the annual abundance indices during the 1979–89 period is 0.36 /100 km vs. 1.60 /100 km for the 1990–2000 period. Thus, there appears to have been a marked increase in average bowhead abundance in the study area since 1989 [3].

The increase after 1989 was most pronounced in the Shelf Break stratum (40–200 m deep), usually followed by the Middle Shelf stratum. Especially high abundance was recorded in these strata in 1990, 1995, and 1999 (Fig. 9.10C,D). However, in the Nearshore stratum, bowhead abundance was highest in 1997 (5.63 /100 km). Bowhead abundance was low in the Continental Slope stratum during almost all survey years (mean = 0.30 /100 km), with the exception of 1982 (1.82 /100 km).

On an E–W basis, observed increases in bowhead abundance since 1989 were most pronounced in the Kaktovik and Demarcation Bay regions (Fig. 9.11C, D). The years of post-1989 peak abundance in those two regions (and to a lesser extent the Camden Bay region) coincide. The pattern in the Komakuk region appears quite different, with peaks in bowhead abundance observed in 1991, 1994 and 1998, and no strong tendency for abundance to be higher in 1990–2000 than earlier.

Estimated Numbers of Bowheads Present

The numbers of bowheads present in the study area at various times were estimated for a "restricted study area" consisting of the Camden Bay, Kaktovik, and Demarcation regions from the shore to the 200 m depth contour (Fig. 9.1). The estimates were based on 81 surveys or combinations of surveys, each of which was flown on one day or two consecutive days during the 1979–2000 period (Table 9.2). These estimates are based on line-transect methodology with allowance for low detectability of whales close to the trackline, the decrease in detectability with increasing lateral distance, missed whales at the surface, and missed whales below the surface (see Methods and Chapter 15). The estimated numbers of bowheads within the "restricted study area" ranged from 0 (during many surveys) to a maximum of 4505 bowheads (based on 765 km of survey coverage on 13 Sept. 1999). The standard errors associated with the single-survey estimates were typically about as large as the estimates themselves.

Seasonal Patterns in Bowhead Numbers.—A plot of the 10-day moving average of bowhead abundance within the restricted study area indicates that, on average, the period of peak bowhead abundance occurs during September and the first half of October (Fig. 9.12). Within most half-month periods the estimated numbers of bowheads present were highly variable. All six seasonal periods included

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[2] Bowhead abundance in 1982, especially in the Demarcation region, may have been higher than indicated on Figures 9.10 and 9.11. Johnson (1984) found very high numbers of bowheads (128 individuals seen) on 22 Sept. 1982 in a portion of his nearshore study area between 141°W (international border) and 143°45'W (near Kaktovik). This corresponds to 33.8 bowheads seen/100 km (69 bowheads in 204 km of systematic transect flown). Johnson sampled the area from the shore to 20 n.mi. offshore (40–60 m depth). This area was not sampled during the 17 Sept.–5 Oct. 1982 period by any of the studies included in the present analysis.

[3] It was suggested by the Scientific Review Board (see Annex A) that we should also compare the data for 1979–90 vs. 1991–2000 to assess the sensitivity of the results to the specific choice of "cutpoint". The mean indices of abundance would then be 0.696 whales/100 km (*n* = 11) vs. 1.353 whales/100 km (*n* = 10).

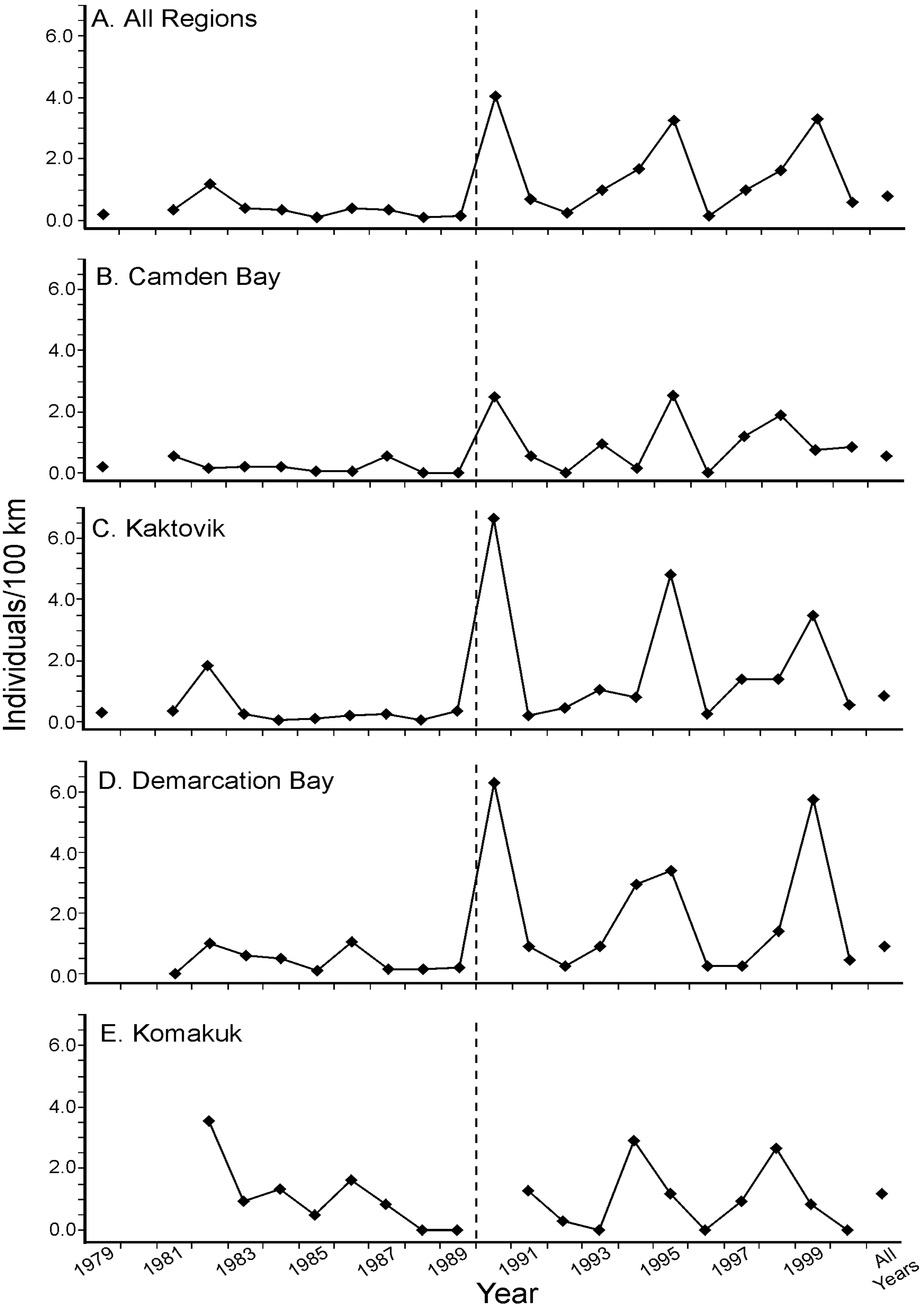

FIGURE 9.11. Annual variation in relative abundance of bowheads in ***(A)*** all regions of the study area, and ***(B)*** – ***(E)*** four specific longitudinal zones, based on "transect" surveys in the 139°–146°W region of the Beaufort Sea, August–October of 1979–2000. No symbol is plotted when <200 km of "transect" surveys.

TABLE 9.2. Estimated numbers of bowhead whales in a restricted portion of the eastern Alaskan Beaufort Sea study area, based on August - October surveys by MMS, LGL[a] and COPAC. Considers the Camden Bay, Kaktovik and Demarcation regions shoreward of the 200 m depth contour. Based on line transect methods, including allowance for $f(0)$, $g_a(0)$, and $g_d(0)$ correction factors (see Chapter 15).

Half-Month Period	Year	Study	Date	Effort (km)	Bhds seen on Trans[b]	Bhds/ 100 km[c]		No. Bhds[c]		Ref. To Survey Details[d]
						Est.	S.E.[c]	Est.	S.E.[c]	
1	1982	MMS	06 Aug	585	0			0		
	1984	MMS	02 Aug	405	0			0		
1-15	1984	MMS	14 Aug	407	0			0		
Aug	1985	MMS	08 Aug	411	1	1.33	1.52	191	219	18
	Max[e]							**191**		
	Ave	**(*n* =4)**						**47.8**		
2	1982	MMS	28 Aug	408	0			0		
	1984	MMS	29 Aug	541	2	3.86	4.31	556	621	19
16-31	1985	MMS	18/19 Aug	439	0			0		
Aug	1986	MMS	16 Aug	405	0			0		
	1986	MMS	20 Aug	559	0			0		
	1986	MMS	24 Aug	532	0			0		
	1986	MMS	28 Aug	497	0			0		
	1993	COPAC	18 Aug	471	0			0		
	1994	MMS	31 Aug	480	8	9.13	8.33	1317	1201	7
	1995	MMS	31 Aug - 1 Sep	475	0			0		
	Max[e]							**1317**		
	Ave	**(*n* =10)**						**187.3**		
3	1982	MMS	15 Sep	496	2	2.20	2.27	317	327	18
	1983	MMS	03 Sep	408	0			0		
1-15	1983	MMS	07 Sep	483	0			0		
Sep	1985	LGL	06 Sep	410	0			0		
	1985	LGL	13 Sep	689	1	0.79	1.14	115	165	7
	1986	MMS	03 Sep	495	1	1.10	1.31	159	189	18
	1986	LGL	04 Sep	495	6	6.80	7.19	981	1037	7
	1986	MMS	11 Sep	530	2	2.06	2.05	297	296	18
	1986	LGL	11 Sep	703	4	3.12	2.95	450	425	7
	1987	MMS	11 Sep	402	4	5.45	5.36	786	773	7
	1988	MMS	14/15 Sep	573	0			0		
	1993	COPAC	01 Sep	600	4	3.91	3.55	565	512	16
	1993	COPAC	08 Sep	759	5	3.87	4.16	558	601	16
	1993	COPAC	10 Sep	471	1	1.25	1.36	180	197	16
	1993	COPAC	12 Sep	1166	0			0		
	1993	COPAC	15 Sep	556	4	4.22	4.24	609	611	16
	1994	MMS	01/02 Sep	405	5	6.77	6.22	977	897	7
	1996	MMS	10 Sep	416	1	3.06	3.84	441	554	8
	1998	LGL	11 Sep	558	3	3.16	2.91	455	419	16
	1999	MMS	07 Sep	588	12	11.19	9.62	1615	1388	7
	1999	MMS	11 Sep	478	14	16.04	13.26	2314	1912	7
	1999	MMS+LGL	12 Sep	429	2	2.55	4.70	368	678	7
	1999	LGL	13 Sep	765	41	31.23	25.67	4505	3702	10

… continued

TABLE 9.2. (continued)

Half-Month Period	Year	Study	Date	Effort (km)	Bhds seen on Trans[b]	Bhds/ 100 km[c]		No. Bhds[c]		Ref. To Survey Details[d]
						Est.	S.E.[c]	Est.	S.E.[c]	
	2000	MMS	1-Sep	569	2	2.22	2.22	320	321	9
	2000	MMS	3-Sep	508	4	4.31	4.09	622	590	7
	2000	LGL	12-Sep	934	2	1.25	1.32	180	190	10
	Max[e]							**4505**		
	Ave	**(*n* =26)**						**646.7**		
4	1979	MMS	18/19-Sept	478	1	1.15	2.99	165	432	7
	1985	LGL	18-Sep	768	3	2.14	2.12	309	306	7
15-30	1985	MMS	18-Sep	502	0			0		
Sep	1985	LGL	25-Sep	737	1	1.72	2.37	249	342	8
	1985	MMS+LGL	26/27-Sept	432	1	1.27	1.33	183	191	7
	1986	SWEPI+LGL	20-Sep	482	3	3.41	3.29	492	475	7
	1986	LGL	22-Sep	767	11	7.86	7.10	1133	1024	7
	1986	SWEPI+MMS	25-Sep	533	4	4.11	3.83	593	552	7
	1987	MMS	29/30-Sept	629	2	2.01	1.97	289	285	9
	1988	MMS	17/18-Sept	581	1	2.19	2.62	316	378	8
	1988	MMS	24-Sep	410	0			0		
	1993	COPAC	16-Sep	438	2	2.68	2.66	387	384	16
	1993	COPAC	19-Sep	1200	17	8.26	8.62	1191	1243	10
	1993	COPAC	20-Sep	597	11	10.74	9.58	1550	1383	10
	1993	MMS	24-Sep	451	2	2.43	2.57	351	371	7
	1993	COPAC	29/30-Sept	728	3	2.42	2.45	349	353	16
	1996	MMS	28/29-Sept	519	0			0		
	1997	MMS	26-Sep	427	0			0		
	1997	MMS	28-Sep	421	3	3.91	3.84	564	555	7
	1998	LGL	17-Sep	1018	19	10.96	9.46	1580	1364	16
	1998	MMS	18-Sep	578	15	16.36	13.68	2360	1973	9
	1999	MMS	16/17-Sept	521	4	4.21	4.04	607	583	7
	1999	LGL	26-Sep	481	22	26.65	22.97	3845	3313	10
	2000	MMS	20-Sep	465	0			0		
	Max[e]							**3845**		
	Ave	**(*n* =24)**						**688.0**		
5	1981	MMS	11-Oct	645	2	4.97	5.97	717	861	17
	1985	MMS	13/14-Oct	462	0			0		
1-15	1989	MMS	5-Oct	405	0			0		
Oct	1992	MMS	4-Oct	434	0			0		
	1993	COPAC	02/03-Oct	569	7	7.16	6.82	1033	983	10
	1993	COPAC	5-Oct	626	2	1.88	2.38	271	344	16
	1993	MMS	7-Oct	401	3	4.09	4.63	591	668	7
	1993	MMS	8-Oct	521	7	7.36	10.92	1062	1575	7
	1993	COPAC	08 Oct	630	19	17.58	16.46	2536	2374	10
	1993	MMS	13 Oct	406	1	1.35	1.92	195	277	7
	1998	MMS	08/09 Oct	586	3	3.23	3.10	466	447	9
	2000	MMS	10 Oct	426	1	2.98	4.26	430	613	8
	Max[e]							**2536**		
	Ave	**(*n* =24)**						**608.4**		

… continued

TABLE 9.2. (concluded)

Half-Month Period	Year	Study	Date	Effort (km)	Bhds seen on Trans[b]	Bhds/ 100 km[c] Est,	Bhds/ 100 km[c] S.E.[c]	No. Bhds[c] Est.	No. Bhds[c] S.E.[c]	Ref. To Survey Details[d]
6 16-31 Oct	1985	MMS	19/20-Oct	444	0			0		
	1993	MMS	16-Oct	420	0			0		
	1993	COPAC	27-Oct	556	0			0		
	1998	MMS	22-Oct	456	0			0		
	1998	MMS	26/27-Oct	471	0			0		
	Max[e]							**0**		
	Ave	**(*n* =5)**						**0**		

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[a] Includes surveys listed as LGL and SWEPI.

[b] Excludes sightings between trackline and inner truncation distance (159 - 600 m, depending on aircraft altitude & type); also excludes sightings beyond outer truncation distance (900 - 3000 m, depending on aircraft altitude, sea conditions and ice cover).

[c] Calculated by the DISTANCE program including use of $f(0)$, $g_a(0)$ and $g_d(0)$ correction factors to allow for whales missed by observers.

[d] Numbers refer to ID numbers in Table 15.2 (in Chapter 15). Table 15.2 indicates the specific aircraft type, as well as ranges of altitude, sea conditions (Bf), ice cover and $f(0)$ values associated with a given survey or combination of surveys for which bowhead numbers were estimated.

[e] Minimum estimate was zero for each 1/2 month period.

some surveys when no bowheads were estimated to be present (Table 9.2). Based on the average estimated numbers of bowheads during each of the six seasonal periods, peak numbers of bowheads occurred in the restricted study area during late September, with an average of 688 bowheads present (*n* = 24 surveys or combinations of surveys, Table 9.2). Substantial average numbers were also estimated for early September (647 bowheads, *n* = 26) and early October (608 bowheads, *n* = 12). Much lower averages were calculated for August, with an estimated 47.8 bowheads present within the restricted study area during the first half of August (*n* = 4 surveys), and 187.3 bowheads present during the second half (*n* = 10). No bowheads were estimated to be present during the second half of October (*n* = 5). These estimates are based on sightings within a defined range of lateral distances along systematic transects. During some surveys, no bowheads were seen in these restrictive conditions, resulting in a “zero” estimate, but one or more bowheads were known to be present based on other sightings not meeting the criteria for inclusion in the line-transect estimation process.

If we consider only the 1990–2000 period, the average estimated numbers of bowheads present in the restricted study area were as follows: 439 during late August (*n* = 3 surveys), 914 during early September (*n* = 15), 983 during late September (*n* = 13), 732 during early October (*n* = 9), and 0 during late October (*n* = 4). No data were available for early August during 1990–2000.

Annual Patterns in Estimated Bowhead Numbers.—As noted earlier, there appears to have been an increase in bowhead abundance in the eastern Alaskan Beaufort Sea study area in recent years, based on observed trends in indices of abundance during the 1979–2000 period. The estimated numbers of bowheads present on the specific occasions listed in Table 9.2 provide another opportunity to examine this issue. Although the sample sizes are small in most seasons, these values include allowance for some of the factors affecting bowhead sightability (Chapter 15). We compared the estimated numbers of bowheads present at various times during 1979–89 vs. 1990–2000, restricting the analysis to the 1 Sept.–15 Oct. periods when peak numbers of bowheads were estimated to be in the restricted study area. The

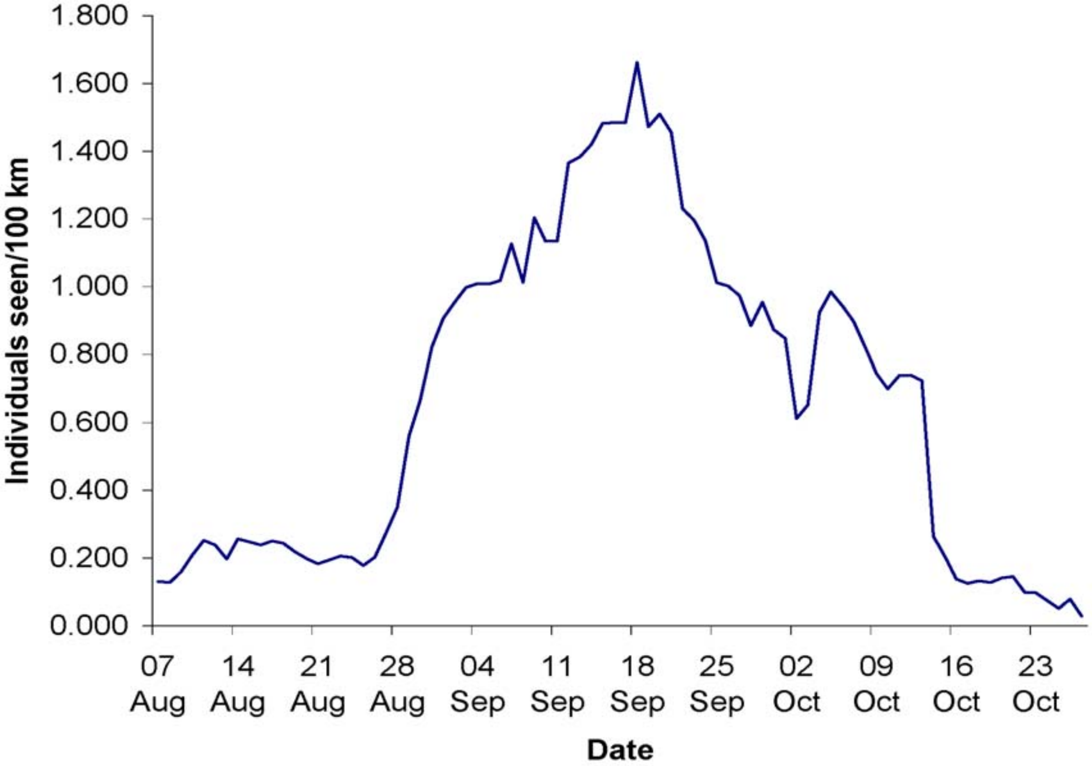

FIGURE 9.12. Plot of daily 10-day moving average of bowhead abundance (individuals seen/100 km) in the restricted eastern Alaskan Beaufort Sea study area, 7 Aug.–27 Oct., 1979-2000, based on data from Appendix 9.1. Restricted study area excludes Komakuk region and Continental Slope depth stratum.

September and early October estimates for 1990–2000 (n = 37) were significantly higher than those for 1979–89 (n = 25, t = –3.24, df = 46, two-tailed P = 0.002). None of the estimates in Table 9.2 are from 1990, so the results would be unchanged if 1979–1990 were compared with 1991–2000.

Estimates of Numbers of Bowhead "Whale-days".—Estimates of the numbers of “whale-days” of use of the restricted study area were calculated for the five years of the MMS feeding studies (1985–86, 1998–2000) as briefly described in the Methods. These calculations use daily 10-day moving averages of bowhead abundance (Fig. 9.12, Appendix 9.1) and the estimated numbers of bowheads present on certain days within those years (from Table 9.2). As an example of how the numbers are calculated, we consider the 1985 calculations shown in Table 9.3 in greater detail. There were 10 survey dates (or combined dates) during 1985 with sufficient survey coverage to generate estimates of bowhead numbers. These survey results are listed in Table 9.2 and the whale-days calculations are summarized in Table 9.3. Estimated numbers of bowheads ranged from 0 (five surveys) to 309 (18 Sept.). Each estimate of whale numbers was converted to a date-adjusted index of bowhead abundance by dividing the estimate by the 10-day moving average of bowhead abundance (from Appendix 9.1 and depicted in Fig. 9.12) for that date. Moving average values ranged from 0.128 (8 Aug.) to 1.662 (18 Sept.) for estimates >0 bowheads. For 1985 the date-adjusted indices of bowhead abundance ranged from 0 to 1496.4 and averaged 219.7 (Table 9.3). The latter number represents the date-adjusted index of bowhead abundance for the restricted study area in 1985. This average was multiplied times the sum (54.341) of all daily 10-day moving average indices of bowhead abundance during the 7 Aug. – 27 Oct. period. The resulting figure (11,937) represents the estimated number of bowhead “whale-days” in the restricted study area during the 7 Aug. – 27 Oct. period in 1985.

TABLE 9.3. Estimated average bowhead “whale days” in the restricted eastern Alaskan Beaufort Sea study area, 7 Aug.–27 Oct., 1985-86 and 1998-2000.

							A.	**B.**	**A. x B.**
	Half-Month Period	Study	Survey Date	Survey Effort (km)	Est. No. Bhds Present[a]	Density Index (10-Day M.A.)[b]	Date-Adjusted Index of Abundance	Sum of Daily M.A. Bhd Densities[a]	Total Whale-Days
1985	1	MMS	08 Aug	411	191	0.128	1496.4		
"	2	MMS	18/19 Aug	439	0		0.0		
"	3	LGL	06 Sep	410	0		0.0		
"	3	LGL	13 Sep	689	115	1.384	83.1		
"	4	LGL	18 Sep	768	309	1.662	185.9		
"	4	MMS	18 Sep	502	0		0.0		
"	4	LGL	25 Sep	737	249	1.012	246.0		
"	4	MMS+LGL	26/27 Sep	432	183	0.988	185.3		
"	5	MMS	13/14 Oct	462	0		0.0		
"	6	MMS	19/20 Oct	444	0		0.0		
	Mean No. Bhds						**219.7**	54.341	**11,937**
1986	2	MMS	16 Aug	405	0		0.0		
"	2	MMS	20 Aug	559	0		0.0		
"	2	MMS	24 Aug	532	0		0.0		
"	2	MMS	28 Aug	497	0		0.0		
"	3	MMS	03 Sep	495	159	0.998	159.4		
"	3	LGL	04 Sep	495	981	1.008	973.1		
"	3	MMS	11 Sep	530	297	1.135	261.7		
"	3	LGL	11 Sep	703	450	1.135	396.6		
"	4	SWEPI+LGL	20 Sep	482	492	1.510	325.8		
"	4	LGL	22 Sep	767	1133	1.231	920.8		
"	4	SWEPI+MMS	25 Sep	533	593	1.012	585.8		
	Mean No. Bhds						**329.4**	54.341	**17,899**
1998	3	LGL	11 Sep	558	455	1.135	401.0		
"	4	LGL	17 Sep	1018	1580	1.485	1064.3		
"	4	MMS	18 Sep	578	2360	1.662	1419.6		
"	5	MMS	08/09 Oct	586	466	0.785	593.6		
"	6	MMS	22 Oct	456	0		0.0		
"	6	MMS	26/27 Oct	471	0		0.0		
	Mean No. Bhds						**579.8**	54.341	**31,507**
1999	3	MMS	07 Sep	588	1615	1.126	1433.7		
"	3	MMS	11 Sep	478	2314	1.135	2039.3		
"	3	MMS+LGL	12 Sep	429	368	1.366	269.5		
"	3	LGL	13 Sep	765	4505	1.384	3255.6		
"	4	MMS	16/17 Sep	521	607	1.485	408.9		
"	4	LGL	26 Sep	481	3845	1.002	3838.6		
	Mean No. Bhds						**1874.3**	54.341	**101,850**
2000	3	MMS	01 Sep	569	320	0.906	353.4		
"	3	MMS	03 Sep	508	622	0.998	623.5		
"	3	LGL	12 Sep	934	180	1.366	131.8		
"	4	MMS	20 Sep	465	0		0.0		
"	5	MMS	10 Oct	426	430	0.700	614.4		
	Mean No. Bhds				310.4		**344.6**	54.341	**18,727**

[a] Line transect estimate, corrected for missed whales (from Table 9.2).

[b] From Appendix 9.2.—10-d moving average (for this date) of raw "individuals seen/100 km".

The results are shown in Table 9.3. The estimated numbers of whale-days within the restricted study area during the 7 Aug.–27 Oct. period for the five years ranged from a low of 11,937 whale days in 1985, to a high of 101,850 whale days in 1999. During 4 of 5 years, the estimates were in the range 11,937 to 31,507.

Discussion

Local and Traditional Knowledge of Bowhead Occurrence

Whale hunters and other residents of Kaktovik, within the present eastern Alaskan study area, know much about the seasonal and geographic patterns in bowhead use of that area and adjacent Canadian waters (see Chapter 2 and Annex B). Kaktovik residents occasionally see bowheads in eastern Alaskan waters as early as July, and sightings become more common in August. However, when Kaktovik residents travel along the Yukon coast in July and August, they see more bowheads there than in eastern Alaskan waters. Sightings near Kaktovik are most common in September, the primary hunting season for bowheads passing Kaktovik. Some bowheads remain in the area well into October. Bowheads are often seen close to shore near Kaktovik. Some residents noted that bowheads may linger in specific areas for several days and that bowheads often tend to feed near water-mass boundaries or off river mouths. Waters near Icy Reef and Arey Island (see Fig. 2.1) are places where local residents have seen bowheads lingering.

Tendency for more Sightings in Recent Years

The observed variability in annual bowhead abundance seems very high considering that most of the bowhead population apparently migrates through the study area each year in late summer and autumn. A number of factors may account for this variability:

1. variability in weather and sighting conditions.
2. variability in survey aircraft, observers and methods over the 22 year period considered.
3. bowheads often migrate in "pulses", separated by periods of reduced abundance; depending on survey timing relative to pulses, numbers seen could vary considerably.
4. surveys in different years have started and ended on varying dates and often have not spanned the full autumn migration period of bowheads.
5. migrating whales may be less detectable than feeding or socializing whales (see Chapters 13, 15).
6. the bowhead population has increased substantially over the study period.

The effects of the 1st, 2nd and 5th factors on annual average sighting conditions could, in theory, be corrected to some extent based on the detectability factors derived in Chapter 15. We have not attempted to apply such correction factors to all of the survey coverage used in calculating bowheads/100 km. (The factors from Chapter 15 were applied for the specific dates when there was sufficient survey coverage to allow an estimate of whale numbers in the area—see Table 9.2.)

The effects of the 4th and 6th factors, i.e., annual study period and bowhead population trend, on annual average sighting rates can also be corrected to some extent, as described below.

Our analysis of seasonal variation indicated that, on average, peak bowhead abundance in the study area, as measured by "bowheads seen/100 km", occurs during the first and second half of September (Fig. 9.5). Survey coverage in September was more consistent and extensive than that in August and October. If we re-examine annual abundance, restricting the analysis to the September period, then there are 21 years in the 1979–2000 study period with a combined September survey coverage of 93,159 km. Excluding 1981 (with only 37 km of survey coverage), there were 20 years with September survey coverage ranging from 1270 to 16,406 km. Among these years "bowheads seen /100 km" ranged from low values of 0.10 (1979), 0.11 (1988) and 0.13 (1985) to high values of 3.32 (1999), 3.55 (1995) and 4.70 /100 km (1990). Thus, the ratio of the highest observed September abundance index (4.70 /100 km) to the lowest (0.10) was 47 : 1, which is not substantially different from the comparable ratio considering the full August–October period (4.05 : 0.09, or 45 : 1). Thus, restricting the analysis to September did not appreciably lessen the observed annual variability. It is possible that there is sufficient year to year variability in the timing of bowhead migration that comparing the same seasonal period (in this case the month of September) in each year does not adequately capture the period of peak bowhead abundance in all years.

The BCB stock of bowhead whales was estimated, as of 1993, to contain ~8200 animals with a 95% confidence interval of 7200–9400 individuals (Zeh et al. 1996; Raftery and Zeh 1998; Ferrero et al. 2000). This estimate is lower than the population of 10,400–23,000 bowhead whales estimated to be present before commercial whaling (Woodby and Botkin 1993). About a decade ago, the population was believed to be increasing at a rate of ~3.2% per year (Punt and Butterworth 1999) despite annual Alaskan subsistence harvests of 14 to 74 bowheads from 1973 to 1996 (Suydam et al. 1995). If a 3.2% rate of increase had been in effect throughout the 1979–2000 study period, and the BCB bowhead population in 1993 was 8200 animals, then the population may have increased from 5276 individuals in 1979 to 10,223 in 2000. This near doubling of the population over the study period would explain part of the observed increase in estimated bowhead abundance from the 1979–89 period to the 1990–2000 period.

We re-tested the early (1979–89) vs. late (1990–2000) estimates of bowhead numbers for the restricted study area (Flaxman Island to Canadian border, shore to 200 m contour) during September–early October after "adjusting" for the assumed 3.2% annual increase in population over the study period. The adjustment factor, $\times 1.032^{(1993\text{–Year})}$, standardized each year's overall bowhead population relative to that estimated for 1993 (8200), assuming that the population had increased at a 3.2% annual rate. The adjustment factors ranged from 1.554 in 1979 to 0.802 in 2000 (Appendix 9.2). After adjusting for the assumed 3.2% annual increase in overall population size, the September and early October population estimates from the later period (n = 37) were still significantly higher than those in the early period (n = 25, t = –2.48, df = 54, two-tailed P = 0.016). Thus, the observed increase in bowhead abundance in the 1990s is greater than expected based on the assumed annual increase in the size of the bowhead population passing through the study area. As noted in "Results", there were no relevant data for 1990, so the above calculation would be unaffected if 1979–90 were compared with 1991–2000.

The fact that bowhead abundance in the study area has increased over the 22-year study period at a rate higher than the assumed rate of increase in the bowhead population presumably represents some change in the distribution and movements of the whales. Some possible changes that might account for the observed trend to increased numbers of bowheads in the restricted study area include • a higher proportion of bowheads migrating through the study area in September and early October in recent years as compared to earlier years, • a higher proportion of bowheads migrating through the restricted study area (vs. farther north) in recent years as compared to earlier years, • the western edge of the summer feeding range expanding west from Canada into the eastern Alaskan Beaufort Sea, • or a greater tendency on the part of bowheads to linger in the restricted study area before beginning rapid migration (possibly related to climatic change).

The increase in bowhead numbers during the 1990s was documented for the September–early October period. This increase might be related to changes in the timing of the main migration period through the restricted study area, i.e., perhaps a higher proportion of bowheads migrated through the restricted study area during September and early October during recent years (1990–2000) than in earlier years (1979–89). There were few August data from the later (1990–2000) period for comparison with earlier years, and the late October sample of estimated numbers was very small, especially for the early period (1979–89, $n = 1$). Thus, it is not possible to determine from the data we examined whether there have been changes in the timing of the main migration period over the 1979–2000 period.

This study was limited to the region south of 71º10'N. Thus, we have no information about the numbers of bowheads that may have migrated west through waters north of the study area. Radio tracking of bowheads indicates that at least some autumn migrating bowheads travel in waters north of the continental shelf (Wartzok 1990; Mate et al. 2000). In general, aerial surveys show that densities far offshore are low. Moore et al. (1989) found relatively low bowhead abundance in the area north of our study area (MMS blocks 8 and 9, 71°10'N–72°N). During the first half of September 1979–86, they found 0.26 bowheads /survey hour in MMS blocks 8 and 9 (5 bowheads in 19.4 hours of surveys), vs. 1.74 bowheads/survey hour (338 bowheads in 194.3 hours of surveys) in blocks 4–7, which closely correspond to our study area. Thus, relative bowhead densities in our study area in early September were ~6.75 times higher than in the region north of our study area. However, the region north of our study area is large and even low densities of bowheads might represent substantial numbers of individuals. Survey coverage north of our study area has been sparse, and there are no published data indicating whether or not bowhead abundance in that region has changed over the years during the autumn migration period.

The increased numbers of bowheads observed in the restricted study area during the 1990s may indicate that the area has increasingly been used as a feeding area by bowheads. This may reflect in part a westward expansion of the late summer/early autumn feeding range as the BCB bowhead stock has increased in size. Alternatively, the expansion of the feeding range could reflect improved feeding conditions (i.e., prey availability) in those waters in the 1990s. Increased prey availability is presumably related to oceanographic processes (e.g., currents, upwellings, eddies, and frontal features) that concentrate zooplankton into dense patches that can be selectively fed upon by bowhead whales. Bowhead distribution has been associated with high prey concentrations between the boundary of the Mackenzie River plume and colder marine waters (Thomson et al. 1986; Chapter 6). The zooplankton sampling conducted as part of the present study in 1985–86 and 1998–2000 (see Chapter 5) was not designed to quantify trends (if any) in overall zooplankton availability in the study area. However, extensive net and echosounder sampling was done in each of those years, and no obvious trend in zooplankton availability was evident.

Moore (2000) and Treacy (2002) found that bowhead distribution in the Alaskan Beaufort Sea during late summer and autumn varied with ice conditions. In years of light and moderate ice, the highest densities of bowheads tended to occur in nearshore waters, where dense patches of plankton are sometimes found (see Chapter 5). In heavy ice years, bowheads tend to occur in outer shelf and slope waters. However, Treacy (2002) noted that this trend was less evident east of Kaktovik (and near Barrow) than in the intervening area. Wind regimes and the resulting surface currents are primary determinants of not only autumn ice conditions, but also the locations of major oceanographic features such as the Mackenzie River plume. Moore (2000) speculated that the northwesterly winds that typically result in heavy ice conditions near shore may also result in conditions that are not conducive to the concentration of prey organisms in nearshore waters. If so, bowheads may not linger in nearshore waters during heavy ice years due to a lack of foraging opportunities.

The last decade has been notable for light ice conditions in the Alaskan Beaufort. For example, 8 of the 10 years in the 1990–99 period were classed as light ice years, as compared with 6 of 11 years during 1979–89 (Treacy 2000). The 1990s included years (1990, 1993, 1995, 1997 and 1998) with extremely light summer ice coverage relative to that during the 1978–98 period as a whole (Serreze et al. 1995; Maslanik et al. 1996, 1999). Ice conditions in 1997 ranked 7th lightest of 45 years from 1953 to 1997, and 1998 ranked 3rd lightest for the 47 years 1953–99 (Treacy 2000). This tendency to light ice conditions in recent years may have been associated with unusually good feeding opportunities for bowheads and unusually high bowhead abundance within our study area.

Unusually light ice conditions in the 1990s may have been related to wind patterns affected, in recent years, by large scale processes such as the Arctic Oscillation. This is a pressure oscillation that, when in a “positive” phase (to which it shifted in 1989), tends to reduce pressure over the North Pole, pump more warm air into the Arctic, and open leads in the Arctic Ocean ice (Maslanik et al. 1996; Kerr 1999).

Given the long lifespans of bowhead whales (George et al. 1999), individual bowheads may experience numerous natural long-term cycles of weather patterns, pressure oscillations, and ice conditions during their lives. The observed light ice conditions in recent years may be part of a natural oscillation that has resulted in temporary increased feeding opportunities in the eastern Alaskan Beaufort Sea. Alternatively, these conditions could be related to anthropogenic factors (e.g., greenhouse warming) that may be part of a continuing trend. Interpretation of the paleoclimate record indicates that, in the arctic, the 20th century was the warmest century of the past 400 years (Serreze et al. 2000). Some climate models project continued decreases in sea ice thickness and extent throughout the present century (Vinnikov et al. 1999). This could result in a markedly different ice–ocean–atmosphere regime in the Arctic (Johannessen et al. 1999). Such changes might further alter the importance of the eastern Alaskan Beaufort Sea to bowhead whales.

Although there are several possible reasons for the increased utilization of the eastern Alaskan Beaufort Sea during some recent years, the actual reasons remain a matter of speculation. The gradually increasing population size is no doubt one factor, but this alone is not sufficient to account for the observed increase. A substantial part of the increase must represent a change in the distribution and/or movements of some or all BCB bowhead whales during late summer and early autumn. These changes might represent a westward expansion of the summer feeding range, perhaps associated with the increased population size, or with climatic fluctuations and trends, or (most likely) with a combination of several such factors.

Summary

Previous studies plus observations by local people have shown that some bowhead whales may spend at least part of the summer feeding period off the north coast of Alaska. Many others summer in Canadian waters but continue to feed as they begin to travel west through the Alaskan Beaufort Sea during September and October. Bowhead use of the Alaskan Beaufort Sea during late summer and autumn has been documented since 1979 by systematic aerial surveys, mainly conducted or sponsored by BLM and MMS. The surveys have gathered much information that can be used to evaluate bowhead use of the eastern Alaskan Beaufort Sea during August–October, including relative utilization according to year, season, and region within the study area.

This study describes the seasonal distribution and numbers of bowheads observed in the eastern Alaskan Beaufort Sea and adjacent Canadian waters during August–October of 1979–2000, based on existing and new aerial survey data from the 139°–146°W region, south of 71°10'N. The 21 years of data considered here (no data were available from 1980) include ***(1)*** annual aerial surveys by MMS, ***(2)*** some of the aerial surveys conducted during industry-sponsored monitoring programs (1986 and 1993), and ***(3)*** surveys that we conducted specifically to assess the importance of the eastern Alaskan Beaufort Sea to bowheads in 1985–86 and 1998–2000. The combined dataset includes more data from the eastern Alaskan Beaufort Sea than have been analyzed by previous authors; it involves 155,000 km of systematic aerial surveys within the "Flaxman Isl.-to-Herschel Isl." study area. For periods where sufficient aerial survey data are available, we have estimated the numbers of bowheads present in the part of the study area inshore of the 200 m contour off Alaska ("Flaxman-to-border"). These estimates are based on line transect techniques, including correction factors for whales missed by the aerial surveyors (see Chapter 15 for derivation of correction factors).

The "Flaxman-to-Herschel" study area was divided into four E–W regions, and four water-depth strata—a total of 16 analysis zones. For seasonal analyses, the data were categorized into six half-month (15- or 16-day periods) from 1 Aug. to 31 Oct.

When standardized for survey effort, the overall average abundance index during systematic aerial surveys under acceptable sighting conditions (Aug.–Oct. combined) was 0.77 bowheads seen/100 km. Bowhead abundance differed significantly among the four depth strata, with highest average abundance recorded in the Shelf Break stratum (40–200 m deep), followed by the Middle Shelf stratum (20–40 m) and Nearshore stratum (<20 m); average abundance was lowest in the Continental Slope stratum (>200 m deep). Differences in bowhead abundance among the four E–W regions were marginally significant, with bowhead abundance highest in the east and declining with increasing longitude.

Local residents occasionally see bowheads in the study area during July and August; they see peak numbers in September, and some bowheads during October.

Aerial surveys showed that bowhead abundance and distribution varied significantly by half-month period during August–October of 1979–2000. Moderate numbers of bowheads were present during early August, especially in offshore waters (>200 m deep) of the three easternmost regions of the study area. Bowhead abundance was somewhat lower during the second half of August, and there was a slight shoreward shift in the distribution of bowheads from early to late August.

During the first half of September the relative abundance of bowheads in the study area increased. Also, their distribution shifted inshore and expanded westward to span the full width of the study area, coincident with increased migration into and through the study area. Peak bowhead abundance was recorded during the second half of September, when bowheads were most abundant in the Shelf Break and Middle Shelf strata (20–200 m deep).

Bowhead relative abundance in the study area was lower during early October, and the highest densities were again shoreward of the 200 m contour. By late October, the relative abundance of bowheads was very low.

The percentage of the bowhead sightings recorded as "traveling" was similar (86–100%) over the six half-month periods. For traveling whales, the headings were significantly non-uniform (and predominantly westward or northwestward) in all half-month periods except for late August. However, the variation in headings was larger up to 15 Sept. than thereafter.

Few bowheads were identified as feeding during systematic aerial surveys. The low apparent numbers of feeding bowheads reflect, in large part, the difficulty of recognizing feeding activity in the brief glimpses of whales that typically occur during systematic aerial surveys. Areas where feeding was seen most commonly included Nearshore waters close to Komakuk (Yukon); Nearshore, Middle Shelf and Shelf Break waters off Demarcation Bay; and Middle Shelf and Shelf Break waters off Camden Bay.

During the 1979–2000 period, the relative abundance of bowheads recorded during aerial surveys has varied markedly from year to year. Eight years had abundance indices higher than the overall average of 0.77 bowheads seen/100 km. The highest indices were recorded in 1995 (3.23 /100 km), 1999 (3.32 /100 km) and 1990 (4.05 /100 km). Seven of the eight years with above-average bowhead abundance were in the 1990s and most (9 of 13) of the years with below-average bowhead abundance occurred prior to 1990. The average of the annual abundance indices was 0.36 bowheads seen/100 km during the 1979–89 period vs. 1.60 bowheads/100 km for the 1990–2000 period. The increase since 1989 was larger than can be accounted for by the previously-reported rate of increase of this population (3.2% per year).

The numbers of bowheads present in the "Flaxman-to-border" area were estimated whenever survey coverage allowed, considering waters inshore of the 200 m contour (i.e., 3 of 4 E–W zones, and 3 of 4 depth strata). These line-transect estimates were based on 81 surveys or combinations of surveys flown during 1- or 2-day periods during 1979–2000, and include allowance for missed whales. The estimates ranged from 0 (during many surveys) to a maximum of 4505 bowheads (based on 765 km of survey coverage on 13 Sept. 1999).

Within most half-month periods, the estimated numbers of bowheads present were highly variable. All six half-month periods included some surveys for which no bowheads were estimated to be present. However, the average estimated numbers of bowheads present in the restricted study area during the six half-month periods followed the same pattern as the abundance indices described above for the overall study area: moderate in August, high in September and early October (peaking during late September), and almost none during the second half of October.

We compared the estimated numbers of bowheads present in the "Flaxman-to-border" area during 1979–89 vs. 1990–2000, considering only the September and early October periods when peak numbers of bowheads were present. The estimates from the 1990–2000 period were, on average, significantly higher than those from 1979–89 even after de-trending to remove the assumed annual 3.2% population increase over the 22-year study period. Thus, the increased sighting rates in the 1990–2000 period are apparently attributable in part to an increase in the relative utilization of the present study area as compared with other areas.

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APPENDIX 9.1. Daily 10-day moving average of bowhead abundance (individuals seen/100 km) in the restricted eastern Alaskan Beaufort Sea study area, 7 August-27 October, 1979-2000. Restricted study area excludes Komakuk region and Continental Slope depth stratum. No surveys were flown on 4 August, 22 August, or 24 October.

August					**September**					**October**				
Day	No. of Bhds Seen	Km of Survey Coverage	No. Bhds Seen/ 100 km	10-Day Moving Average	Day	No. of Bhds Seen	Km of Survey Coverage	No. Bhds Seen/ 100 km	10-Day Moving Average	Day	No. of Bhds Seen	Km of Survey Coverage	No. Bhds Seen/ 100 km	10-Day Moving Average
1	0	8.7	0.000	-	1	15	2419.4	0.620	0.906	1	5	758.7	0.659	0.847
2	0	1065.5	0.000	-	2	24	1187.0	2.022	0.953	2	9	873.5	1.030	0.612
3	0	2.7	0.000	-	3	25	2988.3	0.837	0.998	3	15	1232.7	1.217	0.653
4	-	-	-	-	4	31	1942.7	1.596	1.008	4	7	934.6	0.749	0.924
5	0	425.7	0.000	-	5	29	2127.0	1.363	1.007	5	7	1804.9	0.388	0.985
6	0	912.7	0.000	-	6	20	1668.7	1.199	1.018	6	4	898.5	0.445	0.944
7	1	481.4	0.208	0.131	7	28	3039.4	0.921	1.126	7	9	1344.1	0.670	0.897
8	1	638.1	0.157	0.128	8	19	2273.7	0.836	1.013	8	46	1752.4	2.625	0.824
9	1	414.5	0.241	0.159	9	13	1952.4	0.666	1.204	9	5	724.5	0.690	0.746
10	1	179.6	0.557	0.209	10	19	2307.2	0.824	1.134	10	9	1964.8	0.458	0.700
11	2	445.2	0.449	0.252	11	53	3684.4	1.439	1.135	11	2	1064.8	0.188	0.739
12	0	135.2	0.000	0.239	12	31	4477.4	0.692	1.366	12	0	906.8	0.000	0.740
13	0	137.2	0.000	0.198	13	79	3279.9	2.409	1.384	13	1	676.3	0.148	0.724
14	3	546.3	0.549	0.257	14	2	1023.7	0.195	1.420	14	0	722.0	0.000	0.265
15	1	74.6	1.340	0.248	15	32	2379.6	1.345	1.482	15	0	227.2	0.000	0.206
16	0	1133.1	0.000	0.239	16	83	1872.0	4.434	1.485	16	1	485.0	0.206	0.138
17	0	843.9	0.000	0.251	17	45	3921.9	1.147	1.485	17	0	312.6	0.000	0.125
18	5	1152.2	0.434	0.244	18	31	2434.7	1.273	1.662	18	2	477.1	0.419	0.133
19	0	195.9	0.000	0.219	19	34	2221.1	1.531	1.472	19	0	447.8	0.000	0.128
20	3	1194.5	0.251	0.200	20	19	2255.7	0.842	1.510	20	2	489.9	0.408	0.141
21	3	565.0	0.531	0.183	21	10	788.7	1.268	1.456	21	0	49.3	0.000	0.145
22	-	-	-	0.195	22	34	2018.5	1.684	1.231	22	0	636.9	0.000	0.099
23	0	306.0	0.000	0.206	23	0	784.7	0.000	1.196	23	0	62.8	0.000	0.098
24	0	839.5	0.000	0.202	24	36	2780.5	1.295	1.135	24	-	-	-	0.074
25	2	712.7	0.281	0.178	25	9	1598.2	0.563	1.012	25	0	351.4	0.000	0.051
26	0	156.6	0.000	0.202	26	51	3057.0	1.668	1.002	26	0	132.9	0.000	0.079
27	0	335.9	0.000	0.275	27	1	874.0	0.114	0.974	27	0	1062.8	0.000	0.028
28	0	976.3	0.000	0.351	28	10	1590.4	0.629	0.885	28	0	375.4	0.000	-
29	3	882.9	0.340	0.560	29	12	2231.7	0.538	0.954	29	0	313.3	0.000	-
30	3	944.4	0.318	0.667	30	5	1048.3	0.477	0.873	30	1	332.0	0.301	-
31	9	1545.5	0.582	0.822						31	0	219.8	0.000	-
Total	38	17251.8	0.220	6.815		800	66227.9	1.208	35.483		125	21634.9	0.578	12.044

APPENDIX 9.2. Annual indices of bowhead abundance (individuals seen/100 km) in the eastern Alaskan Beaufort Sea, 1 August-31 October 1979-2000. Restricted study area excludes Komakuk region and Continental Slope depth stratum. Adjusted indices have been standardized to a population of 8200 bowheads in 1993. "Base years" (last column) were used in calculations in Chapter 11 (Rates of Movement and Residence Times...).

	Entire Study Area						Restricted Study Area						
Year	No. of "Transect" Bhds Seen	Km of Transect Survey Coverage	No. Bhds Seen/ 100 km	Est. Pop. Size^a	Adjust. Factor for Pop incr.	Adjust. No. Bhds Seen/ 100 km	No. of "Transect" Bhds Seen	Km of Transect Survey Coverage	No. Bhds Seen/ 100 km	Est. Pop. Size	Adjust. Factor for Pop incr.	Adjust. No. Bhds Seen/ 100 km	Lowest three (Base Years)
1979	11	4960.0	0.22	5276	1.554	0.34	10	4757.7	0.21	5276	1.554	0.33	
1980	-	-	-	5445	1.506	-	-	-	-	5445	1.506	-	
1981	5	1396.2	0.36	5619	1.459	0.52	5	973.7	0.51	5619	1.459	0.75	
1982	118	9873.1	1.20	5799	1.414	1.69	24	5407.6	0.44	5799	1.414	0.63	
1983	31	7692.2	0.40	5984	1.370	0.55	5	3343.1	0.15	5984	1.370	0.20	
1984	29	8525.8	0.34	6176	1.328	0.45	20	4014.6	0.50	6176	1.328	0.66	
1985	21	17509.2	0.12	6373	1.287	0.15	12	9544.4	0.13	6373	1.287	0.16	0.162
1986	83	21031.1	0.39	6577	1.247	0.49	59	15584.5	0.38	6577	1.247	0.47	
1987	27	8181.8	0.33	6788	1.208	0.40	21	5529.2	0.38	6788	1.208	0.46	
1988	7	7894.7	0.09	7005	1.171	0.10	6	4825.7	0.12	7005	1.171	0.15	0.146
1989	7	4411.7	0.16	7229	1.134	0.18	4	2995.1	0.13	7229	1.134	0.15	0.151
1990	99	2444.2	4.05	7461	1.099	4.45	95	2172.8	4.37	7461	1.099	4.81	
1991	16	2359.8	0.68	7699	1.065	0.72	13	1495.1	0.87	7699	1.065	0.93	
1992	16	6023.0	0.27	7946	1.032	0.27	14	3773.1	0.37	7946	1.032	0.38	
1993	204	21070.2	0.97	8200	1.000	0.97	200	16969.0	1.18	8200	1.000	1.18	
1994	45	2666.1	1.69	8462	0.969	1.64	36	2083.4	1.73	8462	0.969	1.67	
1995	102	3157.8	3.23	8733	0.939	3.03	96	2035.9	4.72	8733	0.939	4.43	
1996	5	3554.4	0.14	9013	0.910	0.13	5	2374.3	0.21	9013	0.910	0.19	
1997	35	3496.9	1.00	9301	0.882	0.88	32	2644.3	1.21	9301	0.882	1.07	
1998	147	8950.8	1.64	9599	0.854	1.40	120	6530.2	1.84	9599	0.854	1.57	
1999	159	4788.5	3.32	9906	0.828	2.75	155	3924.2	3.95	9906	0.828	3.27	
2000	32	5369.2	0.60	10223	0.802	0.48	31	4136.7	0.75	10223	0.802	0.60	
Grand Total	1199	155356.6					963	105114.7					

10. HABITAT USE BY DIFFERENT SIZE CLASSES OF BOWHEAD WHALES IN THE EASTERN ALASKAN BEAUFORT SEA DURING LATE SUMMER AND AUTUMN

William R. Koski and Gary W. Miller [1]

Introduction

Habitat segregation of different size classes of bowhead whales in the Bering–Chukchi–Beaufort (BCB) population has been documented in summering areas in the Canadian Beaufort Sea and Amundsen Gulf (Cubbage and Calambokidis 1987; Koski et al. 1988). Those studies, and observations by Kaktovik residents (Chapter 2 and Annex B), indicate that small subadult whales tend to occupy shallow nearshore areas along the Yukon coast. Large subadults tend to be found farther off the Yukon coast and north of the Mackenzie Delta and Tuktoyaktuk Peninsula. Adults tend to be found even farther east. Large adult whales comprise most of the bowheads found in Amundsen Gulf. Data from the eastern Alaskan Beaufort Sea in the 1980s suggested that, during late summer and early autumn, subadults also tended to occur close to shore in that area, with larger whales being seen more commonly farther offshore (Koski et al. 1988).

Temporal, as well as spatial, segregation by age class has been seen in parts of the BCB bowhead range. Whalers from Kaktovik have suggested that, in late summer, small bowheads arrive in nearshore waters of the eastern Alaskan Beaufort Sea earlier in the season than larger whales but that all sizes of whales are seen near Kaktovik over the autumn season (Chapter 2). However, the harvest data from Kaktovik do not show any seasonal trend in the proportion of small whales harvested, presumably because whalers always attempt to harvest small whales (Chapter 2). Temporal segregation also occurs during spring migration past Barrow (Zeh et al. 1993; Angliss et al. 1995). A large proportion of the whales passing Barrow early in the spring migration period are small subadult whales and a large proportion passing near the end of the period are large adult whales. Females accompanied by recently-born calves are among the last whales to pass Barrow in spring (Koski et al. MS).

Temporal and spatial segregation of the BCB stock of bowhead whales by age and habitat has not been examined in detail for areas other than Barrow in spring and Canadian waters in summer. However, for the Baffin Bay and Hudson Bay stocks, there is also evidence that, in summer, different components of the stocks concentrate in different parts of their overall ranges (Finley 1990, 2001).

The eastern Alaskan Beaufort Sea may, in some years, be an important feeding area for bowhead whales during late summer and autumn. At this time of year bowheads commence their westward migration to overwintering areas (Moore and Reeves 1993; Mate et al. 2000), at times either stopping to feed or feeding while traveling (Chapter 12). During 1998–2000, we used photogrammetric methods consistent with those applied in the 1980s to collect additional data on utilization of the eastern Alaskan Beaufort Sea by different categories of bowhead whales. This chapter examines bowhead size data collected during late August through early October of 1982 to 2000 in relation to year, location within the study

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[1] LGL Ltd., environmental research associates, 22 Fisher St., POB 280, King City, Ont. L7B 1A6. *Phone:* 905-833-1244; *e-mail:* bkoski@lgl.com, gmiller@lgl.com

area, water depth, and date. It assesses the population structure of bowhead whales found in this area and evaluates whether there was habitat and/or seasonal segregation by whales of different sizes (ages) and of different status (subadults vs. mother/calf pairs vs. other adults). This information is relevant in evaluating the importance of the study area to the different components of the bowhead whale population, and is factored into subsequent energetic calculations (Chapters 22, 23).

Methods

The study area considered here, as in Chapters 9 and 11-13, consists of the eastern Alaskan Beaufort Sea and adjacent Canadian waters, from Flaxman Island almost to Herschel Island (longitudes 146° to 139°W; Fig. 10.1). Hereafter, this study area is referred to as the eastern Alaskan Beaufort Sea, although it includes some adjacent Canadian waters. Almost all of the available data came from areas ≤200 m deep.

Data Sources

Length measurements used here were obtained during numerous behavioral and photogrammetry studies conducted in the study area shown in Figure 10.1 during late August to early October from 1982 to 2000. Table 10.1 lists, for each study, the effort, funding agency, and number of whales measured. The largest proportion of the data presented here came from studies funded by the U.S. Minerals Management Service (MMS) in 1985, 1986, and 1998–2000.

TABLE 10.1. Sources of bowhead whale length measurements for this study. Additional effort and photos outside the present study area during some listed studies are not included.

	Number of			Date		
Year	Days with Flights	Photo Sessions	Measured Whales	Range of Photos	Study Sponsor	Source of Data
1982	3	3	11	16 Aug - 4 Sept	National Marine Fisheries Service	Davis et al. (1983)
1984	4	4	34	17 Aug - 14 Sept	Indian & Northern Affairs Canada	Davis et al. (1986a)
1985	8	10	123 [a]	11-29 Sept	U.S. Minerals Manage. Service	Richardson (1987)
1985	2	4	60 [a]	28 Aug - 8 Sept	Sohio Alaska Petroleum et al.	Davis et al. (1986b)
1985	1	1	2	19 Sept	Shell Western Explor. & Prod. Inc.	Johnson et al. (1986)
1986	11	13	173 [b]	3-27 Sept	U.S. Minerals Manage. Service	Richardson (1987)
1986	10	12	41 [b]	5 Sept - 3 Oct	Shell Western Explor. & Prod. Inc.	Koski & Johnson (1987)
1998	8	18	111	14-22 Sept	U.S. Minerals Manage. Service	This study
1999	12	31	329	10-29 Sept	U.S. Minerals Manage. Service	This study
2000	6	9	27	13-21 Sept	U.S. Minerals Manage. Service	This study
Total	65	105	901 [a,b]	16 Aug - 3 Oct		

[a] Five whales were photographed during two 1985 studies so only 180 different whales were measured in 1985.

[b] Five whales were photographed during both 1986 studies so only 209 different whales were measured in 1986.

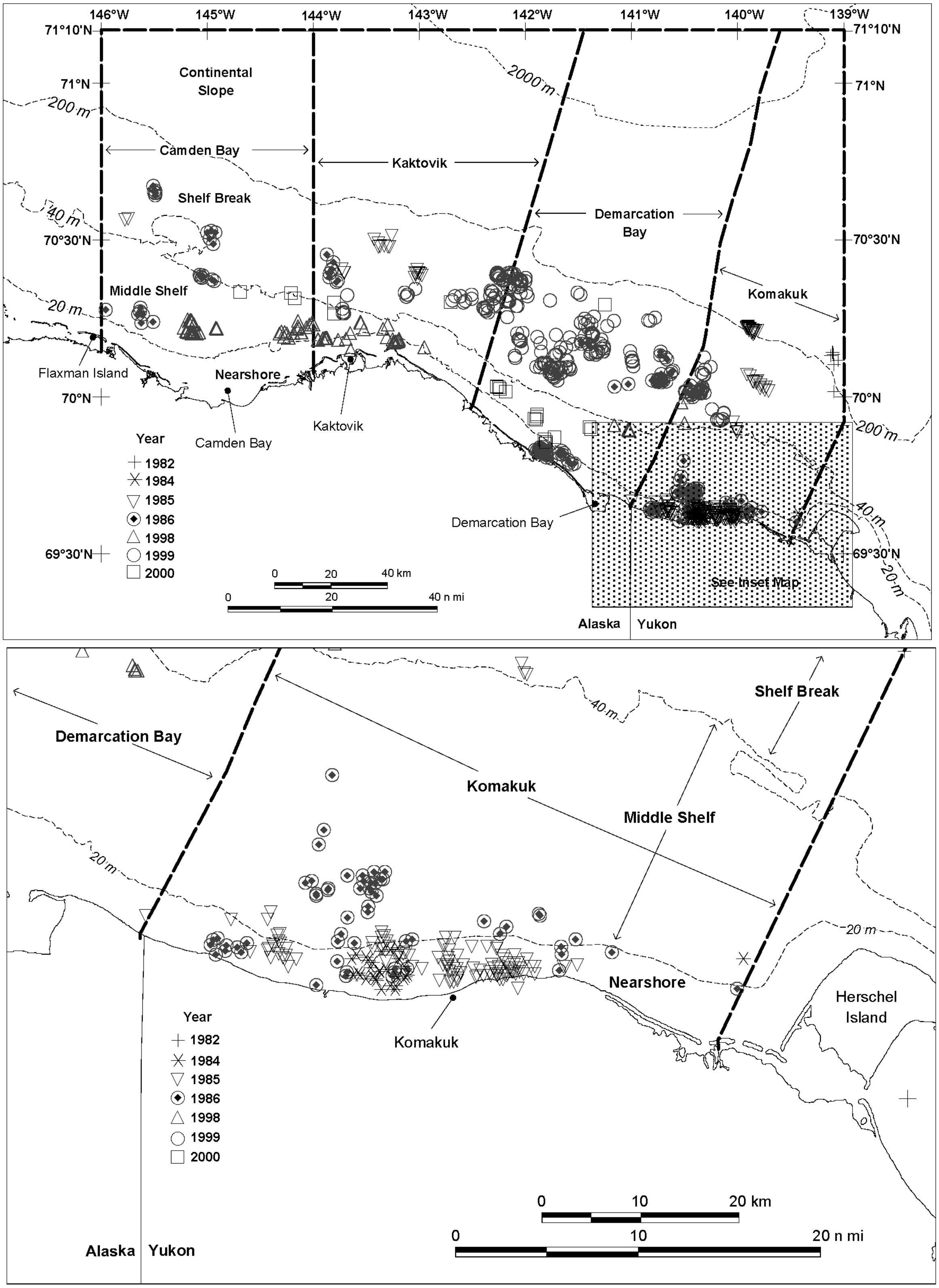

FIGURE 10.1. Locations where each individual photographic whale image was taken to obtain length data, 1982–86 and 1998–2000. Each different whale is shown only once for each year, E–W geographic region, depth stratum, and half-month time period, at the location where it was first photographed.

Photogrammetry

We used the calibrated vertical photography technique developed by LGL and described by Koski et al. (1992). Briefly, the aircraft flew at an airspeed of ~160 km/h and (cloud ceiling permitting) an altitude of ~137 m (450 ft), and passed directly over bowheads. Photographs were taken through the aircraft's ventral camera port with one of two hand-held Pentax medium-format cameras (6×7 cm film size), each with a 105 mm *f*2.4 lens, pointed directly downward. Shutter speed was 1/500th or, when possible, 1/1000th second. We used Ektachrome 200 or 400, or Fujichrome Provia 400, which are color positive films, or occasionally (in 1985) Ilford XP1 black and white negative film pushed to ISO (ASA) 1600. Aircraft altitude was read manually from the radar altimeter's analog display and/or from a digital readout at the moment the camera shutter fired. The altitude was recorded manually on data sheets. Calibration targets of known dimensions were deployed 1–3 times each season and photographed with each of the cameras used during that season. These photos were taken from the same altitudes as were flown during whale photography sessions. Both whale and calibration photographs were most commonly taken from 120–140 m a.s.l. Whale images and calibration targets were measured using a stereo microscope and stage micrometer as described by Koski et al. (1992). The measured image sizes were converted to whale lengths by accounting for systematic biases introduced by the cameras (focal plane shutter distortion or inaccurate nominal lens length) and by inaccurate output from the radar altimeter. The resulting length measurements varied in reliability depending on the circumstances during photography, the position of the whale relative to the water surface, and the quality of the whale image. Length data categorized as "accurate" (grades 1–6 of Koski et al. 1992) are generally accurate to within a few 10s of centimeters. Length data categorized as "approximate" are obtained by estimating whale length from measurements of fluke width or snout-to-blowhole distance, or from photos taken when the aircraft altitude was changing rapidly; "approximate" lengths are generally accurate to within ~1 m. "Accurate" and "approximate" length data are used here when we describe size distributions of whales within the study area. Only "accurate" lengths (i.e., grades 1–6 of Koski et al. 1992) are used in describing life history information.

All images with potential to be reidentified were printed and compared with one another to check for whales photographed more than once within each field season. These procedures are summarized by Rugh et al. (1992, 1998). When a whale was photographed more than once in a given year and season (considering summer and early autumn as a single season), all "accurate" length measurements were averaged to obtain a "best length". Only a single measurement is presented for each whale for each period or for each geographic area where it was photographed, regardless of the number of times that whale was photographed. The sample sizes are different for the various analyses because some whales were photographed on two or three days during a year and those whale lengths are included once in each category where they occurred. For example, a whale photographed in the Komakuk block on one day and the Camden block later in the same year would be included once in the length–frequency distributions for both Komakuk and Camden but only once in the length–frequency distribution for that year.

During late summer and early autumn, whales less than ~7 m long are generally calves less than 1 year old. Some calves may be as long as 7.5 m by September. Whales over 13 m long are considered to be mature adults (Nerini et al. 1984; Koski et al. 1992, 1993) although some females with calves are as small as 12.2–13 m, and some females longer than 13.5 m are not mature (Nerini et al. 1984; Koski et al. 1993). Animals <13 m long are referred to as subadults in this paper unless they were closely accompanied by a calf. Subadults are further broken down into small (<10 m) and large (≥10 m) subadults. "Others" are all whales excluding mothers and calves.

Geographic and Temporal Categories

Length–frequency distributions of whales are presented below for four east–west subdivisions of the study area (Fig. 10.1). Length–frequency distributions are also presented by water depth category: nearshore (depth <20 m), middle shelf (20–40 m), shelf break (40–200 m), and continental slope (>200 m).

Length–frequency distributions of bowhead whales in the study area are examined for each year when photographs were obtained during 1982–2000, and for half-month periods (all years combined) from mid-August to mid-October. For each of these periods and/or locations, length–frequency distributions were condensed to numbers of whales in each of five status categories: calves, small subadults, large subadults, adults excluding mothers, and mothers. Chi-square goodness of fit tests were used to test for differences among periods and/or locations in the proportions of whales in the five categories.

Results

Overall Length–Frequency Distribution

A total of 901 length measurements of different bowhead whales were obtained in the eastern Alaskan Beaufort Sea in 1982–2000 (Fig. 10.2). An additional 33 photographs of these 901 whales were obtained on 1–2 additional dates during the same year.

Most if not all bowheads that summer in the Canadian Beaufort Sea and Amundsen Gulf migrate west through the eastern Alaskan Beaufort Sea at a wide range of distances from shore during their migration from Canadian summering areas to overwintering areas in the Bering Sea (Moore and Reeves 1993). If all segments of this bowhead population make equal use of the study area, the whales photographed there during our study should reflect the length–frequency distribution of the population. Of the whales we photographed, 6.2% were calves, 64.7% subadults, and 29.1% adults. In contrast, the overall population was estimated to include 5.2% calves, 53.7% subadults, and 41.1% adults during 1985–92, based on 1898 whales photographed during the spring migration past Point Barrow and corrections to the length–frequency distribution for periods without photographic effort (Angliss et al. 1995). Proportionally more subadults and fewer adults were photographed in the eastern Alaskan Beaufort Sea than reported by Angliss et al. (1995) ($\chi^2 = 31.61$, df = 2, $P = 1.37\times10^{-7}$). The proportion of bowheads photographed in the study area that were calves was not significantly different than in the results of Angliss et al. (1995) ($\chi^2 = 0.93$, $P = 0.335$).

Year-to-Year Variation

The proportions of whales of different status were significantly different among years whether mothers and calves were included ($\chi^2 = 171.1$, df = 24, $P = 3.67\times10^{-24}$) or excluded ($\chi^2 = 135.3$, df = 12, $P = 5.26\times10^{-23}$) from the analysis (Fig. 10.3). Much of this year-to-year difference was due to the considerable variation in the size distribution and proportion of subadult whales that were photographed in the study area among years. 1984 and 1998 had the highest proportions of small subadult whales, 1986 had equal numbers of small and large subadults, and 1985 and 1999 had more large subadults than small subadults (Table 10.2).

In all years except 1999, subadult whales predominated among the whales measured (Fig. 10.3). Excluding mothers and calves, subadults made up 76–100% of the measured whales in the study area during 1982–98 and 2000; in 1999, subadults made up only 52% (Table 10.2).

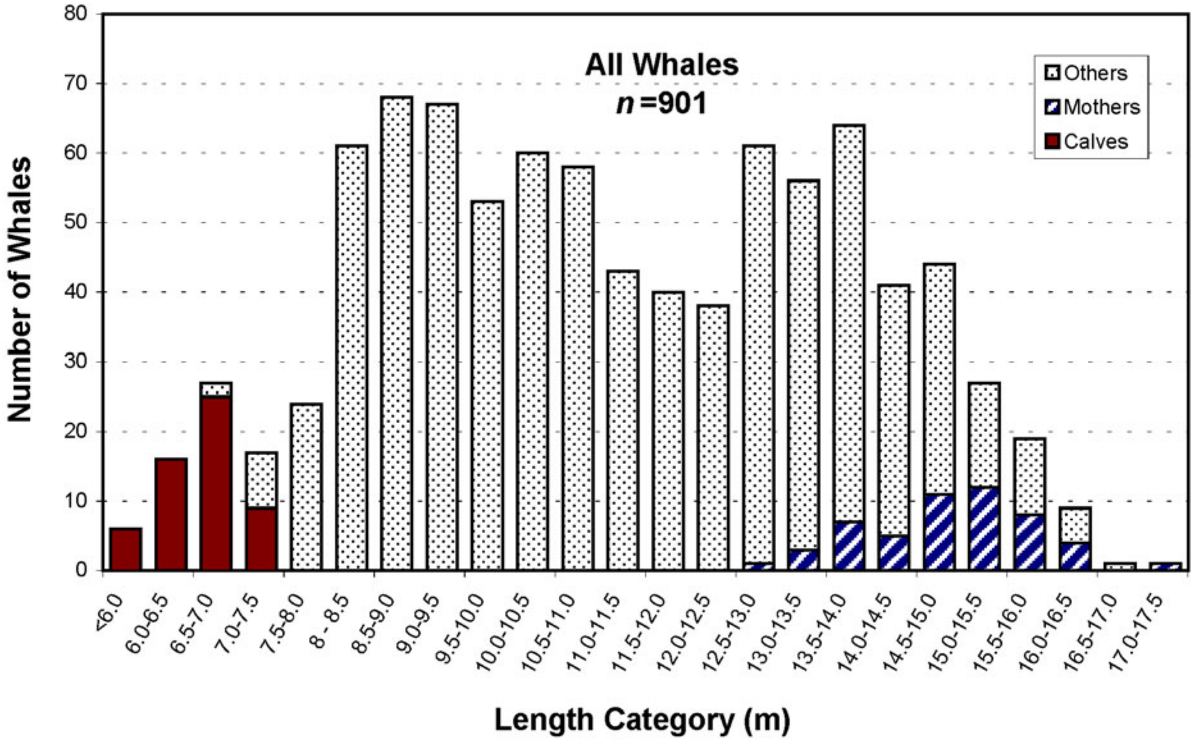

FIGURE 10.2. Overall length–frequency distribution of bowhead whales photographed in the study area, 1982–2000. Within-day and between-day repeats are excluded.

TABLE 10.2. Percentages of whales by size class within the study area, 1982–2000.

Year	1982	1984	1985	1986	1998	1999	2000	Total
All whales								
Calves	18.2	2.9	2.2	10.5	2.7	6.4	11.1	6.2
All subadults excl. calves	63.6	94.1	83.3	66.5	81.1	45.3	59.3	64.7
Small	27.3	76.5	35.6	34.0	45.9	17.9	33.3	31.4
Large	36.4	17.6	47.8	32.5	35.1	27.4	25.9	33.3
All adults	18.2	2.9	14.4	23.0	16.2	48.3	29.6	29.1
Non-mother adults	0.0	0.0	12.2	15.8	13.5	41.3	18.5	23.4
Mothers	18.2	2.9	2.2	7.2	2.7	7.0	11.1	5.7
Number measured	*11*	*34*	*180*	*209*	*111*	*329*	*27*	*901*
Excluding mothers and calves								
All subadults	100.0	100.0	87.2	80.8	85.7	52.3	76.2	73.4
Small	42.9	81.3	37.2	41.3	48.6	20.7	42.9	35.6
Large	57.1	18.8	50.0	39.5	37.1	31.6	33.3	37.8
Adults	0.0	0.0	12.8	19.2	14.3	47.7	23.8	26.6
Number measured	*7*	*32*	*172*	*172*	*105*	*285*	*21*	*794*

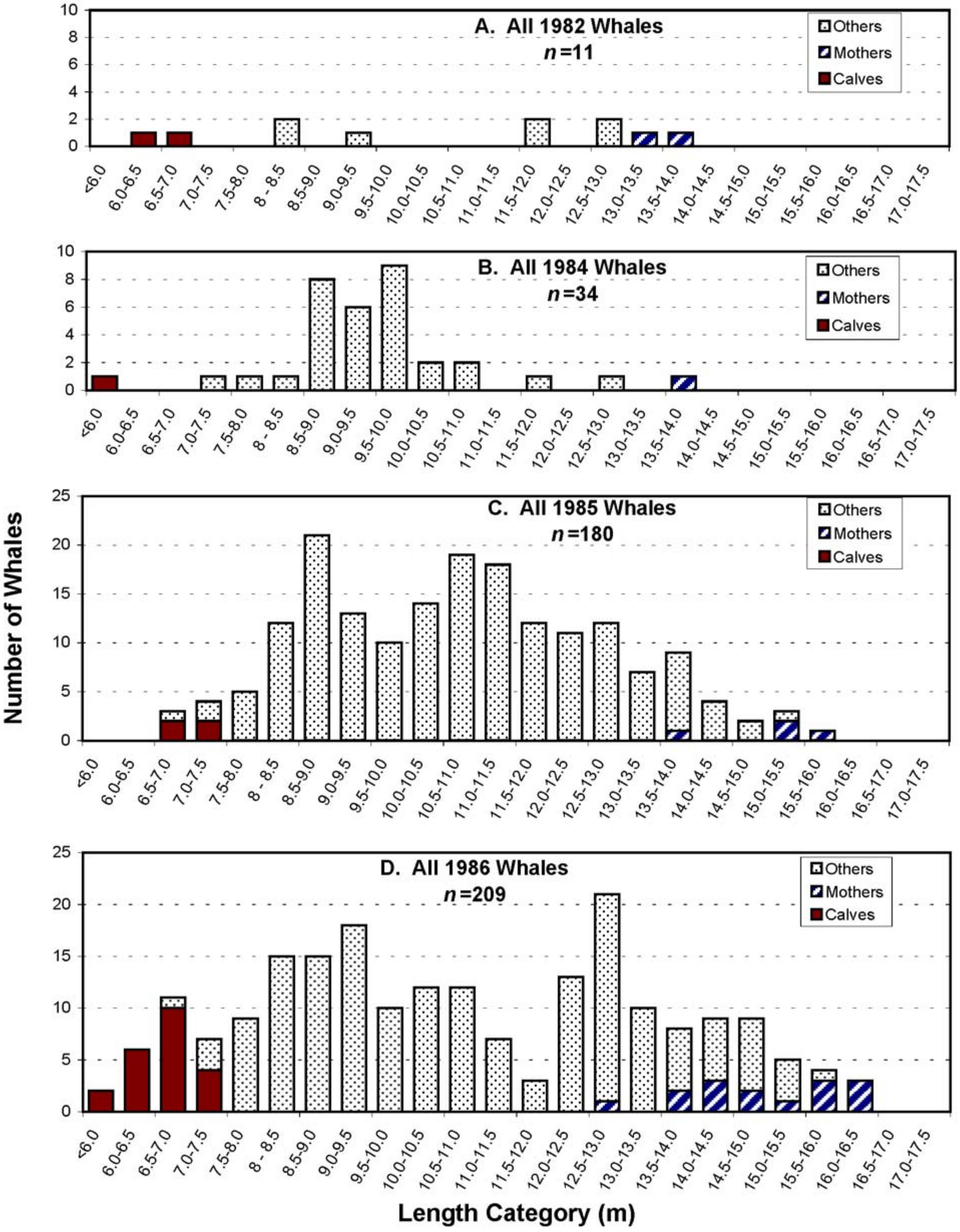

FIGURE 10.3. Length–frequency distributions of bowhead whales photographed in the study area each year, 1982–2000. Within-day and between-day repeats are excluded.

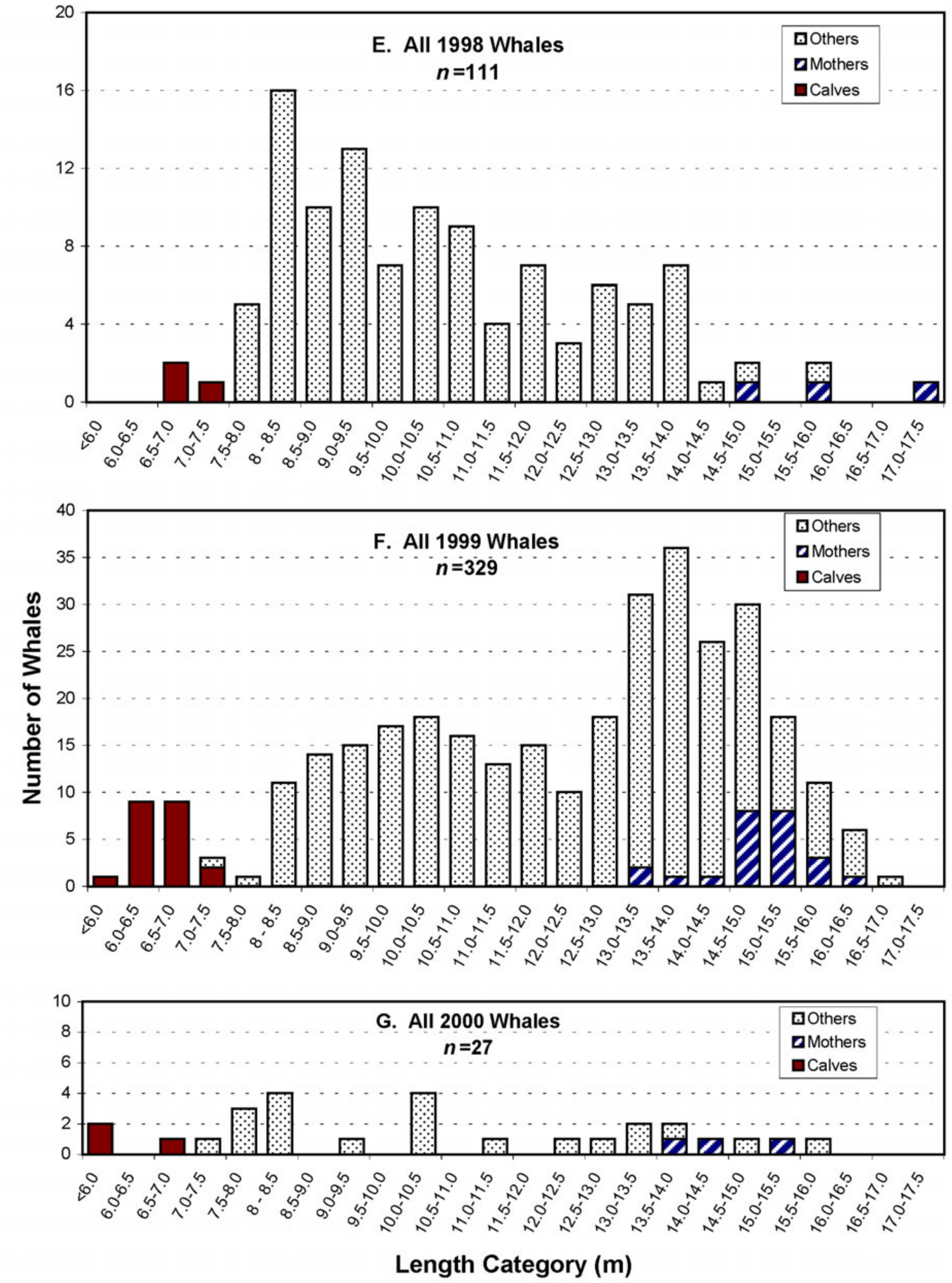

FIGURE 10.3. Concluded.

There was considerable variation in the percentages of measured whales that were mothers and calves (excluding 1982, $\chi^2 = 17.45$, df = 5, $P = 0.0037$). Calves made up 10.5, 6.4 and 11.1% of whales in 1986, 1999 and 2000, but only 2.2–2.9% in 1984, 1985 and 1998. The 1982 sample was too small (n = 11) to provide a meaningful percent calves value.

Variation by Region

The proportions of calves, small subadults, large subadults, adults excluding mothers, and mothers were significantly different among the four geographic subdivisions of the study area ($\chi^2 = 99.97$, df = 12, $P = 5.7\times10^{-16}$). Most (81%) of the whales in the eastern part of the study area (Komakuk block) were subadults (Fig. 10.4A). Subadults also predominated in the Demarcation and Camden blocks (57 and 58%, respectively); 33–35% of whales there were adults. Equal numbers of adults and subadults were photographed in the Kaktovik block.

Differences in the proportions of mothers and "others" in the four survey blocks were only marginally significant ($\chi^2 = 7.33$, df = 3, $P = 0.062$). There were somewhat more mothers in the Camden and Demarcation blocks (10.6% and 8.1%) than in the other blocks (4.2–4.4%).

Variation by Water Depth

There was a significant change in the status of bowheads with increasing water depth categories ($\chi^2 = 237.57$, df = 12, $P = 5.3\times10^{-44}$). Small subadults made up 57%, 41%, and 15% of whales in water depths <20 m, 20–40 m, and 40–200 m, respectively (Table 10.3). In contrast, adults excluding mothers made up 2%, 14%, and 38%, respectively, of whales in the same depth categories (Table 10.3; Fig. 10.5). The small sample of whales photographed in waters >200 m deep was 7% small subadults and 33% adults (excluding mothers).

The proportional occurrence of mothers (calves excluded) differed significantly among depth strata ($\chi^2 = 18.03$, df = 3, $P = 0.00043$), primarily because mothers with calves tended to avoid waters <20 m deep (Fig. 10.5; Table 10.3). The proportions of mothers (calves excluded) were not significantly different among the three strata >20 m deep ($\chi^2 = 2.06$, df = 2, $P = 0.357$).

The categories of bowheads seen in each geographic subdivision of the study area are summarized by water depth category in Table 10.3. The same trends that were seen in the overall length–frequency distribution were present within each geographic area (Fig. 10.6). The proportional occurrence of whales of different status was not significantly different between the Komakuk and Demarcation blocks for water depths <20 m ($\chi^2 = 2.67$, df = 4, $P = 0.614$), nor among the four geographic areas for water depths 20–40 m ($\chi^2 = 15.75$, df = 12, $P = 0.203$). (Areas and depth strata with <25 whales have been excluded from statistical tests because of small expected values.) However, for water depths 40–200 m, there were significant differences in whale status (mothers and calves excluded) among the Komakuk, Demarcation and Kaktovik areas ($\chi^2 = 27.94$, df = 4, $P = 1.28\times10^{-5}$). This difference was due to a more pronounced shift in size distributions from small to large bowheads with increasing water depth in the Kaktovik block than in the Komakuk block (Fig. 10.6).

Temporal Variation

There was a significant change in the status of bowhead whales within the eastern Alaskan Beaufort Sea over the mid-August to mid-October period when bowhead whales are common in that area ($\chi^2 = 94.37$, df = 12, $P = 7.00\times10^{-15}$). During 16–31 August, 93% of measured whales were subadults (small subadults + large subadults). The percentage of subadults declined to 73%, 56% and 35% during 1–15 September, 16–30 September and 1–15 October, respectively (Fig. 10.7). Corresponding increases in the percentages of adults (including mothers) were observed during the four time periods (4, 20, 38, and 48%, respectively).

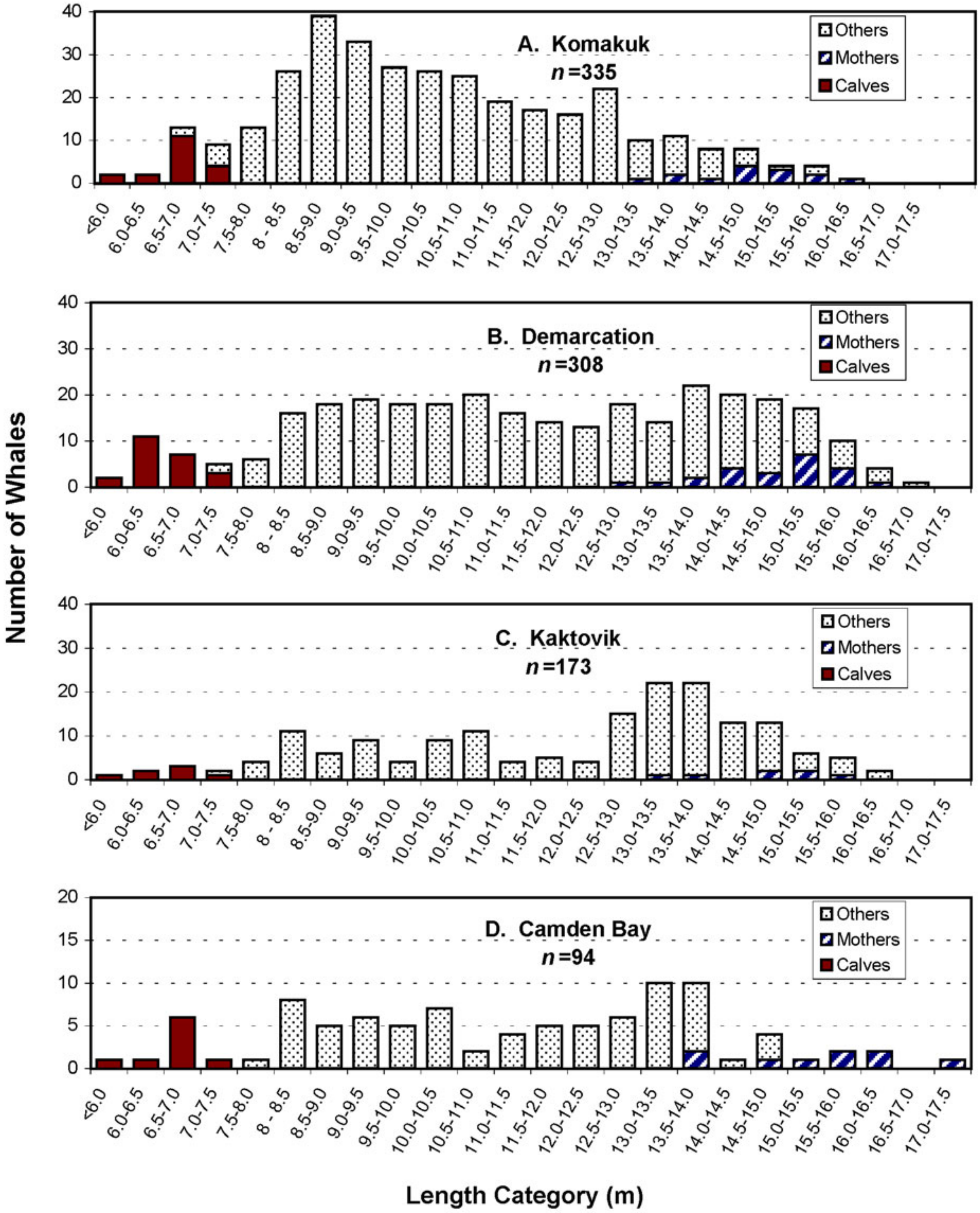

FIGURE 10.4. Length–frequency distributions of bowhead whales photographed in various areas, 1982–2000: ***(A)*** Komakuk, ***(B)*** Demarcation, ***(C)*** Kaktovik and ***(D)*** Camden Bay. Repeats are included once in each area during each year; otherwise, within-day and between-day repeats are excluded.

TABLE 10.3. Numbers and percentages (in parentheses) of whales of various size classes by water depth category and geographic subdivision in the eastern Alaskan Beaufort Sea, 1982–2000. Whales photographed more than once in a given water depth category and geographic subdivision in a given year are counted only once.

Area Water Depth Category	Calves	Small Subadults (<10 m)	Large Subadults (10-13 m)	Adults (>13 m)			Overal Total
				Mothers	Others	Total	
Komakuk							
<20 m	3 (2)	102 (55)	77 (41)	1 (1)	4 (2)	5 (3)	187
20-40 m	2 (4)	27 (52)	18 (35)	1 (2)	4 (8)	5 (10)	52
40-200 m	13 (18)	15 (21)	19 (26)	10 (14)	15 (21)	25 (35)	72
>200 m	1 (3)	2 (7)	15 (50)	2 (7)	10 (33)	12 (40)	30
Demarcation							
<20 m	1 (3)	21 (57)	14 (38)	1 (3)	0 (0)	1 (3)	37
20-40 m	1 (3)	13 (43)	11 (37)	1 (3)	4 (13)	5 (17)	30
40-200 m	21 (9)	45 (19)	73 (30)	21 (9)	81 (34)	102 (42)	241
>200 m	0	0	0	0	0	0	0
Kaktovik							
<20 m	0 (0)	15 (88)	2 (12)	0 (0)	0 (0)	0 (0)	17
20-40 m	0 (0)	13 (45)	12 (41)	1 (3)	3 (10)	4 (14)	29
40-200 m	7 (6)	7 (6)	34 (27)	6 (5)	73 (57)	79 (62)	127
>200 m	0	0	0	0	0	0	0
Camden							
<20 m	0	0	0	0	0	0	0
20-40 m	7 (9)	24 (31)	24 (31)	7 (9)	15 (19)	22 (29)	77
40-200 m	2 (12)	1 (6)	5 (29)	2 (12)	7 (41)	9 (53)	17
>200 m	0	0	0	0	0	0	0
All Areas							
<20 m	4 (2)	137 (57)	93 (39)	2 (1)	4 (2)	6 (3)	240
20-40 m	10 (5)	77 (41)	65 (35)	10 (5)	26 (14)	36 (19)	188
40-200 m	42 (9)	68 (15)	131 (29)	37 (8)	172 (38)	209 (46)	450
>200 m	1 (3)	2 (7)	15 (50)	2 (7)	10 (33)	12 (40)	30

There was also a significant seasonal difference in the proportions of mothers vs. others photographed during late summer and early autumn ($\chi^2 = 10.20$, df = 3, $P = 0.017$). Mothers formed 1.4%, 6.6%, 5.6%, and 17.4%, respectively, of the whales photographed in the four half-month periods from late August to early October. However, the number of whales measured in October was small (4 mothers and 15 others).

The significant increase in the sizes (status) of whales as the season progressed was attributable to two factors: a tendency for the whales in shelf-break waters (40–200 m deep) to be larger late in the season, and a tendency for the whales to be farther offshore (where larger whales predominated) late in the season (Table 10.4, Fig. 10.8). In water 40–200 m deep, the proportions of whales of different status differed significantly between early and late September ($\chi^2 = 25.03$, df = 4, $P = 0.000050$). At those depths, the proportion of adults

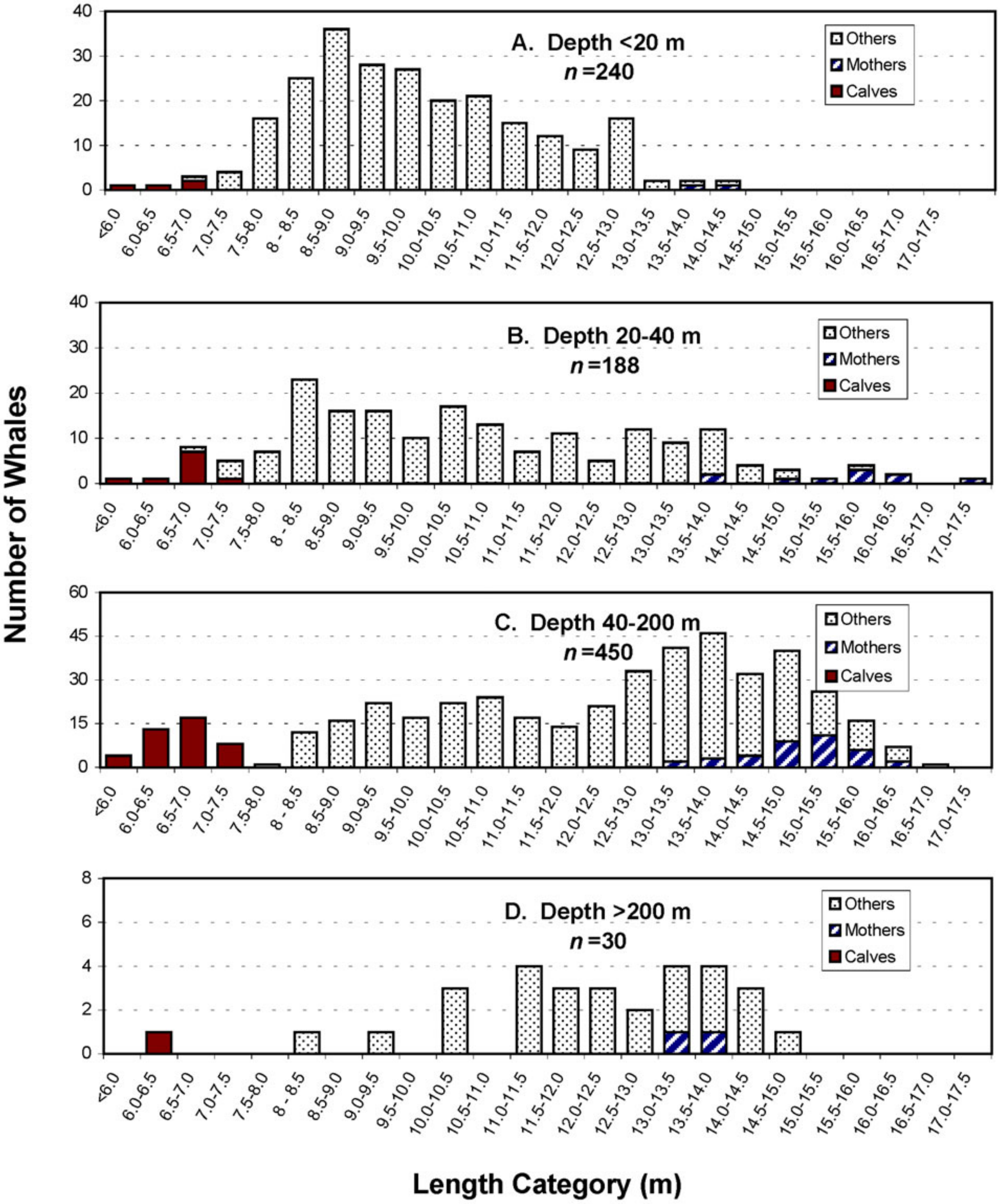

FIGURE 10.5. Length–frequency distributions of bowhead whales photographed in various depths of water, 1982–2000. Within-day and between-day repeats are excluded.

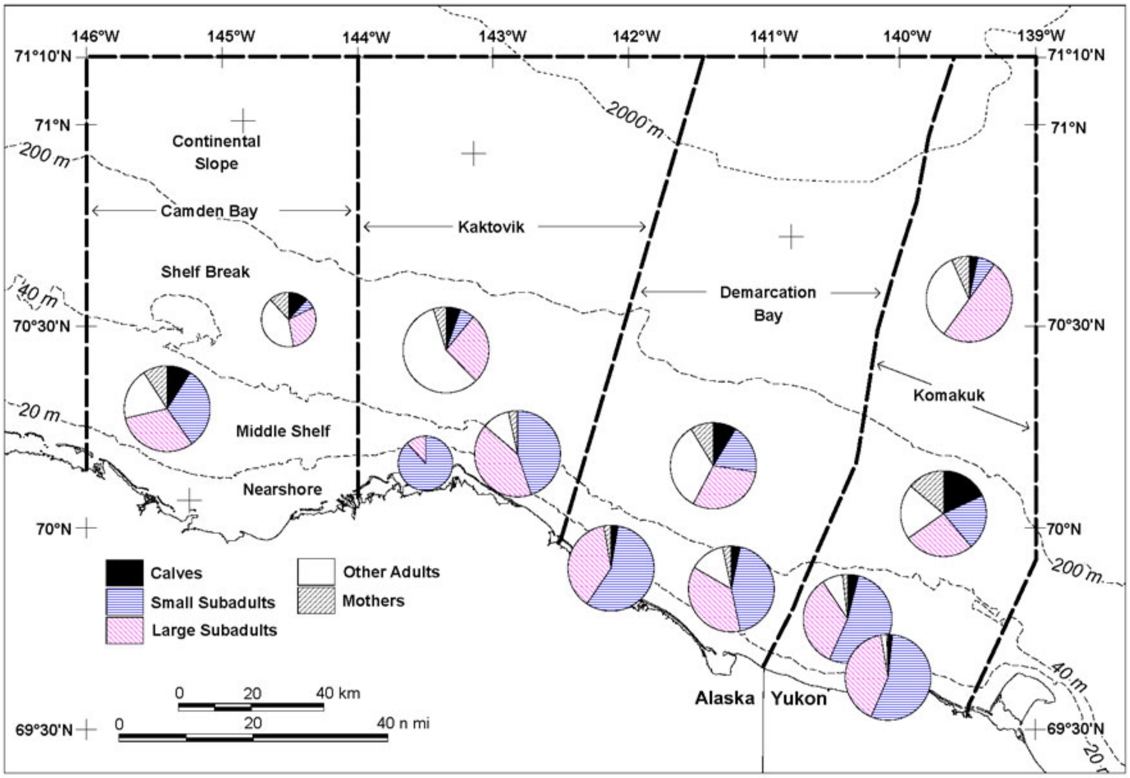

FIGURE 10.6. Proportions of whales of various size classes by water depth category and geographic subdivision in the eastern Alaskan Beaufort Sea, 1982–86 and 1998–2000. Large pie-charts have >25 different measured whales; small charts have 15–25 whales. No charts are shown for areas with <15 whales.

increased progressively from late August to late September. In contrast, in water depths <20 m, the proportions of whales of different sizes did not differ significantly with date over the late August–late September period ($\chi^2 = 4.60$, df = 6, $P = 0.80$). Similarly, in water 20–40 m deep, the proportions were not much different between early and late September ($\chi^2 = 6.54$, df = 4, $P = 0.162$). The seasonal trend in shelf-break waters, combined with a seasonal increase in the proportion of the bowheads photographed in those waters, were the main components of the overall seasonal increase in the sizes of the whales.

Discussion

When Kaktovik residents traveling to and from Canada encounter bowheads near the Yukon coast in July and August, these animals tend to be small individuals (Chapter 2 and Annex B). Kaktovik residents also report that the sizes of the bowheads seen in the Kaktovik area tend to vary over the course of the late summer and autumn. Small whales tend to predominate early in the season, when whaling starts. Larger whales tend to occur later in the season. This, combined with the hunters' selectivity for small whales (Chapter 2), means that most whales harvested at Kaktovik are small to moderate in size. However, exceptions do occur, and there is overlap in the dates when small and large whales are present near Kaktovik.

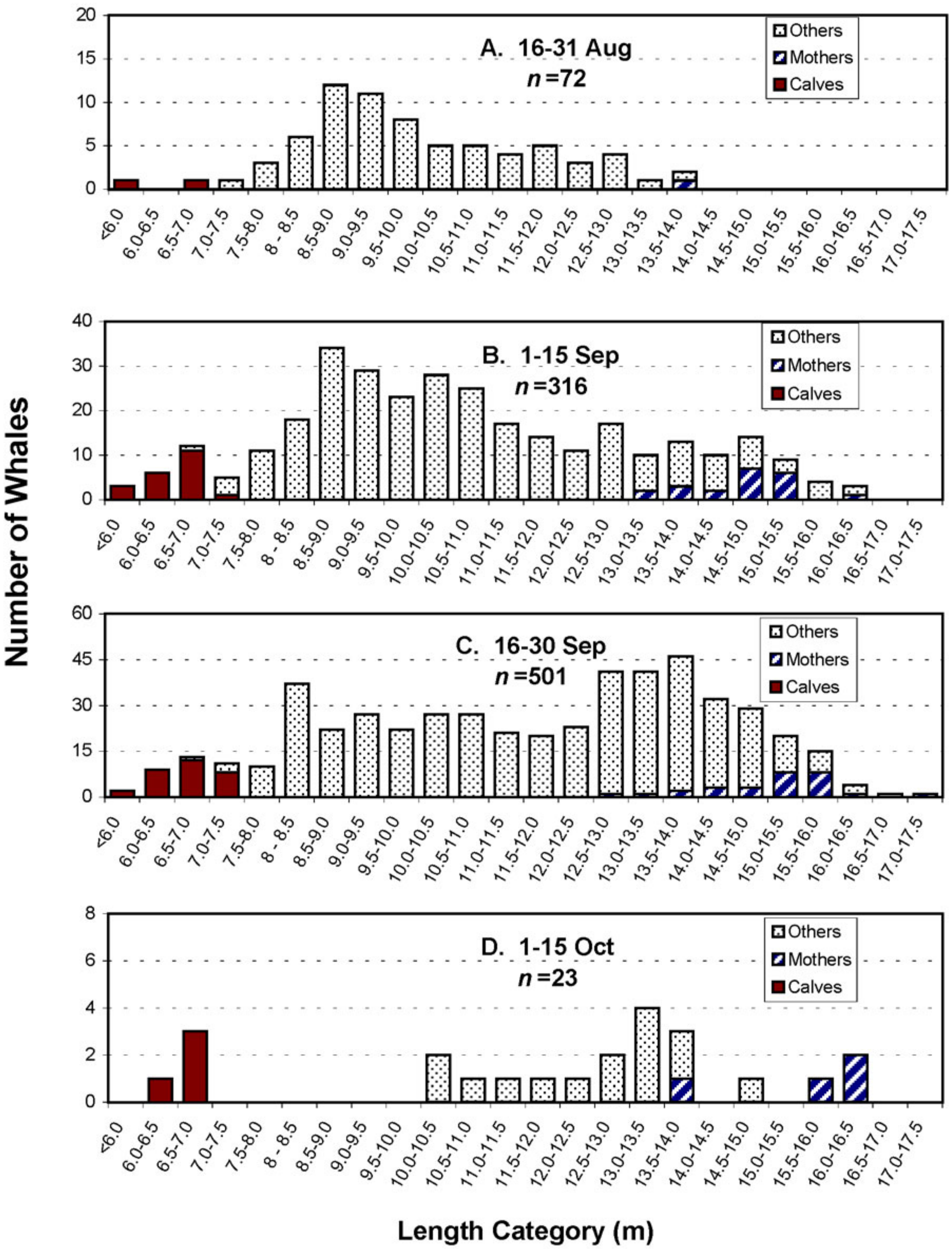

FIGURE 10.7. Length–frequency distributions of bowhead whales photographed during half-month periods, 1982–2000. Within-day and between-day repeats are excluded.

TABLE 10.4. Numbers and percentages (in parentheses) of whales of various size classes by water depth category during each half-month period in the eastern Alaskan Beaufort Sea, 1982–2000. Whales photographed more than once in a given water depth during each time period in a given year are counted only once.

Date Interval Water Depth Category	Calves	Small Subadults (<10 m)	Large Subadults (10-13 m)	Adults (>13 m)			Overall Total
				Mothers	Others	Total	
16-31 August							
<20 m	1 (2)	28 (62)	14 (31)	1 (2)	1 (2)	2 (4)	45
20-40 m	0 (0)	5 (56)	4 (44)	0 (0)	0 (0)	0 (0)	9
40-200 m	1 (6)	7 (41)	8 (47)	0 (0)	1 (6)	1 (6)	17
>200 m	0 (0)	1 (100)	0 (0)	0 (0)	0 (0)	0 (0)	1
1-15 September							
<20 m	1 (1)	63 (58)	43 (39)	1 (1)	1 (1)	2 (2)	109
20-40 m	1 (2)	24 (48)	21 (42)	0 (0)	4 (8)	4 (8)	50
40-200 m	18 (12)	33 (22)	46 (30)	18 (12)	37 (24)	55 (36)	152
>200 m	1 (14)	1 (14)	3 (43)	2 (29)	0 (0)	2 (29)	7
16-30 September							
<20 m	2 (2)	46 (53)	37 (43)	0 (0)	2 (2)	2 (2)	87
20-40 m	5 (4)	48 (41)	37 (32)	6 (5)	20 (17)	26 (22)	116
40-200 m	24 (9)	28 (10)	72 (26)	22 (8)	129 (47)	151 (55)	275
>200 m	0 (0)	0 (0)	12 (55)	0 (0)	10 (45)	10 (45)	22
1-15 October							
<20 m	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
20-40 m	4 (31)	0 (0)	3 (23)	4 (31)	2 (15)	6 (46)	13
40-200 m	0 (0)	0 (0)	5 (50)	0 (0)	5 (50)	5 (50)	10
>200 m	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0

Moore and DeMaster (1998), Moore (2000) and Moore et al. (2000) examined the overall habitat use of bowheads, gray whales (*Eschrichtius robustus*) and white whales (*Delphinapterus leucas*) during late summer and early autumn in the Alaskan Beaufort Sea and Chukchi seas. Their analyses were based on the systematic aerial surveys conducted by or for MMS in 1982–91 (Moore et al. 1989; Treacy 1992). Moore and DeMaster (1998) found that bowheads selected offshore waters (mean water depth 900 m) during July and August, and nearshore and shelfbreak waters (mean water depth 109 m) during September and October. Further analyses by Moore (2000) and Moore et al. (2000) found that bowheads selected nearshore waters during light and moderate ice conditions and slope waters during heavy ice conditions.

Chapter 9 examines bowhead habitat use in a smaller area—our study area vs. the entire Alaskan Beaufort and Chukchi seas—but over a longer time period (1979–2000 vs. 1982–91). Besides using data from 11 additional years of MMS surveys, Chapter 9 also uses survey data from this study and some industry-funded studies not used by Moore (2000) and Moore et al. (2000). Averaged over August–October, highest densities of whales were recorded in the shelf break area (depths 40–200 m) and lowest densities were recorded over the continental slope (>200 m). However, in August the highest densities were over the continental slope. Chapter 9 also documents that the highest densities of bowheads were recorded during the second half of September and, when averaged over the season, in the Komakuk zone. Average densities of whales gradually declined from east (Komakuk zone) to west (Camden Bay zone).

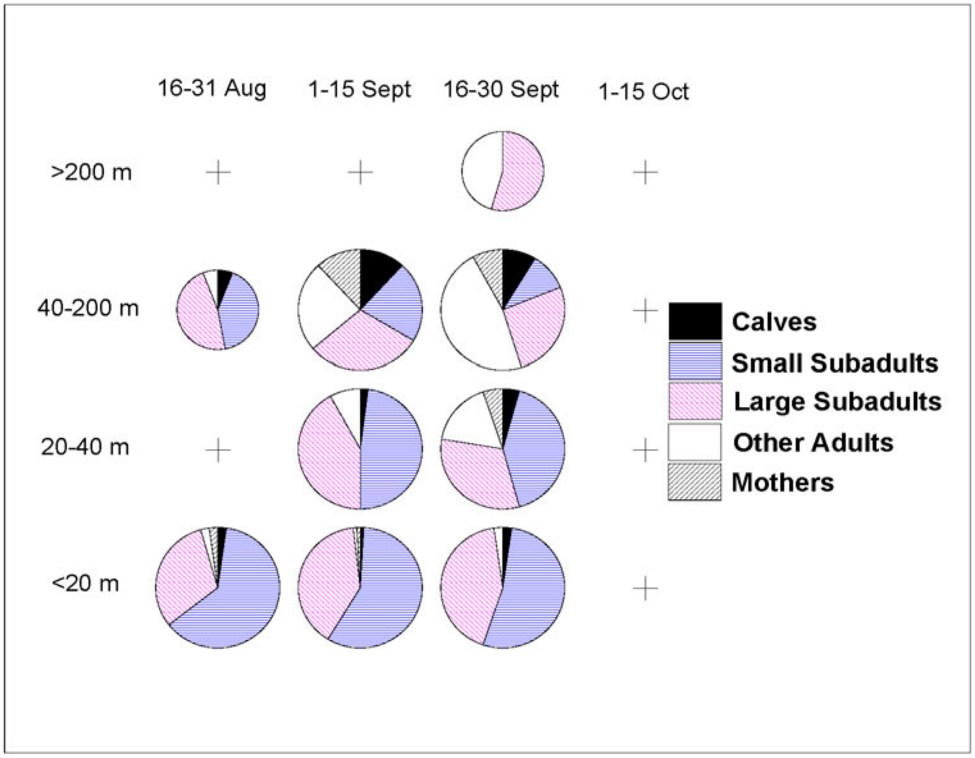

FIGURE 10.8. Proportions of whales of various size classes by water depth category during each half-month period in the eastern Alaskan Beaufort Sea, 1982–86 and 1998–2000. Large pie-charts have >25 different measured whales; small charts have 15–25 whales. No charts are shown for situations with <15 whales.

However, the above studies did not have information on the sizes of whales seen during their surveys. The apparent seasonal change in habitat use may have resulted, in part, from differences in the movement patterns of different components of the population. Additional insight into bowhead whale use of the Alaskan Beaufort Sea can be obtained by integrating our findings on age and seasonal segregation with those of Moore (2000), Moore et al. (2000), and Chapter 9 on overall seasonal distribution.

Most of the BCB bowhead whale population is believed to migrate west through the eastern Alaskan Beaufort Sea during its migration from summering areas in the Canadian Beaufort Sea and Amundsen Gulf to overwintering areas in the Bering Sea (Moore and Reeves 1993). Bowheads feed within the present study area during this migration, but the amount of feeding varies from year to year (Chapter 12). Our data indicate that, in all years, subadult bowheads move primarily through shallow nearshore waters and adults move primarily through deeper waters during late summer and autumn. This size segregation has also been noted by subsistence whalers at Kaktovik (Chapter 2). The apparent preference for shallow nearshore waters during years with light and moderate ice conditions may reflect the prolonged use of these nearshore waters by subadult whales for feeding rather than a shift in distribution from offshore to nearshore waters. No ice was present in our study area during the study periods in 1986 and 1998–2000, but even in those years most adult whales moved west through deeper waters (i.e., they were not photographed in shallow waters where primarily subadults were photographed).

There was a significant difference between the length–frequency distribution of the whales found in our study area in late summer and fall as compared with that for bowheads migrating into the Beaufort Sea in spring (*cf.* Angliss et al. 1995). Our sample is biased because our photographic surveys did not include all of the late summer–early autumn migration period. Although residents of Kaktovik have noted that in some years bowheads are seen near Kaktovik as early as July and as late as late October (Chapter 2), most bowheads pass Kaktovik from late August to mid-October. We acquired some data on dates ranging from 16 August to 3 October. However, during the primary years of this study (1985–2000), the average dates when our photographic work began and ended were 8 and 27 September (Table 10.1). Data on the timing of the bowhead migration in our study area indicate that, in an average year, 20% of the migration has entered our study area during the period from 26 August through 7 September, and 29% of the migration enters the study area after 27 September. Fourteen percent of our photographs were obtained before 8 September and 10% were obtained after 27 September (Table 10.5A). If we correct our photographic sample to account for the under-sampling during the early and late periods, the percent subadults declines to 61.3% from 64.7% and the percent adults increases to 32.6% from 29.2% (Table 10.5B). Thus, the corrected percentage that were adults (32.6%) is still much lower than the 41.1% adults in the spring data of Angliss et al. (1995).

A major factor affecting the distribution of bowheads during late summer and early autumn is food (Bradstreet and Fissel 1987; Bradstreet et al. 1987; Chapter 6). Bowheads concentrate and linger in areas where food is abundant (Moore et al. 1995; Chapters 6 and 11). Feeding was the most frequently observed activity of bowheads in the eastern Alaskan Beaufort Sea during September of most years (Chapter 12), and at least 75% of the bowheads harvested there have food in their stomachs (Chapter 18). Thus, the overall higher proportion of subadults among the measured whales suggests that the eastern Alaskan Beaufort Sea was more important as a feeding area for subadult bowheads than adults during the years of our study. However, the deeper waters of the eastern Alaskan Beaufort Sea are important as an autumn migration corridor for adult whales in all years, and are important feeding areas in some years. For example, in 1999 adult bowheads spent an estimated 66% of their time in the study area feeding in waters >20 m deep (Chapter 12). Stomach-content data from bowheads harvested at Kaktovik show that most adults as well as most subadults had been feeding in the area (Chapter 18).

There was substantial year-to-year variation in the proportions of adult, large subadult, and small subadult bowheads in the eastern Alaska Beaufort Sea. This indicates that different segments of the population lingered in the area for different periods in different years. In some years, most notably 2000, few bowheads of any size category were photographed despite considerable effort to obtain photographs. This and other evidence indicates that no segment of the population lingered in the study area in September 2000 (Chapter 11).

There was considerable among-year variation in the geographic locations where bowheads were seen and photographed. This was probably related to the local abundance of bowhead prey and the differing locations of water mass boundaries that affect zooplankton (Chapters 5, 6). Similar among-year variation in bowhead distribution has been documented in summering areas in the Canadian Beaufort Sea (Richardson et al. 1987; Moore and Reeves 1993).

Systematic aerial surveys suggest that bowheads have made greater use of the present study area in the 1990s than in the 1980s (Chapter 9). Whether there has been a corresponding change in utilization of different parts of the study area by different categories of bowhead whales is uncertain, given the few years with intensive photographic work and the large among-year variation within each decade. However, in the mid-1980s, subadult bowheads frequently concentrated in shallow nearshore waters somewhere in the eastern part of our study area from the Kongakut River Delta to Herschel Island, and lingered in those areas for periods of days to a few weeks (Chapter 11). High concentrations of zooplankton, especially the small copepod *Limnocalanus*, were often found in nearshore waters during those years (Chapter 5, 6). In contrast, few bowheads were recorded there in 1998–2000 and those that were recorded there did not appear to linger (Chapter 11). *Limnocalanus* was absent or scarce in nearshore waters of the study area in 1998–2000 (Chapters 5, 6).

TABLE 10.5. Numbers and percentages of whales of various size classes ***(A)*** photographed during three time periods during this study, and ***(B)*** corrected for seasonal bias in sampling effort based on aerial survey data from Chapter 9 (Appendix 9.1). In (B), italicized values are numbers expected if effort early and late in the season had been comparable to that in the 8–27 Sept. period.

		Small	Large	Adults			All	Percentage
	Calves	Subadults	Subadults	Mothers	Others	Total	Whales	of Whales
A: Photographed								
Before 8 Sept.	4	67	46	4	2	6	123	13.6
8-27 Sept.	46	211	227	41	167	208	692	76.7
After 27 Sept.	6	5	27	6	43	49	87	9.6
Total	56	283	300	51	212	263	902 [a]	
% of whales	6.2	31.4	33.3	5.7	23.5	29.2	100.0	
B: Corrected for Sampling Effort								
Before 8 Sept.	*9*	*148*	*101*	*9*	*4*	*13*	*271*	20.0
8-27 Sept.	46	211	227	41	167	208	692	51.0
After 27 Sept.	*27*	*23*	*122*	*27*	*194*	*222*	*393*	29.0
Total	82	381	451	77	366	443	1357	
% of whales	6.0	28.1	33.2	5.7	27.0	32.6	100.0	

[a] One whale was photographed during both the "8-27 Sept." and "after 27 Sept." periods.

Large numbers of subadult bowheads have been recorded in shallow nearshore waters along the Yukon Coast and off the Tuktoyaktuk Peninsula during summer and early autumn in some years (Davis et al. 1986b; Moore and Reeves 1993:332). Subadults are probably attracted to these areas by abundant food resources (Bradstreet and Fissel 1987; Bradstreet et al. 1987; Chapter 6). Subadult bowheads may concentrate in shallow nearshore areas because they are not physiologically well adapted to feeding in deep offshore waters. Their dive durations tend to be shorter than those of adult whales (Richardson et al. 1995; Chapters 13, 14). In deep water, subadults may not be able to spend enough time at depths where food organisms are abundant to feed efficiently. The shorter baleen of subadults, and consequent effects on feeding efficiency, may be a factor as well.

There was segregation among age classes in the timing of migration into and through the study area. Small subadult whales arrived in the study area, especially the nearshore zone, in late August and early September (Table 10.4). They were still present during late September, but were scarce or perhaps absent from the study area by early October. Large subadults and mothers with calves became common in early September, and other adults arrived mainly in late September and early October. The tendency for progressively larger whales to move through the area progressively later in the autumn season is similar to the pattern of the spring migration (Zeh et al. 1993; Angliss et al. 1995). However, the pattern for mothers and calves is different in spring and autumn. During spring, mothers and calves are the last segment of the population to pass Barrow (Angliss et al. 1995; Koski et al. MS). In contrast, during late summer and autumn, mothers and calves started to arrive in the eastern Alaskan Beaufort Sea rather early in the migration period (early September), when subadult whales were the predominant animals present. Mothers and calves were also among the last whales present in the study area during October.

Although mothers and calves tended to avoid shallow nearshore areas, they were more evenly dispersed in the remainder of the study area than were other age groups. Proportions of mothers and calves were generally similar among the four geographic blocks and water depths >20 m although the proportions of subadults and adults varied markedly among those same areas.

Summary

This chapter examines year, location, water depth, and date effects on the size and status of bowhead whales occurring in and near the eastern Alaskan Beaufort Sea (depths ≤200 m) during late summer and early autumn. It assesses the population structure of bowhead whales found in this area and evaluates whether there was habitat or seasonal segregation by whales of different sizes (ages) and status (subadult and adult), including mothers and calves. This information is relevant in evaluating the importance of the study area to the different components of the bowhead whale population, and is a factor in subsequent energetic calculations.

We used the calibrated vertical photography technique developed by LGL to obtain vertical photographs of 901 different whales during mid-August to early October of 1982–86 and 1998–2000 in the area between Flaxman and Herschel islands (longitudes 146° to 139°W). Whale images were measured directly from the film and the measured image sizes were converted to whale lengths by accounting for systematic biases introduced by the cameras and the radar altimeter.

Subadults, adults and calves made up 64.7, 29.2 and 6.2%, respectively, of the bowheads photographed in the "Flaxman Isl.-to-Herschel-Isl." area over all years of this study. We found proportionally more subadults and fewer adults within that area than are estimated to be in the overall population. Some, but not all, of this difference was a result of the fact that most of our effort was in the peak whale migration period, with little effort during the initial 20% and final 29% of the bowhead migration through our study area. The presence of a relatively high proportion of subadults in our length–frequency distribution even after allowance for the seasonal bias in sampling suggests that the parts of the eastern Alaskan Beaufort Sea ≤200 m deep are relatively more important for subadult bowheads than for adults.

There was significant variation in length–frequency distributions of whales among years, geographic subdivisions of the study area, water depth categories, and time periods. This variation was due to variable use of the study area by each age class in different years, differences in the water depths preferred by different age classes, and different migration timing by each age class. Small subadult whales (<10 m long) are the dominant group in shallow (<20 m) nearshore habitats, with progressively fewer small subadult whales and more adults as water depth increases. Small subadults start to arrive in the study area during late August, numbers peak in early September, and they have passed through the study area by early October. Large subadults start to arrive in late August but are scarce until September; moderate numbers are still present in early October. Mothers and calves start to arrive in early September and are common in the study area until early October. Other adults arrive mainly in late September and are common in early October.

In the mid-1980s, large numbers of subadult bowheads tended to occur in shallow nearshore areas in the eastern part of the study area from the Kongakut River Delta to Herschel Island, and they lingered in that area for days to a few weeks. Few whales were seen in that nearshore area during 1998–2000, and those that were seen there did not appear to linger.

Acknowledgements

We thank the numerous LGL personnel, aircraft charter companies, and pilots who assisted in collecting the photogrammetry data over the years. The U.S. Minerals Management Service, Alaska OCS Region, sponsored the 1998–2000 work, the majority of the 1985–86 work, and this analysis. Other studies in the 1980s, as listed in Table 10.1, were sponsored by Shell Western Exploration & Production

Inc., the U.S. National Marine Mammal Laboratory (Seattle, WA), the Canadian Department of Indian Affairs & Northern Development, and a consortium organized by Sohio Alaska Petroleum Co. (now BP). Projects in Alaska were conducted under the provisions of Scientific Research Permits 517, 518 and 481–1464 issued by the National Marine Fisheries Service. Many other Acknowledgements relevant to the project as a whole are included in Chapter 1.

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11. RATES OF MOVEMENT AND RESIDENCE TIMES OF BOWHEAD WHALES IN THE BEAUFORT SEA AND AMUNDSEN GULF DURING SUMMER AND AUTUMN

William R. Koski, Tannis A. Thomas, Gary W. Miller,
Robert E. Elliott, Rolph A. Davis, and W. John Richardson [1]

Introduction

Bowhead whales travel long distances between wintering areas in the Bering Sea and summering areas in the Beaufort Sea and Amundsen Gulf (Braham et al. 1984; Moore and Reeves 1993). Baleen whales are generally understood to undertake annual migrations to take advantage of abundant food resources on the summering grounds. In the case of the bowhead whale, behavioral observations and stomach contents of harvested animals suggest that considerable feeding occurs in the eastern and central Beaufort Sea during summer and early autumn of at least some years (Würsig et al. 1985, 1989; Lowry 1993; Chapters 12, 18). Measurements taken from bowheads harvested and photographed during April–May and September–October indicate that they gain weight during June–September and lose weight during October–April, suggesting that summer feeding areas are important to bowheads (J.C. George, NSB-DWM, pers. comm.; Chapter 22). However, isotopic evidence suggests that bowheads obtain a major part of their annual food requirements outside the Beaufort Sea (Schell and Saupe 1993; Chapter 20). Regardless of the relative importance of different feeding areas, during summer and early autumn bowheads are expected to spend more time in areas where food resources are more abundant. Therefore, one method of assessing the relative importance to bowheads of different areas within the summering range is to compare the amount of time that individual bowheads spend in different parts of the summer range (residence times).

The eastern Alaskan Beaufort Sea borders on important summer feeding areas offshore of the Mackenzie Delta and Yukon coast (Bradstreet et al. 1987; Chapter 6). However, significant numbers of bowhead whales normally are not encountered over the continental shelf in Alaska until the onset of the main fall migration period, which begins in late August or early September (Moore and Reeves 1993; Chapter 9). Nevertheless, the Alaskan Beaufort Sea from Kaktovik to Demarcation Bay has been identified as a potentially important feeding area of bowhead whales, primarily during September. This is based on stomach contents of bowheads harvested at Kaktovik (Lowry and Frost 1984; Lowry 1993; Chapter 18) and frequent sightings of feeding bowheads (Ljungblad et al. 1986; Richardson 1987; Chapter 12).

To determine the importance of the eastern Alaskan Beaufort Sea to the annual energetic requirements of bowhead whales, we need to know (1) how long whales remain in that area, (2) what proportion of that time is spent feeding, and ultimately (3) how much food they consume while there. In this chapter we estimate residence times in the eastern Alaskan Beaufort Sea and adjacent Canadian waters, and compare them to residence times at locations farther east in the Canadian Beaufort Sea and Amundsen Gulf. We also provide information on short-term rates of movement; those data contribute to our estimates of

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[1] LGL Ltd., environmental research associates, 22 Fisher St., POB 280, King City, Ont. L7B 1A6. *Phone:* 905-833-1244; *email*: bkoski@lgl.com

residence times, and are used in later chapters to help estimate how much food bowheads may consume while in the study area. [Rates of movement are important in determining how much water bowheads might filter in a given amount of time given data on the proportion of their time spend feeding (Chapter 12), and on prey availability (Chapters 5, 6).]

Our primary study area is the central Beaufort Sea from Flaxman Island and western Camden Bay to Herschel Island (146°W to 139°W; Fig. 11.1), hereafter referred to as the "eastern Alaskan" Beaufort Sea (although it includes some Canadian waters). This study area was the same as that used in Chapters 9 ("extensive" study area), 10, and 12-13. For comparative purposes, we also estimate residence times and rates of movement in two other areas farther east: "Yukon East", extending from Herschel Island to the Yukon/ Northwest Territories border; and Amundsen Gulf at the eastern end of the Beaufort Sea.

The estimates of residence times are based on data obtained via ***(1)*** aerial photography in all three areas during 1982–2000, ***(2)*** aerial observations of bowhead whale behavior in the "eastern Alaskan" (Flaxman-to-Herschel) area during 1985–2000, ***(3)*** aerial surveys in that area during 1979–2000, and ***(4)*** telemetry data collected by Wartzok et al. (1989, 1990) in 1988 and 1989, and Mate et al. (2000) in 1992. First, we present data on the intervals between medium-term (between-day) photographic resightings as an indication of minimum residence times. A second method examines the putative rates of movement for whales resighted over periods of hours based on within-day photographic or visual resightings. Low and high rates of movement would be indicative of, respectively, relatively stationary vs. mobile animals. Thirdly, we use indices of abundance from aerial surveys to estimate variability in residence times from year to year. Finally, we use position data obtained during telemetry studies to estimate the amount of time that tagged whales spent in our study area.

Many of the estimates of residence time that are presented are based on small sample sizes and/or are biased. Nevertheless, complementary results from different techniques, when taken together, provide useful information on minimum residence times for some individual whales, on year-to-year differences in the use of a specific part of the Beaufort Sea, and on relative use of different parts of the eastern Beaufort Sea and Amundsen Gulf during a given year.

Methods

The data for this study were obtained during a large number of studies of bowhead whale behavior and life history conducted in the Beaufort Sea and Amundsen Gulf in 1982–2000. Table 11.1 lists the photogrammetry studies and numbers of whale images that contributed to the analyses presented here. The "eastern Alaska" (i.e., Flaxman-to-Herschel) studies funded by U.S. Minerals Management Service and (in 1986) SWEPI, designated in boldface in Table 11.1, also included behavioral observations that provided data on speeds of movement. The circumstances of the behavioral studies, and their data collection procedures, are described in detail in Chapters 12 and 13. Figure 11.1 shows the geographic areas included. The geographic areas selected for analysis had intensive coverage and/or large numbers of bowheads photographed during at least one year in the 1982–2000 period.

Photogrammetry

We used the calibrated vertical photography technique developed by LGL and described by Koski et al. (1992). This method was used in all three parts of the Beaufort Sea. Briefly, the aircraft flew at an airspeed of ~160 km/h and (cloud ceiling permitting) an altitude of ~137 m (450 ft), and passed directly over bowheads. Photographs were taken through the aircraft's ventral camera port with one of two hand-held Pentax medium-format cameras (6×7 cm film size), each with a 105 mm *f*2.4 lens, pointed directly

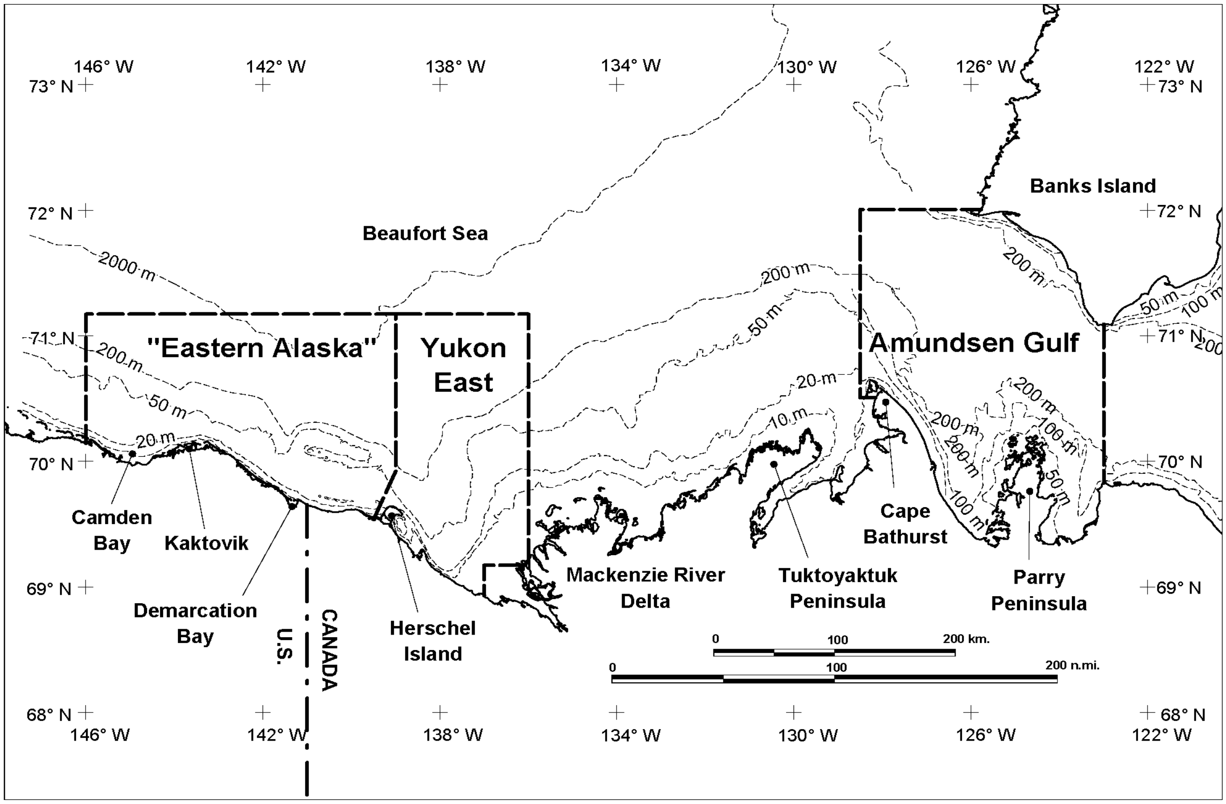

FIGURE 11.1. Areas where aerial photographs were obtained during 1982–2000 to estimate speeds of movement and residence times of bowhead whales. Table 11.1 shows years with coverage in each area.

downward. Shutter speed was 1/500th or, when possible, 1/1000th second. We used primarily Ektachrome 200 or 400 ISO (ASA) or Fujichrome 400 ISO color positive film, or occasionally (in 1985) Ilford XP1 black and white negative film pushed to ISO 1600.

All images with potential to be reidentified were printed and compared with one another to check for whales photographed more than once within each field season. These procedures are summarized by Rugh et al. (1992, 1998). To be considered for inter-year comparisons and analyses, "photo quality" has to be 2– or better and "identifiability" has to be M– or better for one of the zones on the whale (Rugh et al. 1998). (See Appendix 11.1 for inter-year re-identifications found to date among whales photographed in the study area during 1998–2000.) For the purposes of the within-year comparisons conducted here, whales with distinctive temporary markings but otherwise no permanent markings (i.e., identifiability = U) were upgraded to M–.

Whale images were measured directly from the film using a stereo microscope and stage micrometer as described by Koski et al. (1992) and in Chapter 10. The measured image sizes were converted to whale lengths by accounting for systematic biases introduced by the cameras (focal plane shutter distortion or inaccurate nominal lens length) and by inaccurate output from the radar altimeter. The resulting length measurements varied in reliability depending on the circumstances during photography, the position of the whale relative to the water surface, and the quality of the whale image. The "accurate" length measurements are generally accurate to within a few 10s of centimeters and the poorest quality measurements (excluding those from oblique photographs) are generally accurate to within ~1 m (Koski et al. 1992). All qualities of length measurements except those from oblique photographs were used to

TABLE 11.1. Sources of bowhead whale photographs for this study. Studies in bold typeface provided behavior data as well.

Year	Zone	Potentially Reidentifiable Whales	Span of Study (d)[a]	Days With Photos[b]	Source of Data/Sponsor
1982	Yukon East	354	25	9	Davis et al. (1983)/NMFS
1984	Amundsen Gulf	138	15 (21)[a]	3 (4)	Davis et al. (1986a)/DIAND
1984	Amundsen Gulf	16	1	1	NMML (unpubl. data)/NMFS
1984	Yukon East	492	29 (31)	12 (13)	Davis et al. (1986a)/DIAND
1984	Yukon East	43		3	Davis et al. (1986a)
1984	Yukon East	17	4	2	NMML (unpubl. data)/NMFS
1985	Amundsen Gulf	115	41	11	Davis et al. (1986b)/SOHIO
1985	Amundsen Gulf	2	1	1	Ford et al. (1987)/COGLA
1985	Yukon East	553	32	12 (14)	Davis et al. (1986b)/SOHIO
1985	Yukon East	39	7	3	Duval (1986)/COGLA
1985	Eastern Alaska	54	12 (33)	2 (10)	Davis et al. (1986b)/SOHIO
1985	Eastern Alaska	2	1	1	Johnson et al. (1986)/SWEPI
1985	**Eastern Alaska**	**121**	**19**	**8**	**Richardson (1987)**/MMS
1986	**Eastern Alaska**	**216**	**25 (31)**	**12 (19)**	**Richardson (1987)**/MMS
1986	**Eastern Alaska**	**51**	**29**	**9**	**Koski & Johnson (1987)**/SWEPI
1998	**Eastern Alaska**	**141**	**9**	**8**	**This study**/MMS
1999	**Eastern Alaska**	**397**	**21**	**11**	**This study**/MMS
2000	**Eastern Alaska**	**33**	**9**	**6**	**This study**/MMS
Total		2784			

[a] Parentheses indicate the span if all studies from that year for that area are considered.

[b] Parentheses indicate total days with photos in a given year considering all listed studies.

COGLA = Canadian Oil and Gas Lands Administration
DIAND = Canada Department of Indian Affairs and Northern Development
MMS = U.S. Minerals Management Service
NMFS = U.S. National Marine Fisheries Service
SOHIO = Standard Alaska Production Company (now BP Exploration, Alaska, Inc) and others
SWEPI = Shell Western Exploration & Production, Inc.

classify whale status. The categories were calf, subadult, adult, and mother. During late summer and early autumn, whales less than about 7 m long are generally calves less than 1 year old. Some calves may be as long as 7.5 m by September. Whales over 13 m long are considered to be mature adults (Nerini et al. 1984; Koski et al. 1992, 1993) although some females with calves are as small as 12.2–13 m, and some females longer than 13.5 m are not mature (Nerini et al. 1984; Koski et al. 1993). Animals <13 m long are here referred to as subadults unless they were calves or mothers accompanied by a calf.

Behavioral Observation Procedures

We used the aerial observation procedures of Würsig et al. (1985) and Richardson et al. (1985, 1995a) to observe the behavior of undisturbed bowheads in the "eastern Alaska" area. Throughout each observation session, two or three full-time observers on the right side of the aircraft dictated standardized behavioral observations and whale position data via the intercom into a single audio recorder and also into the audio channel of a video recorder. A third or fourth part-time observer on the right side operated a video camera whenever whales were at the surface. During each surface/dive sequence by bowheads, observers described the same behavioral attributes as recorded in our previous studies of bowhead behavior (e.g., Würsig et al. 1984, 1985, 1989; Dorsey et al. 1989; Richardson et al. 1995a). Aircraft altitude was almost always ≥460 m, which is high enough to avoid significant aircraft disturbance (Richardson et al. 1985, 1995c; Patenaude et al. 2002). Airspeed during circling was about 160–185 km/h (86–100 kt).

Computing Rates of Movement

BOS.—During behavioral observation sessions (BOSs) in 1985–86, dye markers were dropped from the plane and used as reference points for visual estimates of successive whale positions and, hence, the distances that whales moved between surfacings.

During observation sessions in 1998–2000, a portable computer with data logging software (WINGPS), plugged into the aircraft's Global Positioning System (GPS), automatically recorded time and aircraft position (latitude and longitude) at 1-s intervals. Using the output from this system, we estimated the positions of whales during the behavioral observation sessions. We used the aircraft's successive GPS positions to estimate the location about which the aircraft was circling, which was usually close to the whale position. These times and positions could then be used to estimate the rates of movement of whales that were resighted within and between observation sessions.

Photoidentification.—Many bowheads, particularly the larger and older ones, have distinctive scars or other markings, such as sloughing skin, that make them individually identifiable in vertical photographs (Rugh et al. 1992, 1998). Photographs taken more than 15 min apart were used to document the short-term movements of recognizable individual whales of measured sizes. The time and position were recorded at the exact time when each photograph was taken, and were used to estimate the rate of movement between photographs. When multiple photographs were obtained for an individual whale on a given date, only the first and last photographs were used. Aircraft positions were obtained via Very Low Frequency (VLF) navigation systems in 1985–86 and GPS in 1998–2000. Although the absolute accuracy of the VLF systems was often no better than ~1 km, relative positions over short intervals were usually determined within a few hundred meters.

Estimating Residence Times

We used data from several different sources to estimate residence times of whales and then compared the results. The data sources included resighting intervals, within-day rates of movement obtained from photogrammetry, speeds estimated during behavioral observation sessions, aerial survey data, and telemetry data. For the "eastern Alaska" zone, ten different estimates of residence time were obtained using combinations of data from the various sources. For the "Yukon East" and Amundsen Gulf zones, three estimates based on photogrammetry were obtained.

Some of our estimates of residence times in the "eastern Alaska" zone distinguish between bowheads that were migrating (= traveling) vs. feeding vs. lingering. Lingering included socializing, resting, and other activities. Some of our estimates of residence times in the "eastern Alaska" zone involved use of the estimated "net westward speed". This is the vector component of speed measured parallel to the coast, which is oriented from ~108° True to 288° True in the "eastern Alaskan" zone. The net westward speed ignores the offshore–onshore (NNE–SSW) component of movement. Net westward speeds of traveling whales were assumed to be 3.67 km/h based on the mean speed of traveling whales as documented during BOSs in the "eastern Alaskan" Beaufort Sea during all years of this study (see Results and Appendix 11.7B). Net westward speeds of feeding whales were assumed to be –0.71 km/h (i.e., eastward at 0.71 km/h), and net westward speeds of lingering whales were assumed to be 0.55 km/h based on the same data source. Net westward speeds were not calculated for whales in the two Canadian zones.

The following subsections describe the ten estimates of residence time derived for the “eastern Alaska” zone. Of these, estimate #1 (resighting intervals), #3 (SODA, best-fit), and #4 (SODA, constant survival) were also calculated for the Yukon East and Amundsen Gulf zones.

1. Photogrammetry: Intervals Between Resightings.—The interval between the first and last sighting of an individually-identifiable whale in a given zone in one year provides a minimum estimate of its residence time there. We included only between-day resightings. This estimate is negatively biased for individual whales because it does not include an estimate of the time the whale was present before it was first photographed, or the time it was there after being photographed the last time. We attempted to account for this bias in the next three estimates, described below. Despite the negative bias in estimating residence times of individual whales, this method could overestimate average residence time for the population as a whole. Whales that move rapidly through the study area are less likely to be resighted than those that linger, and hence are less likely to contribute to the overall mean estimate of residence time.

2. Photogrammetry: Intervals Between Resightings + Travel.—Data from resightings as described above were used to estimate the time that bowheads lingered in the study area and the distance across the study area that they traveled while lingering. The minimum time taken to travel from the eastern boundary of the study area to the “lingering area”, and from there to the western boundary of the study area, were estimated by subtracting the net westward distance traveled while lingering from the width of the “eastern Alaska” study area (270 km) and assuming that whales traveled at a net westward speed of 3.67 km/h (migration speed). A net eastward movement would result in a negative net westward movement and an overall movement in the study area >270 km. The time lingering (interval between resightings) was added to the travel time to estimate the overall residence time in the zone.

3. Photogrammetry: Stop-over Duration, Best Fit.—The above two methods of estimating residence time do not make use of all available information from photographs taken each year. In particular, they do not consider failure to resight a whale when photographs are taken subsequent to the initial sighting. We used the SODA (Stop Over Duration Analysis) model in conjunction with MARK to obtain unbiased estimates of residence time in our study areas (Schaub et al. 2001). SODA is a computer model that estimates the period of residence before and after each encounter of an animal using information on recapture history and sampling effort. The two estimates of time in the study zone (before and after each capture) are added together to obtain an unbiased estimate of residence time. If photographic effort is distributed across the full width of the study zone, then this method provides a direct estimate of the average time in the zone, not just the residence time at a specific feeding location.

Stop-over durations (“time in zone”) were calculated using the procedure of Schaub et al. (2001) with modifications given in Reboulet et al. (2001). First, two types of capture–recapture data were entered into a matrix: the intervals between sampling events, and the intervals between resightings of whales. Then, MARK (White and Burnham 1999; Cooch and White 2001) was used to fit several survival and recruitment models to our data, producing a summary matrix that ranked several different models according to Akaike’s Information Criterion (AIC). The “best-fit” model was chosen based on the AIC. SODA, using the “best-fit” model, then produced estimates of average time in the study zone before and after each encounter. These estimates were added together to estimate residence time in the zone. The variance of the residence time estimate was computed using SODA, which uses a boot-strapping procedure to resample the capture–recapture history.

4. Photogrammetry: Stop-over Duration, Constant Survival.—The procedure described above in #3 was repeated assuming constant survival and recruitment rather than using the "best-fit" model as determined by MARK. The "best-fit" model is recommended in situations where survival or recruitment may vary among sampling intervals. We ran the more "conventional" constant survival and recruitment model for comparison, but the assumptions of constant survival and recruitment are probably not valid for our study area.

5. Photogrammetry: Within-day Speeds.—Speeds from within-day photographic resightings >15 min apart were used to estimate the mean net westward speed of bowheads moving through our study area each year. The distance across the study area (270 km) was divided by the mean within-day net westward speed (km/h) in each year to estimate the mean residence time (in hours) for that year. The calculations of net speed for each pair of sightings/resightings assumed that whales migrated westward through the study area on a heading of 288° (Chapter 9), and that only the westward (positive) or eastward (negative) component of movements contributed to net movements. Unlike methods 1 and 2, which are based on whales that linger in the study area, this estimate of residence time is based on data for all age and sex classes. However, it is still biased because whales that moved slowly were more likely to be resighted than those that moved rapidly and because all age and sex classes do not appear to be photographed in proportion to their abundances in the population. This bias results from their different habitat preferences within the study area and from the concentration of our photographic effort during the peak of the bowhead migration season—see Chapter 10.

6. Behavior: Overall Speeds.—Whales observed during BOSs also provided data on speeds of movement within the study area. The distance across the study area was divided by the mean net westward overall speed from BOSs. This estimate suffers from the same biases as the #5 estimate, particularly the tendency to oversample feeding whales and to undersample rapidly-migrating whales that are difficult to follow. A further limitation of this method is that the number of different whales contributing to speed estimates is lower for the BOS data than for the within-day photogrammetry data.

7. Behavior: Activity Speeds.—Information on the activities of bowheads during each year of the study (see Chapter 12) and on the speeds of whales during those activities permitted another calculation of residence time. For each year, we calculated a weighted mean net westward speed based on observed speeds of traveling, feeding, and lingering whales, and on observed proportions of time engaged in those activities each year (see Table 11.5, later). The proportion of time traveling, as observed during BOSs within a given year (Chapter 12: Table 12.2), was multiplied by 3.67 km/h, the mean net westward speed of traveling whales in all years as determined from BOSs (Appendix 11.7B). The proportion of time feeding was multiplied by –0.71 km/h, the mean net westward (actually 0.71 km/h eastward) speed of feeding whales in all years as determined from BOSs. The proportion of time lingering (socializing, resting, unknown etc.) in a given year was multiplied by 0.55 km/h, the mean speed during these activities in all years (Appendix 11.7B). These three numbers were added to compute a mean speed through the study area for each year. This mean speed was divided into the distance across the study area to compute the average residence time each year.

8. Aerial Survey: Densities.—Density indices for bowhead whales in the "eastern Alaska" study area during each late summer and autumn season from 1979 to 2000 have been determined based on systematic aerial surveys (Chapter 9; Appendix 9.2). The observed densities for each year are assumed to vary according to the residence time of whales in the study area. It is assumed that, in the three years with the lowest observed densities (1985, 1988, and 1989, hereafter called the "base years"), whales moved across the 270-km-wide study area without stopping. At a net westward speed of 3.67 km/h, this would require 3.1 days. In other years, it is assumed that the mean residence time in that year was proportional to the densities estimated to have been present (Corr. No. Bhds Seen/100 km column in Appendix 9.2). For example, if the density in a given year was twice the mean density in the three base years, the mean residence time is estimated to be twice that of the base years or 6.2 days. The density data from years before 2000 in Appendix 9.2 have been increased by 3.2% per year to standardize densities for assumed annual increases in population size. This was necessary because the bowhead population increased at an estimated annual rate of 3.2% per year from the late 1970s until at least 1993 (Punt and Butterworth 1999). Preliminary bowhead census results from 2001 indicate that the population has continued to increase at about the same rate (George et al. 2002). Without this adjustment, a 3.2% annual increase in densities would result in a similar increase in apparent residence times even if residence times were constant across years.

9. Aerial Survey: Whale-Days.—An estimate of average residence time can be calculated by dividing the number of whale-days of use of our study area by the number of whales that passed through the study area during each season. Chapter 9 (Table 9.3) estimates the number of whale-days of use by bowhead whales considering the area between the coastline and the 200 m contour from the U.S./Canada border to Camden Bay during 1985–86 and 1998–2000.

Because our "Eastern Alaska" zone includes a larger area, extending from ~Herschel Island to Camden Bay, we multiplied the number of whale-days from Chapter 9 by 1.316 to allow for the increased width of our study vs. the "restricted" study area used in Chapter 9. The revised total number of whale-days was divided by the estimated population size in that year, adjusted downward to exclude the estimated proportion of the whales that migrate west through deep waters north of the study area. This proportion was estimated as 0.186 based on relative densities given in Moore and Reeves (1993:334) for 1979 to 1989. The population size was estimated to have been 8200 in 1993 and to have increased at an annual rate of 3.2% per year during 1979–93 (Punt and Butterworth 1999) and, by extrapolation, during 1993–2000.

10. Telemetry Data.—Telemetry data provide a more continuous record of bowhead locations, and hence use of an area, than photographs or aerial observations of behavior. Three studies have tracked bowheads through the "eastern Alaskan Beaufort Sea" (Wartzok et al. 1989, 1990; Mate et al. 2000). We estimated the time that each whale spent in our study area based on tracks for each whale shown in the published paper (Mate et al. 2000) or technical reports (Wartzok et al. 1989. 1990). Constant travel was assumed between the last sighting of each whale before they entered our "eastern Alaskan Beaufort Sea" study area and the first sighting in the study area, and between the last sighting in and the first sighting west of our study area.

Results

1. Photos: Intervals Between Resightings

The interval between first sighting and last resighting of an individual whale provides a minimum estimate of the residence time of that whale in the area. Table 11.2 summarizes these intervals for the whales resighted in the Amundsen Gulf, Yukon East, and "Eastern Alaska" (i.e., Flaxman-to-Herschel) zones during years with sufficient photographic effort such that at least a few resightings were expected. There was considerable variation in the mean interval between resightings both among years and between zones. This measure will underestimate residence time for whales that were resighted, as there is no allowance for time spent in the zone before the first and after the last sighting. However, these results take no account of whales that were sighted only once, and thus may overestimate the average residence time for all whales that enter the zone.

TABLE 11.2. Within-year resighting intervals of bowhead whales from photographs taken in different geographic areas in the Beaufort Sea and Amundsen Gulf, late summer to early autumn 1982-2000. Photographs were not taken on each day in each area; therefore resighting intervals do not have equal probability of being recorded even if individual whales remained in the survey area. Only the first and last sighting of each whale in each year is included.

Zone	Unique Whales	Span of	Number of Resightings at Interval 1-21 days																							
Year	Photographed	Study (d)[a]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Mean	s.d.	*n*
Amundsen Gulf																										
1984	154	21	-[b]	-	-	-	1	0	-	-	1	-	-	-	-	2	0	-	-	-	-	0	X	10.50	4.36	4
1985	117	41	4	1	4	3	1	1	0	-	-	0	0	0	0	0	0	0	0	0	1	0	0	4.00	4.42	15
All years																								5.37	5.08	19
Average of means for 1984 & 1985																								7.25		2
Yukon East																										
1982	354	25	1	9	0	1	0	1	0	0	-	-	0	1	0	-	0	0	1	1	1	0	0	5.94	6.55	16
1984	509	31	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.00	1.41	2
1985	592	32	6	0	3	0	0	0	4	2	0	0	0	3	0	0	1	0	0	0	1	1	0	7.10	5.99	21
All years																								6.36	6.10	39
Average of means for 1982-1985																								5.01		3
Mean of all resightings in Canadian waters																								6.03	5.76	57
Average of means for each Canadian area in each year																								5.91		5
"Eastern Alaska" [c]																										
1985	177	33	0	1	2	0	1	0	0	0	0	0	2	0	0	1	0	1	-	0	-	-	0	8.13	5.51	8
1986	267	31	4	3	0	1	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	4.18	4.45	11
1998	141	9	1	0	0	0	0	0	-	0	X[d]	X	X	X	X	X	X	X	X	X	X	X	X	1.00	-	1
1999	397	21	2	1	1	2	1	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	X	4.10	2.51	10
2000	33	9	0	0	0	0	0	0	0	0	X	X	X	X	X	X	X	X	X	X	X	X	X	-	-	0
All years																								5.10	4.46	30
Average of means for "Eastern Alaska" in each year																								4.35		4

[a] Span includes both the first and last days with photographs in the area. Maximum resighting interval is one day less than the span.

[b] "-" indicates that resighting intervals of this length could not have been obtained because of the sampling intervals.

[c] Includes Yukon west of Herschel Island (Fig. 11.1).

[d] "X" indicates that resighting intervals of this length would have been beyond the span of the study.

In the "Eastern Alaska" zone, yearly mean resighting intervals ranged from 1.00 days in 1998 (but based on only one resighting) to 8.13 ± s.d. 5.51 days in 1985 (*n* = 8) and averaged 4.35 days over the four years with photographic resightings (Table 11.2). The mean of all individual resighting intervals from all years was 5.10 ± 4.46 days (*n* = 30). The lack of resightings in 2000 was a strong indication of rapid movements through the study area because the effort to find whales to photograph in "Eastern Alaska" was greater in 2000 than in any earlier year. In 1998, the lack of additional resightings beyond the one reported was also indicative of rapid movements through the area. Some whales stopped briefly near Kaktovik in 1998; we consistently encountered whales feeding there, but they did not appear to linger there for more than hours before resuming their westward migration. We resighted only one whale photographed near Kaktovik in 1998, despite repeated photographic coverage of the area. The resighted whale traveled west at an average speed of 2.55 km/h over a 24.4 h period (Appendix 11.2).

In 1985, 1986 and 1999, unlike 1998 and 2000, whales seemed to be present in the same locations from day to day and were apparently feeding there. During those years, the mean intervals between resightings were 4.10 to 8.13 days and net speeds during those intervals were low (Appendix 11.2). In 1985, sightings and resightings were in shallow nearshore waters near Komakuk (Fig. 11.2). In 1986, sightings were generally slightly farther offshore and extended from 15 km east to 15 km west of Demarcation Bay. In 1999, all sightings and resightings were in shelf waters ~50–70 m deep from northeast of Demarcation Bay to northeast of Kaktovik (Fig. 11.2).

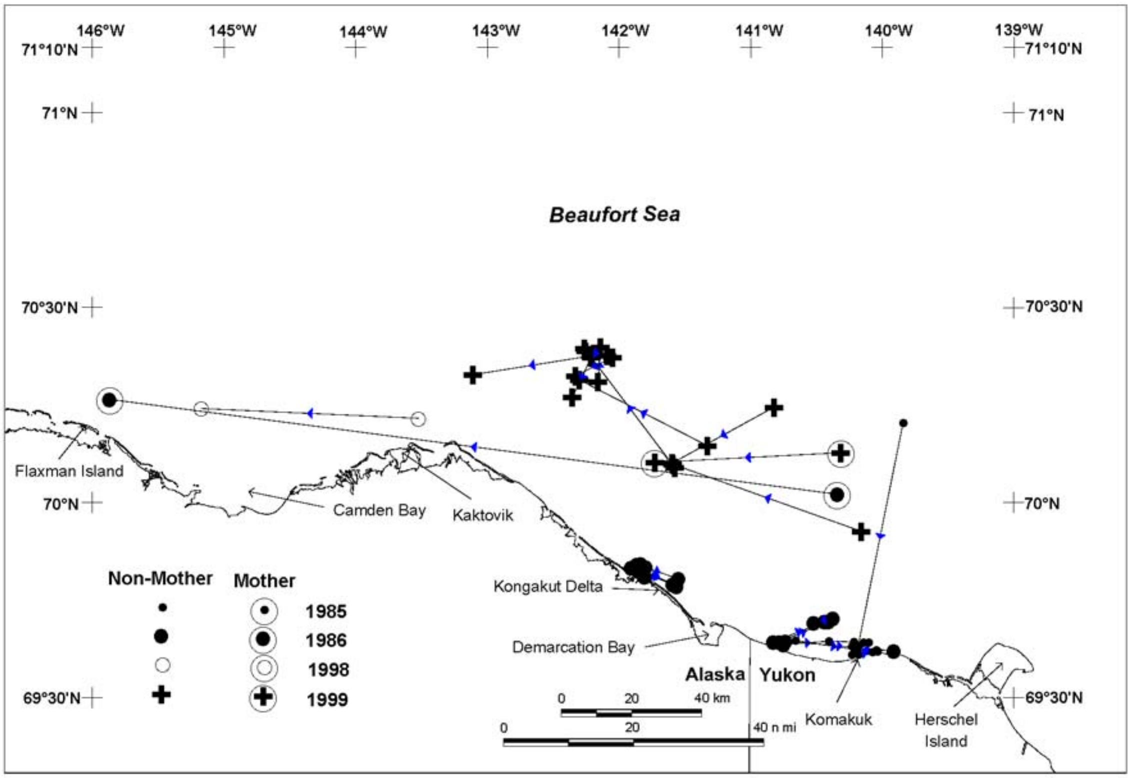

FIGURE 11.2. Locations of between-day resightings of bowhead whales in the "Eastern Alaska" area, based on aerial photographs obtained during 1985–86 and 1998–2000. Arrows indicate sequence of photographs. No resightings were obtained in 2000. Sightings of mothers and calves are indicated by circles around symbols.

The mean interval between resightings was longer in the two Canadian zones than in “Eastern Alaska” (6.03 vs. 5.10 d, *n* = 57 vs. 30). The resighting intervals varied among the Canadian and “Eastern Alaska” zones in the same years, and among years in each zone (Table 11.2). These mean values understate the differences between the Canadian and “Eastern Alaska” zones because only one resighting interval contributed to the mean value for “Eastern Alaska” during 1998 and none contributed during 2000; both 1998 and 2000 were years when residence times in “eastern Alaska” were short. The average of the yearly mean resighting intervals is a slightly better measure; it showed a slightly greater disparity between the two Canadian zones (5.91 d) as compared with the “Eastern Alaska” zone (4.35 d). However, even the latter measure does not allow for the lack of resightings and associated low residence time in Eastern Alaska in 2000. Thus, the mean value for “Eastern Alaska” is positively biased compared to values for Canadian waters.

In 1984, the mean interval between resightings was shorter in the Yukon East zone (2.00 d) than in the Amundsen zone (10.50 d), whereas in 1985 the opposite was true (7.10 d vs. 4.00 d). Resighting intervals in both Canadian zones varied considerably among years (Table 11.2). In 1984, there was frequent photographic coverage in the Yukon zone so the low resighting rate for that year indicates rapid movements out of the zone. Also, there were many chances for resightings >6 days in the Amundsen zone in 1985, but only one resighting was made at >6 days. This suggests that whales did not remain in the Amundsen zone for as long in 1985 as in 1984, when there was much less photographic coverage but three resightings at >6 days.

2. Photos: Intervals Between Resightings + Travel

Whales that were resighted in the “Eastern Alaska” zone traveled mean distances of 210–274 km, depending on year (Table 11.3), from the eastern edge of the zone to their first photographic sighting location and from their last photographic sighting location to the western edge of the zone. Assuming a net westward traveling speed of 3.67 km/h over those distances, they were in the “Eastern Alaska” zone for 2.38–3.12 d in addition to the time that they spent lingering between resightings (Table 11.3). Thus the estimated mean residence times for whales that were resighted in the zone, including an allowance for travel, were 11.24, 7.12, 3.38, 6.90 and 3.07 days for 1985, 1986, 1998, 1999 and 2000 (Table 11.3).

TABLE 11.3. Calculations of yearly mean residence time in "Eastern Alaska" from mean intervals between resightings + traveling time. Negative distances indicate movements eastward.

	Between Sightings		Before & After Sightings			
Year	Alongshore Distance (km)	**A**: Mean Interval (d) [a]	**B:** Assumed Speed (km/h)	**C:** Distance (km) [b]	**D:** Time (d) **C**/(24h/d x **B**)	Time in Study Area = **A** + **D**
1985	-4.38	8.13	3.67	274.38	3.12	11.24
1986	11.38	4.18	3.67	258.62	2.94	7.12
1998	59.98	1.00	3.67	210.02	2.38	3.38
1999	23.69	4.10	3.67	246.31	2.80	6.90
2000	---	---	3.67	270.00	3.07	3.07

[a] From Table 11.2.

[b] From width of "Eastern Alaska" zone (270 km) minus alongshore distance between sightings.

3. Photos: Stop-over Duration, Best Fit

For the "eastern Alaskan" Beaufort Sea, estimates of time in the study area based on the best-fit SODA models were similar to the mean resighting intervals (Table 11.4). In contrast, for the Amundsen Gulf and Yukon East zones, most SODA estimates were substantially higher than mean resighting intervals (but with wide uncertainties). The average of the four yearly estimates of residence time from SODA for the two Canadian zones is 12.58 days, which is more than twice as long as the corresponding estimate (5.91 d) from resighting intervals (Table 11.4).

In the "eastern Alaskan" Beaufort Sea, the estimated periods in the zone based on the "best-fit" SODA models were 5.3, 3.8 and 4.4 days in 1985, 1986 and 1999, respectively. The average of the three yearly estimates was 4.50 days. The corresponding mean resighting intervals were 8.1, 4.2 and 4.1 days and the average of the three yearly estimates was 4.35 days (Table 11.4). Thus, for two of three years with sufficient data for the SODA procedure, the estimated mean time in the zone was less than the mean resighting interval. This reflects the fact that the mean resighting intervals apply primarily to whales that lingered in the study area for long enough to be resighted, whereas the SODA procedure uses all photographs and photographic effort to estimate mean residence times that may be shorter than the intervals between resightings in the zone.

TABLE 11.4. Comparison of mean sighting interval and estimated time in the study area. Mean sighting interval is from Table 11.2. Time in the study area was computed from SODA (Schaub et al. 2001) using two models: ***(A)*** the best fit model for survival and recruitment based on AIC, and ***(B)*** the model assuming constant survival and recruitment. Note that resighting intervals and time in the study area are estimates of somewhat different parameters (see text).

Zone	Resighting Interval (d)			Stop-over Duration			
				(A) Best Fit		***(B)*** Constant Survival	
Year	Mean	s.d.	*n*	Mean	s.d.	Mean	s.d.
Amundsen Gulf							
1984	10.5	4.36	4	-[a]	-	-	-
1985	4.0	4.42	15	7.2	9.09	16.0	7.73
Average of means	7.25		2	7.2		16.0	
Yukon East							
1982	5.9	6.55	16	23.1	19.00	20.0	11.67
1984	2.0	1.41	2	3.4	5.11	4.1	2.59
1985	7.1	5.99	21	16.6	56.98	27.9	6.00
Average of means	5.01		3	14.37		17.33	
Average of means for all Canadian areas in each year	5.91		5	12.58		17.00	
"Eastern Alaska"							
1985	8.1	5.51	8	5.3	4.90	19.5	6.43
1986	4.2	4.45	11	3.8	3.73	9.0	3.42
1998	1.0	-	1	-	-	-	-
1999	4.1	2.51	10	4.4	2.61	13.4	4.30
2000	-	-		-	-	-	-
Average of means	4.35		4	4.50		13.97	

[a] '-' indicates that the model could not generate reliable estimates due to too few recaptures or resampling events.

4. Photos: Stop-over Duration, Constant Survival

We also computed the mean (± s.d.) time in the zone assuming constant survival, recruitment, and catchability, for comparison with the best-fit models (Table. 11.4). In most cases, the constant survival, recruitment, and catchability model produced estimates of residence times that were considerably higher than either the estimates derived from the best-fit models or the mean intervals between resightings (Table 11.4). However, the assumptions of constant survival, recruitment, and catchability were probably violated during our photographic surveys.

5. Photos: Within-day Speeds

The distances and times between same-day photographic resightings were determined for 52 bowheads in the Amundsen Gulf zone, 125 bowheads in the Yukon East zone, and 136 bowheads in the "Eastern Alaska" zone (Appendix 11.4A, 11.5). As expected, the distances between sightings tended to increase as the time between sightings increased (Fig. 11.3), indicating that (on average) whales gradually moved away from the location where they were initially photographed. However, the apparent or net speeds declined as the interval between sightings increased (Fig. 11.4). Several factors, some artifactual and some resulting from bowhead behavior, may contribute to this trend (see Discussion).

Overall swimming speeds as determined from within-day repeated photographs were 2.84 ± s.d. 1.94 km/h in the "Eastern Alaska" zone and 2.78 ± 1.79 km/h in the combined Yukon East and Amundsen Gulf zones. These speeds did not differ significantly ($t = 0.28$, 2-tailed $P = 0.78$, df = 294). Appendices 11.4A and 11.5 show n values and other related details. In addition, the net westward speed of movement relative to the expected migratory direction (288° True) was calculated for whales in the "eastern Alaskan" Beaufort Sea in order to estimate residence times. The mean net westward speed from photographs was 0.32 km/h (Appendix 11.4B), indicating that much of the 2.84 km/h mean speed noted above was in directions other than westward.

Within the "Eastern Alaska" zone, the overall mean speeds of subadults and adults (mothers excluded) were not significantly different (2.84 vs. 2.52 km/h; $t = -0.86$, 2-tailed $P = 0.39$, df = 103). However, in all years except 1999, the mean speed of adults was faster than that of subadults (Appendix 11.4A). Overall mean speeds of mothers were significantly faster than other adults (3.83 vs. 2.52 km/h; $t = -2.31$, 2-tailed $P = 0.024$, df = 58) but much of that movement by mothers was not in a westerly direction. When the direction of movement relative to the migration corridor was considered, the difference was marginally significant ($t = 1.98$, $P = 0.053$, df = 58), and net speeds of mothers had a net *easterly* component whereas other adults had a net westerly component (–0.61 vs. 0.97 km/h, relative to a heading of 288° W; Appendix 11.4B).

Speeds in the "Eastern Alaskan" zone varied among years, with low speeds in 1999 when direction was ignored. Speeds of all whales combined (calves excluded) were significantly different among 1985 (mean = 3.57 km/h), 1986 (3.54 km/h), 1998 (2.27 km/h), and 1999 (1.73 km/h) (Kruskal-Wallis $\chi^2 = 25.16$, df = 3, $P = 0.000014$). The results were quite different when the net westward component of speed was considered. Net westward speeds were –0.89 (i.e., 0.89 km/h eastward), 0.17, 1.92, and 0.67 for the same four years, respectively (Appendix 11.4B). These values were also significantly different (Kruskal-Wallis $\chi^2 = 20.67$, df = 3, $P = 0.00012$).

There was some evidence of year-to-year differences in mean speeds of subadults and adults, direction ignored. The mean speeds for subadults were marginally different among 1985, 1986 and 1998 (3.51, 2.78 and 2.00 km/h, respectively; Kruskal-Wallis $\chi^2 = 7.663$, df = 3, $P = 0.0535$); the sample size in 1999 was low. Sample sizes for adults (mothers excluded) were too small in most years for statistical comparison of years. However, the mean speed of adults in 1999 (1.41 km/h, $n = 22$) was the lowest value detected for any age class

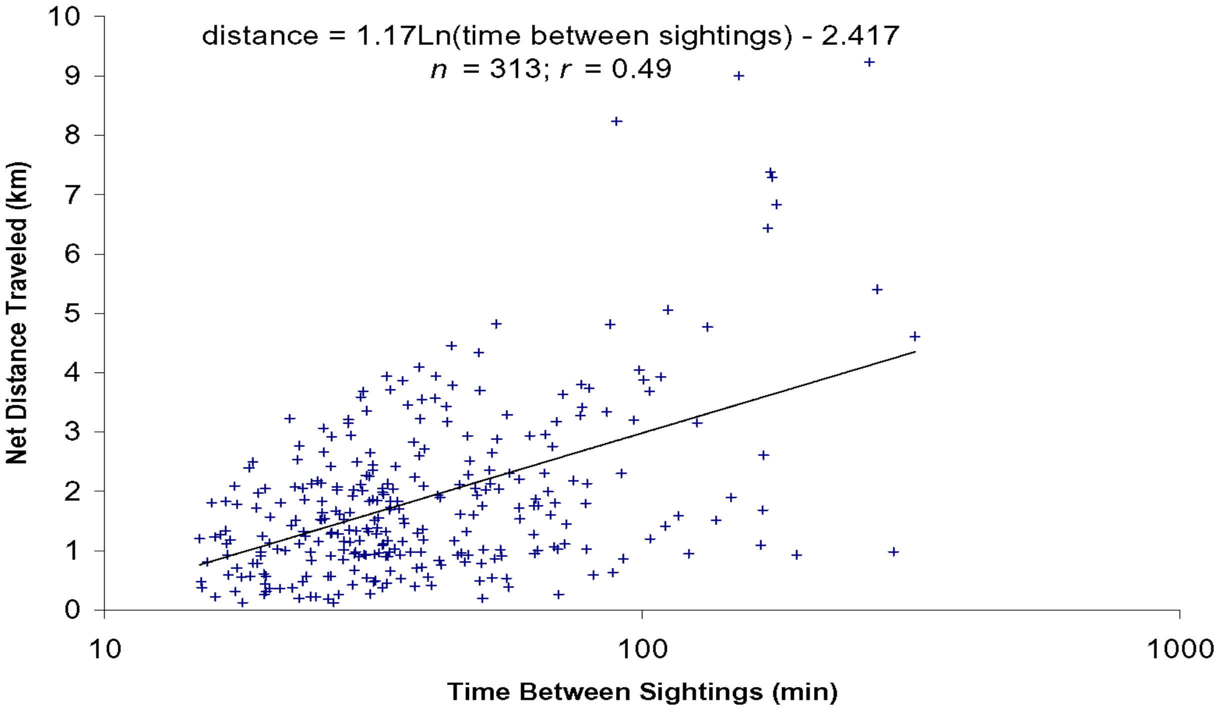

FIGURE 11.3. Net distance traveled vs. time between sightings for within-day resightings of whales from photographs, eastern Alaskan and Canadian Beaufort seas and Amundsen Gulf, 1982-2000. Resightings <15 min apart are excluded.

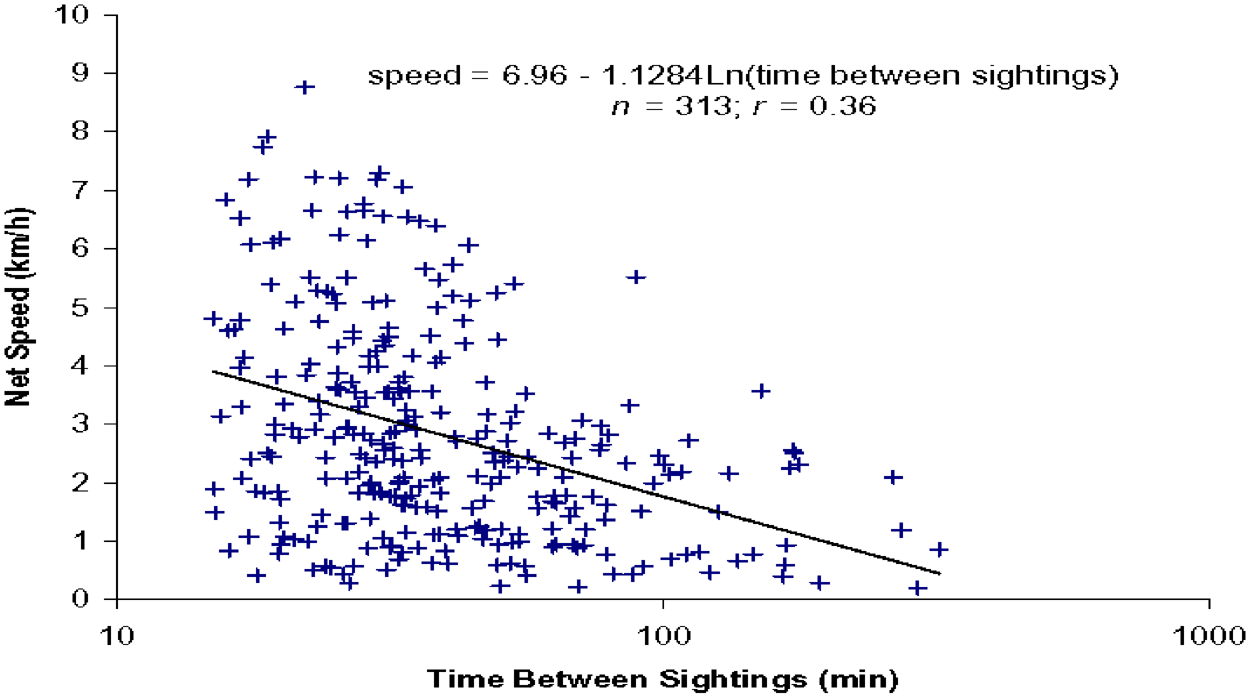

FIGURE 11.4. Net speed vs. time between sightings for within-day resightings of whales from photographs, eastern Alaskan and Canadian Beaufort seas and Amundsen Gulf, 1982-2000. Resightings <15 min apart are excluded.

in any year with $n > 5$ resightings. In comparison, the mean speed for adults in the "Eastern Alaska" zone in all other years combined was 3.63 km/h ($n = 22$). Corresponding yearly values of net westward speed for subadults and adults are given in Appendix 11.4B; year-to-year patterns differed from those for overall speed.

In the combined Canadian zones, the overall mean speeds of subadults and adults (excluding mothers) were not significantly different (2.88 vs. 2.65 km/h; $t = -0.791$, 2-tailed $P = 0.430$, df = 168). In the Yukon East zone, there were marginal among-year differences in net speeds of all whales (calves excluded) during 1982, 1984 and 1985 (Kruskal-Wallis, $\chi^2 = 5.01$, df = 2, $P = 0.082$). However, there were no significant differences among net speeds of subadults for the same three years (Kruskal-Wallis, $\chi^2 = 0.17$, df = 2, $P = 0.92$).

The vector mean headings of whales resighted (calves excluded) in the "Eastern Alaska" zone was 328° T (± a.d. 72°); corresponding values for the combined Canadian zones were 25°T ± 78°. The high angular deviations (calculated according to Batschelet 1981) indicate that the headings were highly variable. In the "Eastern Alaska" zone, mean headings in 1985 and 1986, when subadult whales were lingering and feeding in this zone, were eastward: 94° ± a.d. 63° in 1985, and 50° ± 75° in 1986. In contrast, mean headings in 1998 and 1999 were predominantly westward and the angular deviations were somewhat lower (295°± a.d. 31° and 310° ± 52°— see Appendix 11.4A). This indicates that whales photographed in "Eastern Alaska" were deviating from a generally westward course less frequently in 1998 and 1999 than in 1985 and 1986.

When the mean net westward speeds from photographic resightings (Appendix 11.4B) were divided into the distance across the study area (270 km), the estimates of residence times for the "Eastern Alaska" zone based on the mean within-day speeds for each year were indeterminate, 66, 5.7, 16.8 and 51 days for 1985, 1986, 1998, 1999 and 2000, respectively. The 1985 value is indeterminate (but presumably relatively high) because the mean of the net westward speeds that year was negative. The 2000 value (51 d) is based on only five within-day resightings and should be discounted given the strong evidence of other types that bowheads did not linger in the eastern Alaska area during 2000. The Discussion evaluates potential biases in these results.

6. Behavior: Overall Speeds

Swimming speeds of whales were determined on a few occasions during behavioral observation sessions in the "Eastern Alaska" zone when we identified recognizable bowheads during their surface-dive sequences. We refer to "net distance" and "net speed" because these calculations assume straight-line travel while the whale was out of sight below the surface. Actual distance and speed were undoubtedly higher during some dives. Over all years and activities, the mean net speed of whales (calves excluded) during BOSs was 3.20 ± s.d. 1.88 km/h in the "Eastern Alaska" zone (Appendix 11.6A). The speeds were significantly different among years (Kruskal-Wallis, $\chi^2 = 40.72$, df = 4, $P = 3.1 \times 10^{-8}$) with the slowest speeds recorded in 1985 (1.24 km/h) and 1999 (2.09 km/h), and notably higher speeds in 1986, 1998 and 2000 (3.96, 3.97 and 3.57 km/h, respectively; see Appendix 11.6A for details).

The net westward component of swimming speed, as documented during BOSs, was also calculated for use in estimating residence times in the "Eastern Alaska" zone. The net westward speeds were notably slower than the net speeds (means 1.99 vs. 3.20 km/h). Similar to the result for net speed, the net westward speeds were significantly different among years (Kruskal-Wallis, $\chi^2 = 9.73$, df = 3, $P = 0.021$; 1985 excluded). The slowest mean speeds were in 1985, 1998 and 1999 (0.26, 1.53 and 1.20 km/h), with higher means in 1986 and 2000 (2.54 and 2.91 km/h, respectively; Fig.11.5, see Appendix 11.6B for details).

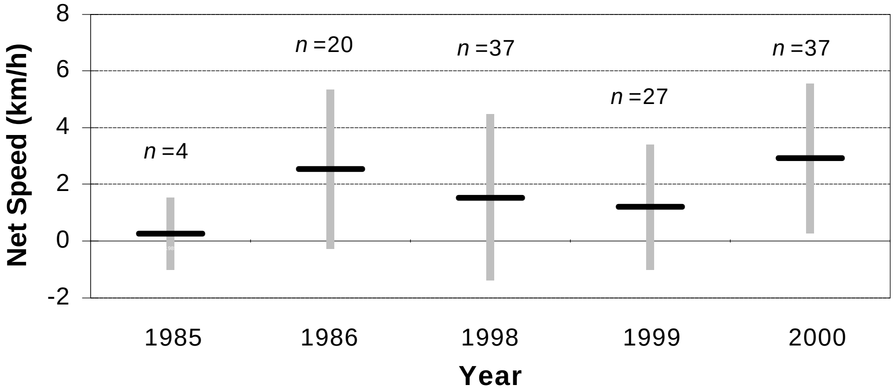

FIGURE 11.5. Net speed in a nominal westward migratory direction (288° True) during dives of all undisturbed bowhead whales (calves excluded) during behavior observation sessions in the "Eastern Alaska" zone, 1985, 1986 and 1998-2000. Horizontal bars represent mean speed and vertical bars show ± 1 s.d. n is the number of different dives measured; the numbers of different whales that provided data for each year were approximately 4, 10, 12, 16, and 11, respectively. See Appendix 11.6B for details.

Mean residence times in the "Eastern Alaska" zone each year were estimated by dividing the yearly means of the net westward components of speed into the distance across the study area (270 km). The resulting estimated residence times are 43, 4.4, 7.4, 9.4 and 3.9 days for 1985, 1986, 1998, 1999 and 2000, respectively. Potential biases are evaluated in the Discussion. However, it is important to note that observations in Canadian waters west of Herschel Island are included, especially for 1985 when 10 of 18 speed estimates came from Canadian waters (see Chapter 12, Fig. 12.1). Also, these estimates would be biased if there were disproportionate sampling of whales that were feeding vs. traveling (see below).

7. Behavior: Activity Speeds

We also examined net speeds of whales according to their activity. Results are shown in Appendices 11.7A, showing overall speeds, and 11.7B, showing westward alongshore components of speed. Figure 11.6 summarizes the latter results.

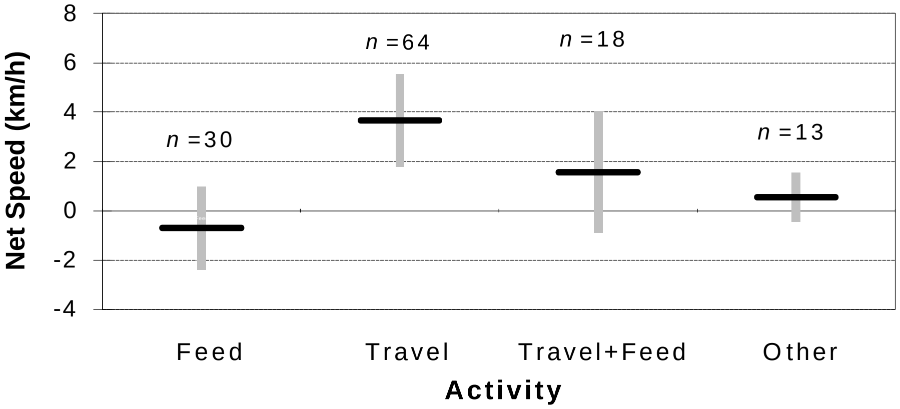

FIGURE 11.6. Net speed in a nominal westward migratory direction (288° True) during dives of all undisturbed bowhead whales (calves excluded) involved in different activities in the "Eastern Alaska" zone, 1985, 1986 and 1998-2000. Horizontal bars represent mean speed and vertical bars show ± 1 s.d. *n* is the number of different dives measured; the number of different whales that provided data for each activity were approximately 17, 21, 8 and 8, respectively. See Appendix 11.7B for details.

For ***feeding*** bowheads (calves excluded), the average net speed during a dive was 1.54 ± s.d. 1.21 km/h, while traveling an average net distance of 0.31 ± 0.19 km (Appendix 11.7A). We also looked at rates of movement for feeding bowheads of different age classes, although sample sizes for these subcategories were small. Subadults had higher net swimming speeds (2.45 ± 1.53 km/h) than adults aside from mothers (1.18 ± 0.51 km/h). As above, we refer to "net distance" and "net speed" because these calculations assume straight-line travel while the whale was out of sight below the surface. We also calculated the westward alongshore component (288° True) of the net speeds for use in residence time calculations. The mean westward component for feeding non-calves was –0.71 ± 1.55 km/h (Fig 11.6). This indicates that, on average, whales moved gradually *eastward* from their initial positions while feeding.

Speeds of ***traveling*** whales were determined on a few occasions when we followed recognizable bowheads during their surface–dive sequences. For traveling bowheads, the average net speed during a dive was 4.50 ± s.d 1.22 km/h, while traveling an average net distance of 0.99 ± 0.76 km. Sample sizes for specific age classes are again small, but mean speeds of traveling whales were similar for adults and subadults (4.55 vs. 4.42 km/h). The westward component of the speed of traveling whales (calves excluded) was 3.67 ± 1.74 km/h (Fig. 11.6). Results for traveling adults and subadults were similar (4.04 vs. 4.16 km/h).

Swimming speeds of whales categorized as ***traveling plus feeding*** (combined) were intermediate between (and more variable than) those for traveling or feeding whales. The average net speed during a dive was 3.31 ± s.d. 1.55 km/h, while traveling a net distance of 0.81 ± 0.49 km. The westward component of the speed of traveling plus feeding whales was 1.57 ± 2.32 km/h (Fig. 11.6).

Swimming speeds of small numbers of whales engaged in ***other activities*** besides feeding and traveling were combined into a fourth activity called other/unknown. This included whales that were categorized as engaged in social+feed, travel+social+feed, resting, aerial activities, and unknown activities. Sample sizes were too low to treat these activities separately. The average net speed during a dive by a bowhead engaged in other/unknown activities was 1.54 ± 1.37 km/h, while traveling an average net distance of 0.31 ± 0.30 km. The westward component of the speed was 0.55 ± 0.86 km/h (Fig. 11.6).

The derivation of estimated mean residence times for the "Eastern Alaska" zone based on the westward component of the activity speeds and the proportion of time engaged in various activities is shown, for each year, in Table 11.5. Residence time estimates are 11.0, 19.9, 13.7, 24.2 and 4.1 days for 1985, 1986, 1998, 1999 and 2000, respectively. The activity budgets likely underestimate the amount of time traveling in most years (see Discussion). Thus, with the possible exception of 2000 (when there was little "lingering"), these values probably overestimate the actual residence times.

8. Aerial Survey Densities

The mean of the relative densities during the "base years" (1985, 1988 and 1989) for the entire study area was 0.146 bowheads/100 km, corrected for changes in population size over the 1979-2000 period (see Methods and Appendix 9.2 *in* Chapter 9). The residence time for 1985 was calculated by dividing the relative density for that year (0.154 bowheads/100 km) by the base year and multiplying that value by 3.1 days. The resulting value (3.28 days) was the estimated average residence time of a whale in the "Eastern Alaska" zone in 1985. Other residence times estimates based on the aerial survey densities are 10.5, 2.20, 3.82, 5.82, 29.8, 58.4 and 10.2 days for 1986, 1988, 1989, 1992, 1998, 1999 and 2000, respectively. The 1988 value (2.20 days) is implausibly low given how much time it would require for whales to swim directly across the 270-km-wide study area without stopping (3.1 d at 3.67 km/h), and the 1999 value (58.4 d) is implausibly high.

TABLE 11.5. Calculation of residence time using activity speeds (vector mean westward) and activity budgets. Vector mean speeds from Appendix 11.7B; activity budgets from Chapter 12: Table 12.2.

	Feeding			Traveling			Other Activities			All Activities			
Year	**A**: Mean Speed[1] (km/h)	**B**: Proport'n of All Activities	**C**: =AXB	**A**: Mean Speed[1] (km/h)	**B**: Proport'n of All Activities	**D**: =AXB	**A**: Mean Speed[1] (km/h)	**B**: Proport'n of All Activities	**E**: =AXB	**F**: Mean Speed[1] (km/h) =C+D+E	**G**: Mean Speed (km/d) =FX24 h	**H**: Distance Traveled	Residence Time (d) =H/G
1985	-0.71	0.39	-0.28	3.67	0.31	1.14	0.55	0.30	0.16	1.02	24.59	270	10.98
1986	-0.71	0.58	-0.41	3.67	0.24	0.88	0.55	0.18	0.10	0.57	13.60	270	19.86
1998	-0.71	0.38	-0.27	3.67	0.24	0.88	0.55	0.38	0.21	0.82	19.64	270	13.74
1999	-0.71	0.66	-0.47	3.67	0.24	0.88	0.55	0.10	0.05	0.47	11.18	270	24.16
2000	-0.71	0.09	-0.06	3.67	0.74	2.72	0.55	0.17	0.09	2.74	65.88	270	4.10

[1] Mean speeds are the mean vector components of speed toward 288° True. A negative speed indicates a component of speed toward 108° True.

9. Aerial Survey Whale-Days

The average residence time of a bowhead in the "Eastern Alaska" zone in 1985 based on whale-days was calculated in the following way: (1) The number of whale-days (11,934, from Chapter 9: Table 9.3) was multiplied by 1.316 to adjust for the larger size of our study area (adjusted whale days = 15,705). (2) The estimated population size in 1985 (6373, Appendix 9.2) was multiplied by 0.814 (the estimated proportion of the population passing south of the 200 m contour) to estimate the number of whales that passed through the study area in that year (whales passing = 5188). (3) The adjusted whale days were divided by the number of whales that passed through the study area to estimate the average residence time of a whale in the study areas in 1985 (15,705 whale-days/5188 whales = 3.03 d). Corresponding estimates for 1986, 1988, 1998, 1999 and 2000 are 4.40, 0.84, 5.31, 16.62 and 2.96 days, respectively. The 1988 value (0.84 days) is very unrealistic given how much time it would require for whales to swim directly across the 270-km-wide study area.

10. Telemetry

Telemetry data provide a more continuous record of bowhead locations and hence use of an area than photographs or aerial observations of behavior. Three telemetry studies have collected information on bowhead movements in or through the "eastern Alaskan" Beaufort Sea.

- Wartzok et al. (1989) tracked a 12-m whale to the eastern border of the "Eastern Alaska" zone on 24 Sept. 1988 and relocated it at Barrow, about 640 km to the west, on 2 Oct. Assuming a constant speed, the whale would have been in the "Eastern Alaska" zone for about 3.4 days.
- Wartzok et al. (1990) tracked four subadult whales (9.5–12.5 m) through our study area during 21–29 Sept. 1989; the estimated residence times of these whales based on locations taken 1–5 days apart were 4, 2.5, 7, and 4 days.
- Mate et al. (2000) deployed satellite-linked transmitters on 12 bowhead whales in the Canadian Beaufort Sea during early September 1992. Five of these whales were tracked in the "Eastern Alaska" zone. Three bowheads were tracked entering the zone, presumably to feed, for 2.3, 5.5 and 4.5 d (excluding short periods when whales moved east of the study area). Their tags stopped transmitting before their westward migration through the area, and possibly before other incursions into our study area to feed. Allowing for a minimum transit time of 2.5 d through the study area, their minimum

residence times in the "Eastern Alaska" zone during the fall period were 4.8, 8.0 and 7.0 days. Two other whales were tracked until they moved west of the study area. The residence times for those whales were 6.0 and 12.3 d (allowing for a 15 h excursion outside the study area on 3–4 Sept.).

The mean residence times in 1988, 1989 and 1992 were 3.40, 4.38 and 6.45 d, respectively, and the mean residence time of the three years with telemetry data was 4.74 d.

Residence Time

The straight-line distance across the "Eastern Alaska" zone, i.e., from Herschel Island to western Camden Bay/Flaxman Isl., is 270 km when measured near the 40-m contour. A steadily migrating bowhead would pass through the study area in 3.1 days if it traveled at a mean speed of 3.67 km/h, which is the mean westward-component speed observed for traveling whales (Fig. 11.6). Thus, the residence time of a typical bowhead whale that swam across the "Eastern Alaska" zone (Herschel Isl. to Camden Bay/Flaxman Isl.) without stopping, either to feed or for other reasons, would be 3.1 d. The corresponding time in the area from the Alaska/Yukon border to the west side of Camden Bay would be 2.4 d. We have one record of a mother and calf sighted near both the eastern and western boundaries of the "Eastern Alaska" (Flaxman-to-Herschel) zone. That pair of whales took 3.9 days to travel from 51 km west of the eastern boundary to 2 km east of the western boundary, i.e., across 80% of the "Eastern Alaska" zone. At that rate, it would have taken them 4.9 days to cross that zone if they traveled at a steady speed. Telemetry data have shown similar transit times by some other individual bowheads (see above).

Table 11.6 summarizes the residence time calculations based on the various photogrammetric, behavioral, aerial survey, and telemetry methods described above. The residence times computed from the different data sources were highly variable, indicating that the different data and/or methods are biased in varying ways. The expected biases are summarized in the right column of Table 11.6, and discussed further below. In general, for the five years of the feeding study *per se*, the lowest residence times were estimated for 1998 and 2000, and the highest residence times were for 1985 and 1999.

Discussion

Local and Traditional Knowledge of Residence Times

Whale hunters and other residents of Kaktovik, within the eastern Alaskan study area, have noted certain areas and times when bowhead whales linger, either to feed or for other reasons (see Chapter 2 and Annex B). Kaktovik residents sometimes see bowheads in a given area for 1–2 weeks or more. One such area is between Icy Reef and Demarcation Bay. Canadian waters along the Yukon coast east of Herschel Island are another area where bowheads (small individuals) apparently linger for extended periods, sometimes more than two weeks. However, it is uncertain from the hunters' observations whether the same individual whales remain for that long, as individual whales are not recognized. One hunter indicated that bowheads tend to remain longer when the water is open than when ice is present.

Year-to-Year Differences in Use of the Study Area

Estimates of residence times are potentially biased by the activities of whales as they enter and move through our study area. There are year-to-year differences in the frequencies of different activities, and in the cohorts of the population that are engaged in particular activities. Many of the data that are used to estimate residence times may depend on whale activities, so we summarize year-to-year differences in whale use of the study area that might cause biases in our residence time estimates for each year.

TABLE 11.6. Summary of estimates of mean residence times (days) of bowhead whales in the "Eastern Alaska" zone (Flaxman Isl. to Herschel Isl.) by year, 1985-2000. From various sources of information about resighting intervals of photographed whales, rates of movement, whale activities, and relative abundance. Estimates considered to be unbiased are in boldface; unreliable estimates are in italics. See Discussion for further evaluation of reliability.

	Year										
	1985	1986	1988	1989	1992	1998	1999	2000	Mean	Sample Size	Reliability of Estimate
1. Photos: Intervals Between Resightings	8.13	4.18	-	-	-	1.00	4.10	-	4.35	small	potential + or - bias
2. Photos: Intervals Between Resightings + Trave	11.24	7.12	-	-	-	3.38	6.90	3.07	6.34	small	potential + or - bias
3. Photos: Stop-over Duration, Best Fit	**5.30**	**3.81**	-	-	-	-	**4.36**	-	**4.49**	**small-mod**	**unbiased**
4. Photos: Stop-over Duration, Constant Survival	*19.50*	*9.04*	-	-	-	-	*13.40*	-	*14.0*	*small-mod*	*unreliable due to assumptions*
5. Photos: Within-day Speeds	undet.	*66.20*	-	-	-	*5.86*	*16.80*	*51.10*	*33.9*	*high*	*+ and - biases*
6. Behavior: Overall Speeds	*43.30*	4.42	-	-	-	7.35	9.38	3.87	6.26	*high*	*unreliable*
7. Behavior: Activity Speeds	*11.00*	*19.90*	-	-	-	*13.70*	*24.20*	*4.10*	*14.6*	*moderate*	*positive bias*
8. Aerial Survey: Densities	*3.28*	*10.50*	*2.20*	*3.82*	*5.82*	*29.80*	*58.40*	*10.20*	*17.2*	*moderate*	*unreliable, based on raw sightings*
9. Aerial Survey: Whale Days	**3.03**	**4.40**	**0.84**			**5.31**	**16.62**	**2.96**	**5.53**	**small-mod**	**unbiased**
10. Telemetry Data			**3.40**	**4.38**	**6.45**				**4.74**	**small**	**unbiased**
Mean of reliable approaches (1, 2, 3, 6, 9 & 10)	6.92	4.79	2.12	4.38	6.45	4.26	8.27	3.30	5.06		

***Canadian Zones*.**—Past studies have documented size segregation of bowheads in their summering areas in the Canadian Beaufort Sea (Cubbage et. al. 1987; Koski et al. 1988). Further, based on frequency of between-day sightings, Koski et al. (1988) concluded that small bowheads lingered off the Yukon coast in 1982 and 1985, but they entered and left the same area in 1984. This change in behavior is reflected in our estimates of resighting intervals for those years (Table 11.2). Between-year differences in use of the Yukon East zone are even more pronounced when residence times are estimated via SODA based on the best-fit models (Table 11.4). Those new estimates very likely provide the best available information on residence times of the many bowheads (mainly subadults) that occurred in the Yukon East zone in the specific years of study. However, the distribution and numbers of bowheads in this zone are highly variable from summer to summer. In some years (e.g., 1980, 1981) very few bowheads occur close to the Yukon coast, whereas in other years large numbers concentrate along the coast southeast of Herschel Island (Richardson et al. 1987; Moore and Reeves 1993). Residence times of the few bowheads that occurred along the Yukon coast in 1980 and 1981 are unknown, but residence times during years with high numbers are very unlikely to be representative for years with low densities.

***"Eastern Alaska" Zone.*—**All cohorts of the Bering–Chukchi–Beaufort bowhead whale population that summer in Canadian waters pass through the "eastern Alaskan" Beaufort Sea (Flaxman Isl to Herschel Isl.) during their migration toward wintering areas in the Bering Sea (Moore and Reeves 1993; Chapter 10). However, changes in their activities and speeds as they pass through the area could result in biases in estimates of speeds and residence times. In 1985, small bowheads lingered in the SE part of the "Eastern Alaska" zone (Fig. 11.2) and few bowheads of any cohort were seen in the rest of the area. Most behavior observations (Chapters 12–14) and photographic resightings in the "Eastern Alaska" zone in 1985 came from the SE part of that zone, and involved primarily small subadult whales (Appendix 11.4; Chapter 10). Thus, estimates of activities, speeds, and resighting intervals for 1985 are not representative of those in the central and western parts of the "Eastern Alaska" zone or of larger whales in the eastern part of the zone. The biases in the data have resulted in underestimates of average speed and overestimates of average residence time for the overall bowhead population that passed through the area in 1985.

In 1986, whale use of the "Eastern Alaska" zone as a whole (Flaxman-to-Herschel) was similar to that in 1985, but whale distribution within the zone differed somewhat. We were able to conduct photogrammetry and behavior observations over a larger part of the zone in 1986 (see Fig. 10.1 and 12.1 in Chapters 10, 12). Primarily small whales lingered in the zone, as in 1985, but they concentrated in areas slightly farther west than in 1985 (west rather than east of the U.S.–Canada border; Fig. 11.2). Estimates of residence time for 1986 from SODA and from within-day speeds, as derived from both BOS data and photogrammetry, are less biased than in 1985 because they include data from throughout the study area. Nonetheless, they are still biased because of the preponderance of data from small whales, which lingered in the southeastern part of the study area.

In 1998, whales (primarily subadults, Chapter 10) were seen consistently near Kaktovik. Despite repeated photographic coverage of the area near and west of Kaktovik (Fig. 10.1, Chapter 10) only one between-day photographic resighting was made (Fig. 11.2; Appendix 11.2). This indicates that whales stopped in the Kaktovik area only briefly. Estimates of speeds from within-day resightings from both photogrammetry and behavioral observations are negatively biased because rapidly moving whales are under-represented. Hence, average residence times based on those data are overestimated.

In 1999, adult whales stopped to feed in the middle shelf waters of the "Eastern Alaska" zone for extended periods (Fig 11.2; Appendix 12.2; Chapter 10) and the mean speed of adults was lower (1.41 km/h) than in other years combined (3.63 km/h) (Appendix 11.4A). Subadults appeared to move through the study area faster than adults; there were few between-day resightings of subadults (Appendix 11.2). Therefore, overall speeds from behavior and photogrammetry were underestimates of speeds for the entire population, and mean residence time was correspondingly overestimated.

In 2000, all whales moved through the "Eastern Alaska" zone rapidly and few whales were seen at any time during the study. There were no between-day resightings despite much effort (Appendix 11.2). Mean residence times estimated from within-day speeds obtained during BOSs were likely near the actual residence times because very little back and forth movement appeared to have occurred. Speeds from photogrammetry sessions are seriously biased because sample size was small and 40% of measured movements came from a single session with feeding and socializing whales.

Intervals Between Resightings

The mean interval for between-day photographic resightings in the "Eastern Alaska" zone averaged 4.35 d over four of the five years of our study and yearly mean intervals were highly variable among years (range 1.0–8.1 d; Table 11.2). The comparable statistic for two summering areas in the Canadian Beaufort Sea and Amundsen Gulf was 5.91 d and was also highly variable (range 2.00–10.5 d). These results suggested that bowheads tend to be more sedentary in the Yukon East and Amundsen Gulf zones than in the "Eastern Alaska" zone, although the difference in the averages is not large. The average interval between sightings would be smaller for the "Eastern Alaska" zone if a value for 2000 had been obtained and included in the mean. During 2000, rates of movement were so rapid that no whales were resighted.

The mean interval between resightings tends to underestimate residence times for those whales that do linger in the area because it does not include any allowance for time spent in the study area before the initial sighting and after the last sighting. This bias can be considerable and may result in estimates of residence times that are less than 50% of the actual value (see Schaub et al. 2001). On the other hand, if a high proportion of the animals move through the study area rapidly, the mean interval may overestimate the mean residence time for the population as a whole because residence times shorter than the sampling intervals are not represented in the data. Mate et al. (2000) found that bowheads are highly mobile during the late summer and early autumn, and sometimes move considerable distances within a 24-h period. Three of eight whale tracks reported by Mate et al. (2000) included brief movements from our "Eastern Alaska" zone to the Yukon East zone and then back to "Eastern Alaska" during periods when they were mostly present in the "Eastern Alaska" zone. Photogrammetry studies have also documented movements between zones, varying in frequency among years. In some years whales remained along the Yukon coast for prolonged periods, and in other years they rapidly passed through the same area (Koski et al. 1988). Thus, intervals between sightings may underestimate residence time during years when whales linger in the study area but overestimate when movements through the area are rapid. Between-year comparisons of residence times using intervals between resightings may not be reliable.

Intervals between resightings as high as 16, 19 and 20 d were recorded in the "Eastern Alaska", Amundsen, and Yukon East zones, respectively, indicating that some whales remained in each zone for prolonged periods in some years. It is not known how long these specific whales were present before and after the first and last sightings, nor whether they temporarily moved out of the zone in question at any time between the first and last sightings.

Allowance for traveling time before the first and after the last photograph of an individual whale within the study area (estimate #2 in Table 11.6) results in a less biased estimate of residence time for that individual whale. This estimate is still negatively biased for the individuals that are resighted because it makes no allowance for presence before or after the documented residence period, and it assumes rapid movements to and from the lingering area. As noted above, it is not known how this estimate might relate to the population as a whole.

Stop-over Duration

The SODA procedure provides a robust estimate of mean residence time. The models use the available data on sampling effort and recapture history to make unbiased estimates of the time that the whale was present in the study area before it was photographed (immigration) and the time that it remained in the study area after it was photographed (emigration). The models are able to estimate residence time by summing these two values even when recapture probability is low, time present in the study area is low, and information is not available from other sources to estimate immigration and emigration (Schaub et al. 2001).

The mean residence time estimated using SODA was based on all cohorts of the population that were photographed, not just the cohorts that were resighted. The overall photographic samples may still be biased samples of the whales that passed through the study area because we did not obtain photographic coverage during the early and especially the late parts of the migration period (see Chapter 10). However, the overall photographic samples are less biased than the resighting data. In some years, primarily one cohort of the population was resighted during the sampling period (i.e., subadults during 1985). Other cohorts that passed through the study area too rapidly to be resighted were nonetheless sampled photographically and those data are used by SODA.

In 1982 and 1985, estimates of residence time in the Yukon zone from SODA were much longer (23.1 and 16.6 d, respectively) than the mean interval between sightings (5.9 and 7.3 d, respectively). When most of the population moved through the study area without stopping, but part of the population lingered (e.g., in the “Eastern Alaska” zone in 1985), SODA took account of the low overall resighting rate. For “Eastern Alaska” in 1985, the resulting mean residence time estimate from SODA (5.3 d) for the whole population was lower than the mean interval between resightings for those individuals that lingered in the area long enough to be resighted (8.1 d).

Residence time estimates from SODA suggest that bowhead whales remained in Canadian zones on average almost three times as long as they remained in the “Eastern Alaska” zone (12.6 d vs. 4.5 d (Table 11.4)). This difference was probably related to the activities of whales when they were present in those zones. While in Canadian waters, bowheads spent an average of 71% of their time feeding and 9% traveling. While in the “Eastern Alaskan” Beaufort Sea, bowheads spent an average of 47% of their time feeding and 31% traveling (Chapter 12: Fig. 12.9).

Photogrammetry: Within-day Speeds

Over short time periods bowheads gradually moved away from the locations where they were initially photographed but over time their net speeds declined. This suggests that some of the movements were local movements probably associated with feeding. Short-term reactions to the photogrammetry aircraft may also be involved (Patenaude et al. 2002). Overall within-day speeds were not significantly different between “Eastern Alaska” (2.84 km/h) and the Canadian zones (2.78 km/h). These overall average speeds from both areas were slower than speeds of migrating whales (4.50 km/h), consistent with behavioral and stomach content evidence that feeding forms a significant part of the activities of whales in “Eastern Alaska” (Chapters 12, 18) and with behavioral observations of feeding in the Canadian zones (Würsig et al. 1984, 1985, 1989).

Within the “Eastern Alaska” zone, speeds were significantly different among years (excluding 2000 when there were too few data). This difference appears to be mainly attributable to the slow movements of adults in 1999 (mean 1.41 km/h)—slower than adults in other years combined (3.63 km/h), and slower than subadults in that year (2.78 km/h) and all earlier years (3.51, 2.78 and 2.00 km/h in 1985, 1986 and 1998, respectively (Appendix 11.4A). This suggests that feeding by the adult whales that predominated in 1999 was more localized than feeding by subadults that predominated in some other years. Similar differences were not found in the Canadian zones where no strong differences existed among years or between adults and subadults.

The net westward component of speed was also highly variable among years and some of the data were clearly biased. In 1985, the net westward speed was –0.89 km/h indicating that the net movement of the sampled whales was more to the east than to the west—not a credible result for the population and season as a whole. In 1986, the net westward speed was so slow (0.17 km/h) that the sampled whales would have taken 66 days (on average) to pass through the study area.

Residence time estimates based on within-day speeds from photogrammetry are biased and can either over- or underestimate rates of movement. Some of the potential biases are as follows:

- The activities of the whales that are photographed may not be representative of activities of whales that are not photographed. In particular, migrating whales are more difficult to detect (and hence photograph) than feeding or socializing whales because they are submerged a greater proportion of the time (Chapters 13, 14).
- Some movements may be back-and-forth movements, in which the net distance westward and the net westward speed over a short period of time could overestimate the total distance and net westward speed that would be traveled by those whales over a longer period of time.
- As time passes and average distances increase, the whales that travel fastest tend to move out of the area where photographs are taken, causing progressively more serious underestimation of average speeds.

Behavior Speeds

Swimming speeds determined from BOSs in the “Eastern Alaska” zone were significantly different among years. These differences were attributable to the different activities and age classes of whales that lingered there in different years. The primary activity recorded for bowheads in the “eastern Alaskan” Beaufort Sea during late summer and autumn of 1985–86 and 1998–2000 was feeding. The average net speed of feeding whales determined from BOSs was 1.54 ± s.d. 1.21 km/h, which is considerably slower than speeds of traveling whales (4.50 ± 1.22 km/h). The net westward speed of feeding whales was –0.71 km/h, indicating a net movement eastward while they were feeding. These slower net speeds by feeding whales indicate that they remained longer in the study area than they would have if they were simply migrating through it. Based on very small sample sizes, the net speeds of subadult feeding whales were faster (2.45 km/h) than those of adult feeding whales (1.18 km/h), consistent with other evidence (Chapters 10, 13) that the two age classes had different feeding strategies in the study area. The observed rates of movement of traveling whales in the “eastern Alaskan” Beaufort Sea in autumn (4.50 ± s.d. 1.22 km/h) are similar to those recorded during spring migration at Barrow where traveling was the predominant activity (4.0 km/h, Rugh 1990; 3.89 ± 1.48 km/h, Richardson et al. 1995b).

Speeds estimated from BOSs overestimate rates of movement over longer periods of time for whales that are lingering in the study area (primarily feeding whales). However, because individual whales were followed, activity speeds are less likely to seriously underestimate speeds of rapidly migrating whales than are the other methods. Thus, residence times calculated using activity speeds have the potential to be less biased than those based on resightings from photogrammetry. The activities of whales can vary from year to year (Chapter 12) and the biases associated with the yearly estimates of the activity budgets have not been quantified. Our estimates of residence time based on activity budgets and activity speeds are higher than our estimates of residence time based on the seemingly-robust SODA best-fit method. This suggests that activity budgets in Chapter 12 may underestimate the proportion of time spent traveling in most or all years of our study.

Aerial Surveys

The two estimates of residence time based on aerial survey data vary considerably even though they are based on the same raw data. The estimates based on raw density indices are highly variable and do not parallel those from SODA or, indeed, any of the other procedures (Table 11.6). The raw density indices are a tabulation of total sightings divided by total effort in each year without consideration of when or where the surveys were conducted. Surveys conducted during August or late October would generally contribute few sightings and would tend to reduce the mean density index for a given year. Similarly, surveys of offshore areas or failure to conduct surveys during the mid-September period (near the peak of the migration) would tend to lower the density index for that year; whereas, a large amount of coverage during mid-September would likely result in a high density index for that year.

The residence time estimates based on estimates of whale-days in the study area include corrections to raw sighting data to account for date of survey, geographic effort, aircraft type, sea state, ice, and aircraft altitude (Chapters 9, 15). The resulting estimates of residence time are generally comparable to those from the SODA best-fit procedure.

The aerial survey estimates are not strictly comparable to the other estimates in that they include data collected before and after the behavioral and photogrammetry studies, i.e., earlier and later in the "autumn" migration period. Thus the aerial survey estimates, particularly those based on whale-days, are more representative of the entire late summer to early autumn period than are the other methods.

Telemetry Data

The telemetry data provide more continuous records of the presence or absence of bowheads in our study area than the other methods, but the times between locations are often a day or more. Thus the times that whales entered or left the study area were estimated and the estimates of time in the study area are not precise. Furthermore, during the telemetry studies summarized here, all of the tagged whales were subadult whales, so they do not provide information on adult whales or mothers and calves. Finally, behavior observations were not conducted during the years of the telemetry studies so we can only infer the activities of whales based on their movement patterns. Even so, the telemetry data are generally consistent with the most reliable estimates from other years in suggesting a mean residence time in the present study area of ~4.7 days.

Best Estimates of Residence Times

Estimates of bowhead whale residence time in the "Eastern Alaska" (Flaxman-to-Herschel) zone as estimated from various sources of data varied from 0.8 for1988 aerial survey whale-days to 58.4 days for 1999 aerial survey densities. Considering the six most reliable approaches, annual estimates varied from 0.8 to 16.6 d, and averaged 5.1 d (Table 11.6). A steadily traveling whale would require 3.1 d to travel across the "Eastern Alaska" zone (Herschel Isl. to Flaxman Isl.) or 2.4 d to travel from the Alaska/Yukon border to Flaxman Isl., based on the 3.67 km/h net westward speed documented for traveling bowheads. The various methods that were used have differing biases, as discussed above, and some procedures are clearly more reliable than others (Table 11.6).

The "best estimates" of residence time appear to be those based on intervals between photographic resightings (with and without allowance for travel time), on "stop-over duration analysis" (SODA) using the "best-fit" models, on behavior overall speeds, on aerial survey estimates of whale-days in the study area, and on telemetry data. Estimates of residence time based on speeds determined from behavioral observations and photogrammetry are highly variable. The variability probably arises from different activities of the whales during different years or in different parts of our study area, compounded by difficulties in obtaining unbiased estimates of the proportion of the whales engaged in these activities over the study area as a whole in each year (Chapter 12).

Summary

To determine the importance of the eastern Alaskan Beaufort Sea to bowhead whales, we need to know how long whales remain in the area. This is one key factor in estimating how much food bowheads consume while there. We also need to know how fast they travel while feeding to estimate how much water they might filter. This chapter documents short-term rates of movement of bowhead whales and estimates average residence times in the eastern Alaskan Beaufort Sea and adjacent Yukon waters, i.e., from Flaxman Isl. (146°W) to Herschel Isl. (139°W).

We estimated rates of movement from within-day sightings of photographed bowhead whales in the "Flaxman-to-Herschel" portion of the Beaufort Sea and compared them to similar data collected during the 1980s off the Yukon east of Herschel Island (Yukon East) and in Amundsen Gulf.

Over periods of 15 min to a few hours, bowheads gradually moved away from the location where they were initially photographed, but as the interval between the initial sighting and resighting increased, speeds declined. This suggested that some movements were local, in part associated with feeding. Within-day speeds were not significantly different between the "Flaxman-to-Herschel" zone and the more easterly Canadian zones. Within the "Flaxman-to-Herschel" zone there was a significant difference in speeds among years. The difference appeared to be due to slower speeds by feeding adults photographed in 1999 than by primarily subadult whales photographed in other years.

The primary activities recorded for bowheads during late summer and autumn were feeding and traveling. Based on the successive locations of bowheads observed during prolonged behavioral observation sessions, the average rate of movement of bowheads in the "Flaxman-to-Herschel" zone was about 1.54 km/h for feeding whales vs. 4.50 km/h for traveling whales. The mean alongshore component of the net speed, measured along the 288°–108° (True) axis, was 0.71 km/h *eastward* for feeding whales and 3.67 km/h westward for traveling whales.

We also attempted to estimate residence times of bowhead whales in the "Flaxman-to-Herschel" area using four general types of data: photoidentification data, behavioral observations, aerial survey results, and telemetry data. Photoidentification data from the 1980s were also used to estimate residence times in the Yukon East and Amundsen Gulf zones. ***(1)** Photographic resightings* were used to determine within-day rates of movement and intervals between resightings for the "Flaxman-to-Herschel" zone and for the Yukon East and Amundsen Gulf zones in all years with sufficient data. Net speeds from within-day photographic resightings were the basis for one estimate of residence times of whales in each zone. Resighting intervals indicated minimum residence times for the specific whales resighted. A computer program (SODA, "stop-over duration analysis") was used to derive an unbiased estimate of residence time in each zone based on data on photographic effort as well as resightings. ***(2)*** *Behavioral observations* of bowhead whales were used to determine short-term rates of movement of whales, and net westward speeds of whales engaged in different activities, in the "Flaxman-to-Herschel" zone during late summer and autumn of 1985–86 and 1998–2000. ***(3)*** *Aerial survey* data were used to estimate residence times in that area based on relative densities during aerial surveys and based on numbers of whales estimated to be present during aerial surveys. ***(4)*** Data on whale locations obtained during *telemetry* studies in three years were used to estimate residence times of whales in the "Flaxman-to-Herschel" zone.

Annual residence time estimates for the "Flaxman-to-Herschel" zone were extremely variable among years and among different methods of analysis applied to the same year. We attribute the latter variability to biases in the different methods that interacted with year-to-year variability in sampling effort, whale distribution, and whale activities. For example, most behavioral data and some photographs collected in 1985 were from feeding whales off the Yukon coast ("border-to-Herschel Isl."); activities and speeds of those whales were not representative of whales in Alaskan waters in 1985. In general, estimates based on behavior data, and to a lesser extent photogrammetry data, were positively biased.

We identified six calculation methods based on photoidentification, behavioral observation, aerial survey, and telemetry data that provided residence time estimates most representative of actual residence times. However, even with these six methods, a few of the residence time estimates were recognizably biased. The annual residence time estimates for the "Flaxman-to-Herschel" area during 1985–86, 1988, 1989, 1992, and 1998–2000 based on these six methods varied from 2.1 to 8.3 d and averaged 5.1 d. A sensitivity analysis (*in* Appendix 23.1) indicated that the 95% confidence limit for the 5.1-d estimate of the mean residence time was 4.2 to 6.1 d.

Residence times varied dramatically among years because of different levels of use of the "Flaxman-to-Herschel" zone for feeding during late summer and autumn. In 1985 and 1986, the eastern part of the area was used for feeding by subadult bowheads during late summer. In 1998, subadult whales briefly stopped to feed in central and western parts of the study area during their migration through the study area. In 1999, adult whales stopped to feed for extended periods in eastern and central parts of the study area. During 2000, most whales migrated through the study area without stopping.

The mean interval for between-day photographic resightings was 4.35 days in the "Flaxman-to-Herschel" zone and 5.91 days in Canadian zones east of there. Estimates for both areas were highly variable among years. A tendency for residence times in the "Flaxman-to-Herschel" zone to be shorter than those in more easterly Canadian areas became more evident when the SODA model was used to estimate total residence times, allowing for time present before the first and after the last sighting, and for whales photographed only once. SODA showed that mean residence times for the Canadian zones were considerably longer (12.6 d) than mean resighting intervals (5.9 d), whereas mean residence times for the "Flaxman-to-Herschel" zone were lower than (1985) or similar to (1986, 1999) the mean resighting intervals. The shorter residence times in the latter zone compared to the Yukon East and Amundsen Gulf zones are consistent with distributional and behavioral data in suggesting that bowhead whales spent less time feeding in the "Flaxman-to-Herschel" area than in adjacent Canadian zones in most years. Furthermore, residence time estimates for eastern Alaska would be further reduced if data from Canadian waters west of Herschel Island (the Komakuk area) were excluded from the "Flaxman-to-Herschel" zone.

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APPENDIX 11.1. Between-year resightings, various origins and years, to MMS study area and vicinity, 1998 and 1999[1].

Where Resighted/ Source of Oiginal Photo[1]	Year	Whale No.	First Photographed Date	Loc'n[2]	Lat.	Long.	Resighting Date	Lat.	Long.	Net Dist. Between Sightings (km)	Re-sighting Interval (yr)
Offshore Demarcation											
NMFS[3]	1989-99	7728	28 Apr	BR	71 32.7	155 16	30 Sep	70 14.9	141 27	522	10 & 13
Nearshore Kaktovik											
DIAND	1984-98	4298	24 Aug	KP	69 20.9	138 28	19 Sep	70 12.1	144 11	239	14
MMS Spr.	1994-98	10104	7 May	BR	71 35.1	154 40	15 Sep	70 11.2	143 53	422	4
Offshore Camden Bay											
SOHIO	1985-98	6106	14 Sep	KP	69 08.6	138 02	20 Sep	70 13.8	145 08	299	13
MMS[4]	1985-98	4586	22 Sep	OK	70 11.9	139 51	20 Sep	70 13.8	145 08	199	13 & 14
SOHIO	1985-98	6007	13,14 Sep	KP	69 10.4	138 06	20 Sep	70 12.9	144 55	287	13
MMS	1986-98	7394	26 Sep	OK	70 07.1	140 40	20 Sep	70 13.7	145 08	169	12
NMFS	1986-98	8132	4 May	BR	71 32.3	155 29	20 Sep	70 14.3	145 09	402	12

[1] **NMFS** = Spring studies near Barrow, AK, by National Marine Fisheries Service. **DIAND** = 1984 summer study by LGL for Canadian Department of Indian Affairs and Northern Development (Davis et al. 1986a). **MMS Spr.** = 1994 spring study near Barrow, AK, by LGL for MMS (Richardson et al. 1995b). **SOHIO** = 1985 study by LGL for Standard Alaska Production Co. and others (Davis et al. 1986b). **MMS** 1985 86 Feeding studies by LGL for MMS (Richardson 1987).

[2] **BR** = Barrow, AK; **OE** = Offshore Komakuk; **KP** = King Point, Yukon Territory; **NK** = Nearshore Kaktovik; **OC** = Offshore Camden Bay.

[3] Same whale photographed in 1986 by Cascadia Research Collective (Tuktoyaktuk Peninsula Shelf) on 31 August (Ford et al. 1987).

[4] Same whale photographed in 1984 (DIAND Study, in Franklin Bay, N.W.T.) on 31 August, and in 1985 on 6 September (SOHIO, KP).

APPENDIX 11.2A. Rates and directions of movement determined from between-day resightings of bowhead whales in the "eastern Alaskan" Beaufort Sea (including Yukon west of Herschel Isl.), late summer and autumn 1985-2000.

		Time Between Resightings (h)				Net Distance Traveled (km)				Apparent Speed (km/h)				Net Direction of Movement (Degrees True)	
	n	Min	Max	Mean	s.d.	Min	Max	Mean	s.d.	Min	Max	Mean	s.d.	Mean	Angular Dev.
1985															
Calves	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subadults	7	50.6	385.1	184.98	136.10	2.6	66.2	17.41	22.60	0	0.2	0.09	0.07	109	59.9
Adults	1	260.6	260.6	260.62	-	1.5	1.5	1.54	-	0	0	0.01	-	233	-
Mothers	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
All non-calves	8	50.6	385.1	194.44	128.81	1.5	66.2	15.42	21.67	0	0.2	0.08	0.07	126	65.6
1986															
Calves	1	93.9	93.9	93.88	-	213.5	213.5	213.52	-	2.3	2.3	2.27	-	281	-
Subadults	10	23.8	332.1	98.10	107.33	1.2	31.8	10.80	9.22	0.0	0.3	0.14	0.09	118	58.7
Adults	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mothers	1	93.9	93.9	93.88	-	213.5	213.5	213.52	-	2.3	2.3	2.27	-	281	-
All non-calves	11	23.8	332.1	97.72	101.83	1.2	213.5	29.23	61.75	0	2.3	0.33	0.65	123	65.5
1998															
Subadults	1	24.4	24.4	24.40	-	62.1	62.1	62.10	-	2.6	2.6	2.55	-	273	-
1999															
Calves	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subadults	2	46.6	93.0	69.78	32.78	11.9	12.5	12.22	0.41	0.1	0.3	0.20	0.09	224	18.9
Adults	6	22.7	216.0	90.69	72.06	6.7	57.6	31.80	19.94	0.2	0.6	0.39	0.14	313	55.6
Mothers	2	143.4	143.5	143.43	0.08	33.4	53.5	43.45	14.25	0.2	0.4	0.30	0.10	254	13.8
All non-calves	10	22.7	216.0	97.06	60.62	6.7	57.6	30.21	18.87	0.1	0.6	0.33	0.14	273	54.2
2000															
All	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1985-2000															
Calves	1	93.9	93.9	93.88	-	213.5	213.5	213.52	-	2.3	2.3	2.27	-	281	-
Subadults	20	23.8	385.1	121.99	117.96	1.2	66.2	15.87	18.16	0.0	2.6	0.25	0.55	133	66.1
Adults	7	22.7	260.6	114.96	91.94	1.5	57.6	27.47	21.50	0.0	0.6	0.33	0.19	296	57.4
Mothers	3	93.9	143.5	126.92	28.61	33.4	213.5	100.14	98.71	0.2	2.3	0.96	1.14	263	16.8
All non-calves	30	22.7	385.1	120.84	104.57	1.2	213.5	27.01	40.28	0.0	2.6	0.34	0.58	198	76.0

APPENDIX 11.2B. Net rates of movement in nominal westward migratory direction (288o True) determined from between-day resightings of bowhead whales in the "eastern Alaskan" Beaufort Sea (including Yukon west of Herschel Isl.), late summer and autumn 1985-2000.

		Time Between Resightings (h)				Net Distance Traveled (km)				Apparent Speed (km/h)				Net Direction of Movement (Degrees True)	
	n	Min	Max	Mean	s.d.	Min	Max	Mean	s.d.	Min	Max	Mean	s.d.	Mean	Angular Dev.
1985															
Calves	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subadults	7	50.6	385.1	184.98	136.10	-22.6	11.6	-5.13	10.10	0.0	0.0	-0.04	0.06	109	59.9
Adults	1	260.6	260.6	260.62	-	0.9	0.9	0.88	-	0.0	0.0	0.00	-	233	-
Mothers	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
All non-calves	8	50.6	385.1	194.44	128.81	-22.6	11.6	-4.38	9.59	-0.1	0.0	-0.04	0.05	126	65.6
1986															
Calves	1	93.9	93.9	93.88	-	211.7	211.7	211.70	-	2.3	2.3	2.25	-	281	-
Subadults	10	23.8	332.1	98.10	107.33	-30.9	5.0	-8.65	10.25	-0.3	0.2	-0.14	0.23	118	58.7
Adults	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mothers	1	93.9	93.9	93.88	-	211.7	211.7	211.70	-	2.3	2.3	2.25	-	281	-
All non-calves	11	23.8	332.1	97.72	101.83	-30.9	211.7	11.38	67.14	-0.3	2.3	0.08	0.75	123	65.5
1998															
Subadults	1	24.4	24.4	24.40	-	60.0	60.0	59.98	-	2.5	2.5	2.46	-	273	-
1999															
Calves	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subadults	2	46.6	93.0	69.78	32.78	1.6	8.5	5.06	4.86	0.0	0.2	0.10	0.12	224	18.9
Adults	6	22.7	216.0	90.69	72.06	-6.6	57.6	25.71	25.03	-0.3	0.6	0.20	0.33	313	55.6
Mothers	2	143.4	143.5	143.43	0.08	22.3	50.2	36.26	19.07	0.2	0.4	0.25	0.14	254	13.8
All non-calves	10	22.7	216.0	97.06	60.62	-6.6	57.6	23.70	22.60	-0.3	0.6	0.19	0.26	273	54.2
2000															
All	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1985-2000															
Calves	1	93.9	93.9	93.88	-	211.7	211.7	211.70	-	2.3	2.3	2.25	-	281	-
Subadults	20	23.8	385.1	121.99	117.96	-30.9	60.0	-2.61	17.81	-0.3	2.5	0.08	0.57	133	66.1
Adults	7	22.7	260.6	114.96	91.94	22.3	211.7	22.16	24.70	0.2	2.3	0.92	1.16	296	57.4
Mothers	3	93.9	143.5	126.92	28.61	-6.7	57.6	94.74	102.24	-0.3	0.6	0.17	0.31	263	16.8
All non-calves	30	22.7	385.1	120.84	104.57	-30.9	211.7	12.90	43.98	-0.3	2.5	0.18	0.63	198	76.0

APPENDIX 11.3. Rates and directions of movement determined from between-day resightings of bowhead whales in the Canadian Beaufort Sea (east of Herschel Isl.) and Amundsen Gulf, late summer and autumn 1982-1985.

		Time Between Resightings (h)				Net Distance Traveled (km)				Apparent Speed (km/h)				Net Direction of Movement (Degrees True)	
	n	Min	Max	Mean	s.d.	Min	Max	Mean	s.d.	Min	Max	Mean	s.d.	Mean	Angular Dev.
1984 Amundsen Gulf															
Calves	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subadults	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Adults	4	116.6	339.2	249.20	106.02	2.7	79.3	28.44	34.47	0.0	0.2	0.09	0.09	266	66.9
Mothers	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
All Non-Calves	4	116.6	339.2	249.20	106.02	2.7	79.3	28.44	34.47	0.0	0.2	0.09	0.09	266	66.9
1985 Amundsen Gulf															
Calves	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subadults	3	48.9	94.3	71.32	22.74	4.8	47.3	21.15	22.88	0.1	0.5	0.27	0.22	257	67.6
Adults	12	21.2	454.6	101.61	118.67	1.9	86.4	17.60	23.71	0.0	0.5	0.20	0.14	306	65.2
Mothers	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
All Non-Calves	15	21.2	454.6	95.55	106.29	1.9	86.4	18.31	22.77	0.0	0.5	0.21	0.15	298	66.6
1982 Yukon															
Calves	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subadults	11	41.5	455.8	183.27	159.53	4.6	150.3	53.19	59.52	0.0	1.3	0.37	0.45	137	61.0
Adults	5	22.2	46.0	39.53	9.81	1.7	19.0	8.01	6.68	0.0	0.4	0.22	0.17	139	40.5
Mothers	2	43.7	415.3	229.48	262.79	11.3	13.5	12.40	1.55	0.0	0.3	0.17	0.20	61	77.0
All Non-Calves	18	22.2	455.8	148.48	155.25	1.7	150.3	36.11	50.81	0.0	1.3	0.31	0.37	137	58.7
1984 Yukon															
Calves	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subadults	2	20.1	74.5	47.30	38.41	23.6	55.7	39.67	22.72	0.3	2.8	1.54	1.73	232	74.5
Adults	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mothers	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
All Non-Calves	2	20.1	74.5	47.30	38.41	23.6	55.7	39.67	22.72	0.3	2.8	1.54	1.73	232	74.5
1985 Yukon															
Calves	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subadults	31	19.8	481.6	169.65	139.76	2.2	71.6	23.70	14.86	0.0	2.3	0.34	0.47	89	61.8
Adults	3	20.7	189.0	125.81	91.65	26.8	53.9	39.89	13.59	0.1	1.9	0.78	0.96	250	60.4
Mothers	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
All Non-Calves	34	19.8	481.6	165.78	135.74	2.2	71.6	25.13	15.29	0.0	2.3	0.38	0.52	91	65.6
1982-1985															
Calves	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subadults	47	19.8	481.6	161.35	139.93	2.2	150.3	31.12	33.34	0.0	2.8	0.40	0.56	103	66.3
Adults	24	20.7	454.6	116.30	115.87	1.7	86.4	20.20	23.36	0.0	1.9	0.26	0.37	256	74.8
Mothers	2	43.7	415.3	229.48	262.79	11.3	13.5	12.40	1.55	0.0	0.3	0.17	0.20	61	77.0
All Non-Calves	73	19.8	481.6	148.41	135.62	1.7	150.3	27.01	30.28	0.0	2.8	0.35	0.50	110	73.7

APPENDIX 11.4A. Rates and directions of movement determined from within-day resightings (>15 min) of bowhead whales in the "eastern Alaskan" Beaufort Sea (including Yukon west of Herschel Isl.), late summer and autumn 1984-2000.

		Time Between Resightings (min)				Net Distance Traveled (km)				Apparent Speed (km/h)				Net Direction of Movement (Degrees True)	
	n	Min	Max	Mean	s.d.	Min	Max	Mean	s.d.	Min	Max	Mean	s.d.	Mean	Angular Dev.
1984															
Subadults	1	38.7	38.7	38.67	-	3.2	3.2	3.22	-	5.0	5.0	4.99	-	41	-
1985															
Calves	2	27.8	45.8	27.83	12.72	1.0	2.1	1.56	0.77	2.2	2.8	2.47	0.41	164	77
Subadults	22	23.0	264.6	44.47	50.52	0.6	9.2	2.23	1.74	1.3	7.2	3.51	1.67	72	63
Adults	7	24.9	56.1	37.99	11.59	0.8	3.6	2.29	0.93	0.9	5.2	3.84	1.46	141	73
Mothers	1	28.5	28.5	28.50	-	1.4	1.4	1.35	-	2.8	2.8	2.85	-	106	-
All Non-Calves	30	23.0	264.6	42.42	43.48	0.6	9.2	2.22	1.55	0.9	7.2	3.57	1.58	94	63
1986															
Calves	7	16.9	54.5	31.48	12.61	0.9	3.7	2.23	1.33	1.1	7.3	4.42	2.14	119	75
Subadults	19	15.0	87.2	34.00	17.32	0.3	4.8	1.58	1.35	0.5	6.1	2.78	1.67	50	73
Adults	7	25.2	98.8	52.63	28.03	0.3	4.3	2.86	1.46	0.2	7.2	4.10	2.59	343	72
Mothers	7	17.6	35.9	26.06	7.33	0.7	3.9	2.46	1.32	2.4	7.9	5.41	2.15	120	75
All Non-Calves	34 [a]	15.0	98.8	35.79	20.14	0.3	4.8	1.99	1.44	0.2	7.9	3.54	2.22	50	75
1998															
Calves	2	32.3	36.1	34.19	2.68	1.5	1.5	1.50	0.07	2.4	2.9	2.65	0.32	302	18
Subadults	12	16.8	72.2	44.70	22.12	0.2	1.9	1.21	0.62	0.4	6.5	2.00	1.72	289	36
Adults	7	17.6	68.9	44.25	20.27	0.1	2.9	1.80	0.95	0.3	6.1	2.69	1.82	301	25
Mothers	2	28.6	52.2	40.40	16.71	1.1	2.1	1.64	0.69	2.4	2.4	2.43	0.03	306	4
All Non-Calves	21	16.8	72.2	44.14	20.20	0.1	2.9	1.45	0.77	0.3	6.5	2.27	1.65	295	31
1999															
Calves	1	19.6	19.6	19.55	-	1.0	1.0	0.98	-	3.0	3.0	3.00	-	341	-
Subadults	5	16.1	37.7	27.93	9.96	0.2	2.4	1.17	1.05	0.8	7.7	2.78	3.00	303	24
Adults	22	15.2	59.1	31.87	13.49	0.1	1.8	0.79	0.56	0.4	3.5	1.41	0.76	298	48
Mothers	4	15.1	34.0	23.35	8.11	0.2	1.8	0.88	0.71	0.5	3.2	2.17	1.23	293	14
All Non-Calves	31	15.1	59.1	30.13	12.50	0.1	2.4	0.86	0.66	0.4	7.7	1.73	1.43	310	52
2000															
Calves	2	16.4	48.9	32.68	22.97	1.3	2.0	1.65	0.55	2.5	4.6	3.56	1.49	66	79
Subadults	2	50.5	293.5	171.98	171.85	0.2	1.0	0.59	0.55	0.2	0.2	0.22	0.02	180	77
Adults	1	22.6	22.6	22.63	-	2.1	2.1	2.08	-	5.5	5.5	5.51	-	309	-
Mothers	2	27.1	48.9	38.01	15.43	2.0	2.1	2.06	0.02	2.5	4.6	3.55	1.47	64	79
All Non-Calves	5	22.6	293.5	88.52	115.27	0.2	2.1	1.48	0.86	0.2	5.5	2.61	2.44	169	74
1984-2000															
Calves	14	16.4	54.5	31.95	11.97	0.9	3.7	1.86	1.03	1.1	7.3	3.67	1.74	69	75
Subadults	61	15.0	293.5	43.98	46.60	0.2	9.2	1.71	1.42	0.2	7.7	2.84	1.89	13	73
Adults	44	15.2	98.8	37.90	18.45	0.1	4.3	1.55	1.17	0.2	7.2	2.52	1.87	299	61
Mothers	16	15.1	52.2	28.82	10.48	0.2	3.9	1.84	1.13	0.5	7.9	3.83	2.13	56	75
All Non-Calves	122 [a]	15.0	293.5	39.61	35.22	0.1	9.2	1.65	1.29	0.2	7.9	2.84	1.94	328	72

[a] Includes one whale that was not measured and whose status could not be determined.

APPENDIX 11.4B. Net rates of movement in nominal westward migratory direction (288° True) determined from within-day resightings (>15 min) of bowhead whales in the "eastern Alaskan" Beaufort Sea (including Yukon west of Herschel Isl.), late summer and autumn 1984-2000.

		Time Between Resightings (min)				Net Distance Traveled (km)				Apparent Speed (km/h)				Net Direction of Movement (Degrees True)	
	n	Min	Max	Mean	s.d.	Min	Max	Mean	s.d.	Min	Max	Mean	s.d.	Mean	Angular Dev.
1984															
Subadults	1	38.7	38.7	38.67	-	-1.3	-1.3	-1.28	-	-2.0	-2.0	-1.99	-	41	-
1985															
Calves	2	27.8	45.8	27.83	12.72	-0.9	1.6	0.38	1.79	-1.9	2.2	0.12	2.88	164	77
Subadults	22	23.0	264.6	44.47	50.52	-9.1	3.9	-0.73	2.58	-4.6	7.0	-0.58	3.41	72	63
Adults	7	24.9	56.1	37.99	11.59	-3.1	2.1	-1.21	1.68	-4.6	5.0	-1.60	3.12	141	73
Mothers	1	28.5	28.5	28.50	-	-1.4	-1.4	-1.35	-	-2.8	-2.8	-2.85	-	106	-
All Non-Calves	30	23.0	264.6	42.42	43.48	-9.1	3.9	-0.86	2.33	-4.6	7.0	-0.89	3.28	94	63
1986															
Calves	7	16.9	54.5	31.48	12.61	-3.7	3.7	-0.82	2.42	-6.5	7.3	-1.39	4.51	119	75
Subadults	19	15.0	87.2	34.00	17.32	-3.5	2.5	-0.03	1.31	-3.7	3.5	0.14	1.92	50	73
Adults	7	25.2	98.8	52.63	28.03	-3.0	2.6	0.55	2.09	-1.8	5.2	1.87	2.89	343	72
Mothers	7	17.6	35.9	26.06	7.33	-3.7	3.7	-0.77	2.46	-6.5	7.3	-1.56	4.63	120	75
All Non-Calves	34 [a]	15.0	98.8	35.79	20.14	-3.7	3.7	-0.05	1.74	-6.5	7.3	0.17	2.95	50	75
1998															
Calves	2	32.3	36.1	34.19	2.68	1.2	1.5	1.39	0.22	2.1	2.9	2.46	0.58	302	18
Subadults	12	16.8	72.2	44.70	22.12	-0.9	1.8	0.89	0.77	-1.3	6.4	1.55	1.91	289	36
Adults	7	17.6	68.9	44.25	20.27	0.1	2.7	1.61	0.94	0.3	6.1	2.42	1.88	301	25
Mothers	2	28.6	52.2	40.40	16.71	1.1	2.1	1.57	0.71	2.2	2.4	2.31	0.11	306	4
All Non-Calves	21	16.8	72.2	44.14	20.20	-0.9	2.7	1.20	0.87	-1.3	6.4	1.92	1.81	295	31
1999															
Calves	1	19.6	19.6	19.55	-	0.6	0.6	0.59	-	1.8	1.8	1.80	-	341	-
Subadults	5	16.1	37.7	27.93	9.96	-1.1	0.5	0.04	0.69	-3.6	0.9	-0.29	1.91	303	24
Adults	22	15.2	59.1	31.87	13.49	-0.7	1.7	0.57	0.70	-1.8	3.4	0.86	1.14	298	48
Mothers	4	15.1	34.0	23.35	8.11	-0.5	1.7	0.49	0.91	-1.9	3.0	0.83	2.09	293	14
All Non-Calves	31	15.1	59.1	30.13	12.50	-1.1	1.7	0.48	0.72	-3.6	3.4	0.67	1.42	310	52
2000															
Calves	2	16.4	48.9	32.68	22.97	-1.2	0.4	-0.38	1.17	-4.4	0.6	-1.92	3.50	66	79
Subadults	2	50.5	293.5	171.98	171.85	-0.1	0.0	-0.05	0.10	-0.1	0.0	-0.07	0.10	180	77
Adults	1	22.6	22.6	22.63	-	1.9	1.9	1.94	-	5.2	5.2	5.15	-	309	-
Mothers	2	27.1	48.9	38.01	15.43	-2.0	0.4	-0.78	1.74	-4.4	0.6	-1.95	3.53	64	79
All Non-Calves	5	16.4	293.5	88.52	115.27	-2.0	1.9	0.06	1.42	-4.4	5.2	0.22	3.41	169	74
1984-2000															
Calves	14	16.4	54.5	31.95	11.97	-3.7	3.7	-0.17	1.94	-6.5	7.3	-0.47	3.68	69	75
Subadults	61	15.0	293.5	43.98	46.60	-9.1	3.9	-0.12	1.83	-4.6	7.0	0.08	2.60	13	73
Adults	44	15.2	98.8	37.90	18.45	-3.1	2.7	0.48	1.45	-4.6	6.1	0.97	2.37	299	61
Mothers	16	15.1	52.2	28.82	10.48	-3.7	3.7	-0.20	1.91	-6.5	7.3	-0.61	3.60	56	75
All Non-Calves	122 [a]	15.0	293.5	39.61	35.22	-9.1	3.9	0.09	1.72	-6.5	7.3	0.32	2.70	328	72

[a] Includes one whale that was not measured and whose status could not be determined.

APPENDIX 11.5. Rates and directions of movement determined from within-day resightings (>15 min) of bowhead whales in the Canadian Beaufort Sea (east of Herschel Isl.) and Amundsen Gulf, late summer and autumn 1982-1985.

		Time Between Resightings (min)				Net Distance Traveled (km)				Apparent Speed (km/h)				Net Direction of Movement (Degrees True)	
	n	Min	Max	Mean	s.d.	Min	Max	Mean	s.d.	Min	Max	Mean	s.d.	Mean	Angular Dev.
1984 Amundsen Gulf															
Calves	2	25.4	33.8	29.60	5.99	1.0	1.8	1.40	0.60	1.7	4.3	3.03	1.83	337	72
Subadults	3	30.7	33.3	32.29	1.41	1.1	2.3	1.56	0.62	2.0	4.4	2.93	1.31	6	24
Adults	9	33.5	49.9	37.78	5.30	0.4	3.7	1.52	1.02	0.8	4.4	2.36	1.35	281	52
Mothers	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
All Non-Calves	12	30.7	49.9	36.41	5.19	0.4	3.7	1.53	0.91	0.8	4.4	2.50	1.30	308	56
1985 Amundsen Gulf															
Calves	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subadults	10	18.7	54.8	28.97	10.12	0.6	2.1	1.38	0.58	1	5.3	3.14	1.57	16	72
Adults	28	19.5	85.9	35.71	15.77	0.4	3.9	1.76	1.04	0.9	7.1	3.09	1.86	84	60
Mothers	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
All Non-Calves	38	18.7	85.9	33.94	14.68	0.4	3.9	1.66	0.95	0.9	7.1	3.11	1.77	75	65
1982 Yukon East															
Calves	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subadults	9	18.9	126.5	65.85	34.87	0.8	3.9	2.57	1.18	0.8	5.1	2.77	1.58	118	68
Adults	14	24.1	193.9	80.17	54.39	0.4	9.0	2.00	2.18	0.3	3.6	1.74	1.15	99	51
Mothers	2	88.3	137.1	112.70	34.53	0.6	1.5	1.07	0.62	0.4	0.7	0.55	0.16	132	6
All Non-Calves	25	18.9	193.9	77.62	47.07	0.4	9.0	2.13	1.80	0.3	5.1	2.02	1.41	108	57
1984 Yukon East															
Calves	1	32.4	32.4	32.42	-	1.0	1.0	0.96	-	1.8	1.8	1.78	-	235	-
Subadults	30	15.8	110.4	36.26	19.01	0.2	4.1	1.55	0.83	0.5	6.8	3.03	1.95	280	72
Adults	1	77.0	77.0	76.97	-	3.8	3.8	3.80	-	3.0	3.0	2.96	-	22	-
Mothers	1	32.4	32.4	32.42		1.0	1.0	0.96	-	1.8	1.8	1.78	-	235	-
All Non-Calves	32	15.8	110.4	37.41	19.77	0.2	4.1	1.55	0.83	0.5	6.8	2.99	1.90	283	72
1985 Yukon East															
Calves	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subadults	65	16.0	321.2	71.63	61.85	0.4	8.2	2.48	1.85	0.4	8.8	2.79	1.91	305	75
Adults	1	31.2	3.1	31.17	-	2.7	2.7	2.65	-	5.1	5.1	5.11	-	295	-
Mothers	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
All Non-Calves	67 [a]	15.5	321.2	70.19	61.48	0.4	8.2	2.45	1.83	0.4	8.8	2.83	1.91	310	74
1982-1985															
Calves	3	25.4	33.8	30.54	4.53	1.0	1.8	1.25	0.50	1.7	4.3	2.61	1.48	256	66
Subadults	117	15.8	321.2	57.46	51.12	0.2	8.2	2.13	1.55	0.4	8.8	2.88	1.84	313	76
Adults	53	19.5	193.9	48.50	35.67	0.4	9.0	1.84	1.42	0.3	7.1	2.65	1.69	81	68
Mothers	3	32.4	137.1	85.94	52.39	0.6	1.5	1.04	0.45	0.4	1.8	0.96	0.72	160	46
All Non-Calves	174 [a]	15.5	321.2	59.98	47.00	0.2	9.0	2.02	1.51	0.3	8.8	2.78	1.79	25	78

[a] Includes one whale that was not measured and whose status could not be determined.

APPENDIX 11.6A. Net speeds during surface-dive sequences of undisturbed whales in the "eastern Alaskan" Beaufort Sea in each of the five study years (1985, 1986, 1998, 1999, 2000). Numbers in parentheses indicate the number of individual whales observed. Based on observations from a twin engine aircraft at altitude ≥460 m.

Year	Net Speed During Dive (km/h)			Net Distance Traveled (km)			Duration of Dive (min) [a]			Duration of Surfacing (min) [a]		
Status	mean	s.d.	*n*	mean	s.d.	*n*	mean	s.d.	*n*	mean	s.d.	*n*
1985												
Calves	1.03	0.20	4(2)	0.25	0.00	4(2)	15.04	2.89	4(2)	1.64	1.42	4(2)
Subadults	1.36	0.64	3(2)	0.33	0.14	3(2)	16.82	8.54	3(2)	1.88	0.07	2(1)
Adults	0.86	0.50	4(2)	0.35	0.25	4(2)	24.27	4.77	4(2)	2.44	0.31	3(2)
Mothers	0.82	0.50	5(3)	0.20	0.11	5(3)	12.40	6.43	5(3)	2.20	1.01	5(3)
Unknown	1.77	1.14	6(5)	0.27	0.26	6(5)	21.17	17.28	3(2)	0.66	0.46	2(2)
All Non-Calves	1.24	0.85	18(12)	0.28	0.20	18(12)	18.20	9.73	15(9)	1.95	0.90	12(8)
1986												
Calves	2.86	1.89	5(3)	0.45	0.36	5(3)	8.79	3.88	3(2)	0.18	0.13	3(2)
Subadults	1.90	0.17	2(2)	0.15	0.15	2(2)	8.92	0.00	1(1)	1.17	0.00	1(1)
Adults	4.21	1.59	8(3)	1.23	0.51	8(3)	18.43	4.74	8(3)	2.62	1.10	7(2)
Mothers	2.87	1.43	3(2)	0.57	0.40	3(2)	12.20	6.95	3(2)	1.58	1.14	3(2)
Unknown	4.28	2.30	17(6)	1.35	1.23	17(6)	18.64	9.42	14(4)	1.51	0.22	13(5)
All Non-Calves	3.96	2.04	30(13)	1.16	1.02	30(13)	17.46	7.98	26(10)	1.83	0.85	24(10)
1998												
Calves	4.06	1.02	17(4)	0.62	0.18	17(4)	8.36	3.66	8(4)	1.67	1.18	12(4)
Subadults	3.31	1.49	11(4)	0.64	0.52	11(4)	10.27	7.10	8(3)	1.38	0.39	9(4)
Adults	4.95	0.69	5(2)	0.95	0.40	5(2)	11.23	3.67	5(2)	1.76	0.27	5(2)
Mothers	4.05	1.02	19(4)	0.81	0.30	19(4)	13.11	4.64	11(4)	2.77	0.63	16(4)
Unknown	4.27	1.40	2(2)	0.81	0.56	2(2)	7.58	0.00	1(1)	1.65	0.00	1(1)
All Non-Calves	3.97	1.23	37(12)	0.78	0.40	37(12)	11.60	5.32	25(10)	2.17	0.82	31(11)
1999												
Calves	1.73	1.79	4(3)	0.20	0.21	4(3)	7.32	0.00	1(1)	0.68	0.05	2(2)
Subadults	0.86	1.22	2(2)	0.28	0.39	2(2)	1.90	0.00	1(1)	0.33	0.00	1(1)
Adults	1.43	0.72	7(4)	0.35	0.24	7(4)	13.96	2.81	7(4)	2.11	0.89	7(4)
Mothers	1.83	0.57	2(1)	0.33	0.28	2(1)	21.37	0.00	1(1)	1.45	0.03	2(1)
Unknown	2.57	2.19	16(9)	0.65	0.53	16(9)	15.88	2.16	13(7)	2.42	0.43	12(6)
All Non-Calves	2.09	1.83	27(16)	0.52	0.46	27(16)	14.88	3.98	22(13)	2.14	0.76	22(12)
2000												
Calves	3.12	0.73	7(2)	0.38	0.17	7(2)	6.37	3.77	7(2)	1.01	0.58	6(2)
Subadults	4.59	0.68	14(4)	0.41	0.34	14(4)	5.07	5.16	14(4)	0.59	0.52	13(4)
Adults	3.38	1.93	11(3)	0.64	0.43	11(3)	9.12	4.64	11(3)	1.20	0.63	11(3)
Mothers	2.43	1.53	9(2)	0.51	0.65	9(2)	8.73	9.58	9(2)	1.45	0.97	9(2)
Unknown	2.93	2.17	3(2)	1.35	0.99	3(2)	26.54	1.81	3(2)	1.34	0.31	3(2)
All Non-Calves	3.57	1.66	37(11)	0.58	0.55	37(11)	8.90	8.24	37(11)	1.05	0.75	36(11)
ALL Non-Calves	**3.20**	**1.88**	**149**	**0.70**	**0.66**	**149**	**13.39**	**8.04**	**125**	**1.76**	**0.92**	**125**

[a] Durations of dives and surfacings listed here are those for the subsample where net speed was determined. See Chapters 13 and 14 for data from all whales observed.

APPENDIX 11.6B. Net speeds in nominal westward migratory direction (288° T) during surface-dive sequences of undisturbed whales in the "eastern Alaskan" Beaufort Sea in each of the five study years (1985, 1986, 1998, 1999, 2000). Numbers in parentheses indicate the number of individual whales observed. Based on observations from a twin engine aircraft at altitude ≥460 m.

Year	Net Speed During Dive (km/h)			Net Distance Traveled (km)			Duration of Dive (min) [a]			Duration of Surfacing (min) [a]		
Status	mean	s.d.	*n*	mean	s.d.	*n*	mean	s.d.	*n*	mean	s.d.	*n*
1985												
Calves	-0.80	-	1(1)	-0.24	-	1(1)	15.04	2.89	4(2)	1.64	1.42	4(2)
Subadults	1.89	-	1(1)	0.23	-	1(1)	16.82	8.54	3(2)	1.88	0.07	2(1)
Adults	-	-	0(0)	0.35	0.25	0(0)	24.27	4.77	4(2)	2.44	0.31	3(2)
Mothers	-0.42	0.59	2(2)	-0.12	0.18	2(2)	12.40	6.43	5(3)	2.20	1.01	5(3)
Unknown	1.77	-	1(1)	0.27	0.26	1(1)	21.17	17.28	3(2)	0.66	0.46	2(2)
All Non-Calves	0.26	1.16	4(4)	0.00	0.20	4(4)	18.20	9.73	15(9)	1.95	0.90	12(8)
1986												
Calves	-2.11	-	1(1)	-0.42	-	1(1)	8.79	3.88	3(2)	0.18	0.13	3(2)
Subadults	-0.49	2.03	2(2)	-0.11	0.18	2(2)	8.92	0.00	1(1)	1.17	0.00	1(1)
Adults	4.17	1.59	8(3)	1.22	0.51	8(3)	18.43	4.74	8(3)	2.62	1.10	7(2)
Mothers	-1.55	-	1(1)	-0.48	-	1(1)	12.20	6.95	3(2)	1.58	1.14	3(2)
Unknown	2.23	2.70	9(4)	0.62	0.71	9(4)	18.64	9.42	14(4)	1.51	0.22	13(5)
All Non-Calves	2.54	2.69	20(10)	0.73	0.75	20(10)	17.46	7.98	26(10)	1.83	0.85	24(10)
1998												
Calves	2.40	2.19	17(4)	0.35	0.33	17(4)	8.36	3.66	8(4)	1.67	1.18	12(4)
Subadults	-0.83	2.76	11(4)	-0.03	0.58	11(4)	10.27	7.10	8(3)	1.38	0.39	9(4)
Adults	3.38	1.25	5(2)	0.66	0.41	5(2)	11.23	3.67	5(2)	1.76	0.27	5(2)
Mothers	2.23	2.36	19(4)	0.42	0.51	19(4)	13.11	4.64	11(4)	2.77	0.63	16(4)
Unknown	3.22	2.81	2(2)	0.68	0.74	2(2)	7.58	0.00	1(1)	1.65	0.00	1(1)
All Non-Calves	1.53	2.81	37(12)	0.34	0.57	37(12)	11.60	5.32	25(10)	2.17	0.82	31(11)
1999												
Calves	0.70	0.93	3(2)	0.06	0.05	3(2)	7.32	0.00	1(1)	0.68	0.05	2(2)
Subadults	0.53	0.75	2(2)	0.17	0.24	2(2)	1.90	0.00	1(1)	0.33	0.00	1(1)
Adults	-0.43	1.16	7(4)	-0.09	0.28	7(4)	13.96	2.81	7(4)	2.11	0.89	7(4)
Mothers	0.90	1.21	2(1)	0.06	0.06	2(1)	21.37	0.00	1(1)	1.45	0.03	2(1)
Unknown	2.03	2.20	16(9)	0.50	0.54	16(9)	15.88	2.16	13(7)	2.42	0.43	12(6)
All Non-Calves	1.20	2.09	27(16)	0.29	0.51	27(16)	14.88	3.98	22(13)	2.14	0.76	22(12)
2000												
Calves	1.06	2.78	7(2)	0.03	0.35	7(2)	6.37	3.77	7(2)	1.01	0.58	6(2)
Subadults	4.32	0.87	14(4)	0.39	0.34	14(4)	5.07	5.16	14(4)	0.59	0.52	13(4)
Adults	3.11	1.79	11(3)	0.60	0.41	11(3)	9.12	4.64	11(3)	1.20	0.63	11(3)
Mothers	0.52	2.32	9(2)	-0.10	0.56	9(2)	8.73	9.58	9(2)	1.45	0.97	9(2)
Unknown	2.77	2.29	3(2)	1.27	1.05	3(2)	26.54	1.81	3(2)	1.34	0.31	3(2)
All Non-Calves	2.91	2.21	37(11)	0.40	0.60	37(11)	8.90	8.24	37(11)	1.05	0.75	36(11)
ALL Non-Calves	**1.99**	**2.52**	**125**	**0.40**	**0.60**	**125**	**13.39**	**8.04**	**125**	**1.76**	**0.92**	**125**

[a] Durations of dives and surfacings listed here are those for the subsample where net speed was determined. See Chapters 13 and 14 for data from all whales observed.

APPENDIX 11.7A. Net speeds during surface-dive sequences of undisturbed whales engaged in various activities in the "eastern Alaskan" Beaufort Sea (including Yukon west of Herschel Isl.) during September (1985-86, 1998-2000). Numbers in parentheses indicate the number of individual whales observed. Based on observations from a twin engine aircraft at altitude ≥460 m.

Whale Activity	Net Speed During Dive (km/h)			Net Distance Traveled (km)			Duration of Dive (min) [a]			Duration of Surfacing (min) [a]		
Status	mean	s.d.	*n*	mean	s.d.	*n*	mean	s.d.	*n*	mean	s.d.	*n*
Feed												
Calves	1.22	0.82	6(3)	0.29	0.19	6(3)	10.93	1.58	2(2)	0.91	0.93	3(3)
Subadults	2.45	1.53	13(7)	0.39	0.22	13(7)	11.24	6.13	9(4)	1.51	0.41	10(5)
Adults	1.18	0.51	9(5)	0.32	0.16	9(5)	16.12	4.98	9(5)	1.90	0.24	8(4)
Mothers	1.23	0.32	4(2)	0.31	0.13	4(2)	15.15	3.20	4(2)	1.81	0.63	4(2)
Unknown	0.87	0.71	11(6)	0.20	0.17	11(6)	17.19	2.37	6(3)	1.96	0.50	8(5)
All Non-Calves	1.54	1.21	37(20)	0.31	0.19	37(20)	14.64	5.17	28(14)	1.77	0.45	30(16)
Travel												
Calves	3.93	1.02	21(6)	0.58	0.19	21(6)	7.81	3.54	13(6)	1.40	1.10	16(6)
Subadults	4.42	0.93	15(5)	0.40	0.33	15(5)	5.22	5.00	15(5)	0.59	0.52	13(4)
Adults	4.55	1.03	20(6)	1.02	0.45	20(6)	13.14	4.90	20(6)	1.80	0.98	20(6)
Mothers	4.00	0.92	17(4)	0.82	0.44	17(4)	12.41	7.80	10(4)	2.43	0.96	14(4)
Unknown	4.94	1.64	20(8)	1.53	1.06	20(8)	18.99	9.12	17(5)	1.68	0.55	15(5)
All Non-Calves	4.50	1.22	72(23)	0.99	0.76	72(23)	12.71	8.30	62(20)	1.66	1.00	62(19)
Travel+Feed												
Calves	1.45	1.10	2(1)	0.15	0.02	2(1)	-	-	-	-	-	-
Subadults	3.03	2.03	4(2)	0.90	0.86	4(2)	11.63	13.72	3(2)	0.88	0.47	3(2)
Adults	-	-	-	-	-	-	-	-	-	-	-	-
Mothers	3.28	1.36	9(3)	0.70	0.36	9(3)	15.56	5.08	7(3)	2.29	0.78	9(3)
Unknown	3.53	1.76	6(4)	0.92	0.43	6(4)	15.31	0.44	5(3)	2.55	0.35	4(2)
All Non-Calves	3.31	1.55	19(9)	0.81	0.49	19(9)	14.69	6.37	15(8)	2.09	0.87	16(7)
Other/Unknown												
Calves	2.79	1.84	6(4)	0.31	0.34	6(4)	7.93	6.29	5(3)	1.32	1.51	5(3)
Subadults	-	-	-	-	-	-	-	-	-	-	-	-
Adults	1.25	1.44	6(3)	0.38	0.383	6(3)	15.15	11.86	6(3)	2.25	1.36	5(3)
Mothers	1.60	1.64	8(4)	0.23	0.33	8(4)	6.14	6.24	8(4)	1.78	1.30	8(4)
Unknown	1.73	1.13	7(6)	0.35	0.202	7(6)	19.27	12.71	6(5)	1.14	0.62	4(4)
All Non-Calves	1.54	1.37	21(13)	0.31	0.30	21(13)	12.78	11.29	20(12)	1.77	1.20	17(11)
ALL Non-Calves	**3.20**	**1.88**	**149**	**0.70**	**0.66**	**149**	**13.39**	**8.04**	**125**	**1.76**	**0.92**	**125**

[a] Durations of dives and surfacings listed here are those for the subsample where net speed was determined. See Chapters 13 and 14 for data from all whales observed.

APPENDIX 11.7B. Net speeds in a nominal westward migratory direction (288° T) during surface-dive sequences of undisturbed whales engaged in various activities in the "eastern Alaskan" Beaufort Sea (including Yukon west of Herschel Isl.) during September (1985-86, 1998-2000). Numbers in parentheses indicate the number of individual whales observed. Based on observations from a twin engine aircraft at altitude ≥460 m.

Whale Activity	Net Speed During Dive (km/h)			Net Distance Traveled (km)			Duration of Dive (min) [a]			Duration of Surfacing (min) [a]		
Status	mean	s.d.	*n*	mean	s.d.	*n*	mean	s.d.	*n*	mean	s.d.	*n*
Feed												
Calves	-0.96	1.18	4(3)	-0.18	0.22	4(3)	10.93	1.58	2(2)	0.91	0.93	3(3)
Subadults	-1.47	2.06	11(6)	-0.20	0.31	11(6)	11.24	6.13	9(4)	1.51	0.41	10(5)
Adults	-0.36	1.25	7(4)	-0.05	0.35	7(4)	16.12	4.98	9(5)	1.90	0.24	8(4)
Mothers	-1.55	-	1(1)	-0.48	-	1(1)	15.15	3.20	4(2)	1.81	0.63	4(2)
Unknown	-0.10	0.74	11(6)	-0.02	0.16	11(6)	17.19	2.37	6(3)	1.96	0.50	8(5)
All Non-Calves	-0.71	1.55	30(17)	-0.11	0.28	30(17)	14.64	5.17	28(14)	1.77	0.45	30(16)
Travel												
Calves	2.28	2.42	20(6)	0.31	0.37	20(6)	7.81	3.54	13(6)	1.40	1.10	16(6)
Subadults	4.16	1.05	15(5)	0.38	0.33	15(5)	5.22	5.00	15(5)	0.59	0.52	13(4)
Adults	4.04	1.13	20(6)	0.93	0.48	20(6)	13.14	4.90	20(6)	1.80	0.98	20(6)
Mothers	1.10	2.66	17(4)	0.11	0.75	17(4)	12.41	7.80	10(4)	2.43	0.96	14(4)
Unknown	4.14	1.65	12(6)	4.14	1.65	12(6)	18.99	9.12	17(5)	1.68	0.55	15(5)
All Non-Calves	3.67	1.74	64(21)	0.71	0.59	64(21)	12.71	8.30	62(20)	1.66	1.00	62(19)
Travel+Feed												
Calves	1.06	0.99	2(1)	0.09	0.01	2(1)	-	-	-	-	-	-
Subadults	1.78	1.86	4(2)	0.49	0.63	4(2)	11.63	13.72	3(2)	0.88	0.47	3(2)
Adults	-	-	-	-	-	-	-	-	-	-	-	-
Mothers	0.48	2.47	9(3)	0.05	0.47	9(3)	15.56	5.08	7(3)	2.29	0.78	9(3)
Unknown	3.35	1.14	5(3)	0.86	0.31	5(3)	15.31	0.44	5(3)	2.55	0.35	4(2)
All Non-Calves	1.57	2.32	18(8)	0.37	0.57	18(8)	14.69	6.37	15(8)	2.09	0.87	16(7)
Other/Unknown												
Calves	1.18	1.81	3(2)	0.02	0.22	3(2)	7.93	6.29	5(3)	1.32	1.508	5(3)
Subadults	-	-	-	-	-	-	-	-	-	-	-	-
Adults	0.76	1.08	4(2)	0.18	0.23	4(2)	15.15	11.86	6(3)	2.25	1.36	5(3)
Mothers	0.35	0.92	6(3)	0.00	0.14	6(3)	6.14	6.24	8(4)	1.78	1.30	8(4)
Unknown	0.67	0.55	3(3)	0.13	0.06	3(3)	19.27	12.71	6(5)	1.14	0.62	4(4)
All Non-Calves	0.55	0.86	13(8)	0.09	0.17	13(8)	12.78	11.29	20(12)	1.77	1.20	17(11)
ALL Non-Calves	**1.99**	**2.521**	**125**	**0.40**	**0.60**	**125**	**13.39**	**8.04**	**125**	**1.76**	**0.92**	**125**

[a] Durations of dives and surfacings listed here are those for the subsample where net speed was determined. See Chapters 13 and 14 for data from all whales observed.

12. ACTIVITIES AND BEHAVIOR OF BOWHEAD WHALES IN THE EASTERN ALASKAN BEAUFORT SEA DURING LATE SUMMER AND AUTUMN

Bernd Würsig[1], William R. Koski[2], Tannis A. Thomas[2], and W. John Richardson[2]

Introduction

Bowhead whales (*Balaena mysticetus*) of the Bering–Chukchi–Beaufort (BCB) stock migrate into the Beaufort Sea and Amundsen Gulf in spring; reside there from May or June to August, September or even October, depending on the individual; and migrate back to the west in late August–October (Moore and Reeves 1993). The eastward spring migration tends to be through leads well offshore from the Alaskan North Slope (Braham et al. 1980; Moore and Reeves 1993). However, much of the late summer–autumn migration is through waters <200 m deep closer to shore (Mate et al. 2000; Moore 2000; Moore et al. 2000; Treacy 2000, 2002; see also Chapter 9). Summer activities include feeding, socializing, traveling within the summer range, resting, and various aerial behaviors (Würsig et al. 1985, 1989). During the westward migration in late summer–autumn, bowhead whales continue to engage in a variety of activities including not only active travel, but also feeding, socializing, resting, etc. During this westward migration, numerous bowheads travel close to the Inupiat village of Kaktovik, the easternmost Alaskan village on the North Slope. The majority of the bowheads harvested by Kaktovik hunters have food in their stomachs, indicative of recent feeding; copepods are the predominant food items in this area, with lesser proportions of euphausiids, amphipods, and mysids (Lowry 1993; see also Chapter 18).

The activities and behavior of bowhead whales of the BCB stock have received considerable attention in the past 20 years (summaries in Würsig and Clark 1993; Richardson et al. 1995a). These studies of bowhead behavior have concentrated on the summering grounds in the Canadian Beaufort Sea, and spring migration around Alaska. Here we provide corresponding details on the activities of bowheads in and near the eastern Alaskan Beaufort Sea during the late summer–early autumn period (mainly September), including the specific behaviors of whales engaged in the main activities. This information was needed as one part of a broader assessment of the importance of the eastern Alaskan Beaufort Sea to bowhead whales. This account is based on systematic behavioral studies during September of five years—1985, 1986, 1998, 1999, and 2000. The study area consisted of the eastern Alaskan Beaufort Sea and adjacent Canadian waters east to Herschel Island (Fig. 12.1).

In this chapter we distinguish between activities and behaviors. Activities are combinations of behaviors that have a common purpose or function such as feeding, traveling, resting, or socializing. Some specific behaviors are most commonly seen during one particular activity, e.g., mouth opening is most often associated with feeding. Other behaviors such as surfacing, diving, and turning are seen during most or all activities. However, the durations or frequencies of these behaviors often change depending on the activity of the whale.

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[1] Texas A&M University at Galveston, Marine Mammal Research Program, 4700 Ave. U., Bldg 303, Galveston, TX 77551-5923. *Phone:* 409-740-4413; *e-mail:* wursigb@tamug.tamu.edu

[2] LGL Ltd., environmental research associates, 22 Fisher St., POB 280, King City, Ont. L7B 1A6. *Phone:* 905-833-1244; *e-mail:* bkoski@lgl.com

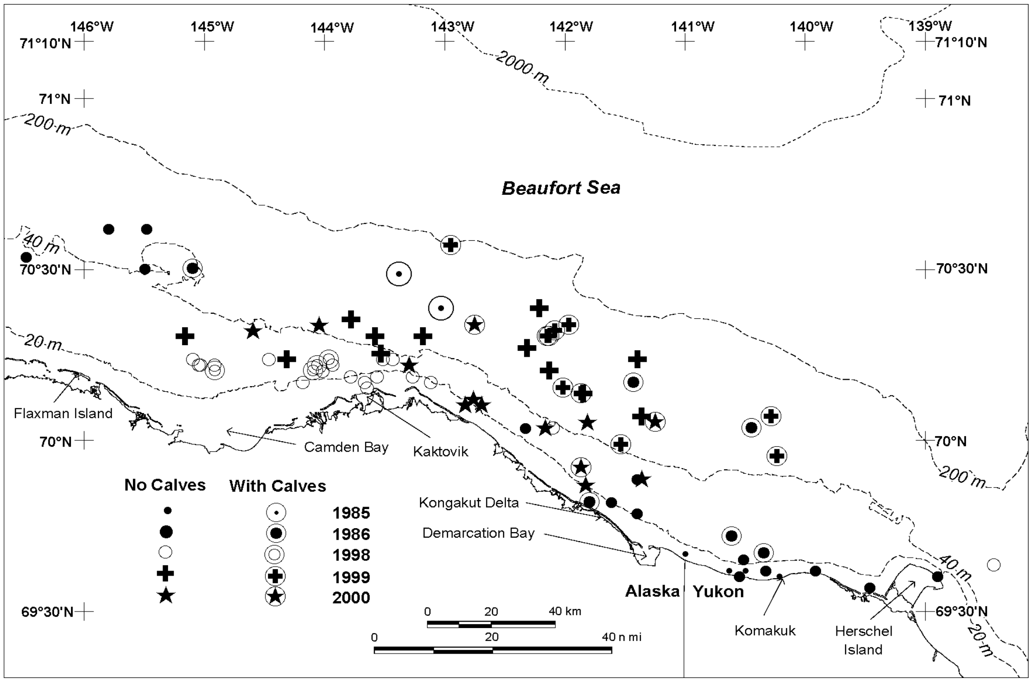

FIGURE 12.1. Locations in and near the eastern Alaskan Beaufort Sea where activities and behavior of bowhead whales were observed systematically during late summer and autumn, by year (1985–86, 1998–2000). Behavioral observation sessions (BOSs) including one or more mother–calf pairs are circled. Based on observations from a twin-engine aircraft circling at altitude ≥460 m; excludes periods with other types of potential disturbance.

Bowhead whales, like other cetaceans, spend far less than 50% of their time in view of observers at or above the water's surface (Richardson et al. 1995a). In most studies of cetacean behavior, it has not been possible to apply radio tags or other instruments. Instead, we attempt to ascertain their general activities and associated specific behaviors from the relatively short glimpses afforded to us while whales surface to breathe or are engaged in other surface behaviors. This means that sub-surface activities, such as presumed water column or bottom feeding, or calves nursing from their mothers, can only be surmised from what the animals do while they are at or near the surface, and from changes in location from one surfacing to the next. Nevertheless, we believe that our glimpses of activities at or near the surface provide generally good indications of major activities while whales are below the surface and out of sight. In this chapter we describe these activities and associated behaviors as they occur in and near the eastern Alaskan Beaufort Sea in September. Many of the activities and behaviors in this area and season are similar to those previously described for summer (Würsig et al. 1985, 1989; Würsig and Clark 1993; Richardson et al. 1995a). In these cases, our descriptions are brief. However, the frequencies of occurrence of various activities and behaviors in the present study area, mainly in September, differ from those previously reported from the Canadian summer range, mainly in August. Some of these differences may be important in assessing the importance of the present study area to bowhead whales.

The major objectives of this chapter are (1) to describe the general activities of bowhead whales while they are off northeastern Alaska in late summer and early autumn, (2) to document the specific behaviors associated with these activities, and (3) to determine the proportion of time engaged in each activity (time budget). We compare our data to previously reported data on activities, behaviors, and time budgets during spring and summer, and also demonstrate variability among years. Companion chapters provide related details on seasonal distribution and numbers in the study area; habitat preferences; rates of movement and residence times; surfacing, respiration and dive cycles; food availability; and diet. The concluding chapters use all of these types of data, along with an energetic model, to assess the importance of the present study areas for feeding by bowhead whales. An ultimate goal, not to be realized here, is to know enough about bowhead whale behavior and ecology through the year to predict feeding and social needs for different phases of their annual migratory cycle.

Methods

Behavioral observations were carried out from a circling DHC-6-300 Twin Otter aircraft in 1985–86 and a Twin Commander 680FL aircraft in 1998–2000.

Data Sources

Behavior of undisturbed whales was observed systematically during five years, almost exclusively in the month of September, with the exception of 2 days in early October 1986. The data were obtained during MMS-sponsored studies of bowhead feeding ecology in 1985–86 (Richardson et al. 1987b) and 1998–2000 (present study), and during a separate 1986 study sponsored by Shell Western Exploration & Production (SWEPI; Koski and Johnson 1987).

A total of 84 Behavioral Observation Sessions (BOSs) were conducted while the aircraft circled above presumably-undisturbed whales (Fig. 12.1). In 1985–86, BOSs lasted from tens of minutes to 3.5 h, plus one 1986 BOS that was 6.7 h long (Appendix 12.1A–C). In 1998–2000, BOSs tended to be 1 h or less in duration (Appendix 12.1D–F). The main reason for shorter BOSs in later years was to increase sample size for time-budget estimates. With the shorter BOSs, we could still determine general whale activities, obtain more BOSs per season, leave sufficient time for photogrammetry after most BOSs (see Chapter 10), and have less variable BOS durations. The larger number of shorter and similar-length BOSs was an advantage for statistical analysis, providing a larger number of independent samples with less pseudoreplication. Total duration of the 84 BOSs of undisturbed whales was 91.9 h, during which we obtained 234 observations of surfacings by mothers and calves, and 1206 records of surfacings by other whales (Table 12.1). Appendix 12.1 lists the individual BOSs and summarizes their locations, the numbers of whales observed, and general whale activities. Of the 84 “undisturbed” BOSs, 69 were within the eastern Alaskan Beaufort Sea proper, and 15 were in Canadian waters (Fig. 12.1; Appendix 12.1A-F).

Aerial Observations

We used the aerial observation procedures of Würsig et al. (1985), Richardson et al. (1985, 1995a), and Thomas et al. (Chapter 13) to describe activities and behaviors of bowhead whales. Three to four observers (rarely, 5) in either a Twin Otter (1985–86) or Twin Commander (1998–2000) circled above whales at altitude 460 m or occasionally 610 m above sea level (a.s.l.)—high enough to avoid significant aircraft disturbance (Richardson et al. 1985; Patenaude et al. 2002). Airspeed during circling, often with some “flaps engaged” to slow the aircraft, was usually <100 knots (185 km/h). We attempted to remain at a radius of 1–2 km from whales that we were observing. Aircraft navigation was primarily via a Very Low Frequency (VLF) system in 1985–86 and Global Positioning System (GPS) in 1998–2000.

Throughout each observation session, two or three full-time observers on the right side of the aircraft dictated standardized behavioral observations and whale position data via the intercom into a single audio recorder and also into the audio channel of a video recorder. Another person on the right side operated a video camera whenever whales were at the surface. In the 1985–86 studies, a fourth (and, rarely,

TABLE 12.1. Summary of number of behavioral observation sessions (BOSs), whales, and observations of surfacings for various group activities during 1985-86 and 1998-2000. Data for mothers and calves are shown separately from "others". Excludes potentially disturbed whales.

	Number of					
	Others			Mothers/Calves		
Activities	BOSs	Whales	Surfacings	BOSs	Whales	Surfacings
Rest	1	1	3	0	0	0
Travel	17	48**	122	2	6	25
Social	8	80	93	0	0	0
Feed	29	315	424	11	29	49
Travel+Social	5	60	89	2	6	25
Travel+Feed	10	124	142	5	10	92
Social+Feed	9	227	248	3	4	27
Travel+Social+Feed	1	8	16	1	4	9
Play	1	2	6	0	0	0
Aerial	2	4	43	0	0	0
Unknown	5	17	20	2	7	7
All activities	88 (84*)	886**	1206	26 (25*)	66	234

* There were 84 different undisturbed BOSs. Some BOSs have more than one activity. Numbers in parentheses indicate the number of different BOSs.

** Some whales may not have been recognized when resighted, so "numbers of whales" likely overestimate the number of different whales.

fifth) observer helped with keeping track of whales and other ancillary tasks. The two primary observers were seated in the co-pilot's seat and the seat behind it. The observer in the co-pilot's seat augmented observations with hand-held 9×35 or 10×42 binoculars as needed. The part-time observer(s) were seated behind the primary observers. During each surface/dive sequence by bowheads, observers described the same behavioral attributes as recorded in our previous studies of bowhead behavior (e.g., Würsig et al. 1984, 1985; Dorsey et al. 1989; Richardson et al. 1995a,b). These data included times when each focal whale surfaced, blew and dove; its headings and turns; occurrence of pre-dive flexes, fluke-out dives and aerial activities (breaches, tail and flipper slaps, etc.); and occurrence of several other behaviors as described in the "Results" section. From details of individual and group behaviors, observers classified the general activity of the focal whale(s) as feeding, traveling, socializing, aerial, play, other, or some combination, distinguished as in previous related studies (e.g., Richardson et al. 1995a).

Special methods were needed to maintain station over whales during prolonged dives. During 1985–86, we dropped sandwich bags with fluorescein dye from the aircraft. The resulting dye mark on the water's surface was visible for 20 to 60 min, depending on wind/sea state. During observation sessions in 1998–2000, a portable computer with data logging software (WINGPS), connected to the aircraft's GPS, automatically recorded time and aircraft position (latitude and longitude) at 1-s intervals. Using the output from this system, we were able to keep station above whales, and to estimate positions of whales during the behavioral observation sessions. Frequently, we used the aircraft's successive GPS positions to estimate the location about which the aircraft was circling, which was usually close to the whale position. These times and positions could then be used to estimate the speeds of travel for whales that were resighted within observation sessions (see Chapter 11).

Adult and subadult whales were distinguished by one of two methods. ***(1)*** For some BOSs, mainly during the 1986 SWEPI and 1998–2000 studies, the photogrammetric method of Koski et al. (1992) was applied immediately after the BOS ended. This provided specific length information for some of the individual whales that had been recognized (from natural markings) during the preceding BOS. Whales ≥13.0 m in length were classified as adults; those <13.0 m long were classified as subadults or calves. ***(2)*** In other cases, the behavioral observers classified some whales as obviously small or large; these were counted as subadults or adults, with intermediate-sized or unclassified individuals being excluded from both categories.

Data Analyses

Behavioral data were transcribed from audiotapes between flights and after the field seasons. The videotape was then examined for details not noted during the real-time behavioral dictation. Video recordings were especially useful for seeing missed blows and other details in 1998–2000, when we used digital video tape with much higher resolution than the standard 8 mm system used in 1985–86. The combined data were coded numerically as in our previous work (see Richardson and Finley 1989:25–28 for details). These records were hand-checked and then entered into a microcomputer (Apple II+ for most 1985–86 data; MS-Windows for 1998–2000) for computerized validation and analysis. The validation program, as developed during prior LGL/MMS projects, was applied each year to check for impossible or implausible combinations of variables; and necessary corrections were made. The 1985–86 data were later re-formatted for consistency with the 1998–2000 data.

Data from the first 20 min of each undisturbed BOS were used to compute time budgets. Only the first 20 min were considered because the lengths of BOSs were highly variable within and among years. During 1985, 1986 and 1998, the observers often continued observations for 1–3 h (or more) if the whales were feeding or traveling, but otherwise terminated observations of a given group of whales after 20–30 min. During 1999 and 2000, BOSs were terminated after 20–60 min as described above.

The proportion of time that whales spent engaged in each activity was determined for each BOS based on the group activity or activities recorded during the first 20 min of observations. Eleven different group activities were recognized in the three studies (Table 12.1). We excluded the unknown category from analyses because unknown activities included some or all of the known activities. Inclusion of "unknown" as an 11th category would have negatively biased estimates of the percentage of time engaged in the 10 known activities. For most BOSs, only one group activity was recorded during the first 20 min of the BOS, in which case the percentage of time engaged in that activity during that BOS was 100%. If there was more than one group activity during the first 20 min of a BOS, then the percentage of the BOS assigned to each group activity was determined from the number of surfacings with each group activity during the 20–min period. In this calculation, each surfacing was weighted by the mean duration of all surface–dive sequences by whales engaged in that activity during the year in question. If group activities are a → j, the proportion of time spent engaged in activity 'a' is

$$\frac{(\#\text{ surfacings (a)})\ \ (\text{mean surface} - \text{dive duration (a)})}{\Sigma\ [(\#\text{ surfacings } (a \rightarrow j))\ (\text{surface} - \text{dive sequence } (a \rightarrow j))]}$$

for each behavioral observation session.

To combine results from a number of BOSs, the percentage of each BOS assigned to a given activity (e.g., feeding) was added to corresponding percentages from other BOSs and divided by the number of BOSs. This provided an estimate of the overall percentage of time engaged in a given activity for a situation of interest, e.g., year, water depth category, or whale status (subadult, adult, mother).

The 10 different group activities (after excluding unknown) were then combined into four general group activities (feed, travel, social, and other). Group activities involving two activities "A" and "B", e.g., "travel+feed", were assumed to be 50% "A" and 50% "B". "Travel+social+feed" was assumed to be 33% travel, 33% socializing, and 33% feeding. This method may slightly under- or overestimate the occurrence of a particular activity during any one BOS. However, on average we believe it to be a fair representation when multiple behaviors occur at the same time (see Discussion).

Detailed data on surfacing, respiration, and dive cycles during these observation sessions are presented in relation to whale activity in Chapter 13, and in relation to whale age in Chapter 14.

Results

Feeding Activities—Descriptions

Near-Surface Feeding.—During late summer and early autumn (mainly September), bowheads in and near the eastern Alaskan Beaufort Sea spent an estimated 8% of their time feeding near the surface (Table 12.2F). Near-surface feeding was seen during 4 of 5 years, the exception being 2000 when little feeding of any type was seen (Table 12.2). Whales feeding at or near the surface were generally recognized readily, because their mouths were open as they traveled forward slowly or at medium speed, with no or only slight white-water along their flanks. From our aerial view, the baleen plates often appeared as a dark shadow between the rostrum and the outline of the submerged lower jaw. The baleen sometimes was not visible, but the open mouth resulted in a higher-than-normal raised rostrum that made the head look particularly thin above or at the surface. The lower jaw, if visible, appeared (from our high viewing angle) to be extended forward and laterally relative to the upper jaw, well beyond its normal closed-mouth position. From a surface vessel, the raised rostrum would be visible, and the back would not.

This behavior is also called skim feeding, as the whales effectively "skim" copepods, euphausiids or other zooplankton from the water near the surface. Skim feeding whales most often swam dorsum up. However, Würsig et al. (1985) observed that skim-feeding can also occur with whales ventrum up ("upside-down"—not seen during this autumn study); or on their sides. This "lateral skim feeding" results in the tail traveling back and forth with one fluke tip generally at or above the surface. These surface fluke swishes remind one of the top part of the caudal appendage of a surface-traveling shark. We suspect that lateral skim feeding occurs when the prey are concentrated particularly close to the surface, in which case upright whales could not propel themselves without the upstroke of the fluke being stopped by the surface. Whales skim feeding on their sides show much of one baleen rack, left or right, and present a particularly impressive view with mouth agape up to an angle of ~60^o (Würsig et al. 1985).

Whales at times skim feed along or very close to a current interface line, where currents meet or where upwelling (or, potentially, downwelling) occurs. There is often a visible "slick" of organic material associated with such lines, and we assume that prey may be particularly rich in these microhabitats. In one typical case of skim feeding along a line of surface debris, we observed two small subadult bowheads skim feeding on their sides 3 km N of Kaktovik on 19 Sept. 1998. We watched the whales for 45 min as they traveled back and forth along the shoreward side of an interface between muddy brackish inshore water and clearer offshore water. When we left the area at the end of our BOS, the whale(s) were still skim feeding.

TABLE 12.2. Percentages of time spent engaged in various activities, subdivided by water depth, during September-October of 1985-86 and 1998-2000. Shallow water is ≤20 m; deep water is >20 m. *n* is number of behavior observation sessions (BOSs) having whales of each status in each depth category. Based on first 20 min of 80 undisturbed BOSs; observations from a twin-engine aircraft at altitude ≥460 m. "Unknown" includes all whales of unknown status; "All Whales" include unknown whales, calves excluded. Unknown activities are excluded.

	Subadult		Adult		Unknown		Mother		All Whales but Calves			
	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep		All Depths
A. 1985												
Feed	32	16	50	0	25	14	0	40	25	14		39
col	0	13	33	0	8	11	0	31	8	11		20
sfc	32	3	17	0	16	3	0	9	16	3		19
Travel	0	5	33	0	25	6	0	19	25	6		31
Social	32	16	17	0	16	14	0	40	16	14		30
Other	0	0	0	0	0	0	0	0	0	0		0
n	2	2	2	0	4	2	0	2	4	2		6
B. 1986												
Feed	42	0	58	16	45	13	0	74	45	13		58
col	29	0	29	16	31	13	0	74	31	13		44
bot	6	0	15	0	7	0	0	0	7	0		7
sfc	7	0	14	0	7	0	0	0	7	0		7
Travel	0	22	0	8	0	24	0	9	0	24		24
Social	11	13	12	6	7	8	0	14	7	8		15
Other	0	12	0	0	0	4	0	0	0	4		4
n	6	4	7	3	11	7	0	4	11	10		21
C. 1998												
Feed	29	25	0	23	17	17	0	50	19	19		38
col	15	25	0	23	0	11	0	6	5	15		20
bot	14	0	0	0	6	0	0	0	6	0		6
sfc	0	0	0	0	11	6	0	44	8	4		12
Travel	0	15	0	35	0	23	0	50	0	24		24
Social	21	8	13	27	17	17	0	0	15	15		30
Other	0	0	0	0	0	9	0	0	0	8		8
n	4	5	2	7	6	12	0	4	7	14		21
D. 1999												
Feed	0	72	0	66	0	68	0	85	0	66		66
col	0	68	0	63	0	64	0	79	0	62		62
sfc	0	4	0	3	0	4	0	6	0	4		4
Travel	0	27	0	25	0	23	0	14	0	24		24
Social	0	0	0	8	0	10	0	0	0	10		10
Other	0	0	0	0	0	0	0	0	0	0		0
n	0	12	0	11	0	20	0	8	0	21	22	21
E. 2000												
Feed	0	0	0	0	7	7	0	0	5	5		9
bot	0	0	0	0	7	7	0	0	5	5		9
Travel	23	77	0	0	0	59	0	66	9	65		74
Social	0	0	0	0	7	7	0	34	5	5		9
Other	0	0	0	0	0	11	0	0	0	7		7
n	1	4	0	0	1	6	0	2	2	9		11
F. All												
Feed	19	27	23	34	23	27	0	55	21	25		47
col	10	26	13	34	12	25	0	42	12	22		34
bot	5	0	5	0	3	1	0	0	3	1		4
sfc	4	1	5	0	7	2	0	13	6	2		8
Travel	5	30	2	21	2	24	0	30	4	27		31
Social	10	6	9	12	9	11	0	12	9	10		18
Other	0	3	0	0	0	3	0	0	0	4		4
n	13	27	11	21	22	47	0	20	24	56		80

Surface skim feeding, alone or in combination with other types of feeding, was generally conducted by animals acting alone or with one other animal nearby; however, there usually were additional animals within 1 km (see Table 12.3C,D, later). The animals were oriented in variable directions, and seemed to pay no or little attention to each other as they criss-crossed the area. Echelon skim feeding, when whales swim side-by-side in staggered formation with mouths open, has been described from August in the Canadian Beaufort Sea (Würsig et al. 1985) and reported from Alaskan waters in fall (Ljungblad et al. 1986; Landino et al. 1994) but was not seen during this study. Echelon feeding is apparently uncommon in the present study area, consistent with the fact that zooplankton biomass was usually low in surface waters (Chapter 5, 6).

Near-Bottom Feeding.—Bowheads spent an estimated 4% of their time near-bottom or bottom feeding during late summer and autumn; this activity was seen in 3 of 5 years of this study (Table 12.2F). Near-bottom feeding was assumed when whales came to the surface with mud on parts of their bodies or with mud streaming behind them. This mud was usually on the back or rostrum (indicating that the whales may have been moving along the bottom upside down), on the flanks, or streaming from the mouth. Whale orientations usually changed from one surfacing to the next, and the whales tended to stay within the same area throughout a BOS. Surfacings with mud on the body did not necessarily indicate that the whales had been feeding at or near the bottom; some of these whales may have been engaged in another activity. Nevertheless, we believe that the presence of mud streaming from the body or especially the mouth was generally indicative of bottom or near-bottom feeding. Conversely, at times we may have failed to recognize near-bottom feeding when it occurred if mud was *not* evident. Near-bottom feeding could occur without mud being evident during surfacings, especially if the bottom was not mud.

At times, mud streamed from the anterior corners of the mouth in spurts or plumes ("mud-pluming"), as whales alternately opened and closed the mouth at the surface. These whales apparently had fed at the bottom, perhaps in a manner similar to that of gray whales (*Eschrichtius robustus)* feeding on epibenthic crustaceans swarming just above the bottom (Kim and Oliver 1989). The mouth action at the surface may be to winnow the prey from pebbles or other inedible food, to work it toward the throat, or simply to clean the mouth and baleen of mud.

Water-Column Feeding.—Bowhead whales were assumed to be feeding in the water column during 34% of our observation time during late summer and autumn (Table 12.2F). We scored bowhead whales as feeding in the water column when they exhibited most or all of the following: (a) stayed in generally the same area throughout a BOS, (b) were oriented in variable directions upon first surfacing, (c) remained stationary or moved slowly while at the surface between dives, and (d) generally dove steeply, often with flukes out. Feeding in the water column could not be observed directly, as we could not see open mouths or other "evidence" of feeding while whales were more than a few meters below the surface. It was thus the least reliably determined, yet overall the most common, form of feeding in and near the eastern Alaskan Beaufort Sea in September/early October. Presumed water-column feeding was estimated as ~4x as common as near-surface feeding and ~8x as common as bottom feeding. It included feeding at all depths except the surface or bottom. Zooplankton often were concentrated in thin layers at mid-water depths (see Chapters 5, 6), and water-column feeding was presumably concentrated at those depths.

During or after 44% of the sessions with apparent water-column feeding, whales were seen or photographed with mouths open while they were stationary or moving only slowly at the surface. In these cases, the whales were not feeding at the surface. We surmise that, after trapping prey in the mouth while water-column feeding, whales at the surface with mouths open were working prey toward the throat in order to swallow the prey. The action may be similar to that which generates "mud-pluming" when feeding gray whales come to the surface (Nerini 1984). BOSs with mouths open are marked in Appendix 12.1. Apparent water-column feeding was at times accompanied by defecations at the surface, but such occurrences were too sporadic for defecation to be used as a reliable indicator of feeding. Nonetheless, defecations indicate recent feeding.

Although neither bottom feeding nor water-column feeding have been observed directly in bowheads, we are confident that most cases labeled as such were identified correctly. We generally do not include a qualifier such as "surmised", "suspected", or "apparent" when describing any particular case of near-bottom or water-column feeding, but the qualifier should be assumed.

Feeding Activities—Occurrence

Overall, feeding was the most common activity of bowheads in and near the eastern Alaskan Beaufort Sea during late summer and autumn. Whales spent an estimated 47% of their time feeding in comparison to 31% traveling, 18% socializing, and 4% engaged in other activities (Fig. 12.2, Table 12.2). Feeding was the dominant activity in 4 of 5 years of the study. It occurred an estimated 38 to 66% of the time in 1985–86 and 1998–99, but only 9% of the time in 2000 (Fig. 12.2).

Water depth affected the allocation of time to different activities. Feeding accounted for 62% of the activities in shallow water (≤20 m) but only 38% in deeper water (Fig. 12.3). Conversely, traveling accounted for only 12% of the activities in shallow areas but 41% in deeper water. For both subadults and adults, ~1/3rd of our observations were of whales in shallow areas (Table 12.2). While there, both subadults and adults spent most of their time feeding: 56% for subadults and 68% for adults (Fig. 12.3). When in deep waters (>20 m), subadults spent slightly more time traveling than feeding (45% vs. 41%), whereas adults spent more time feeding than traveling (51% vs. 31%; Fig. 12.3).

Feeding strategies varied somewhat among years, but water-column feeding was overall the predominant activity recorded during late summer and autumn (34% of all activities, Table 12.2; 74% of feeding activities; Fig. 12.4). It was the most common type of feeding in 4 of 5 years, with the exception being 2000—the year with little feeding (Table 12.2). Surface skim feeding was also seen in all years but 2000; it accounted for 8% of the time and 17% of the feeding time (Table 12.2; Fig. 12.4). Bottom feeding was the least common of the three recognized types of feeding (Fig. 12.4), and was not noted in 1985 or 1999 (Table 12.2). However, in 2000, the infrequent feeding that did occur was all bottom feeding.

Over all years, feeding modes were more diverse for whales feeding in shallow (≤20 m) water than for those feeding in deeper (>20 m) water. In deeper water, almost all recognized feeding by bowheads was recorded as water-column feeding (Fig. 12.4). In contrast, in shallow areas, water-column feeding accounted for only slightly more than half of the feeding time; near-surface and near-bottom feeding each accounted for ~2/7th and 1/7th, respectively, of the feeding in shallow areas (Fig 12.4). Mothers and their calves were found in the deeper areas, and the only feeding mode observed for mothers was water-column feeding.

The type of feeding activity and water depths where feeding occurred varied among years and with age class. Both adults and subadults fed mainly in shallow waters in 1985 and 1986. In contrast, both age classes were seen feeding only in deeper (>20 m) waters in 1999 (Table 12.2; Fig. 12.5). In 1998, adults were only seen to feed in the deeper waters but subadults fed about equally in deep and shallow waters. Feeding in deep water occurred in all years but was relatively rare, except in 1999 when it was common. Feeding in deep water was predominantly feeding in the water column.

Mothers (adults accompanied by first-year calves) were rarely seen in waters ≤20 m deep during BOSs in any of the five years (Fig. 12.1, 12.4) and also were rarely seen there during other types of obser-

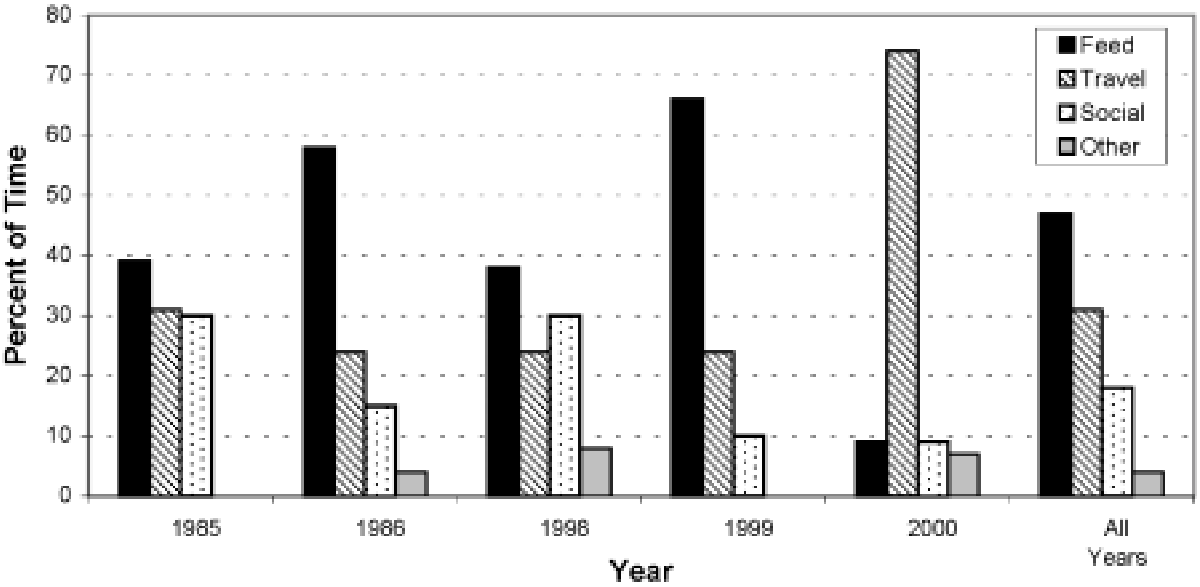

FIGURE 12.2. Percentage of time when bowheads engaged in various activities while in or near the eastern Alaskan Beaufort Sea during late summer and autumn, by year (1985–86, 1998–2000). Based on the first 20 min of 80 undisturbed BOSs, as described in "Methods". Includes all bowhead whales except calves. See Table 12.2 for more details.

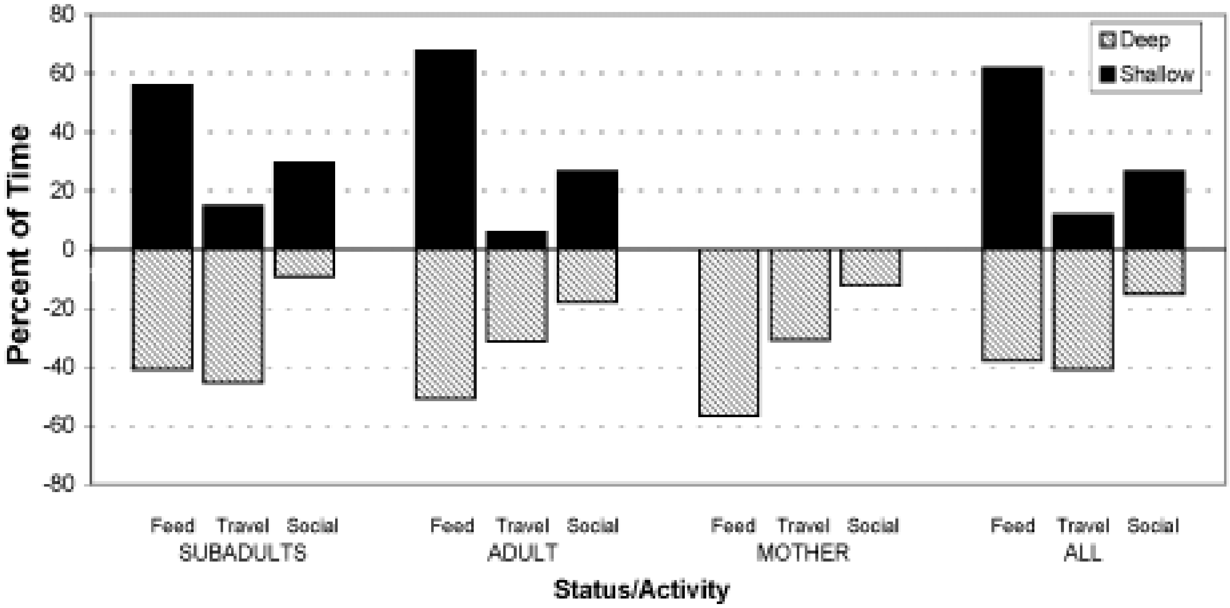

FIGURE 12.3. Percentage of time when bowheads of different status engaged in various activities while in shallow water (≤20 m) and deeper water (>20 m). Based on the first 20 minutes of 80 undisturbed BOSs, as described in "Methods". "All" includes unknown status whales but excludes calves. Adapted from Table 12.2, with percentages recalculated separately by water depth.

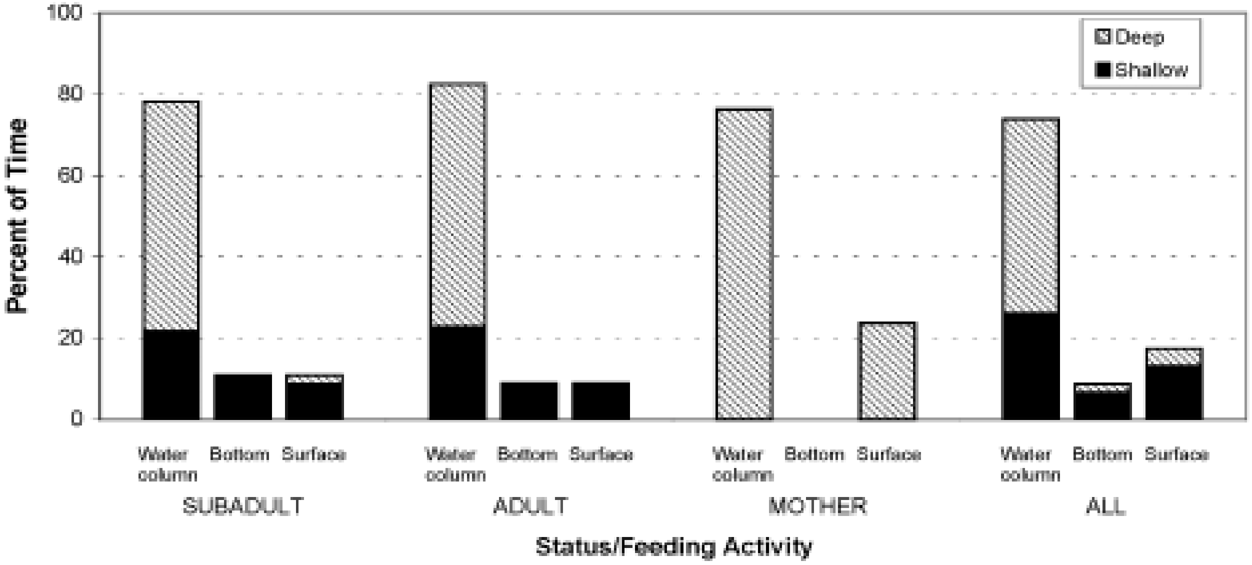

FIGURE 12.4. Percentage of feeding time when bowheads of different status engaged in three types of feeding in two water depths. Shallow water is ≤20 m; deep water is >20 m. Based on the first 20 minutes of 80 undisturbed BOSs, as described in "Methods". "All" includes unknown status whales but excludes calves. Adapted from Table 12.2, with percentages recalculated to consider only feeding.

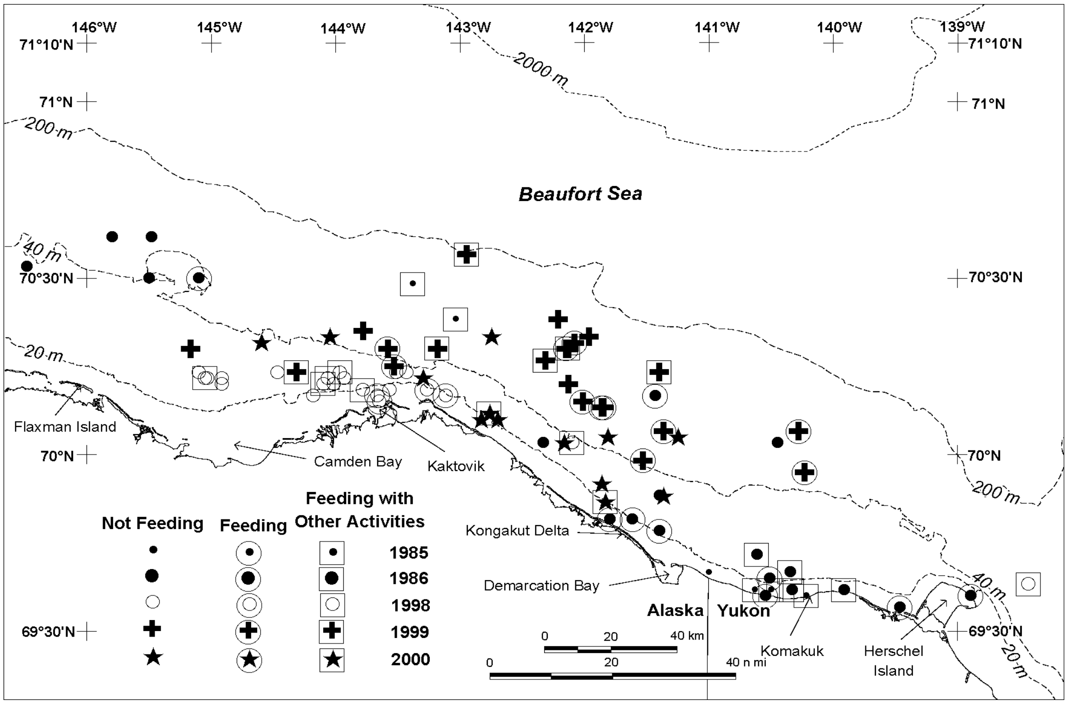

FIGURE 12.5. Locations where feeding was (and was not) seen in and near the eastern Alaskan Beaufort Sea during late summer and autumn, by year (1985–86, 1998–2000). BOSs that included feeding (circles) or combinations of activities that included feeding (squares) are distinguished. Based on observations of bowhead whales from a twin-engine aircraft circling at altitude ≥460 m; excludes periods with other types of potential disturbance.

vations (Chapter 10). Overall, mothers with calves were classified as feeding 55% of the time. For mothers, water-column feeding accounted for 42% of the total observation time, and 76% of the feeding time. The latter figure for mothers is consistent with corresponding values for subadults and for adults without calves (Fig. 12.4). Mothers with calves fed near the surface 13% of the time, i.e., 24% of the feeding time (Fig. 12.4). Mothers were never scored as bottom feeding (Table 12.2; Fig. 12.4).

For whales other than mother–calf pairs ("others"), water column and surface feeding were observed about equally in the first and latter half of September; however, in the first half of September surface feeding was observed in combination with water column and water column+bottom feeding, whereas in the second half of September it was seen alone and in combination with water-column feeding (Table 12.3A). Bottom feeding occurred in both parts of the month, as evident from the combined data for whales engaged in bottom feeding and water-column+bottom feeding. Feeding by "others" was more often interspersed with traveling and socializing in the second half of the month even though feeding alone and social+feed each were observed about equally during the first and second halves of September (Table 12.3A).

Most of the observed feeding was recorded in areas with water depths <50 m, with surface and bottom feeding being noted mainly in water 10–19 m deep (Table 12.3B). Travel+feed and social+feed by "others" were found most often in 20–49 m depths. However, in large part because of inter-year variability, it is not possible to predict preferred depth categories for specific feeding activities by bowhead whales in this study area.

Group size for feeding whales was usually one whale: 82% of feeding whales and 60–69% of whales engaged in feeding+other activities were singletons. One exception was whales classified as surface feeding (only), with 57% of these in groups of two (Table 12.3C). Bottom feeders were usually found to be widely spaced, with no more than 2 or 3 whales within 1 km. However, when bottom, surface and water-column feeding were all occurring, >6 whales were present 52% of the time (Table 12.3D). Surface and water-column feeders (and combinations of the two) tended to be aggregated, typically with 4+ whales within 1 km. This same tendency for larger aggregations was true for combinations of travel+feed, social+feed, and travel+social+feed (Table 12.3D, right hand columns).

Appendix 12.2 provides similar information about observations of mothers and calves in relation to date, water depth and group size. Feeding by mothers was observed in both early and late September, but combined travel+feed occurred mainly in the latter half of September. Feeding and combined travel+feed occurred mainly in water depth 20–49 m. The group size was usually two (i.e., calf but no other whale within 5 whale-lengths of mother), typically with 2–6 whales within a 1 km radius (Appendix 12.2).

During some BOSs with whales feeding in the water column, at the bottom, or a combination of these, we had the strong impression that there was partial synchrony in surfacings and dives. Typically, several whales were at the surface simultaneously within our circle of observation, followed by a long—at times over 10 minutes—period when most or all whales were below the surface. However, our variable-duration (but often short) observation sessions did not provide data suitable for quantitative analysis of synchrony. Nonetheless, we strongly suspect that bowheads feeding (and traveling) in the present study area sometimes coordinated their surfacing/dive cycles, including some cases when the whales were >1 km from each other.

Travel

Traveling was the second most common activity of bowheads during late summer and early autumn in and near the eastern Alaskan Beaufort Sea (Fig. 12.2). These bowheads spent an estimated 31% of their time traveling. They were seen traveling during all five years of this study (Fig. 12.2; Table 12.2).

TABLE 12.3. Circumstances of observations of undisturbed bowhead whales engaged in various group activities. The table shows number of surfacings and numbers of whales observed during September-October 1985-86 and 1998-2000, as observed from an aircraft at altitude ≥460m. Mothers and calves are excluded. Because a given whale is counted more than once if more than one surfacing is observed, some data are not independent and statistical analysis is not justified. Also, we tended not to observe actively socializing groups for prolonged periods, and this affects the percentages of whales engaged in various activities. "Total *n*" varies because not all variables could be determined for each surfacing.

	Number of Surfacings												
	Feed								Travel+	Travel+		Social+	All
	All	col	bot	sfc	col+bot	col+sfc	all three	Travel	Feed	Social	Social	Feed	three
A. Date													
1-15 Sept	231	126	0	0	35	7	63	4	15	0	54	127	0
16-31 Sept	192	119	17	21	0	35	0	103	127	89	39	121	16
1-15 Oct	0	0	0	0	0	0	0	15	0	0	0	0	0
Total *n*	423	245	17	21	35	42	63	122	142	89	93	248	16
# Whales	314	200	7	19	17	33	38	47	124	60	80	226	8
B. Water Depth (m)													
1-9	97	26	0	1	35	35	0	0	0	0	0	46	0
10-19	162	64	17	18	0	0	63	15	9	0	52	74	0
20-49	136	127	0	2	0	7	0	99	91	76	39	122	0
50-99	16	16	0	0	0	0	0	8	40	0	0	0	16
100-250	0	0	0	0	0	0	0	0	2	13	0	6	0
Total *n*	411	233	17	21	35	42	63	122	142	89	91	248	16
# Whales	302	188	7	19	17	33	38	47	124	60	78	226	8
C. Group Size (within 5 body lengths)													
1	334	181	17	6	29	38	63	95	85	30	6	158	11
2	52	34	0	12	5	1	0	24	42	29	18	55	5
3	19	16	0	3	0	0	0	3	4	13	35	19	0
4	3	0	0	0	0	3	0	0	11	13	28	15	0
7	0	0	0	0	0	0	0	0	0	4	6	1	0
Total *n*	408	231	17	21	34	42	63	122	142	89	93	248	16
# Whales	299	186	7	19	16	33	38	47	124	60	80	226	8
D. # Bowheads within 1 km													
1	5	4	0	1	0	0	0	54	0	0	0	0	0
2	48	31	17	0	0	0	0	40	10	10	18	0	0
3	51	8	0	0	35	0	8	3	7	7	20	6	0
4	77	35	0	20	0	0	22	14	56	0	49	15	0
5	12	12	0	0	0	0	0	6	54	15	0	54	0
6	54	47	0	0	0	7	0	5	15	0	0	0	16
>6	144	76	0	0	0	35	33	0	0	57	6	113	0
Total *n*	391	213	17	21	35	42	63	122	142	89	93	188	16
# Whales	291	177	7	19	17	33	38	47	124	60	80	170	8

Traveling whales tended to move in one direction, with only slight variations in heading (±10–15°) from one surfacing to the next. They moved at medium to fast speed (~3 to 6 km/h) while at the surface, generally with some white water (a "wake") streaming off their sides. Mean speeds during dives, as determined from positions and times of successive surfacings, indicated that traveling bowheads maintained a similar speed below the surface (mean speed 4.5 ± s.d. 1.22 km/h, Chapter 11). In late summer and autumn, travel was almost always in a generally westward direction (see "Orientation" subsection, below). Traveling whales were usually found in a relatively straight line of several animals, one more or less behind the other, separated by distances ranging from several body lengths to several kilometers. They thus traveled along an invisible "road", and we gained the impression that they were communicating with each other to do so, presumably by sound (see Discussion).

We scored whales as "travel+feed" when they showed one or more of the behavioral characteristics described for feeding, such as coming up with mud, defecating, or fluking out; but when they also covered substantial distances in a consistent direction either while at the surface or during their dives. "Travel+feed" whales usually surfaced very slowly, moved forward while blowing, and kept their general travel orientation. Headings of a given whale during successive surfacings tended to be similar, and changes in orientations at the surface were slight. Subsequent positions tended to progress gradually westward rather than back and forth through a given area. Headings of "travel+feed" whales averaged westward, but with more variability than those of whales scored as "traveling" without feeding (see "Orientation" subsection, later).

In all years except 2000, travel behavior occurred somewhat less than did feeding, with 31, 24, 24, and 24% of time spent traveling in 1985, 1986, 1998, and 1999, respectively (Fig. 12.2, Table 12.2). In 2000, however, most of the few whales seen in the study area traveled through without lingering. Travel accounted for 74% of the total activity budget of whales in 2000.

For "others", traveling—either alone or in combination with feeding or socializing—was seen more often in the latter half of September than the first (Table 12.3A). Observations in October were very limited but all involved traveling. Traveling *per se* tended to be seen mainly in 20–49 m depth, with one or two whales per group, and one or two whales within 1 km. When traveling occurred in combination with other activities (especially socializing), group sizes tended to be slightly larger but were still commonly one or two; the number of whales within 1 km tended to increase to 4+ (Table 12.3B,C,D). Traveling mother–calf pairs showed similar depths, group sizes, and "whales within 1 km" values as for "other" whales that were traveling (Appendix 12.2).

Social Activities

Socializing was the third most common activity of bowheads during late summer and early autumn in and near the eastern Alaskan Beaufort Sea (Fig. 12.2). Bowheads spent an estimated 18% of their time there in social activities, and were seen socializing during all years of this study (Table 12.2; Fig. 12.2).

We termed activities "social" when whales interacted by pushing, nudging, or slapping each other with flippers or tail. We did not categorize whales as "social" when they were merely swimming or resting side-by-side. Active social interactions run the gamut from subtle (at times perhaps greeting) displays to apparently violent, aggressive, or sexual behaviors. During this study we saw the same types of social activities that have been seen during summer in the Canadian Beaufort Sea, as described by Würsig et al. (1985, 1993).

Social activities tended to occur with lower frequency than either feeding or traveling when all years were combined, although social and travel activities occurred about equally in 1985 and "social" was more common than "travel" in 1998 (Table 12.2; Fig. 12.2). A low level of socializing, with whales subtly nudging each other, was quite common during travel, and socializing while feeding was even more common (Table 12.3). The combined "social+feed" category most often involved whales that were apparently feeding in the water column or surface feeding (Appendix 12.1).

Social activity by itself was more common in the first half of September than during the second half (12 % vs. 5 % of surfacings during each period, respectively; Table 12.3A). However, social activity in combination with travel or travel+feed was seen only in the latter half of the month. (Travel in general became commoner in late September—see previous subsection and Table 12.3A). Overall, socializing was recorded for similar percentages of surfacings in early and late September (41% vs. 36%, respectively). Whales categorized as social-only and social+feed tended to occur in water depths 10–49 m; social+travel was seen mainly in 20–49 m, but also (15%) in 100–250 m (Table 12.3B).

Vigorous socializing that included apparent sexual activity was observed and filmed on 19 and 20 Sept. 1998. On 19 Sept., low cloud prevented observations from altitude 1500 ft a.s.l. On 20 Sept., two separate surface-active groups were observed systematically (Appendix 12.1D). In the 20 Sept. cases, up to seven whales at a time interacted vigorously, creating much whitewater and making it impossible to sort out who was doing what. Extended penises were seen on several occasions , strongly indicating but not proving that mating was taking place. Most animals appeared to be males and the activity appeared to be centered about a single, larger, presumed female. Photogrammetry at the end of each BOS showed that the whales were 10.6 to 13.9 m long (Fig. 12.6). Of the 18 different measured whales, 16 were 11.9 m or longer, but only 8 of 18 exceeded 13.0 m—the length at which an average female bowhead is assumed to become sexually mature (Koski et al. 1993). The length at which male bowheads become sexually mature is poorly documented, but is believed to be near 12 m (Koski et al. 1993). The groups remained sexually active during the low-altitude photogrammetry sessions.

Mother–Calf Associations

Probable mothers and their calves were seen during all five years of study, almost always in water >20 m deep (Fig. 12.1). When all years are combined, the proportions of time that mothers engaged in various general activities were similar to the proportions for "others" (Fig. 12.3; Table 12.2).

Apparent nursing, as indicated by repeated dives toward the teat area of the mother, was observed during 35% of the mothers' surfacings (17 of 49; Appendix 12.2). Nursing was probably more common than this, as we probably did not notice it as often as it occurred. Calves did not appear to play with objects or around mother. We also saw no breaches by either mothers or calves during BOSs, and only 2 cases of tail-slapping by calves. In general, we gained the impression that—during September—calves stay close to their mothers and are not highly active, at least during the years and area of this study. We did not see or photograph any calf that appeared to be independent of its mother (i.e., weaned). Although calves stayed close to their mothers during September, we did not see them riding on the backs of mothers, which is common for neonate calves during spring (Würsig et al. 1999).

Orientations

The headings of whales engaged in each recognized activity are of special interest in this study as consistent westward orientation during late summer and autumn can be presumed to indicate migration; absence of consistent westward orientation presumably indicates that activities other than migration were dominant. Whales engaged in feeding or simultaneous socializing and feeding were not oriented consistently westward, or in any other specific direction (Fig. 12.7A,B). However, for feeding whales, a test for

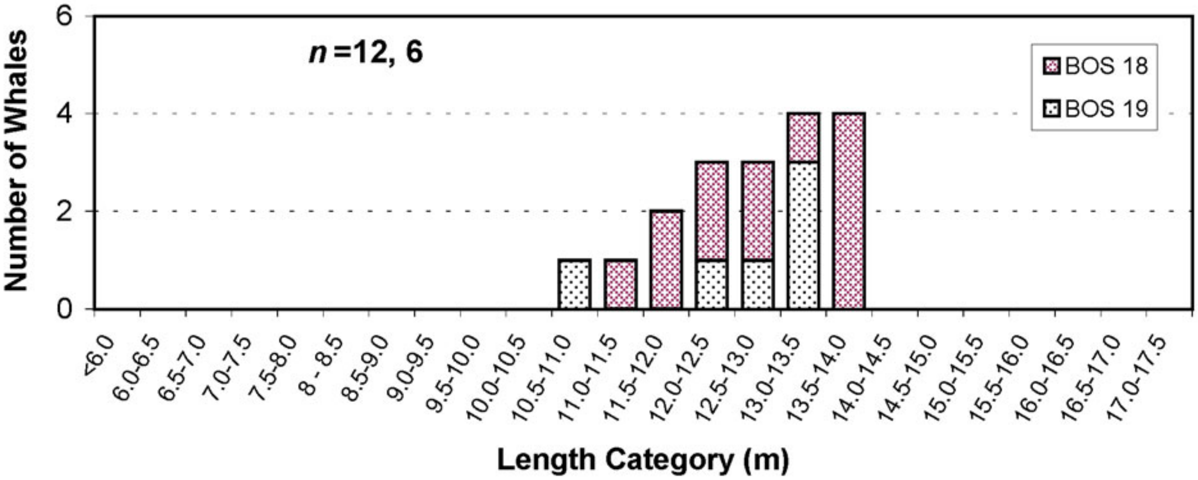

FIGURE 12.6. Length-frequency distributions of bowheads engaged in sexual activity, 20 Sept. 1998, as determined by aerial photogrammetry.

bimodal orientation (Batschelet 1981) indicated that headings were more commonly toward the NE-ENE and SW-WSW than in other directions (Fig. 12.7A). As expected, traveling bowheads were oriented consistently westward (Fig. 12.7C). Whales engaged in active socializing, travel+feed, and travel+social all showed significant westward orientation, although with more apparent variance than for traveling whales (Fig. 12.7D–F vs. C).

Mothers and calves showed significant orientation toward the southwest when classified as travel+feed, and a tendency (non-significant) to orient in directions other than west when feeding only (Fig. 12.8). Mothers and calves engaged in travel+feed exhibited a higher proportion of south and southeast headings than evident for "other" whales involved in travel (*cf.* Fig. 12.7).

Time Budget Summary

Over the five years of our study, feeding was the most common activity of bowhead whales in and near the eastern Alaskan Beaufort Sea during late summer and autumn (mainly September). Over all years, bowheads spent 47% of their time feeding, 31% traveling, 18% socializing, and 4% engaged in other activities (Fig. 12.2; Table 12.2). Other activities included resting, play, and aerial activities such as breaching, tail slapping, and flipper slapping. Times when activities were recorded as unknown have been omitted when calculating these percentages.

The relative frequencies of the three major activities within the present study area and season differed significantly among years ($\chi^2 = 16.91$, df = 6, $P = 0.0096$). This analysis was based on the number of BOSs classified as including each activity each year, with 1985 excluded because of too few BOSs (Table 12.4A). In four of the five years, feeding was the most common activity observed. In two of these years (1985 and 1998), traveling and socializing were only slightly less common than feeding (Fig. 12.2). However, in 1986 and 1999, feeding was the predominant activity (58 and 66%, respectively), traveling was secondary (24 and 24%), and socializing was of tertiary importance (15 and 10%). In the fifth year (2000), travel was the major activity (74%) and both feeding and socializing were infrequent (each 9%).

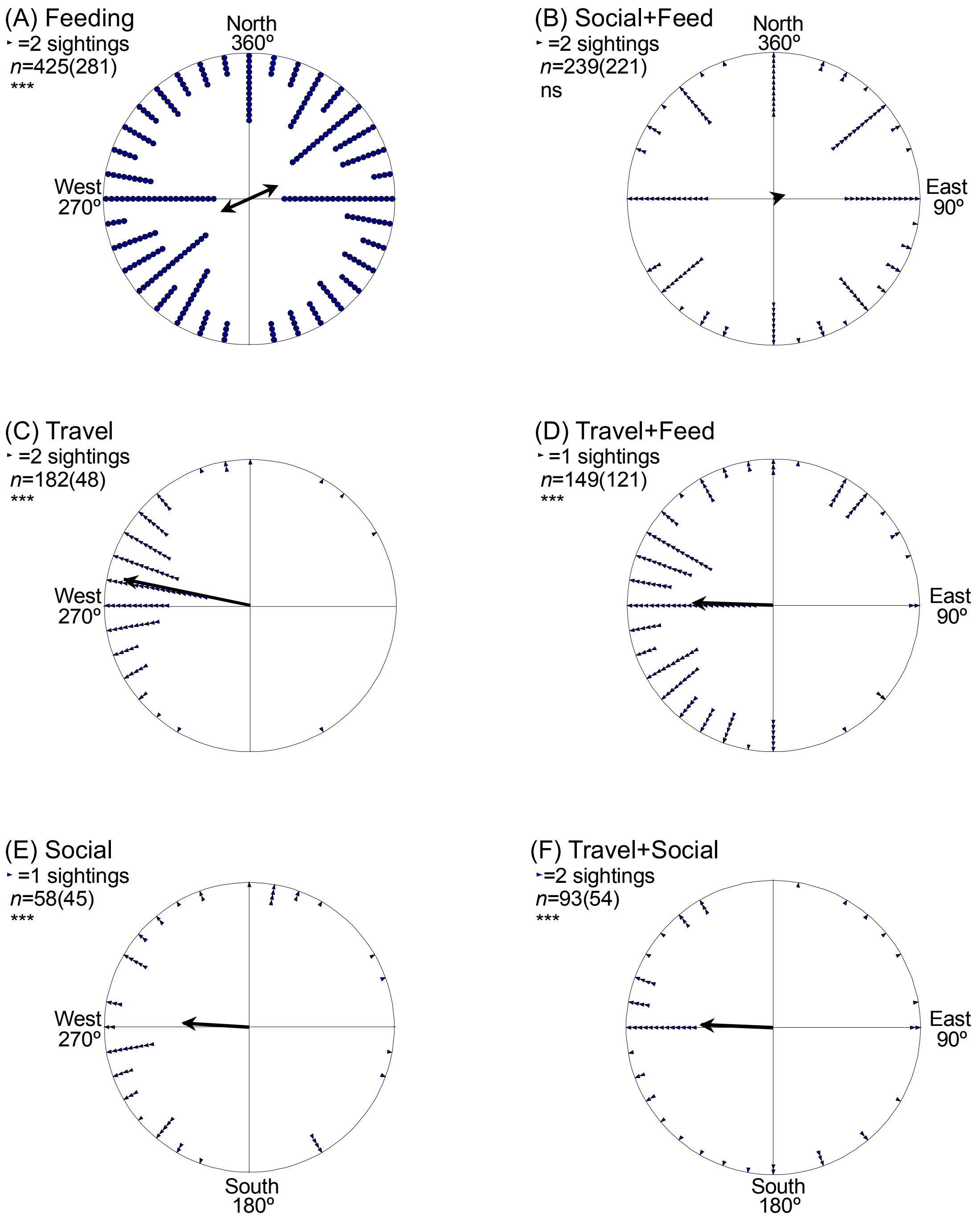

Figure 12.7. Headings (True) of bowheads engaged in various activities in or near the eastern Alaskan Beaufort Sea during late summer and autumn of 1985–86 and 1998–2000. Excludes mothers, calves, and potentially disturbed whales. Each surfacing with a known heading is counted separately in the circular plots and in calculating the vector mean and its length (plotted relative to radius). Numbers in parentheses are the maximum numbers of different whales observed; however, some resightings would not have been recognized as such so these numbers are overestimates. Significance levels are based on Rayleigh tests using the smaller (parenthetical) "*n*" values. *** means $P \leq 0.001$; ns means $P > 0.1$.

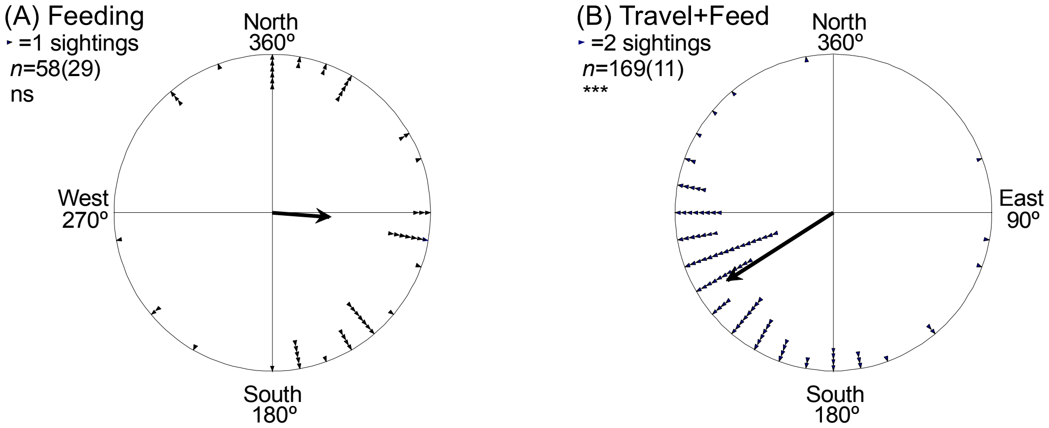

FIGURE 12.8. Headings (True) of bowhead mothers and calves engaged in various activities in and near the eastern Alaskan Beaufort sea during late summer and autumn of 1985-86 and 1998-2000. Otherwise as in Figure 12.7.

The time budgets of whales did not appear to differ markedly among whales of different status, i.e., mothers vs. other adults vs. subadults. (Calves were excluded from this and most other analyses in this chapter.) The proportions of BOSs during which feeding, traveling, and socializing were observed did not differ significantly among mothers, other adults, and subadults (Table 12.4B; $\chi^2 = 1.91$, df = 4, $P = 0.75$). Feeding was observed 46–57% of the time, traveling 23–35%, and socializing 12–21% of the time regardless of whale status (based on Table 12.2, all water depths combined). However, the frequencies of activities varied with water depth. Mothers were not seen in water depths of 20 m or less during BOSs, and traveling by adults and subadults occurred primarily in water deeper than 20 m (Fig. 12.3).

Comparable time budget information has not previously been reported for bowheads observed during spring or summer. We calculated the percentages of time engaged in feeding, traveling, and socializing during the 4-year spring study of Richardson et al. (1995b) and the 5-year summer study of Würsig et al. (1985, 1989). We used the same procedures as used in this Chapter for late summer and early autumn. In particular, we again considered only the first 20 min of each BOS in order to minimize biases associated with preferential observation of whales engaged in some specific activities, and excluded potentially disturbed whales. The proportions of time engaged in the three major activities were quite different during late summer/early autumn (this study) than during either spring or summer (Fig. 12.9). During the present study, feeding was less common (and traveling more common) than observed during summer in the Canadian Beaufort Sea. However, feeding was much more common (and traveling much less common) during this study than during spring migration east of Point Barrow, Alaska.

Discussion

Local and Traditional Knowledge of Bowhead Activities

Whale hunters and other residents of Kaktovik, within the eastern Alaskan study area, know much about the seasonal and geographic patterns in bowhead use of that area and of adjacent Canadian waters (see Chapter 2 and Annex B). They report that autumn bowhead migration through the present study area tends to be pulsed rather than steady. Local knowledge of the activities and behavior the bowheads is less

TABLE 12.4. Number of bowhead observation sessions (BOSs) with bowhead whales engaged in feeding, traveling and socializing in and near the eastern Alaskan Beaufort Sea during late summer and autumn ***(A)*** by year and ***(B)*** according to whale status, 1985, 1986, 1998, 1999 and 2000. When a BOS included more than one general activity either simultaneously or in series, a fraction of that BOS was assigned to each activity as described in the "Methods". Other activities not included in the tabulation.

	Number of BOSs		
	Feeding	Traveling	Socializing
A: Year			
1985	2.34	1.86	1.80
1986	12.05	5.00	3.12
1998	8.00	5.00	6.33
1999	13.86	5.04	2.10
2000	1.00	8.22	1.00
B: Whale Status			
Subadult	18.40	14.00	6.40
Adult	18.24	7.36	6.72
Mother	11.00	6.00	2.40

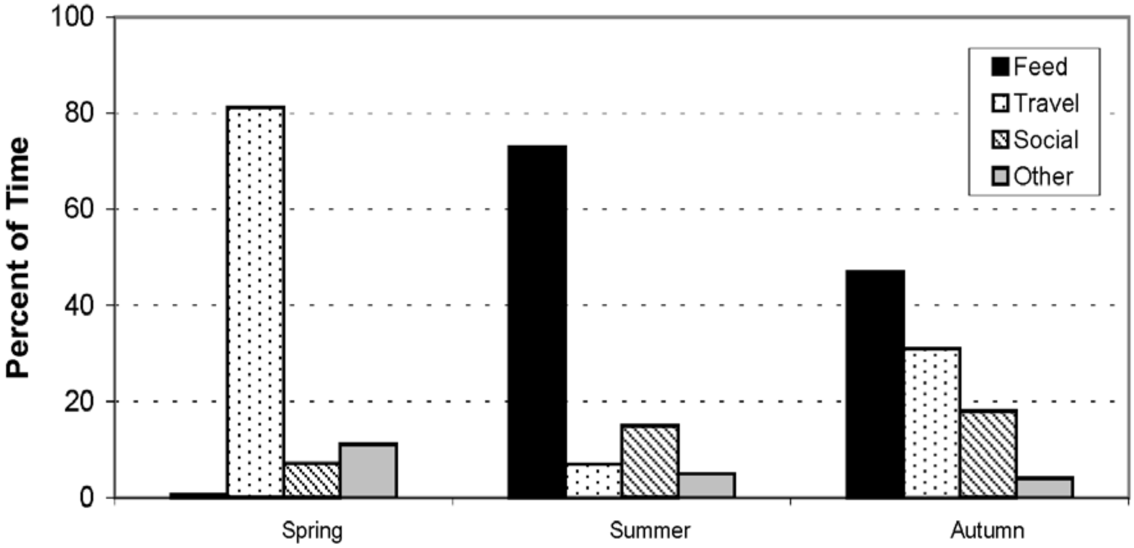

FIGURE 12.9. Percentage of time when bowheads engaged in various activities during spring near Point Barrow, summer in the Canadian Beaufort Sea, and late summer/early autumn (present study). Based on the first 20 min of 55 spring BOSs (from Richardson et al. 1995b), 90 summer BOSs (from Würsig et al. 1985, 1989), and 80 late summer/early autumn BOSs (this study). All observations were from a twin-engine aircraft circling at altitude ≥460 m; excludes periods with other types of potential disturbance. Includes all whales except calves.

detailed (Chapter 2 and Annex B), as many of the bowhead sightings are from motorized boats, and bowheads seen from such a vessel are often reacting to the boat rather than engaging in their "normal" behavior. However, some residents noted that bowheads may linger in specific areas such as the Icy Reef and Arey Island areas for as much as 1 to 2 weeks, and that bowheads often tend to feed near water-mass boundaries or off river mouths. They note that waterbirds also tend to feed at these locations. Some hunters report seeing concentrations of whale food (zooplankton) in the water, and there are indications that bowheads tend to concentrate in those areas. One hunter mentioned that, in September, bowheads sometimes go back and forth in certain areas, presumably feeding. The majority of the bowheads harvested by Kaktovik hunters have food in their stomachs, indicative of recent feeding.

Possible Human Influences

The bowhead whales in and near the eastern Alaskan Beaufort Sea during late summer–early autumn (mainly September) were not exposed much to industrial activity when we observed them. In 1985–86, there was little industrial activity in the area east of Camden Bay where our observations were obtained, and in 1998–2000 there was none. There was offshore drilling and seismic exploration farther west in Camden Bay, where the second of the 1986 studies was centered. However, observations close to specific industrial activities were excluded (see Appendix 12.1C). In contrast, the summer study in the Canadian Beaufort Sea during 1980–84 included many observations within the zone where seismic surveys and offshore construction and drilling were underway (Richardson et al. 1987a). In calculating the summer time budget (Fig. 12.9), we excluded observations close to industrial activities. However, many whales observed in the Canadian Beaufort Sea during the summers of 1980–84 would have been exposed to industrial activities during the days and weeks preceding our observations. Also, some of those classified as presumably undisturbed were nonetheless exposed to faint sounds from distant industrial activities while we were observing them (Richardson et al. 1985, 1986, 1990). We believe that the summer data classified as "presumably undisturbed" and summarized in Figure 12.9 were largely unaffected by industrial activities when observed. However, during days previous to our observation sessions, the bowheads observed in the Canadian Beaufort Sea during summer had no doubt been exposed (on average) to more industrial activity than the whales observed in and near the eastern Alaskan Beaufort during late summer and autumn.

In all five years of this study, the 13–m vessel used by the present project for zooplankton sampling operated within the area where we observed bowhead behavior. The boat caused some localized disturbance to bowheads, especially when purposefully sampling near feeding whales (Chapter 6). However, this vessel usually moved slowly, and always did so when sampling around bowheads. On one occasion in 1986, photoidentification data showed that bowheads displaced by the sampling vessel had returned to their original location 1–2 days later (Thomson and Richardson 1987).

The behavioral observations described here, including spring and summer data as well as late summer–early autumn data, were obtained by observers aboard twin-engined aircraft circling whales at altitudes of 460–610 m (1500–2000 ft) and radii of 1–2 km. This observation procedure has been found to cause little if any disturbance to bowheads (Richardson et al. 1985; Patenaude et al. 2002). However, the whales would have been able to hear the aircraft at least faintly and intermittently. Also, they might have been able to see it.

Aerial photogrammetry was conducted extensively during all five years of the present study. This procedure requires the aircraft to fly at low altitude (typically ~145 m or 475 ft) directly over the whales. The aircraft often travels back and forth above a group of whales for tens of minutes to obtain photos of most of the whales present. This procedure causes some bowheads to dive abruptly or otherwise react, although the proportion doing so is low (Patenaude et al. in 2002). Our standard procedure was to complete high-altitude behavioral observations of a given group of whales before descending to low altitude to photograph them.

Some bowhead hunting occurred in our study area each year during September while the project was occurring. However, in 1998–2000, most hunting near Kaktovik occurred before our study started (see Chapter 2). In addition, none of our BOSs in any year were conducted within 10 km of active hunting for bowheads. Most September BOSs were conducted considerably more than 10 km east of the hunters or (for some 1986 BOSs) well to the west.

Overall, the present behavioral dataset for late summer and early autumn involves whales that were exposed to relatively little human activity during the observations, or during preceding days. Furthermore, we have excluded data collected when there was a known potential for appreciable human disturbance. Our knowledge of potential disturbance effects may not be complete, but we are confident that none of the data used here were collected in the presence of strong disturbance. The present behavioral dataset for late summer and early autumn, including data in this chapter and related data on surfacing–respiration–dive cycles, swimming speeds, and habitat use as described in other chapters, may be valuable as baseline data for future analyses concerning effects of human presence and underwater noise.

General Activities

Our definitions of general activities (feeding, traveling, socializing, and "other") and the specific behaviors that make up these activities follow the descriptions used for whales and dolphins elsewhere. Wells et al. (1999) and Mann et al. (2000) provide detailed summaries for a variety of species. Nevertheless, when constructing time budgets, complications arise because whales can engage in different activities within short periods of time, and sometimes simultaneously. For example, our assignation of 33% to each activity when a whale was classified as "feed+social+travel" has the potential to either overestimate or underestimate any of these three general activities during any given BOS. However, we believe that these potential biases will balance out among the activities and BOSs; and that our overall estimates of time spend on each activity are reasonably accurate, albeit not perfect.

Our estimates of the proportion of time spent in various activities may have been biased by our different abilities to detect whales engaged in different activities. Durations of surfacings and dives vary according to whale status, water depth, and season (Tables 14.1, 15.6). The net affect is to slightly overestimate feeding in shallow water relative to deep water, and to overestimate socializing relative to other activities. However, these differences are reduced whenever more than one whale is present in the area being observed.

Feeding

Whales engaged in feeding at the surface, in the water column, and at or near the bottom, as previously described from studies during spring (Carroll et al. 1987; Richardson et al. 1995b), summer (Würsig et al. 1985, 1989), and autumn (Landino et al. 1994). Our results are similar to those of several other studies of bowhead whales (summarized in Würsig and Clark 1993) in indicating that whales change areas and modes of feeding readily, presumably in response to changes in locations and densities of prey as demonstrated in Chapter 6. Additional evidence of feeding in the study area comes from the stomachs of the whales harvested by Kaktovik whalers during late summer and early autumn. At least 75% (24 of 32) of these stomachs contained food (Lowry 1993; Chapter 18). Most of the food in these stomachs consisted of copepods, which would not remain in the stomachs for long. Thus, at least 75% of the whales harvested at Kaktovik had been feeding recently.

The fact that bowhead whales often occurred in loose aggregations at feeding sites, especially when surface and water-column feeding (Table 12.3D), suggests that they may coordinate their feeding by communicating with each other by sound, as postulated by Würsig and Clark (1993). Aggregating does not prove that the whales were actually communicating with each other to locate feeding areas. However, we observed one instance of a bowhead rapidly approaching a group of feeding bowheads from a long distance, suggesting that they may have been communicating acoustically: During early September 1997, a single bowhead whale was seen swimming strongly southeast ~15 km northwest of a feeding aggregation of 20–30 bowhead whales in shallow water near Prudhoe Bay, Alaska (WRK, unpubl. data). The whale was not followed to determine if it joined the feeding group, but the rapid speed and unusual southeastward heading of the whale suggest that it was intentionally approaching the feeding area from a distance ≥15 km.

Feeding bowhead whales seen in this study were generally alone or in small groups, as has been found for other baleen whales whose feeding does not depend on close cooperation. (Cooperative feeding in baleen whales includes some forms of lunge feeding by groups of humpback whales, e.g., Jurasz and Jurasz (1979), and echelon feeding by bowheads—see below.). Clapham (1993, 1996) suggested that group size is determined by the quantity of prey available in an area, and that scarcity of prey may be most responsible for small and unstable groups of whales.

We never saw—during the five years of this study—the highly-coordinated echelon formations of surface-feeding whales originally described for bowheads feeding in the Canadian Beaufort Sea during summer (Würsig et al. 1985). Other workers have occasionally seen echelon-feeding in the Alaskan Beaufort Sea during late summer and autumn (Ljungblad et al. 1986; Landino et al. 1994). It is possible, but remains unproved, that some echelons form when bowheads feed on larger, more maneuverable, prey such as euphausiid or mysid crustaceans, instead of calanoid copepods. However, the most impressive case of echelon feeding observed in the Canadian Beaufort (18 Aug. 1981) was at a time and location when copepods (*Calanus hyperboreus*) dominated the zooplankton biomass (Würsig et al. 1985; see also Chapter 6). Copepods also were the predominant zooplankters in the water column during the present study, especially where bowheads were feeding (Chapter 6).

There was substantial variability in whether whales were feeding near the surface, in the water column, or near the bottom. This changed with location, season, and year. Similar variability has been described for summer (Würsig et al. 1985, 1989). In the eastern and central Beaufort Sea, locations where bowheads choose to feed have higher than average biomass of zooplankton in the water column as a whole, and a biomass of at least 800 mg/m^3 at the depth of maximum biomass (Chapter 6). Locations in the Beaufort Sea where such concentrations of zooplankton occur vary from year to year and probably with date, and the depth of maximum biomass varies with location (Chapter 5). Seasonal and geographic changes in food distribution represent the norm for many marine mammals (Bowen and Siniff 1999), and bowhead whales are no exception.

The predominant feeding mode of bowheads during summer and early autumn is water-column feeding, but near-surface feeding sometimes occurs. It is rare for there to be dense concentrations of prey in the top few meters of the water column of the Beaufort Sea (Chapters 5 and 6), and we are uncertain of the importance of surface skim feeding. Euphausiids and mysids occasionally swarm at the surface in the arctic, and were significant components of the stomach contents in a few whales harvested in the present study area, and in most bowheads harvested farther west near Point Barrow (Chapter 18). It is possible that some cases of surface feeding are on these types of prey aggregations. However, neither euphausiids nor mysids were common during the aforementioned 18 August 1981 case of near-surface feeding in echelon formation. Northern right whales also skim feed near the surface but spend most of their feeding time below ~10 m depth (Watkins and Schevill 1976).

The variable occurrence of the small copepod *Limnocalanus glacialis* in nearshore waters appears to be especially important to bowheads. In years and locations when *Limnocalanus* is abundant along the coast of the central Beaufort Sea (Yukon and eastern Alaska), bowheads (especially subadults) concentrate and feed in those areas (Chapters 6, 10). The occurrence of this nominally "brackish-water" species appears to be affected by wind and oceanographic factors that affect the distribution of water from the Mackenzie River (Chapters 5, 6).

In 2000, very little feeding was observed in the study area, and most if not all bowheads apparently traversed the area quickly without lingering to feed. Prey availability in the present study area was lower in 2000 than in other years of this study (Chapter 5). Nevertheless, some of the whales landed in September 2000 by hunters at Kaktovik, as well as at Cross Island to the west and Pt. Barrow farther west, had food in their stomachs (see Chapter 18). At least in the Kaktovik area, it is probable that some whales were feeding as they traveled west during September 2000.

Traveling

Whales traveled westwards more consistently in late September–early October than in early September. Feeding continued to occur in the eastern Alaskan study area during late September, but combined feeding and traveling was more common then than in early September (Table 12.3). During combined feeding and travel, bowheads moved predominantly westward (Fig. 12.7D). Westward travel without simultaneous feeding or socializing were infrequent in early September, but became common in late September. We assume that most of the traveling whales observed in late September were actively migrating, given their generally westward orientation and other evidence of migration from distributional surveys (Chapter 9), photographic re-identifications (Koski et al. 1988), acoustic tracking (Greene et al. 2001, 2002), and radio-tagging (Wartzok 1990; Mate et al. 2000).

Traveling bowheads tended to be singletons or groups of two, but other bowheads were often present within 1 km. This is consistent with previous studies in and near this area (Würsig et al. 1985; Richardson et al. 1995a). Migratory travel in spring is usually also by single whales, again with others present in the general area (Carroll and Smithhisler 1980; Zeh et al. 1993; Richardson et al. 1995b). Spring migration tends to occur in pulses lasting many minutes to many hours, with dozens and sometimes hundreds of whales following a particular "corridor", often consisting of ice leads and polynyas. Bowheads call often during spring migration, and whales in a "pulse" are probably in acoustic contact (Würsig and Clark 1993).

Kaktovik hunters state that autumn bowhead migration through the present study area is sometimes pulsed (e.g., I. Akootchook *in* Chapter 2), and aerial surveys sometimes show large day-to-day changes in numbers (e.g., Chapter 9). Moore et al. (1989) recorded underwater sounds near Kaktovik throughout most of the late summer and autumn in 1986, one of our study years. They found periods of several days with almost-continuous calling by bowheads, indicative of a prolonged pulse of whales, and periods of several days when no calls were recorded, apparently indicative of intervals between pulses. Acoustic monitoring near Prudhoe Bay (~200 km farther west) during September has also detected large numbers of bowhead calls, and has shown a strongly pulsed structure to hourly call counts (Greene et al. 1999, 2001, 2002). Some of this structure is probably an artifact of changes in background sound levels, which mask faint calls. However, acoustic data, along with the variable aerial survey results and observations of subsistence whalers, show that autumn as well as spring migration is in pulses, and suggest that migrating bowheads are often in acoustic contact with one another. The lesser frequency and amount of ice in autumn than in spring means that, in many years, precise routes of whales are less affected by ice in autumn.

Although whales were below the surface and out of sight most of the time when they were classified as traveling (for details, see Chapter 13), we believe that little feeding was done by whales classified as traveling. Speeds of traveling bowheads averaged 4.50 ± s.d. 1.22 km/h (Chapter 11). Because of the large gape of the bowhead mouth when they feed, it is unlikely that they would travel this fast if they were feeding appreciably while traveling.

Socializing

Social behavior occurred throughout September, with mainly low levels of interactions, similar to those seen in summer (Würsig et al. 1985). Social activity was more common during late summer and autumn than in spring (Fig. 12.9); however, a general decrease from a high in late winter and early spring to late spring and summer has been described before (summary by Würsig and Clark 1993).

We saw apparent surface-sexual aggregations in September, as have been described for right (*Eubalaena* spp., e.g., Donnelly 1967), gray (Houck 1962), and bowhead whales (Everitt and Krogman 1979) during winter/spring. These surface-active groups are speculated to consist mainly of males aggregating (and competing) around one or more females in estrus (Brownell and Ralls 1986). It is unknown whether sexual behavior in summer/autumn represents actual breeding behavior. Similar seemingly "out-of-season" sexual behavior has been observed during late summer in Davis Strait bowheads near Baffin Island (Finley 1990) and during autumn in Bering–Chukchi–Beaufort bowheads in the eastern Canadian Beaufort Sea (Würsig et al. 1993). In the present study, two groups involved in presumed sexual activity were approaching or had recently attained sexual maturity, based on their measured lengths. However, these groups did not contain large bowheads that are known to be sexually mature, which are generally present in that area at the time when sexually activity was seen (Chapter 10). Our observations appeared to be of male–female encounters, and so—unlike homosexual activities described by Finley (1990)—could have reproductive functions. However, based on a gestation period of 12–14 months and the lack of sightings of recently-born calves outside the calving period (primarily April–May but extends from February–July), these sexual encounters in early autumn are not likely to have a reproductive function (Koski et al. 1993; Würsig et al. 1993). Our few observations of sexual behavior in nearly- or recently-mature bowheads are consistent with speculation (see also Finley 1990; Würsig et al. 1993) that sexual activity outside the breeding season is experimental or play in nature. Similar out-of-season sexual behavior has been described in some other species of baleen whales, e.g., by Sauer (1963) and Fay (1963) among gray whales off St. Lawrence Island, Bering Sea, in summer.

Mothers and Calves

Mothers socialized with other bowheads (aside from their calves) sporadically during late summer and autumn and very rarely in spring (Richardson et al. 1995b). This seasonal difference may be related to encounter rates of mothers and calves with other whales. The migration period of mothers and calves overlaps more with that of "others" during autumn in the present study area than during spring in the Point Barrow region. During spring, most mothers and calves pass Barrow 3–4 weeks after the peak of subadult movements and 1–2 weeks after the peak of adult movement (Braham et al. 1980; Richardson et al. 1995b). During late summer and autumn, mothers and calves start migrating in early September, part way through the migration of small subadults, and continue to migrate throughout the remainder of the autumn season, thus overlapping with movements by most other categories of bowheads (Chapter 10).

Mother-calf associations were generally similar in late summer and early autumn to those in spring and especially summer, but calves were of course substantially larger during the present study than earlier in the season. For related data on mothers and calves, see Koski et al. (1993) and, for spring, Würsig et al. (1999), Richardson et al. (1995b); for summer, Würsig et al. (1985, 1989); for late summer–autumn, Chapter 10. One notable seasonal difference is that calves did not "ride" on the backs of mothers in August–September, whereas this is often seen in May (Würsig et al. 1999). By August, calves are probably too large to make this behavior possible, and/or too well-developed for it to be necessary. The absence of observations of calf "play" during this study, and the very low level of surface-active behavior by calves, represented a waning of activity from summer (*cf.* Würsig et al. 1985, 1989). We did not see lone calves during late summer or autumn, indicating that weaning had not started. (In spring, summer and autumn, calves are sometimes seen alone at the surface, but extended observations show that they are soon joined by their mothers, whose dives tend to be longer than those of their calves—see Chapters 13 and 14). Calves are probably still learning the migration route, feeding strategies, and other life skills from their mothers prior to weaning, which occurs sometime between the calf's first autumn and the subsequent spring migration to the Beaufort Sea (Koski et al. 1993).

Orientations

Consistent orientation to the west is probably a good indication of migratory travel in late summer and early autumn. The consistent westward headings of traveling whales, and the less consistent but nonetheless significant westward tendencies during travel+feed, travel+social, and even socializing *per se* (Fig. 12.7), indicated that whales were generally moving west while engaged in these activities.

Bowheads categorized as feeding (the most common activity) and social+feed during September were not consistently oriented west. The feeding whales (mothers and calves excluded) showed significantly bimodal orientation toward northeast and southwest. This axis is perpendicular to shore in much of the present study area (*cf.* Fig. 12.1), and perhaps represents onshore–offshore movements of whales between nearshore feeding areas and the main southeast–northwest migration corridor farther offshore. Satellite-tag and photo-identification data on tracks of bowheads in the present area show that some whales linger in the area or "double back" to the east (Mate et al. 2000; Chapter 11). Thus, a wide variety of orientations is to be expected for feeding whales.

Feeding mother–calf pairs were significantly oriented, but toward directions *other than* west (Fig. 12.8A). Reasons for this are unknown, but these animals clearly did not show much indication of westward migration. Mothers and calves engaged in travel+feed exhibited significant southwesterly orientation, different from the predominantly westward headings of "other" bowheads engaged in travel+feed (Fig. 12.8B vs. 12.7B); we do not speculate why.

Time Budgets

Bowhead whales observed in spring just east of Point Barrow spent most of their time traveling (Richardson et al. 1995b), and those observed in the Canadian Beaufort Sea in summer spent most of their time feeding (Würsig et al. 1985) (Fig. 12.9). The time spent engaged in various activities in the present study area during late summer and autumn differed from both spring and summer in that bowheads spent substantial parts of their time both feeding and traveling (Fig. 2.9). The change in activities from spring (near Point Barrow) to summer is not unexpected. Although feeding occurs near Point Barrow in spring, the amounts of food found in the stomachs of bowheads harvested there during spring are usually small (Carroll et al. 1987; Chapter 18). Assuming that the eastern Beaufort Sea is an important feeding area, it makes sense for the animals to migrate quickly to the main summer feeding range in spring and, once there, to feed as much as possible throughout the summer. Carbon isotope ratios in bowhead and zooplankton tissues suggest that the summer range (eastern Beaufort Sea) is not the primary feeding area (Schell and Saupe 1993; Chapter 20). However, this conclusion is difficult to reconcile with the high proportion of the summer devoted to feeding (Fig. 12.9), the occurrence of prey in the stomachs of most bowheads harvested at Kaktovik (Chapter 18), and other evidence (Chapter 22).

The activity budgets of bowheads in the present study area during late summer and autumn were variable among years. During the westward migration toward additional feeding areas in the western Beaufort Sea (e.g., Landino et al. 1994; Treacy in prep.; Chapter 18) and western Chukchi Sea (e.g., Moore et al. 1995), activities appear to change from traveling to feeding on an opportunistic basis where food is abundant (Chapter 6). The eastern Alaskan Beaufort Sea is one area where some bowheads stop to feed for periods of hours (1998) to days or even a few weeks (1986, 1999; Chapter 11). In other years, such as 2000, they apparently migrate through that area without stopping, though some limited feeding probably occurs as they travel. These variations in stopover frequency, location, and duration result in year-to-year differences in activity budgets of bowheads in the present study area. In some years, e.g., 1986, parts of the eastern Alaskan Beaufort Sea appear to be a westward extension of late-summer feeding areas in the western part of the Canadian Beaufort Sea (Yukon coast). However, utilization of eastern Alaskan waters varies greatly from year to year.

The time budget derived in this study for late summer–autumn is based mainly on September data. We have shown that the proportions of time devoted to feeding vs. migration differed in early vs. late September. Although September is the month of peak utilization of the present study area, appreciable numbers of bowhead whales occur there during August and early October as well, and a few are present in late October (Chapter 9). The time budget for the overall August–October period may differ somewhat from that described here for September.

Averaged across years, the proportional occurrence of feeding and traveling is considerably different during summer in the Canadian Beaufort vs. September in eastern Alaska. The latter area is not used by bowheads in the same manner as is the Canadian summer range. However, the eastern Alaskan part of the Beaufort Sea is more than a migration corridor. It is used by feeding whales to variable degrees in different years.

It is beyond the scope of this chapter to assess the importance of the observed feeding in the eastern Alaskan Beaufort Sea in meeting the overall energy requirements for the year, and in assuring the well-being of the individuals and the population (see Chapters 22 and 23). However, from an ecological perspective, in years when "casual" or infrequent feeding occurs within this area, that feeding is unlikely to be vital to survival and successful reproduction. When more intensive and prolonged feeding occurs there, for several days or perhaps a few weeks, that feeding could be important to the well being and reproductive performance of those whales. This issue is addressed further in Chapter 22, "Energetics", and Chapter 23, "Integration".

Summary

Chapter 12 describes the general activities of bowhead whales while they are off northeastern Alaska, and in adjacent Canadian waters, during late summer and early autumn (feeding, traveling, socializing, and combinations thereof). It also documents the specific behaviors associated with these activities, and determines the proportion of time engaged in each activity (time budget). During September of 1985, 1986, 1998, 1999, and 2000 (and early October in 1986), systematic behavioral observations were obtained from twin-engine aircraft circling at an altitude of 460 m (occasionally 610 m) a.s.l., with a minimum of three observers describing and videotaping behavioral events. We obtained data on the activities and behaviors of whales during 84 Behavioral Observation Sessions totaling 91.9 h of observations under presumably undisturbed conditions. Of these, 69 sessions were off northeast Alaska (Flaxman Isl. to border) and 15 were in Canadian waters from the Alaska-Yukon border to Herschel Island. We compared our data for this "Flaxman-to-Herschel" area in September/early October to previously reported data on activities, behaviors, and time budgets during spring and during summer, and demonstrated seasonal differences. For the late summer/early autumn period, the time-budgets also differed among years.

Feeding was the most common activity of bowhead whales in and near the eastern Alaskan Beaufort Sea in September/early October during 1985, 1986, 1998, and 1999; but not in 2000. Over the five seasons, bowheads engaged in feeding for ~47% of the total time (9% in 2000; 38–66% in other years). Overall, ~34% of the time was spent feeding in the water column, 8% on near-surface ("skim-") feeding, and 4% on near-bottom feeding. Almost all observed feeding in water >20 m deep was water-column feeding; surface and bottom feeding were proportionally more common in areas ≤20 m deep, but there too water-column feeding was the most common activity. Mothers and first-year calves were rarely sighted in waters ≤20 m deep, and the most common activity of mothers was feeding in the water column in areas >20 m deep. Most whales fed singly. Bottom feeders were usually widely spaced, but water-column and skim feeders generally were more aggregated, typically with 4+ whales within 1 km of each other. We did not see skim feeding in echelon formation during late summer–early autumn, although it has been reported previously in the Alaskan Beaufort Sea. The estimated proportion of time devoted to feeding during September/early October (47%) was intermediate between values during spring migration east of Point Barrow, Alaska (1%), and on the summer range in the Canadian Beaufort Sea (71%).

Traveling was the second-most common activity, accounting for 31% of time overall; but 74% in 2000. Travel tended to be in areas 20–49 m deep and in groups of one to two whales. Whales spent more time traveling during the latter half of September than in early September. Traveling whales were oriented mainly westward. Bowheads commonly interspersed feeding and socializing with travel during the latter half of September. The estimated proportion of time devoted to traveling (31%) was also intermediate between that during spring migration (81%) and that on the summer range (9%).

Socializing accounted for 18% of the time during September/early October, and other activities (aside from feeding, travel or socializing) accounted for 4%. Socializing tended to consist of low-level behaviors such as nudges and other touches, with the exception of apparent sexual aggregations of up to seven whales per aggregation on two days in September 1998. First-year calves stayed close to their mothers, showed little surface-active behavior, and were not observed to play. No lone calves were seen, indicating that calves had not been weaned.

Although feeding was the most common activity of bowhead whales in and near the eastern Alaskan Beaufort Sea during September/early October, there was much intra- and inter-season variability in the amount and type of feeding, other activities, and specific behaviors, and in the locations (within the study area) where these activities occurred. These variable results are generally consistent with the apparent variability in prey availability in the study area, as documented in other parts of this study. However, bowheads observed in 1999 spent a high proportion of their time feeding, and exhibited relatively long residence times, even though average zooplankton abundance (at least inshore of the 50 m contour) was relatively low that year. Overall, the importance of the study area for late-summer feeding by bowhead whales varies considerably from year to year, and is difficult to predict for any one late summer–early autumn season.

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APPENDIX 12.1a. Behavioral observation sessions, 1985. ‘Boxed’ locations are in Canadian waters.

Date 1985	Behav. Obs. Sess. #	Location	Time of Obs.	Number of Whales		Feeding	Traveling	Active Socializing	Predominant Orientation	Predominant Speeds of Travel	Depth (m)
				in Circle	in General Area						
12 Sept	1	69°37'N 140°30'W	16:28- 18:17	5-8	30-40	skim feeding[b]		some-low level	random	slow-medium	10
13 Sept	2[a]	69°37' N 140°07' W	16:08- 17:04	7-10	20-30	skim feeding[b]	possibly slow travel	some-low level	mainly west	slow-medium	8
19 Sept A	3[a]	69°54' N 142°00' W	9:03- 12:19	1	3	water column			mainly west	zero-slow	20
19 Sept B	4	69°40' N 141°00' W	12:31- 13:00	4	8-10		strongly directed		nearly all west	medium	13
22 Sept	5[a]	70°14' N 139°56' W	10:44- 12:50	6-8	15-22	water column		up to 5 socializing	random	zero-slow	280
23 Sept A	6	69°37' N 140°38' W	11:27- 12:13	3-4	5-8	water column	possibly slow travel		mainly west	slow	14
23 Sept B	7[a]	70°24' N 143°45' W	16:40- 18:15	4-6	4-6	water column	possibly slow travel		north-west	slow	40
24 Sept	8	69°36' N 140°13' W	10:58- 11:43	4-6	15-25	skim feeding[b]		some	random	zero-slow	15
26 Sept A	9[a]	69°52' N 139°58' W	10:34- 12:00	4	4-5	water column			north-west	slow	40
26 Sept B	10	70°29' N 143°23' W	15:08- 16:30	4-6	13-18	water column		some	random	zero-medium	42
29 Sept	11	70°23' N 143°02' W	9:26- 10:34	5-6	12-15	water column	possibly	some	south-west	slow-medium	50

[a] Behavioral observation session not used in analysis because it was considered disturbed.

[b] Whales observed or photographed with mouths open and/or defecations.

APPENDIX 12.1b. Behavioral observation sessions, 1986. 'Boxed' locations are in Canadian waters.

Date 1986	Behav. Obs. Sess. #	Location	Time of Obs.	Number of Whales		Feeding	Traveling	Active Socializing	Predominant Orientation	Predominant Speeds of Travel	Depth (m)
				in Circle	in General Area						
3 Sept A	1	69°36'N 138°54'W	12:13-13:03		10-15	water column			random	medium	8
3 Sept B	2	69°34' N 139°28' W	13:15-13:26		6-10	water column			random		10
5 Sept	3	69°49' N 141°48' W	10:45-12:06	10-13	20	water column; surface; bottom[b]			random	slow-medium	11
7 Sept	4	69°49' N 141°37' W	11:32-12:44	6	12	water column			random	slow-medium	20
8 Sept	5	69°47' N 141°24' W	14:38-16:07	6-8	8	water column			random	slow-medium	19
9 Sept	6	69°37' N 140°20' W	16:09-16:43	6-8	6-8	water column[b]		some	mostly SW, W & NW	slow-medium	13
10 Sept	7[a]	69°44' N 141°21' W	10:22-11:16	8-10	10-15	water column[b]		some	random	slow-medium	15
14 Sept	8	69°40' N 140°21' W	10:25-11:46		40-50	water column and surface[b]			random	slow-medium	20
15 Sept	9	69°43' N 140°37' W	10:01-11:46	6-8	40-50	water column[b]		some-low level	random	slow	27
16 Sept	10	69°36' N 140°33' W	11:26-12:11	5-8	5-8	water column and surface[b]			random	slow-medium	5
19 Sept	11	69°37' N 139°55' W	11:22-12:36	6-8	50	water column and surface[b]		some	random	slow-medium	9
22 Sept A	12	70°02' N 142°20' W	16:33-17:08	1	2				west and south-west	slow	22
22 Sept B	13	69°53' N 141°24' W	17:21-18:12	2	2		yes	yes	west	slow-medium	32
26 Sept A	14[a]	70°03' N 140°30' W	11:42-12:53	6-8	20-30	water column and surface			south-west north-west	slow-medium	44
26 Sept B	15[a]	70°09' N 141°52' W	15:39-16:21	1	1					zero	43
26 Sept C	16	70°10' N 141°26' W	16:30-17:55	5-6	5-6	water column			random	zero-slow	48
27 Sept	17	70°02' N 140°27' W	12:41-13:37	3-6	20+		possibly slow travel	some	west and north-west	zero-medium	45

[a] Behavioral observation session not used in analysis because it was considered disturbed.

[b] Whales observed or photographed with mouths open and/or defecations.

APPENDIX 12.1c. Behavioral observation sessions, S-1986 (SWEPI). ‘Boxed’ location is in Canadian waters.

Date S-1986	Behav. Obs. Sess. #	Location	Time of Obs.	Number of Whales in Circle	Number of Whales in General Area	Feeding	Traveling	Active Socializing	Predominant Orientation	Predominant Speeds of Travel	Depth (m)
4 Sept	1	69°49'N 141°48'W	13:55-16:23	4	7	water column; surface; bottom[b]			random	zero-slow	10-18
5 Sept	2[a]	69°39'N 141°51'W	14:35-15:57	5	8	water column and bottom			random	slow-fast	10
8 Sept	3	69°39'N 140°31'W	15:03-15:57	3	12	water column and bottom[b]			random	slow-medium	9
9 Sept	4	70°30'N 145°06'W	14:55-18:23	3-5	10	water column			random	zero-slow	46
10 Sept	5[a]	70°29'N 144°23'W	12:05-14:55	2-3	4				south-east	slow	42-55
11 Sept	6[a]	70°25'N 144°02'W	10:58-14:25	3	10	water column			random	zero-medium	37-46
17 Sept A	7[a]	70°09'N 144°34'W	11:22-11:55	1	1	water column			east	slow	18
17 Sept B	8[a]	70°09'N 144°34'W	16:29-16:39	1	1	water column			west	unk	18
19 Sept	9	70°32'N 146°29'W	14:03-17:05	2	3		strongly directed		west	medium	36
26 Sept	10	70°37'N 145°48'W	14:07-16:40	1	2		strongly directed		west	medium	46
28 Sept	11[a]	69°39'N 141°51'W	14:35-15:57								
3 Oct	12	70°37'N 145°29'W	12:01-13:00	6	18		slow travel		north-west	slow	66
6 Oct	13	70°30'N 145°30'W	10:49-17:33	1	1		strongly directed		north-west	medium	36-45

[a] Behavioral observation session not used in analysis because it was considered disturbed.

[b] Whales observed or photographed with mouths open.

APPENDIX 12.1d. Behavioral observation sessions, 1998. 'Boxed' locations are in Canadian waters.

Date 1998	Behav. Obs. Sess. #	Location	Time of Obs.	Number of Whales in Circle	Number of Whales in General Area	Feeding	Traveling	Active Socializing	Predominant Orientation	Predominant Speeds of Travel	Depth (m)
13 Sept A	1[a]	69°41'N 139°05'W	11:46- 11:59	3	3	water column			north-east	slow	35
13 Sept B	2	69°38' N 138°26' W	12:16- 13:00	4	7	water column		some-low level	mainly west	slow	51-100
15 Sept A	3	70°11' N 143°34' W	10:34- 11:03	4	9			up to 4 socializing	mainly west	slow	16
15 Sept B	4	70°11' N 143°47' W	11:51- 13:21	4	20	water column[b]		up to 4 socializing	mainly west	slow	18
15 Sept C	5	70°12' N 144°55' W	18:11- 19:34	2	6		possibly slow travel		nearly all west	zero-slow	27
16 Sept A	6	70°13' N 145°03' W	10:30- 12:02	3	5	water column[b]		up to 3 socializing	nearly all west	slow	28
16 Sept B	7	70°13' N 145°02' W	17:13 17:48	3	5				random	slow	30
16 Sept C	8	70°14' N 144°28' W	17:54 18:43	2	2			2 whales chasing	random	slow	28
18 Sept A	9	70°13' N 144°04' W	10:11 12:37	4	14	water column[b]	possibly slow travel		nearly all west	zero-slow	25
18 Sept B	10	70°02' N 142°06' W	16:21 18:44	5	16	water column	possibly slow travel		west	slow	30
19 Sept A	11	70°14' N 143°31' W	10:52 11:50	2	3			breaching	west	slow	26
19 Sept B	12[a]	70°10' N 143°45' W	11:54 12:05	4	16			up to 3 socializing	random	zero-medium	16
19 Sept C	13	70°10' N 144°11' W	12:15 12:24	3	6			up to 3 socializing	random	slow	20
19 Sept D	14	70°12' N 144°01' W	12:27 13:43	2	3		strongly directed		nearly all west	slow-medium	23
19 Sept E	15	70°10' N 143°40' W	18:55 19:40	4	4	skim feeding[b]		some-low level	random	slow-medium	12
20 Sept A	16	70°09' N 143°39' W	9:51 10:01	1	1	low-level skim feeding[b]			south	slow	9
20 Sept B	17	70°11' N 143°16' W	10:04 11:45	14	30	water column[b]		some-low level	random	zero-slow	15
20 Sept C	18	70°14' N 145°06' W	14:33 15:34	7	10		possibly slow travel	up to 7 socializing	random	zero-slow	28
20 Sept D	19	70°13' N 144°55' W	17:00 17:12	7	8			up to 7 socializing	random	slow	27
22 Sept A	20	70°10' N 143°07' W	9:20 10:53	2	4	bottom feeding			random	slow	14
22 Sept B	21	70°14' N 143°26' W	11:00 11:13	1	1			breaching	south-west	slow-medium	25
22 Sept C	22	70°13' N 143°56' W	11:36 11:58	2	2		possibly slow travel		west	slow-medium	27
22 Sept D	23	70°14' N 143°58' W	11:59 13:08	3	3	water column[b]	possibly slow travel		random	slow-medium	28
22 Sept E	24	70°12' N 144°06' W	16:11 17:28	2	4	skim feeding[b] and water column	possibly slow travel		south to west	slow	25

[a] Behavioral observation session not used in analysis because it was considered disturbed.

[b] Whales observed or photographed with mouths open.

APPENDIX 12.1e. Behavioral observation sessions, 1999. 'Boxed' locations are in Canadian waters.

Date 1999	Behav. Obs. Sess. #	Location	Time of Obs.	Number of Whales		Feeding	Traveling	Active Socializing	Predominant Orientation	Predominant Speeds of Travel	Depth (m)
				in Circle	in General Area						
10 Sept	1	70°18'N 142°08'W	13:19-14:21	6	9	water column[b]	possibly slow travel	some-low level	random	slow	75
11 Sept A	2	70°18' N 142°09' W	11:16-11:40	7	10	water column[b]			random	slow	80
11 Sept B	3	70°20' N 141°58' W	11:44-12:08	7	10				south-east	slow	125
11 Sept C	4	70°04' N 140°17' W	12:35-13:41	5	8	water column[b]			south-west	slow	40
12 Sept A	5	70°19' N 142°05' W	13:36-14:37	3	8	water column			random	zero-slow	100
12 Sept B	6	69°57' N 140°14' W	15:04-15:24	6	10	water column and surface[b]		up to 3 socializing	west	slow	48
16 Sept A	7	70°08' N 141°51' W	11:00-12:05	6	13	water column[b]			random	slow	45
16 Sept B	8	69°59' N 141°32' W	15:59-16:30	6	12	water column			random	zero-slow	40
16 Sept C	9	70°04' N 141°22' W	17:00-18:03	1	2	water column			nearly all west	random	48
16 Sept D	10	70°12' N 142°08' W	18:16-19:16	5	7		strongly directed		west	slow	43
17 Sept A	11	70°08' N 141°52' W	9:14-9:50	8	15	water column[b]			north-east	zero-slow	43
17 Sept B	12	70°16' N 142°19' W	10:15-11:16	4	12	water column[b]	possibly slow travel		west	slow-medium	75
17 Sept C	13	70°09' N 142°01' W	12:18-12:38	8	13	water column[b]			random	zero-slow	42
17 Sept D	14	70°15' N 143°32' W	16:41-17:26	4	6	water column			random	zero-slow	31
17 Sept E	15	70°14' N 144°19' W	17:36-18:26	4	10	water column	possibly slow travel		west	zero-medium	30
20 Sept	16	70°18' N 143°35' W	14:08-14:39	4	15	water column		some-low level	random	zero-slow	31
21 Sept	17	70°18' N 145°10' W	10:54-11:42	4	4		strongly directed		west	slow-medium	35
26 Sept A	18	70°21' N 143°47' W	10:24-10:54	3	3			up to 3 socializing	random	zero-slow	48
26 Sept B	19	70°34' N 142°57' W	11:25-12:34	3	4	water column	possibly slow travel		south-west	slow	200
26 Sept C	20	70°23' N 142°13' W	14:20-14:40	15	50		strongly directed	some-low level	west	slow	130
29 Sept	21	70°14' N 141°24' W	10:36-11:06	3	5	water column[b]		some-low level	south-west	north	250
30 Sept	22	70°18' N 143°11' W	10:58-11:28	2	6	water column[b]	possibly slow travel		south-west	slow	48

[a] Behavioral observation session not used in analysis because it was considered disturbed.

[b] Whales observed or photographed with mouths open.

APPENDIX 12.1f. Behavioral observation sessions, 2000. All locations are in Alaskan waters.

Date 2000	Behav. Obs. Sess. #	Location	Time of Obs.	Number of Whales		Feeding	Traveling	Active Socializing	Predominant Orientation	Predominant Speeds of Travel	Depth (m)
				in Circle	in General Area						
13 Sept A	1	70°13'N 143°18'W	13:43-14:37	1	1				north	slow	25
13 Sept B	2	70°20' N 142°45' W	14:53-16:03	3	3		strongly directed		south-west	slow-medium	100
18 Sept A	3	70°20' N 144°03' W	11:08-12:08	2	8		strongly directed		west	slow-medium	40
18 Sept B	4	70°03' N 141°15' W	16:29-17:05	2	2				north-west	slow	45
18 Sept C	5	70°03' N 141°49' W	17:31-18:24	1	1				north	zero	42
19 Sept A	6	69°53' N 141°22' W	10:34-11:34	1	1		strongly directed		west	medium	40
19 Sept B	7	69°55' N 141°52' W	13:13-13:56	3	3		possibly slow travel	some-low level	random	slow-medium	27
20 Sept A	8	70°19' N 144°36' W	10:15-11:20	1	1		strongly directed		west	medium	35
20 Sept B	9	70°02' N 142°10' W	14:07-15:10	1	6		strongly directed		west	slow	27
20 Sept C	10	70°07' N 142°46' W	17:22-18:57	2	3	bottom feeding	possibly slow travel		west	slow-medium	22
21 Sept	11	69°52' N 141°50' W	11:17-12:22	4	5	bottom feeding[b]		up to 4 socializing	random	zero-slow	20
23 Sept	12	70°06' N 142°50' W	16:56-18:03	1	1		strongly directed		west	medium	15
25 Sept	13	70°06' N 142°42' W	10:39-11:03	1	1		strongly directed		west	medium	22

[a] Behavioral observation session not used in analysis because it was considered disturbed.

[b] Whales observed or photographed with mouths open.

APPENDIX 12.2. Circumstances of observations of undisturbed bowhead calves, mothers and others engaged in travelling and/or feeding (socializing excluded). Calves and mothers that are and are not nursing are shown separately. Table shows number of surfacings and numbers of whales observed during September-October 1985-86 and 1998-2000, as observed from an aircraft at altitude ≥460m. Because a given whale is counted more than once if more than one surfacing is observed, some data are not independent and statistical analysis is not justified. "Total *n*" varies because not all variables could be determined for each surfacing.

	Calf							Mother							Other Whales[a]			
	Travel		Feed		Travel+Feed			Travel		Feed		Travel+Feed						
	Not	Nurse	Not	Nurse	Not	Nurse	ALL	Not	Nurse	Not	Nurse	Not	Nurse	ALL	Feed	Travel	Travel +Feed	ALL[a]
A. Date																		
1-15 Sept	13	2	13	3	3	0	34	8	2	8	1	1	0	20	231	4	15	250
16-31 Sept	0	0	8	8	22	45	83	0	0	5	3	10	11	29	192	103	127	422
1-15 Oct	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	15
Total n	13	2	21	11	25	45	117	8	2	13	4	11	11	49	423	122	142	687
# Whales	4	0	13	4	4	1	26	1	1	9	2	4	1	18	314	47	124	485
B. Water Depth (m)																		
1-9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	97	0	0	97
10-19	0	0	2	0	0	0	2	0	0	0	0	0	0	0	162	15	9	186
20-49	8	1	16	11	18	45	99	5	1	11	4	7	11	39	136	99	91	326
50-99	0	0	2	0	3	0	5	0	0	1	0	1	0	2	16	8	40	64
100-250	5	1	1	0	4	0	11	3	1	1	0	3	0	8	0	0	2	0
Total n	13	2	21	11	25	45	117	8	2	13	4	11	11	49	411	122	142	675
# Whales	4	0	13	4	4	1	26	1	1	9	2	4	1	18	302	47	124	473
C. Group Size (within 5 body lengths)																		
1	2	0	12	0	7	0	21	0	0	2	0	0	0	2	334	95	85	514
2	8	2	7	11	18	37	83	6	2	9	4	11	10	42	52	24	42	118
3	3	0	2	0	0	8	13	2	0	2	0	0	1	5	19	3	4	26
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	11	14
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total n	13	2	21	11	25	45	117	8	2	13	4	11	11	49	408	122	142	672
# Whales	4	0	13	4	4	1	26	1	1	9	2	4	1	18	299	47	124	470
D. # Bowheads within 1 km																		
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	54	0	59
2	8	1	0	0	8	6	23	5	1	0	0	2	3	11	48	40	10	98
3	5	1	1	0	10	4	21	3	1	1	0	6	2	13	51	3	7	61
4	0	0	2	0	4	35	41	0	0	1	0	2	6	9	77	14	56	147
5	0	0	7	3	0	0	10	0	0	5	1	0	0	6	12	6	54	72
6	0	0	5	8	3	0	16	0	0	4	3	1	0	8	54	5	15	74
>6	0	0	6	0	0	0	6	0	0	2	0	0	0	2	144	0	0	144
Total n	13	2	21	11	25	45	117	8	2	13	4	11	11	49	391	122	142	655
# Whales	4		13	4	4	1	26	1	1	9	2	4	1	18	291	47	124	462

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[a] See Table 12.3 for additional breakdown for "Other Whales", including results for those engaged in socializing (excluded from ALL columns in this table).

13. SURFACING, RESPIRATION AND DIVE CYCLES OF BOWHEAD WHALES IN THE EASTERN ALASKAN BEAUFORT SEA DURING LATE SUMMER AND AUTUMN AS RELATED TO WHALE ACTIVITY

Tannis A. Thomas [1], William R. Koski [1], W. John Richardson [1], and Bernd Würsig [2]

Introduction

Feeding, traveling, and socializing are the three dominant activities of bowhead whales (*Balaena mysticetus*) observed in the eastern Alaskan Beaufort Sea during the late summer and autumn. The surfacing, respiration, and dive (SRD) cycles of bowheads vary with whale activity, at least during spring and summer—the seasons when these cycles have been studied (Würsig et al. 1984; Dorsey et al. 1989; Richardson et al. 1995a,b, MS). These types of variation are relevant in deriving correction factors to allow for whales missed during aerial surveys, and in analyses of whale energetics. Both of those topics are important in this study: In estimating numbers of whales present based on aerial survey results, it is important to know the relative time spent at vs. below the surface, and also the typical durations of surfacings. In calculating the amount of food a bowhead can consume, the typical duration of a feeding dive is one important factor. In addition, though not of direct relevance in this study, data on SRD cycles are useful indicators in assessing reactions of whales to human activities (e.g., Richardson et al. 1986).

Many studies have shown that specific environmental factors and whale status can affect SRD variables of baleen whales engaged in a particular activity such as feeding or traveling. In spring and summer, SRD cycles of bowhead whales engaged in feeding or traveling can vary with age–sex category, year, water depth, and other environmental variables (Würsig et al. 1984; Dorsey et al. 1989; Richardson et al. 1995a,b, MS). These relationships have not previously been investigated in any detail for the late summer–early autumn period when bowheads are present in the eastern Alaskan Beaufort Sea.

In this chapter, we use behavioral data collected in the late summer and autumn of 1985–86 and 1998–2000 to investigate the influence of whale activities and other factors on SRD cycles of bowhead whales during that season. We first consider the main factors individually, and then use multiple regression to assess the joint effects of various factors on four measures of SRD cycles. Companion chapters provide related data on the seasonal distribution of bowheads in the study area (Chapter 9), age segregation (Chapter 10), residence times (Chapter 11), and general activities (Chapter 12). In addition, Chapter 14 provides additional information, beyond that in this chapter, on the influence of bowhead age on SRD cycles. Chapter 15 uses some of the present results in deriving correction factors for aerial surveys.

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[1] LGL Ltd., environmental research associates, 22 Fisher St., POB 280, King City, Ont. L7B 1A6. *Phone:* 905-833-1244; *e-mail:* bkoski@lgl.com or wjr@lgl.com.

[2] Texas A & M University at Galveston, Marine Mammal Research Program, 4700 Ave. U., Bldg 303, Galveston, TX 77551-5923. *Phone:* 409-740-4413; *e-mail:* wursigb@tamug.tamu.edu

Methods

Data Sources

We combined data from three studies of bowhead behavior in the eastern Alaskan Beaufort Sea and adjacent Canadian waters (longitudes 138°–146°W) during the periods 3 September–6 October in 1985–86 and 10–30 September in 1998–2000 (Table 13.1). In four of five years, some behavioral observations were obtained as much as 98 km east of the Alaska/Yukon border in the western part of the Canadian Beaufort Sea. Locations where systematic behavioral data were obtained are mapped in Figure 12.1 and listed in Appendices 12.1a-f (in Chapter 12). We excluded data when bowheads may have been disturbed by an aircraft flying at <457 m (1500 ft) altitude or by industrial activities. Also excluded were all data concerning calves, which were recognized by their size, light color, morphology, behavior, and (in almost all cases) close association with an adult. Thus, this chapter concerns "non-calves", including adults associated with calves — presumed to be "mothers".

TABLE 13.1. Sources of data on bowhead whale surfacing, respiration and dive cycles for this study. Behavioral observation sessions (BOS) categorized as rest, play and unknown/other were excluded because they were not used in the analyses.[a] Also excluded are surfacings of calves.

	Number of		Date Range	No. BOSs by Area	
Year	BOS	Surfacings	of BOS	of Beaufort Sea	Source of Data
1985	6	133	12-29 Sept	E. Alaskan (3); W. Canadian (3)	Richardson (1987)
1986	13	310	3-27 Sept	E. Alaskan (5); W. Canadian (8)	Richardson (1987)
1986	7	120	4 Sept - 6 Oct	E. Alaskan (6); W. Canadian (1)	Koski & Johnson (1987)
1998	19	365	13-22 Sept	E. Alaskan (18); W. Canadian (1)	This study
1999	21	194	10-30 Sept	E. Alaskan (19); W. Canadian (2)	This study
2000	10	84	13-25 Sept	E. Alaskan (10)	This study

[a] See Figure 12.1 and Appendix 12.1a-f (in Chapter 12) for map and list of BOS locations.

Field Procedures

All aerial observations of behavior were obtained from either a Twin Otter turboprop aircraft (1985–86) or a Twin Commander 680FL piston-engined aircraft (1998–2000). The aircraft was based at Kaktovik, Alaska, for the duration of each season's fieldwork except during study (2), when the aircraft was based in Deadhorse (Prudhoe Bay). The Twin Otter aircraft (studies 1 and 2) were equipped with wingtip fuel tanks for extended endurance, GNS 500A Very Low Frequency navigation systems, radar altimeters, inverters for 120 V/60 Hz power, bubble windows, and ventral camera ports. The Twin Commander aircraft used in study (3) had ventral camera hatches, two photo-grade glass windows that were used for video taping and binocular observations, bubble windows at other observation positions, extended fuel capacity, and winglets that improve slow-speed handling. In each study, the field crew consisted of three or four biologists plus two pilots. The co-pilot moved to a rear seat once the aircraft was at survey altitude over the sea, allowing a biologist to move to the co-pilot's seat until the aircraft began to return to base.

We used the aerial observation procedures of Würsig et al. (1985) and Richardson et al. (1985, 1995a,b) to observe the behavior of bowheads. A focal group of bowheads was observed systematically while the aircraft circled at an altitude of at least 457 m a.s.l. and at a radius of 1–2 km. With this procedure, bowheads show very little evidence of disturbance by the aircraft (Patenaude et al. 2002). At most times while the focal whales were at the surface, they were videotaped using a hand-held video camera (usually with tele-extender).

Whale activities (e.g., traveling, feeding, socializing) and specific behaviors were defined and distinguished as in previous related studies (Richardson et al. 1995a,b, MS). We recognize only one type of dive, often referred to by others as a "sounding" or long dive. Dive durations were recorded only when whales were individually identified from one surfacing to the next, usually on the basis of distinctive marks. Shallow submergences between breaths were not counted as dives or as interruptions of a surfacing. A surfacing is a period when a whale is at or just below the surface, including a full breath sequence. We obtained four standard measures of SRD cycles: the interval between successive blows in a surfacing (blow interval), the number of blows per surfacing, the duration of surfacing (surface time), and the duration of dives between surfacings (dive time). When analyzing blow-interval data, we used the median of all blow intervals within a given surfacing as a single measure of blow interval for that surfacing.

After completing the behavioral observations of a given group of whales, we often used the aerial photogrammetric method of Koski et al. (1992) to document their lengths and individual identities. Whales <13 m and ≥13 m long were considered to be subadults and adults. When no photogrammetric data were available, whales that were obviously small or large were counted as subadults and adults; others were not classified.

Behavioral data were transcribed from audiotape between flights and after each field season. The videotape was then examined for details not noted during the real-time behavioral dictation. The combined data were coded numerically as in our previous work (see Richardson and Finley 1989:25–28 for details). These records were hand-checked, and then entered into an Apple II (1985–86) or MS-Windows (1998–2000) format for computerized validation and analysis. A validation program that checks for impossible or implausible combinations of variables, as developed during prior LGL/MMS projects, was applied to the data and necessary corrections were made.

Categories of Behavior

Whale activities were divided into nine categories: rest, travel, socialize, feed, travel+social, travel+feed, social+feed, travel+social+feed, play, and unknown/other. These activities are described in Chapter 12. Rest, play and unknown/other were excluded from the analyses either because their sample sizes were too small (1% rest and 1% play) or because the activities were heterogeneous and/or ill-defined (unknown/other, 8%). When isolated whales engaged in repeated "aerial behavior", including breaches, tail and flipper slaps, and rolls around the longitudinal axis, their activity was generally classified as "unknown/other" and thus excluded from the present analyses.

Analysis Procedures

For each whale activity, we used ANOVA to test for significant ($P \leq 0.05$) year-to-year differences in each of the four standard measures of SRD cycles. Years for which the sample size was <5 were excluded. If there were no significant differences among years, we then used ANOVA to determine whether whales engaged in related activities, e.g., traveling vs. traveling+feeding combined, had similar SRD cycles. If so, these related activities were combined prior to additional comparisons with other activities. When ANOVA showed significant differences, we used *post hoc* tests to determine which particular groups were different: the Tamhane procedure when variances were unequal (Tamhane 1979), and otherwise the Bonferroni procedure.

We used multiple regression analysis to identify environmental, temporal, and whale-related variables correlated with the four standard measures of a SRD cycle: number of blows per surfacing, duration of surfacing, median blow interval, and duration of dive. Procedures were generally consistent with those of Richardson et al. (1995a,b, MS). Data from calves and all potentially disturbed whales were excluded. Prior to each multiple regression analysis, data on median blow intervals were logarithmically transformed to compensate for skewness. (This was not necessary for the other three dependent variables.) Separate multiple regression analyses were done for whales engaged in three specific activities: traveling, feeding, and socializing.

Twenty-five variables were considered as potential predictors of the four dependent variables:

YEAR: = 1986? = 1998? = 1999? = 2000? (4 measures, each 0 for no or 1 for yes; 1985 was the standard)
DATE: date, in days after 2 September, and date-squared
TIME: decimal hour (0–24 scale, local time), and hour-squared
LOG.DEPTH: water depth (m), log transformed because of skewness
LOG.DIST: distance from shore (km), log transformed because of skewness
SEA.STATE: sea state (0–5 on Beaufort scale)
ICE.%: percent ice cover
GT.5%.ICE: 1 if greater than 5% ice cover; 0 otherwise
GRP.ACT.T+S: 1 if whale was traveling and socializing; 0 otherwise
GRP.ACT.T+F: 1 if whale was traveling and feeding; 0 otherwise
GRP.ACT.S+F: 1 if whale was socializing and feeding; 0 otherwise
SUBADULT: 1 if whale was a subadult; 0 otherwise
ADULT: 1 if whale was an adult; 0 otherwise
MOTHER: 1 if whale was a mother; 0 otherwise
No. BHD.1KM: estimated number of bowhead whales within 1 km of the focal whale, log transformed because of skewness
GRP.SIZ: estimated number of bowheads within five whale lengths of focal whale
ACT.SOCIAL: 1 if actively socializing; 0 otherwise
PASS.SOCIAL: 1 if passively socializing ("proximity"); 0 otherwise
AERIAL: 1 if aerial behavior(s) seen; 0 otherwise
FLUKE: 1 if pre-dive fluke-out; 0 otherwise

Years and many of the other variables were represented by dummy 0/1 variables (Draper and Smith 1981:241). By not including a dummy variable for 1985, that year was established as the standard year to which others were compared. Date (in days after 2 September), date^2, hour, and hour^2 were included to allow for possible non-linear temporal effects. Water depths were estimated based on location, bathometric charts, and NOAA bathometric datasets (as described in Chapter 9).

Predicted variables were included in the regression models if their nominal significance levels were ≤0.05. A forward and backward-stepping procedure was used (Systat Version 9, 1998). We ran each analysis twice, once forward and once backward, and used the one that ended up with a higher multiple correlation value. In most situations, the forward and backward procedures produced similar results. Little emphasis is given to correlations with nominal $P > 0.01$ given three considerations: (1) the large number of tests done; (2) the tendency, in stepwise multiple regression, for nominal P-values to overestimate the value of individual variables as predictor variables (Draper and Smith 1981:310); and (3) the frequent inclusion of data from >1 surfacing or dive by a given whale, with the result that sample sizes may overestimate actual degrees of freedom (Machlis et al. 1985).

For each whale activity, two multiple regression equations were calculated for each of the four dependent variables: (1) using all surfacings or dives for which all 25 predictor variables were known, and (2) using all surfacings or dives for which 22 predictors were known. In the latter case, the three whale status variables (SUBADULT, ADULT, MOTHER) were excluded. Whale status was unknown about half the time, so exclusion of these status variables resulted in a notably larger sample size, at the expense of excluding some potentially important predictor variables.

Results

Whales engaged in feeding and travel exhibited strong year-to-year differences in surfacing, respiration and dive (SRD) cycles; for both of those whale activities, 3 of 4 SRD variables differed significantly among years. Socializing whales showed no significant year-to-year variability in SRD cycles. Whales engaged in "travel+social" or "travel+feed" showed significant year-to-year variability only in one variable: median blow interval (ANOVA; $P < 0.001$, and $P = 0.015$, respectively). For whales engaged in combined "social+feed", durations of surfacings differed among years (ANOVA, $P = 0.004$). For combined "travel+social+feed" there were too few data for analysis.

Feeding Whales

In whales categorized as "feeding" (without simultaneous traveling or socializing), the overall mean of the median blow intervals in 1986 and 1998–99 was 13.08 ± s.d. 6.34 s ($n = 324$; Appendix 13.1), with yearly means ranging from 12.60 to 13.90 s. (These values, and all others in this chapter, exclude observations of potentially disturbed bowheads and of calves. Appendix 13.1 tabulates many of the numerical values mentioned here.) Median blow interval was the one variable that did not differ significantly among years (ANOVA, $P = 0.291$; Fig. 13.1A). Number of blows per surfacing averaged 5.89 ± 3.61 ($n = 123$), with yearly means ranging from 4.38 to 8.33. (Note: Figures 13.1-13.5 show medians, not the means quoted in text, thus accounting for apparent discrepancies.) Year to year variability was highly significant, with values in 1986 being significantly lower than other years (Fig. 13.1B). Duration of surfacing averaged 1.28 ± 0.74 ($n = 157$) min, with yearly means ranging from 1.02 to 1.68. These surface times varied significantly from year to year, with 1986 values being significantly lower than for other years (Fig. 13.1C). The overall mean dive duration was 8.94 ± 7.12 ($n = 63$) min, with yearly means ranging from 7.37 to 14.95. Dive times varied significantly from year to year (ANOVA, $P = 0.004$) with dives in 1999 being significantly longer than in other years (Fig. 13.1D).

Previous studies in the Beaufort Sea during spring and summer have shown that surfacing, respiration, and dive cycles often depend on environmental situations such as water depth (Würsig et al. 1984; Dorsey et al. 1989; Richardson et al. 1995a,b, MS). In this study area and season, whales feeding in water >20 m deep had significantly longer surfacings and dives, and more blows per surfacing, than whales feeding in water ≤20 m deep ($P<0.001$ in each case; Fig. 13.2). An average surfacing-dive cycle by an undisturbed whale feeding in shallow (≤20 m) water, calves excluded, consisted of a 1.10 min surfacing with 4.9 ± 3.4 blows followed by a 5.84 ± 5.62 min dive (Appendix 13.1). The median blow intervals averaged 13.1 s. In contrast, an average surfacing–dive cycle by an undisturbed whale feeding in water deeper than 20 m, calves excluded, consisted of a 1.77 min surfacing with 8.5 blows per surfacing followed by a 16.09 min dive. Median blow intervals averaged 13.1 s. Water depths for surfacings categorized as shallow and deep were, respectively, 5–20 m and 28–100 m (means 12 vs. 45 m).

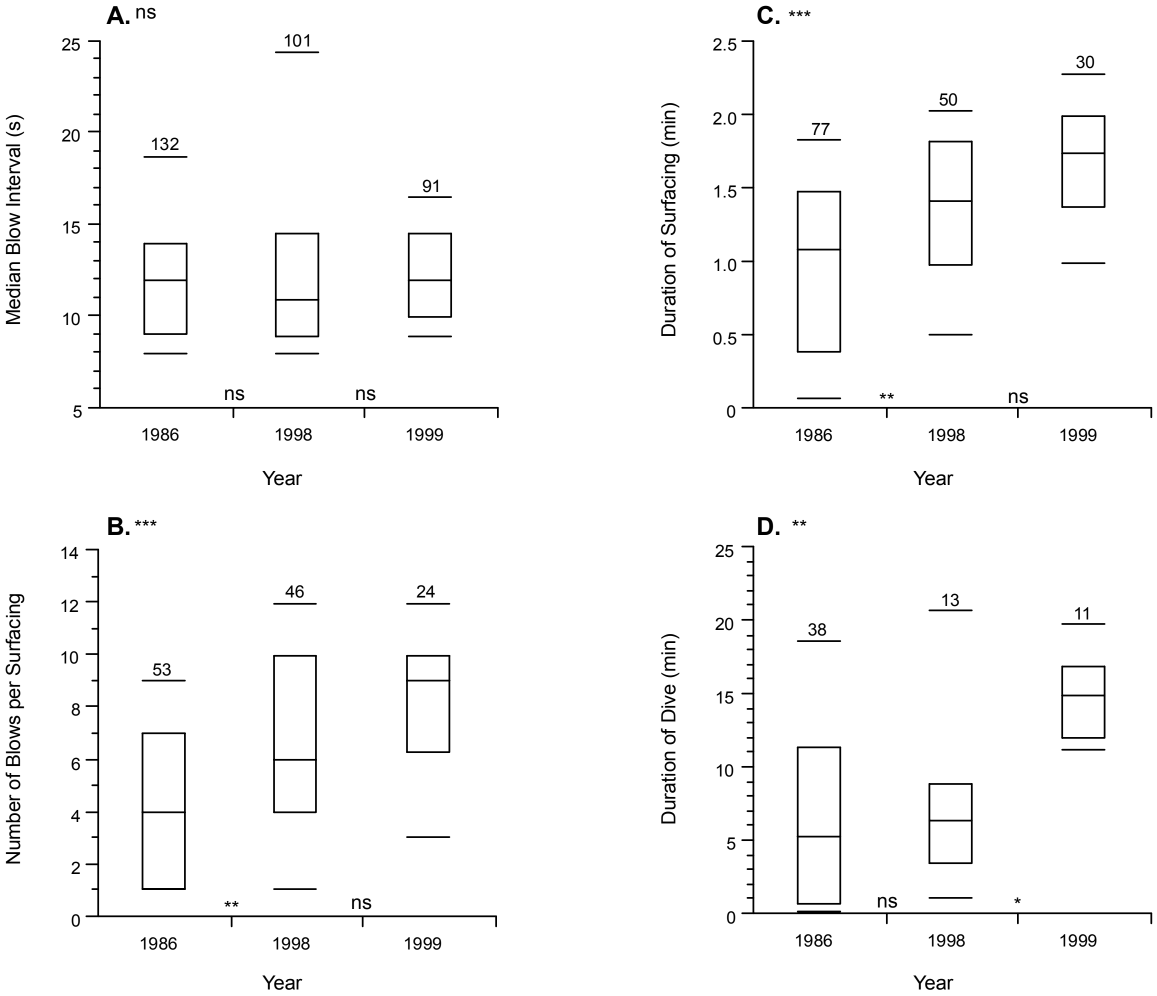

FIGURE 13.1. Year-to-year comparison of surfacing, respiration, and dive variables for **feeding** bowhead whales. Calves and potentially disturbed whales are excluded; individual years are excluded when $n < 5$. In the Box plots, the bottom and top lines represent the 10th and 90th quantiles; boxes show 25th, 50th, and 75th quantiles; numbers are sample sizes. Overall significance of among-year difference (by ANOVA) is shown at the top of each panel. Significance of differences between adjacent pairs of categories are shown at bottom, based on the multiple comparison procedures of Tamhane (when variances unequal, panels A, D) or Bonferroni (when variances equal, panels B, C). Significance levels coded as *** for $P \leq 0.001$; ** for $0.001 < P \leq 0.01$; * for $0.01 < P \leq 0.05$; ns for $P > 0.10$; and in later Figures (*) for $0.05 < P \leq 0.1$.

Appendix 13.1 lists the average percent of time at the surface for each category of whale, and the average number of blows per minute ("blow rate"). These values are based on dividing mean duration of surfacing or mean number of blows per surfacing (respectively) by mean duration of surfacing plus mean duration of dive. Feeding whales were at the surface an average of 12.5% of the time, and their mean blow rate was 0.58 blows/min.

Traveling Whales

In whales categorized as "traveling" (without simultaneous feeding or socializing), the overall median blow interval for presumably undisturbed noncalves in 1985–86 and 1998–2000 averaged 16.27 ± s.d. 4.78 s ($n = 108$) (Appendix 13.1), with yearly means ranging from 14.58 to 18.09 s. Median blow

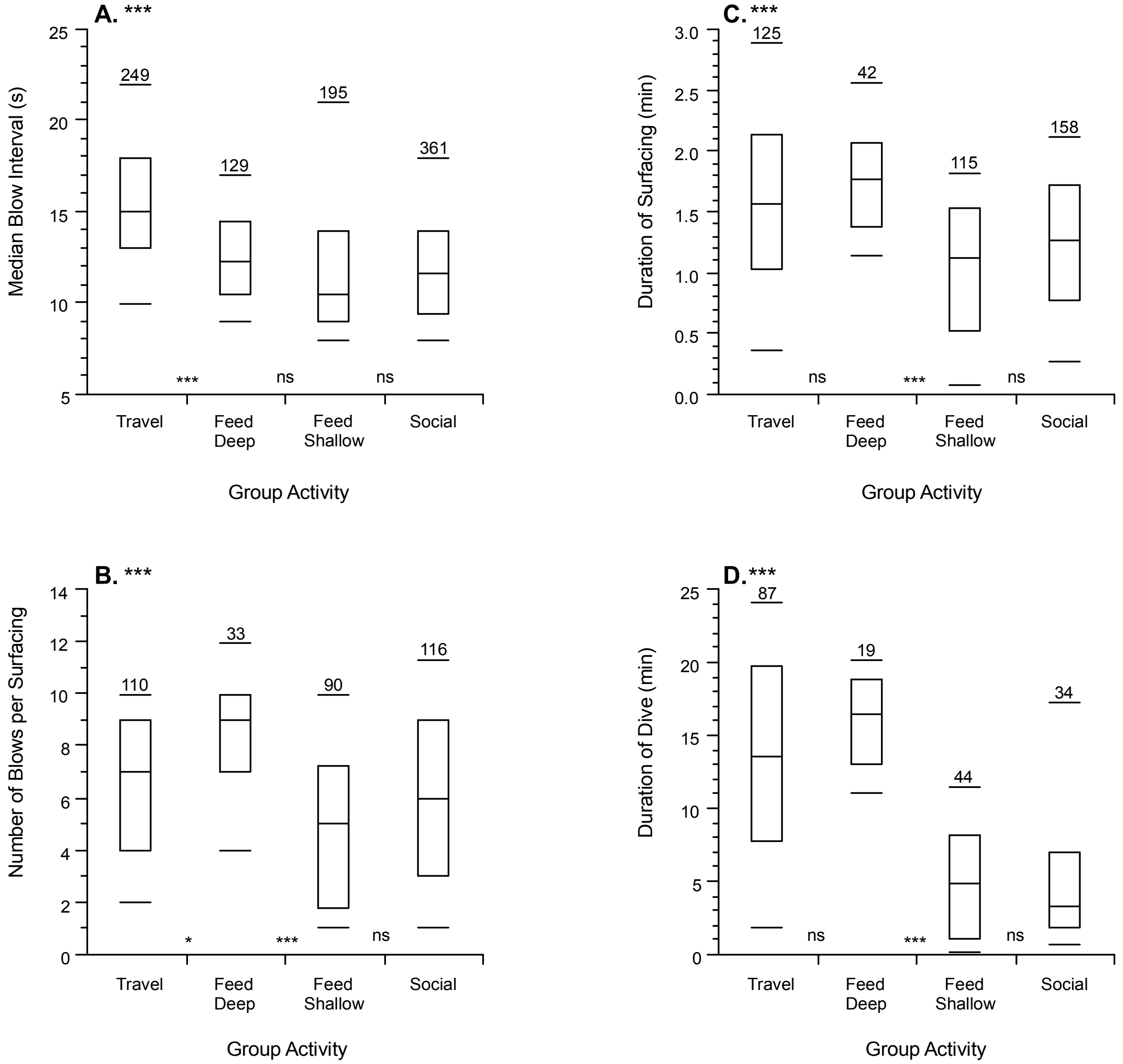

FIGURE 13.2. Comparison of surfacing, respiration, and dive variables by whale activity in 1985–86 and 1998–2000. Whale activities are traveling (including travel+feed), feeding in deep and shallow water (>20 m and ≤20 m), and socializing (including travel+social, social+feed, travel+social+feed). Otherwise as in Figure 13.1, except that A, C and D used Tamhane multiple comparisons, and B used Bonferroni multiple comparisons. See Appendix 13.1 for mean ± s.d. values.

intervals did not differ significantly among years (ANOVA, $P = 0.121$; Fig. 13.3A). Number of blows per surfacing averaged 6.13 ± 3.33 ($n = 68$), with yearly means in 1986, 1998, and 2000 ranging from 4.27 to 8.00 during the three years with $n > 5$. Year to year variability was significant, with values in 2000 being lower than for other years (Fig. 13.3B). Duration of surfacing averaged 1.56 ± 0.97 ($n = 75$) min, with means for three years ranging from 0.96 to 2.04. Those surface times differed significantly among years, with 2000 values being significantly lower than for other years (Fig. 13.3C). The overall mean dive duration was 13.99 ± 8.09 ($n = 66$), with means for three years ranging from 9.85 to 18.13. Those mean dive times differed significantly among years with dives being significantly longer in 1986 than in other years (Fig. 13.3D). On average, traveling bowheads were at the surface 10.0% of the time, with a mean blow rate of 0.39 blows/min (Appendix 13.1).

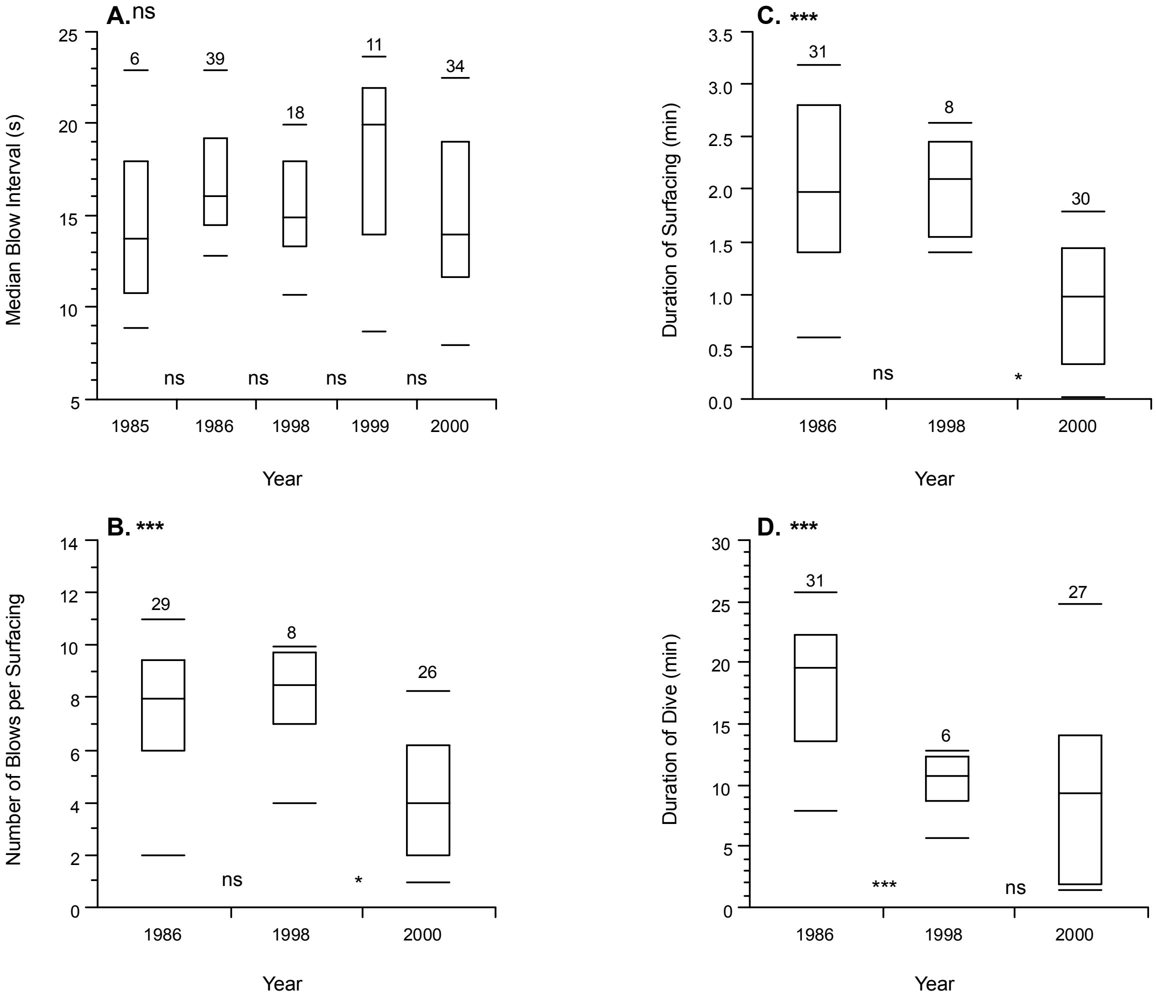

FIGURE 13.3. Year-to-year comparison of surfacing, respiration, and dive cycles for **traveling** bowhead whales. Otherwise as in Figure 13.1, except that A and D used Tamhane multiple comparisons, and B and C used Bonferroni multiple comparisons.

We compared the SRD cycles of traveling whales with those of whales engaged simultaneously in travel plus other activities (travel+feed, travel+social, and travel+social+feed) to determine if some of these groups could be combined. Median blow intervals and dive durations differed significantly among these whale activities (Fig. 13.4A,D). Multiple comparisons showed no differences between travel and travel+feed, but occurrence of socializing along with travel did result in altered blow intervals and dive durations. Number of blows per surfacing did not vary significantly among the various categories of traveling whales ($P = 0.258$; Fig. 13.4B), and the differences in duration of surfacing were not large ($P = 0.026$; Fig. 13.4C). Again, multiple comparisons showed no significant difference between travel and travel+feed (Fig. 13.4B,C).

Thus, it was appropriate to combine SRD data for whales in the "travel" and the "travel+feed" categories. For these whales, an average surfacing–dive cycle consisted of a 1.65 min surfacing and a 13.66 min dive. There was an average of 6.4 blows per surfacing. Median intervals between successive blows within a surfacing averaged 15.76 s (Appendix 13.1). On average, these bowheads were at the surface 10.8% of the time, with a mean blow rate of 0.42 blows/min (Appendix 13.1).

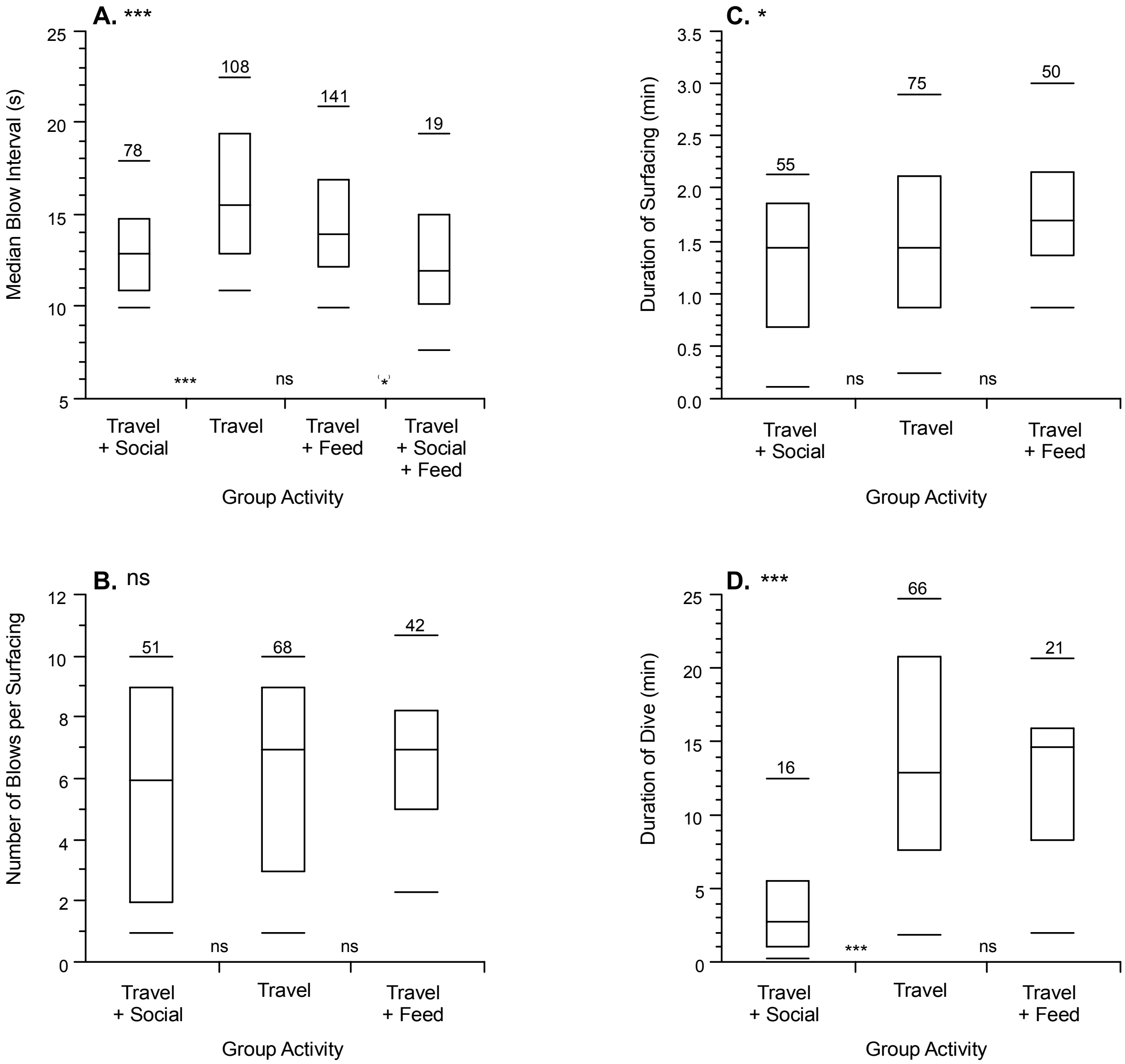

Figure 13.4. Comparison of surfacing, respiration, and dive variables for **traveling** bowhead whales with and without other activities in 1985–86 and 1998–2000. Otherwise as in Figure 13.1, except that A, C and D used Tamhane multiple comparisons, and B used Bonferroni multiple comparisons. See Appendix 13.1 for mean ± s.d. values.

Traveling whales (travel and travel+feed combined) were then compared to whales engaged in feeding and socializing. Traveling whales had similar surface and dive times as whales feeding in water >20 m deep (Fig. 13.2C,D). However, traveling whales had significantly longer surface and dive times than whales feeding in water ≤20 m deep or socializing whales ($P = 0.003$ for surface times of traveling vs. socializing whales; otherwise $P < 0.001$; Fig. 13.2C,D). Median blow intervals of traveling whales were significantly higher than for whales engaged in feeding or social activities (Fig. 13.2A). Number of blows per surfacing for traveling whales differed significantly from that for whales feeding in deep or in shallow water ($P = 0.012$ and $P = 0.014$, respectively; Fig. 13.2B).

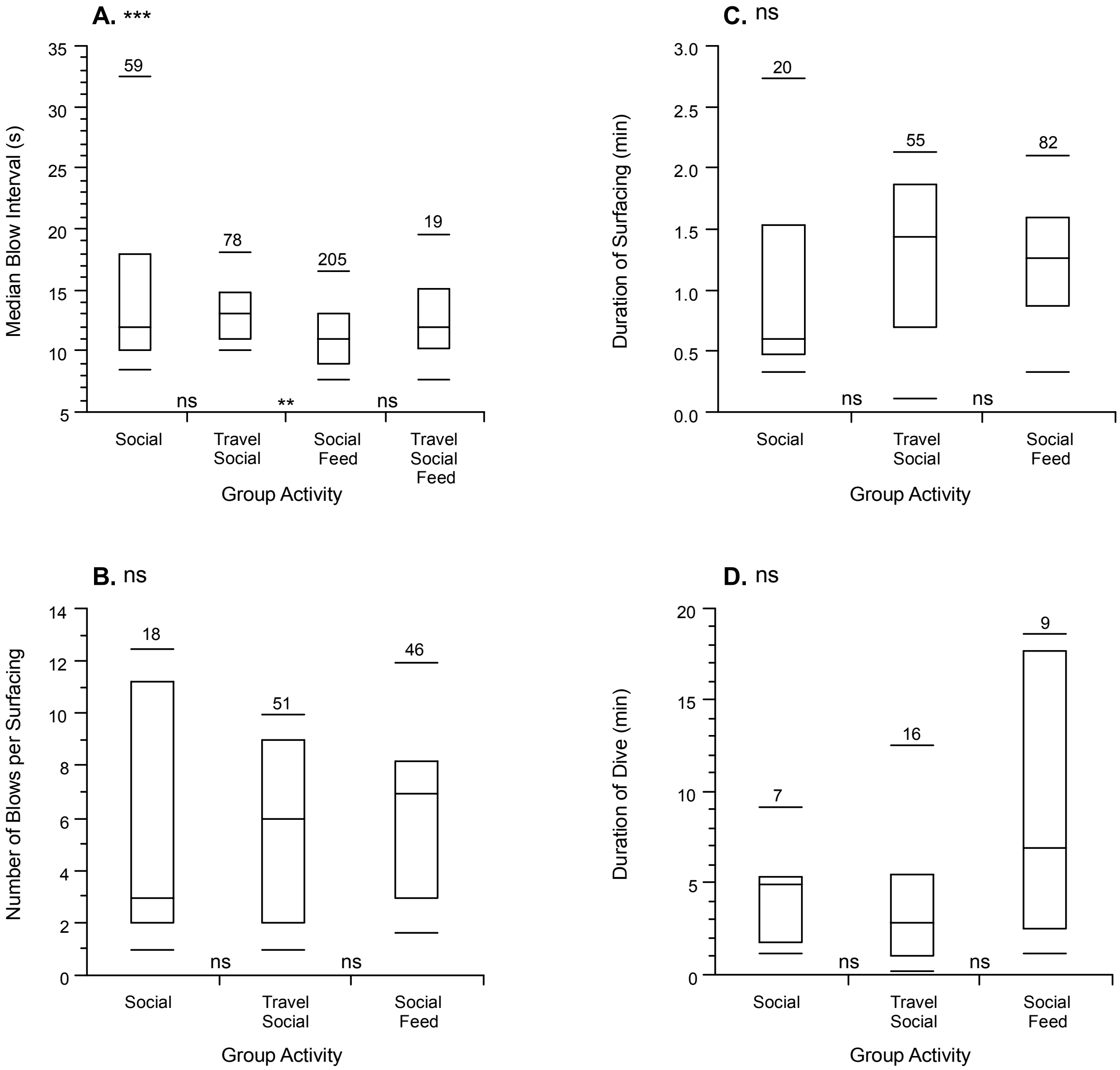

Figure 13.5. Comparison of surfacing, respiration, and dive variables for **socializing** bowhead whales with and without other activities in 1985–86 and 1998–2000. Otherwise as in Figure 13.1, except that all multiple comparisons used the Tamhane procedure for unequal variances. See Appendix 13.1 for mean ± s.d. values.

Socializing Whales

We compared SRD cycles of socializing whales with those of whales engaged simultaneously in socializing plus other activities (social+travel, social+feed, and travel+social+ feed) to determine if some of these activities could be combined. Median blow intervals differed significantly among these whale activities, but multiple comparisons showed no significant difference between social and travel+social, or between social and travel+social+feed ($P = 0.590$ and 0.345, respectively; Fig. 13.5A). Number of blows per surfacing, duration of surfacing, and duration of dive did not differ significantly among these whale activities (ANOVA, $P = 0.387$, 0.436, 0.142, respectively; Fig. 13.5B,C,D).

Thus, it seemed appropriate to combine SRD data for all activities involving social activity (i.e., social, travel+social, social+feed, travel+social+feed). An average surfacing–dive cycle by an undisturbed socializing bowhead, calves excluded, consisted of a 1.29 min surfacing and a 5.54 min dive. There was an average of 6.0 blows per surfacing. Intervals between successive blows within a surfacing averaged 12.67 s (Appendix 13.1). On average, these bowheads were at the surface 18.9% of the time, with a mean blow rate of 0.88 blows/min (Appendix 13.1).

Socializing whales were then compared to whales engaged in traveling and feeding. Socializing whales had similar SRD cycles as whales feeding in water ≤20 m deep (Fig. 13.2A–D). Median blow interval for socializing whales was significantly lower than for traveling whales ($P < 0.001$; Fig. 13.2A). Number of blows per surfacing was significantly lower in socializing whales than in whales feeding in water >20 m deep ($P = 0.002$; Fig. 13.2B). Surface and dive times were significantly shorter for socializing whales than for traveling whales or whales feeding in deep water ($P = 0.003$ for surface times of socializing vs. traveling whales; otherwise $P < 0.001$; Fig. 13.2C,D).

Factors Related to Surfacing, Respiration and Dive Cycles

The preceding analyses describe relationships of surfacing, respiration, and dive variables to three whale activities and various combinations thereof, along with years and (for feeding whales) water depth. However, some of these factors are interrelated, such as the depths where whales tended to occur in different years, and other potentially important factors have not yet been considered. Multiple regression analysis was used to help assess the relationships of SRD variables to various environmental, temporal, and whale-related variables.

Feeding Whales.—All four surfacing respiration and dive variables had significant simple correlations with several predictor variables (Table 13.2, columns headed "r"). For example, all four behavior variables for feeding whales tended to be low in 1986, as evident from the negative correlations with "1986", and high in 1999. All four variables tended to be higher in deeper water and with greater distance from the shore. All four variables tended to be higher when there was some traveling intermixed with feeding.

When all 25 predictor variables were considered for inclusion in multiple regression equations, all four measures of SRD cycles tended to be correlated with whale status after allowance for other variables. Values tended to be high for mothers and/or low for subadults (Table 13.2, columns headed "r_p"). Other predictor variables that showed strong (nominal $P \leq 0.01$) partial correlations with one or more of the SRD variables were year 2000, date, number of bowheads within 1 km, and flukes-out when diving.

When whale status was excluded from the multiple regression equation, thereby increasing sample sizes, all four behavior variables tended to be higher with increased distance from the shore (Table 13.2, columns headed "stat*us* ex*cluded* r_p"). Since water depth and distance from the shore are strongly intercorrelated ($r = 0.910 – 0.917$), it can also be said that all four SRD variables tended to be higher in deeper water, which is what we saw in Figure 13.2. The strong positive relationships of the SRD variables to distance from shore very likely occurred because adult whales tended to occur farther offshore (Chapter 10), and adults tended to have higher values of all four SRD variables (Chapter 14). Other variables that showed strong (nominal $P \leq 0.01$) partial correlations with one or more of the SRD variables were date, time, group activity = travel+feed, number of bowheads within 1 km, group size, and flukes-out.

Traveling Whales.—All four surfacing respiration and dive variables had significant simple correlations with several predictor variables (Table 13.3). For example, all four SRD variables for traveling whales tended to be high in 1986 and with increasing sea states. All four variables were higher for mothers and/or adults and lower for subadults.

TABLE 13.2. Comparison of surfacing, respiration, and diving behavior of bowheads **feeding** in the Eastern Alaskan Beaufort Sea (1985-86 and 1998-2000) before and after allowance for environmental, temporal, and whale-related variables. Symbols show the direction and nominal significance of correlations between a dependent variable (top) and various environmental, temporal, activity, and age variables (predictors, left). For each dependent variable, the three columns summarize the simple correlations (r) and partial correlations (r_p) when three whale status variables are included or excluded.

Predictor variable		Duration of surfacing (min)			No. blows per surfacing			Median blow interval (s)[a]			Duration of dive (min)		
				stat. exc.			stat. exc.			stat. exc.			stat. exc.
Name	Scale	r	r_p	r_p	r	r_p	r_p	r	r_p	r_p	r	r_p	r_p
1986	0-1	- - -			- - -			- - -			- - -	+	
1998	0-1	+			ns			+++			ns	+	
1999	0-1	++			+++			(+)			++	+	
2000	0-1	(-)	- - -		ns			ns		-			
Date (1 = 3 Sept.)	1-34	+++			+++	+++	++	ns	- - -	- - -	++		
Date^2	$(1\text{-}34)^2$	+++			++	- - -		ns			(+)		
Time	0-24	++		-	ns			+++		- - -	(+)		
Time^2	$(0\text{-}24)^2$	++		+	ns			+++		+++	+		
Sea State	Bf	ns			ns		-	+++	+		ns		
Ice Cover	%	+			ns			ns			ns	+	
>5% Ice Cover[b]	0-1	++			+	+		ns			ns		
Dist. From Shore	log (km)	+++		+++	+++		+++	+++		+++	+++		+++
Water Depth	log (m)	+++			+++			+++			+++		
Group Activ = Trav. + Feed[b]	0-1	+++			(+)			+++	+	++	+		
Group Activ = Soc. + Feed[b]	0-1	ns			ns			- - -			ns		
Group Activ = Trav.+Soc.+Feed[b]	0-1	ns			ns			ns			ns		
Subadult[b]	0-1	- - -	(-)	Exc.	ns	- -	Exc.	- - -	-	Exc.	-	-	Exc.
Adult[b]	0-1	ns		Exc.	ns		Exc.	ns		Exc.	ns		Exc.
Mother[b]	0-1	+++	++	Exc.	ns		Exc.	+++	+++	Exc.	ns		Exc.
No. Bhd. Within 1 km	log No.	ns			ns			- - -	- -	- -	-		
Group Size	1-4	ns			ns			+++		++	ns		
Active Socializ.[b]	0-1	ns			ns	-	-	ns			ns		
Passive Socializ.[b]	0-1	ns			ns			ns			ns		
Aerial Behav.[b]	0-1	ns			ns			(+)			ns		
Pre-dive Flukes-out[b]	0-1	+		+	+++	+++	+++	- - -	- - -	- - -	ns		
Sample size		290	121	286	212	98	208	689	243	567	94	53	94
Multiple correlation			0.482	0.438		0.592	0.514		0.648	0.476		0.453	0.589
Adjusted % var. explained			21.3	17.4		30.8	24.6		40.2	21.5		12.1	33.2
Overall significance			***	***		***	***		***	***		*	***

Note: Pluses indicate positive and significant correlations or partial correlations; minuses indicate negative relationships: ns, $P > 0.1$; (+) or (-), $0.05 < P \le 0.1$; + or -, $0.01 < P \le 0.05$; ++ or - - , $0.001 < P \le 0.01$; +++ or - - -, $P \le 0.001$. Calves and potentially disturbed whales are excluded.

[a] Median blow intervals were log transformed to avoid skewness.

[b] 0 = false, 1 = true.

TABLE 13.3. Comparison of surfacing, respiration, and diving behavior of bowheads **traveling** in the Eastern Alaskan Beaufort Sea (1985-86 and 1998-2000) before and after allowance for environmental, temporal, and whale-related variables. Symbols show the direction and nominal significance of correlations between a dependent variable (top) and various environmental, temporal, activity, and age variables (predictors, left). For each dependent variable, the three columns summarize the simple correlations (r) and partial correlations (r_p) when three whale status variables are included or excluded.

Predictor variable		Duration of surfacing (min)			No. blows per surfacing			Median blow interval (s)[a]			Duration of dive (min)		
				stat. exc.			stat. exc.			stat. exc.			stat. exc.
Name	Scale	r	r_p	r_p	r	r_p	r_p	r	r_p	r_p	r	r_p	r_p
1986	0-1	(+)	- - -		+	- - -	- - -	(+)			+++		
1998	0-1	ns			ns			ns			ns		
1999	0-1	+			(+)			ns			ns		
2000	0-1	- - -	- - -	- - -	- - -	- - -	- - -	ns			- -		
Date (1 = 3 Sept.)	1-34	ns			ns			ns			ns		
Date^2	$(1\text{-}34)^2$	ns			ns			(-)			ns		
Time	0-24	ns			(+)	+		ns			+	+++	+++
Time^2	$(0\text{-}24)^2$	ns			(+)			ns			+		
Sea State	Bf	+			(+)			+		+++	+++		
Ice Cover	%	+			(+)			ns	++		ns		
>5% Ice Cover[b]	0-1	++			+			ns			+		
Dist. From Shore	log (km)	+			+			ns	++		+++		+++
Water Depth	log (m)	(+)			(+)			ns			+++		
Group Activ = Trav. + Soc.[b]	0-1	-		- -	ns			- - -	- -		- - -	- - -	- - -
Group Activ = Trav. + Feed[b]	0-1	+			(+)			ns			ns		
Group Activ = Trav.+Soc.+Feed[b]	0-1	ns			ns			-	- - -		ns		
Subadult[b]	0-1	- - -	- - -	Exc.	- - -	- - -	Exc.	- - -		Exc.	- - -	- - -	Exc.
Adult[b]	0-1	++		Exc.	+++		Exc.	ns		Exc.	+++		Exc.
Mother[b]	0-1	ns		Exc.	ns		Exc.	+++	+++	Exc.	ns		Exc.
No. Bhd. Within 1 km	log No.	ns			ns		- -	- -			-		
Group Size	1-4	ns		+	ns		+	ns		+	ns		+
Active Socializ.[b]	0-1	ns			ns			- - -		- - -	ns		
Passive Socializ.[b]	0-1	ns			ns			ns	+		- - -		
Aerial Behav.[b]	0-1	ns			ns			ns			ns		
Pre-dive Flukes-out[b]	0-1	ns			ns			- - -		- - -	ns		
Sample size		181	121	181	162	109	162	346	182	318	104	81	104
Multiple correlation			0.539	0.366		0.627	0.392		0.583	0.387		0.745	0.677
Adjusted % var. explained			27.8	11.9		37.6	13.8		31.8	13.9		53.8	43.7
Overall significance			***	***		***	***		***	***		***	***

Note: Pluses indicate positive and significant correlations or partial correlations; minuses indicate negative relationships: ns, $P > 0.1$; (+) or (-), $0.05 < P \le 0.1$; + or -, $0.01 < P \le 0.05$; ++ or - - , $0.001 < P \le 0.01$; +++ or - - -, $P \le 0.001$. Calves and potentially disturbed whales are excluded.

[a] Median blow intervals were log transformed to avoid skewness.

[b] 0 = false, 1 = true.

When all 25 predictor variables were considered for inclusion in a multiple regression equation, all four behavior variables tended to be correlated with whale status. Values tended to be high for mothers or low for subadults (Table 13.3, columns headed "r_p"). Other variables that showed strong (nominal $P \leq 0.01$) partial correlations with one or more of the behavior variables were year 1986 and year 2000, time, ice cover, distance from shore, group activity = travel+social, and group activity = travel+social+feed.

When whale status was excluded from the multiple regression equation, all four behavior variables tended to increase with increasing group size, although not very strongly ($0.01 <$ nominal $P \leq 0.05$ in each case; Table 13.3). Other variables that showed strong (nominal $P \leq 0.01$) partial correlations with one or more of the behavior variables were years 1986 and 2000, time, sea state, distance from shore, group activity = travel+social, number of bowheads within 1 km, active socializing, and flukes.

Socializing Whales.—Median blow interval was the only SRD variable that showed strong ($P \leq 0.01$) simple correlations with any of the predictor variables (Table 13.4). For example, median blow intervals of socializing whales tended to be short in 1986, and when socializing was intermixed with feeding (as evident from the negative correlations). Median blow intervals showed significant positive correlations with numerous other variables (Table 13.4).

When all 25 predictor variables were considered for inclusion in a multiple regression equation, median blow interval tended to be longer for mothers, with high sea states, and when passive socializing was occurring (Table 13.4, "r_p" column). Duration of surfacing and number of blows per surfacing showed very little relationship to the predictor variables, with multiple correlation coefficients of 0.350 and 0.502, respectively. The sample size for "duration of dive" was too low for a meaningful multiple regression analysis of that variable.

When whale status was excluded from the multiple regression equation, median blow interval tended to be longer with greater distance from shore, and shorter later in the season and during dives terminating with "flukes out" (Table 13.4).

Discussion

Feeding Whales

Whales engaged in feeding showed among-year variability in SRD variables. There were noticeable increases in the number of blows per surfacing, duration of surfacings, and duration of dives across years (Fig. 13.1). Some of this year-to-year variability may be attributable to the water depths in which the whales were feeding. In 1986, 93% of the surface–dive cycles by feeding whales occurred in shallow (≤20 m) water. In contrast, in 1998, 72% were in shallow water; in 1999, none were in shallow water. Bowheads in the Beaufort Sea concentrate their feeding at places and depths where zooplankton concentrates (Chapter 6). Richardson et al. (1995a) described how differences in depths of prey concentrations likely cause differences in SRD cycles of bowheads. When the prey is deep, whales feed most efficiently if dives are long. This minimizes the proportion of feeding time spent in descent and ascent. If dives are long, whales must respire more times per surfacing and are likely to remain at the surface longer. When the present observations in the Eastern Alaskan Beaufort Sea were split into shallow (≤20 m) and deeper (28–100 m, mean 45 m) water, we found significant increases in the duration of surfacings and dives, and more blows per surfacing, for bowheads feeding in deeper water (Fig. 13.2).

TABLE 13.4. Comparison of surfacing, respiration, and diving behavior of bowheads **socializing** in the Eastern Alaskan Beaufort Sea (1985-86 and 1998-2000) before and after allowance for environmental, temporal, and whale-related variables. Symbols show the direction and nominal significance of correlations between a dependent variable (top) and various environmental, temporal, activity, and age variables (predictors, left). For each dependent variable, the three columns summarize the simple correlations (r) and partial correlations (r_p) when three whale status variables are included or excluded.

Predictor variable		Duration of surfacing (min)			No. blows per surfacing			Median blow interval (s)[a]			Duration of dive (min)[c]
				stat. exc.			stat. exc.			stat. exc.	
Name	Scale	r	r_p	r_p	r	r_p	r_p	r	r_p	r_p	r
1986	0-1	ns		+	ns			- - -			ns
1998	0-1	(-)			ns		-	++	+	-	ns
1999	0-1	ns			ns			+			ns
2000	0-1	(-)	-		(-)		- -	(+)			ns
Date (1 = 3 Sept.)	1-34	ns			(+)		+	ns		- - -	ns
Date^2	(1-34)^2	(+)			(+)		-	ns			ns
Time	0-24	ns			ns			(+)			ns
Time^2	(0-24)^2	ns			ns			(+)			ns
Sea State	Bf	ns			ns			+++	+++		ns
Ice Cover	%	+			ns			ns			ns
>5% Ice Cover[b]	0-1	+		+	ns			ns			ns
Dist. From Shore	log (km)	ns			ns	+++		+++		+++	ns
Water Depth	log (m)	ns			ns			+++			ns
Group Activ = Trav. + Soc.[b]	0-1	ns			ns			++		+	-
Group Activ = Soc. + Feed[b]	0-1	ns			ns			- - -			(+)
Group Activ = Trav.+Soc.+Feed[b]	0-1	ns			ns			ns			ns
Subadult[b]	0-1	ns		Exc.	ns		Exc.	-		Exc.	ns
Adult[b]	0-1	(+)		Exc.	+		Exc.	ns		Exc.	ns
Mother[b]	0-1	ns		Exc.	ns		Exc.	+++	+++	Exc.	ns
No. Bhd. Within 1 km	log No.	(+)			(+)			ns			ns
Group Size	1-4	ns			ns			+++			ns
Active Socializ.[b]	0-1	ns			ns			++			ns
Passive Socializ.[b]	0-1	ns			ns			++	++		ns
Aerial Behav.[b]	0-1	ns			ns			+++			ns
Pre-dive Flukes-out[b]	0-1	ns			(+)			ns		- -	ns
Sample size		158	49	138	116	41	103	361	92	315	34
Multiple correlation			0.350	0.254		0.502	0.341		0.655	0.382	
Adjusted % var. explained			10.4	5.1		23.2	8.0		40.3	13.2	
Overall significance			*	*		***	*		***	***	

Note: Pluses indicate positive and significant correlations or partial correlations; minuses indicate negative relationships: ns, $P > 0.1$; (+) or (-), $0.05 < P \leq 0.1$; + or -, $0.01 < P \leq 0.05$; ++ or - - , $0.001 < P \leq 0.01$; +++ or - - -, $P \leq 0.001$. Calves and potentially disturbed whales are excluded.

[a] Median blow intervals were log transformed to avoid skewness.

[b] 0 = false, 1 = true.

[c] not enough data to run a multiple regression analysis.

The multivariate analysis allowed us to examine the relative importance of several factors potentially affecting the SRD variables of bowheads feeding in the Eastern Alaskan Beaufort Sea while taking into account the effects of other factors. Two important overall results were evident. (1) For all four SRD variables analyzed, whale status (age) had a strong effect. As compared with subadults, the larger and older whales (mothers and adults) tended to have longer surfacings and dives, with more blows and longer blow intervals. (2) When whale status was excluded from the multivariate analysis, all four behavioral variables were higher with increased distance from shore. Whale status and distance from shore were strongly intercorrelated—mothers and adults tended to occur farther offshore than subadults (see also Chapter 10). Also, distance from shore is strongly correlated with water depth, so it can also be said that all four SRD variables were higher in deeper water.

Multivariate analyses have important limitations when applied to uncontrolled field data with many intercorrelated predictor variables (James and McCulloch 1990). Given these intercorrelations, it is difficult to determine which factor(s) had a direct influence on SRD variables. However, when whale status, distance from shore, and water depth were all considered as potential predictors, there were stronger partial correlations with whale status than with distance from shore or water depth (Table 13.2). This suggests that whale status may have had a more direct influence.

Our results for bowhead whales feeding in water >20 m deep can be compared with those for bowheads feeding in Baffin Bay in water >50 m deep (Richardson et al. 1995a). Average dive durations during these situations were similar: 15.80 min in Baffin Bay vs. 15.73 min [3] in this study. However, surfacing and respiration parameters had significantly higher mean values in Baffin Bay (Table 13.5). The differences are probably related mainly to water depth. In our study, most “deep water” feeding was in water 28–100 m deep (mean 45 m), whereas in the Baffin Bay study most of the observed feeding was in water 100–250 m deep. This difference may account for the higher surface and respiration times seen in the Baffin Bay study. The differences between the two areas would be even more striking if the whales feeding in shallow (≤20 m) parts of the present study area were considered; no shallow-water feeding was seen in the Baffin Bay study.

SRD values for bowheads in the Canadian Beaufort Sea in summer (mainly August) have been reported by Dorsey et al. (1989), but average values for all feeding whales observed in summer were not specifically reported. SRD data for the fraction of those bowheads that were observed feeding in waters >50 m deep were reported by Richardson et al. (1995a). However, their analysis also included the few September 1985–86 data from deep (>50 m) parts of the present study area, and thus are not entirely independent of the present data. Therefore, we have redone the summer analysis to make the data directly comparable and non-overlapping. Median blow intervals were similar for feeding whales (deep and shallow water) in both studies (Table 13.5). Duration of surfacing was significantly lower in the Canadian Beaufort for whales feeding in deep water, but there was little difference for whales feeding in shallow water (Table 13.5). Number of blows per surfacing and mean dive duration were significantly lower in the Canadian Beaufort for feeding in both deep and shallow water (Table 13.5).

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[3] Some SRD values quoted here and in Table 13.5 differ slightly from corresponding values quoted in “Results” because “mothers” are excluded from Table 13.5. This was done in order to allow direct comparisons with other studies where “mothers” were excluded or absent. Appendix 13.1 summarizes the SRD values for “mothers” vs. “others” as observed during the present study.

TABLE 13.5. Comparisons of surfacing, respiration and dive variables between the current study and three other studies of undisturbed bowhead whales. "Feed Deep" includes all whales feeding in water > 20 m, and "Feed Shallow" includes all whales feeding in water $\leq$ 20 m. Mothers and calves were excluded in all studies for these comparisons. Comparisons are based on *t*-tests. Where the ' symbol appears, a modified *t*-test assuming unequal variances was used. Asterisks show significance levels as in Figure 13.1.

	Eastern Alaskan Beaufort Sea, Fall (Current Study)												**Other Study**											
Group Activity Status	Median Blow Intervals (s)			Number of Blows per Surfacing			Duration of Surfacing (min)			Duration of Dive (min)			Median Blow Intervals (s)			Number of Blows per Surfacing			Duration of Surfacing (min)			Duration of Dive (min)		
	mean	s.d.	*n*	mean	s.d.	*n*	mean	s.d.	*n*	mean	s.d.	*n*	mean	s.d.	*n*	mean	s.d.	*n*	mean	s.d.	*n*	mean	s.d.	*n*
													Canadian Beaufort Sea, Summer[a]											
Feed Deep	12.73	3.93	114	8.68	2.77	31	1.73	0.56	38	15.73	5.07	15	13.36	8.54	264	3.74	2.67	114	0.91	0.66	118	3.83	4.16	34
Comp. test	ns'			***'			***			***'														
Feed Shallow	13.08	7.54	195	4.93	3.40	90	1.10	0.71	115	5.84	5.62	44	14.04	7.45	330	3.94	3.06	145	1.25	1.66	185	2.86	4.42	99
Comp. test	ns			*			ns'			***'														
All Social[d]	12.42	5.59	341	6.14	3.77	108	1.27	0.72	149	5.67	5.35	26	13.77	6.39	445	4.21	2.94	230	1.12	0.80	261	2.77	3.61	83
Comp. test	***'			***			(*)			**'														
													Baffin Bay, Fall[b]											
Travel	16.03	4.91	98	6.08	3.43	62	1.52	0.99	69	13.83	8.10	61	17.10	6.01	86	6.00	3.54	76	1.49	0.86	91	9.36	5.66	82
Comp. test	ns'			ns'			ns			***'														
Social	15.25	8.68	59	5.83	5.07	18	1.08	0.82	20	4.50	2.67	7	17.70	11.62	50	2.10	2.86	35	1.19	1.81	78	1.64	1.66	45
Comp. test	ns'			**			ns'			*'														
Feed Deep	12.73	3.93	114	8.68	2.77	31	1.73	0.56	38	15.73	5.07	15	16.90	3.70	86	17.30	6.72	23	4.74	1.77	46	15.80	7.09	29
Comp. test	***'			***			***'			ns'														
													Beaufort Sea, Spring at Barrow[c]											
Travel	16.03	4.91	98	6.08	3.43	62	1.52	0.99	69	13.83	8.10	61	18.08	7.64	451	5.02	3.30	355	1.35	1.03	367	6.63	6.27	244
Comp. test	***'			*'			ns			***'														

[a] Canadian Beaufort data reanalyzed to make them comparable to the current study. Only August data were used, and for feeding whales only data in water depths between 0 and 100 m were used.

[b] Baffin Bay data are from Richardson et al. (1995a).

[c] Spring Barrow data are from Richardson et al. (1995b).

[d] All Social includes whales engaged in socializing, travel+social, social+feed, and travel+social+feed.

Traveling Whales

Whales engaged in traveling showed significant among-year variability in 3 of 4 SRD variables. There were noticeable decreases in the number of blows per surfacing, the duration of surfacings, and the duration of dives from year 1986 to 2000 (Fig. 13.3). Some of this variability may be attributable to the proportion of small whales observed each year. In 1986, 8% of the documented surface–dive cycles by traveling whales whose status was determined involved subadults; in 2000, 45% involved subadults. For traveling (and feeding) bowheads, subadult whales have shorter surfacings and dives with fewer blows per surfacings than adult whales (Tables 13.2, 13.3; see also Chapter 14).

Traveling whales, including those engaged in both traveling and feeding, tended to have SRD cycles similar to those of whales feeding in water >20 m deep (Fig. 13.2). Some of this similarity may be attributable to the habitat that the whales are occupying. Traveling whales tended to occur in deeper areas (Chapter 12), including some of the areas used by whales feeding in deep water.

Two important overall results from the multivariate analysis were as follows: (1) For traveling whales, like feeding whales, whale status (age) had a strong influence on all four SRD variables. As compared with other whales, subadults tended to have short surfacings and dives with few blows per surfacing. Mothers tended to have long intervals between blows. (2) When whale status was excluded from the multivariate analysis, all four behavioral variables were higher with larger group sizes.

Traveling whales observed in our September study had surfacing and respiration parameters similar to those of bowheads migrating along the coast of Baffin Island in autumn (Richardson et al. 1995a). However, the mean duration of dives was significantly higher in our study than in the Baffin Bay study (Table 13.5). SRD values for bowheads migrating near Barrow, Alaska, in spring (Richardson et al. 1995b, MS) showed significantly higher median blow intervals and significantly lower dive durations and number of blows per surfacing than whales traveling in our study (Table 13.5). Ice cover was often heavy (1–80%) in the Barrow study, but usually light (<10%) in our study and the Baffin Bay study. The shorter mean duration of dives documented in spring may have been, at least in part, an artifact of the ice conditions. Heavy ice conditions often make it difficult to re-sight whales after long dives, resulting in more serious underestimation of average dive durations when there is much ice. Consistent with this, dive durations documented for migrating bowheads in the Alaskan Beaufort in autumn 1983 (a heavy ice year) were significantly shorter than those in 1985–86 with little ice (Richardson et al. 1995a).

Socializing Whales

Whales engaged in socializing were compared with those exhibiting other activities that included socializing: social+travel, social+feed, and travel+social+feed. The SRD variables of socializing whales were similar for whales engaged in all activities involving socializing (Fig. 13.5). Socializing whales and whales feeding in shallow water tended to have similar breathing characteristics—relatively short surfacings and dives with few blows per surfacing and short intervals between blows (Fig. 13.2). Some of this similarity may be attributable to the habitat that the whales were occupying. Most of these activities occurred in shallow water.

Results from the multivariate analysis were quite different from those for feeding and traveling whales. There was little relationship between duration of surfacing or number of blows per surfacing and the environmental, temporal, and whale-related variables considered in this study (Table 13.4). However, there were significant simple and partial correlations between blow intervals and several predictor variables.

Socializing whales observed in our study had significantly longer dives and more blows per surfacing than bowheads socializing in Baffin Bay (Richardson et al. 1995a) or the Canadian Beaufort Sea during late summer (Table 13.5). Duration of surfacing was slightly higher ($P = 0.07$) and median blow interval was significantly lower in our study than in the Canadian Beaufort Sea (Table 13.5). Reasons for these differences are uncertain, but may relate to differences in the physical circumstances of the observations, the age/status of the animals observed, or the relative intensity and frequency of social activity in the various regions and seasons. The Canadian Beaufort observations were in August, in a wide variety of locations with differing water depths, distances from shore, and ages of whales. The Baffin Bay data came from late August and early September, <4 km from shore in water ≤50 m deep, in an area occupied mainly by subadult whales. The present data were mainly from September, >4 km from shore and in areas occupied by whales of varying ages (see Chapter 10). The estimated number of bowheads within 1 km was usually greater in our study and the Canadian Beaufort study than in the Baffin Bay study, but the socializing observed in Baffin Bay was often quite boisterous.

Summary

Data on surfacing, respiration and dive (SRD) cycles of bowhead whales during late summer and early autumn were needed to derive correction factors for whales missed during aerial surveys, and as a basis for analyses of bowhead energetics. Bowheads were observed systematically during September and early October of 1985–86 and 1998–2000 in the Eastern Alaskan Beaufort Sea and adjacent Canadian waters (Flaxman Island to Herschel Island). Bowhead behavior was observed from an aircraft circling at an altitude of ≥457 m (≥1500 ft), high enough to avoid significant aircraft disturbance. Data collected near other human activities were excluded. We documented the durations of surfacings and dives, number of blows (respirations) per surfacing, and intervals between successive blows. These four variables were defined as in our recent studies of bowhead behavior in other seasons and regions. We first summarized the SRD variables for various categories of whale activity, year, and (for feeding whales) water depth. The main bowhead activities distinguished here are feeding, traveling, and socializing. Then we used multiple regression to assess the joint effects of these and other temporal, environmental, and whale-behavior variables on the four measures of SRD cycles.

Whales engaged in ***feeding*** showed a noticeable increase in the number of blows per surfacing and the durations of surfacings and dives across years. Some of this variability may be attributable to the water depth in which the whales were feeding. In the 1980s most of the observed surfacing–dive cycles occurred in shallow (≤20 m) water, whereas in the 1990s more of observations came from deeper water. An average SRD cycle by an undisturbed bowhead feeding in shallow (≤20 m) water, calves excluded, consisted of a 1.10 min surfacing with 4.9 blows spaced 13.1 s apart, followed by a 5.84 min dive. A corresponding average SRD cycle in water >20 m deep (average 45 m) consisted of a 1.77 min surfacing with 8.5 blows spaced 13.1 s apart, followed by a 16.09 min dive. Whale status and distance from shore had a strong effect on the SRD cycles of bowheads feeding in and near the Eastern Alaskan Beaufort Sea. During feeding, surfacings and dives were longer, with more blows per surfacing and longer intervals between blows, with increasing distance from shore, and for older, larger whales as compared with subadults.

Traveling bowheads (including those feeding while traveling) tended to have surfacing and dive cycles similar to those of bowheads feeding in water >20 m deep. Some of this similarity may be attributable to the habitat that the whales are occupying, as traveling whales tended to be in water >20 m deep. An average SRD cycle by a traveling bowhead (including bowheads that were feeding as they traveled) consisted of a 1.65 min surfacing with 6.4 blows spaced 15.76 s apart, followed by a 13.66 min dive.

Whale status and group size had a strong influence on the SRD cycles of bowheads traveling in and near the Eastern Alaskan Beaufort Sea. The standard measures of these cycles were higher for mothers and for increased group sizes, and were shorter for subadults.

Socializing whales and whales feeding in shallow water tended to have similar breathing characteristics. Some of this similarity may be attributable to the habitat (shallow water) that the whales were occupying. An average SRD cycle by a socializing bowhead (including bowheads that intermixed socializing with other activities) consisted of a 1.29 min surfacing with 6.0 blows spaced 12.67 s apart, followed by a 5.54 min dive.

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APPENDIX 13.1. Surfacing, respiration and dive behavior of undisturbed bowhead whales engaged in various activities during September and early October 1985-86 and 1998-2000. Calves are excluded. Based on observations from an aircraft at altitude ≥460

Group Activity	Median Blow Intervals (s)			Number of Blows per Surfacing			Duration of Surfacing (min)			Duration of Dive (min)			% Time at	Number of Blows per
Status	mean	s.d.	*n*	mean	s.d.	*n*	mean	s.d.	*n*	mean	s.d.	*n*	Surface	Minute
Feed	13.08	6.34	324	5.89	3.61	123	1.28	0.74	157	8.94	7.12	63	12.5	0.58
Mother	15.78	2.53	15	6.00	2.83	2	2.17	0.72	4	17.46	2.59	4	11.0	0.31
Other	12.95	6.44	309	5.89	3.63	121	1.25	0.73	153	8.36	6.96	59	13.0	0.61
Feed Deep	13.08	3.91	129	8.52	2.81	33	1.77	0.58	42	16.09	4.65	19	9.9	0.48
Mother	15.78	2.53	15	6.00	2.83	2	2.17	0.72	4	17.46	2.59	4	11.0	0.31
Other	12.73	3.93	114	8.68	2.77	31	1.73	0.56	38	15.73	5.07	15	9.9	0.50
Feed Shallow	13.08	7.54	195	4.93	3.40	90	1.10	0.71	115	5.84	5.62	44	15.9	0.71
Mother	-	-	0	-	-	0	-	-	0	-	-	0	-	-
Other	13.08	7.54	195	4.93	3.40	90	1.10	0.71	115	5.84	5.62	44	15.9	0.71
Travel+Feed	15.37	5.88	141	6.88	3.04	42	1.78	0.79	50	12.64	6.08	21	12.3	0.48
Mother	21.24	8.19	21	7.50	2.46	10	2.40	0.88	11	13.34	6.14	11	15.3	0.48
Other	14.34	4.71	120	6.69	3.21	32	1.60	0.68	39	11.88	6.24	10	11.9	0.50
Travel	16.27	4.78	108	6.13	3.33	68	1.56	0.97	75	13.99	8.09	66	10.0	0.39
Mother	18.55	2.24	10	6.67	2.25	6	1.99	0.52	6	15.87	8.65	5	11.2	0.37
Other	16.03	4.91	98	6.08	3.43	62	1.52	0.99	69	13.83	8.10	61	9.9	0.40
Travel plus Travel + Feed	15.76	5.43	249	6.42	3.23	110	1.65	0.91	125	13.66	7.64	87	10.8	0.42
Mother	20.37	6.92	31	7.19	2.34	16	2.26	0.78	17	14.13	6.82	16	13.8	0.44
Other	15.10	4.86	218	6.29	3.35	94	1.55	0.89	108	13.56	7.85	71	10.3	0.42
Social	15.25	8.68	59	5.83	5.07	18	1.08	0.82	20	4.50	2.67	7	19.4	1.04
Mother	-	-	0	-	-	0	-	-	0	-	-	0	-	-
Other	15.25	8.68	59	5.83	5.07	18	1.08	0.82	20	4.50	2.67	7	19.4	1.04
Travel+Social	13.46	3.38	78	5.76	3.40	51	1.31	0.82	55	4.04	4.40	16	24.5	1.08
Mother	18.17	4.52	7	4.43	2.70	7	1.28	1.07	7	3.50	2.28	6	26.8	0.93
Other	12.99	2.90	71	5.98	3.47	44	1.32	0.79	48	4.36	5.39	10	23.2	1.05
Social+Feed	11.63	4.96	205	6.41	3.52	46	1.31	0.70	82	9.20	7.24	9	12.5	0.61
Mother	15.78	1.11	9	-	-	0	3.70	-	1	17.90	-	1	17.1	-
Other	11.44	4.98	196	6.41	3.52	46	1.28	0.65	81	8.12	6.91	8	13.7	0.68
Travel + Social + Feed	12.63	3.70	19	7.00	-	1	2.75	-	1	4.63	3.87	2	37.3	0.95
Mother	17.23	2.91	4	7.00	-	1	2.75	-	1	1.90	-	1	59.1	1.51
Other	11.40	2.86	15	-	-	0	-	-	0	7.37	-	1	-	-
All Social	12.67	5.57	361	6.04	3.71	116	1.29	0.76	158	5.54	5.32	34	18.9	0.88
Mother	16.91	3.08	20	4.75	2.66	8	1.71	1.28	9	5.10	5.55	8	25.2	0.70
Other	12.42	5.59	341	6.14	3.77	108	1.27	0.72	149	5.67	5.35	26	18.3	0.89

14. SURFACING, RESPIRATION AND DIVE CYCLES OF BOWHEAD WHALES IN THE BEAUFORT SEA: CALVES, SUBADULTS AND ADULTS

Tannis A. Thomas [1], W. John Richardson [1], William R. Koski [1], and Bernd Würsig [2]

Introduction

The surfacing, respiration and dive (SRD) cycles of bowhead whales in the Beaufort Sea have been documented in several studies, including studies of whales migrating through the Alaskan Beaufort Sea in spring and fall, and whales summering in the Canadian Beaufort Sea. Some information about differences in SRD cycles among calves, mothers, and "other bowheads" has been published. For example, in the case of bowheads migrating near Point Barrow, Alaska, in May, the durations of surfacings and dives, and the median blow intervals, were all substantially ($P < 0.001$) longer for mothers than for calves (Richardson et al. 1995b; Koski et al. MS). Most calves observed in May are very young, as most calving occurs in April–May (Nerini et al. 1984; Koski et al. 1993). In summer (mainly August), when calves are ~3 mo older, mean durations of surfacings and dives were again longer for mothers than for calves (Würsig et al. 1984). In contrast to the spring results, mean number of blows per surfacing during summer was higher for mothers than for calves, and mean blow intervals were similar for the two groups.

The only previous study that has separated the data for subadults vs. "adults aside from mothers" was the aforementioned study of the behavior of bowheads migrating in spring. Dive durations and median blow intervals were significantly shorter in subadults; duration of surfacing and number of blows per surfacing were similar for the two groups (Richardson et al. 1995b, MS). Recent results from the eastern Alaskan Beaufort Sea during late summer and early autumn indicate that SRD cycles of subadults and adults engaged in feeding and traveling also tend to differ in that area and season (Chapter 13). No similar analysis of age effects has been done previously for bowheads observed in other seasons (e.g., summer).

The durations of surfacings and dives of different categories of bowhead whales, and the number of respirations per surfacing, are important in the calculation of energy requirements and potential water filtering capacity (Chapter 22). Also, these parameters are important in determining correction factors for whales missed by aerial surveyors (Chapter 15). If there are significant differences among age and size classes, this may have important effects on calculated feeding capacity, energy need, and numbers present. These probable effects assume increased importance because of the tendency for different size classes of bowheads to occur in different parts of the eastern Alaskan study area (Chapter 10). Furthermore, utilization of this and other regions by different size classes of bowheads may differ among years (Chapter 10).

A limitation in previous season-specific analyses of the effects of age and whale status (e.g., mothers vs. other adults) on SRD cycles of bowheads has been the small sample sizes for certain age classes, activities, and seasons. Also, during a given season, most calves are in a particular narrow age

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[1] LGL Ltd., environmental research associates, 22 Fisher St., POB 280, King City, Ont. L7B 1A6. *Phone:* 905-833-1244; *e-mail:* wjr@lgl.com or bkoski@lgl.com.

[2] Texas A & M University at Galveston, Marine Mammal Research Program, 4700 Ave. U., Bldg 303, Galveston, TX 77551-5923. *Phone:* 409-740-4413; *e-mail:* wursigb@tamug.tamu.edu

range, and their SRD cycles may change rapidly with season as they mature. In this chapter, we use all available SRD data collected during spring, summer, and autumn studies of bowheads in the Beaufort Sea (1980–2000) for which the size category of some whales is reliably known. We compare the SRD cycles of bowhead calves as observed in spring and late summer/fall (i.e., neonates vs. calves a few months old), subadults, adults other than mothers, and mothers. Companion chapters provide related data on the seasonal distribution of bowheads in the eastern Alaskan study area (Chapter 9), age segregation (Chapter 10), residence times (Chapter 11), and general activities (Chapter 12). Chapter 13 provides additional information on the influence of whale activities and other factors on SRD cycles for bowheads occurring in the eastern part of the Alaskan Beaufort Sea during late summer and early autumn.

Methods

Data Sources

We combined data from six studies of bowhead behavior in the Beaufort Sea during the spring, late summer, and fall: (1) A study of bowheads engaged in feeding and socializing in the Canadian Beaufort Sea during late July or early August to late August or early September of 1980–84 (Würsig et al. 1984; Dorsey et al. 1989; Richardson et al. 1995a). (2) A study of bowhead whales feeding and migrating in the Alaskan Beaufort Sea during September of 1983 (Ljungblad et al. 1984; Richardson et al. 1995a). (3) A study of bowheads engaged in feeding, socializing, and autumn migration in the eastern Alaskan Beaufort Sea during September and early October of 1985–86 (Richardson [ed.] 1987). (4) A study of bowhead responses to offshore drilling in the Camden Bay area during September and early October of 1986, including some observations of undisturbed whales distant from industrial activities (Koski and Johnson 1987). (5) A study of bowheads engaged in spring migration in the Alaskan Beaufort Sea during April and May of 1989–94 (Richardson et al. 1995b, MS). (6) The current study of bowheads engaged in feeding, socializing, and autumn migration during September of 1998–2000. Additional details about the sources of data, organized by season and year, are summarized in Table 14.1. We excluded data when bowheads may have been disturbed by an aircraft flying at <457 m (1500 ft) altitude or by actual or simulated industrial activities. Only bowheads of known status (i.e., subadult, adult other than mother, mother, or calf) were used in the analysis.

Field Procedures

Aerial observations of behavior were obtained from three types of twin-engine aircraft: • a Britten–Norman Islander with piston engines for most of study (1), • deHavilland Twin Otters with turboprop engines in studies (2)–(5) and on 1–12 August 1983 during study (1); and • a Twin Commander 680FL with piston engines in study (6). All aircraft were equipped with radar altimeters. The aircraft used in 1980–94 were equipped with Very Low Frequency (VLF) navigation systems; those used in 1991–2000 were equipped with GPS. Most aircraft were equipped with extended-range fuel tanks, either in the wings or internally, plus inverters for 120 V/60 Hz power, bubble windows, and ventral camera ports. In each study, the field crew consisted of three or four biologists plus one or two pilots. When present, the co-pilot moved to a rear seat once the aircraft was at survey altitude over the sea, allowing a biologist to move to the co-pilot's seat until the aircraft began to return to base.

We used the aerial observation procedures of Würsig et al. (1985) and Richardson et al. (1995a,b) to observe the behavior of bowheads. A focal group of bowheads was observed systematically while the aircraft circled at an altitude of at least 457 m a.s.l. and at a radius of 1–2 km. With this procedure, bowheads show little evidence of disturbance by the aircraft (Patenaude et al. 2002). At most times while the focal whales were at the surface, they were videotaped using a hand-held video camera (usually with tele-extender).

TABLE 14.1. Sources of data on bowhead whale surfacing, respiration and dive cycles for this study. Behavioral observation sessions (BOS) categorized as rest, play and unknown/other were excluded because they were not used in the analyses. Also excluded were bowheads of unknown status.

	Number of		Date Range		Area of	
Year	BOS	Surfacings	of BOS	Season	Beaufort Sea	Source of Data
1989	4	141	3-27 May	Spring	Western Alaskan	Richardson et al. (1995b)
1990	20	321	29 April - 25 May	Spring	Western Alaskan	Richardson et al. (1995b)
1991	2	37	4-20 May	Spring	Western Alaskan	Richardson et al. (1995b)
1994	14	156	3-20 May	Spring	Western Alaskan	Richardson et al. (1995b)
1980	8	42	3-31 Aug	Summer	Canadian	Würsig et al. (1984), Dorsey et al. (1989)
1981	9	75	8 Aug - 7 Sept	Summer	Canadian	Würsig et al. (1984), Dorsey et al. (1989)
1982	6	88	8-24 Aug	Summer	Canadian	Würsig et al. (1984), Dorsey et al. (1989)
1983	4	14	7-22 Aug	Summer	Canadian	Würsig et al. (1984), Dorsey et al. (1989)
1984	9	25	17 Aug - 2 Sept	Summer	Canadian	Würsig et al. (1984), Dorsey et al. (1989)
1983	5	34	12-28 Sept	"Fall"	E. Alaskan & West. Canadian	Ljungblad et al. (1984)
1985	5	25	12-29 Sept	"Fall"	E. Alaskan & West. Canadian	Richardson (1987)
1986	10	84	5-27 Sept	"Fall"	E. Alaskan & West. Canadian	Richardson (1987)
1986	6	64	4 Sept - 3 Oct	"Fall"	E. Alaskan & West. Canadian	Koski & Johnson (1987)
1998	14	265	13-22 Sept	"Fall"	E. Alaskan & West. Canadian	This study
1999	18	92	10-30 Sept	"Fall"	E. Alaskan & West. Canadian	This study
2000	9	79	13-25 Sept	"Fall"	Eastern Alaskan	This study

Whale activities (e.g., traveling, feeding, socializing) and specific behaviors were defined and distinguished as in previous related studies (Richardson et al. 1995a,b, MS). We recognize only one type of dive, often referred to by others as a "sounding" or long dive. Dive durations were recorded only when whales were individually identified from one surfacing to the next, usually on the basis of distinctive marks. Shallow submergences between breaths are not counted as dives or as interruptions of a surfacing. A surfacing is a period when a whale is at or just below the surface, including a full breath sequence. We obtained four standard measures of SRD cycles: the interval between successive blows in a surfacing (blow interval), the number of blows per surfacing, the duration of surfacing (surface time), and the duration of dives between surfacings (dive time). When analyzing blow-interval data, we used the median of all blow intervals within a given surfacing as a single measure of blow interval for that surfacing.

After completing the behavioral observations of a given group of whales, we often used the aerial photogrammetric method of Koski et al. (1992) to document their lengths and individual identities. This was done frequently in studies (4)–(6), and occasionally during studies (1) and (3). Whales <13 m and ≥13 m long were considered to be subadults and adults. When no photogrammetric data were available, whales that were obviously small or large were counted as subadults and adults; others were not classified. Calves were recognized by their size, light color, morphology, behavior, and (in almost all cases) close association with an adult. Lone "calves" were categorized as such only when they were seen well and it was certain that they were young-of-the-year. Mothers were recognized by their size, morphology, and close association with a calf.

Behavioral data were transcribed from audiotape between flights and after the field season. The videotape was then examined for details not noted during the real-time behavioral dictation. The combined data were coded numerically as in our previous work (see Richardson and Finley 1989:25–28 for details). These records were hand-checked, and then entered into an Apple II (1980–86) or MS-Windows (1989–2000) format for computerized validation and analysis. A validation program that checks for impossible or implausible combinations of variables, as developed during prior LGL/MMS projects, was applied to the data and necessary corrections were made. The 1980–86 data were converted to the more recent format before analysis.

Activity Categories

Whale activities were divided into ten categories: rest, travel, socialize, feed, travel+social, travel+ feed, social+feed, travel+social+feed, play, and unknown/other. These activities are described in Chapter 12. As in Chapter 13, seven categories were combined into three composite categories as follows: (1) Travel, including travel and travel+feed; (2) Feed, including only feeding whales; and (3) Social, including socializing whales, travel+social, social+feed, and travel+social+feed. Rest, play, and unknown/other were excluded from the analyses because their sample sizes were either too small (rest and play) or because the activities were heterogeneous and/or ill-defined (unknown/other). When isolated whales engaged in repeated "aerial behavior", including breaches, tail and flipper slaps, and rolls around the longitudinal axis, their activity was generally classified as "unknown/other" and thus excluded from the present analyses.

Analysis Procedures

For each whale activity, we used ANOVA to test for significant ($P \leq 0.05$) effects of whale status on each of the four standard measures of SRD cycles. When ANOVA showed significant differences, we used *post hoc* tests to determine which whale status differed: the Tamhane procedure when variances were unequal (Tamhane 1979), and otherwise the Bonferroni procedure. For whales categorized as "traveling" (travel and travel+feed combined), we used ANOVA to test for significant ($P \leq 0.05$) year to year, seasonal, and nursing vs. not nursing differences in each of the four standard measures of SRD cycles. Categories for which the sample size was <5 were excluded. Logarithmic transformations were used on the distributions of the four SRD variables when they were right-skewed.

Results

Status Differences

In whales categorized as "traveling" (travel and travel+feed combined), the overall mean of the median blow intervals in all years was 14.35 ± s.d. 5.00 s (n = 105) for subadults, 19.19 ± s.d. 7.87 s (n = 246) for adults other than mothers, and 19.56 ± s.d. 7.52 s (n = 84) for mothers (Table 14.2). Median blow intervals varied significantly with whale status; values for subadults were significantly lower than those for adults and mothers (Fig. 14.1A). Number of blows per surfacing did not differ significantly with whale status (Table 14.2; ANOVA, $P = 0.875$; Fig. 14.1B). Duration of surfacing averaged 1.21 min for subadults, 1.59 min for adults, and 1.62 min for mothers (Table 14.2). These surface times were only marginally different (ANOVA, $P = 0.089$; Fig. 14.1C). The overall mean dive duration was 4.78 min for subadults, 8.79 min for adults, and 8.83 min for mothers (Table 14.2), and varied significantly with whale status (ANOVA, P = 0.005); dives by subadults were significantly shorter than those by adults other than mothers or by mothers (Fig. 14.1D).

In whales categorized as "feeding" (without simultaneous traveling or socializing), the overall mean of the median blow intervals in all years was 11.34 ± s.d. 4.86 s (n = 102) for subadults, 13.41 ± 4.89 (n = 61) for adults other than mothers, and 16.22 ± s.d. 3.67 s (n = 33) for mothers (Table 14.2). Median blow interval was the one SRD variable that differed significantly with whale status; values for adults were significantly lower than for mothers and higher than for subadults (Fig. 14.2A). Number of blows per surfacing did not differ significantly with whale status (ANOVA, $P = 0.101$; Fig. 14.2B). Neither did duration of surfacing or dive duration ($P = 0.229$ and 0.558, respectively; Fig. 14.2C,D).

TABLE 14.2. Surfacing, respiration and dive behavior of undisturbed bowhead whales engaged in various activities during the spring, summer, and fall. Neonates refers to calves in the spring. Traveling includes travel alone and travel+feed. Feeding includes only whales that were only feeding. Socializing includes whales that were social, travel+social, social+feed, and travel+social+feed. Data in each box are a subset of those in line preceding box. Based on observations from an aircraft at altitude ≥460 m. The only lines that include any data from mothers or calves engaged in nursing are the 3 lines labeled "Nursing".

Group Activity Status Season	Median Blow Intervals (s)			Number of Blows per Surfacing			Duration of Surfacing (min)			Duration of Dive (min)		
	mean	s.d.	*n*	mean	s.d.	*n*	mean	s.d.	*n*	mean	s.d.	*n*
Traveling												
Subadult	14.35	5.00	105	5.51	3.67	69	1.21	1.04	78	4.78	5.20	37
Spring	14.11	5.65	48	6.24	3.79	34	1.35	1.22	39	4.54	5.70	19
Summer	18.70	-	1	4.50	4.95	2	1.22	1.53	2	-	-	0
Fall	14.47	4.43	56	4.82	3.46	33	1.06	0.81	37	5.04	4.76	18
Adult	19.19	7.87	246	5.51	3.33	195	1.59	1.06	200	8.79	7.46	171
Spring	20.52	8.89	161	4.92	3.23	154	1.46	1.08	154	6.69	6.19	134
Summer	16.48	1.97	4	10.00	-	1	2.65	-	1	24.38	2.19	3
Fall	16.70	4.60	81	7.70	2.75	40	1.99	0.86	45	15.72	6.49	34
Mother	19.56	7.52	84	5.75	3.30	68	1.62	1.00	74	8.83	6.40	67
Spring	19.97	8.01	50	5.16	2.96	44	1.38	0.85	48	8.23	6.27	45
Summer	18.26	5.79	16	6.31	4.46	13	2.01	1.36	15	7.60	5.95	14
Fall	19.58	7.73	18	7.45	2.50	11	2.14	0.74	11	14.41	5.69	8
Nursing	23.98	12.63	28	5.11	2.54	19	2.24	1.21	20	12.60	6.76	17
Neonate	12.42	5.50	146	4.64	3.53	140	0.85	0.83	150	2.49	2.26	144
Nursing	14.59	6.78	16	3.52	2.41	23	0.63	0.57	23	0.89	1.10	24
Calf Summer	16.51	8.23	14	3.00	2.07	16	1.17	1.43	19	3.56	3.84	17
Calf Fall	11.70	2.73	33	6.88	4.12	17	1.47	1.01	18	7.06	4.24	13
Nursing	11.94	5.31	17	2.26	3.48	39	0.20	0.35	40	0.83	1.84	42
Feeding												
Subadult	11.34	4.86	102	6.72	3.21	50	1.31	0.58	57	9.24	7.25	16
Adult	13.41	4.89	61	7.00	3.04	22	1.50	0.41	28	11.70	6.31	20
Mother	16.22	3.67	33	4.00	3.16	6	1.66	1.46	9	11.09	7.27	11
Neonate	11.08	3.32	12	8.57	6.36	14	1.87	2.46	14	2.73	1.26	13
Calf Fall	14.37	6.94	18	6.60	4.39	5	1.46	1.18	6	6.56	4.42	5
Socializing												
Subadult	12.21	4.80	63	4.42	2.89	24	0.95	0.56	30	6.48	5.56	13
Adult	16.98	10.02	98	6.05	3.72	42	1.38	0.88	46	4.46	4.47	17
Mother	16.37	5.22	47	4.67	3.93	30	1.62	1.35	36	7.29	6.65	26
Neonate	-	-	0	-	-	0	-	-	0	-	-	0
Calf Fall	9.51	3.65	15	5.70	2.87	10	1.06	1.00	11	2.91	1.85	7

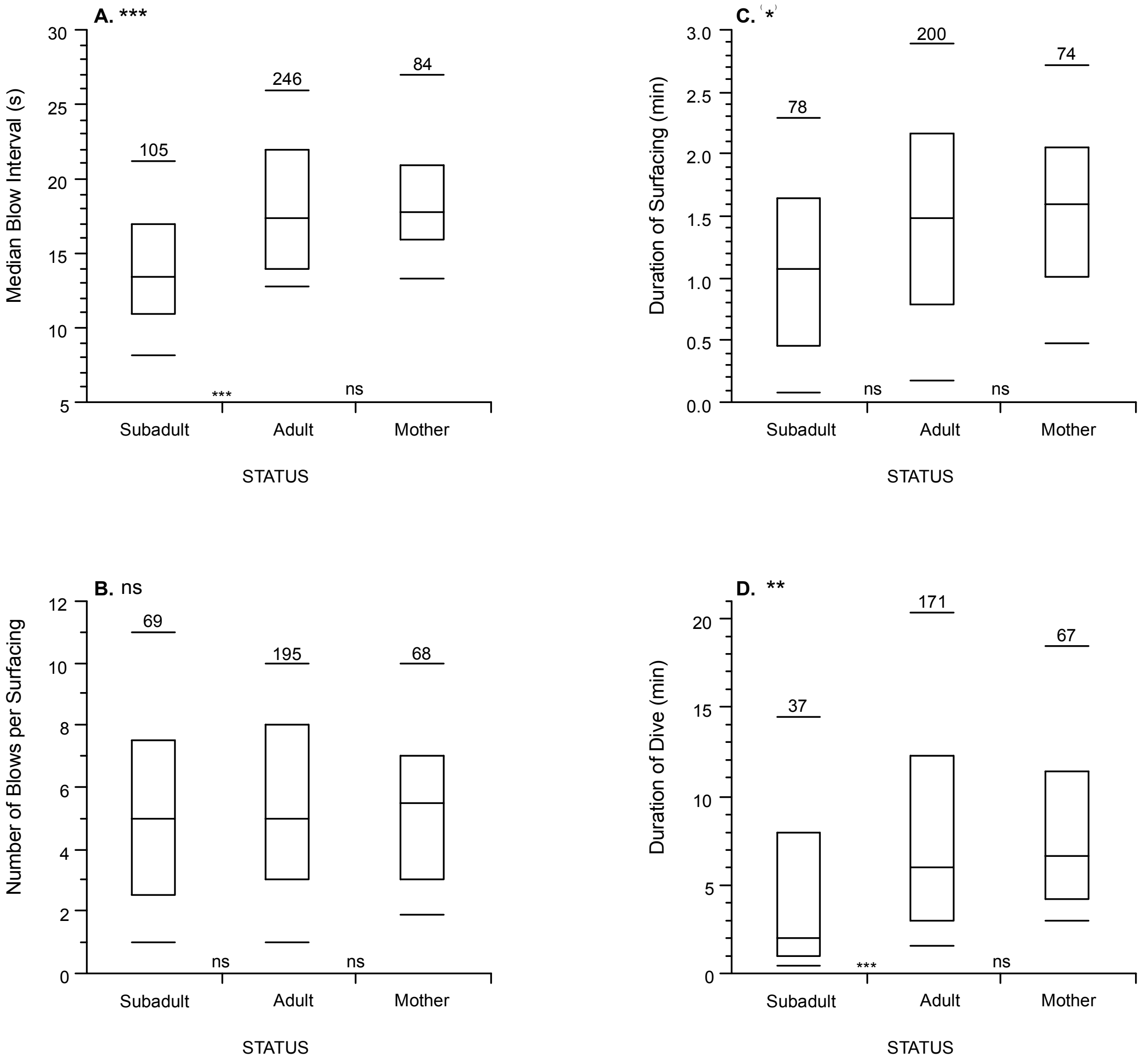

FIGURE 14.1. Whale status vs. surfacing, respiration, and dive variables for **traveling** bowhead whales during all years. Potentially disturbed whales and mothers that are nursing are excluded. In the Box plots, the bottom and top lines represent the 10th and 90th quantiles; boxes show 25th, 50th, and 75th quantiles; numbers are sample sizes. Overall significance of whale status effect (by ANOVA) is shown at the top of each panel. Significance of differences between adjacent pairs of categories are shown at bottom, based on multiple comparison procedures of Tamhane (when variances unequal, panel D) or Bonferroni (equal variances, panels A, B, C). Significance levels coded as *** for $P \leq 0.001$; ** for $0.001 < P \leq 0.01$; * for $0.01 < P \leq 0.05$; (*) for $0.05 < P \leq 0.1$; ns for $P > 0.10$.

In whales categorized as “socializing”, including socializing *per se*, travel+social, social+feed, and travel+social+feed, the overall mean of the median blow intervals in all years was 12.21 ± s.d. 4.80 s ($n = 63$) for subadults, 16.98 ± s.d. 10.02 s ($n = 98$) for adults, and 16.37 ± s.d. 5.22 s ($n = 47$) for mothers (Table 14.2; Fig. 14.3A). Median blow interval again was the one SRD variable that differed significantly with whale status (Fig. 14.3A). Number of blows per surfacing, duration of surfacing, and dive duration did not differ significantly with whale status (ANOVA, $P = 0.156$, 0.328 and 0.302, respectively; Fig. 14.3B–D).

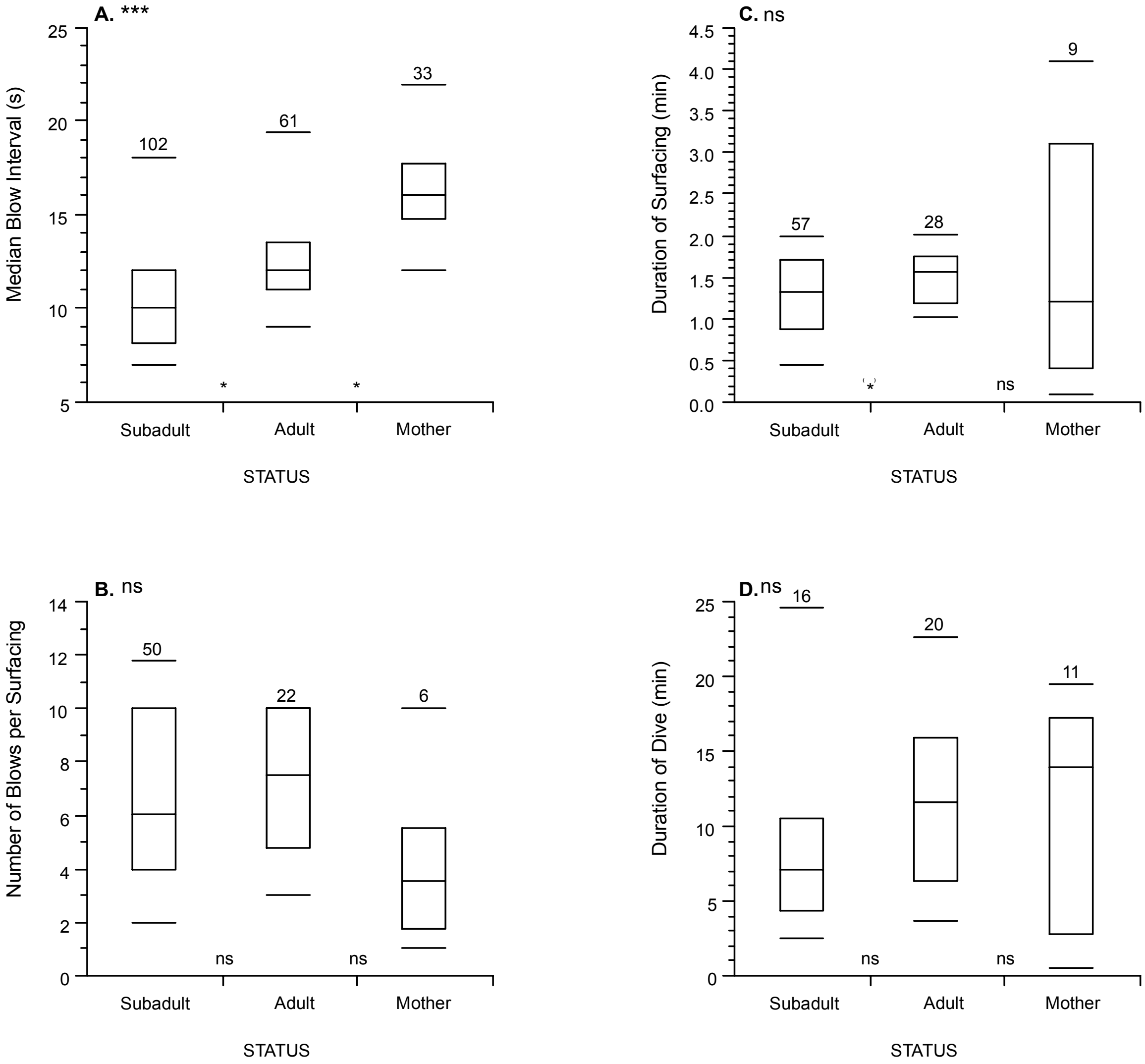

FIGURE 14.2. Whale status vs. surfacing, respiration, and dive variables for **feeding** bowhead whales during all years. Otherwise as in Figure 14.1, except that Tamhane multiple comparisons used in (C), and Bonferroni multiple comparisons in (A, B, D).

Seasonal Differences

In subadults categorized as "traveling", including both travel and travel+feed, the median blow intervals were similar in spring and fall (mean 14.11 vs. 14.47 s; Table 14.2, Fig. 14.4A; $P = 0.716$ based on t-test). Likewise, number of blows per surfacing, duration of surfacing, and dive duration all were similar in spring and fall (Table 14.2; Fig. 14.4B–D; $P = 0.115$, 0.233, and 0.777, respectively).

In adults (other than mothers) categorized as "traveling" (travel and travel+feed), in contrast, all four SRD variables differed significantly between spring and fall (Fig. 14.4). Median blow intervals tended to be longer in the spring than in the fall (mean 20.52 vs. 16.70 s). The other three variables were all higher in fall than in spring.

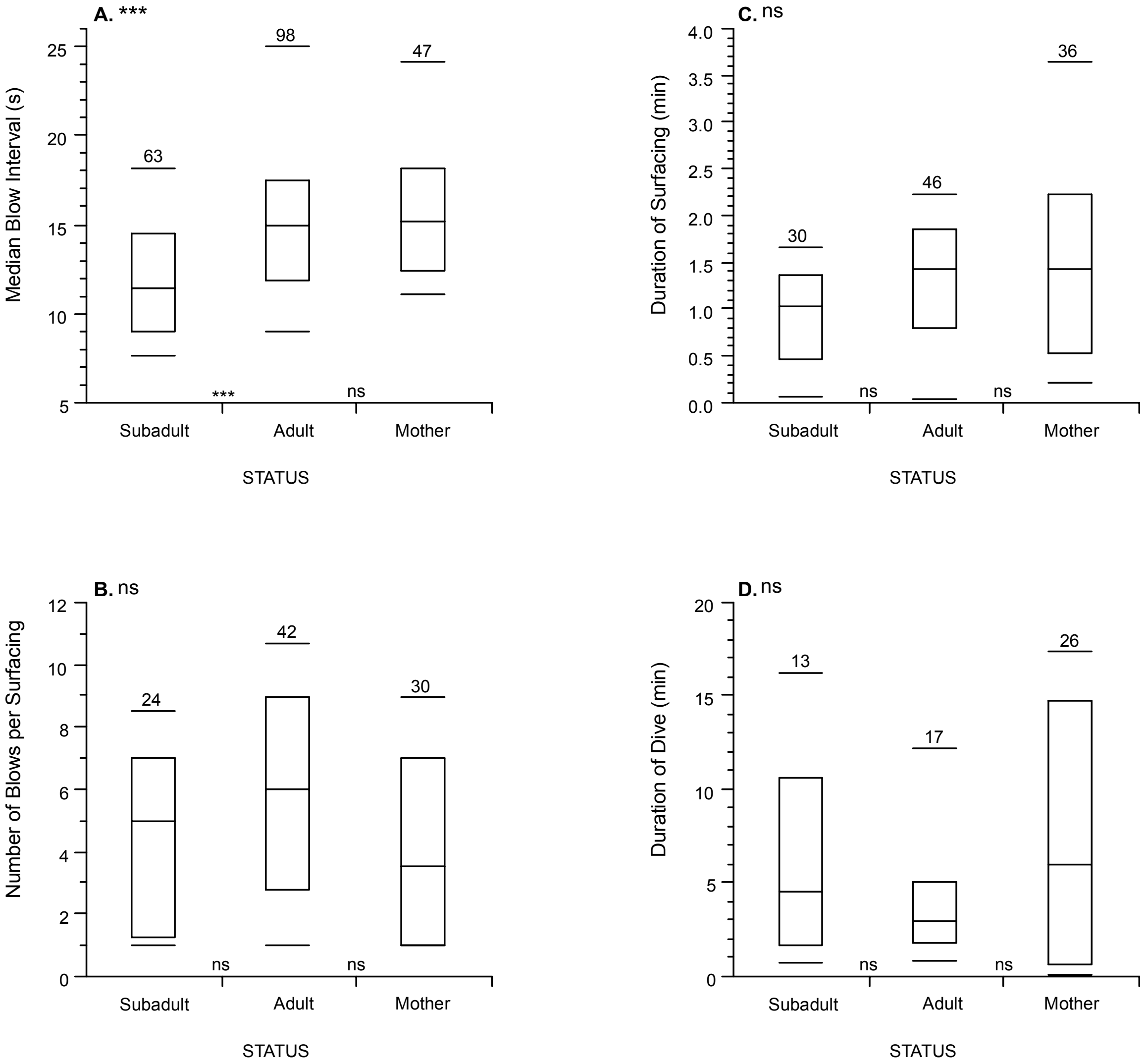

FIGURE 14.3. Whale status vs. surfacing, respiration, and dive variables for **socializing** bowhead whales during all years. Otherwise as in Figure 14.1, except that Tamhane multiple comparisons used in (D), and Bonferroni multiple comparisons in (A–C).

In mothers categorized as "traveling" (travel and travel+feed), median blow intervals did not vary significantly among spring, summer and fall (Fig. 14.5A; Table 14.2; ANOVA, $P = 0.735$). For number of blows per surfacing, seasonal variability was marginally significant (Fig. 14.5B; $P = 0.093$). Durations of surfacings averaged longer in summer and fall than in spring (Fig. 14.5C; $P = 0.017$). Durations of dives averaged longer in fall than in spring or summer (Fig. 14.5D; $P = 0.028$).

In calves categorized as "traveling" (travel and travel+feed combined), median blow intervals varied significantly among seasons (Fig. 14.5A; ANOVA, $P = 0.018$), with values in summer being highest. Number of blows per surfacing also differed among seasons (Fig. 14.5B; $P = 0.010$), but for this variable values in fall were highest. Durations of surfacing were only marginally different among seasons (Fig. 14.5C; $P = 0.061$). However, mean dive duration was notably longer during fall than during spring or summer (Fig. 14.5D; $P < 0.001$).

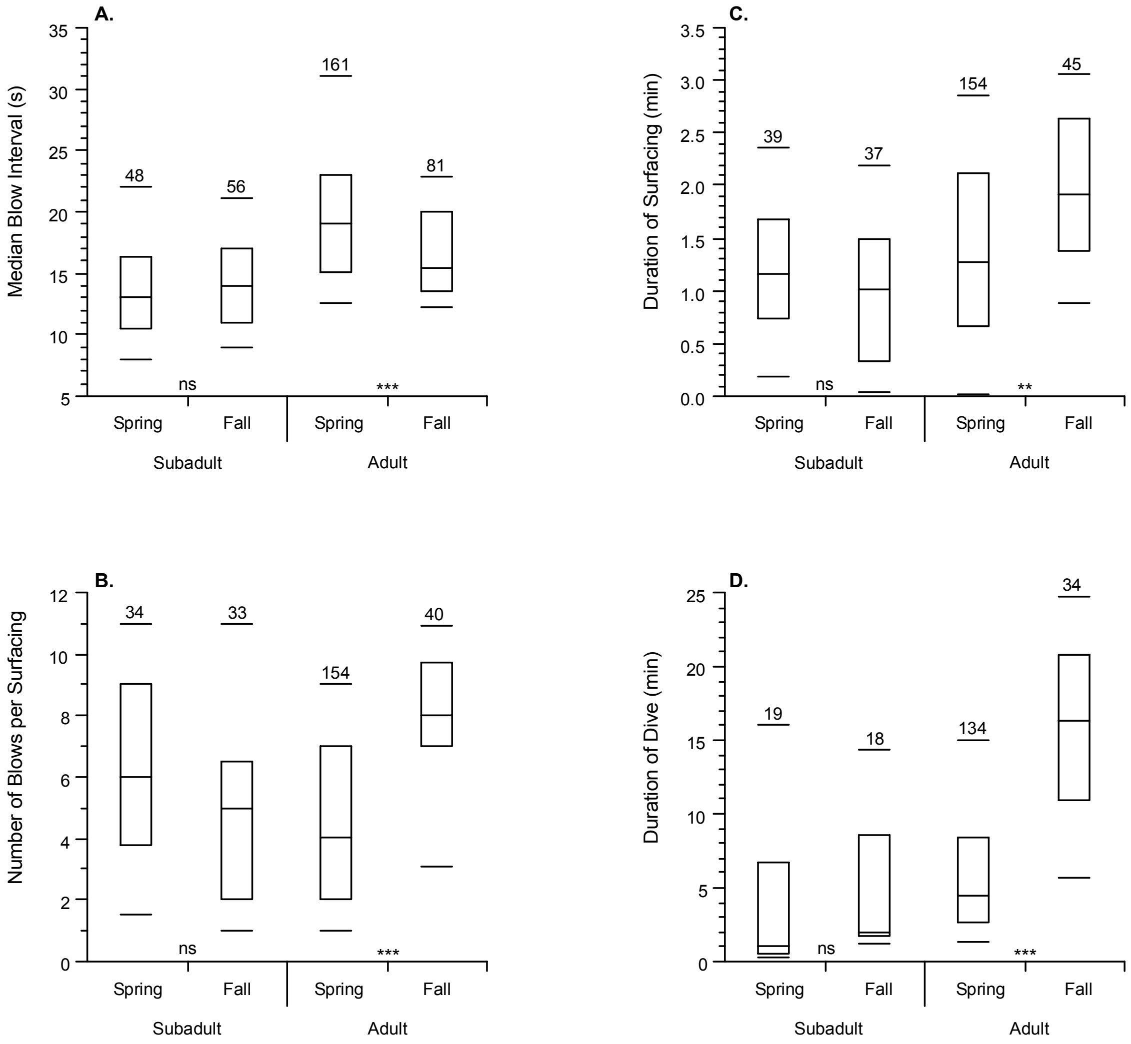

FIGURE 14.4. Seasonal comparison of surfacing, respiration, and dive variables for **traveling subadult and adult** bowhead whales. Data are from spring of 1989–90 and 1994, and fall of 1983, 1986, and 1998–2000. Otherwise as in Figure 14.1, except statistical tests used were independent-sample *t*-tests with Levene's test for equality of variances.

Yearly Differences

Appendices 14.1–14.4 provide data on year-to-year differences in SRD variables of bowhead whales in the Beaufort Sea. Subadults engaged in traveling showed some yearly variability in number of blows per surfacing (Appendix 14.2). Adult whales engaged in traveling showed significant year-to-year variability in all four SRD variables (Appendix 14.3). Mothers engaged in traveling showed significant differences in surface times and number of blows per surfacing, and possibly in dive durations as well (Appendix 14.4).

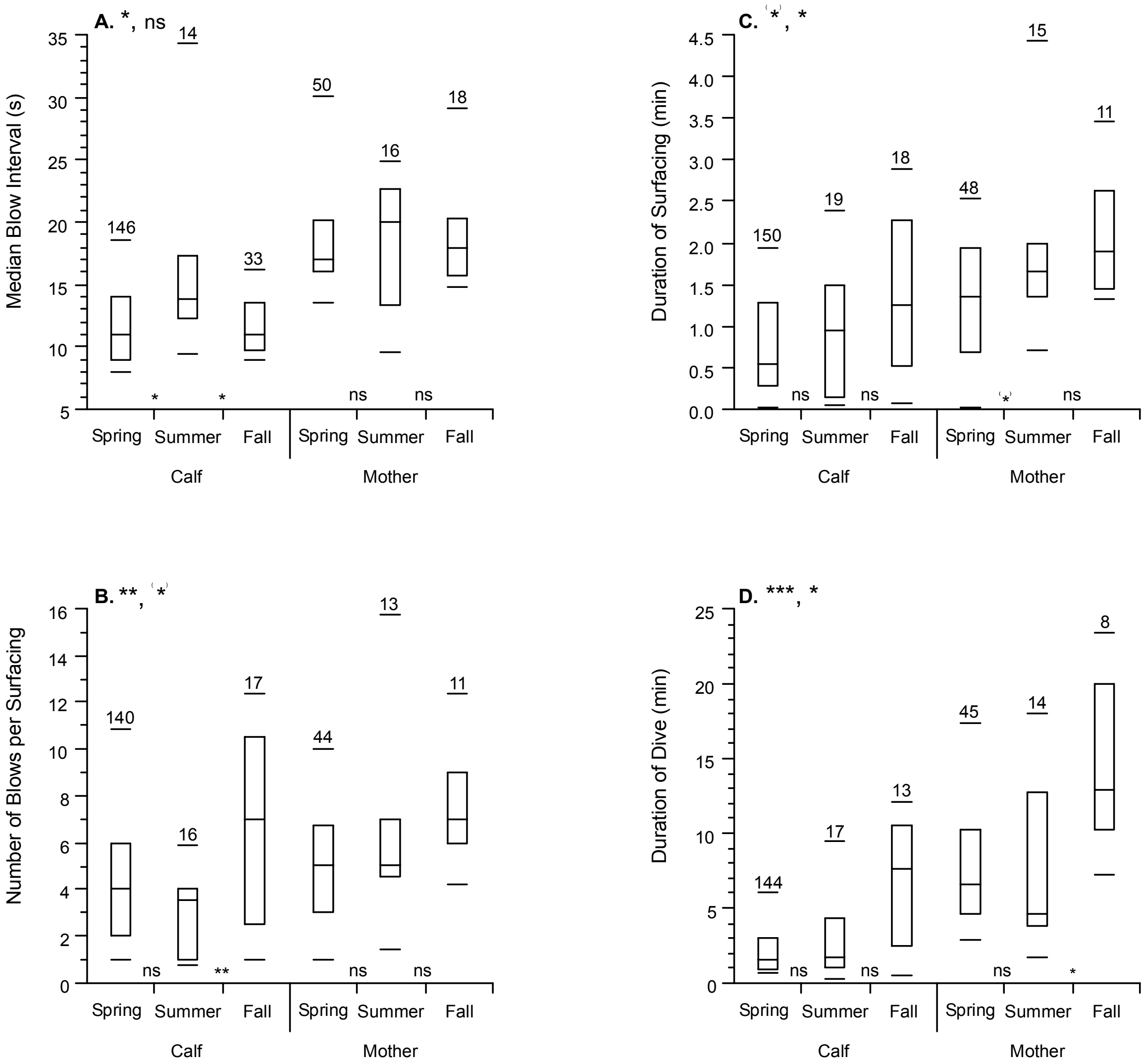

FIGURE 14.5. Seasonal comparison of surfacing, respiration, and dive variables for **traveling mother and calf** bowhead whales. Data are from the spring of 1989–91 and 1994, the summer of 1982, and the fall of 1983 and 1998–2000. Nursing mothers and calves are excluded. Otherwise as in Figure 14.1, except that Tamhane multiple comparisons used for calves in (D), and Bonferroni multiple comparisons used for mothers in (A)–(D).

Nursing vs. Not Nursing

In mothers categorized as traveling, the median blow intervals averaged 19.56 ± s.d. 7.52 s ($n = 84$) for mothers not nursing, and 23.98 ± s.d. 12.63 s ($n = 28$) for mothers nursing (Table 14.2); these values differed significantly (*t*-test, $P = 0.015$; Fig. 14.6A). Number of blows per surfacing did not differ significantly between mothers that were and were not nursing (Table 14.2 and Fig. 14.6B; $P = 0.620$). Durations of surfacings and dives by mothers both averaged significantly longer while nursing than while not nursing (Table 14.2 and Fig. 14.6C,D; $P = 0.021$ and 0.035, respectively).

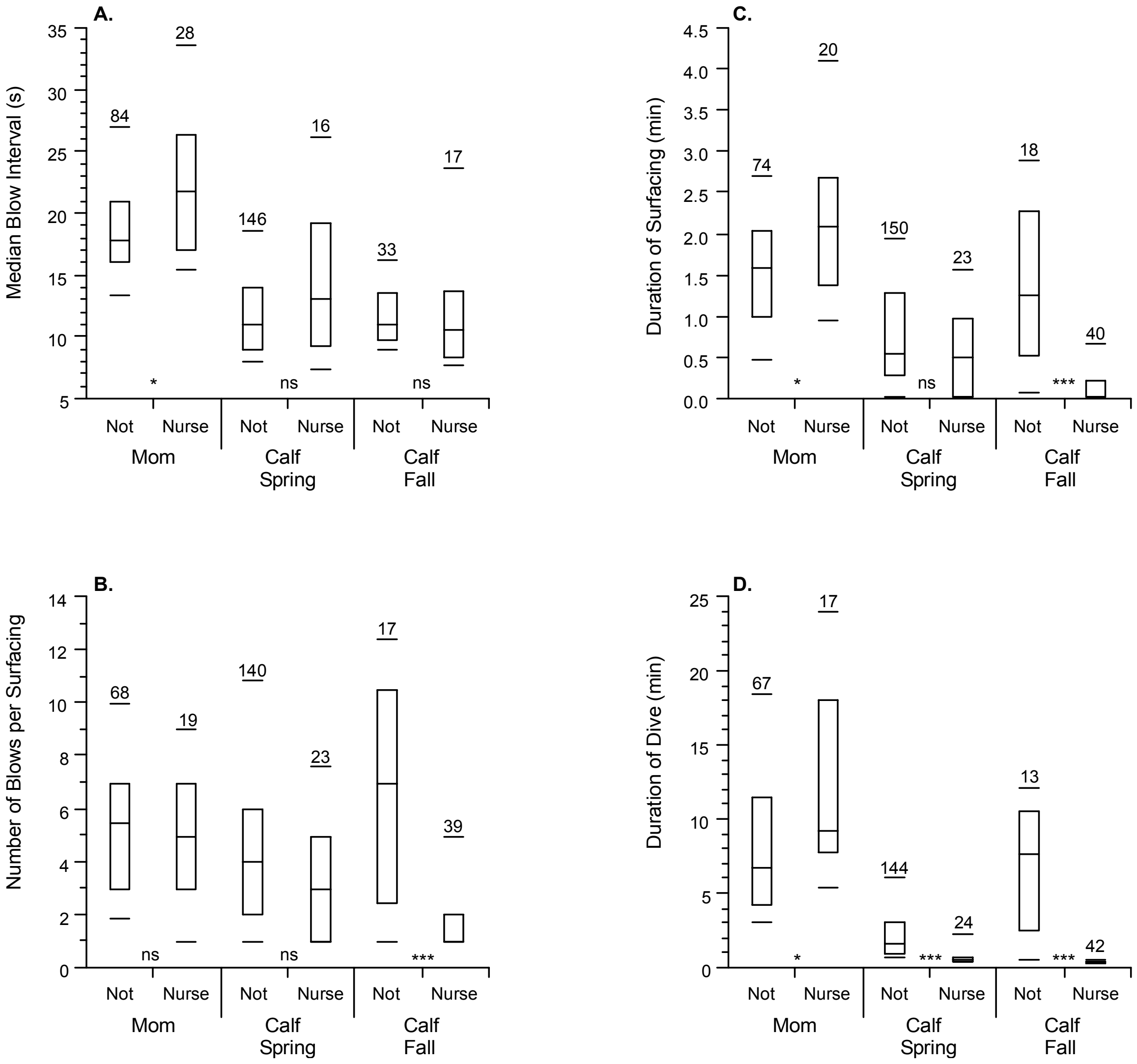

FIGURE 14.6. Comparison of surfacing, respiration, and dive variables for **traveling mothers and calves** during times **with and without nursing**. Otherwise as in Figure 14.1, except that statistical tests used were independent-sample *t*-tests with Levene's test for equality of variances.

In calves that were traveling in spring, median blow intervals were not significantly different for calves that were and were not nursing (means 12.41 vs. 14.59 s; Table 14.2 and Fig. 14.6A; *t*-test, $P = 0.165$). Likewise, number of blows per surfacing and duration of surfacing were not significantly different with and without nursing ($P = 0.139$ and 0.208, respectively; Fig. 14.6B,C). Mean dive durations averaged significantly shorter with than without nursing (0.90 vs. 2.49 min; Fig. 14.6D; $P < 0.001$).

In calves that were traveling in fall (as in spring), median blow intervals did not differ significantly when nursing vs. not nursing (Table 14.2 and Fig. 14.6A; *t*-test, $P = 0.742$). However, in fall, number of blows per surfacing, duration of surfacing, and duration of dive all tended to be lower during nursing (Fig. 14.6B–D, $P < 0.001$ in each case).

Discussion

Variability in SRD Cycles as Related to Age

Subadult whales had lower median blow intervals than adults and mothers, regardless of whale activity, i.e., travel, feed, and social (Fig. 14.1–14.3). Subadults also had shorter dive durations during traveling, and marginally shorter surface durations during feeding, than adults and mothers. Richardson et al. (1995b, MS) found similar results in the subset of these same data involving traveling bowheads observed in spring. Adult whales other than mothers had surfacing–respiration–dive cycles similar to those of mothers, except during feeding when adults had lower median blow intervals than mothers (Fig. 14.2A).

These results show that some aspects of SRD cycles differed significantly between subadults, adults, and mothers. Thus, caution is necessary when comparing bowhead behavior in situations when the proportions of adults and subadults are unknown but potentially varying with location or time. Similar caution is warranted in developing and applying correction factors for bowhead whales missed during aerial surveys because they are below the surface as the survey aircraft passes ("availability bias"—see Chapter 15). Age class segregation has been documented during spring migration past Barrow, Alaska (Zeh et al. 1993; Angliss et al. 1995; Richardson et al. 1995b; Koski et al. MS); on the summering areas in the Canadian Beaufort Sea and Amundsen Gulf (Cubbage and Calambokidis 1987; Koski et al. 1988); and in the eastern Alaskan Beaufort Sea during late summer and autumn (Chapter 10). In the Canadian and eastern Alaskan Beaufort Sea, subadult whales tend to occupy shallow nearshore areas and adults tend to be found farther offshore. During both spring migration past Barrow (Koski et al. MS) and fall migration past Kaktovik (Chapters 2, 10), subadults tend to precede adults, though with much overlap in dates. The mothers and calves tend to migrate past late in the season, especially in spring. Segregation also occurs on the summer range of the Davis Strait–Baffin Bay stock (Finley 1990).

During travel, mean surface and dive durations and number of blows per surfacing were even shorter for calves observed in spring and summer than for subadults (Table 14.2), suggesting that these variables may be related to age or size. Consistent with this, values of these three variables for calves observed in fall were higher than those for calves in spring and summer. However, the values for calves in fall were also higher than those for subadults (Table 14.2). This indicates that other factors aside from simply size and age are involved.

Variability among Seasons

Subadults engaged in traveling showed no spring–fall differences in any of the SRD variables (Fig. 14.4). Adult whales, in contrast, showed differences in all four variables. In fall (as compared to spring) they had shorter median blow intervals and more blows per surfacing, longer surface times, and longer dive times (Fig. 14.4). This seasonal variation may be related to the habitat the whales occupy. In the spring there is more ice to navigate through than in the fall. This probably affects the SRD cycles. Also, the dive durations recorded during spring are probably a biased sample, underestimating the actual average, because of the reduced probability (even from a circling aircraft) of resighting a bowhead once it dives under ice pans.

Mothers and calves engaged in traveling showed seasonal variability in SRD cycles. For both mothers and calves, there was a noticeable increase in the number of blows per surfacing, surface times, and dive times from spring to fall (Fig. 14.5). For calves, this seasonal effect may be attributable to the age and size difference in calves observed during spring vs. fall. Bowheads probably calve from about March to July, but mainly in April–May (Nerini et al. 1984; Koski et al. 1993). Thus, calves encountered during spring (May) vary in age from newborn to about three months. Those calves are smaller and younger than those encountered during summer and autumn periods. Mean calf lengths increase from ~4.7 m in May to 6.8 m in September (Koski et al. 1993). Thus, calf behavior in spring is expected to differ from calf behavior in fall. The seasonal variability observed in the mothers may be attributable, at least in part, to differences in the maternal care given to younger calves in spring vs. older calves in fall (e.g., Würsig et al. 1999).

Nursing vs. Not Nursing

Bowhead whale calves accompany their mothers during their first spring, summer and fall, and are not weaned until sometime in winter or perhaps early spring (Koski et al. 1993). Mother–calf pairs often engage in nursing, and nursing affects SRD cycles of both calf and mother (Fig. 14.6). During travel, nursing dives by calves were much shorter than their other dives in both spring and fall. In fall, calves that were nursing also had shorter surfacings with fewer blows per surfacing than calves that were not nursing. This was not the case for the smaller calves observed in spring. Occurrence of nursing also affected SRD cycles of traveling mothers. When nursing, traveling mothers tended to have long surfacings with long blow intervals. Dive durations by traveling mothers also tended to average slightly longer when nursing.

Summary

Data on age- and size-dependence of surfacing, respiration and dive (SRD) cycles of bowhead whales were needed as a basis for analyses of bowhead energetics. This type of information is also relevant in deriving correction factors for whales missed during aerial surveys, especially when there is geographic and seasonal variation in the ages and sizes of bowheads present.

Bowheads in the Alaskan and Canadian Beaufort Sea were observed systematically at various times in 1980–2000 during spring, summer, and fall. During each of six studies, bowhead behavior was observed from an aircraft circling at an altitude of ≥457 m (≥1500 ft), high enough to avoid significant aircraft disturbance. Data collected in the presence of other human activities were excluded. We documented the durations of surfacings and dives, number of blows (respirations) per surfacing, and intervals between successive blows. These four variables were defined as in our recent studies of bowhead behavior in various seasons and regions. We summarized the SRD variables by whale status (calf, subadult, adult other then mother, mother), various categories of whale activity (traveling, feeding, and socializing), season (spring, summer, fall), year, and nursing vs. not nursing.

Subadult whales had lower median blow intervals than adults and mothers; this was evident for bowheads engaged in all three whale activities studied (traveling, feeding, and socializing). Subadults also had lower dive durations during traveling, and marginally lower surface times during feeding, as compared with adults and mothers. Mothers and other adults had similar SRD cycles, with the exception that, during feeding, other adults had lower median blow intervals than mothers.

Subadults engaged in traveling showed no spring–fall differences in any of the SRD variables. Adult whales, in contrast, showed differences in all four variables. Mothers and calves engaged in traveling showed seasonal variability in SRD cycles. For both mothers and calves, there was a noticeable increase in the number of blows per surfacing, surface times, and dive times from spring to fall.

During travel, nursing dives by calves were much shorter than their other dives in both spring and fall. Occurrence of nursing also affected SRD cycles of traveling mothers. When nursing, traveling mothers tended to have long surfacings with long blow intervals. Dive durations by traveling mothers also tended to average slightly longer when nursing.

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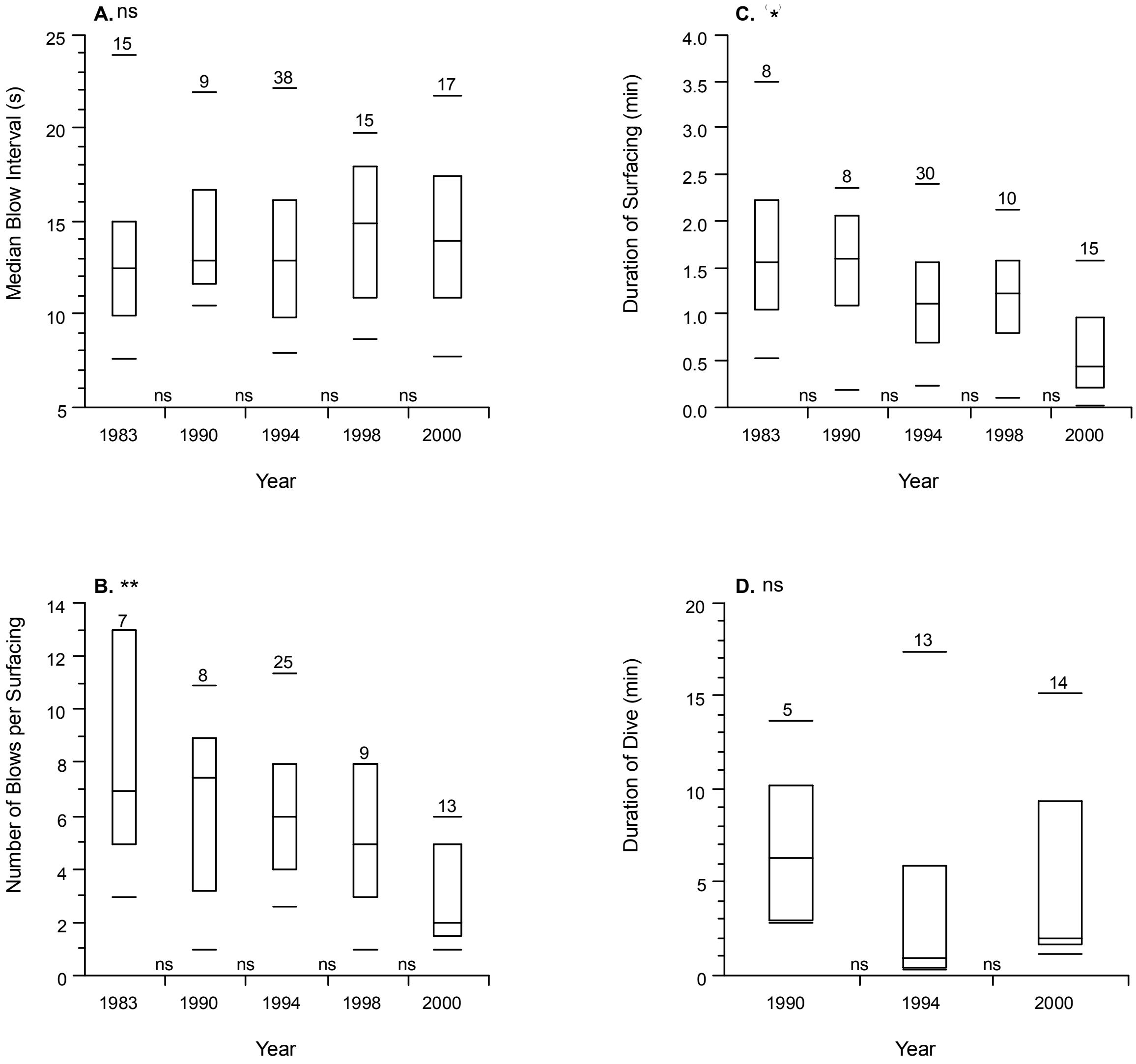
APPENDIX 14.1. Yearly Differences in SRD Variables.

In subadults categorized as traveling, median blow intervals observed in five different years had mean values ranging from 12.60 to 13.90 s, and did not differ significantly among years (ANOVA, $P = 0.990$) (Appendix 14. 2A). Mean number of blows per surfacing ranged from 2.92 to 8.57 over the same five years, and year-to-year variability was significant (ANOVA, $P = 0.003$). Values in 2000 were significantly lower than in 1983 and 1994 (App. 14.2B). Mean duration of surfacing ranged from 0.63 to 1.70 min, with year-to-year differences being only marginally significant ($P = 0.100$; App. 14.2C). The mean dive duration ranged from 4.07 to 8.08 min, with no significant among-year differences ($P = 0.846$; App. 14.2D).

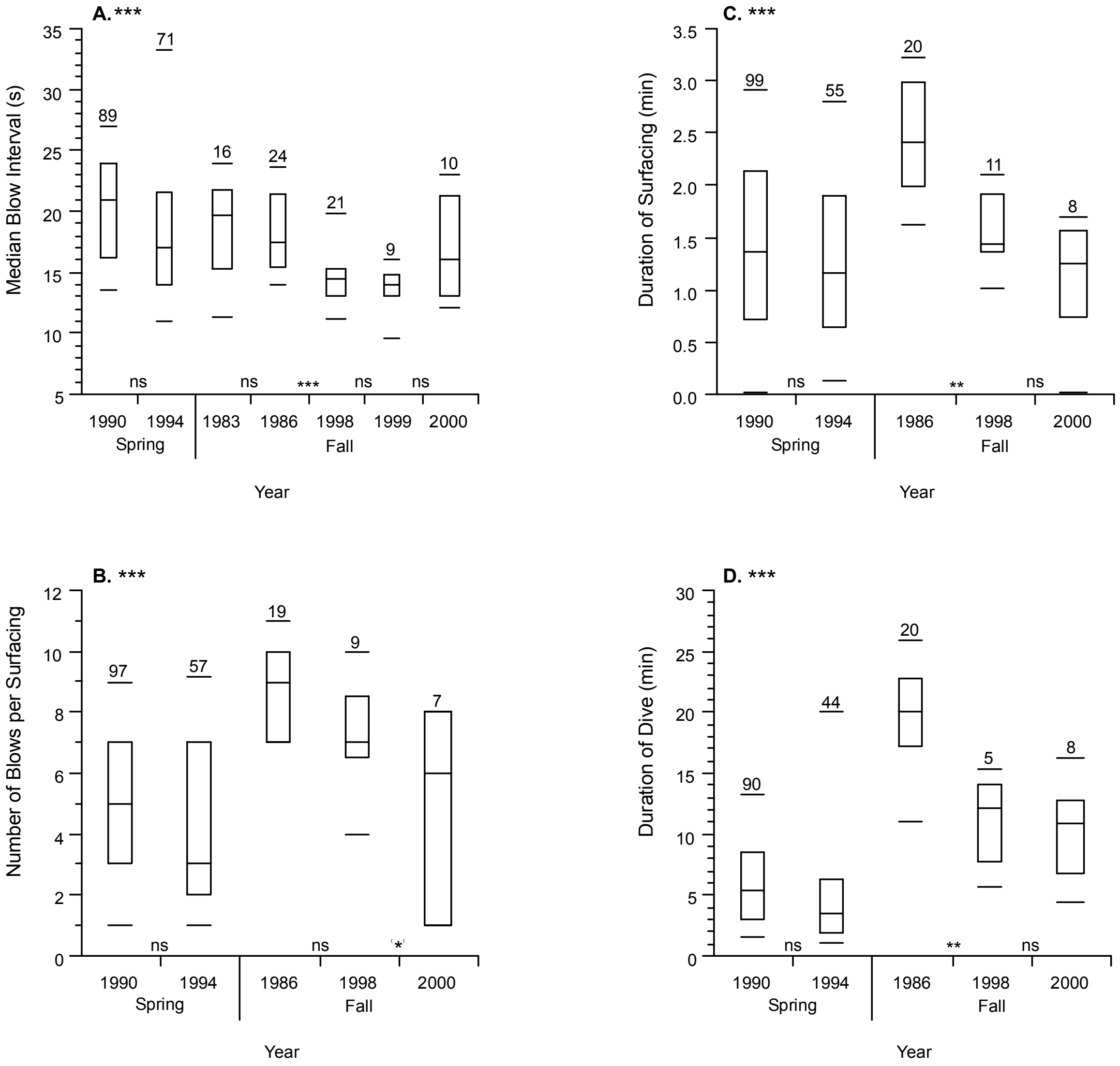
In adults (other than mothers) traveling during spring, SRD cycles in years 1990 and 1994 did not differ (App. 14.3; *t*-tests, $P = 0.341$ for median blow intervals, $P = 0.376$ for number of blows, $P = 0.265$ for duration of surfacing, and $P = 0.915$ for dive duration). In the fall when adults were traveling, median blow intervals observed in five years had mean values ranging from 13.72 to 18.84 s. These values varied significantly among years, with values in 1986 being higher than in 1998 and 1999 (App. 14.3A). Mean number of blows per surfacing during three autumns ranged from 4.71 to 8.79, again with significant year-to-year differences. Values in 1986 were significantly higher than in 2000 (App. 14.3B). Mean duration of surfacing ranged from 1.11 to 2.49 min over three years. These values were significantly different, with 1986 surface times being significantly higher than in 1998 and 2000 (App. 14.3C). The mean dive duration ranged from 10.59 to 19.61 min over three years, again differing significantly among years; values in 1986 were significantly higher than in 1998 and 2000 (App. 14.3D).

In mothers categorized as traveling, median blow intervals observed in five years had mean values ranging from 18.39 to 26.33 s. These values did not differ significantly among years (ANOVA, $P = 0.632$) (App. 14.4A). Mean number of blows per surfacing ranged from 1.57 to 8.67, with significant year-to-year differences; values in 1991 were significantly lower than all other years (App. 14.4B). Mean duration of surfacing ranged from 0.27 to 2.58 min, and varied significantly with year; values in 1991 were significantly lower than during all other years (App. 14.4C). The mean dive duration ranged from 5.49 to 12.60 min. Overall, dive durations did not differ significantly among years (ANOVA, $P = 0.167$), although the few values recorded in 1998 were significantly longer than dive durations in 1982, 1989 and 1991 (App. 14.4D).

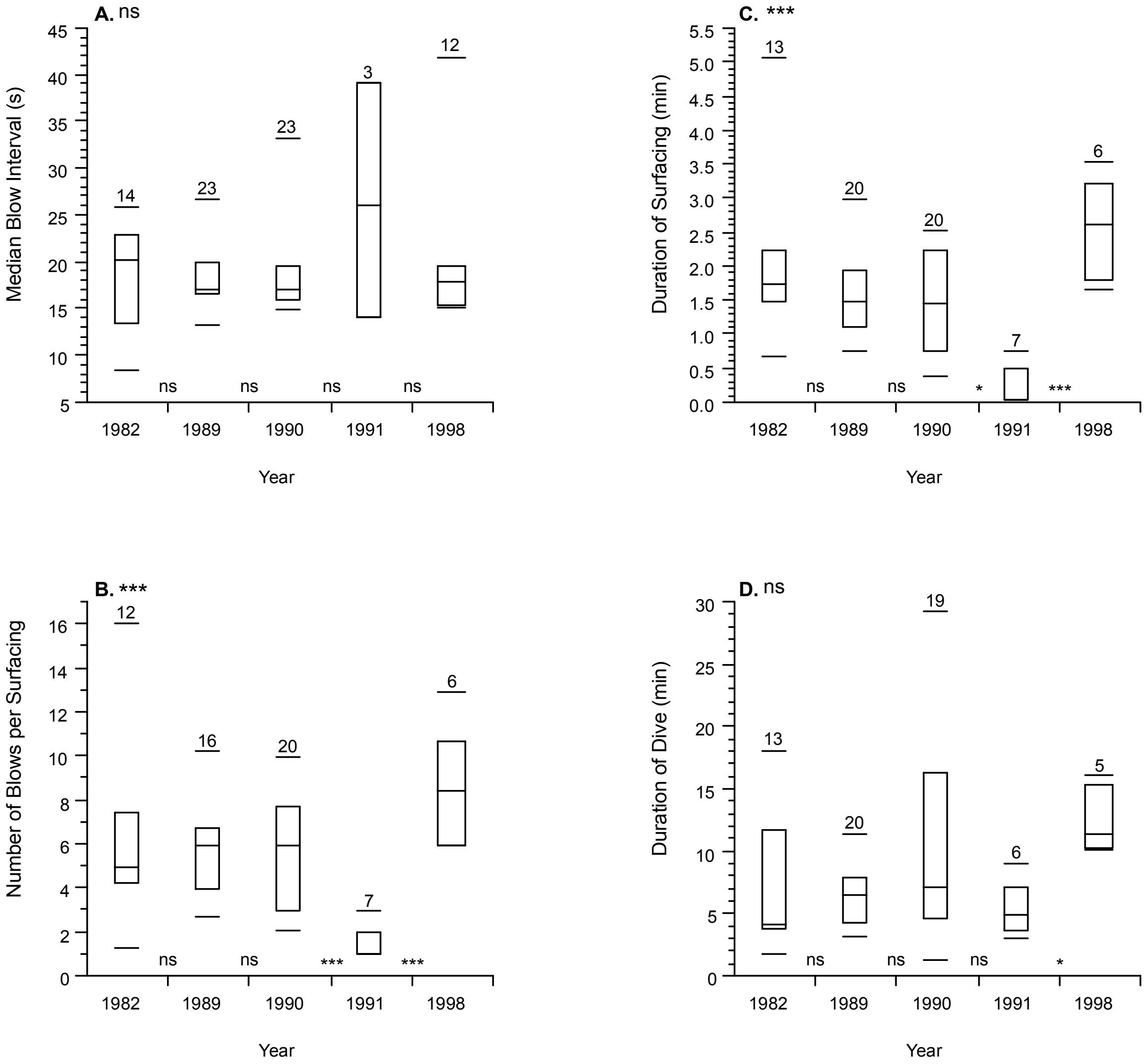
Some of these yearly differences may be related to year-to-year variations in the locations or seasons when whales were observed. SRD cycles of feeding whales, in particular, differ depending on the water depth, and presumably the depth of feeding (e.g., Dorsey et al. 1989; Chapter 13). In other species of baleen whales feeding at known depths, SRD variables are strongly correlated with depth of dive (Würsig et al. 1986; Dolphin 1987a,b). Feeding locations and depths in the Canadian and Alaskan Beaufort Sea have differed among years (Richardson et al. 1987; Chapters 6, 9, 12 and 23). Certain areas were used by feeding whales in more than one year, but feeding has not been observed in any one area in all years when it was surveyed. Although variations in ice cover and human activities may have some influence on areas used for feeding, utilization of ice-free, undisturbed areas also differs from year to year. Variation in locations of food concentrations is apparently one of the main reasons for year-to-year differences in feeding locations. Traveling whales may be influenced by year-to-year differences in feeding locations when they are traveling between feeding areas. Year-to-year (and within-year) changes in feeding locations and depths are likely to influence SRD cycles.



APPENDIX 14.2. Yearly comparison of surfacing, respiration, and dive variables for **traveling subadult** whales during 1983, 1990, 1994, 1998, and 2000. Otherwise as in Figure 14.1, except that Bonferroni multiple comparisons were used in all panels.



APPENDIX 14.3. Yearly comparison of surfacing, respiration, and dive variables for **traveling adult** whales during spring of 1990 and 1994, and fall of 1983, 1986, and 1998–2000. Overall ANOVA results apply to fall data only. Otherwise as in Figure 14.1, except that Bonferroni multiple comparisons were used in all panels.



Appendix 14.4. Yearly comparison of surfacing, respiration, and dive variables for **traveling mother** whales during 1982, 1989, 1990, 1991, and 1998. Nursing mothers are excluded. Otherwise as in Figure 14.1, except that Tamhane multiple comparisons used in (D), and Bonferroni multiple comparisons were used in (A–C).

15. CORRECTION FACTORS TO CALCULATE BOWHEAD WHALE NUMBERS FROM AERIAL SURVEYS OF THE BEAUFORT SEA

Tannis A. Thomas, William R. Koski, and W. John Richardson [1]

Introduction

Not all of the animals present are seen during aerial surveys. Some animals may be missed because of obstruction by parts of the aircraft structure, poor sighting conditions, and limitations of observers in seeing and recognizing the animals. During surveys of marine mammals, sightability is further reduced because most species are below the surface and invisible for a significant fraction of the time. Thus, the raw data from aerial surveys are, at best, indices of relative density of marine mammals at different places and times (Eberhardt et al. 1979; Best 1982; Hiby and Hammond 1989).

The proportion of animals at the surface that are detected is not only <1.0, but also quite variable. It is affected by aircraft altitude and ground speed, seating and window arrangements in the aircraft, glare, wave height, ice cover, behavior of the target species, and nominal transect width. Aircraft altitude affects the width of the strip below the aircraft where, in the absence of a bubble nose or ventral window, downward visibility is blocked or reduced. Even when bubble windows are used by rear-seat observers, downward visibility is reduced because observers concentrate their visual scans to the side. Sometimes a separate observer with direct downward or forward visibility is assigned to "guard the trackline", but then there are complications in merging sightings from the trackline and lateral observers (Buckland et al. 1993). For lateral observers, the area below or close to the aircraft is visible for less time than the area farther to the side (Hain et al. 1999). Visibility, as influenced by haze, fog and precipitation, has obvious effects on the probability of detecting animals that are at the surface. Glare can reduce sightability (Scott and Winn 1980; Holt 1987). Increasing wave height ("sea state") also reduces the sightability of various species (Scott and Winn 1980; Holt 1987; Gunnlaugsson et al. 1988; DeMaster et al. 2001). If aerial surveys could all be conducted in a very standardized way under optimal weather and lighting conditions, many of the complications would be avoided or greatly reduced. However, it is rarely possible to restrict aerial surveys to ideal conditions, and thus the results are subject to the sources of variability mentioned above.

The problems are compounded when data collected with different types of aircraft, or aircraft with different seating and window arrangements, must be combined. Different aircraft give observers different views of the water, and this could result in differences in detectability. Different aircraft also emit different sounds, which can have different effects on the behavior of the animals and thus on detectability (Patenaude et al. 2002).

Animals below the surface and invisible are a particular issue in quantitative aerial surveys of marine mammals. During many aerial survey projects, no allowance has been made for mammals below the surface, other than a general acknowledgement that the calculated densities and numbers are mini-

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[1] LGL Ltd., environmental research associates, 22 Fisher St., POB 280, King City, Ont. L7B 1A6. *Phone:* 905-833-1244; *e-mail:* bkoski@lgl.com or wjr@lgl.com

mum estimates. In some cases, data on surfacing–dive cycles of the species of concern have been used to develop a correction factor for proportion of time at the surface, with or without adjustment for the finite time a given location is in an aerial observer's field of view. Different species are at the surface and potentially detectable for different proportions of the time, and within-species variability causes additional complications (Leatherwood et al. 1982; Barlow 1999). A given species, including the bowhead whale, can be at the surface for different proportions of the time depending on the activity of the animals or the season (Richardson et al. 1995; Chapters 13, 14). Notwithstanding the complications, some correction for animals below the surface as the aircraft passes is essential if there is a need for even approximate absolute estimates of densities and numbers of marine mammals present.

In theory, two parameters, $f(0)$ and $g(0)$, can be computed from raw survey data and other observations of the species of interest to minimize most biases in estimates of actual densities and numbers of marine mammals present at the time of the survey (Buckland et al. 1993). When applied to sightings during line transect surveys, the $f(0)$ factor accounts for the reduced probability of detecting an animal at the surface of the water as its distance from the trackline increases. Factor $f(0)$ is defined as the probability density function of detected distances from the trackline, evaluated at lateral distance zero. The $g(0)$ factor represents the probability of detecting an animal that is on the trackline. When known, it can be used to correct the raw sighting data for animals that are on or near the trackline but not detected during the survey. There are two components to the $g(0)$ factor (Marsh and Sinclair 1989): (1) Animals that are below the surface and not visible, sometimes called "availability bias" and designated $g_a(0)$ here; and (2) animals at the surface but not sighted, called "perception bias" or "detectability bias" and designated $g_d(0)$ here. Availability bias can be estimated from data on surfacing and dive cycles, such as those in Chapter 13. A common approach for estimating detectability bias is to use the "independent double observer" method (Magnusson et al. 1978; Pollock and Kendall 1987). This involves use of two independent observers on the same side of the aircraft and an analysis of the capture–recapture type. Based on the number of animals seen by observer 1, observer 2, and both observers, the proportion of the animals present at the surface that were detected can be estimated.

For bowhead whales, some information about $f(0)$, $g_a(0)$ and $g_d(0)$ has been given in various reports, but this was often based on small samples of data, and little of this information been formally published. Davis et al. (1982) developed preliminary estimates of $g_a(0)$ and $g_d(0)$ for aerial surveys of bowheads summering in the Canadian Beaufort Sea, and applied these factors to the results of strip-transect surveys conducted during the summer of 1981. Moore and Clarke (1991) applied those factors to additional strip-survey data from the Canadian and Alaskan Beaufort Sea during late summer in 1982–84. These studies did not allow for the fall-off in sightability with increasing lateral distance other than by limiting transect width to a 1-km strip on either side of the aircraft.

As part of a study to determine the importance of the eastern Alaskan Beaufort Sea to bowhead whales during late summer and autumn, we needed to estimate numbers of bowheads present at various times from 1979 to 2000 (see Chapter 9). We needed to use aerial survey data collected from different types of survey aircraft flying at different altitudes under various sea-state and ice conditions. Therefore, we needed to develop correction factors that would compensate insofar as possible for the anticipated effects of those factors, as well as detectability and availability bias, on numbers of bowhead whales seen.

In this chapter, we use combined results from our studies of bowhead whales in the eastern Alaskan Beaufort Sea during September and early October of 1985–86 and 1998–2000, plus other aerial survey and behavioral studies of bowheads, to derive the necessary correction factors and to evaluate some of the factors influencing them. ***(1)*** To determine how sightability of bowheads in the Beaufort Sea varies with lateral distance from the survey aircraft and to estimate *f*(0), we analyzed the lateral distances recorded during eight different single- or multi-year aerial survey projects conducted by ourselves and others in the Alaskan and Canadian Beaufort Sea from 1979 to 2000. We subdivided the data by aircraft type and altitude, wave height, and ice cover to determine how *f*(0) is affected by those factors. The DISTANCE program (Thomas 1999) was used to calculate *f*(0). ***(2)*** Detection (= perception) bias, $g_d(0)$, was estimated using data from the "independent double observer" method as applied by Davis et al. (1982) and during the 1985–86 and 1998–2000 phases of the present study of bowhead feeding. ***(3)*** Availability bias, $g_a(0)$, was determined from observations of the surfacing and dive cycles of bowheads in and near the eastern Alaskan Beaufort Sea during late summer–early autumn of five years (Chapter 13). The resulting correction factors have been applied to the raw aerial survey data from the eastern Alaskan study area in order to estimate the densities and numbers of bowheads present at various times during August–October (see Chapter 9, Distribution and Numbers).

Procedures for analysis of line-transect data, including compensation for availability and detection bias, have been the subject of much recent and ongoing work (e.g., Quang and Becker 1996; Borchers et al. 1998; Garner et al. [eds.] 1999). More elaborate approaches are being developed to take account of some of the biases and confounding influences that are not fully dealt with in the relatively straightforward "classical" approaches applied here. The present work should be treated as a first step toward developing an ability to estimate numbers of bowhead whales present based on aerial surveys.

Methods

Data Sources

We used data from eight studies on bowhead whales in the Beaufort Sea during the summer and autumn (Table 15.1). • All eight studies provided sighting data from systematic aerial surveys, suitable for calculating *f*(0) for various aircraft types, survey altitudes, sea states, and ice conditions. • Three of the studies used independent double observers during at least some of the surveys, and thus provided data suitable for calculating detectability bias, $g_d(0)$. • Observed durations of surfacings and dives during three behavioral studies were used to calculate availability bias, $g_a(0)$. Six of the eight studies were mainly or entirely in the Alaskan Beaufort Sea at various times during August–October (Table 15.1). Two studies were in the Canadian Beaufort Sea during July–September.

Field Procedures

Systematic Aerial Surveys*.—**Three types of aircraft were used for most surveys. ***(1) A Twin Commander 680FL aircraft was used for the majority of the 1993 ARCO surveys, all 1996–98 BP and WesternGeco surveys, and the 1998–2000 feeding study. (Some 1993 ARCO surveys used a Twin Commander 500.) There were usually 3–4 observers, with bubble windows for at least the two observers seated behind the pilot and co-pilot. A third observer sat in the co-pilot's seat during the 1996–98 and 1998–2000 projects; that observer had a bubble window in 1996–98. ***(2)*** The 1980–85 and some 1986–87 surveys for MMS (Ljungblad et al. 1986; Moore et al. 1989) were conducted from a TurboGoose aircraft with two observers seated beside large flat windows behind the pilot and co-pilot. A third observer was seated either in the co-pilot's seat or a rear seat, both with flat windows. ***(3)*** All other systematic aerial surveys were conducted from Twin Otter aircraft with varying seating and window arrangements. Many surveys from Twin Otters had an observer in the co-pilot's seat (with flat side window) plus observers behind the cockpit on either the left side or both sides of the aircraft (usually with small or large bubble windows). During the 1997–2000 MMS surveys, the two primary observers were behind the pilot and co-pilot, beside large bubble windows.

TABLE 15.1. Sources of data used to calculate correction factors $f(0)$, $g_a(0)$, and $g_d(0)$ for aerial surveys of bowhead whales in the Beaufort Sea during summer and autumn.

Projects	Season*	Part of Beaufort Sea	Data Used For Correction Factors $f(0)$	$g_a(0)$	$g_d(0)$
1979-2000 Aerial Surveys for or by MMS (Moore et al. 1989; Treacy 2002)	Autumn	Alaskan	X	-	-
1981 Aerial Surveys for SOHIO [now BP] (Davis et al. 1982)	Summer	Canadian	X	-	X
1985 Aerial Surveys during Reproduction Study for Standard Alaska et al. (Davis et al. 1986)	Summer	Canadian	X	-	-
1985-86 Feeding Study for MMS (Richardson et al. 1987)	Autumn	E. Alaskan	X	X	X
1986 Aerial Surveys & Behavior Study for SWEPI (Evans et al. 1987)	Autumn	Alaskan	X	X	-
1993 Aerial Surveys for ARCO (Hall et al. 1994)	Autumn	Alaskan	X	-	-
1996-98 Aerial Surveys for BP & WesternGeco (Miller et al. 1999)	Autumn	Cent. Alaskan	X	-	-
1998-2000 Feeding Study for MMS (Current study)	Autumn	Alaskan	X	X	X

* "Autumn" studies included work in early-mid September and in some cases August.

Overall, all surveys used two primary observers on the left and right sides, and a third observer was usually present on the right side. The left-side observer and at least one right-side observer had bubble windows during most projects except for the 1980–87 surveys from a TurboGoose and a minority (22%) of the 1981 SOHIO surveys. None of the surveys used an observer looking directly downward through a nose bubble or ventral window. However, some coverage of the trackline was obtained during most projects by an observer in the co-pilot's seat and/or downward observations through lateral bubble windows.

Information about survey conditions recorded during all surveys included Beaufort wind force (Bf) or sea state, an evaluation of general visibility, and ice cover. For each bowhead sighting, the position, time, number of whales, presence of calves, apparent whale activity, heading, estimated speed, and lateral distance from the flight line were recorded. Lateral distances were determined using Suunto inclinometers when the whale's position was 90º to the left or right of the flight track, in conjunction with aircraft altitude determined by radar or pressure altimeter.

Survey procedures and conditions varied considerably. Survey altitudes varied from 200 ft (61 m) to 5000 ft (1524 m), although only 0.6% of the surveys were above 2000 ft and most (74%) systematic surveys were at 500 ft to 1500 ft (152–457 m). Ice cover varied from 0% to 99%. Beaufort wind-force (Bf) varied from 0 (calm) to 8 (gale), though surveys usually were terminated soon when Bf exceeded 5–6. All "sea state" values in this paper are based on the Bf scale, which differs from the "sea state" (SS) scale that is often used (see Greene 1995:89 and Table 15.5, later). When the SS scale was used during the original surveys, SS values were converted to Bf values for this analysis. Visibility varied from excellent to impossible during the surveys. For this analysis, we excluded data collected when visibility was recorded as "seriously impaired" or <1km.

***Independent Double Observer Surveys*.—**During systematic surveys for SOHIO in 1981 (Davis et al. 1982) and for the two feeding studies in 1985–86 and 1998–2000, there were two right-side observers who (at least some of the time) observed independently and did not announce their sightings to other observers. The two right-side observers were separated by a bulkhead (1981 and 1985–86 — Twin Otter) or visual screen (1998–2000 — Twin Commander). This visual obstruction prevented the right-side observers from seeing one another. When a bowhead was seen on the right side of the aircraft during these projects, it was not possible to circle to obtain more detailed observations because this would have required notifying the other right-side observer that a bowhead had been seen. However, when a bowhead was seen on the left side, the sighting was announced and the aircraft circled if necessary to document whale activity or other sighting details. Left-side data were not used in double independent observer calculations.

***Behavioral Observations*.—**Durations of surfacings and dives by bowhead whales engaged in feeding, traveling, socializing, and other activities were determined using the systematic aerial observation procedures of Würsig et al. (1984) and Richardson et al. (1995). We considered only the data collected in the eastern Alaskan Beaufort Sea and nearby Canadian waters during September and early October of 1985–86 and 1998–2000 (Table 15.1). Aircraft altitude was 1500 ft (457 m) during most behavioral observation sessions considered here, but occasionally 2000 ft (610 m). Procedures and data are described in Chapter 13.

Analysis Methods

***Lateral Distance Factor, f*(0).—**The number of bowhead sightings in various lateral distance categories, and associated *f*(0) values, were determined based on the systematic aerial survey data from eight studies (Table 15.1). This was done separately for the three different types of aircraft, and for various categories of altitude, Bf, and ice cover. • *Types of aircraft:* The data were first divided into those collected from a Twin Otter, Twin Commander, and TurboGoose. • *Aircraft altitude:* Data were further subdivided into three aircraft altitude categories, <900 ft, 900–1500 ft, and >1500 ft (i.e., <274, 274–457, and >457 m). • *Sea conditions (Bf)* and *ice cover:* Sea conditions were broken down into five categories, Bf states 0–1, 2, 3, 4, and 5–6. Ice cover was categorized as 0% and 25–99% ice cover. Sightings with ice cover 1–24% were too infrequent for analysis.

For each subdivision of the data, the probability density function and *f*(0) associated with the observed distribution of lateral distances were calculated with the program DISTANCE (Thomas 1999, version 3.5, release 5). Models considered were half-normal (with hermite polynomial and cosine series expansions), hazard rate (cosine and simple polynomial), and uniform (cosine and simple polynomial). The final model was selected based on minimizing Akaike's Information Criterion (AIC; Akaike 1973). Left truncation distances were selected so as to exclude the zone below the aircraft where sightability was reduced; the width of this zone depended on altitude and aircraft type (see Results). *f*(0) was calculated both with and without right truncation. Right truncation distances were determined based on a detection probability of 15% relative to that at the optimum lateral distance, as recommended by Buckland et al. (1993).

***Availability Bias, g_a(0).*—**This correction factor takes into account the effects of surfacing and dive behavior on the probability that an animal on or near the trackline will be at the surface while the surveyors are close enough to have a chance of detecting the animal. We computed this correction factor using behavioral data from whales engaged in various activities (traveling, feeding, socializing) in the eastern Alaskan Beaufort Sea during late summer and autumn. We excluded data collected when bowheads may have been disturbed by an aircraft flying at <457 m altitude, or by industrial activities. Calves were excluded because their dive profiles are quite different, and because calves are usually detected after the observer's attention has been attracted by sighting the mother. Calves were recognized by their size, light color, morphology, behavior, and close association with an adult.

Standard Formulation: If all surfacings are of duration s, all dives are of duration u, and the duration of potential detectability as the aircraft travels past the whale location is t, the probability that a whale will be at the surface while it can be seen is

$$g_{\mathrm{a}}(0) = \frac{s}{s+u} + \frac{t}{s+u} = \frac{s+t}{s+u}$$

(Eberhardt 1978). Here, $s/(s+u)$ is the probability that the whale will be at the surface when its location first comes into visual range, and $t/(s+u)$ is the probability that the whale will surface while its location is in visual range.

We calculated t for Twin Commander surveys at 300 m a.s.l. based on the estimated along-transect visual field ~1.25 km to the side of the trackline, and on a sample of actual aircraft ground speeds during 1998–99. To determine the latter, we randomly selected 16 transects (northbound and southbound) from the 1998 survey, and 16 more from 1999. Aircraft ground speed extracted at 1-min intervals (n = 602) was determined from GPS data logged during the flights. For each of the 602 aircraft speed values (in km/s), we calculated t by dividing the approximate view field (1.25 km) by the speed. We then used the mean of all t values (21.6 s) in the formula for $g_a(0)$, and its s.d. (± 1.72 s) in the associated variance formula (below). The uncorrected estimate of the number of animals present can be divided by the correction factor $(s+t)/(s+u)$ to allow for animals that are undetectable because they are below the water as the survey aircraft passes.

The variance of the above standard formulation for $g_a(0)$ was calculated using the delta method (Taylor series expansion) because it is a function of three random variables, s, t and u (B.F.J. Manly, pers. comm.).[2] Thus,

$$\operatorname{var} g_a(0) = \left[{(u-t)^2}\Big/{(s+u)^4} \right] \operatorname{var}(s) + \left[{1}\Big/{(s+u)^2} \right] \operatorname{var}(t) + \left[{(s+t)^2}\Big/{(s+u)^4} \right] \operatorname{var}(u)$$

Allowance for Short Dives: The standard formula for $g_a(0)$ assumes that $t \le u$ and that s and u are constants. In fact, some dives are very short ($u<t$), and s and u are both highly variable (Chapter 13; see also Richardson et al. 1995). Eberhardt (1978) expressed concern about the legitimacy of the $(s+t)$ / $(s+u)$ formula under these conditions. Because $(s+t)$ / $(s+u)$ is an estimate of the probability that an animal will be at the surface for at least part of "observation window" of duration t, the value cannot logically exceed 1.0. In the case of the "$u < t$" category of dive durations, $(s+t)$ / $(s+u) > 1.0$.

Davis et al. (1982) evaluated this and developed a version of the $(s+t)$ / $(s+u)$ formula that allows for some dives of short duration ($u < t$). They computed the probability of detection (s_c+t) / (s_c+u_c) separately for various categories of dive duration. Within each category c, the mean surface and dive times were used to estimate s_c and u_c. Before proceeding, the probability of detection for the "$u < t$" category, was reduced to 1.0 — the maximum potential value. Then the weighted average value of $(s+t)$ / $(s+u)$ was calculated. The weighting factor for each category of dive durations was the total duration of all surfacings and dives in that category. The weighted mean value of (s_c+t) / (s_c+u_c) for all $u > t$ is identical regardless of the number of categories of dive durations that are chosen, and regardless of the particular choice of category boundaries. Thus, the corrected value of $(s+t)$ / $(s+u)$ can be obtained most simply

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[2] We thank Dr. Bryan Manly, Western EcoSystems Technology Inc., Cheyenne, WY, for deriving this formula.

by dividing the paired surface and dive time data into only two categories: (1) n_1 pairs with $u \leq t$, and (2) n_2 pairs with $u > t$. The corrected mean probability of detection is then

$$A = \sum_{i=1}^{n_2}\left(s_{2i} + u_{2i}\right) \text{ x } \frac{\left(\sum_{i=1}^{n_2} s_{2i}\right) \big/ n_2 + t}{\left(\sum_{i=1}^{n_2} s_{2i}\right) \big/ n_2 + \left(\sum_{i=1}^{n_2} u_{2i}\right) \big/ n_2}$$

$$g_a(0) = \frac{\left[\sum_{i=1}^{n_1}\left(s_{1i} + u_{1i}\right) x 1.0\right] + A}{\sum_{c=1}^{2}\sum_{i=1}^{n_c}\left(s_{ci} + u_{ci}\right)}$$

Examples of this calculation are shown in the Results (see Table 15.3, later). If any dive times have duration < t, then the corrected value will be less than the biased conventional $(s+t)$ / $(s+u)$ value based on overall mean surface and dive times. If all $u \geq t$, then the conventional and corrected values will be the same.

Detectability Bias, $g_d(0)$.—This factor for whales at the surface but not detected was calculated from sighting data collected when two right-side observers observed independently (Magnusson et al. 1978). This method is mathematically equivalent to a mark–recapture analysis. Two key assumptions are as follows: (1) There is no communication between observers, so sightings by the two individuals are independent. (2) Each whale or group is individually recognizable to the extent that one can determine unequivocally whether each whale or group seen by one observer was also seen by the other. Both assumptions were met in the three studies whose data were used (Table 15.1). This calculation is based on the number of whale groups sighted by only one observer vs. the number seen by both observers (see "Results").

Results

Lateral Distance Factor f(0)

Altitude Effects.—The zone directly below an aircraft where sightability is reduced varies in width depending on aircraft altitude. The higher the altitude, the wider the zone. We divided aircraft altitudes into three categories: (1) <900 ft, (2) 900–1500 ft, and (3) >1500 ft (i.e., <274, 274–457, and >457 m). For Twin Otter aircraft, detection probability was apparently reduced within lateral distances 150 m, 300 m, and ~600 m (respectively) on either side of the aircraft (Fig. 15.1). During calculation of $f(0)$, sightings within these distances of the trackline were excluded and lateral distances were measured relative to the left truncation distances thus defined.

Aircraft Type Effect.—The width of the strip directly below the aircraft where sightability is reduced varied among aircraft types. For Twin Otter surveys at altitudes of 900–1500 ft, the left truncation point is 300 m on either side of the plane; i.e., a 600 m strip directly below the aircraft is excluded from line-transect calculations (Fig. 15.1B). With the Twin Commander at the same altitude, reduced

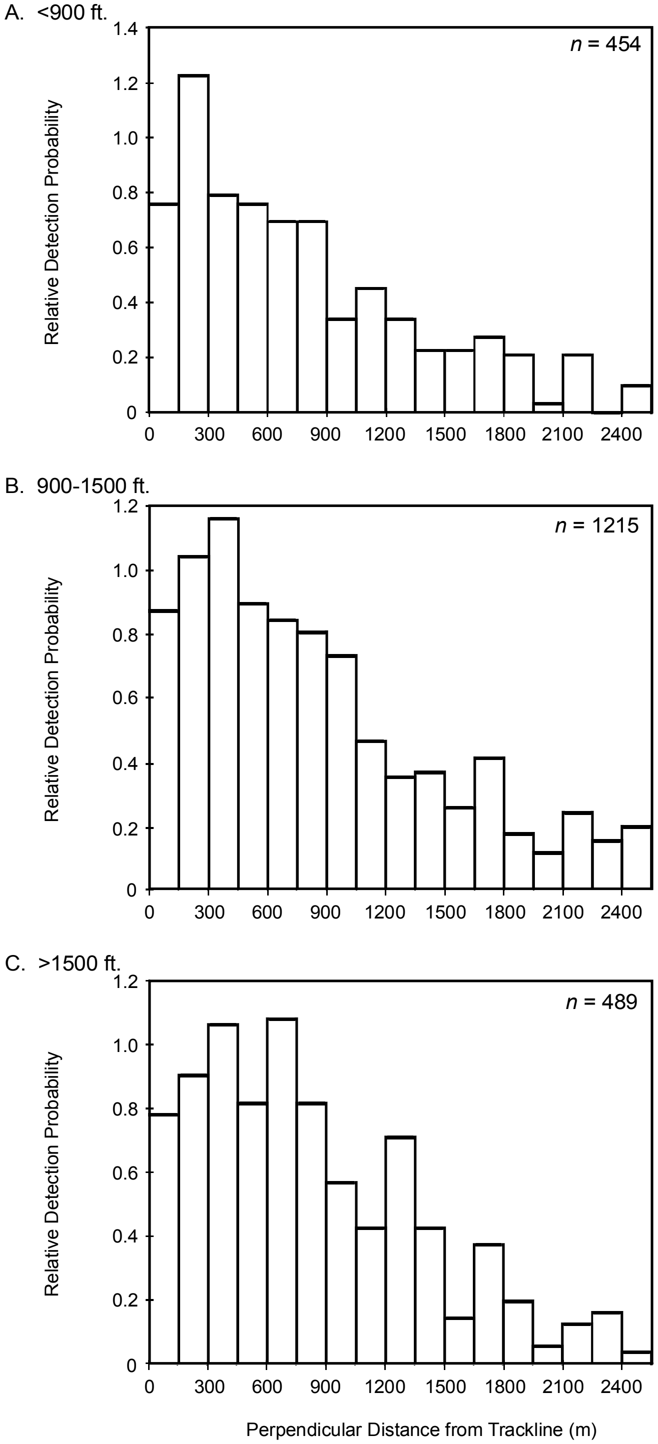


FIGURE 15.1. Aircraft altitude vs. relative detection probability at various perpendicular distances for bowhead whale sightings from Twin Otter aircraft flying at altitudes ***(A)*** <900 ft, i.e. <274 m; ***(B)*** 900–1500 ft, i.e. 274–457 m; and ***(C)*** >1500 ft, i.e. >457 m. *n* = number of sightings.

sightability extended to ~450 m on either side of the plane, requiring that a 900 m strip below the aircraft be excluded (Fig. 15.2A). For the TurboGoose, detectability was marginally less at 300–450 than at 450–600 m (Fig. 15.2B), i.e., intermediate as compared with the other two aircraft. We have set the left truncation distance at 300 m for the TurboGoose.

Bf ("Sea State") Effects.—Sighting data were classified into five Beaufort (Bf) categories. For this analysis, we consider (separately) sightings from the Twin Otter and Twin Commander aircraft flying at altitudes 900–1500 ft. These were the two aircraft type/altitude categories with sufficient sample size for meaningful analysis. The left truncation distance (L_{trun}) was set as 300 m for the Twin Otter and 450 m for the Twin Commander (as above).

Twin Otter: For Bf 0 to 1, the *f*(0) factor is 3.72 based on all sightings beyond L_{trun} = 300 m, or 2.61 after the additional exclusion of sightings >2700 m from the trackline, i.e., >2400 m laterally ("right") from L_{trun} (Fig. 15.3A; Table 15.2). This right truncation distance (R_{trun}) is the lateral distance where detection probability diminished to 15% of that at L_{trun}. R_{trun} distances quoted below are measured relative to L_{trun}.

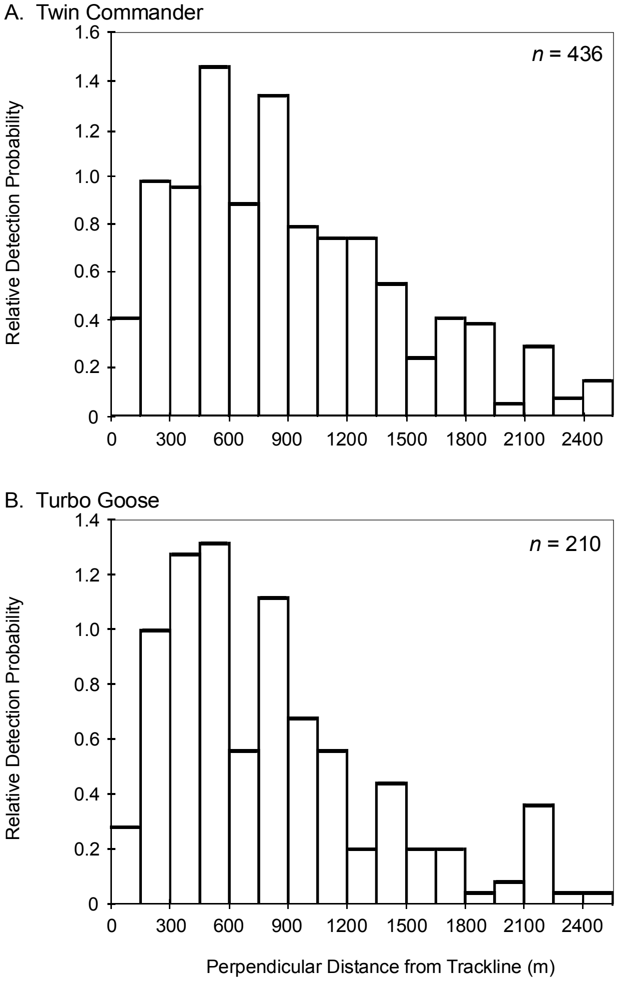


FIGURE 15.2. Aircraft type vs. relative detection probability at various perpendicular distances for bowhead whale sightings from ***(A)*** Twin Commander and ***(B)*** TurboGoose aircraft flying at altitudes 900–1500 ft, i.e. 274–457 m. See Figure 15.1B for corresponding Twin Otter data. *n* = number of sightings.

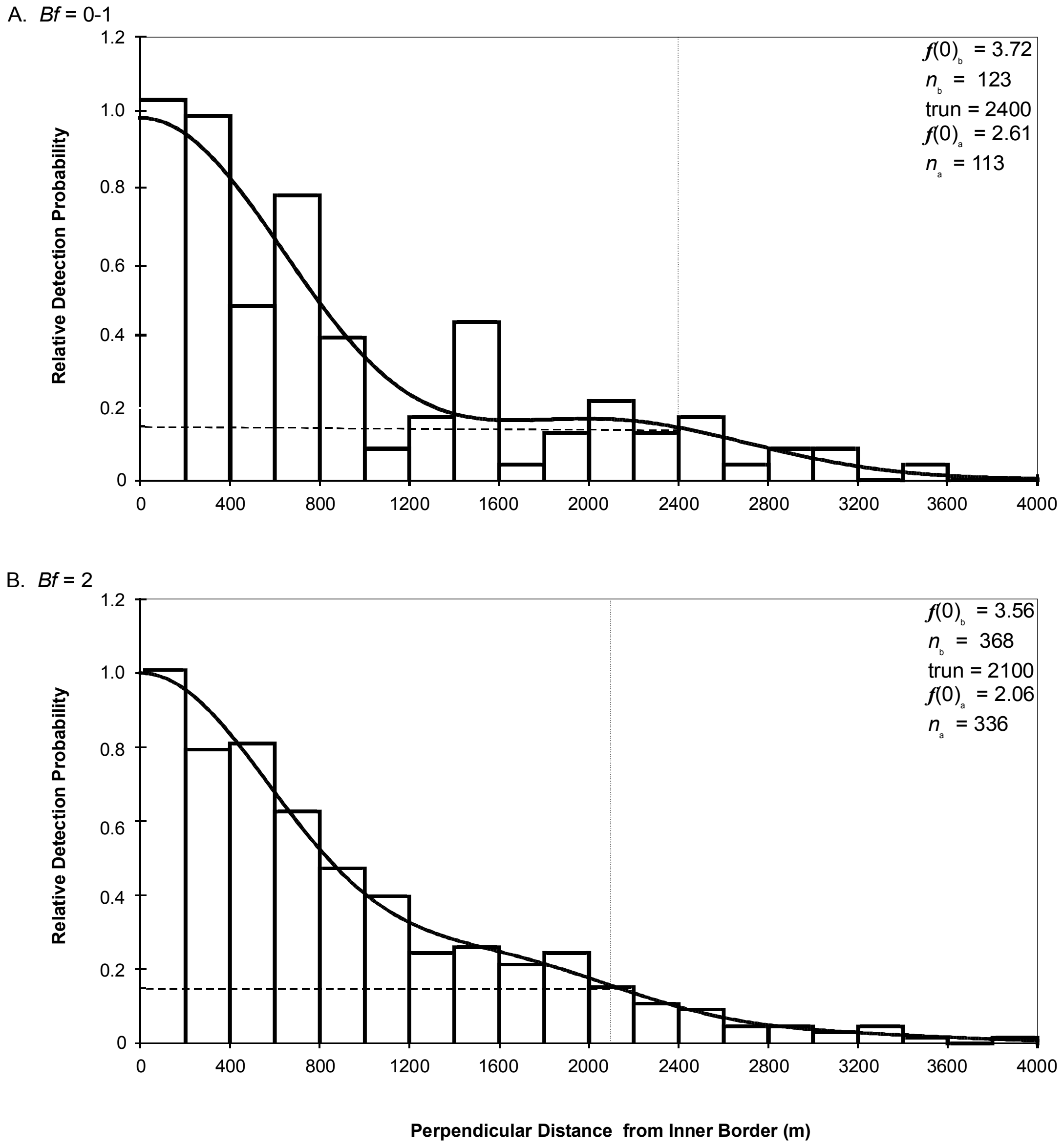
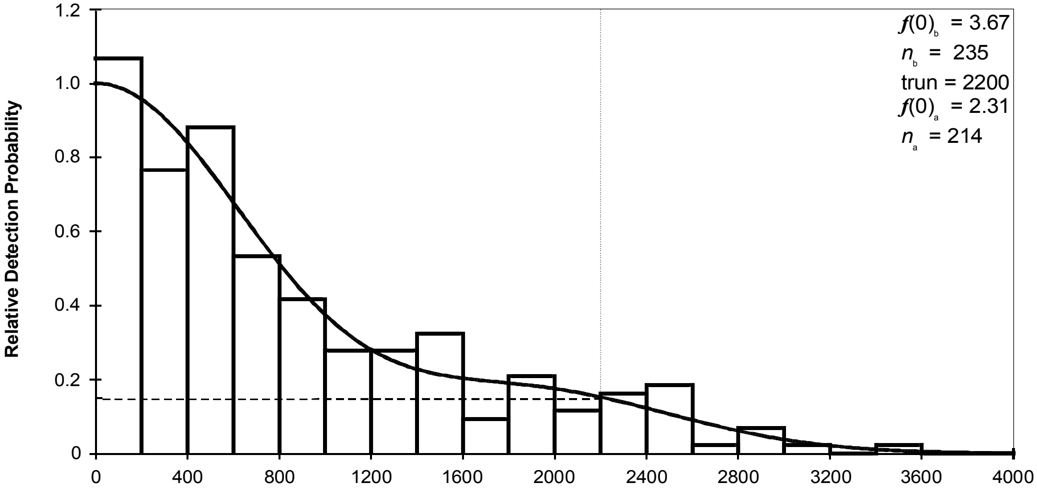
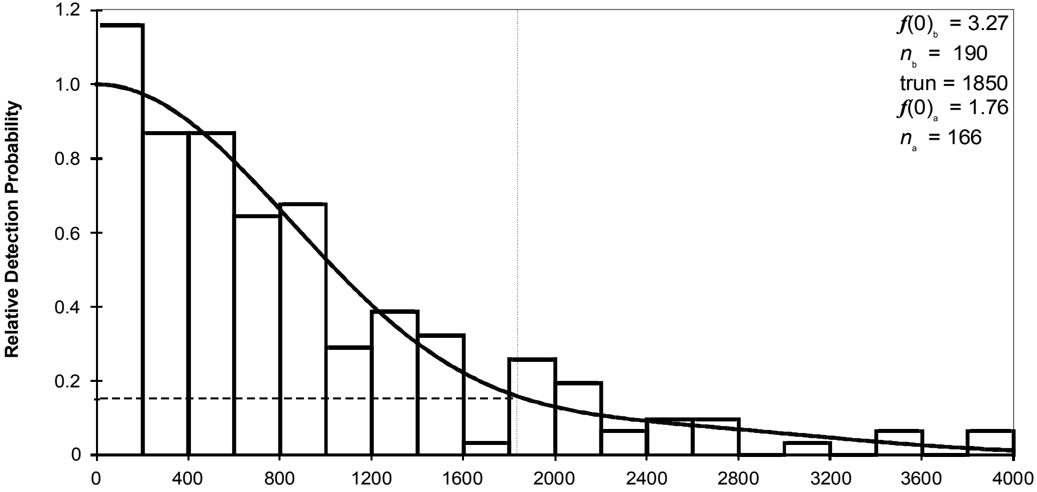


FIGURE 15.3. Beaufort sea state (Bf) vs. relative detection probability at various perpendicular distances from inner border of transect (L_{trun} = 300 m from trackline) for bowheads observed from **Twin Otter** aircraft flying at altitudes 900–1500 ft (274–457 m). ***(A)*** Bf 0 and 1, ***(B)*** Bf 2, ***(C)*** Bf 3, ***(D)*** Bf 4, and ***(E)*** Bf 5 and 6. $f(0)_b$ and n_b apply to all sightings beyond inner border. trun = right truncation distance (in meters) relative to inner border, based on relative detection probability of 0.15 (dashed line). $f(0)_a$ and n_a apply to sightings between inner border and trun. $f(0)$ factors are calculated from a half-normal key model with cosine adjustment terms.

C. *Bf* = 3



D. *Bf* = 4



E. *Bf* = 5-6

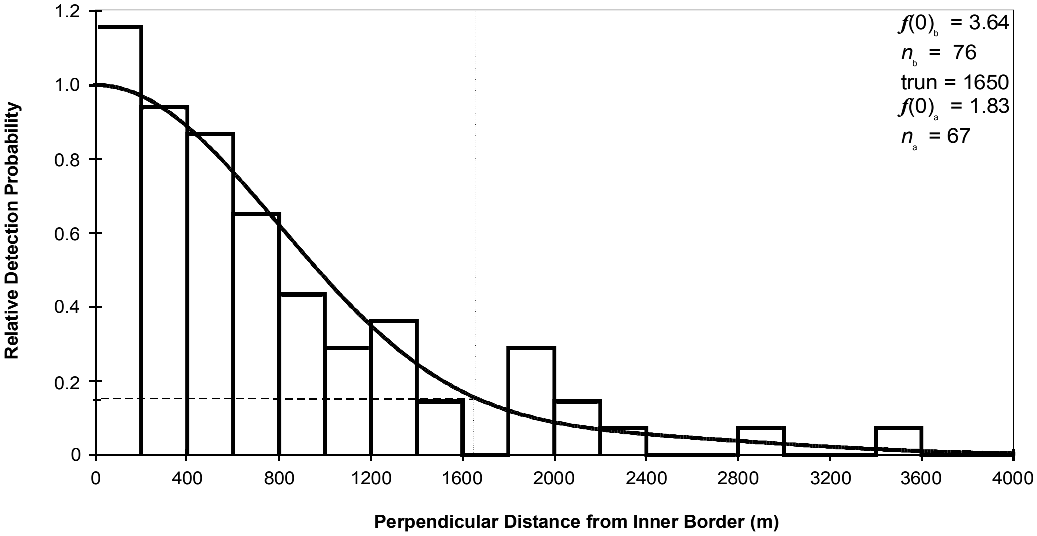


FIGURE 15.3. Continued.

TABLE 15.2. Truncation distance and estimated values of $f(0)$ for combinations of aircraft type, altitude, Beaufort sea state, and ice cover. $f(0)$ values are given before and after right truncation. All curves were fitted with a half-normal cosine model.

					Right Trun. (m) rel. to		Before R-trun		After R-trun	
ID[a]	Altitude (ft)	Bf Sea State	Ice	Left Trun. (m)	Track-line	Left Trun.	$f(0)$	No. of Sightings	$f(0)$	No. of Sightings
Twin Otter										
1	900-1500	0-1	0-99%	300	2700	2400	3.72	123	2.61	113
2	900-1500	2	0-95%	300	2400	2100	3.56	368	2.06	336
3	900-1500	3	0-95%	300	2500	2200	3.67	235	2.31	214
4	900-1500	4	0-50%	300	2150	1850	3.27	190	1.76	166
5	900-1500	5-6	0-10%	300	1950	1650	3.64	76	1.83	67
6	900-1500	0-4	0%	300	2400	2100	3.35	702	2.07	631
7	900-1500	0-4	0-25%	300	2700	2400	4.11	770	2.24	707
8	900-1500	0-4	25-99%	300	1250	950	5.61	93	1.61	73
9	>1500	0-4	0-25%	600	3000	2400	4.91	299	2.58	263
Twin Commander										
10	<900	0-4	0-5%	150	2550	2400	5.73	116	2.38	104
11	900-1500	0-1	0-5%	450	3250	2800	2.55	95	2.11	89
12	900-1500	2	0-5%	450	2050	1600	3.51	82	1.61	71
13	900-1500	3	0-5%	450	2150	1700	3.56	70	1.74	62
14	900-1500	4	0-5%	450	1875	1425	4.26	77	2.28	70
15	900-1500	5-6	0-5%	450	1350	900	6.88	26	1.28	26
16	900-1500	0-4	0-5%	450	2850	2400	6.34	287	2.4	265
Turbo Goose										
17	<900	0-4	25-99%	150	1100	950	2.89	38	2.57	33
18	900-1500	0-4	0-25%	300	2700	2400	3.38	109	2.23	88
19	900-1500	0-4	25-99%	300	1250	950	5.48	84	1.67	64

[a] ID is a reference number for cross-reference to Chapter 9.

Figure 15.3 and Table 15.2 show the results for the Twin Otter flying at altitude 900–1500 ft with various Bf values. The overall $f(0)$ values derived without right truncation did not change much as Bf increased (range 3.27–3.72). As expected, the lateral distances at which detectability had diminished to 15% of the maximum tended to decrease as Bf sea states increased, from R_{trun} = 2400 m at Bf 0–1 to 1650 m at Bf 5–6 (i.e., from 2700 m to 1950 m from trackline). The $f(0)$ values derived after allowing for the variable R_{trun} tended to diminish with increasing Bf, from 2.61 at Bf 0–1 to 1.76–1.83 at Bf 4–6.

Twin Commander: For Bf 0 to 1, the $f(0)$ factor is 2.55 based on all sightings beyond L_{trun} = 450 m, or 2.11 after excluding sightings >2800 m from L_{trun} (i.e., 3250 m from the trackline; Fig. 15.4A; Table 15.2). The overall $f(0)$ values derived without right truncation increased progressively as Bf increased, from 2.55 at Bf 0–1 to 6.88 at Bf 5–6. The lateral distances at which detectability had diminished to 15% of the maximum decreased markedly as Bf sea states increased, from R_{trun} = 2800 m at Bf 0–1 to just 900 m at Bf 5–6 (i.e., 3250 m to 1350 m from trackline). These results indicate that observers had much reduced ability to sight bowheads at long lateral distances when Bf sea states increased from 0 to 6. The $f(0)$ values derived after allowing for the strong trend in R_{trun} were variable but did not form a steady progression.

Ice Cover Effects.—Ice cover was stratified into two categories, 0% and 25–99%, and limited to Bf sea states 0–4. Sightings from areas with 1–24% ice cover were not used due to low sample sizes. The analysis was based on sightings from a Twin Otter flying at altitudes 900–1500 ft, for which L_{trun} was 300 m. In this situation, ice cover had a substantial effect on R_{trun} and $f(0)$ (Fig. 15.5; Table 15.2). When all sightings beyond L_{trun} were considered, $f(0)$ increased from 3.35 with no ice to 5.61 with 25–99% ice. The lateral distance at which detectability diminished to 15% of maximum (R_{trun}) was much higher with no ice than with 25–99% ice (2100 vs. 950 m; i.e., 2400 vs. 1250 m from trackline). After allowing for the large difference in R_{trun}, $f(0)$ was higher with no ice than with 25–99% ice (2.07 vs. 1.61). Very similar trends were evident for the TurboGoose flying at 900–1500 ft altitude over 0–25% ice vs. 25–99% ice (Table 15.2). These results show that observers had reduced ability to sight bowheads at long lateral distances when substantial ice was present.

Availability Bias Factor $g_a(0)$

Behavioral observations from three studies in the central Beaufort Sea during September–October (Table 15.1) provided information about the durations of 440 surfacings and 182 dives by "presumably undisturbed" bowheads, excluding calves. The data for whales engaged in a variety of activities were examined to determine how surfacing–dive profiles, proportion of time near the surface, and the "availability" correction factor $g_a(0)$ vary with whale activity (Table 15.3). Availability factors were calculated without and with the adjustment to allow for short dives (see Methods). Feeding is the most common activity in the eastern Alaskan Beaufort Sea during the autumn (Chapter 12). The probability that a typical feeding whale near the trackline will be at the surface while that location is visible to an aerial surveyor is about 0.153. Traveling is the second most common activity and the corresponding probability for traveling whales is about 0.125. The availability factor was lower for traveling whales than for any other whale activity that we examined. Socializing whales, with $g_a(0) = 0.234$, were about twice as likely to be sighted as compared with traveling whales (Table 15.3).

During aerial surveys, observers frequently do not have the whales in view for sufficient time to determine the whale activity. Therefore an overall $g_a(0)$ is needed that combines the data from all activities. The overall $g_a(0)$ value calculated with the adjustment for short dives was 0.144 (Table 15.3E). This overall factor was used to estimate the number of whales in the eastern Alaskan study area on dates when systematic aerial surveys were done (Chapter 9). The corresponding overall $g_a(0)$ value calculated in the conventional manner without the adjustment for short dives (see Methods) was 0.148 ± s.e. 0.113.

Detectability Bias Factor $g_d(0)$

Besides missing submerged bowheads, aerial surveyors fail to detect some of the bowheads that are at the surface close to the trackline as the aircraft passes. To estimate the proportion detected, two surveyors observed independently from the right side of the aircraft during three studies (Table 15.1). Based on the lateral distance distributions shown earlier, we considered the sightings at lateral distances 300–700 m from a Twin Otter and 450–850 m from a Twin Commander (i.e., 0–400 m from the inner truncation distance) when survey altitude was 900–1500 ft. This is the survey band where the detection probability for whales at the surface is assumed to be near 1.0 during calculation of $f(0)$. Beaufort states at times when these double independent surveys were done ranged from 0 to 6 with a median of 3.

There were 32 sightings of bowheads 0–400 m from the inner boundary of the transect by right-side observers during these double independent observer surveys. Of these, 13 bowheads were seen by both observers ($B = 13$), 12 by only the front observer ($S_1 = 12$), and 7 by only the rear observer ($S_2 = 7$).

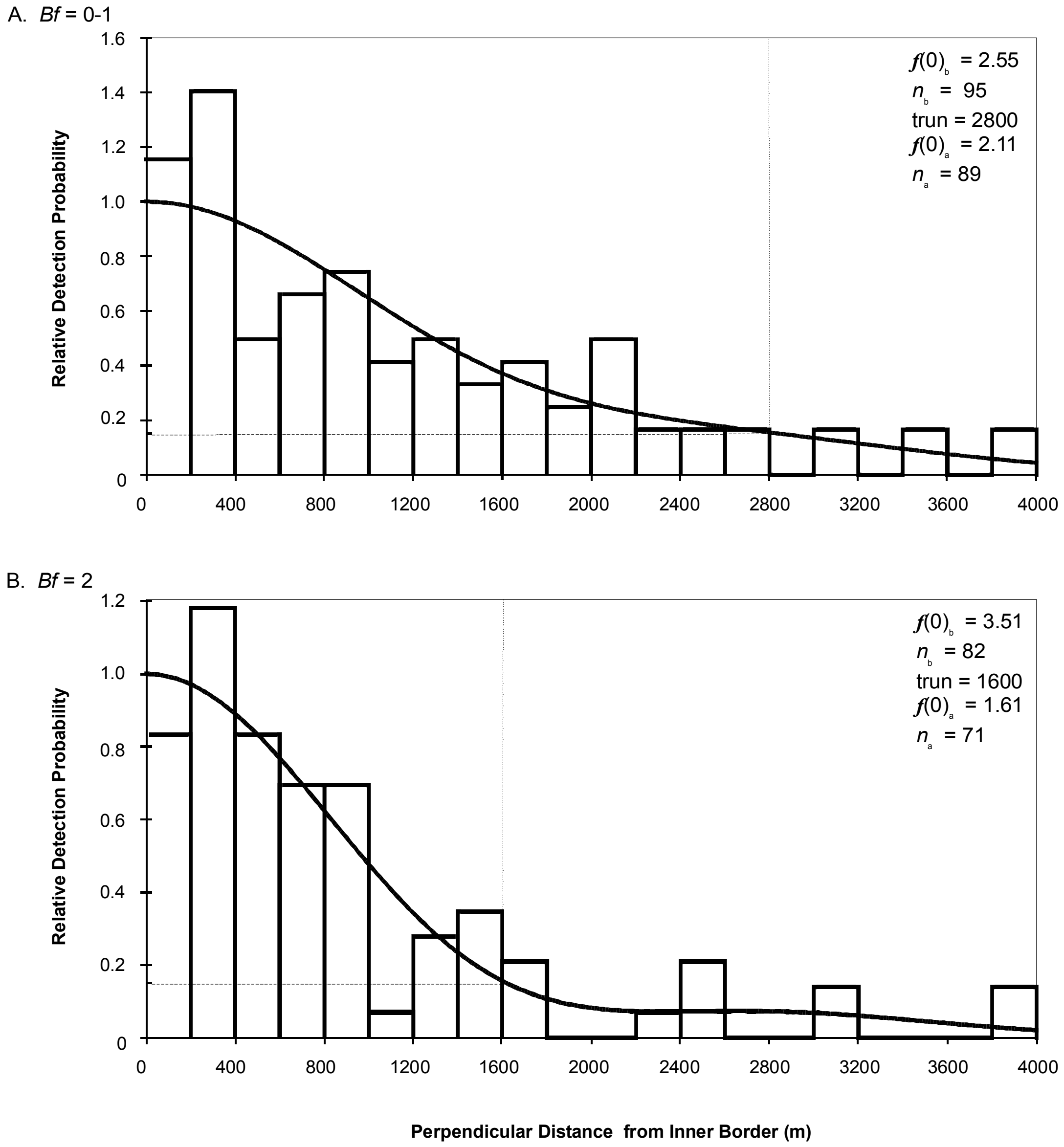


FIGURE 15.4. Beaufort sea state vs. relative detection probability at various perpendicular distances from inner border of transect (L_{trun} = 450 m from trackline) for bowheads observed from **Twin Commander** aircraft flying at altitudes 900–1500 ft (274–457 m). Otherwise as in Figure 15.3.

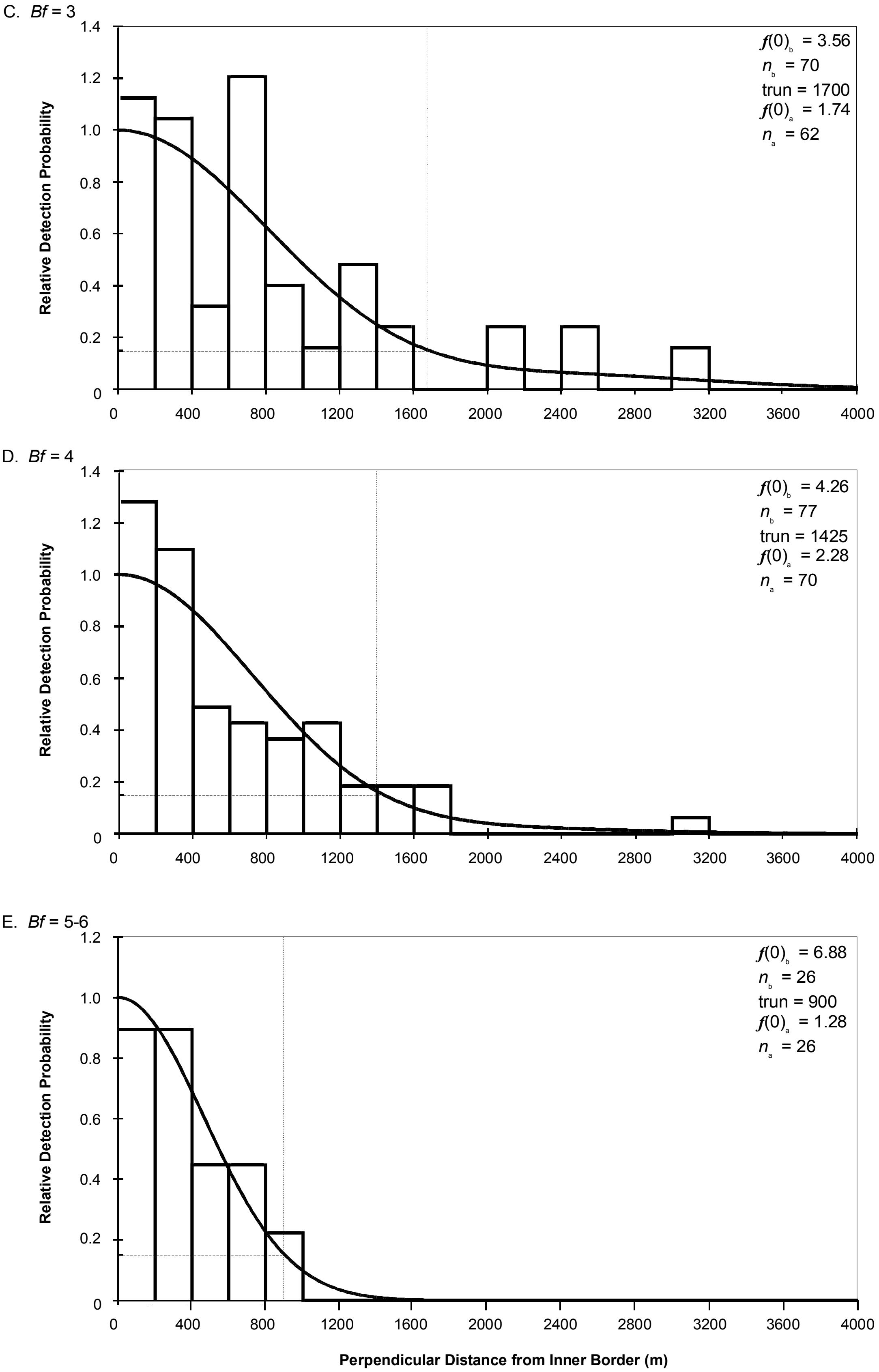


FIGURE 15.4. Continued

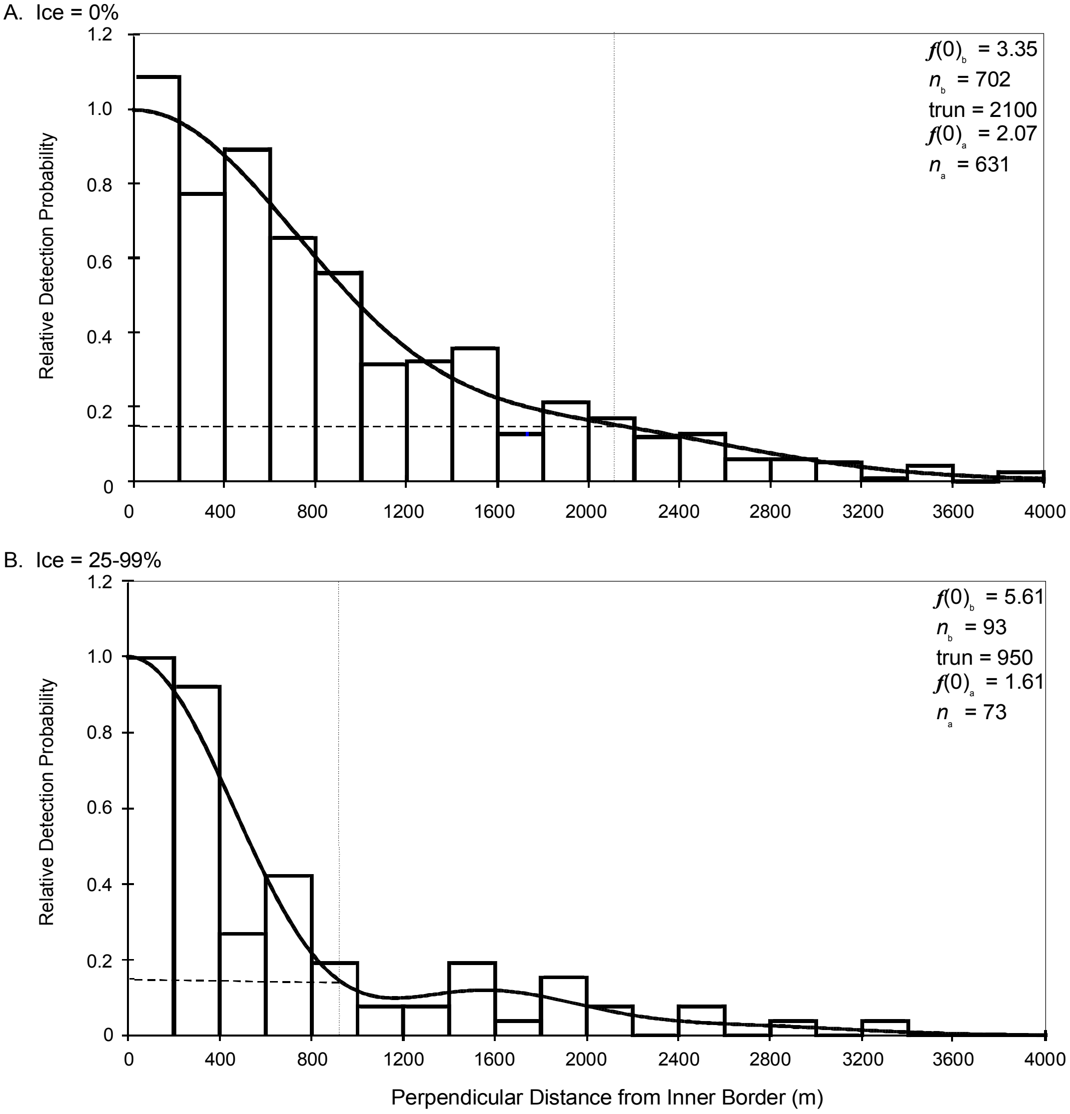


FIGURE 15.5. Ice cover vs. relative detection probability at various perpendicular distances from inner border of transect (L_{trun} = 300 m from trackline) for bowheads observed from a Twin Otter aircraft flying at altitudes 900–1500 ft (274–457 m). ***(A)*** Ice cover 0%, and ***(B)*** ice cover 25–99%. Otherwise as in Figure 15.3.

Table 15.3. Calculation of the probability that an average bowhead whale near the trackline will be at the surface while within an aerial surveyor's field of view, $g_a(0)$. All times are in seconds. Based on behavioral observations of presumably undisturbed whales in and near the eastern Alaskan Beaufort Sea during September and early October, calves excluded. See "Methods" for data sources and calculation details.

Group Activity	Sum of Dive Durations	Sum of Surface Times	# Dives and Surfacings	Mean Surface Time (s)	Mean Dive Time (u)	$\frac{s+21.596}{s+u}$
A. Traveling Whales						
Dives ≤21 s	-	-	-	-	-	-
Dives >21 s	54,054	7027	65/75	93.7	831.6	0.125
All dives	54,054	7027	65/75	93.7	831.6	0.125
B. Feeding Whales						
Dives ≤21 s	90	37	7/3	12.3	12.9	-
Dives >21 s	32,647	11,986	56/154	77.8	583.0	0.150
All dives	32,737	12,023	63/157	76.6	519.6	0.165
					Corrected[a]	0.153
C. Traveling + Feeding Whales						
Dives ≤21 s	-	-	-	-	-	-
Dives >21 s	15,757	5337	20/50	106.7	787.8	0.143
All dives	15,757	5337	20/50	106.7	787.8	0.143
D. Socializing Whales						
Dives ≤21 s	34	6	2/2	3.0	17.0	-
Dives >21 s	11,258	12,240	32/156	78.5	351.8	0.233
All dives	11,292	12,246	34/158	78	332	0.242
					Corrected[a]	0.234
E. All Activities						
Dives ≤21 s	124	43	9/5	8.6	13.8	-
Dives >21 s	113,716	36,590	173/435	84.1	657.3	0.143
All dives	113,840	36,633	182/440	83.3	625.5	0.148
					Corrected[a]	0.144

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[a] See "Methods" section re procedure for calculating corrected $(s+t)/(s+u)$.

Based on the method of Magnusson et al. (1978), the estimated number of singles or groups present within the 400-m strip was

$$\hat{N} = \frac{(S_1 + B + 1)(S_2 + B + 1)}{(B + 1)} - 1 = 38.0$$

The actual number of singles or groups sighted by one or both observers was 32, or 84% of the estimated N = 38 present at the surface within the narrow strip and available for detection.

Again following Magnusson et al. (1978), the probability that a single observer would detect a bowhead or group of bowheads that is at the surface within the designated 400-m strip is as follows:

$$g_d(0) = {(S_1 + S_2 + 2B)}\Big/{2\hat{N}} = 0.592$$

Thus, if a single observer is present on one side of the aircraft, the uncorrected number of bowheads seen by that observer in the narrow strip where sightability is near-optimum should be divided by 0.592 to allow for animals present at the surface but not detected. If two observers are present on one side, their joint uncorrected count should be divided by 0.84.

The estimated variances of $\hat{N}$ and $g_d(0)$ are required when calculating the confidence limits for the estimated numbers of bowheads present. Magnusson et al. (1978) provided a formula for $\mathrm{var}(\hat{N})$, but this did not allow for the fact that S_1, S_2, and B are random variables, not constants (D.G. Chapman, pers. comm., 1982). The variances can be approximated using the delta method (Taylor series expansion) as shown in Figure 15.6. Raw counts of bowheads by a single observer on one side of the aircraft can be corrected for animals present at the surface but not seen by dividing by 0.592 ± s.e. 0.1604. The $g_d(0)$ factor was also calculated for each study separately:

	$g_d(0)$	s.e.($g_d(0)$)	Sightings
1981 Aerial Survey for SOHIO	0.731	0.2949	13
1985–86 Feeding Study	0.625	0.3574	7
1998–2000 Feeding Study	0.533	0.2425	12
All Studies	0.592	0.1604	32

These $g_d(0)$ correction factors are independent of any correction for submerged whales. As derived here, they apply only to the strip within 0–400 m of the inner truncation distance, i.e., to the strip where detection is near-optimum. The $f(0)$ factors, described earlier, account for the reduced probability of detecting a whale as its distance from the trackline increases.

When g_d was re-calculated for the strip 400–1000 m from the inner truncation distance, we found $g_d = 0.421$ ± s.e. 0.1285 ($n = 32$), confirming the reduced probability of detecting a whale as its distance from the trackline increases (Table 15.4). If a strip transect method involving a wider strip were to be used without allowance for fall-off in detectability at longer lateral distances, then a different g_d factor based on all double-independent sightings within that wider strip-width would be required. For the data-set considered here, g_d calculated for a strip 0–1000 m from the inner truncation distance was 0.505 ± s.e. 0.1018 ($n = 64$; Table 15.4).

The variance of the estimated N is approximated using the delta method (Taylor series expansion) as follows:

$$\operatorname{var}(\hat{N}) \cong \left(\frac{\partial\hat{N}}{\partial S_1}\right)^2 \operatorname{var}(S_1) + \left(\frac{\partial\hat{N}}{\partial S_2}\right)^2 \operatorname{var}(S_2) + \left(\frac{\partial\hat{N}}{\partial B}\right)^2 \operatorname{var}(B)$$

where the partial derivatives are evaluated at the mean values approximated by S_1, S_2 and B (12, 7 and 13 respectively, for the present data). Now,

$$\frac{\partial\hat{N}}{\partial S_1} = \frac{(S_2+B+1)}{(B+1)} = \frac{21}{14}$$

$$\frac{\partial\hat{N}}{\partial S_2} = \frac{(S_1+B+1)}{(B+1)} = \frac{26}{14}$$

$$\frac{\partial\hat{N}}{\partial B} = \frac{(B+1)[(S_1+B+1)+(S_2+B+1)]-(S_1+B+1)(S_2+B+1)}{(B+1)^2} = \frac{8}{14}$$

Assuming S_1, S_2 and B have approximate Poisson distributions, their variances can be assumed equal to the observed values. Thus,

$$\operatorname{var}(\hat{N}) = \left(\frac{21}{14}\right)^2 (12) + \left(\frac{26}{14}\right)^2 (7) + \left(\frac{8}{14}\right)^2 (13) = 55.3878$$

$$s.e.(\hat{N}) = \sqrt{55.3878} = 7.442$$

The variance of the detection probability $g_d(0)$ must also be calculated using the delta method because $g_d(0)$ is a function of four random variables, S_1, S_2, B and N, whose means are here estimated as 12, 7, 13 and 38. Given that

$$g_d(0) = \frac{S_1+S_2+2B}{2\hat{N}}$$

Then we have

$$\operatorname{var}(\hat{g}_d(0)) \cong \left(\frac{\partial\hat{g}_d(0)}{\partial S_1}\right)^2 \operatorname{var}(S_1) + \left(\frac{\partial\hat{g}_d(0)}{\partial S_2}\right)^2 \operatorname{var}(S_2) + \left(\frac{\partial\hat{g}_d(0)}{\partial B}\right)^2 \operatorname{var}(B) + \left(\frac{\partial\hat{g}_d(0)}{\partial\hat{N}}\right)^2 \operatorname{var}(\hat{N})$$

again evaluating the partial derivatives at the estimated mean values. Thus,

$$\frac{\partial\hat{g}_d(0)}{\partial S_1} = \frac{1}{2\hat{N}} = \frac{1}{76}$$

$$\frac{\partial\hat{g}_d(0)}{\partial S_2} = \frac{1}{2\hat{N}} = \frac{1}{76}$$

$$\frac{\partial\hat{g}_d(0)}{\partial B} = \frac{1}{\hat{N}} = \frac{1}{38}$$

$$\frac{\partial\hat{g}_d(0)}{\partial\hat{N}} = -\frac{S_1+S_2+2B}{2(\hat{N})^2} = -\frac{1}{64.18}$$

Assuming that S_1, S_2 and B have approximate Poisson distributions, and using the previous estimate of $\operatorname{var}(\hat{N}) = 55.3878$, then

$$\operatorname{var}(\hat{g}_d(0)) = \left(\frac{1}{76}\right)^2 (12) + \left(\frac{1}{76}\right)^2 (7) + \left(\frac{1}{38}\right)^2 (13) + \left(-\frac{1}{64.18}\right)^2 (55.3878) = 0.025739$$

and the corresponding standard error is $\sqrt{0.025739} = 0.1604$

FIGURE 15.6. Calculation of variance of the $g_d(0)$ factor. We are grateful to the late Dr. D.G. Chapman, Univ. of Washington, Seattle, and Dr. P.H. Peskun, York Univ., Toronto, who derived this method for Davis et al. (1982).

TABLE 15.4. Double independent observer results for various lateral distances, plus calculated values for the detectability bias factor, g_d. Strip widths are measured from the left truncation distance, which varied with aircraft type.

		Strip Width (m)		
	Parameter	0-400[a]	400-1000	0-1000
Sightings by				
Front observer only	S_1	12	14	26
Rear observer only	S_2	7	10	17
Both observers	B	13	8	21
Total sightings		32	32	64
Estimated no. groups	N	38	47.6	84.1
Single-obs. detection prob.	g_d	0.592	0.421	0.505
	s.e. g_d	0.1604	0.1285	0.1018

[a] Results from the 0-400 m zone are assumed to estimate detection probability at the optimum lateral distance, i.e., $g_d(0)$.

Discussion

Lateral Distance Factor f(0)

Line transect methods for estimating densities and numbers of animals have the advantage, over strip transects, of allowing for differences in detection probability as a function of distance from the trackline. However, standard line transect methods assume that detectability is maximum on the trackline and diminishes with increasing lateral distance. During many aerial survey projects, it is not possible to observe the trackline below (or in front of) the aircraft. Even if one or more observers can see the trackline, this is at the periphery of their vision if they are also required to watch for animals to the side of the aircraft. Consequently, in the projects considered here, as in many others, detectability was reduced close to the trackline as compared with that at an "optimum" lateral distance (Fig. 15.1, 15.2). In this situation, a standard approach for line transect analysis is to offset the inner edge of the survey area to the "optimum" lateral distance, and to exclude sightings within the strip of reduced detectability closer to the trackline (e.g., Hiby et al. 1984; Dohl et al. 1986; Buckland et al. 1993). That approach was used here. The resulting "left-truncated" distribution of lateral distances is suitable as a basis for fitting standard line-transect models. Alternative methods retaining sightings in the reduced-sightability zone close to the trackline have been described, e.g., Quang and Lanctot (1991), but are not widely used. In this study, the left-truncation distance was determined for surveys at varying altitudes and from three types of aircraft.

Line transect methodology (unlike strip transect methods) can use sightings at lateral distances large enough that detection probability is considerably reduced relative to that at the optimum lateral distance (Buckland et al. 1993). This is important in surveys of infrequently-sighted animals, as it provides a larger sample size than would be obtained if only the sightings near the optimum distance could be considered, as during strip transect surveys. However, in fitting a line-transect model to the distribution of lateral distances, model fit may be improved by excluding sightings beyond some lateral distance where detection probability is low, e.g., 15% of that at the optimum distance (Buckland et al. 1993). In this study, we analyzed the data both without and with right truncation, for comparison. Results were obtained separately for different aircraft types, Beaufort (Bf) sea states, and ice conditions.

Altitude and Aircraft Type: The width of the zone below the aircraft where sightability was reduced varied depending on aircraft altitude. The width of this zone, and thus the left truncation distance, varied directly with altitude. Most surveys of bowhead whales, especially in recent years, have been flown between 900 and 1500 ft a.s.l. (274–457 m), and the following discussion is based on surveys at these altitudes.

The type of aircraft affected the width of the reduced-sightability zone below the aircraft. This zone was narrower for Twin Otters than for Twin Commanders, with the TurboGoose being intermediate. Some of these differences may have been attributable to differences in the usual window and seating configurations in the particular aircraft used here, rather than to any inherent differences among the aircraft. In the Twin Commander, the seats were lower (relative to the windows) than is often the case in Twin Otters. Even with bubble windows in the Twin Commander, observers could not comfortably look downward (as well as sideways) during an extended aerial survey. The flat side windows in the TurboGoose no doubt restricted downward visibility despite their large size. The presence of an observer with forward visibility in the co-pilot's seat during many Goose surveys counteracted this to some degree.

Sea-State (Bf): The effects of wave (Bf) conditions and ice cover were also examined to determine how they affected the rate at which the probability of detecting a bowhead whale at the surface of the water diminishes as its distance from the trackline increases. The right truncation distance, where sighting probability is 15% of that at the optimum lateral distance, is one measure of this effect. For both the Twin Otter and the Twin Commander, the right truncation distance diminished from Bf state 0–1 to Bf 5–6. For the Twin Otter, R_{trun} values were similar for Bf 0–3 (2100–2400), and lower for Bf 4–6 (1650–1850 m) (Fig. 15.3). Based on this measure, surveys under Bf conditions 0 to 3 would appear to be most useful in calculating density estimates. However, for the Twin Commander, R_{trun} was high for Bf 0–1 (2800 m), notably lower for Bf 2–4 (1425–1700 m), and lower still for Bf 5–6 (900 m; Fig. 15.4). Restricting surveys to Bf 0–1 conditions is not practical, so (at least for surveys in a Twin Commander) there is a need for different right truncation distances and correspondingly different $f(0)$ factors depending on Bf conditions.

Strip-transect surveys by LGL in the Canadian and Alaskan Beaufort Sea during the 1980s demonstrated that observed densities of bowheads tended to decrease as sea-state increased (Table 15.5). For example, as compared with surveys under Bf 0–3 conditions, the average observed density during surveys with Bf 4–5 was reduced to 51% in the Canadian Beaufort Sea (1981 and 1983 data), and to 67% in the Alaskan Beaufort Sea (1984–86 data). Part of this effect may be attributable to the effects of increasing sea-state on the maximum distance at which bowheads at the surface are detectable. However, the six studies contributing to Table 15.5 were all done from Twin Otter aircraft, and the densities were calculated based on sightings in the strips 100–1100 or 200–1200 m from the trackline, depending on survey altitude. Within 1 km of L_{trun}, the shape of the lateral-distance function from a Twin Otter is not strongly dependent on Bf (Fig. 15.1). Therefore, much of the sea-state effect evident in Table 15.5 probably was attributable to a reduction in detectability of bowheads close to the trackline as sea-state increased. That effect is not fully taken into account by the calculation of different R_{trun} and $f(0)$ values for different sea states. Ideally, different $g_d(0)$ factors should also be determined for different sea states. However, we do not have sufficient data from double-independent observer surveys to allow this (see below).

Ice Cover: We found that the number of sightings at increasing lateral distances diminished more rapidly with 25–99% ice cover than with 0% ice cover (Twin Otter) or 0–25% ice cover (TurboGoose).

TABLE 15.5. Effect of sea state on observed densities of bowheads during strip transect surveys of the Beaufort Sea. Transect width 1 km on each side of aircraft, with L_{trun} = 100 m or 200 m for surveys at 500 ft (152 m) or 1000 ft (305 m) altitude, respectively.

Sea State[a]	Bf State[a]	Canadian Beaufort Sea Aug. - Sept.[b] km	#	#/1000 km^2	Alaskan Beaufort Sea Sept. - Oct.[c] km	#	#/1000 km^2
0	0	2285	19	4.16	4320	17	1.60
1	2	7623	59	3.87	12,067	23	0.95
2	3	10,885	83	3.81	8928	29	1.62
3	4	7717	25	1.62	4858	9	0.93
4	5	4704	24	2.55	1974	3	0.76
5+	6+	1006	0	0	985	2	1.02
0-2	0-3	20,792	161	3.87	26,314	69	1.31
3-4	4-5	12,421	49	1.97	6832	12	0.88

[a] These results were originally classified by sea state; equivalent Beaufort states (Bf) are shown.

[b] From 1981 data of Davis et al. (1982) and 1983 data of McLaren and Davis (1985), combined.

[c] From Evans et al. (1987), summarizing four LGL studies in 1984-86.

The associated R_{trun} values (950 vs. 2100–2400 m) provide one measure of this. Also, for both aircraft types, *f*(0) was strongly dependent on ice cover. When right-truncation was applied, *f*(0) decreased with increasing ice cover. Thus, ice cover tended to reduce sightability of bowheads, especially at longer distances from the trackline, relative to that in open-water.

Before conducting this analysis, our subjective impression was that ice can either greatly impair or substantially increase sightability of bowheads, depending on ice type. If ice is broken up into a myriad of small pans, it is very difficult to sight bowheads amidst all the other objects in the water. However, if most of the sea is covered by large, featureless pans with just a few isolated areas of open water, observers can ignore large parts of the field of view and concentrate their attention on the few areas where a bowhead could surface. In this largely-retrospective analysis, we usually could not separate these two categories of ice from the data available to us. We expect that R_{trun} and *f*(0) factors would differ substantially between these two types of ice if they were distinguished.

Availability Bias Factor $g_a(0)$

Bowhead whales are below the surface and invisible to aerial surveyors the majority of the time. The proportion of time bowheads are below the surface varies with whale. In the eastern Alaskan Beaufort Sea during late summer and early autumn, traveling whales had the lowest probability of detection (availability bias factor), and whales engaged in socializing had the highest. Socializing whales were twice as likely to be sighted by aerial observers than were traveling whales. Feeding is the most common activity in the eastern Alaskan Beaufort Sea during this season (Chapter 12) and the probability of detecting feeding whales during aerial surveys is only slightly higher than that of detecting traveling whales (Table 15.3). Detection probability for bowheads feeding in water >20 m deep was very similar to that of traveling bowheads (Table 15.6), which were mainly in water >20 m deep.

TABLE 15.6. Variation in availability correction factor $g_a(0)^a$ depending on whale activity and study area/season. Mean surfacing and dive duration are from Thomas et al. (Chapter 13), incorporating data of Richardson et al. (1995, MS). Mothers and calves excluded; exclusion of mothers accounts for slight differences in E Alaska values relative to Table 15.3. See Table 13.4 for ± s.d and *n.*

Season and Area	Water Depth	Mean Duration (min) of Surfacing	Mean Duration (min) of Dive	% Time at Surface	$g_a(0)^a$
Traveling Whales					
Spring at Barrow, AK	-	1.35	6.63	16.9	0.214
"Autumn", E Alaska	-	1.52	13.83	9.9	0.122
Autumn, Baffin Bay	-	1.49	9.36	13.7	0.171
Feeding Whales					
Summer, Canadian Beaufort	≤20 m	1.25	2.86	30.4	0.392
Summer, Canadian Beaufort	>20 m	0.91	3.83	19.2	0.268
"Autumn", E Alaska	≤20 m	1.10	5.84	15.9	0.210
"Autumn", E Alaska	>20 m	1.73	15.73	9.9	0.120
Late summer, Baffin Bay	>50 m	1.77	15.8	10.1	0.121
Socializing Whales					
Summer, Canadian Beaufort[b]	-	1.12	2.77	28.8	0.380
"Autumn", E Alaska[b]	-	1.27	5.67	18.3	0.235
Late Summer, Baffin Bay	-	1.19	1.64	42.0	0.548

[a] $(s + t)/(s + u)$, with t assumed to be 21.6 s, not corrected for dive durations $<t$.

[b] Includes socializing combined with travel, feeding, or both.

Mean surfacing and dive durations, and the percentage of time at the surface, can differ substantially depending on study area and season as well as whale activity (see Chapter 13; summarized in Table 15.6). "Availability" factors derived for bowheads in one area and season may not apply directly to bowheads engaged in the same activity in another area or season. Surfacing and dive durations of bowheads can also depend significantly on specific environmental, temporal, and whale-activity variables, as shown in Chapter 13 for the eastern Alaskan area in late summer–early autumn, and in Richardson et al. (1995, MS) for other areas and seasons. Therefore, estimates of "percent time at surface" and "availability" based on pooled observations of whales at different times and places are inevitably approximations. These "average" correction factors may be appropriate for the combined data from a variety of days of surveying, but may not be appropriate to a given whale or to a specific day of aerial surveys.

Detectability Bias Factor g_d(0)

Aerial surveyors fail to detect some of the bowheads that are at the surface as the aircraft passes. The detectability (= perception) bias factor $g_d(0)$ estimates the proportion detected in the strip where observation conditions are optimal (commonly referred to as "along the track line") based on surveyors observing independently from the same side of the aircraft. This correction factor is independent of the correction for whales missed as a function of increasing distance from the trackline, $f(0)$. We calculated $g_d(0)$ for the strip within 400 m of the inner truncation distance, where $f(0)$ is assumed to be near 1.0. For that strip, our estimates of $g_d(0)$ for bowheads are 0.59 ± s.e. 0.16 for a single observer, and 0.84 for two observers on the same side of the aircraft.

The g_d values for the zones 400–1000 m (and 0–1000 m) from the inner truncation distance were lower than $g_d(0)$ based on sightings in the 0–400 m zone (Table 15.4). The data came from surveys in both Twin Otter (1981, 1985–86) and Twin Commander (1998–2000) aircraft. The lower detectability factor in the 400–1000 m zone was presumably attributable mainly to the Twin Commander data. The relative number of bowhead sightings 400–1000 m vs. 0–400 m from the inner truncation distance was reduced at high sea states during Twin Commander surveys, but less so during Twin Otter surveys (Fig. 15.4 vs. 15.3).

The available data are insufficient to allow us to calculate separate $g_d(0)$ factors for surveys under different Beaufort sea states (Bf), especially if also partitioned by aircraft type. Aerial survey data from the Canadian Beaufort Sea in summer and, independently, the Alaskan Beaufort Sea in autumn, show that average apparent densities of bowheads as observed from a Twin Otter aircraft tended to diminish with increasing Bf (Table 15.6). This suggests that $g_d(0)$ depends on sea state. However, the relationship may be somewhat weaker than implied by Table 15.6, as those density data are based on strip transects extending 1 km outward from the left truncation distance. Sea state may have some effect on relative detectability in the 400–1000 m vs. 0–400 m zone, even for the Twin Otter (Fig. 15.3). To whatever extent this occurs, the lower densities recorded during Twin Otter Surveys at high sea states may be partly a result of sea state effects on $f(0)$ as well as on $g_d(0)$. However, the factor primarily responsible for the lower observed densities at high sea states during Twin Otter surveys was probably a reduction in $g_d(0)$.

During the double independent observer method as used here, the two observers view essentially the same area at the same time. This is both a strength (providing matched data) and a problem. Factors affecting detectability by one observer also affect the other observer, and this can cause bias (Pollock and Kendall 1987). There has been considerable recent discussion of improved procedures for analysis of double-independent observer data, taking account of factors expected to influence sightability (e.g., Borchers et al. 1998; Chen 1999). In future work it may be useful to apply these approaches to the bowhead data.

In general, estimation of bowhead abundance from aerial survey data is likely to be improved by application of line transect models that take into account the simultaneous influences of the various factors discussed here, and others, on detection probability. At least some of the effects of aircraft type, aircraft altitude, lateral distance, sea state, ice cover and whale activity are already considered in a univariate sense in this analysis. Additional factors that might be built into a multivariate line-transect detection model for bowheads include aircraft groundspeed, bubble vs. flat windows, number of observers, whale group size, visibility, glare, and ice type. In the meantime, the correction factors developed here provide at least a preliminary basis to estimate absolute abundance of bowhead whales in the Beaufort Sea from aerial survey data.

Summary

Aerial surveys have been used to estimate the number of bowheads present in the eastern Alaskan Beaufort Sea at various times during late summer and autumn for the present study. However, meaningful estimates of numbers present can only be made if the raw aerial survey data are adjusted using appropriate correction factors for missed whales. Not all whales present close to an aerial survey trackline are detected by the aerial surveyors, and raw aerial survey results underestimate the densities and numbers of whales present. (1) Sightability is often reduced directly below the aircraft and, beyond some “optimum” lateral distance, diminishes with increasing lateral distance. (2) Some whales are below the surface and undetectable as the aircraft passes; this is “availability bias”. (3) Not all whales at the surface at the optimum lateral distance are detected; this is "detectability bias", sometimes called "perception bias". In theory, three correction factors, designated $f(0)$, $g_a(0)$, and $g_d(0)$, can be computed to compensate in large part for these three biases. We estimated these three correction factors for aerial surveys of bowhead whales, and investigated their variability.

Lateral Distance from Trackline and f(0): Aerial survey data were used to determine the effect of lateral distance on sightability, and the influences of aircraft type, survey altitude, wave height, and ice cover. Eight aerial-survey studies in the Alaskan and Canadian Beaufort Sea during 1979–2000 provided data on distances of bowhead sightings from the trackline. Altitude and aircraft type affected the size of the zone directly below an aircraft where sightability was reduced. The higher the altitude, the wider the zone. Twin Otter aircraft had a narrower zone of reduced sightability below the aircraft than did Twin Commanders; a TurboGoose was intermediate. Wave height (expressed as Beaufort sea state, Bf) and ice cover each affected the rate at which sightability diminished with increasing distance from the trackline. Also, the effect of Bf state depended on aircraft type. With increasing Bf conditions and ice cover, the relative number of sightings at the longer lateral distances diminished. As a result, the lateral distance where sighting probability diminished to 15% of that at the optimum distance declined with increasing Bf state and ice cover, and $f(0)$ values also changed.

Availability Bias Factor $g_a(0)$*:* This factor estimates the proportion of whales that are at the surface and potentially visible to aerial surveyors as the aircraft passes overhead. We determined this factor for whales in the eastern Alaskan Beaufort Sea and adjacent Canadian waters (Flaxman Isl. to Herschel Isl.) during September–October based on three studies of bowhead behavior in that area during 1985–86 and 1998–2000. This correction factor varied substantially with whale activities. The probability was lowest for traveling whales, slightly higher for feeding whales, and notably higher for whales engaged in socializing: $g_a(0) = 0.125$, 0.153, and 0.234, respectively. Our overall estimate of $g_a(0)$ for an average bowhead in the eastern Alaskan Beaufort Sea during late summer and autumn is 0.144. These factors are slightly higher than the corresponding proportions of time the whales spend at the surface, as the factors assume that any whale near the trackline will be sighted if it surfaces during an (approx.) 21.6-s period while that area is in view.

Detectability Bias Factor $g_d(0)$*:* This factor estimates the proportion of whales at the surface near the trackline that are detected by observers. We estimated $g_d(0)$ based on the double independent observer method, as applied during three aerial survey projects in the Canadian (1981) and Alaskan (1985–86, 1998–2000) Beaufort Sea. This method applies an analysis of the capture–recapture type to sightings by two surveyors observing independently from the same side of the aircraft, considering sightings within a 400-m strip of where detectability is optimal. Our estimates of $g_d(0)$ for bowheads are 0.59 ± s.e. 0.160 for a single observer, and 0.84 for two observers on the same side of the aircraft. Detectability was lower in a 600-m strip just beyond the inner 400-m strip ($g_d = 0.42 \pm 0.129$ for one observer). Other aerial survey evidence indicates that this factor very likely is affected by sea state.

The correction factors developed here are used elsewhere (Chapter 9) to convert raw aerial survey data into estimates of the actual numbers of bowheads present in the eastern Alaskan Beaufort Sea on various occasions.

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16. BOWHEAD WHALE DISTRIBUTION, NUMBERS AND ACTIVITIES: SUMMARY AND CONCLUSIONS

William R. Koski and W. John Richardson[1]

The project plan called for the use of aerial surveys, aerial observations of behavior, and aerial photographic methods to document the distribution, abundance, behavior, sizes, and residence times of bowheads in the study area. More specifically, the purposes of the aircraft-based fieldwork were to

- determine distributions and raw numbers of bowheads within the study area during late summer/early-autumn feeding periods in that area,
- determine correction factors for sightability during aerial surveys,
- use the above data to estimate whale-days of utilization of the study area,
- document the proportion of time spent feeding,
- characterize feeding behavior (near-surface/water-column/bottom), and
- determine residence times of individual bowheads.

Each of these types of data has been collected and described in Chapters 9–15. Where possible, the variability in the various measured variables has been characterized. Much of this variability relates to year-to-year differences in the environment and in the use of the area by bowhead whales.

The aerial survey crew had the additional critical task of providing the boat-based crew with information about locations of bowhead whales (especially feeding whales) on a real-time basis. This was necessary to allow the boat-based crew to locate bowheads for the purpose of sampling the zooplankton around feeding whales, as described in Chapter 6.

The distribution, numbers, and activities of bowhead whales in the eastern Alaskan Beaufort Sea during late summer and autumn are described in Chapters 9–15. Data in these chapters come from field studies conducted in that area during September of 1998–2000 and from a closely-related study in the same area during 1985–86, augmented with data from other studies of bowheads in and near that area during 1979 to 2000. The aerial surveys conducted annually since 1979 by or for MMS (e.g., Treacy 2002) were of particular value in augmenting the specific feeding-study work. However, several other projects also provided important aerial survey and photogrammetric data in various years. As called for in the project plan, three different study methods were used to collect most of the field data: (1) aerial surveys, (2) behavioral observations from a circling aircraft, and (3) vertical aerial photogrammetry. Aircraft-based field studies during the present study were conducted from 10 to 24 September in 1998, 10 to 30 September in 1999, and 8 to 25 September. Aircraft-based field studies during the comparable 1985–86 study were from 4 September to 3 October in 1985 and 2 to 27 September in 1986. The project aircraft, a Twin Commander in 1998–2000 and a Twin Otter in 1985–86, was based at Kaktovik, AK, throughout those five field seasons. Additional information on bowhead distribution and numbers spec-

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[1] LGL Ltd., environmental research associates, 22 Fisher St., POB 280, King City, Ont. L7B 1A6. *Phone:* 905-833-1244; *e-mail:* bkoski@lgl.com, wjr@lgl.com

ific to these five years was provided by systematic aerial surveys conducted by MMS from 1 August to 20 October in 1985, 15 August to 17 October in 1986, 31 August to 27 October in 1998, 3 to 17 September in 1999, and 1 September to 12 October in 2000.

Bowhead whales are in the eastern Alaskan study area from August (and sometimes July) through mid- or late October. The specific feeding-study work in 1985–86 and 1998–2000 was largely limited to the period of peak bowhead abundance during September. However, comparable data of various types acquired during other studies in August and October helped in addressing utilization of the study area throughout the period when significant numbers of bowheads are in the area.

For most components of the aerial work, the study area was the area from Camden Bay in Alaska (145º or 146ºW, depending on task) to Herschel Island in the Yukon (139ºW), and from the shore north to ~71º10'N, which was well beyond the continental shelf. For several of the specific analyses of bowhead distribution and habitat utilization, the study area was divided into four E–W regions, and four water-depth strata—a total of 16 analysis zones. From west to east, the four analysis regions were the Camden Bay, Kaktovik, Demarcation Bay, and Komakuk regions (overall, "Flaxman Isl. to Herschel Isl."). The most easterly of the four analysis zones (Komakuk) consisted of Canadian waters between the Alaska–Yukon border and Herschel Island. Data from that area have been excluded from certain analyses in order to address bowhead utilization of the eastern Alaskan Beaufort Sea proper. For seasonal analyses, the data were categorized into six half-month (15- or 16-day periods) from 1 August to 31 October.

The eastern part of the Alaskan Beaufort Sea is not the only part of the Alaskan Beaufort where bowhead whales feed during late summer and autumn. Feeding has been reported occasionally in the central Alaskan Beaufort (Flaxman Island to Colville River, 146°–151°W), and more commonly from the western Alaskan Beaufort (Landino et al. 1994; Treacy in prep.). The stomach contents of bowheads harvested at Barrow in fall also show that feeding occurs very commonly in the western Alaskan Beaufort, just east of Barrow, during fall (Lowry 1993; Chapter 18). The few stomach content samples from Cross Island in the central Alaskan Beaufort (Chapter 18) are consistent with Inupiat reports that bowheads often feed in that region as well. This project's focus on the eastern Alaskan Beaufort Sea is a result of specific interest in the importance of that area for feeding (see Chapter 1). We do not suggest that the eastern Alaskan Beaufort Sea is unusually important for feeding as compared to other parts of the Alaskan Beaufort.

Distribution and Abundance

Bowhead abundance differed significantly among the four depth strata within the "Flaxman Isl. to Herschel Isl." study area, with highest average abundance recorded in the Shelf Break stratum (40–200 m deep), followed by the Middle Shelf stratum (20–40 m) and Nearshore stratum (<20 m); average abundance was lowest in the Continental Slope stratum (>200 m deep). Differences in bowhead abundance among the four E–W regions were marginally significant, with average bowhead abundance for the August–October period being highest in the east and declining to the west (Chapter 9). The Komakuk zone was not sampled uniformly, and some parts of that zone, especially its Nearshore and (to a lesser degree) Middle Shelf strata, may be more important to bowheads than demonstrated here.

Local residents occasionally see bowheads in the study area during July and August; they see peak numbers in September, and some bowheads during October (Chapter 2).

Aerial surveys showed that bowhead abundance and distribution varied significantly by half-month period during August–October of 1979–2000. Moderate numbers of bowheads were present during early August, especially in the Continental Slope zone (>200 m deep) of the three easternmost regions, i.e., Kaktovik to Komakuk. Fewer bowheads were present during the second half of August, and there was a slight shoreward shift in the distribution of bowheads from early to late August. This suggests that, during late August, bowheads may have been moving from offshore Alaskan waters toward the coast, as has been seen farther east along the Yukon coast. During the first half of September, numbers of bowheads in the "Flaxman to Herschel" study area increased. Also, their distribution shifted inshore and expanded westward to span the full width of the study area, coincident with increased migration into and through the study area. Peak bowhead abundance in the study area was recorded during the second half of September, when bowheads were most abundant in the Shelf Break and Middle Shelf strata (i.e., depths 20–200 m). Fewer bowheads were present during early October, and the highest densities were again shoreward of the 200 m contour. By late October, only small numbers of bowheads were present and densities were higher in the western half of the study area.

The activities of bowheads seen during aerial surveys were categorized insofar as possible, although this is difficult to do during the brief period while a whale is in view during a straight-line aerial survey. The percentage of bowhead sightings during aerial surveys that were recorded as "traveling" was similar (86–100%) over the six half-month periods. For traveling whales, the headings were significantly non-uniform (and predominantly westward or northwestward) in all half-month periods except for late August. However, the variation in headings was larger up to 15 September than thereafter. Behavioral studies, summarized below, indicate that the "percent traveling" figures from aerial surveys (86–100%) were overestimated.

Few bowheads were identified as feeding during the systematic aerial surveys. The low apparent numbers of feeding bowheads are, in large part, an artifact of the difficulty of recognizing feeding activity during the brief glimpses of whales that typically occur during systematic aerial surveys. (Behavioral studies, summarized below, provided more comprehensive data on feeding.) Areas where feeding was seen most commonly included Nearshore waters close to Komakuk (Yukon); in Nearshore, Middle Shelf and Shelf Break waters off Demarcation Bay; and in Middle Shelf and Shelf Break waters off Camden Bay. (During behavioral studies, feeding was also seen in Nearshore waters off Kaktovik after the whaling period. Aerial surveys generally avoided that area while Kaktovik whalers were whaling, so there were fewer opportunities to see feeding there during aerial surveys.)

During the 1979–2000 period, the relative abundance of bowheads recorded during aerial surveys of the "Flaxman to Herschel" area has varied markedly from year to year. Eight years had abundance indices higher than the overall average of 0.77 bowheads seen per 100 km of surveying. The highest indices were recorded in 1990 (4.05 /100 km), 1999 (3.32 /100 km) and 1995 (3.23 /100 km). Seven of the eight years with above-average bowhead abundance were in the 1990s, and 9 of 13 years with below-average bowhead abundance occurred prior to 1990. The average of the annual abundance indices was 0.36 bowheads seen/100 km during 1979–89 vs. 1.60 /100 km for 1990–2000. The increase since 1989 was larger than can be accounted for by the previously-reported rate of increase of this population (3.2% per year). This same trend was present in numbers of whales, corrected for biases and missed whales, estimated to be present in the area from Demarcation Bay to Camden Bay inshore of the 200 m contour during September and early October. The increased sighting rates since 1989 are apparently attributable in part to an increase in the relative utilization of the present study area as compared with other areas.

The abundance indices during the years when most of our behavioral and zooplankton data were collected were

- 0.12 and 0.39 bowheads seen/100 km in 1985 and 1986, respectively (9th and 3rd highest of 10 indices before 1990), and

- 1.64, 3.32, and 0.60 bowheads seen/100 km in 1998, 1999 and 2000, respectively (5th, 2nd and 9th highest of 11 indices since 1989).

Thus, based on the aerial survey data, our behavioral and zooplankton field studies were conducted during two years of relatively high bowhead use (1986 and 1999), one year of average use (1998), and two years of low use (1985 and 2000). Behavioral and zooplankton data were obtained during years of relatively high and relatively low bowhead use during both the 1979–89 and 1990–2000 periods.

The numbers of bowheads present inshore of the 200 m contour in the "Flaxman-to-border" area off Alaska (i.e., in 3 of our 4 E–W zones, and 3 of 4 depth strata) were estimated whenever survey coverage allowed. These line transect estimates included allowance for aircraft type, aircraft altitude, and missed whales. The estimates ranged from 0 during many surveys to 4505 (± s.e. 3702) bowheads. The 4505 figure was based on 765 km of survey coverage on 13 September 1999. Within most half-month periods, the estimated numbers of bowheads present were highly variable, but average numbers followed the same seasonal pattern as the abundance indices described above for the overall study area.

Total numbers of whale-days of utilization of continental shelf waters (depth <200 m) in the "Flaxman to border" area have been estimated for the five principal years of study. These estimates are based on estimated numbers of bowheads present on various days (with allowance for missed whales), and on the seasonal pattern of whale abundance. Total whale-days for the area ranged from ~12,000 to 31,000 in four years, but was 102,000 in 1999. The accuracy of these values is unknown, but the lower values are surprisingly low. The estimated size of this bowhead population was ~6500 in the mid-1980s and ~10,000 in the late 1990s. A bowhead would require ~2.4 days to swim steadily from the Canadian border to western Camden Bay (Flaxman Isl.) even if it did not stop to feed (Chapter 11). A possible explanation for the relatively low whale-days estimates in some years is that more bowheads than now thought may migrate west through deep (>200 m) offshore areas where aerial survey coverage is limited.

Habitat Use by Size Class

Photogrammetric methods (Koski et al. 1992) were used in Chapter 10 to investigate geographic and seasonal patterns in the size composition of bowhead whales in and near the eastern Alaskan Beaufort Sea (Flaxman Isl. to Herschel Isl.). Subadults, adults and calves made up 64.7, 29.2 and 6.2%, respectively, of the bowheads photographed in that area (including the Komakuk region) over all years of this study (1982, 1984–86, 1998–2000). We found proportionally more subadults and fewer adults within that area than are estimated to be in the overall population even after allowance for our under-sampling during the early and late parts of the migration. The presence of a relatively high proportion of subadults suggests that the parts of the "eastern Alaskan Beaufort Sea" ≤200 m deep were relatively more important for subadult bowheads than for adults, at least during the years of our study (Chapter 10).

There was significant variation in length–frequency distributions of whales among years, geographic subdivisions of the study area, water depth categories, and time periods. This variation was due to variable use of the study area by each age class in different years, differences in the water depths preferred by different age classes, and different migration timing by each age class. Small subadult whales (<10 m long) are the dominant group in shallow (<20 m) nearshore habitats, with progressively fewer small subadult whales and more large subadults and adults as water depth increases. Small subadults start to arrive in the study area during late August, numbers peak in early September, and they have passed through the study area by early October. Large subadults start to arrive in late August but are scarce until September; moderate numbers are still present in early October. Mothers and calves start to arrive in early September and are common in the study area until early October. Other adults arrive mainly in late September and are common in early October.

In the mid-1980s, large numbers of subadult bowheads tended to occur in shallow nearshore areas in the eastern part of the study area from the Kongakut River Delta to Herschel Island, and they lingered in that area for days to a few weeks. Few whales were seen in that nearshore area during 1998–2000, and those that were seen there did not appear to linger.

Rates of Movement and Residence Times

We estimated rates of movements from within-day sightings of photographed bowhead whales in the "Flaxman–to–Herschel" portion of the Beaufort Sea, including the eastern Alaskan Beaufort plus the Yukon coast west of Herschel Isl. We compared those results to similar data collected farther east during the 1980s, off the Yukon east of Herschel Isl. (Yukon East) and in Amundsen Gulf (Chapter 11). Within-day speeds were not significantly different between the "Flaxman–to–Herschel" zone and the more easterly Canadian zones. Within the "Flaxman–to–Herschel" zone there was a significant difference in speeds among years. The difference appeared to be due to slower speeds by feeding adults in 1999 than by primarily subadult whales in other years.

The main activities recorded for bowheads during late summer and autumn were feeding and traveling. Based on the successive locations of bowheads observed during prolonged behavioral observation sessions, the average rate of movement of bowheads in the "Flaxman–to–Herschel" zone was ~1.54 km/h for feeding whales vs. 4.50 km/h for traveling whales. The mean alongshore component of the net speed, measured along the 288º–108º (True) axis, was 0.71 km/h *eastward* for feeding whales, and 3.67 km/h westward for traveling whales.

We also attempted to estimate residence times of bowhead whales in the "Flaxman–to–Herschel" zone using four general types of data: photoidentification data, behavioral observations, aerial survey results, and telemetry data. Photoidentification data from the 1980s were also used to estimate residence times in the Yukon East and Amundsen Gulf zones. ***(1)*** Photographic resightings were used to determine within-day rates of movement and intervals between resightings for the "Flaxman–to–Herschel" zone and for the Yukon East and Amundsen Gulf zones in all years with sufficient data. Net speeds from within-day photographic resightings were the basis for one estimate of residence times of whales in each zone. Resighting intervals indicated minimum residence times for the specific whales resighted. A computer program (SODA, "stop-over duration analysis") was used to derive an unbiased estimate of residence time in each zone based on data on photographic effort, sightings, and resightings (Reboulet et al. 2001; Schaub et al. 2001). ***(2)*** *Behavioral observations* of bowhead whales were used to determine short-term rates of movement of whales, and net westward speeds of whales engaged in different activities, in the "Flaxman–to–Herschel" zone during late summer and autumn of 1985–86 and 1998–2000. ***(3)*** *Aerial survey data* were used to estimate residence times in that area based on relative densities during aerial surveys and based on numbers of whales estimated to be present during aerial surveys. ***(4)*** Data on whale locations obtained during *telemetry* studies in three years were used to estimate residence times of whales in the "Flaxman–to–Herschel" zone.

Annual residence time estimates for the "Flaxman–to–Herschel" zone were extremely variable among years and among different methods of analysis applied to the same year. We attribute the latter variability to biases in the different methods that interacted with year-to-year variability in sampling effort, whale distribution, and whale activities. For example, most behavioral data and some photographs collected in 1985 were from feeding whales off the Yukon coast ("border–to–Herschel Isl."); activities and speeds of those whales were not representative of whales in Alaskan waters in 1985. In general, estimates based on behavior data, and to a lesser extent photoidentification data, were positively biased.

We identified six calculation methods based on photoidentification, behavioral observation, aerial survey, and telemetry data that provided residence-time estimates most representative of actual residence times. However, even with these six methods, a few of the residence time estimates were recognizably biased. The annual residence time estimates for the "Flaxman–to–Herschel" area during 1985–86, 1988, 1989, 1992, and 1998–2000 based on these six methods varied from 2.1 to 8.3 d and averaged 5.1 d. A sensitivity analysis (in Appendix 23.1) indicated that the 95% confidence limit for the 5.1-d estimate of mean residence time was 4.2 to 6.1 d.

Residence times varied dramatically among years because of different levels of use of the "Flaxman–to–Herschel" zone for feeding during late summer and autumn. In 1985 and 1986, the eastern part of the area was used for feeding by subadult bowheads during late summer. In 1998, subadult whales briefly stopped to feed in central and western parts of the study area during their migration through the study area. In 1999, adult whales stopped to feed for extended periods in eastern and central parts of the study area. During 2000, most whales migrated through the study area without stopping.

The mean interval for between-day photographic resightings was 4.35 days in the "Flaxman–to–Herschel" zone and 5.91 days in Canadian zones east of there, and estimates for both areas were highly variable among years. The tendency for residence times in the "Flaxman–to–Herschel" zone to be shorter than those in the Canadian areas became more evident when the SODA model was used to estimate total residence times, including allowance for time present before the first and after the last sighting, and for whales photographed only once. SODA showed that the mean residence time estimates for the Canadian zones were considerably longer (12.6 d) than the mean resighting intervals (5.9 d), whereas the mean residence times for the "Flaxman–to–Herschel" zone were either lower than (1985) or similar to (1986, 1999) the mean resighting intervals. The shorter residence times in the latter zone compared to the Yukon East and Amundsen Gulf zones are consistent with distributional and behavioral data in suggesting that bowhead whales spent less time feeding in the "Flaxman–to–Herschel" area than in the more easterly Canadian zones in most years. Furthermore, residence time estimates for eastern Alaska would be further reduced if data from Canadian waters west of Herschel Island (the Komakuk area) were excluded from the "Flaxman–to–Herschel" zone.

Activities and Behavior

We used data obtained during our behavior observation sessions to describe and quantify the activity budgets of bowhead whales while they were in the "eastern Alaskan" Beaufort Sea, including some data from the Komakuk zone east of the Alaska–Yukon border (Chapter 12). Of 84 observation sessions under presumably undisturbed conditions, 69 were off northeast Alaska (Flaxman Island to border) and 15 were in Canadian waters from the Alaska/Yukon border to Herschel Island.

Feeding was the most common activity of bowhead whales in and near the eastern Alaskan Beaufort Sea in September/early October during 1985, 1986, 1998, and 1999; but not in 2000. Over the five seasons, bowheads engaged in feeding for ~47% of the total time (9% in 2000; 38–66% in other years). Overall, ~34% of the time was spent feeding in the water column, 8% on near-surface ("skim-") feeding, and 4% on near-bottom feeding. Almost all observed feeding in water >20 m deep was water-column feeding; surface and bottom feeding were proportionally more common in areas ≤20 m deep, but there too water-column feeding was the most common activity. Mothers and first-year calves were rarely sighted in waters ≤20 m deep, and the most common activity of mothers was feeding in the water column in areas

>20 m deep. Most whales fed singly. Bottom feeders were usually widely spaced, but water-column and skim feeders generally were more aggregated, typically with 4+ whales within 1 km of each other. We did not see skim feeding in echelon formation during late summer–early autumn, although it has been reported previously in the Alaskan Beaufort Sea. The estimated proportion of time devoted to feeding during September/early October (47%) was intermediate between values during spring migration east of Point Barrow, Alaska (1%), and on the summer range in the Canadian Beaufort Sea (71%).

Traveling was the second-most common activity, accounting for 31% of time overall; but 74% in 2000. Travel tended to be in areas 20–49 m deep and in groups of one to two whales. Whales spent more time traveling during the latter half of September than in early September. Traveling whales were oriented mainly westward. Bowheads commonly interspersed feeding and socializing with travel during the latter half of September. The estimated proportion of time devoted to traveling (31%) was also intermediate between that during spring migration (81%) and that on the summer range (9%).

Socializing accounted for 18% of the time during September/early October, and other activities (aside from feeding, travel or socializing) accounted for 4%. Socializing tended to consist of low-level behaviors such as nudges and other touches, with the exception of apparent sexual aggregations of up to seven whales per aggregation on two days in September 1998. First-year calves stayed close to their mothers, showed little surface-active behavior, and were not observed to play. No lone calves were seen, indicating that calves had not been weaned.

Although feeding was the most common activity of bowhead whales in and near the eastern Alaskan Beaufort Sea during September/early October, there was much intra- and inter-season variability in the amount and type of feeding, other activities, and specific behaviors, and in the locations (within the study area) where these activities occurred. These variable results are generally consistent with the apparent variability in prey availability in the study area, as documented in other parts of this study. However, bowheads observed in 1999 spent a high proportion of their time feeding, and exhibited relatively long residence times, even though average zooplankton abundance (at least inshore of the 50 m contour) was relatively low that year (Chapter 5). Overall, the importance of the study area for late-summer feeding by bowhead whales varies considerably from year to year, and is difficult to predict for any one late summer–early autumn season.

The activity budgets summarized above do not consider the variable detectability of bowheads engaged in different activities while we were searching for whales to observe. Based on availability correction factors presented in Chapter 15 and summarized below, traveling whales are, on average, available to be detected ~12.5% of the time. Feeding and socializing whales are available to be detected ~15.3 and 23.4% of the time, respectively. If group size and other factors were equal (they are not), feeding and socializing whales would be 1.2 and 1.9 times more likely to be detected and observed than traveling whales. Thus the activity budgets presented above may overestimate the proportion of time engaged in feeding, and particularly in socializing, and underestimate the proportion of time spent traveling through the study area.

Surfacing, Respiration and Dive Cycles vs. Whale Activity

Data on surfacing, respiration and dive (SRD) cycles of bowhead whales during late summer and early autumn (Chapter 13) were needed to derive correction factors for whales missed during aerial surveys, and as a basis for analyses of bowhead energetics. Bowheads were observed systematically during September and early October of 1985–86 and 1998–2000 in the Eastern Alaskan Beaufort Sea and adjacent Canadian waters (“Flaxman–to–Herschel” area).

Whales engaged in ***feeding*** showed a noticeable increase in the number of blows per surfacing and the durations of surfacings and dives across years. Some of this variability may be attributable to the water depth in which the whales were feeding. In the 1980s most of the observed surfacing–dive cycles occurred in shallow (≤20 m) water, whereas in the 1990s more of observations came from deeper water, particularly during 1999. An average SRD cycle by an undisturbed bowhead feeding in shallow (≤20 m) water, calves excluded, consisted of a 1.10 min surfacing with 4.9 blows spaced 13.1 s apart, followed by a 5.84 min dive. A corresponding average SRD cycle in water >20 m deep (average 45 m) consisted of a 1.77 min surfacing with 8.5 blows spaced 13.1 s apart, followed by a 16.09 min dive. Whale status and distance from shore had a strong effect on the SRD cycles of bowheads feeding in and near the Eastern Alaskan Beaufort Sea. During feeding, surfacings and dives were longer, with more blows per surfacing and longer intervals between blows, with increasing distance from shore, and for older, larger whales as compared with subadults.

Traveling bowheads (including those feeding while traveling) tended to have surfacing and dive cycles similar to those of bowheads feeding in water >20 m deep. Some of this similarity may be attributable to the habitat that the whales are occupying, as traveling whales tended to be in water >20 m deep. An average SRD cycle by a traveling bowhead (including bowheads that were feeding as they traveled) consisted of a 1.65 min surfacing with 6.4 blows spaced 15.76 s apart, followed by a 13.66 min dive. Whale status and group size had a strong influence on the SRD cycles of bowheads traveling in and near the Eastern Alaskan Beaufort Sea. The standard measures of these cycles were higher for mothers and for increased group sizes, and were shorter for subadults.

Socializing whales and whales feeding in shallow water tended to have similar breathing characteristics. Some of this similarity may be attributable to the habitat (shallow water) that the whales were occupying. An average SRD cycle by a socializing bowhead (including bowheads that intermixed socializing with other activities) consisted of a 1.29 min surfacing with 6.0 blows spaced 12.67 s apart, followed by a 5.54 min dive.

Surfacing, Respiration and Dive Cycles vs. Whale Age

Data on age- and size-dependence of surfacing, respiration and dive (SRD) cycles of bowhead whales (Chapter 14) were needed as a basis for analyses of bowhead energetics. This type of information is also relevant in deriving correction factors for whales missed during aerial surveys, especially when there is geographic and seasonal variation in the ages and sizes of bowheads present. For this analysis we included behavioral data collected during spring bowhead migration around northwestern Alaska (Richardson et al. 1995b) and during summer in the Canadian Beaufort Sea (Dorsey et al. 1989; Richardson et al. 1995a), along with data from the “eastern Alaskan” area (Flaxman Isl. to Herschel Isl.) in late summer–early autumn. All data were collected by the aerial observation method in 1980–2000.

Subadult whales had shorter median blow intervals than adults and mothers; this was evident for bowheads engaged in all three whale activities studied (traveling, feeding, and socializing). Subadults also had shorter dive durations during traveling, and marginally shorter surface times during feeding, as compared with adults and mothers. Mothers and other adults had similar SRD cycles, with the exception that, during feeding, other adults had shorter median blow intervals than mothers.

Subadults engaged in traveling showed no spring–fall differences in any of the SRD variables. Adult whales, in contrast, showed differences in all four variables. Mothers and calves engaged in traveling showed seasonal variability in SRD cycles. For both mothers and calves, there was a noticeable increase in the number of blows per surfacing, surface times, and dive times from spring to fall.

During travel, nursing dives by calves were much shorter than their other dives in both spring and fall. Occurrence of nursing also affected SRD cycles of traveling mothers. When nursing, traveling mothers tended to have long surfacings with long blow intervals and slightly longer than average dive durations.

Correction Factors for Aerial Surveys

Aerial surveys have been used to estimate the number of bowheads present in the eastern Alaskan Beaufort Sea at various times during late summer and autumn for the present study (Chapter 9). Meaningful estimates of numbers present can only be made if the raw aerial survey data are adjusted using appropriate correction factors for missed whales (Chapter 15). Not all whales present close to an aerial survey trackline are detected by the aerial surveyors, and raw aerial survey results underestimate the densities and numbers of whales present. (1) Sightability is often reduced directly below the aircraft and, beyond some "optimum" lateral distance, diminishes with increasing lateral distance. (2) Some whales are below the surface and undetectable as the aircraft passes. (3) Not all whales at the surface at the optimum lateral distance are detected. In theory, three correction factors, designated $f(0)$, $g_a(0)$, and $g_d(0)$, can be computed to compensate in large part for these three biases (Marsh and Sinclair 1989; Buckland et al. 1993).

Lateral Distance from Trackline and f(0): Aerial survey data were used to determine the effect of lateral distance on sightability, and the influences of aircraft type, survey altitude, wave height, and ice cover. Eight aerial-survey studies in the Alaskan and Canadian Beaufort Sea during 1979–2000 provided data on distances of bowhead sightings from the trackline. Altitude and aircraft type affected the size of the zone directly below an aircraft where sightability was reduced. The higher the altitude, the wider the zone. Twin Otter aircraft had a narrower zone of reduced sightability below the aircraft than did Twin Commanders; a TurboGoose was intermediate. Wave height (expressed as Beaufort sea state, Bf) and ice cover each affected the rate at which sightability diminished with increasing distance from the trackline. Also, the effect of Bf state depended on aircraft type. With increasing Bf conditions and ice cover, the relative number of sightings at the longer lateral distances diminished. As a result, the lateral distance where sighting probability diminished to 15% of that at the optimum distance declined with increasing Bf state and ice cover, and $f(0)$ values also changed.

Availability Bias Factor $g_a(0)$*:* This factor estimates the proportion of whales at the surface and potentially visible to aerial surveyors as the aircraft passes overhead. We determined this factor for whales in the "Flaxman Isl.–to–Herschel Isl." area during September–October based on three studies of bowhead behavior in that area during 1985–86 and 1998–2000. This correction factor varied substantially with whale activities. The probability was lowest for traveling whales, slightly higher for feeding whales, and notably higher for whales engaged in socializing: $g_a(0) = 0.125$, 0.153, and 0.234, respectively. Our overall estimate of $g_a(0)$ for an average bowhead in the eastern Alaskan Beaufort Sea during late summer and autumn is 0.144. These factors are slightly higher than the corresponding proportions of time the whales spend at the surface, as the factors assume that any whale near the trackline will be sighted if it surfaces during an (approx.) 21.6-s period while that area is in view.

Detectability Bias Factor $g_d(0)$*:* This factor estimates the proportion of whales at the surface near the trackline that are detected by observers. We estimated $g_d(0)$ based on the double independent observer method, as applied during three aerial survey projects in the Canadian (1981) and Alaskan (1985–86, 1998–2000) Beaufort Sea. This method applies an analysis of the capture–recapture type to sightings by two surveyors observing independently from the same side of the aircraft, considering sightings within a

400-m strip of where detectability is optimal. Our estimates of $g_d(0)$ for bowheads are 0.59 ± s.e. 0.160 for a single observer, and 0.84 for two observers on the same side of the aircraft. Detectability was lower in a 600-m strip just beyond the inner 400-m strip ($g_d = 0.42 \pm 0.129$ for one observer). Other aerial survey evidence indicates that this factor very likely is affected by sea state.

These correction factors were used in the "Distribution and Abundance" chapter (Chapter 9) to convert raw aerial survey data into estimates of the actual numbers of bowheads present in the eastern Alaskan Beaufort Sea on various occasions.

Disturbance to Feeding Bowhead Whales

The studies of bowhead feeding ecology in 1985–86 and 1998–2000 did not include any specific effort to study the reactions of bowhead whales to disturbance or noise. That topic has been addressed in various other studies sponsored by MMS and others, with work up to 1995 being summarized in Richardson and Malme (1993) and Richardson et al. (1995c). Subsequent reports have primarily concerned reactions of migrating bowheads exposed to various types of industrial activities during active travel in spring or fall (Richardson et al. 1995b, 1999; Davies 1997; Miller et al. 1999; Schick and Urban 2000; Greene et al. 2002; Patenaude et al. 2002).

The Discussion section of Chapter 12 includes a subsection on "Possible Human Influences" on bowheads during the feeding studies in 1985–86 and 1998–2000. As discussed there, bowheads observed in this study were not exposed to much industrial activity when we observed them. Most of our observations in 1985–86 were well east of the areas where a drillship and seismic vessels were active, and any observations close to such activities were excluded from consideration. There was no drilling or seismic exploration in the eastern part of the Alaskan Beaufort Sea during the summer or autumn in 1998–2000. The boat that we used for zooplankton sampling caused some localized disturbance when it approached feeding bowheads. On one occasion in 1986, photoidentification data showed that feeding bowheads displaced by the sampling vessel had returned to their original location 1–2 days later (Thomson and Richardson 1987). Aerial observations of behavior, from an aircraft circling at 460 m (1500 ft) altitude, cause very little if any disturbance, and straight-line aerial surveys also cause little disturbance (Richardson et al. 1986; Patenaude et al. 2002). Aerial photogrammetry flights at low altitude (typically ~145 m or 475 ft) cause some bowheads to dive abruptly or otherwise react, although the proportion doing so is low (Patenaude et al. 2002). Some bowhead hunting occurs in our study area each year during September, with powerboats being used to approach the whales. Bowheads flee in response to approaching boats.

Whales of various species seem less responsive to noise and disturbance when they are actively engaged in certain activities, including feeding and mating (reviewed in Chapter 9 of Richardson et al. 1995c). A few of these observations have pertained specifically to bowhead whales. For bowheads on the summer feeding grounds in the Canadian Beaufort Sea, our impression has been that animals involved in feeding, socializing or mating seem less responsive to aircraft, including low-altitude photogrammetric flights, than were bowheads not engaged in one of these activities (Richardson and Malme 1993). Photographed individuals were often found in the same areas on subsequent days (Koski et al. 1988; see also Chapter 11), so these low-altitude overflights did not displace many (if any) bowheads from summer feeding areas. However, feeding bowheads can be disturbed if exposed to a sufficiently strong disturbing stimulus. Bowheads on the summer feeding grounds in the Canadian Beaufort Sea usually showed a strong avoidance reaction when a small ship or motor vessel approached directly toward the whales at a distance as great as 2–4 km (Richardson et al. 1985; Richardson and Malme 1993). Feeding bowheads also ceased feeding and moved away upon exposure to a seismic vessel within a few kilometers or a playback of dredge sounds (Richardson et al. 1986, 1990). However, bowheads were seen as close as 6 km from seismic vessels operating on the summer feeding grounds, whereas migrating bowheads in the Alaskan Beaufort were rarely seen within 20 km of seismic vessels (Richardson et al. 1986 vs. 1999; Miller et al. 1999).

Studies and observations of several other species of baleen whales in the presence of boats and ships also indicate that those species tend to be less responsive to vessels when feeding. This has been noted for North Atlantic right whales, humpback whales, and blue, fin, sei, and Bryde's whales (see review and references in Richardson et al. 1995c, p. 262*ff*). Feeding whales of these species will react to approaching vessels, but the reaction distance tends to be less than observed when the animals are not engaged in feeding, socializing or mating. Brodie (1981a,b) indicated that various baleen whales continue to feed in areas with high fish abundance despite the presence of large numbers of fishing vessels in those areas. However, he noted that many marine mammals, in order to feed, may have no alternative but to occupy areas where they are chronically exposed to noise, and that this tolerance should not be assumed to mean that the animals are indifferent to the noise.

Similar observations have been obtained for beluga whales. Although belugas are not baleen whales, it is interesting to note that feeding belugas also are less prone to react to aircraft and to vessels than are belugas engaged in some other activities (Bel'kovich 1960; Kleinenberg et al. 1964; Frost et al. 1984; Blane 1990). However, Blane (like Brodie) notes that the continued use of some areas with much boat traffic reflects the value of these areas to the whales, and should not be interpreted as meaning that the whales were undisturbed.

In summary, it appears that bowhead whales, like other whales, may be somewhat less responsive to various human activities when feeding than when not engaged in feeding, socializing or mating. However, feeding bowheads (and other whales) nonetheless can be disturbed and displaced if the disturbance is sufficiently close and strong. Also, it has been suggested that feeding whales that appear to tolerate various human activities may be stressed or otherwise affected even though they do not show a strong avoidance response. In general, the evidence that whales tend to be somewhat tolerant of disturbance when feeding is rather weak. There have been very few direct comparisons, with consistent methods, of the proclivity for disturbance when whales are exposed to the same type of human activity while engaged in feeding vs. other activities. Although whales may well, on average, show weaker disturbance reactions while feeding, their feeding can nonetheless be interrupted and the whales can be displaced if the disturbance is sufficiently strong. Reactions to approaching ships and powerboats seem especially strong.

Conclusions

There were substantial differences in the numbers, distribution, size classes, residence times, activity budgets, and specific behaviors of bowhead whales in and near the eastern Alaskan Beaufort Sea during late summer and early autumn of the five years with feeding studies. Bowhead use of that area during August–October is highly variable. Systematic aerial survey data from 1979–2000 suggest that the five years when the feeding studies were conducted included years with low, moderate and high use by bowheads and thus may be reasonably representative of the range of possible usage patterns. However, usage in any future year probably will differ in at least minor ways from that in any of our five years of study.

Most bowhead whales of the Bering–Chukchi–Beaufort stock migrate through the eastern Alaskan Beaufort Sea each year during late summer or early autumn en route to autumn feeding areas farther west and wintering areas in the Bering Sea. Behavioral observations (and also the stomach contents of bowheads harvested at Kaktovik—Chapter 18) show that feeding is a common activity while these whales are in the eastern Alaskan Beaufort Sea. Over the five years studied, the two most common activities of bowheads, at least during daytime when aerial observations were possible, were feeding (47%) and traveling (31%). The proportions of time engaged in these two activities during late summer and early autumn were intermediate between those observed during spring, when bowheads spend most of their time traveling and little time feeding, and during summer, when bowheads spend most of their time feeding and little time traveling. However, the estimated proportions of time spent feeding during late summer and autumn ranged from 9% to 66% in different years. The inter-annual differences in numbers estimated to have been present probably were related to how long whales stopped to feed in the study area, and thus to residence times.

The abundance and locations of zooplankton concentrations had a strong influence on bowhead feeding locations (Chapter 6), and very likely also influenced residence times in the study area. We found that different size classes of bowhead whales had different habitat preferences and different timing of migration through the study area. Small subadult whales preferred Nearshore waters. As water depth increased, small subadults became less common and the proportion of large subadults and adults increased. When prey was locally abundant in Nearshore and Middle Shelf waters, as in 1985 and 1986, some subadult whales lingered in the study area to feed, and many larger whales (which tended to be found in deeper water) traveled through the study area without stopping to feed. When prey biomass was higher in Shelf Break waters (40–200 m) than closer to shore, as in 1999, large subadult and adult whales lingered to feed there, and most small subadult whales traveled through without stopping. When prey was sparse in the eastern part of the study area, as in 2000, most if not all whales traveled through that area without stopping. Over all years of this study, subadult whales seemed to make more use of the study area than adults, but there was year-to-year variation in the use by different age classes. Possible reasons for these year-to-year differences in utilization are discussed further in Chapter 23, "Integration".

Recommended Research

The present study incorporated aerial survey data from August to October, but most of the other techniques for studying bowhead utilization of the eastern Alaskan study area were applied primarily in September. September is known, from aerial surveys, to be the month of peak utilization of the eastern Alaskan Beaufort Sea by westward-migrating bowheads. However, information from aerial surveys and from local residents indicates that bowheads can be present in appreciable numbers from August to October, with occasional sightings in July (Chapters 2 and 9). Zooplankton biomass and energy content are expected to vary seasonally, and the tendency for active migration is also expected to increase seasonally. Thus, utilization of the area by bowheads is expected (and in many ways is already known) to vary with date during the July–October period. *More data on distribution, activities, size segregation, and residence times of bowhead whales in the eastern Alaskan Beaufort Sea during the early and late parts of the season, e.g., July-August and October, would be helpful in better understanding the importance of the area to bowheads.*

The present study was conducted in and near the eastern Alaskan part of the Beaufort Sea, for reasons explained in Chapter 1. Some similar studies have been done on parts of the summer feeding grounds in the Canadian Beaufort Sea. Aerial surveys across the full width of the Alaskan Beaufort Sea have provided data on seasonal distribution and movements of bowheads in the central and western parts of the Alaskan Beaufort. However, there is little information on autumn activities, size segregation, and residence times of bowhead whales in these more westerly parts of the Alaskan Beaufort Sea, or along the northeast coast of the Chukotsk Peninsula in the western Chukchi Sea. Available data from aerial surveys and stomach contents indicate that feeding is common in some of these more westerly areas during autumn, especially at various locations from western Harrison Bay to Barrow (Treacy in prep.). *To understand the relative importance of autumn feeding areas west of the present eastern-Alaskan area, studies of bowhead activities, size segregation, and residence times in the more westerly areas during autumn would be useful.* Insofar as possible, these studies in the more westerly areas should occur throughout the seasonal period when bowheads occur in these areas, as evident from previous scientific studies and the experience of local residents.

Given the documented year-to-year variability in bowhead utilization of feeding areas in eastern Alaskan waters over the 5 seasons of intensive study, *any follow-up study of bowhead utilization in different months or in different areas should be planned for a duration of at least 3 years if at all possible.*

There is partial segregation of size (and age) classes of bowheads when they are passing through the eastern Alaskan Beaufort Sea during late summer and autumn, with larger (older) whales tending to be farther offshore (see Chapter 10). To date, observations of activities, residence times, and size segregation in feeding bowheads have been largely limited to bowheads in nearshore and inner-shelf waters, where subadult whales predominate. Although aerial surveys have extended north into deep-water areas, aerial survey coverage in those areas has been less intensive than in the areas closer to shore, and survey coverage has been limited in August, when bowheads seem to prefer deep water areas. *Within the eastern Alaskan Beaufort Sea, it would be desirable to obtain additional data on bowhead utilization of deeper waters throughout the summer and autumn.* In the deeper areas, a higher proportion of the bowheads are larger, older individuals, and in those areas zooplankton may concentrate at deeper depths, especially in the later parts of the season.

Direct observations of bowhead activities in the eastern Beaufort Sea (and elsewhere) are limited to daylight hours. Commencing in August, there are some hours of darkness in the Beaufort Sea region, and the duration of darkness increases rapidly as autumn progresses. Vertical migration of zooplankton has not been studied in this area and season. Foraging behavior of bowhead whales is likely to be affected by any pronounced vertical migration by concentrations of prey. This and other factors could result in differences in whale activities by day vs. night. Krutzikowsky and Mate (2000) found little evidence of day–night differences in several behavioral variables, based on satellite telemetry methods applied to bowheads in the Beaufort and Chukchi Seas during September (Mate et al. 2000). However, *the possibility of day–night differences in bowhead activities deserves further study, perhaps via VHF or UHF telemetry (e.g., Croll et al. 1998) as well as expanded use of satellite telemetry.*

New technology has considerable potential for providing additional data concerning bowhead utilization of various parts of the Beaufort Sea and other areas. *Additional studies utilizing satellite-linked and VHF (or UHF) radio tags are recommended as these have the potential to provide new levels of detail concerning distribution, movements, residence times, behavior, and disturbance responses of bowheads.* Ideally, these data would be acquired for whales tagged at different locations and seasons, and the size/age, status, and (where possible) sex of each whale would be determined. *Passive acoustic detection, localization, and (occasionally) tracking of bowheads can also provide data on seasonal distribution, movements, and disturbance responses during autumn migration (Greene et al. 2002).* The latter approach has potential applications in assessing bowhead use of specific regions within the Beaufort Sea or elsewhere, although it is doubtful whether passive acoustic data could be related specifically to feeding whales.

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DIET AND REGIONAL OCCURRENCE OF FEEDING

17. INTRODUCTION TO DIET AND REGIONAL OCCURRENCE OF FEEDING COMPONENTS OF STUDY

W. John Richardson [1]

This component of the study sought to determine ***(1)*** what types of prey bowhead whales of the Bering–Chukchi–Beaufort (BCB) stock eat, and ***(2)*** what parts of their seasonal range provide the predominant part of this food. The principal and most direct method for determining what bowheads eat was analysis of the stomach contents of bowheads harvested by Inupiat whalers (Chapter 18). The project also included a pilot study of the fatty acid composition of bowhead blubber in relation to the fatty acid composition of potential zooplankton prey (Chapter 19). It was hoped that this approach might, when further developed, provide a method for assessing food consumption over a longer period (and larger geographic area) than can be assessed from stomach contents. To assess the proportion of the food consumed in different parts of the seasonal range, the carbon and nitrogen isotope ratios in bowhead tissues were compared with those in the prey from the eastern Beaufort Sea vs. the Bering–Chukchi area (Chapter 20).

Stomach Contents

Prior to this study, the most recent analysis of the stomach contents of BCB bowheads was the review by Lowry (1993). At that time, relatively few samples of stomach contents were available from bowheads harvested in the Beaufort Sea during autumn. This study has provided many additional data on stomach contents of bowheads harvested at Kaktovik in autumn, and at Barrow in autumn and spring. It has also provided some initial data on stomach contents of bowheads harvested at Cross Island by Nuiqsut hunters. The study of stomach contents was done by Lloyd Lowry and Gay Sheffield of the Alaska Department of Fish and Game (ADF&G), under subcontract to LGL.

- ***Kaktovik:*** During the present study, ADF&G acquired stomach-content (and tissue) samples from whales harvested at Kaktovik during 1997, 1998, 1999, and 2000. Gay Sheffield of ADF&G was stationed in Kaktovik during each of those whaling seasons to collect stomach contents, tissue samples, and standard measurements as each whale was landed. The stomach-content samples were later analyzed by ADF&G (Chapter 18). Bowhead tissue samples collected at Kaktovik by ADF&G were provided to other researchers for purposes of the fatty-acid analysis (Chapter 19) and the isotope analysis (Chapter 20). In addition, standard measurements of the whales harvested at Kaktovik were provided to the North Slope Borough Department of Wildlife

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[1] LGL Ltd., environmental research associates, 22 Fisher St., POB 280, King City, Ont. L7B 1A6. *Phone:* 905-833-1244; *e-mail:* wjr@lgl.com

Management (NSB-DWM) for inclusion in their harvest database. Additional tissue samples were provided to NSB-DWM for use in their "bowhead health" study. These samples were collected under the provisions of Scientific Research Permits 797 (1997) and 481-1464 (1998–2000) issued by the National Marine Fisheries Service.

- ***Cross Island:*** **A**dditional stomach-content samples were obtained from some of the whales harvested in 1999–2000 at Cross Island by Nuiqsut whaling crews (also under permit 481-1464). Cross Island is located in the Prudhoe Bay region, between Kaktovik and Barrow. Mark Major of Phillips Petroleum made these collections possible.
- ***Barrow:*** J.C. George and Dr. T. O'Hara of the NSB-DWM provided many stomach samples from bowheads harvested at Barrow in spring and autumn during this study (1997–2000). NSB-DWM also made available archived but previously-unanalyzed samples from bowheads harvested at Barrow during spring and autumn seasons prior to 1997.

ADF&G have analyzed these new or previously-unanalyzed stomach-content samples and associated data, and have combined these results with previously reported results on stomach contents of bowheads in the Beaufort Sea. Based on this overall database, they describe and compare the frequency of recent feeding, and the predominant prey items in the stomachs, for bowheads harvested at different locations and seasons. They also compare the diet data for whales of different age and gender (see Lowry and Sheffield, Chapter 18).

Fatty Acids

The types and relative amounts of various fatty acids differ among prey organisms, and these differences are reflected in the fatty acid composition of the animals that consume them (see Introduction to Chapter 19 for background). Fatty acids are the largest constituent of lipids and those of carbon chain length 14 or greater are often deposited in animal tissue with minimal modification from diet. Based on this, in recent years fatty acid signature analysis has been developed as a new method to examine foraging ecology in free-ranging animals (Iverson 1993).

Early in this study, in 1997–98, it was recognized that analysis and comparison of fatty-acids in bowhead tissues and potential prey organisms had the potential to provide additional data on diet beyond those available from stomach-contents analysis. Two subcontractors involved in related aspects of the project (ADF&G and University of Alaska Fairbanks) both recommended that a fatty-acids study of bowheads be included in the project. Stomach contents provide data on the types of foods eaten shortly before death, and thus close to the harvest site(s). However, they do not show what the harvested whales ate during previous days and weeks. This is a concern because, in the Beaufort Sea, bowhead whales are harvested at only three locations. No stomach-content data on diet are available from the summering grounds in the Canadian Beaufort Sea, or from many other parts of the annual range. Also, some harvested whales provide no stomach-content sample, either because that whale had not eaten shortly before being struck, or because the stomach contents were lost before the stomach could be examined. The fatty acid method has the potential to overcome these problems and to complement the data available from stomach samples.

There has been no previous study of the fatty acids in bowheads, and relatively few such studies have been done in other cetaceans. However, it was suspected that analyses of the fatty acid composition of potential prey species (zooplankton) and bowhead blubber samples might help resolve questions concerning bowhead diet. For example, euphausiids are common in bowhead stomachs; however, field studies generally find high concentrations of copepods near feeding bowheads. Fatty acid analysis may help clarify the relative contributions of these two taxa to the bowhead diet, including their average contributions over much longer periods than are represented by the stomach contents of harvested whales (weeks vs. hours). For purposes of fatty acid analysis, the availability of blubber tissue from harvested whales is particularly advantageous, as the samples of the inner part of the blubber are considered most suitable for such a study (Hooker et al. 2001). Inner blubber is available from harvested whales, but is often not available in other studies where the samples must be obtained via remote biopsy methods (see Chapter 19).

Blubber samples were collected from bowheads taken in the subsistence harvests at Kaktovik and Barrow as part of this project. These collections were started in 1997 in anticipation that fatty-acids in bowheads and their prey would be studied at some point during the project. Samples of zooplankton were available from the zooplankton sampling program conducted by LGL in the eastern Alaskan Beaufort Sea near Kaktovik during 1998–2000 (see Chapters 5, 6). However, analysis of the fatty acid content of these samples did not start until later in the project, mainly for budgetary reasons. Budgetary provision was made to conduct a pilot study on fatty acids in bowheads and their prey during the 3rd year of this 4-yr project (1999–2000). Although all concerned recognized the potential of this method, the project's Scientific Review Board (SRB) advised that the effort on this topic be limited to no more than a pilot study, given the need to avoid spreading limited resources thinly across too many disciplines. In practice, a pilot study on this topic was conducted during 1999–2000, with some limited follow up into 2001. Laboratory analysis and evaluation of fatty acid data were done by Dr. Sara Iverson at Dalhousie University, Halifax, N.S., in conjunction with ADF&G. Results are reported by Iverson et al. in Chapter 19. The method shows promise, but during the present study it was not implemented early enough, or with sufficient resources, to allow it to go beyond the pilot-study stage. After seeing the results of the pilot study, the SRB recommended (in Feb. 2002) that this approach be included as a component of future bowhead feeding studies (see Annex A).

Stable Isotopes

Preliminary analyses of the carbon-isotope composition of bowhead whales and their prey were conducted as part of the 1985–86 feeding study (Schell et al. 1987, 1989; Saupe et al. 1989). That work confirmed earlier indications that the ^{13}C : ^{12}C ratio was different in zooplankton of the eastern Beaufort Sea as compared with the Bering and Chukchi seas. The early work suggested that bowhead tissues consisted mainly of carbon from the Bering–Chukchi zooplankton. However, the temporal record of feeding found along the length of the baleen provided isotopic evidence of some feeding in the eastern Beaufort Sea. Subsequent work by Dr. Don Schell and colleagues provided further evidence consistent with their original findings (e.g., Schell and Saupe 1993; Schell et al. 1998). Through continued analysis of the temporal record of carbon isotope ratios along the length of bowhead baleen, Schell (2000, 2001) also found evidence of a long-term decline in the productivity of the Bering–Chukchi system. He suggested that this might result in an increased importance of the Beaufort Sea as a food source for BCB bowheads.

The suggestion that BCB bowheads acquire most of their annual food intake from the Bering and Chukchi seas and not the summering grounds in the Beaufort Sea was, and is, controversial. Other baleen whales feed primarily in summer. Feeding is the most commonly-observed activity of bowhead whales in the Canadian Beaufort Sea from late July until early September (Würsig et al. 1985, 1989; Chapter 12). (There are no specific observations of their activities in the Canadian Beaufort Sea from June to mid-July.) In most years, feeding is also the most common activity in the eastern Alaskan Beaufort Sea during

September, though somewhat less frequent there than in Canadian waters in summer (Chapter 12). Zooplankton concentrations near whales feeding in the Beaufort Sea are, on average, much denser than those elsewhere in the Beaufort Sea, indicating that the bowheads are selecting the areas where feeding opportunities are most favorable (Chapter 6). The stomachs of bowhead whales harvested during late summer and autumn both near Kaktovik and near Barrow (in the eastern and western Alaskan Beaufort Sea, respectively) often contain large volumes of zooplankton prey (Lowry 1993; Chapter 18). There is also some recent evidence that some bowheads have larger energy reserves when leaving the Beaufort Sea in autumn than when arriving in spring (see Chapter 22).

The isotopic method cannot distinguish prey acquired in the Canadian vs. eastern Alaskan parts of the Beaufort Sea. It is the importance of the smaller "eastern Alaskan" area that is the central issue in this study. However, if it were conclusively demonstrated that bowheads consume little of their annual food intake in the eastern Beaufort Sea as a whole, that would be a strong indication that the eastern Alaskan portion of the eastern Beaufort Sea area must not contribute very much of the annual food intake. If that determination were made, the key question that this project seeks to answer would be resolved.

Given the apparent inconsistencies in the isotope vs. other evidence concerning the amount of feeding in the eastern Beaufort Sea, it was considered important to include an expanded stable-isotope study as part of the present project. The results are provided in Chapter 20 by Sang Heon Lee and Dr. Don Schell of the University of Alaska Fairbanks, who conducted this work under subcontract to LGL during 1998–2000. Particular emphasis was placed on acquiring samples from more bowheads than previously available, especially for autumn, and on comparing feeding strategies of adult vs. subadult bowheads.

After the draft of this report was completed in January 2002, an independent study of stable isotopes in bowhead whales from the Beaufort Sea was published by Hoekstra et al. (2002). That study included data on isotope ratios in tissue subsamples from some of the same individual bowheads analyzed by Lee and Schell for Chapter 20. There were some apparent discrepancies in the data from these two studies, and the conclusions were somewhat different. Chapter 20 has been revised to discuss the Hoekstra et al. results. The updated version of Chapter 20 also takes account of further isotopic analyses of samples from whales where there were apparent discrepancies in the data from the two studies. These reanalyses confirm the accuracy of the measurements that Lee and Schell reported in their draft report.

Various reviewers of the draft of Chapter 20, including the project's SRB, recommended that a sensitivity analysis be performed to assess uncertainty in isotope-based estimates of the percent of their annual food intake that BCB bowheads obtain in the eastern Beaufort Sea. Dr. Trent McDonald, a statistician with Western EcoSystems Technology Inc. (WEST), Cheyenne, WY, worked with Dr. Schell to complete such an analysis, and this is now included as an Appendix to Chapter 20.

Other Evidence on Diet and Regional Feeding

The three specific studies introduced above were designed to provide new information about bowhead diet in the Alaskan Beaufort Sea, and the regional/seasonal allocation of feeding by bowheads. However, several other components of this project also provided data of direct or indirect relevance:

Local and traditional knowledge (LTK) contributed by Kaktovik whalers and other Kaktovik residents indicated that bowheads sometimes linger and feed at particular locations in the Kaktovik area, and that some bowheads are in the area as early as August (Chapter 2 and Annex B). Hunters sometimes observe concentrations of whale food in the water during summer and fall.

Zooplankton sampling near feeding whales vs. elsewhere in the study area confirmed that zooplankton distribution in the eastern Alaskan Beaufort Sea is patchy, and that bowheads are very selective in choosing places where they linger to feed (Chapters 5, 6).

Systematic aerial surveys of the eastern Alaskan study area, over many years, have documented the areas where bowheads tend to concentrate, including seasonal trends in the favored areas (Chapter 9). Those surveys have also provided some fleeting glimpses of feeding behavior. Correction factors have been developed to convert the raw aerial survey data into estimates of actual numbers of whales present in the study area, allowing for the proportion of time the whales spend below the surface and invisible (Chapters 13, 14) and for the whales that are at the surface but missed by aerial surveyors (Chapter 15). Photogrammetric and photoidentification studies of bowheads in the eastern Alaskan Beaufort Sea have provided more specific information about the locations favored by whales of different status (subadults, mother/calf pairs, other adults), including seasonal and year-to-year variability in the concentration areas (Chapter 10). Photographic, behavioral and radio-telemetry data have both provided information about residence times of individual bowheads (Chapter 11). Systematic behavioral observations have documented the frequency of occurrence of feeding in the eastern Alaskan Beaufort Sea as compared with feeding frequency on the summer range in the Canadian Beaufort and along the spring migration route near Point Barrow (Chapter 12).

Observations of feeding by bowheads in other areas, such as the Canadian Beaufort Sea (Würsig et al. 1985, 1989), central and western Alaskan Beaufort Sea (e.g., Ljungblad et al. 1986; Landino et al. 1994; Treacy in prep.), and off northeastern Russia (Moore et al. 1995), also provide information on regional feeding. This needs to be considered when assessing the results of the three specific studies described in the next three chapters. As noted in the introduction to Chapter 16, the eastern part of the Alaskan Beaufort Sea is not the only part of the Alaskan Beaufort where bowhead whales feed during late summer and autumn. The significance of all the results is addressed further in Chapter 22, Energetics, and Chapter 23, Integration and Conclusions.

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18. STOMACH CONTENTS OF BOWHEAD WHALES HARVESTED IN THE ALASKAN BEAUFORT SEA

Lloyd F. Lowry[1,2] and Gay Sheffield[1]

Introduction

The bowhead (*Balaena mysticetus*) is the only baleen whale that spends its entire life in cold northern waters. In Alaska, bowheads migrate in spring from their Bering Sea wintering grounds to the Beaufort Sea. The return migration generally occurs during the late summer and fall. The whales travel from their eastern Beaufort Sea summering grounds, westward along the coast, and into the Chukchi Sea (Fraker and Bockstoce 1980; Moore and Reeves 1993). At least some of them travel southwest to the northeast coast of the Chukotsk Peninsula in autumn before returning to the Bering Sea for the winter.

Examination of the stomach contents of bowhead whales harvested by Alaska Natives provides an opportunity to study their diet. Bowheads are harvested by hunters from three communities along the Alaskan coast of the Beaufort Sea (Fig. 18.1), and access to bowheads varies regionally (Stoker and Krupnik 1993). Due to whale movement patterns and ice conditions, whalers from the community of Kaktovik, in the eastern Alaskan Beaufort Sea, hunt only during the fall—mainly in September and early October (see Chapter 2). The same is true of whalers from Nuiqsut, in the central Alaskan Beaufort Sea, who hunt from Cross Island. However, whalers from Barrow, in the western Alaskan Beaufort Sea, have access to bowheads during both the spring (April–June) and fall (September–October) migrations.

Since 1976, stomach contents samples from bowhead whales have been collected by personnel from the North Slope Borough Department of Wildlife Management (NSB-DWM), the Alaska Department of Fish and Game (ADF&G), and the National Marine Fisheries Service. Diet data from 30 bowhead whales harvested in the Alaskan Beaufort Sea from 1976 to 1988 were reported by Lowry et al. (1978), Lowry and Burns (1980), Lowry and Frost (1984), Carroll et al. (1987), and Lowry (1993). Planktonic crustaceans, especially copepods and euphausiids, were the most important food items found in those studies.

As part of the MMS/LGL study “Bowhead whale feeding in the eastern Alaskan Beaufort Sea”, we collected stomach content samples from bowheads harvested at Kaktovik during 1997–2000. We also acquired and analyzed field records and previously-unanalyzed stomach content samples from other bowheads taken in the Beaufort Sea that were made available to us by the NSB-DWM and other sources. Our objectives were to ***(1)*** evaluate the frequency of bowhead feeding in this region by examining the field records and stomach contents samples from harvested whales; and ***(2)*** to quantify the composition of the diet of bowheads in the Alaskan Beaufort Sea based on analysis of stomach contents from harvested whales.

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[1] Alaska Department of Fish & Game, Division of Wildlife Conservation, 1300 College Rd., Fairbanks, AK 99701.

[2] Current address: University of Alaska, School of Fisheries and Ocean Sciences, 1550 Coyote Trail, Fairbanks, AK 99709. *Phone:* 907-455-6885; *e-mail:* llowry@eagle.ptialaska.net

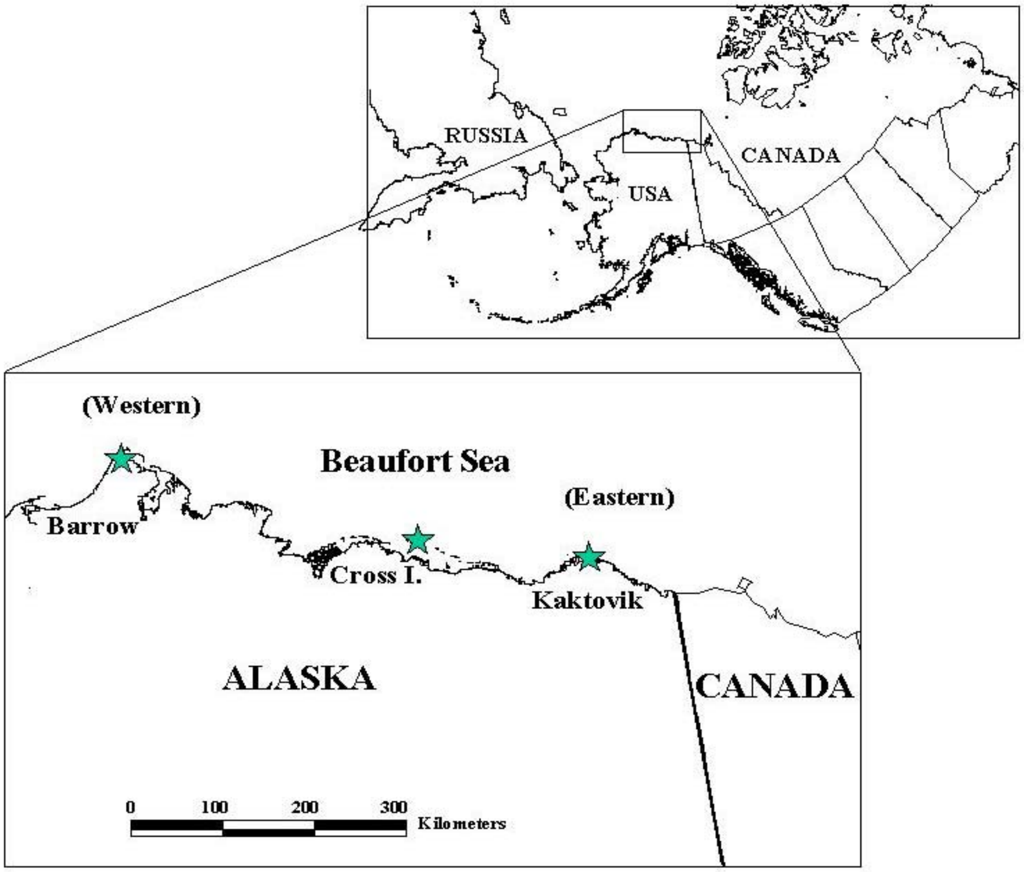

FIGURE 18.1. Map of Alaska and the Beaufort Sea showing the three coastal whaling locations in the Beaufort Sea area: Barrow, Cross Island, and Kaktovik.

Methods

Field Records and Feeding Status

The NSB-DWM provided field records from bowheads harvested by Alaska Native whalers during 1969–2000. We classified each harvested whale as either “feeding”, “not feeding”, or “uncertain” based on descriptive field records and laboratory data on stomach contents. If field records indicated that a substantial amount (i.e., at least 10 items or 1 liter) of prey was present in the stomach, the whale was classified as feeding. If field records indicated that the stomach was empty, the whale was classified as not feeding. If field records recorded the presence of only a small amount of prey (i.e., less than 10 items or less than 1 liter), or that food was present but no quantity was indicated, the feeding status of the whale was recorded as uncertain. For some whales field records did not provide any information about stomach contents, but collected samples were available for laboratory analysis. In those instances, a whale was classified as feeding if the sample contained 10 or more identifiable prey items, not feeding if there were no identifiable prey items, and uncertain if the sample contained fewer than 10 prey items. Items such as algae, feathers, and pebbles were not considered to be food items. Data were grouped by harvest location and harvest season. The proportions of feeding whales from different harvest locations and seasons were compared using chi-square tests.

Collection and Analyses of Stomach Contents Samples

An ADF&G Marine Mammal Biologist was stationed in Kaktovik to sample bowheads taken during September 1997, 1998, 1999, and 2000. The stomach of each whale landed at Kaktovik during those years was examined as soon as possible, usually within a few hours after the animal was brought to shore. An estimate was made of the total stomach contents volume and a sample of contents was collected from the forestomach, when possible. Stomach contents samples were kept frozen until examined in the laboratory.

The NSB-DWM provided us with stomach contents samples from bowheads harvested at Barrow and Kaktovik during 1986–2000. Atlantic Richfield Company and Phillips Petroleum provided samples from some of the whales taken at Cross Island in 1999–2000 by hunters from Nuiqsut. Those samples were either preserved in 70% isopropyl alcohol or 10% buffered formalin, or were frozen.

In the laboratory, samples were gently rinsed in freshwater on a 1.0 mm screen with a 0.42 mm screen layered underneath. Prey items were sorted macroscopically into major taxonomic groups, examined microscopically, and identified to the lowest taxonomic level possible. Current taxonomic nomenclature (Anonymous 1984) was used to name prey. Voucher specimens of prey items were stored in 70% isopropyl alcohol. The water displacement volume of sorted prey items was measured to the nearest 0.1 ml. Data were entered into an electronic database (FoxPro 2.5) that also contained all previously existing data on stomach contents of bowhead whales harvested in Alaska. Included in the database were the location and date of harvest, sex and total length of the animal, and any available data regarding diet including field and/or laboratory records.

For analysis of stomach contents, prey data from individual whales were grouped into major prey types (i.e., copepod, euphausiid, etc.). Results from all bowhead stomachs that have been examined since 1976, and that included 10 or more prey items, were used in analyses. Comparisons were done for whales harvested in fall at Kaktovik vs. fall at Barrow, for whales harvested at Barrow in spring vs. fall, for males vs. females, and for whales <13 m vs. ≥13 m in length. The division into size categories is based on the length at which bowheads reach sexual maturity, which is ~13 m (Koski et al. 1993).

We analyzed the bowhead whale prey data in two ways. ***(1)*** When a group of whales included at least five animals, the frequency of occurrence of major prey types was calculated as the number of samples containing that prey divided by the total number of samples examined. Then, the frequencies of all prey types consumed were compared using 2 by 2 contingency tables with an experiment wise error rate of $\alpha = 0.05$ using Bonferroni's procedure (Neter et al. 1990). All whale stomachs for which ≥10 prey items were enumerated were used in the frequency of occurrence analysis. ***(2)*** Principal components analysis with varimax rotation (Johnson and Wichern 1982) was used to define diet indices, and multiple regression analysis was then applied to those indices to test for possible simultaneous effects of the following covariates on diet: location, season, whale sex, whale length, and collection year. Principal components analysis was applied to data on the rank order of prey importance in each individual bowhead stomach, considering 16 identified prey groups (Appendix 18.1). For each prey group, importance was defined as the ratio of the volumetric contribution of that prey type to the total volume of the sample examined. Therefore, only specimens with quantitative data on prey composition were used in this analysis. For each stomach used in the analysis, principal component scores after varimax rotation ("dietary indices") were computed for the three principal components that explained the greatest amount of variance in the dataset. Those dietary indices were then used as the dependent variables in multiple regression analyses to assess relationships between the covariates and diet. Type 3 sums of squares were used to compute *P*-values for the significance of each covariate. Type 3 sums of squares for each covariate were computed by including all other covariates in the model before computing that covariate's sum of squares.

Results

Data and Specimen Collection

Field records were obtained from 444 bowheads harvested in the Beaufort Sea during 1969–2000, of which 242 had their stomachs examined during butchering.

Thirteen bowheads were harvested during the 1997–2000 whaling seasons at Kaktovik, and stomach contents samples were collected from 12 of them (Appendix 18.2). Additional samples not described in previous papers were obtained from 73 bowheads harvested during 1986–2000 at Barrow (69), Kaktovik (1), and Cross Island (3). Recognizable prey were found in 72 of the 85 new samples.

Bowhead Feeding, Kaktovik Fall

Information on feeding status is available from 32 bowheads taken at Kaktovik during 1979–2000 (Fig. 18.2). Twenty-four were considered to have been feeding, and five were categorized as not feeding (Appendix 18.3). Feeding status was uncertain for the other three whales. Of the 29 whales whose feeding status was classified, 9 were ≥13 m long; 7 of those had been feeding and 2 had not. Of the 20 whales <13 m long, 17 had been feeding and 3 not.

At least 46 species of prey occurred in whales taken at Kaktovik including the following: gastropods–1 species; chelicerata–1; copepods–10; mysids–2; cumaceans–2; isopods–2; gammarid amphipods–16; hyperiid amphipods–4; euphausiids–2; shrimps–3; and fishes–3 (Appendix 18.1).

Stomach samples were available from 21 of the 24 bowheads classified as feeding (Appendix 18.3), and copepods occurred in all 21 of those stomach samples (Table 18.1). Amphipods (both gammarid and hyperiid), euphausiids, and mysids all occurred in more than half the samples. Copepods were the dominant prey by volume in 62% of the 21 samples with volumetric data, and euphausiids were dominant in 24% (Fig. 18.3). The most commonly eaten species of copepods were *Calanus hyperboreus* and *C. glacialis. Limnocalanus* was found in only 3 of 21 stomach contents samples (whales 86KK1, 92KK1, 00KK3), despite its abundance near whales observed feeding in nearshore areas during some years (*cf.* Chapter 6). The most commonly eaten euphausiid was *Thysanoessa raschii* (Table 18.2)

TABLE 18.1. Percent frequency of occurrence of major prey types identified from bowhead whales harvested near Kaktovik, Cross Island, and Barrow. Includes samples with ≥10 prey items.

Prey type	Kaktovik fall (*n* = 21)	Cross Island fall (*n* = 3)	Barrow fall (*n* = 69)	Barrow spring (*n* = 30)
Copepod	100	100	20	80
Euphausiid	62	33	94	93
Gammarid amphipod	81	67	55	23
Hyperiid amphipod	67	67	28	33
Mysid	57	0	49	20
Fish	48	0	26	3
Decapod	52	67	29	7
Isopod	24	0	19	0
Cumacean	24	33	13	3

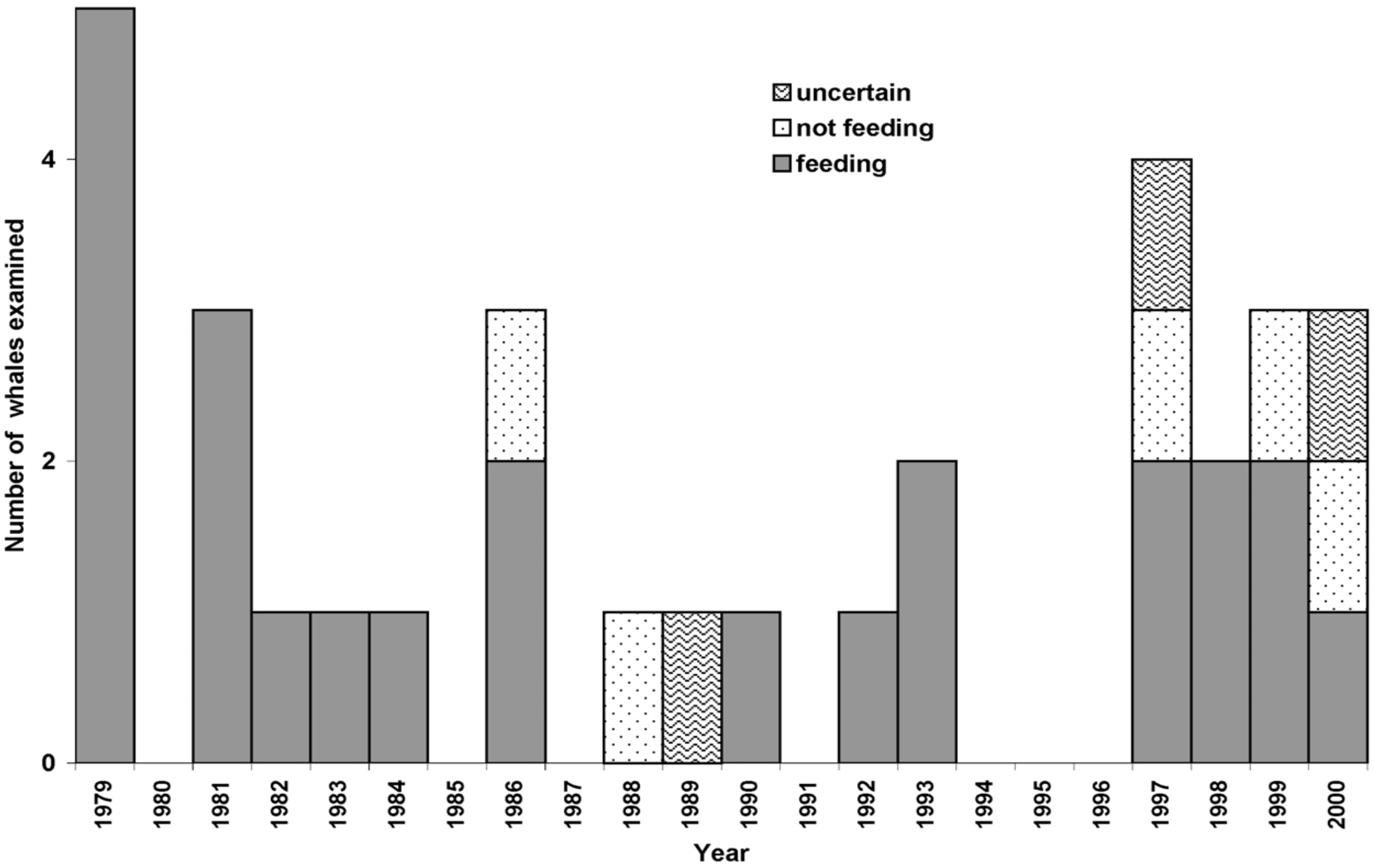

FIGURE 18.2. The feeding status of 32 bowhead whales harvested and examined in the eastern Alaskan Beaufort Sea near Kaktovik, Alaska, 1979–2000. In some of these years, the harvest included additional whales whose stomachs were not examined (see Chapter 2).

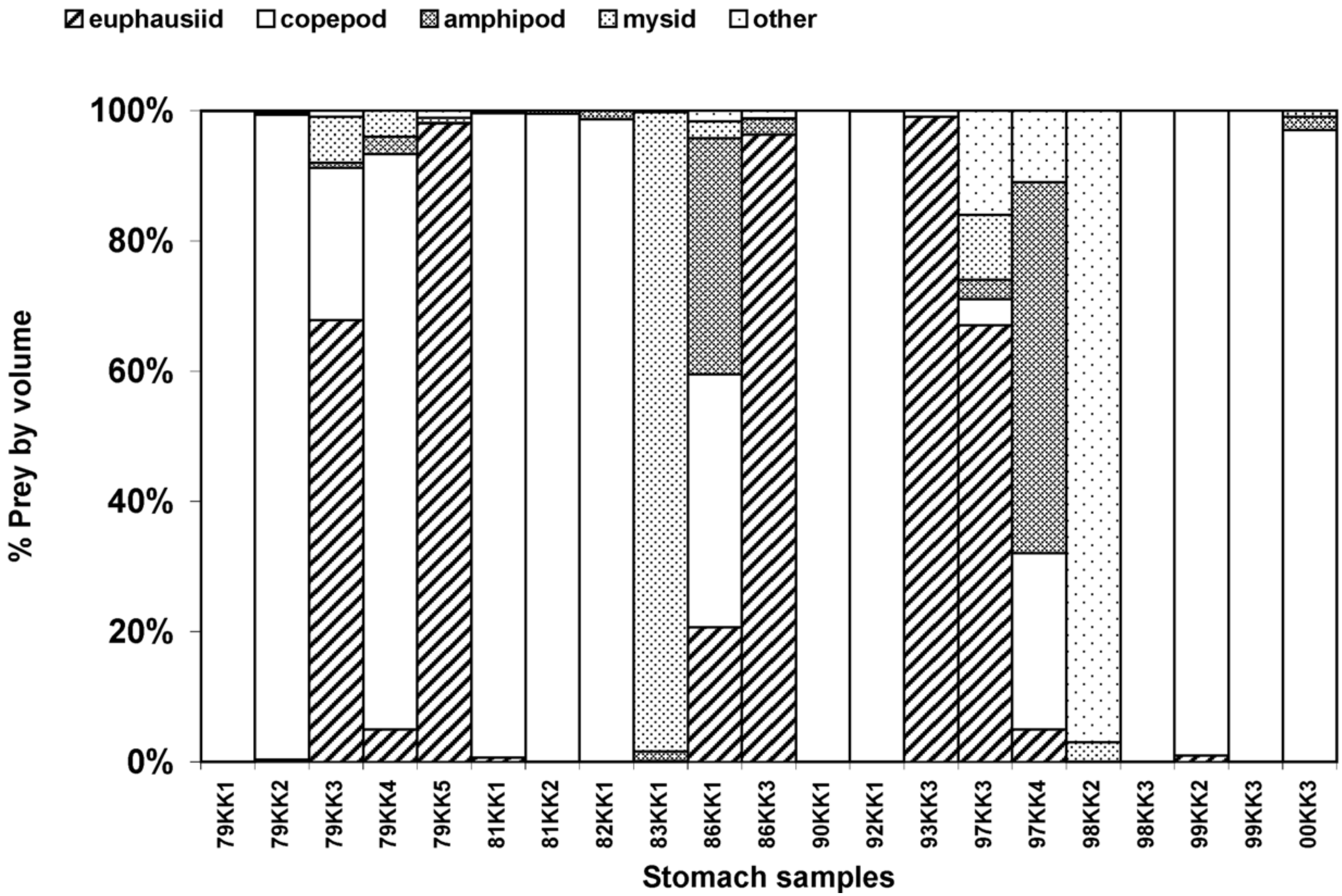

FIGURE 18.3. Percent prey by volume for 21 individual bowhead whales harvested in the eastern Alaskan Beaufort Sea near Kaktovik, Alaska, during the fall, 1979–2000.

TABLE 18.2. Number of identified occurrences of copepod and euphausiid species in stomach contents samples from bowhead whales harvested near Kaktovik, Cross Island, and Barrow.

Prey species	Kaktovik fall (*n* = 21)	Cross Island fall (*n* = 3)	Barrow fall (*n* = 69)	Barrow spring (*n* = 30)
Copepod				
Calanus cristatus	-	-	-	2
C. finmarchicus	1	-	-	-
C. glacialis	10	2	8	20
C. hyperboreus	15	3	4	5
Chiridius obtusifrons	1	-	-	2
Derjuginia tolli	1	-	-	-
Euchaeta glacialis	2	1	1	4
Heterorhabdus sp.	2	-	-	-
Limnocalanus grimaldi	3	-	-	-
Metridea lucens	2	-	-	-
M. longa	4	-	-	4
Pseudocalanus sp.	4	-	-	1
Euphausiid				
Thysanoessa inermis	2	-	7	8
T. raschii	6	-	26	14

Bowhead Feeding, Cross Island Fall

Information on feeding status is available from five animals taken near Cross Island during 1987–2000. Four were considered to have been feeding and one was not feeding.

At least 9 species of prey occurred in whales taken near Cross Island including the following: copepods–3 species; cumaceans–1; gammarid amphipods–2; hyperiid amphipods–2; euphausiids–1 (Appendix 18.1).

Copepods occurred in all three stomach contents samples from Cross Island (Table 18.1). Gammarid amphipods, hyperiid amphipods, and decapods each occurred in two of the three samples, while euphausiids and cumaceans each occurred in one. Only one of the samples from Cross Island was in suitable condition for sorting and volumetric analysis, and it contained >99% copepods. *Calanus hyperboreus* occurred in all three Cross Island stomach samples, and *C. glacialis* occurred in two (Table 18.2).

Bowhead Feeding, Barrow Fall

Information on feeding status is available from 106 bowheads harvested near Barrow during the fall, 1976–2000 (Fig. 18.4). One stomach, from a calf 7.0 m in length, contained only milk, and this animal was not considered in analyses of feeding status. Seventy-seven were considered to have been feeding (Appendix 18.4), and 26 were categorized as not feeding. The feeding status of two whales is uncertain. Of the 103 whales whose feeding status was classified, 36 were ≥13 m long; 27 of those had been feeding and 9 had not. Of the 67 whales <13 m long, 50 had been feeding and 17 not.

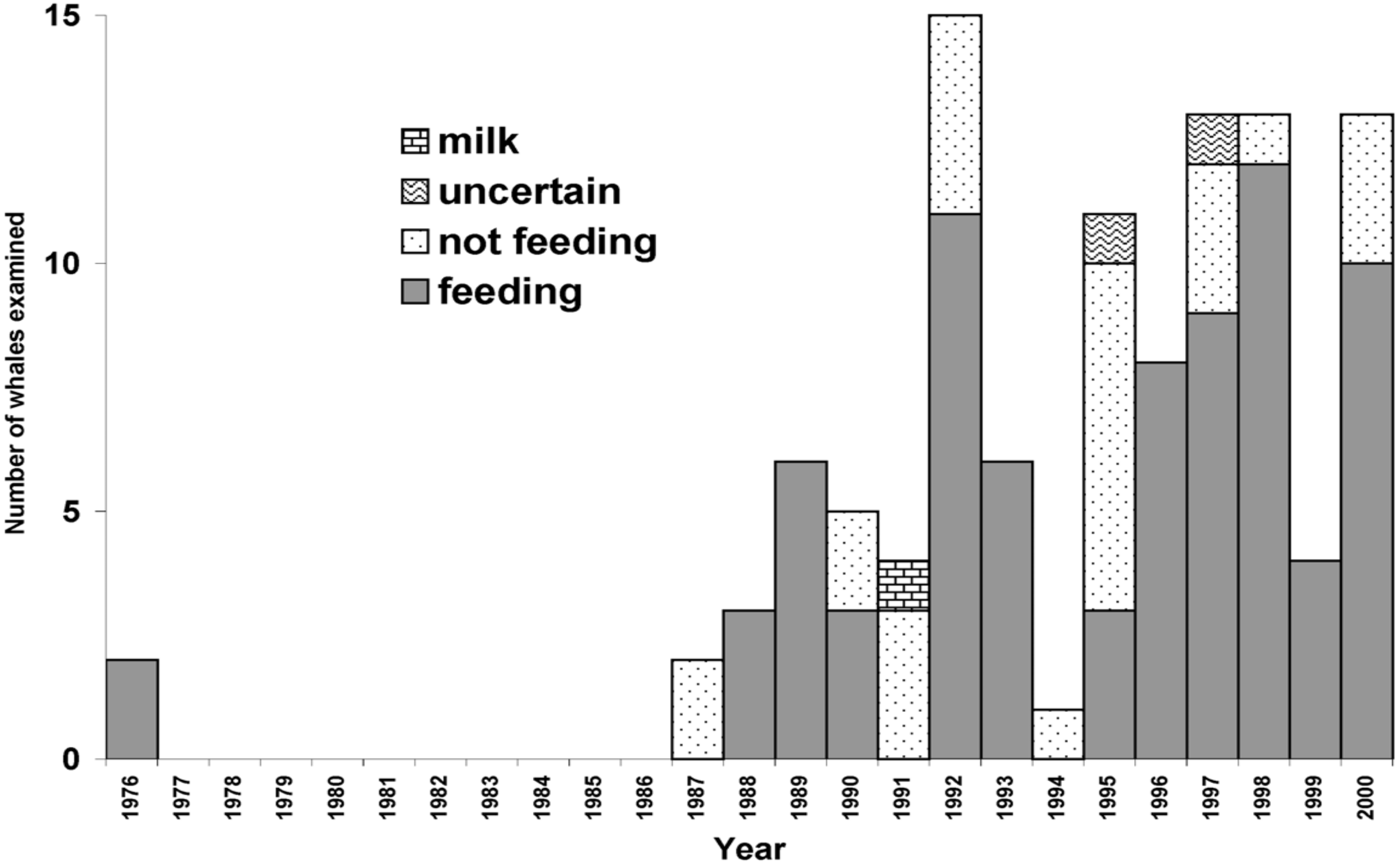

FIGURE 18.4. The feeding status of 106 bowhead whales harvested and examined during the fall in the western Alaskan Beaufort Sea near Barrow, Alaska, 1976–2000. In some of these years, the harvest included additional whales whose stomachs were not examined.

At least 54 species of prey occurred in whales taken near Barrow in fall including the following: cnidarians–1 species; annelids–1; bivalves–1; copepods–5; mysids–3; cumaceans–2; isopods–1; gammarid amphipods–21; hyperiid amphipods–1; euphausiids–2; shrimps–5; and fishes–11 (Appendix 18.1).

Euphausiids were the main prey item in stomach contents samples of bowheads harvested in fall near Barrow, occurring in 94% of the 69 samples (Table 18.1). Copepods occurred in only 20% of the samples. Euphausiids were the dominant prey by volume in 88% of the 64 samples with volumetric data, and copepods were dominant in 5% (Fig. 18.5). The predominant species of euphausiid eaten was *Thysanoessa raschii*, and *Calanus glacialis* and *C. hyperboreus* were the most commonly eaten copepods (Table 18.2).

Bowhead Feeding, Barrow Spring

Information on feeding status is available from 100 bowheads taken near Barrow during the spring, 1969–2000 (Fig. 18.6). One stomach, from a calf 5.3 m in length, contained only milk, and this animal was not considered in analyses of feeding status. Thirty were considered to have been feeding (Appendix 18.5), and 60 were categorized as not feeding. The feeding status of eight whales is uncertain. Of the 90 whales of known length whose feeding status was classified, 19 were ≥13 m long; 6 of those had been feeding and 13 had not. Of the 71 whales <13 m long, 24 had been feeding and 47 not.

At least 40 species of prey occurred in whales harvested near Barrow in spring including the following: cnidarians–1 species; gastropods–6; bivalves–4; copepods–7; mysids–2; cumaceans–2; gammarid amphipods–8; hyperiid amphipods–4; euphausiids–2; shrimps–2; echinoderms–1; and fishes–1 (Appendix 18.1).

Euphausiids occurred in 93% of the 30 samples. Euphausiids were the dominant prey by volume in 63% of the 28 samples with volumetric data and copepods were dominant in 27% (Fig. 18.7). Copepods were the dominant item in 6 of 11 whales taken in 1977–88 but only 1 of 17 taken in 1993–98 (Fig. 18.7). *Thysanoessa raschii* was the most commonly eaten species of euphausiid, and *Calanus glacialis* was the most commonly eaten copepod (Table 18.2).

Comparisons of Bowhead Diet Between Sexes, Sizes, Regions, and Seasons

There was no significant difference in the proportion of bowheads that was feeding in the fall at Kaktovik and Barrow ($\chi^2 = 0.69$; df = 1; $P > 0.1$). For whales harvested near Barrow, a larger proportion was feeding in the fall than in the spring ($\chi^2 = 35.77$; df = 1; $P < 0.001$).

There were differences in the frequency of occurrence of prey types between bowheads harvested in fall at Kaktovik and Barrow (Table 18.1). Copepods occurred more often in whales harvested near Kaktovik ($\chi^2 = 43.04$; df = 1; $P < 0.001$), whereas euphausiids ($\chi^2 = 10.61$; df = 1, $P < 0.005$ and hyperiid amphipods ($\chi^2 = 12.39$; df = 1; $P < 0.001$) occurred more often in whales harvested near Barrow.

Bowheads harvested at Barrow showed seasonal differences in the frequency of occurrence of prey types (Table 18.1), with copepods occurring significantly more often in whales harvested in the spring ($\chi^2 = 31.52$; df = 1; $P < 0.001$). There were also marginally significant ($0.05 < P < 0.1$) differences for isopods and decapods, which were found more frequently in whales harvested in fall. Euphausiids occurred with similar frequency in fall and spring ($\chi^2 = 0.0106$; df = 1; $P >> 0.1$).

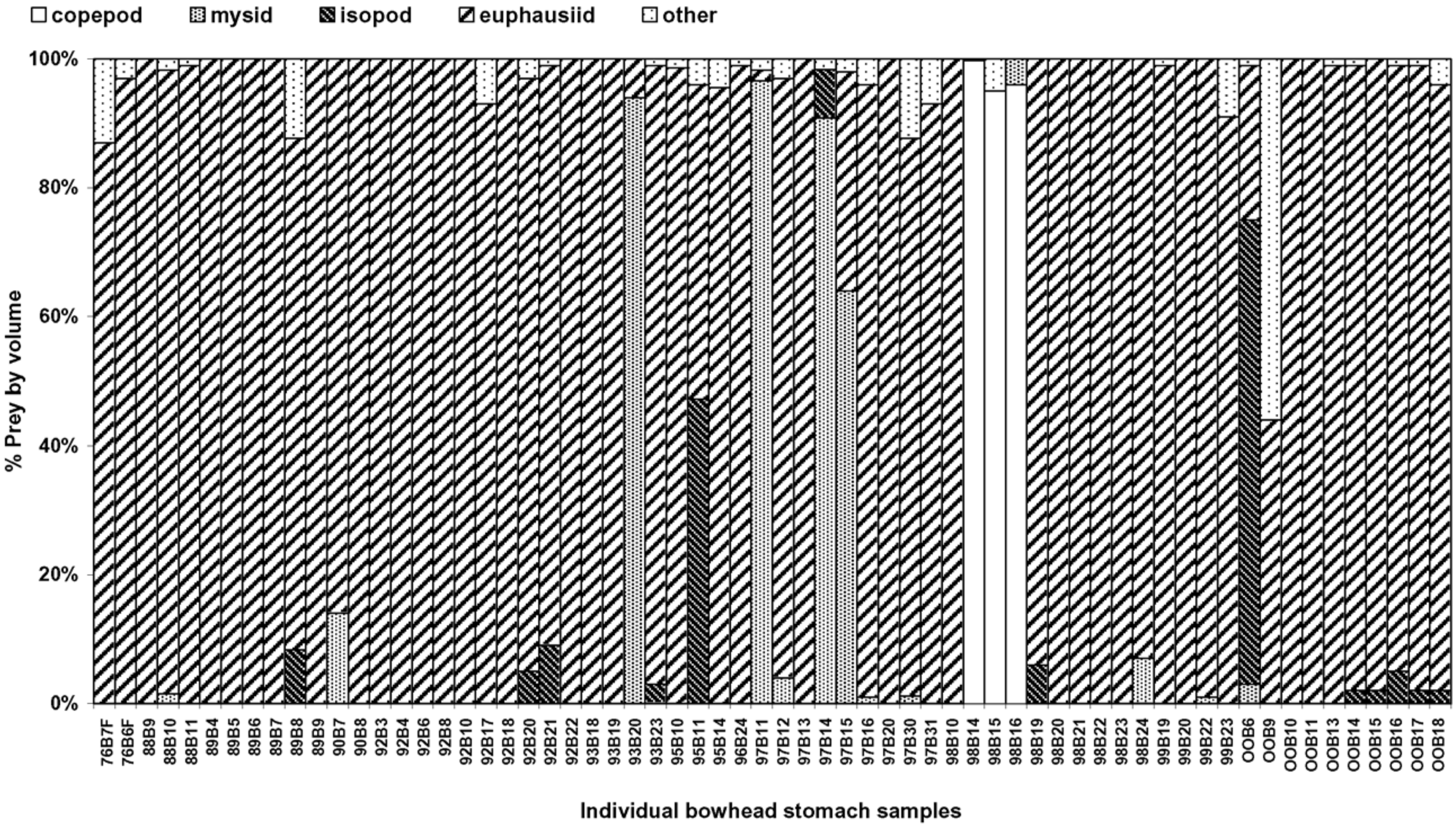

FIGURE 18.5. Percent prey by volume for 64 individual bowhead whales harvested in the western Alaskan Beaufort Sea near Barrow during the fall, 1976–2000.

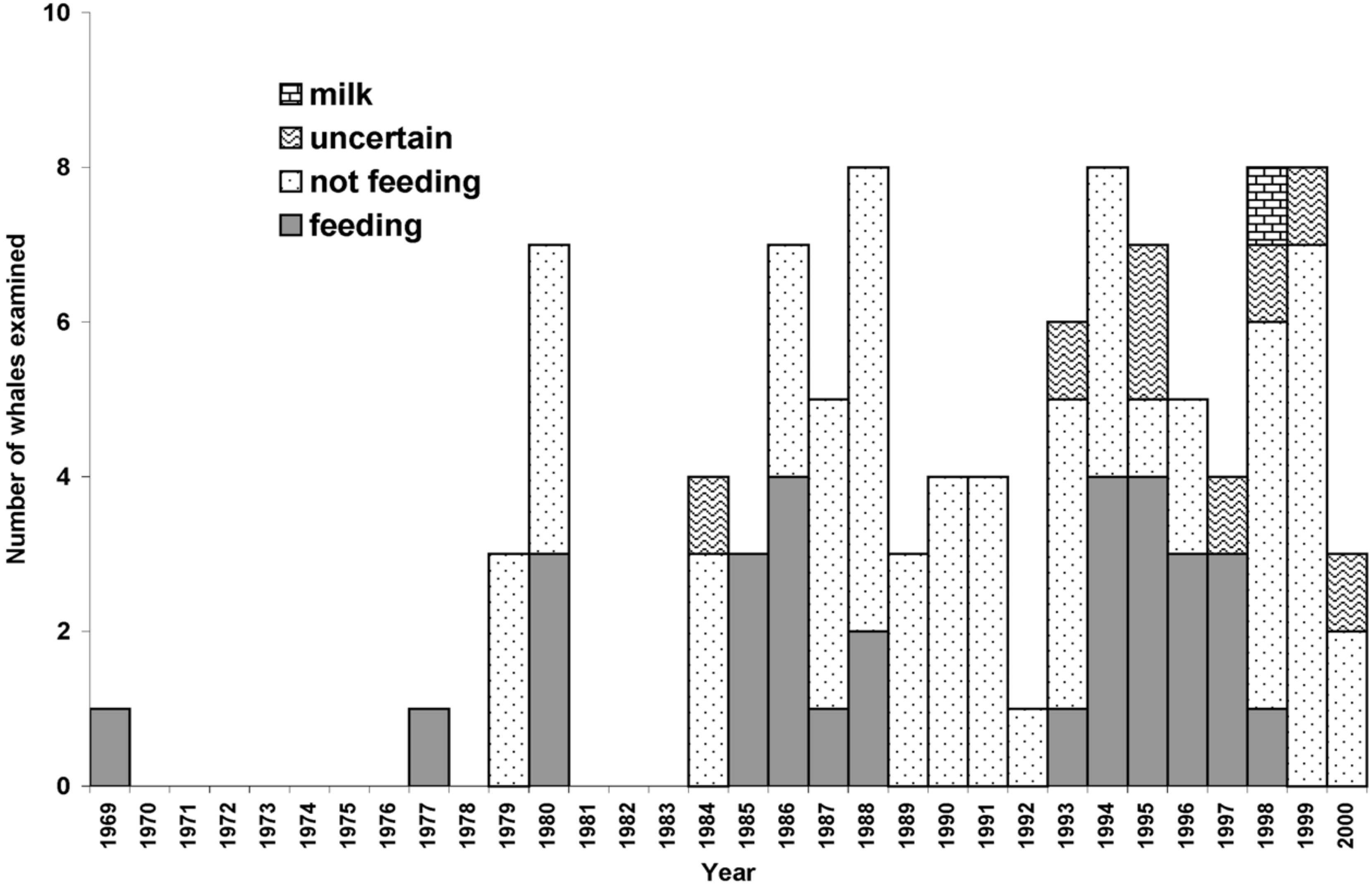

FIGURE 18.6. The feeding status of 100 bowhead whales harvested and examined during the spring in the western Alaskan Beaufort Sea near Barrow, Alaska, 1969–2000. In some of these years, the harvest included additional whales whose stomachs were not examined.

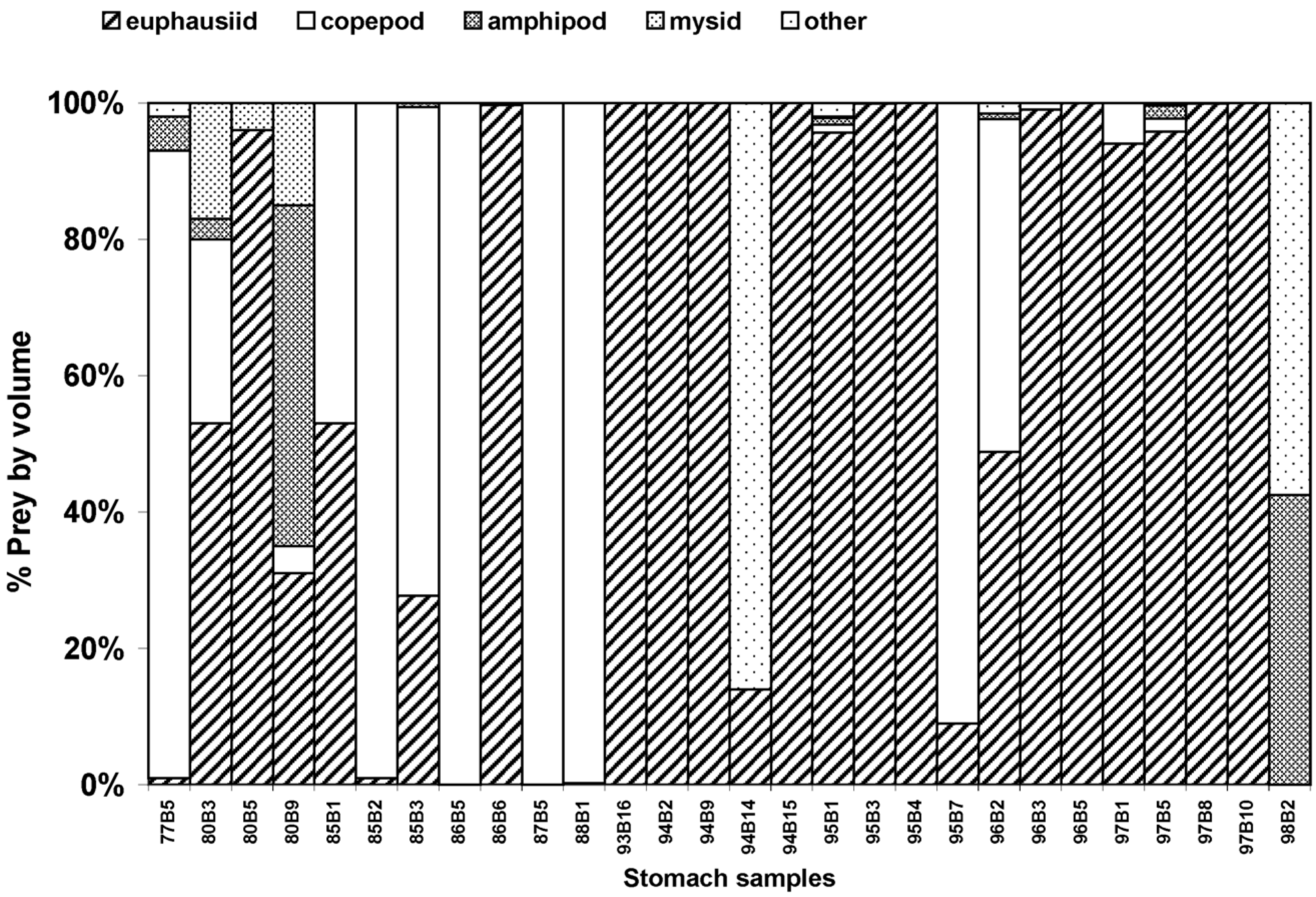

FIGURE 18.7. Percent prey by volume for 28 individual bowhead whales harvested in the western Alaskan Beaufort Sea near Barrow during the spring, 1977–98.

Within each major location and season (Kaktovik fall, Barrow fall, Barrow spring) there were no significant differences in the frequency of occurrence of prey types in male and female bowheads (Bonferonni-adjusted χ^2 tests; $P > 0.1$). Likewise, there were no significant differences in whales <13 m and ≥13 m long ($P > 0.05$), although at Barrow in fall there were marginally ($0.05 < P < 0.1$) more mysids and fish in whales <13 m long. Sample size from Cross Island was too small to test for differences in prey occurrence by sex or size. When all samples were considered in aggregate (Table 18.3), the frequency of occurrence of prey types was virtually identical in males and females ($P > 0.1$ for all tests). There were some small differences between length classes, with copepods, mysids, fishes, and isopods occurring more frequently in small whales, but the differences were not statistically significant ($P > 0.1$ for all tests).

In the principal components analysis (with varimax rotation), the three most important "dietary indices" accounted for 48.9% of the variance in the ranked volumetric data on prey. Multiple regression analysis was applied, in turn, to each of these three indices to determine whether that measure of diet differed with location, season, whale length, or whale sex. All three dietary indices showed a significant effect of season, while location was significant for one index (Table 18.4). There was no evidence for effects of sex, length class, or year on diet ($P > 0.1$ in each case). The index that showed a difference for both location and season (Factor 1) was one that strongly contrasted the ranking of copepods and euphausiids in the diet (Appendix 18.6).

Estimates of the volume of stomach contents are available for 46 bowheads harvested at Kaktovik and Barrow (Appendices 18.3–18.5). The estimates are imprecise and often given as ranges, and therefore they are not suitable for statistical analysis. However, a summary of those observations (Table 18.5) shows that at both Kaktovik and Barrow, fall stomachs frequently contained 20 liters or more, and sometimes had over 100 liters of contents. Estimates of contents volumes at Barrow in the spring were generally lower, and never exceeded 60 liters.

Discussion

Using field records and laboratory results we determined that 105 bowheads taken in the Alaskan Beaufort Sea during September–October had been feeding and 32 had not. There was no appreciable difference in the percentage feeding among Kaktovik, Cross Island, and Barrow (Table 18.6). Our estimate of 77% overall frequency of feeding in fall bowheads is likely to be an underestimate for several reasons. For example, of the five Kaktovik whales that were recorded as not feeding, two were not killed until 24–48 hours after the initial bomb strike, and another was very young, classified as an ingutuk by the whalers. The three Kaktovik whales assigned uncertain feeding status each had small amounts of prey in their stomachs. Also, some stomach contents samples were received in such poor condition (e.g., filled with congealed blood) that locating and identifying prey was difficult or impossible. Stomachs of whales taken in fall often contained relatively large amounts of prey, and were often described as "full" in field records. The frequency of feeding in bowheads taken at Barrow in spring was significantly less than at either Barrow or Kaktovik in the fall, and estimated quantities of contents in the stomach were considerably smaller.

Prior to this study, our understanding of the diet composition of bowhead whales in the Alaskan Beaufort Sea was based on samples collected from 30 animals (Lowry 1993). As a result of this project, quantitative diet data based on laboratory analysis of stomach samples are now available for a total of 123 animals.

TABLE 18.3. Percent frequency of occurrence of major prey types identified in bowhead whales harvested near Kaktovik, Cross Island, and Barrow, separated by sex and size.

Prey type	Males (*n* = 61)	Females (*n* = 58)	Length<13m (*n* = 83)	Length≥13m (*n* = 36)
Copepod	49	50	55	36
Euphausiid	87	88	88	86
Gammarid amphipod	49	55	53	50
Hyperiid amphipod	39	33	35	39
Mysid	43	45	51	28
Fish	23	26	30	11
Decapod	28	28	27	31
Isopod	15	16	18	8
Cumacean	10	16	12	14

TABLE 18.4. *P* values from multiple regression analyses testing for differences in three indices of bowhead diet according to location, season, whale sex and length class, and year. Diet indices ("Factors") are based on a principal components analysis (with varimax rotation) of the rank order of volumetric importance of major prey types identified in 123 bowhead whale stomachs from the Alaskan Beaufort Sea. See Appendix 18.6 for variable weightings in each factor.

Variable	Factor 1	Factor 2	Factor 3
Location	**<0.01**	0.16	0.22
Season	**<0.01**	**<0.01**	**0.01**
Sex	0.52	0.92	0.62
Length class	0.33	0.19	0.23
Year	0.06	0.60	0.10
% variance in diet explained by this factor	18.0	15.4	15.5

TABLE 18.5. Estimates of volume of stomach contents in bowhead whales harvested near Kaktovik and Barrow.

Estimated contents volume	Kaktovik fall (*n* =18)	Barrow fall (*n* = 16)	Barrow spring (*n* = 14)
% with ≥ 20 liters	39	56	29
% with ≥ 100 liters	11	33	0
range (liters)	2–150	1–189	1–60

TABLE 18.6. Percentages of bowhead whales taken in the Alaskan Beaufort Sea that were categorized as feeding, by location, season, and size category. Numbers in parentheses are total sample sizes.

	Length <13m	Length ≥13m	All lengths
Kaktovik fall	85 (20)	78 (9)	83 (29)
Cross Island fall	100 (2)	67 (3)	80 (5)
Barrow fall	75 (67)	75 (36)	75 (103)
Barrow spring	34 (71)	32 (19)	33 (90)

Copepods and euphausiids were the main bowhead prey items near Kaktovik, which agrees with previously presented results from this area (Lowry and Burns 1980; Lowry and Frost 1984; Lowry 1993). Of the two groups, copepods were the most important as they were present in every stomach sample and were essentially the only item in 12 of the 21 stomachs with food (Fig. 18.3). However, euphausiids were also an important prey item and dominated the contents of five whale stomachs. Other crustaceans and fishes also were eaten, but they generally were minor components of samples that consisted mostly of copepods or euphausiids.

This project examined the first three stomach contents samples from bowheads taken near Cross Island. Based on that small sample, whales in the Cross Island area were feeding mostly on copepods.

In the western Beaufort Sea near Barrow the bowhead diet during September–October was dominated by euphausiids, which made up almost the entire contents of 54 of the 64 samples we examined (Fig. 18.5). These results confirm the importance of euphausiids in the fall diet of bowheads in this region, a conclusion that had previously been based on samples from only five stomachs (Lowry 1993). Copepods were the predominant prey in three stomachs and mysids in four. Interestingly, the only whales with copepods dominant were taken on the same day in 1998, and two of the four with mysids dominant were taken in on the same day in 1997. This may be indicative of temporal/spatial patches of prey that are being found and exploited by the whales.

Regional differences in diets of fall-harvested bowheads may be explained by regional differences in prey availability. Copepods are known to dominate the zooplankton of the Canadian and eastern Alaskan Beaufort Sea and euphausiids are not considered abundant there (Bradstreet and Fissel 1986; Chapter 5 of this report). In that region, bowheads often occur at locations where copepods dominate the biomass (Griffiths and Buchanan 1982; Chapter 6 of this report). In contrast, euphausiids have been found in substantial quantities in the western Beaufort Sea, where copepods were less abundant (Griffiths et al. 1987).

In bowheads taken at Barrow during April–June, 14 of 28 samples contained almost entirely euphausiids and 6 had nearly all copepods, but several contained mixtures of different crustacean groups. Copepods occurred significantly more often in whales that fed near Barrow in spring than in fall. This difference could be partly due to the locations where whales are taken, as spring hunting occurs in the Chukchi Sea to the west of Point Barrow and fall whales are taken in the Beaufort Sea mostly to the north and east of the Point (J.C. George, NSB-DWM, pers. comm.). In contrast with previous studies that found that copepods were the dominant prey of bowheads taken during the spring migration in 1980–88 (Carroll et al. 1987; Lowry 1993), this study suggests that euphausiids are overall the more important prey near Barrow in spring as well as autumn. It appears that there may have been a change in the spring diet of bowheads at Barrow, with euphausiids being more important in the 1990s than formerly (Fig. 18.7). It is unknown whether this apparent change in diet near Barrow in spring is due to changes in oceanic conditions that may have altered abundance patterns of copepods or euphausiids, differences in specific locations where whales were harvested or where they were feeding, or some other factor.

The frequencies of occurrence of various prey types in stomachs of male and female bowheads were nearly identical, and indications of slight age/size effects on diet were no more than marginally significant. Lowry (1993) examined size-related differences in diet in a sample of 32 bowheads and concluded there was a slightly greater tendency for benthic taxa to occur in whales <10.5 m long. Our analysis of a larger sample also suggests slight differences in the diet of small (<13 m) versus larger (≥13 m) whales. Prey groups such as mysids, fish, and isopods that occurred relatively infrequently in larger whales were found more commonly in small whales. These differences are slight (Table 18.3) and not statistically significant. The differences may reflect size-related differences in feeding abilities or in feeding areas, as has been suggested for bowheads in the eastern Canadian Arctic (Finley 2001). There was no difference in the frequency with which food was found in stomachs of small and large whales (Table 18.6).

The samples collected and analyzed by this project, combined with previous studies, have resulted in a relatively large set of data on bowhead whale feeding in the Alaskan Beaufort Sea. The frequency of feeding and types of food being eaten are now well described for whales taken at Kaktovik in fall and at Barrow during both fall and spring. It is difficult to use bowhead stomach contents data to estimate the overall diet composition for a location/season for a number of reasons. These include variation in the state of digestion of samples, the wide range in the volumes of collected samples, and the lack of data on total volume of stomach contents. Nonetheless, we calculated preliminary estimates of diet composition based on the data shown in Figures 18.3, 18.5 and 18.7 and two methods of calculation: ***(1)*** averaging the percent volumes of contents for each prey type found in individual whales, and ***(2)*** calculating the percent of times that a prey type was the dominant component of a stomach contents sample. The two methods produced remarkably consistent estimates (Table 18.7).

TABLE 18.7. Estimates of bowhead whale diet in the Alaskan Beaufort Sea based on averaging the percent composition by volume in individual stomach contents samples, and on the percent of times a prey type was the dominant component of stomach contents samples

	Kaktovik (*n* = 21)		Barrow fall (*n* = 64)		Barrow spring (*n* = 28)	
	mean % volume	% times dominant	mean % volume	% times dominant	Mean % Volume	% times dominant
copepod	61	62	5	5	28	27
euphausiid	22	24	84	88	61	63
amphipod	5	5	1	0	4	4
mysid	6	5	6	6	1	0
other	6	5	4	1	5	7

Results of this study change our previous understanding of the feeding ecology of bowhead whales in two important ways. First, feeding near Barrow during the spring migration is not just occasional, but rather a common event as evidenced by the fact that nearly a third of the animals sampled there had been feeding. However, the frequency of feeding is clearly less near Barrow in spring than near either Barrow or Kaktovik in fall, and the amount of food in the stomachs tends to be lower in spring. Second, bowhead whales feed regularly in the nearshore waters of the eastern, central, and western Alaskan Beaufort Sea during September–October. With food found in more than three-quarters of the animals examined, this entire region should be considered an integral part of the summer-fall feeding range of bowheads. This idea is supported by the distribution of sightings of feeding whales made during aerial surveys. When accumulated over many fall seasons, these have been widely distributed across the nearshore region of the Alaskan Beaufort Sea (Ljungblad et al. 1986; Treacy in prep.; see also Figures 6.1A, 9.6–9.9, and 12.5 in Chapters 6, 9, 12). Results of both stomach analysis and aerial observations suggest that reference to the passage of bowheads through this region as a "westward fall migration" is misleading. At the least, it is a very incomplete description of their activities in the region. In fact, a major activity of bowheads in the Alaskan Beaufort Sea during fall is feeding, with whales moving west when prey are not available in sufficient numbers (Chapter 6), or when the whales choose not to feed, or when they combine feeding with simultaneous westward travel (Chapter 12).

Acknowledgements

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Summary

This study documents bowhead whale feeding in the Alaskan Beaufort Sea based on stomach contents of whales harvested by Alaska Natives. We examined field records and archived data from previous studies of bowhead stomach contents, and we analyzed similar samples from 85 additional bowhead whales harvested during 1986–2000 near Kaktovik, Barrow, and Cross Island. All available data from bowheads harvested near those locations were used to characterize and compare diet by harvest location and season (i.e., Kaktovik fall; Barrow fall; Barrow spring), and by whale size and sex.

Thirty-two bowheads harvested near Kaktovik during fall 1979–2000 have been examined for evidence of feeding. Of 29 whales whose feeding status could be classified as "feeding" or "not feeding", at least 83% had been feeding prior to death. Copepods, most commonly *Calanus hyperboreus* and *C. glacialis*, were the most important prey; copepods occurred in all 21 stomachs with food and were the dominant prey by volume in 62% of the samples. Euphausiids, mainly *Thysanoessa raschii,* were also an important food item. Estimated volume of stomach contents was as much as 150 liters, and in 7 of 18 cases was greater than 20 liters.

Four of five bowheads harvested near Cross Island during 1987–2000 were recorded as having been feeding. Copepods were the main prey in the three stomach contents samples examined.

Stomachs of 106 bowheads harvested in fall near Barrow during 1976–2000 were examined. Of the 103 "non-calf" whales that could be classified as "feeding" or "not feeding", at least 75% had been feeding prior to death. Euphausiids were the most important prey; they occurred in 94% of the stomachs with food and were the dominant prey by volume in 88%. Estimated volumes of stomach contents were as much as 189 liters, and in many cases were recorded as ≥100 liters or "full".

Stomachs of 100 bowheads harvested in spring near Barrow during 1969–2000 were examined. Of the 90 whales that could be classified as "feeding" or "not feeding", at least 33% had been feeding prior to death. Euphausiids occurred in 93% of the samples and were the dominant prey in 61%. Copepods were also an important diet item, especially in samples collected before the 1990s. Estimated volumes of stomach contents were smaller than for whales taken in fall, and never exceeded 60 liters.

There was no significant difference in the proportion of bowheads that had been feeding in the fall near Kaktovik and Barrow. However, there was a significant difference in composition of the fall diet at these locations. Copepods occurred more often and were more frequently the dominant prey by volume in whales from Kaktovik. Euphausiids occurred more often and were more frequently the dominant prey by volume in whales from Barrow.

At Barrow, the frequency of feeding in harvested bowheads was significantly greater in the fall than in the spring. Copepods occurred significantly more often in whales harvested near Barrow in the spring than in the fall.

Male and female bowheads ate essentially the same food items. The data suggest the possibility of a slight difference in the prey eaten by small (<13 m) and larger (≥13 m) whales. There was no difference in the frequency of feeding of small versus large whales.

Preliminary estimates of the overall bowhead diet composition by location/season were as follows: Kaktovik fall, 61–62% copepod, 22–24% euphausiid, 15–17% other prey; Barrow fall, 5% copepod, 84–88% euphausiid, 7–11% other prey; and Barrow spring, 27–28% copepod, 61–63% euphausiid, and 10–11% other prey.

Coastal waters of the entire Alaskan Beaufort Sea are used for feeding by bowhead whales during September–October, and this region should be considered as part of their normal summer–fall feeding range. During spring, feeding by bowheads near Barrow is more common than previously thought, but the frequency of feeding is less than in the fall.

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Appendix 18.1. List of prey and other items consumed by bowhead whales harvested in the Alaskan Beaufort Sea, 1969–2000. Locations and seasons where whales were harvested are indicated after each taxon (BS=Barrow/Spring, BF=Barrow/Fall, K=Kaktovik, C=Cross Island). Numbers identify the 16 taxa used in the principal components analysis.

1. CNIDARIA
Scyphozoa $^{\text{BS, BF}}$

2. ANNELIDA
Polychaeta $^{\text{BF}}$

MOLLUSCA
3. **Gastropoda** $^{\text{K}}$
Limacina helicina $^{\text{BS}}$
Margarites sp. $^{\text{BS}}$
Natica sp. $^{\text{BS}}$
Natica clausa $^{\text{BS}}$
Neptunea sp. $^{\text{BS}}$
4. **Bivalvia** $^{\text{BF}}$
Astarte sp. $^{\text{BS}}$
Liocyma fluctuosa $^{\text{BS}}$
Nuculana sp. $^{\text{BS}}$
Tellinidae $^{\text{BS}}$
Yoldia sp. $^{\text{BS, BF}}$

5. CHELICERATA
Pycnogonidae $^{\text{K}}$

CRUSTACEA
6. **Ostracoda** $^{\text{BS}}$
7. **Copepoda** $^{\text{BS, BF, K, C}}$
Aetideidae $^{\text{BF}}$
Calanus sp. $^{\text{BS, BF, K}}$
Calanus cristatus $^{\text{BS}}$
Calanus finmarchicus $^{\text{K}}$
Calanus glacialis $^{\text{BS, BF, K, C}}$
Calanus hyperboreus $^{\text{BS, BF, K, C}}$
Chiridius obtusifrons $^{\text{BS, K}}$
Derjuginia tolli $^{\text{K}}$

Copepoda (cont.)
Euchaetidae $^{\text{K}}$
Euchaeta sp. $^{\text{BS, K}}$
Euchaeta glacialis $^{\text{BS, BF, K, C}}$
Heterorhabdus sp. $^{\text{K}}$
Limnocalanus grimaldii $^{\text{K}}$
Metridea sp. $^{\text{BS, K}}$
Metridea lucens $^{\text{K}}$
Metridea longa $^{\text{BS, K}}$
Pseudocalanus sp. $^{\text{BS, K}}$
8. **Mysidacea** $^{\text{BS, BF, K}}$
Mysis sp. $^{\text{BF, K}}$
Mysis litoralis $^{\text{BS, BF, K}}$
Mysis occulata $^{\text{BF, K}}$
Neomysis sp. $^{\text{BS, BF}}$
Neomysis rayii $^{\text{BS, BF}}$
9. **Cumacea** $^{\text{K, C}}$
Brachydiastylis resima $^{\text{BS}}$
Diastylis sp. $^{\text{BF, K}}$
Diastylis dalli $^{\text{K}}$
Diastylis galbra $^{\text{K}}$
Diastylis sulcata $^{\text{BF}}$
Leuconidae $^{\text{BF}}$
Leucon sp. $^{\text{BF}}$
Leucon nasica $^{\text{BS}}$
10. **Isopoda** $^{\text{K}}$
Munnopsis sp. $^{\text{K}}$
Saduria sp. $^{\text{BF, K}}$
Saduria entomon $^{\text{BF, K}}$
Amphipoda $^{\text{BS, K, C}}$
11. Gammarid amphipods $^{\text{BS, BF, K, C}}$
Acanthostepheia sp. $^{\text{BS, BF, K}}$
Acanthostepheia behringiensis $^{\text{BF,K}}$
Acanthostepheia incarinata $^{\text{K}}$

Amphipoda (cont.)
Acanthostephia malmgreni $^{\text{BF}}$
Aceroides latipes $^{\text{K}}$
Anonyx sp. $^{\text{BS, BF, K, C}}$
Anonyx nugax $^{\text{BS}}$
Ampelisca macrocephala $^{\text{BF}}$
Apherusa glacialis $^{\text{K}}$
Arrhis sp. $^{\text{BF}}$
Atylus carinatus $^{\text{BF, K}}$
Boeckosimus affinis $^{\text{BF}}$
Boeckosimus krassini $^{\text{BF}}$
Boeckosimus litoralis $^{\text{K}}$
Byblis sp. $^{\text{BS, BF}}$
Erichthonius sp. $^{\text{BS}}$
Eusirus cuspidatus $^{\text{BS, BF}}$
Gammarus sp. $^{\text{BS, BF, K}}$
Gammarus zaddachi $^{\text{BF}}$
Gammaracanthus sp. $^{\text{BF}}$
Gammaracanthus loricatus $^{\text{BF,K}}$
Harpinia sp. $^{\text{BS}}$
Lysianassidae $^{\text{BF, K}}$
Melita sp. $^{\text{BF}}$
Melita quadrispinosa $^{\text{BF}}$
Monoculodes sp. $^{\text{BF, K}}$
Monoculodes zervoni $^{\text{BF}}$
Oedicerotidae $^{\text{BF}}$
Onissimus sp. $^{\text{BF, K}}$
Onissimus glacialis $^{\text{K}}$
Onissimus litoralis $^{\text{K}}$
Onissimus nanseni $^{\text{K}}$
Podoceridae $^{\text{BF}}$
Pontoporeia femorata $^{\text{BF}}$
Protomedeia sp. $^{\text{BF}}$
Rhacotropis sp. $^{\text{BS, BF, K}}$

Amphipoda (cont.)
Rozinante fragilis $^{\text{BF, K}}$
Weyprechtia sp. $^{\text{BF, K, C}}$
Weyprechtia heuglini $^{\text{BF, K}}$
Weyprechtia pinguis $^{\text{BF, K}}$
12. Hyperiid amphipods $^{\text{BS, BF, K}}$
Hyperia sp. $^{\text{BS, K}}$
Hyperia galba $^{\text{BS, K}}$
Hyperia medusarum $^{\text{BS, K}}$
Hyperoche medusarum $^{\text{BS}}$
Parathemisto sp. $^{\text{BS}}$
Parathemisto abyssorum $^{\text{BS, K, C}}$
Parathemisto libellula $^{\text{BF, K, C}}$
13. **Euphausiacea** $^{\text{BS, BF, K, C}}$
Thysanoessa sp. $^{\text{BS, BF, K}}$
Thysanoessa inermis $^{\text{BS, BF, K}}$
Thysanoessa raschii $^{\text{BS, BF, K}}$
14. **Decapoda** $^{\text{BF, K, C}}$
Crangonidae $^{\text{K}}$
Argis sp. $^{\text{BS, BF}}$
Eualus sp. $^{\text{BS, BF}}$
Eualus gaimardi $^{\text{BF, K}}$
Heptacarpus sp. $^{\text{BF}}$
Hippolytidae $^{\text{BF}}$
Pandalus goniurus $^{\text{K}}$
Sabinea sp. $^{\text{BF}}$
Sabinea septemcarinata $^{\text{BF, K}}$
Sclerocrangon sp. $^{\text{BF}}$
Sclerocrangon boreas $^{\text{BF}}$
decapod zoea $^{\text{BF, K, C}}$

15. ECHINODERMATA
Ophiuroidea $^{\text{BS}}$

16. VERTEBRATA
Osteichthyes $^{\text{BF, K}}$
Ammodytes sp. $^{\text{BF}}$
Agonidae $^{\text{BF}}$
Gadidae $^{\text{C}}$
Boreogadus sp. $^{\text{BF}}$
Boreogadus saida $^{\text{BS, K}}$
Cottidae $^{\text{BF}}$
Icelinus sp. $^{\text{BF}}$
Lepidopsetta bilinicata $^{\text{BF}}$
Lycodes sp. $^{\text{BF}}$
Myxocephalus sp. $^{\text{BF}}$
Myxocephalus quadricornis $^{\text{K}}$
Pleuronectidae $^{\text{BF}}$
Pungitius pungitius $^{\text{K}}$
Stichaeidae $^{\text{BF}}$
Zoarcidae $^{\text{BF}}$

PHAEOPHYCEAE
plant material $^{\text{BF}}$

OTHER
baleen $^{\text{BS, BF, K, C}}$
bird feathers $^{\text{BF, K}}$
plastic sheeting $^{\text{BF, K}}$
wood $^{\text{BF, K}}$
sediments $^{\text{BS, BF, K}}$

APPENDIX 18.2. Number of bowhead whales stomach samples examined as part of this study. Figures show the number of stomach samples containing recognizable prey, with the total number of samples examined in parentheses. Excludes samples reported in Lowry (1993) and other previous papers.

Year	Barrow Spring	Barrow Fall	Kaktovik	Cross Island
1986	0 (1)	-	-	-
1987	1 (1)	-	-	-
1988	-	-	-	-
1989	-	-	-	-
1990	-	-	1 (1)	-
1991	-	-	-	-
1992	-	-	-	-
1993	1 (4)	6 (6)	-	-
1994	4 (4)	-	-	-
1995	4 (4)	3 (5)	-	-
1996	3 (3)	1 (1)	-	-
1997	3 (3)	9 (9)	3 (4)	-
1998	1 (2)	12 (12)	2 (2)	-
1999	0 (1)	3 (3)	2 (3)	1 (1)
2000	-	9 (10)	1 (3)	2 (2)
Total	17 (23)	43 (46)	9 (13)	3 (3)

APPENDIX 18.3. Whales harvested near **Kaktovik during fall**, 1979–2000, and included in this analysis: identification number, sex, total length, estimated volume of stomach contents, volume of prey in rinsed laboratory sample, and field notes. Dashes indicate that no information is available. Animals classified as not feeding are indicated by *. Animals with uncertain feeding status are indicated by **.

ID	Sex	Total Length (m)	Stomach Content (L)	Lab sample (ml)	Field Notes
79KK1	M	12.7	44	2,406	---
79KK2	F	10.7	18	545	---
79KK3	M	10.3	22	400	---
79KK4	M	10.8	18	131	---
79KK5	M	10.8	37	358	---
81KK1	F	17.4	18	146	---
81KK2	M	14.0	3	19	Krill in the forestomach
81KK3	F	16.2	--	--	Stomach sample contained copepods – lost
82KK1	M	16.0	--	99	A few liters in the stomach
83KK1	F	14.7	38-57	183	Reddish paste containing krill
84KK1	F	9.8	--	--	Several gallons of shrimp-like prey reported
86KK1	F	7.6	>30	11	Stomach completely full; feeding at capture site
86KK2 *	F	17.2	--	--	---
86KK3	M	10.4	15	197	All stomach chambers contained prey
88KK1 *	F	14.9	--	--	---
89KK3 **	M	11.8		--	Euphausiids reported but none in sample
90KK1	F	10.5	--	782	Stomach contained food and much blood
92KK1	F	15.2	>10	730	---
93KK2	M	8.7	--	--	Prey from forestomach sampled - lost
93KK3	M	9.7	--	15	---
97KK1 **	F	8.7	--	--	---
97KK2 *	M	13.2	--	--	---
97KK3	F	8.3	13	57	Reddish fluid and prey in the forestomach
97KK4	M	14.6	2	8	Reddish oily fluid
98KK2	F	8.9	12	103	Reddish fluid and krill in the forestomach
98KK3	M	9.2	11	201	Reddish fluid and krill in the forestomach
99KK1 *	F	7.7	--	--	Clear pink fluid in stomach
99KK2	M	12.9	150	801	A suspension of reddish liquid and prey
99KK3	M	8.3	136	500	Large copepods present
00KK1 *	F	9.2	--	--	Digested prey reported but none in sample
00KK2 **	M	12.1	--	--	Digested prey reported but none in sample
00KK3	F	8.8	15	129	Stomach contains a thick red liquid with prey

APPENDIX 18.4. Whales harvested near **Barrow during fall**, 1976–2000, and included in this analysis: identification number, sex, total length, estimated volume of stomach contents, volume of prey in rinsed laboratory sample, and field notes. Dashes indicate that no information is available. Animals classified as not feeding are indicated by *. Animals with uncertain feeding status are indicated by **.

ID	Sex	Total Length (m)	Stomach Content (L)	Lab sample (ml)	Field Notes
76B6F	F	16.0	--	18	---
76B7F	F	14.3	109	33	---
87B6 *	F	15.7	--	--	Flensers cut open; empty
87B7 *	M	8.5	--	--	Stomach empty
88B9	M	14.6	--	40	Krill mixed with blood and baleen fragments
88B10	M	15.1	--	65	Prey items clearly recognizable
88B11	F	15.6	--	58	Many intact euphausiids present
89B4	M	14.1	1	10	Large amount spilled on ground, probably was full
89B5	M	14.0	--	230	Full stomach
89B6	M	13.2	--	140	Full stomach; stomach punctured
89B7	F	14.6	--	200	Full stomach
89B8	M	11.8	--	24	Full stomach: 1/3 krill, 2/3 seawater
89B9	M	8.2	--	140	Stomach filled to capacity
90B7	F	8.4	--	8	---
90B8	M	12.9	--	70	Stomach quite full with prey
90B9	F	12.9	--	750	Prey mixed with blood and plant matter
90B10 *	F	13.5	--	--	Empty stomach
90B11 *	F	14.0	--	--	Empty stomach
91B9 *	F	7.9	--	--	Stomach filled only with seawater and blood
91B10 *	F	11.2	--	--	Flensers cut open; empty
91B11 *	M	12.0	--	--	Stomach empty
92B3	F	14.6	--	76	Stomach full and distended
92B4	F	16.2	--	500	---
92B5	M	13.7	--	-	Stomach contents with invertebrates spilled on the ground
92B6	M	14.6	10	370	---
92B7 *	F	14.2	--	--	Empty stomach
92B8	F	15.7	--	12	Full stomach
92B10	F	14.6	--	275	---
92B11 *	M	15.0	--	--	Stomach filled with blood
92B12 *	F	12.0	--	--	No prey identified
92B15 *	M	11.7	--	--	Empty stomach
92B17	F	7.5	--	94	---
92B18	M	8.8	--	2	---
92B20	F	8.5	10	140	---
92B21	M	10.0	100	700	Full stomach
92B22	F	9.8	10	135	---
93B18	M	9.3	--	900	Full stomach

APPENDIX 18.4. Continued.

ID	Sex	Total Length (m)	Stomach Content (L)	Lab sample (ml)	Field Notes
93B19	M	13.6	--	26	Full stomach – mostly with liquid
93B20	F	15.5	--	273	Stomach probably full but rolled under viscera
93B21	M	10.9	18-30	456	Stomach contents estimated from 2 chambers with 10% spillage
93B22	M	12.6	--	631	---
93B23	M	8.0	--	3,422	---
94B16 *	F	11.5	--	--	Only water and gravel present
95B9 *	M	17.4	--	--	Empty stomach
95B10	F	15.0	--	720	---
95B11	M	13.0	--	390	Full of water and krill
95B12 *	F	12.3	--	--	Empty stomach
95B13 *	F	16.5	--	--	Empty stomach
95B14	M	13.9	--	662	Full to distension with euphausiids
95B15 **	M	15.8	--	--	Less than 10 prey present
95B16 *	F	14.1	--	--	Only water and gravel present
95B17 *	F	7.5	--	--	Mixture of only blood and seawater(?)
95B18 *	F	7.6	--	--	Contained only bloody water
95B19 *	M	13.1	--	--	Contained only bloody water
96B6	F	12.7	--	N/A	6 liters of stomach contents collected - lost
96B7	M	12.7	--	N/A	6 liters of stomach contents collected - lost
96B8	M	12.7	--	N/A	1.5 liters of stomach contents collected - lost
96B9	F	12.1	--	N/A	1 liter of stomach contents collected – lost
96B10	M	13.4	--	N/A	6 liters of stomach contents collected - lost
96B11	F	14.3	--	N/A	4 liters of stomach contents collected - lost
96B12	F	11.4	--	--	4 liters of stomach contents collected – lost
96B24	F	10.8	20-28	337	---
97B11	M	13.6	--	131	Stomach full of euphausiids
97B12	M	15.3	--	39	Stomach rather full
97B13	M	9.4	23	1,152	Stomach full with 10% lost to spillage
97B14	F	8.6	5-10	82	Stomach about ¼ full
97B15	F	8.9	--	63	Stomach filled with mud containing euphausiids/molluscs
97B16	F	8.3	--	21	---
97B17 *	M	10.5	--	--	No prey present, examined day after butchering
97B18 *	M	10.8	--	--	No prey present, examined day after butchering
97B20	M	8.6	--	255	Very full stomach
97B27 *	M	9.5	--	--	Contained only bloody fluid
97B29 **	M	8.5	--	--	"A few" krill seen in the stomach

APPENDIX 18.4. Continued.

ID	Sex	Total Length (m)	Stomach Content (L)	Lab sample (ml)	Field Notes
97B30	F	8.0	--	8	Mostly krill and bloody fluid
97B31	F	8.8	--	5	---
98B10	F	12.9	189	138	Stomach full to distension
98B14	M	8.2	--	86	Copepods in reddish watery liquid
98B15	F	8.5	--	164	Copepods in reddish watery liquid
98B16	M	9.2	--	133	Copepods in reddish watery liquid; stomach lost to flensing
98B17	M	8.6	--	43	Full stomach; reddish watery liquid with benthic organisms
98B18	M	11.5	--	5	Partly full stomach
98B19	M	9.7	--	227	Very full stomach
98B20	F	11.8	113-151	551	Stomach full to distension
98B21	M	15.1	--	23	---
98B22	F	8.0	113	223	Stomach very full with euphausiids
98B23	M	11.7	--	250	Stomach distended with food
98B24	F	10.3	--	74	Very full stomach
98B25 *	F	9.7	--	--	Contained only bloody fluid
99B19	F	8.1	--	264	Sample collected from spilled contents
99B20	F	9.0	--	181	---
99B22	F	9.7	--	265	Very full stomach
99B23	M	10.9	--	240	---
00B6	M	14.7	--	29	---
00B7*	M	8.7	--	--	Empty stomach
00B8 *	U	8.6	--	142	Sample consisted of thick gray mud
00B9	F	7.9	--	5	---
00B10	F	9.4	--	9	---
00B11	M	13.8	--	6	---
00B12 *	M	10.9	--	--	Empty stomach
00B13	M	9.4	--	481	---
00B14	F	9.9	--	258	Full stomach
00B15	F	8.9	--	795	Stomach mostly full
00B16	F	10.0	>18	619	---
00B17	M	9.5	18-26	586	---
00B18	F	8.9	18	2,339	---

APPENDIX 18.5. Whales harvested near **Barrow during spring**, 1969–2000, and included in this analysis: identification number, sex, total length, estimated volume of stomach contents, volume of prey in rinsed laboratory sample, and field notes. Dashes indicate that no information is available. Animals classified as not feeding are indicated by *. Animals with an uncertain feeding status are indicated by **.

ID	Sex	Total Length (m)	Stomach Content (L)	Lab sample (ml)	Field Notes
69B1	U	U	--	50	---
77B5	M	10.6	--	20	Contents spilled from the stomach
79B1 *	M	8.7	--	--	Stomach empty
79B2 *	M	10.3	--	--	Stomach empty
79B3 *	M	8.3	--	--	Stomach empty
80B1 *	F	10.9	--	--	Contained dark watery fluid
80B3	M	8.5	--	3	---
80B5	M	10.4	1	73	---
80B6 *	M	8.5	--	--	Empty stomach
80B7 *	F	10.0	--	--	Contained congealed blood
80B8 *	M	8.7	--	--	Contained congealed blood
80B9	F	13.6	40	140	38 liters of water and 2 liters of euphausiids
84B1 *	M	9.1	--	--	Empty stomach
84B2 *	F	8.5	--	--	Contained reddish fluid, no prey present
84B3 **	M	7.5	--	--	Less than 10 prey
84B4 *	F	8.3	--	--	Contained reddish fluid, no prey present
85B1	M	9.0	5-10	13	Krill in the forestomach
85B2	M	12.4	16-24	126	---
85B3	M	9.5	5-10	53	Krill found in each stomach chamber; very fresh
86B1	M	8.2	--	--	Small amount of krill in the forestomach and fundic chamber.
86B2	M	8.7	--	--	Small amount of krill in the forestomach and fundic chamber.
86B3 *	F	8.9	--	--	Dark watery fluid only
86B4 *	M	8.9	--	--	Empty stomach
86B5	M	8.1	12	56	12 liters of fluid with krill in the forestomach.
86B6	F	12.3	60	75	Stomach contained about 60 liters solid krill.
86B7 *	M	10.7	--	--	Empty stomach
87B1 *	M	9.3	--	--	Empty stomach
87B2 *	F	9.0	--	--	Empty stomach
87B3 *	M	11.0	--	--	Empty stomach
87B4 *	F	16.8	--	--	Empty stomach
87B5	F	15.7	--	107	---
88B1	F	8.9	--	268	Prey intermixed with blood
88B2 *	M	8.8	--	--	Empty stomach
88B3	F	7.8	8	--	---
88B4 *	F	9.0	--	--	Empty stomach
88B5 *	M	8.9	--	--	Empty stomach
88B6 *	F	8.3	--	--	Empty stomach
88B7 *	F	8.2	--	--	Empty stomach

APPENDIX 18.5. Continued.

ID	Sex	Total Length (m)	Stomach Content (L)	Lab sample (ml)	Field Notes
88B8 *	F	7.5	--	--	Empty stomach
89B1 *	F	9.0	--	--	No prey present
89B2 *	F	14.7	--	--	Empty stomach
89B3 *	F	16.9	--	--	Empty stomach
90B1 *	M	8.4	--	--	Empty stomach
90B3 *	M	11.7	--	--	Empty stomach
90B4 *	F	14.9	--	--	Empty stomach
90B5 *	F	15.9	--	--	Empty stomach
91B1 *	F	7.7	--	--	Empty stomach
91B2 *	F	8.6	--	--	No prey present
91B5 *	F	12.6	--	--	Empty stomach
91B6 *	M	11.0	--	--	Empty stomach
92B1 *	F	8.5	--	--	No prey present
93B3 *	M	13.3	--	--	Empty stomach
93B5 **	F	9.5	--	--	Less than 10 prey
93B9 *	F	9.2	--	--	Dark green liquid only
93B14 *	F	10.5	--	--	Blood only
93B15 *	F	8.7	--	--	Empty stomach
93B16	F	11.0	--	3	---
94B1 *	F	8.5	--	--	Empty stomach
94B2	M	10.2	--	128	At least 2 stomach compartments contained prey
94B8 *	M	7.8	--	--	Empty stomach
94B9	M	10.6	1	160	Stomach contained euphausiids and coelenterate
94B11 *	M	8.7	--	--	Empty stomach
94B12 *	M	8.3	--	--	Empty stomach
94B14	M	8.4	2-4	7	50-100 cc solid material
94B15	M	8.0	--	25	Trace: euphausiids were noted in the pyloric chamber
95B1	M	8.4	4	86	---
95B2 **	F	10.5	--	--	“Undescribed” contents
95B3	F	9.6	37-56	640	Contained prey
95B4	F	8.6	1	13	Prey in the stomach
95B5 **	F	11.7	--	--	Flensers cut stomach, euphausiids reported nearby
95B7	M	15.2	--	1	Much watery fluid in stomach
95B8 *	F	15.2	--	--	Blood present
96B1 *	F	8.5	--	--	Empty stomach
96B2	F	7.7	--	12	Stomach contents quite fresh
96B3	F	7.6	2	23	Maybe a couple liters of krill
96B4 *	F	14.4	--	--	Empty stomach
96B5	F	14.9	--	140	Contents collected from punctured stomach
97B1**	M	10.0	--	18	Stomach contents mostly bloody fluid

APPENDIX 18.5. Continued.

ID	Sex	Total Length (m)	Stomach Content (L)	Lab sample (ml)	Field Notes
97B5	F	10.1	--	53	---
97B8	F	13.6	--	105	Contents collected from stomach
97B10	F	16.7	--	5	---
98B1 *	F	9.2	--	--	Empty stomach
98B2	M	8.5	--	47	Stomach was half full with various benthic prey items.
98B3 *	M	8.5	--	--	Empty stomach
98B4 *	F	13.1	--	--	Empty stomach
98B5 *	M	15.1	--	--	Clear fluid but no prey present
98B6 **	F	10.9	--	--	Less than 10 prey present
98B8 *	M	13.6	--	--	Empty stomach
99B2 **	F	8.2	--	--	“A few” copepods present
99B3 *	F	7.8	--	100	Clear pinkish fluid, no prey present
99B5 *	M	9.0	--	--	Empty stomach
99B8 *	M	11.0	--	--	Empty stomach
99B9 *	M	9.3	--	--	Empty stomach
99B10 *	F	9.4	--	--	Empty stomach
99B12 *	F	9.2	--	--	Empty stomach
99B14 *	M	14.2	--	250	Clear pinkish fluid, no prey present
00B1 *	M	9.4	--	--	Empty stomach
00B2 **	F	14.5	--	--	Flensers cut stomach, less than 10 prey
00B3 *	F	14.6	--	--	Empty stomach

APPENDIX 18.6. Variable weightings from varimax-rotated principal components analysis of the ranked order of importance of prey taxa in bowhead whale stomachs.

Variable	Factor 1	Factor 2	Factor 3
Copepod	3.6393	-0.2684	1.1805
Euphausiid	-1.8970	-0.9822	1.0755
Gamarid amphipod	-0.2754	2.8063	0.3206
Hyperiid amphipod	0.4430	0.0231	1.0826
Mysid	0.2862	1.1176	-2.6272
Fish	-0.0063	0.1257	-1.4615
Decapod	-0.4890	1.7381	1.2454
Isopod	-1.0143	-0.2333	-1.2185
Cumacean	-0.2374	0.0029	-0.0279
Polychaete	-0.2354	-0.6747	-0.2371
Gastropod	0.0813	-0.6261	0.2111
Bivalve	-0.1415	-0.5804	0.0734
Pycnogonid	0.0211	-0.4715	0.0367
Ostracod	0.0311	-0.7021	0.1101
Scyphozoa	-0.1178	-0.7675	0.0933
Ophiura	-0.0880	-0.5078	0.1431

19. FATTY ACIDS IN BOWHEAD WHALES AND POTENTIAL PREY FROM THE ALASKAN BEAUFORT SEA

Sara J. Iverson [1], Lloyd F. Lowry [2] and Gay Sheffield [2]

Introduction

Bowhead whales (*Balaena mysticetus*) spend their life in cold northern waters, and in the western Arctic migrate annually from over-wintering areas in the Bering Sea, along the west coast of Alaska past Point Barrow, then eastward to summering areas in the eastern Beaufort Sea. They usually begin their return westward migration in late summer or fall, passing the coastal village of Kaktovik and then Barrow before entering the Chukchi Sea (Fraker and Bockstoce 1980; Moore and Reeves 1993). Although it is known that bowheads generally feed on zooplankton (Lowry 1993), the species and areas of importance for feeding have been unclear, as has the importance of the eastern Beaufort Sea to annual food consumption. We undertook a pilot study to assess whether analysis of fatty acid signatures in bowheads and their potential prey would be a useful tool for better understanding the foraging ecology and diets of bowheads in Alaskan waters. This was one part of a broader study of the feeding ecology of bowhead whales in the Alaskan Beaufort Sea.

Fatty acids are the largest constituent of lipids and those of carbon chain length 14 or greater are often deposited in animal tissue with minimal modification from diet. Based on this, in recent years fatty acid signature analysis has been developed as a new method to examine foraging ecology in free-ranging animals (Iverson 1993). Lipids in the marine food web are exceptionally complex and diverse. Owing to various restrictions and specificities in the biosynthesis and modification of fatty acids among different taxonomic groups, many components may be traced to a general or even specific ecological origin. Certain "indicator" fatty acids are particularly useful in food web studies because they arise only or mostly from the diet. In phocid seals, ingested fatty acids can be deposited directly into adipose tissue, such that, when a seal is rapidly fattening on a high fat diet, its blubber fatty acid pattern may be nearly identical to that of the diet (Iverson et al. 1995). Even on low fat diets when seals are not rapidly fattening, blubber fatty acids reflect an integration of diet over a period of time (Kirsch et al. 2000). Thus, by sampling a core of blubber from a free-ranging animal, one may obtain information about diet that does not depend on evidence of recent feeding (i.e., stomach contents) or on prey with hard parts. The results may also be indicative of feeding over a longer time interval and larger geographic area than represented in stomach contents.

To date, the methods of fatty acid signature analysis have been used to identify the general trophic level of diets and to detect major and minor shifts in diet within populations (Iverson et al. 1997a; Smith et al. 1997). Fatty acid signatures have indicated that the fine-scale structure of the foraging distribution of harbor seals (*Phoca vitulina richardsi*) could be discerned within Prince William Sound, Alaska

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[1] Department of Biology, Dalhousie University, Halifax, N.S. B3H 4J1. *Phone:* 902-494-2566; *e-mail:* siverson@is.dal.ca

[2] Alaska Department of Fish & Game, Fairbanks, AK Division of Wildlife Conservation, 1300 College Rd., Fairbanks, AK 99701. *Phone:* 907-455-6885; *e-mail:* llowry@eagle.ptialaska.net

(Iverson et al. 1997b). This was likely attributable not only to localized feeding patterns in individual seals, but also to specific differences in the fatty acid composition of prey species depending primarily on their sizes but also habitats (Iverson et al. 1997b). Results from that study as well as studies on the Scotian Shelf of eastern Canada (S. Iverson and W.D. Bowen, unpubl. data) indicate that fatty-acid methods have the ability to accurately identify prey species by their fatty acid signatures, regardless of potential seasonal changes. The method of fatty acid signature analysis is currently being further developed at Dalhousie University to reconstruct the diets of free-ranging seals based on intensive modeling efforts and captive study experiments.

Among the top marine predators, work with fatty acid signatures has progressed rapidly with seals, polar bears and seabirds, primarily because these species return to land at frequent and/or predictable times and thus can be captured and sampled. Cetaceans are more difficult to study because they never move onto land and they rarely are accessible while at sea. Sampling of live cetaceans can generally only be done using remote biopsy techniques, which sample the part of the blubber very near the skin surface. Most cetacean blubber is highly stratified in many physical and biochemical characteristics, including fatty acid patterns, and the outermost layer nearest the skin is relatively inactive. It is the innermost layers (near the body core) that are most physiologically active and where fatty acids from diet are deposited (reviewed in Hooker et al. 2001). Despite these drawbacks, it has been shown that the fatty acid composition of zooplankton and other prey influences the fatty acid composition of blubber lipids of large whales (e.g., Klem 1935; Ackman and Eaton 1966; Pascal and Ackman 1975). However, given the limitations of available biopsy techniques, assessing diets of cetaceans using fatty acids is generally only possible with dead or stranded animals, and thus work to date has been limited. To date, fatty acids have been useful in assessing aspects of diet in belugas, *Delphinapterus leucas*, and northern bottlenose whales, *Hyperoodon ampullatus* (Dahl et al. 2000; Hooker et al. 2001).

The aim of the present pilot study was to examine whether fatty acid signature analysis could be applied successfully to understanding bowhead whale feeding patterns. Samples of bowhead blubber were available from the subsistence harvest by Inupiat whalers, so the usual limitations in applying fatty acid methods to cetaceans did not apply. Our initial question focused on assessing the degree to which fatty acid composition is stratified in bowhead blubber, as is often the case in other cetaceans. With a high degree of stratification, only the inner-most layer of blubber would likely provide useful information about diet. Our second aim was to examine whether fatty acids could be used to detect differences among individual bowhead whales depending upon location, season, sex, or size class. Third, we examined the fatty acid patterns of mixed zooplankton samples collected in the eastern Alaskan Beaufort Sea to assess whether patterns were similar to those observed in the whales. We could thus evaluate the potential for using fatty acids to quantify diet composition. Finally, we analyzed fatty acids in a limited number of samples of potential prey sorted by major taxonomic group. This allowed us to perform a preliminary analysis of the prey composition of bowhead diets based on the fatty acid patterns in potential prey groups and in bowhead blubber.

Methods

Analysis of Fatty Acids in Bowhead Blubber and Prey

Samples of bowhead whale blubber, mixed zooplankton samples, and prey types were provided to Dalhousie University. Bowhead blubber samples were collected by ADF&G and North Slope Borough biologists from the autumn subsistence harvest at Kaktovik and the spring and autumn harvests at Barrow

(Table 19.1). Zooplankton samples were collected by LGL biologists in the eastern part of the Alaskan Beaufort Sea during September of 1998–2000 (see Griffiths and Thomson, Chapter 5). Zooplankton samples from 1998–99 were mixed (unsorted) samples, whereas those from 2000 had been sorted into major taxonomic groups.

Bowhead whale samples consisted of full blubber cores (i.e., through the full layer of blubber from outer skin to muscle). Samples from three whales were chosen for full analysis to evaluate the degree of fatty acid stratification through the bowhead blubber. Those samples were divided into five equal lengths: inner (nearest the body core), mid-inner, mid, mid-outer and outer (nearest the skin surface). Fatty acids from each segment were extracted separately. After these initial analyses it was deemed necessary to analyze only two layers (inner and mid) for the remaining whales.

Samples from a total of 28 whales (Table 19.1), 33 samples of mixed zooplankton, and 32 sorted zooplankton samples, were analyzed. Lipids were extracted quantitatively using a modified Folch method (Folch et al. 1957). Fat content in prey was expressed as an average of duplicate extractions.

For each sample, fatty acid methyl esters were prepared directly from 100 mg of the pure extracted lipid (filtered and dried over anhydrous sodium sulfate), using 1.5 ml 8% boron trifluoride in methanol (w/w) and 1.5 ml hexane, capped under nitrogen, and heated at 100°C for 1 hour. Fatty acid methyl esters were extracted into hexane, concentrated, and brought up to volume (50 mg/ml) with high purity hexane. This method of transesterification, as employed in our lab with fresh reagents, was routinely tested and found to produce identical results to that using Hilditch reagent (0.5 N H2SO4 in methanol).

Duplicate analyses of fatty acid methyl esters were performed on samples using temperature-programmed gas liquid chromatography according to Iverson (1988) and Iverson et al. (1992). We used a Perkin Elmer Autosystem II Capillary FID gas chromatograph (GC) fitted with a 30 m x 0.25 mm (inner diameter) column coated with 50% cyanopropyl polysiloxane (0.25 µm film thickness; J&W DB-23; Folsom, CA). This was linked to a computerized integration system (Turbochrom 4.1 software, PE Nelson). Identifications of fatty acids and isomers were determined from the following sources: known standard mixtures (Nu Check Prep., Elysian, MN); silver–nitrate (argentation) chromatography (Iverson 1988); and GC-mass spectrometry (Hewlett-Packard 6890 GC, 1:20 split injection, Micromass Autospec oa-TOF mass spectrometer, operated at 1000 resolution, scanning masses 120 to 450). Individual fatty acids are expressed as weight percent of total fatty acids after employing mass response factors relative to 18 : 0. Theoretical relative response factors were used for this purpose, with minor adjustments made after tests with quantitative standard mixtures (Nu Check Prep., Elysian, MN). All sample chromatograms and fatty acid identifications were individually checked and corrected, and reintegrated if necessary. Fatty acids are designated by shorthand IUPAC nomenclature of carbon chain length: number of double bonds and location (n-x) of the double bond nearest the terminal methyl group.

Means are presented as mean ± standard error of the mean unless otherwise indicated.

Statistical Analysis of Bowhead Blubber Fatty Acids

Bowhead fatty acid data were analyzed using methods of classification and regression trees (CART) in S-Plus according to methods described in Iverson et al. (1997a) and Smith et al. (1997). In overview, CART uses an algorithm which automatically selects the “best” variable to split data into two named groups (“nodes”) that are as different as possible. The deviance of a node is then a measure of the homogeneity of the observations that fall into each side of that node. The CART algorithm begins at

TABLE 19.1. Bowhead whales analyzed for fatty acid composition of blubber.

ID	Year	Collection location	Season	Sex	Body length (m)	Total core length (cm)	No. of layers analyzed
97B6	1997	Barrow	Spring	F	13.20	16.2	2
97B7				F	13.20	17.2	2
97B11			Fall	M	13.62	17.8	2
97B12				M	15.28	12.3	2
97B13				M	9.40	14.9	2
97B14				F	8.58	12.3	2
97B15				F	8.86	15.9	2
97B16				F	8.30	17.5	2
97B17				M	10.46	16.4	2
97B18				M	10.77	16.7	2
97B19				F	9.29	17.8	2
97KK1		Kaktovik	Fall	F	8.72	13.5	2
97KK2				M	13.16	23.0	2
97KK3				F	8.31	15.4	2
97KK4				M	14.58	21.3	2
98KK1	1998	Kaktovik	Fall	M	10.42	16.2	2
98KK2				F	8.90	16.6	2
98KK3				M	9.24	16.8	2
99B13	1999	Barrow	Spring	M	14.09	21.8	2
99B14				M	14.15	25.9	2
99B15				M	-	18.9	2
99B16				F	14.83	23.1	2
99B19			Fall	F	8.05	16.4	5
99B20				F	9.03	19.8	5
99B24				M	8.84	22.8	5
99KK1		Kaktovik	Fall	F	7.70	16.1	2
99KK2				M	12.88	28.5	2
99KK3				M	8.33	16.3	2

the root node by considering all possible ways to split the data, i.e. all variables (fatty acids) and all possible splitting points within each variable, and chooses that split which maximizes the difference at that node. The observations (whales or prey) in that split are then sent down one of two branches. This splitting is continued in a tree-like form and occurs until one of two stopping criteria (based on a minimum number of observations in a node or a minimum deviance of a node relative to the root node) is met. Tree growth (splitting) ends at a terminal node where a classification is made and the associated misclassification rate (number of observations not correctly classified in the node) is given.

Preliminary Modeling of Bowhead Diets

The use of fatty acid data to estimate diet composition requires "quantitative fatty acid signature analysis" (QFASA). This involves the development of a statistical model that takes account of fatty acid signatures from all possible prey species. QFASA computes, by maximum-likelihood methods, the mixture of prey signatures (species and proportions) most likely to create a signature similar to that of the predator. Such a statistical program must eventually incorporate information on the full range of potential prey signatures and the variability in these signatures with factors such as size-class and geographical location. The mathematical model must also weight the individual fatty acids as a function of their ability to be biosynthesized by the predator. Finally, the relative weighting of prey signatures must reflect the proximate fat content of each prey type, as species with higher fat content will contribute relatively more to the predator's fatty acid "signature" than species of lower fat content.

A model of this sort to estimate the diets of Hawaiian monk seals (*Monachus schauinslandi*) has been under development for several years (Iverson et al., in prep.). We have used experiments on both captive seals and captive mink (*Mustela vison*) to verify the working of the QFASA model and to make improvements as necessary. The objective has been to try to estimate the composition of a predator's diet based on the relationship of its fatty acid signature to the signatures of potential prey. The approach is to take a weighted mixture of the fatty acid profiles of the prey types and to choose the weighting that minimizes the distance of the weighted diet from the predator or predators under consideration, i.e., to minimize how far the predicted diet is from the actual diet. The ultimate success of the QFASA modeling process depends upon having a comprehensive and representative data base on fatty acid signatures in the potential prey. Although we currently have fatty acid data from only seven categories of bowhead prey, we performed a QFASA exercise as a preliminary test of the value of this method in evaluating the composition of the bowhead diet.

Results and Discussion

The full lists of fatty acids identified and quantified in bowhead blubber, mixed zooplankton, and various major groups of zooplankton are presented in Tables 19.2, 19.3, and 19.4, respectively.

Zooplankton were relatively high in fat content, averaging 4.2% fat (range 1–8%) in 1998 and 9.1% fat (range 4–13%) in 1999 (Table 19.3). This difference in fat content between years likely resulted from differences in the species compositions of the zooplankton mixtures in the two years, and/or year-to-year differences in fat content. Data from sorted prey indicated that copepods had the highest fat content at 9.6%, followed by amphipods (6–8%), euphausiids (4.5%), and fish (4.9%). However, the available data are too limited for any evaluation of variation in fat content of potential bowhead prey.

The degree of fatty-acid stratification in the blubber of three individual bowheads (Fig. 19.1) was less than that so-far observed in any other cetacean. In fact, the stratification was quite minimal, which suggests that most portions of the blubber will provide at least some information about diet. However, the inner-most portion likely reflects the most recent diet, and we therefore used inner layer data only in further analyses and presentations.

Although sample sizes of whales are limited, differences in blubber fatty acids (and thus diet) are apparent between samples collected at Barrow in spring, Kaktovik in fall, and Barrow in fall (Fig. 19.2). Classification and regression tree (CART) analysis confirmed this (Fig. 19.3) even though CART generally performs poorly with small sample sizes. Fatty acid composition of bowhead blubber and the mixed zooplankton samples also differed somewhat between years (Table 19.2, Fig. 19.2).

TABLE 19.2. Fatty acid composition of bowhead whale blubber, expressed as weight percent of total fatty acids. See Table 19.1 for sample sizes.

Fatty	1997		1998		1999	
Acid	inner	mid	inner	mid	inner	mid
12:0	0.08 ± 0.01	0.07 ± 0.00	0.09 ± 0.02	0.06 ± 0.01	0.08 ± 0.01	0.07 ± 0.00
13:0	0.02 ± 0.00	0.01 ± 0.00	0.02 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00
Iso14	0.02 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00
14:0	4.63 ± 0.15	4.45 ± 0.08	5.16 ± 0.20	4.53 ± 0.08	4.32 ± 0.23	4.44 ± 0.13
14:1w9	0.17 ± 0.02	0.12 ± 0.01	0.18 ± 0.03	0.11 ± 0.01	0.20 ± 0.03	0.11 ± 0.01
14:1w7	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.01	0.05 ± 0.00	0.04 ± 0.00	0.05 ± 0.00
14:1w5	0.27 ± 0.03	0.45 ± 0.04	0.21 ± 0.02	0.39 ± 0.02	0.22 ± 0.03	0.40 ± 0.05
Iso15	0.12 ± 0.00	0.11 ± 0.00	0.12 ± 0.00	0.10 ± 0.01	0.11 ± 0.01	0.10 ± 0.00
Anti15	0.04 ± 0.00	0.04 ± 0.00	0.04 ± 0.00	0.04 ± 0.00	0.03 ± 0.00	0.03 ± 0.00
15:0	0.26 ± 0.01	0.25 ± 0.01	0.26 ± 0.01	0.25 ± 0.00	0.23 ± 0.01	0.23 ± 0.01
15:1w8	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.02 ± 0.00	0.03 ± 0.00
15:1w6	0.02 ± 0.00	0.03 ± 0.00	0.02 ± 0.00	0.03 ± 0.00	0.02 ± 0.00	0.03 ± 0.00
Iso16	0.06 ± 0.00	0.05 ± 0.00	0.06 ± 0.01	0.05 ± 0.00	0.06 ± 0.01	0.05 ± 0.01
16:0	11.78 ± 0.56	10.07 ± 0.41	14.35 ± 0.54	10.98 ± 0.38	11.72 ± 0.71	10.22 ± 0.53
16:1w11	0.40 ± 0.01	0.44 ± 0.01	0.44 ± 0.04	0.44 ± 0.01	0.41 ± 0.02	0.46 ± 0.02
16:1w9	0.21 ± 0.01	0.21 ± 0.00	0.20 ± 0.02	0.23 ± 0.01	0.19 ± 0.02	0.21 ± 0.01
16:1w7	15.93 ± 0.58	18.82 ± 0.44	15.03 ± 0.67	18.86 ± 0.42	14.71 ± 0.61	17.48 ± 0.45
7Me16:0	0.23 ± 0.01	0.26 ± 0.01	0.24 ± 0.02	0.25 ± 0.01	0.21 ± 0.01	0.25 ± 0.01
16:1w5	0.02 ± 0.00	0.02 ± 0.00	0.07 ± 0.02	0.02 ± 0.00	0.02 ± 0.00	0.03 ± 0.00
16:2w6	0.07 ± 0.00	0.07 ± 0.00	0.07 ± 0.01	0.06 ± 0.00	0.07 ± 0.01	0.06 ± 0.00
Iso17	0.09 ± 0.01	0.08 ± 0.01	0.10 ± 0.01	0.09 ± 0.01	0.08 ± 0.01	0.07 ± 0.01
16:2w4	0.05 ± 0.00	0.04 ± 0.00	0.04 ± 0.00	0.04 ± 0.00	0.04 ± 0.00	0.03 ± 0.00
16:3w6	0.73 ± 0.01	0.77 ± 0.01	0.75 ± 0.04	0.78 ± 0.01	0.69 ± 0.02	0.75 ± 0.02
17:0	0.15 ± 0.01	0.12 ± 0.01	0.14 ± 0.02	0.13 ± 0.01	0.14 ± 0.02	0.12 ± 0.01
16:3w4	0.26 ± 0.03	0.21 ± 0.01	0.27 ± 0.07	0.20 ± 0.00	0.26 ± 0.04	0.23 ± 0.02
17:1	0.16 ± 0.02	0.18 ± 0.01	0.17 ± 0.02	0.20 ± 0.01	0.16 ± 0.02	0.18 ± 0.02
16:3w1	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
16:4w3	0.05 ± 0.00	0.05 ± 0.00	0.04 ± 0.00	0.04 ± 0.00	0.04 ± 0.00	0.04 ± 0.00
16:4w1	0.37 ± 0.04	0.30 ± 0.02	0.45 ± 0.15	0.30 ± 0.02	0.39 ± 0.07	0.35 ± 0.04
18:0	2.60 ± 0.14	2.06 ± 0.13	2.94 ± 0.25	2.32 ± 0.14	2.63 ± 0.17	2.17 ± 0.17
18:1w13	0.05 ± 0.01	0.05 ± 0.01	0.05 ± 0.01	0.07 ± 0.02	0.05 ± 0.02	0.07 ± 0.02
18:1w11	2.10 ± 0.20	2.54 ± 0.34	1.23 ± 0.14	1.81 ± 0.22	1.91 ± 0.15	2.37 ± 0.34
18:1w9	11.70 ± 0.80	11.89 ± 0.46	13.19 ± 1.56	13.30 ± 0.20	11.96 ± 1.19	12.42 ± 0.76
18:1w7	5.03 ± 0.29	5.39 ± 0.21	5.25 ± 0.27	5.74 ± 0.17	4.24 ± 0.29	5.05 ± 0.24
18:1w5	0.58 ± 0.02	0.61 ± 0.02	0.47 ± 0.02	0.56 ± 0.01	0.54 ± 0.02	0.58 ± 0.02
18:2d5,11	0.06 ± 0.00	0.06 ± 0.00	0.04 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00
18:2w7	0.08 ± 0.00	0.08 ± 0.00	0.07 ± 0.00	0.08 ± 0.00	0.07 ± 0.01	0.08 ± 0.01
18:2w6	0.65 ± 0.01	0.65 ± 0.01	0.62 ± 0.01	0.62 ± 0.02	0.62 ± 0.03	0.63 ± 0.02
18:2w4	0.16 ± 0.01	0.18 ± 0.01	0.14 ± 0.01	0.17 ± 0.01	0.12 ± 0.01	0.16 ± 0.01
18:3w6	0.12 ± 0.01	0.12 ± 0.00	0.11 ± 0.00	0.13 ± 0.01	0.12 ± 0.01	0.12 ± 0.01
18:3w4	0.28 ± 0.01	0.30 ± 0.01	0.25 ± 0.01	0.31 ± 0.01	0.25 ± 0.02	0.28 ± 0.01
18:3w3	0.31 ± 0.01	0.33 ± 0.01	0.26 ± 0.02	0.30 ± 0.01	0.26 ± 0.02	0.28 ± 0.01
18:3w1	0.03 ± 0.00	0.03 ± 0.00	0.02 ± 0.01	0.04 ± 0.00	0.02 ± 0.01	0.02 ± 0.01
18:4w3	0.70 ± 0.05	0.67 ± 0.03	0.65 ± 0.11	0.60 ± 0.04	0.75 ± 0.13	0.65 ± 0.04
18:4w1	0.45 ± 0.02	0.51 ± 0.02	0.41 ± 0.06	0.54 ± 0.03	0.43 ± 0.03	0.50 ± 0.03
20:0	0.09 ± 0.01	0.07 ± 0.00	0.08 ± 0.01	0.06 ± 0.00	0.09 ± 0.01	0.07 ± 0.00
20:1w11	1.89 ± 0.11	1.93 ± 0.18	1.58 ± 0.05	1.69 ± 0.16	1.98 ± 0.16	2.01 ± 0.15
20:1w9	9.16 ± 0.95	8.75 ± 0.70	6.80 ± 0.65	7.44 ± 0.42	9.42 ± 1.27	9.04 ± 0.95

…continued

TABLE 19.2 (continued).

Fatty Acid	1997 inner	1997 mid	1998 inner	1998 mid	1999 inner	1999 mid
20:1w7	1.79 ± 0.19	1.56 ± 0.09	1.47 ± 0.02	1.39 ± 0.10	1.78 ± 0.23	1.51 ± 0.14
20:2w9	0.14 ± 0.01	0.11 ± 0.00	0.12 ± 0.01	0.10 ± 0.00	0.14 ± 0.01	0.12 ± 0.01
20:2w6	0.16 ± 0.01	0.16 ± 0.01	0.15 ± 0.00	0.15 ± 0.00	0.15 ± 0.01	0.15 ± 0.01
20:3w6	0.07 ± 0.00	0.07 ± 0.00	0.06 ± 0.00	0.07 ± 0.00	0.07 ± 0.00	0.07 ± 0.00
20:4w6	0.28 ± 0.01	0.27 ± 0.01	0.30 ± 0.03	0.29 ± 0.01	0.30 ± 0.03	0.27 ± 0.02
20:3w3	0.05 ± 0.01	0.06 ± 0.01	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.04 ± 0.00
20:4w3	0.44 ± 0.02	0.48 ± 0.02	0.36 ± 0.01	0.44 ± 0.01	0.43 ± 0.02	0.44 ± 0.01
20:5w3	9.50 ± 0.39	9.94 ± 0.42	10.60 ± 0.43	10.35 ± 0.26	10.83 ± 0.87	10.44 ± 0.68
22:1w11	4.00 ± 0.41	4.75 ± 0.32	3.32 ± 1.04	4.02 ± 0.11	4.18 ± 1.02	5.08 ± 0.53
22:1w9	1.24 ± 0.16	1.08 ± 0.08	0.97 ± 0.18	0.93 ± 0.01	1.41 ± 0.27	1.21 ± 0.14
22:1w7	0.28 ± 0.03	0.26 ± 0.02	0.21 ± 0.05	0.22 ± 0.01	0.28 ± 0.06	0.27 ± 0.03
22:2w6	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
21:5w3	0.43 ± 0.02	0.35 ± 0.01	0.43 ± 0.04	0.37 ± 0.02	0.45 ± 0.02	0.36 ± 0.01
22:4w6	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	0.02 ± 0.00
22:5w6	0.09 ± 0.01	0.07 ± 0.01	0.08 ± 0.02	0.05 ± 0.00	0.08 ± 0.01	0.06 ± 0.01
22:4w3	0.08 ± 0.02	0.09 ± 0.02	0.04 ± 0.01	0.04 ± 0.01	0.05 ± 0.00	0.06 ± 0.01
22:5w3	3.56 ± 0.10	3.05 ± 0.11	3.43 ± 0.04	3.16 ± 0.02	3.63 ± 0.17	3.08 ± 0.09
22:6w3	5.17 ± 0.17	3.93 ± 0.11	5.39 ± 0.29	4.16 ± 0.08	5.80 ± 0.41	4.00 ± 0.14
24:1w9	0.05 ± 0.01	0.05 ± 0.00	0.02 ± 0.01	0.05 ± 0.00	0.05 ± 0.01	0.05 ± 0.01

There was also evidence of differences in fatty acids and thus diet between small and large bowheads (< or > 12 m long) and between male and female bowheads. This is illustrated using two important dietary indicator fatty acids (Fig. 19.4, 19.5), and was also supported by CART analyses (Fig. 19.6, 19.7). In these preliminary analyses, size groups may be largely confounded with sex groups. A larger sample size would be required to further evaluate these possible size and gender effects.

Patterns of major fatty acids of mixed zooplankton are shown in Fig. 19.8. The important issue for this study is how fatty acids in zooplankton compare to those in bowhead blubber. If bowheads were feeding in the Beaufort Sea, fatty acids in the blubber of whales harvested near Kaktovik and Barrow in the late summer and fall should reflect those of prey organisms in the Beaufort Sea during summer and fall. We had samples of both bowheads and mixed zooplankton from the late summer/fall periods of 1998 and 1999. In general, patterns of fatty acids found in the mixed zooplankton were quite similar to those in the bowheads analyzed (Fig. 19.9). In particular, the mass percentage of dietary indicator 20:1w9 was nearly identical in whales and prey, and values in whales and prey changed in similar ways from one year to the next. Dietary indicators whose levels are always somewhat reduced in predators compared to their prey, such as 20:5w3 and 22:1w11, also showed consistent differences between years. The high levels of these fatty acids in bowheads indicate that their prey must have contained even higher levels, and the mixed zooplankton samples did show higher levels than bowhead blubber. Other patterns, such as low 20:1w11 levels as compared to the isomer 20:1w9, are unusual in Alaska ecosystems (Iverson et al. 1997b). This pattern is found in both bowheads and the mixed zooplankton from the Beaufort Sea (Fig. 19.8).

TABLE 19.3. Fat and fatty acid composition of mixed zooplankton samples from the Eastern Alaskan Beaufort Sea, expressed as weight percent of total fatty acids.

	1998 (*n* = 23)	1999 (*n* = 10)
Fat %	4.16 ± 0.42	9.07± 0.96
12:0	0.26± 0.01	0.13± 0.01
13:0	0.06± 0.00	0.02± 0.00
Iso14	0.05± 0.00	0.02± 0.00
14:0	6.52± 0.32	4.00± 0.18
14:1w9	0.54± 0.03	0.17± 0.02
14:1w7	0.09± 0.01	0.04± 0.00
14:1w5	0.16± 0.01	0.17± 0.00
Iso15	0.26± 0.02	0.09± 0.01
Anti15	0.09± 0.01	0.05± 0.00
15:0	0.34± 0.02	0.14± 0.01
15:1w8	0.13± 0.01	0.05± 0.00
15:1w6	0.03± 0.00	0.02± 0.00
Iso16	0.05± 0.01	0.00± 0.00
16:0	7.35± 0.44	4.32± 0.32
16:1w11	0.24± 0.02	0.24± 0.01
16:1w9	0.19± 0.02	0.09± 0.01
16:1w7	17.86 ± 0.30	21.19 ± 0.24
7Me16:0	0.95± 0.11	0.32± 0.03
16:1w5	0.05± 0.01	0.01± 0.00
16:2w6	0.24± 0.01	0.20± 0.01
Iso17	0.08± 0.01	0.06± 0.00
16:2w4	0.03± 0.00	0.05± 0.00
16:3w6	1.26± 0.08	1.21± 0.03
17:0	0.07± 0.01	0.03± 0.00
16:3w4	1.59± 0.10	1.25± 0.04
17:1	0.20± 0.04	0.07± 0.00
16:3w1	0.00± 0.00	0.00± 0.00
16:4w3	0.05± 0.01	0.14± 0.12
16:4w1	2.71± 0.17	2.38± 0.16
18:0	0.39± 0.06	0.28± 0.03
18:1w13	0.01± 0.00	0.03± 0.02
18:1w11	0.00± 0.00	0.02± 0.01
18:1w9	3.97± 0.39	2.48± 0.22
18:1w7	1.47± 0.24	1.49± 0.04
18:1w5	0.77± 0.04	0.57± 0.04
18:2d5,11	0.01± 0.00	0.01± 0.00
18:2w7	0.00± 0.00	0.01± 0.00
18:2w6	0.98± 0.08	0.62± 0.01
18:2w4	0.15± 0.01	0.18± 0.00
18:3w6	0.28± 0.01	0.34± 0.01
18:3w4	0.09± 0.01	0.07± 0.00
18:3w3	0.57± 0.05	0.33± 0.01
18:3w1	0.10± 0.01	0.03± 0.00
18:4w3	3.91± 0.22	2.42± 0.05
18:4w1	0.36± 0.03	0.40± 0.01
20:0	0.11± 0.01	0.03± 0.00
20:1w11	0.43± 0.03	0.69± 0.03
20:1w9	6.90± 0.51	9.89± 0.14
20:1w7	0.72± 0.12	1.67± 0.08
20:2w9	0.11± 0.01	0.11± 0.01
20:2w6	0.13± 0.01	0.13± 0.00
20:3w6	0.05± 0.00	0.09± 0.01
20:4w6	0.31± 0.03	0.76± 0.09
20:3w3	0.01± 0.00	0.02± 0.00
20:4w3	0.47± 0.01	0.51± 0.01
20:5w3	17.39 ± 0.51	18.34 ± 0.39
22:1w11	5.61± 0.36	9.15± 0.21
22:1w9	1.23± 0.16	2.25± 0.08
22:1w7	0.25± 0.03	0.50± 0.02
22:2w6	0.01± 0.00	0.00± 0.00
21:5w3	0.31± 0.01	0.17± 0.01
22:4w6	0.01± 0.01	0.01± 0.00
22:5w6	0.12± 0.01	0.09± 0.00
22:4w3	0.05± 0.00	0.08± 0.00
22:5w3	0.86± 0.04	1.29± 0.05
22:6w3	7.88± 0.40	5.45± 0.19
24:1w9	0.12± 0.01	0.16± 0.03

Patterns of major fatty acids in the major taxa of zooplankton differed substantially. The seven general types of zooplankton contained quite different levels of many fatty acids (Fig. 19.10). In order to investigate the similarity and differences of the various prey types, including those with very small sample sizes, a hierarchical cluster analysis was performed on the prey means. The Kulback–Liebler distance measure was used to determine how similar two prey types were with respect to their fatty acid signatures. The average linkage method was used, which tends to identify spherical clusters. Hierarchical clustering methods produce dendrograms, which indicate how similar prey types may be to one another and if there are natural groupings of types (Fig. 19.11). In general, the broad categories of zooplankton were readily separated from one another based on their fatty acid content.

Table 19.4. Fat and fatty acid composition of major categories of zooplankton from the Eastern Alaskan Beaufort Sea. Fatty acid composition is expressed as weight percent of total fatty acids.

	Chaetognath (*n* = 5)	Copepod (*n* =7)	Euphausiid (*n* = 5)	Fish (*n* = 5)	Gammarid amphipod (*n* = 2)	Hyperiid amphipod (*n* = 6)	Mysid (*n* = 2)
Fat %	4.17 ± 0.64	9.59 ± 0.74	4.51 ± 0.54	4.92 ± 0.46	6.48 ± 1.68	7.88 ± 0.66	2.69
12:0	0.09 ± 0.02	0.26 ± 0.04	0.15 ± 0.02	0.19 ± 0.06	0.10 ± 0.06	0.16 ± 0.03	0.52 ± 0.05
13:0	0.02 ± 0.01	0.03 ± 0.01	0.18 ± 0.07	0.02 ± 0.01	0.03 ± 0.01	0.03 ± 0.00	0.05 ± 0.01
Iso14	0.02 ± 0.00	0.03 ± 0.01	0.15 ± 0.05	0.07 ± 0.04	0.02 ± 0.01	0.10 ± 0.04	0.03 ± 0.00
14:0	3.51 ± 0.39	5.54 ± 0.50	6.29 ± 0.56	4.69 ± 1.03	3.96 ± 0.20	5.76 ± 0.68	6.29 ± 0.99
14:1w9	0.21 ± 0.01	0.19 ± 0.03	0.11 ± 0.03	0.19 ± 0.03	0.07 ± 0.03	0.17 ± 0.01	0.10 ± 0.02
14:1w7	0.05 ± 0.01	0.05 ± 0.01	0.06 ± 0.01	0.05 ± 0.01	0.04 ± 0.00	0.08 ± 0.02	0.10 ± 0.01
14:1w5	0.07 ± 0.02	0.22 ± 0.03	0.36 ± 0.09	0.09 ± 0.00	0.14 ± 0.01	0.14 ± 0.01	0.16 ± 0.03
Iso15	0.19 ± 0.01	0.18 ± 0.02	0.19 ± 0.03	0.20 ± 0.04	0.12 ± 0.04	0.21 ± 0.03	0.19 ± 0.01
Anti15	0.04 ± 0.00	0.06 ± 0.01	0.04 ± 0.00	0.04 ± 0.01	0.02 ± 0.00	0.08 ± 0.01	0.04 ± 0.00
15:0	0.29 ± 0.01	0.25 ± 0.06	0.28 ± 0.02	0.33 ± 0.04	0.22 ± 0.01	0.31 ± 0.04	0.38 ± 0.04
15:1w8	0.07 ± 0.01	0.12 ± 0.02	0.03 ± 0.01	0.07 ± 0.01	0.02 ± 0.01	0.09 ± 0.01	0.05 ± 0.01
15:1w6	0.01 ± 0.00	0.03 ± 0.00	0.02 ± 0.00	0.01 ± 0.00	0.04 ± 0.01	0.02 ± 0.00	0.04 ± 0.01
Iso16	0.06 ± 0.00	0.02 ± 0.01	0.06 ± 0.02	0.06 ± 0.00	0.07 ± 0.01	0.04 ± 0.01	0.07 ± 0.02
16:0	13.99 ± 0.59	8.25 ± 1.93	20.80 ± 0.90	17.42 ± 0.99	14.44 ± 1.32	12.73 ± 1.00	14.51 ± 0.42
16:1w11	0.19 ± 0.01	0.19 ± 0.01	0.33 ± 0.03	0.25 ± 0.01	0.25 ± 0.09	0.24 ± 0.02	0.17 ± 0.01
16:1w9	0.12 ± 0.03	0.09 ± 0.01	0.73 ± 0.20	0.17 ± 0.02	0.21 ± 0.03	0.16 ± 0.02	0.33 ± 0.03
16:1w7	20.54 ± 0.80	28.68 ± 1.35	17.97 ± 0.60	17.26 ± 0.98	35.18 ± 5.75	23.26 ± 0.67	29.47 ± 2.51
7Me16:0	1.40 ± 0.15	0.47 ± 0.04	0.49 ± 0.05	0.71 ± 0.11	0.24 ± 0.01	0.44 ± 0.08	0.37 ± 0.10
16:1w5	0.02 ± 0.00	0.03 ± 0.01	0.04 ± 0.01	0.11 ± 0.03	0.01 ± 0.01	0.05 ± 0.02	0.01 ± 0.00
16:2w6	0.07 ± 0.00	0.13 ± 0.02	0.05 ± 0.01	0.07 ± 0.01	0.07 ± 0.02	0.08 ± 0.00	0.10 ± 0.02
Iso17	0.08 ± 0.01	0.03 ± 0.01	0.07 ± 0.02	0.18 ± 0.10	0.06 ± 0.03	0.09 ± 0.03	0.08 ± 0.01
16:2w4	0.03 ± 0.01	0.03 ± 0.01	0.02 ± 0.00	0.22 ± 0.03	0.02 ± 0.02	0.04 ± 0.01	0.03 ± 0.00
16:3w6	0.52 ± 0.03	1.11 ± 0.12	0.78 ± 0.08	0.49 ± 0.05	0.58 ± 0.22	0.70 ± 0.05	0.88 ± 0.02
17:0	0.11 ± 0.01	0.02 ± 0.01	0.04 ± 0.01	0.13 ± 0.01	0.05 ± 0.01	0.09 ± 0.01	0.06 ± 0.01
16:3w4	0.44 ± 0.03	0.97 ± 0.12	0.31 ± 0.06	0.35 ± 0.05	0.36 ± 0.11	0.61 ± 0.09	0.74 ± 0.02
17:1	0.10 ± 0.00	0.10 ± 0.01	0.09 ± 0.01	0.12 ± 0.01	0.10 ± 0.02	0.14 ± 0.00	0.18 ± 0.08
16:3w1	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
16:4w3	0.07 ± 0.00	0.03 ± 0.01	0.05 ± 0.00	0.08 ± 0.01	0.03 ± 0.02	0.05 ± 0.01	0.03 ± 0.02
16:4w1	0.69 ± 0.05	1.96 ± 0.28	0.60 ± 0.08	0.56 ± 0.09	0.48 ± 0.15	0.97 ± 0.14	1.14 ± 0.14
18:0	0.82 ± 0.05	0.35 ± 0.09	1.05 ± 0.08	2.10 ± 0.23	0.72 ± 0.24	0.56 ± 0.07	0.72 ± 0.04
18:1w13	0.01 ± 0.01	0.00 ± 0.00	0.01 ± 0.00	0.02 ± 0.01	0.05 ± 0.02	0.05 ± 0.03	0.08 ± 0.05
18:1w11	0.00 ± 0.00	0.00 ± 0.00	0.02 ± 0.01	0.07 ± 0.03	0.84 ± 0.10	0.10 ± 0.02	0.02 ± 0.02
18:1w9	4.74 ± 0.30	2.63 ± 0.26	8.18 ± 0.84	6.74 ± 1.02	10.84 ± 2.36	9.19 ± 0.62	8.03 ± 0.86
18:1w7	3.51 ± 0.26	2.46 ± 0.91	7.33 ± 0.54	5.02 ± 0.87	2.72 ± 0.44	3.40 ± 0.05	3.70 ± 0.09
18:1w5	2.83 ± 0.22	0.70 ± 0.05	0.49 ± 0.06	1.25 ± 0.11	0.48 ± 0.10	0.85 ± 0.04	0.35 ± 0.02
18:2d5,11	0.06 ± 0.00	0.02 ± 0.01	0.03 ± 0.00	0.06 ± 0.00	0.06 ± 0.03	0.04 ± 0.01	0.03 ± 0.00
18:2w7	0.00 ± 0.00	0.00 ± 0.00	0.05 ± 0.01	0.01 ± 0.01	0.00 ± 0.00	0.01 ± 0.01	0.01 ± 0.01
18:2w6	0.78 ± 0.09	0.76 ± 0.11	0.70 ± 0.12	0.75 ± 0.05	0.65 ± 0.01	1.04 ± 0.05	0.80 ± 0.02
18:2w4	0.18 ± 0.02	0.20 ± 0.03	0.10 ± 0.00	0.18 ± 0.01	0.08 ± 0.01	0.20 ± 0.02	0.15 ± 0.01
18:3w6	0.16 ± 0.01	0.24 ± 0.03	0.14 ± 0.01	0.16 ± 0.03	1.09 ± 0.39	0.20 ± 0.02	0.36 ± 0.05
18:3w4	0.08 ± 0.01	0.06 ± 0.01	0.02 ± 0.00	0.07 ± 0.01	0.05 ± 0.01	0.11 ± 0.02	0.07 ± 0.01
18:3w3	0.66 ± 0.11	0.62 ± 0.15	0.39 ± 0.10	0.55 ± 0.05	0.31 ± 0.09	1.10 ± 0.13	0.56 ± 0.16
18:3w1	0.00 ± 0.00	0.02 ± 0.01	0.01 ± 0.00	0.05 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	0.04 ± 0.03
18:4w3	1.95 ± 0.15	2.72 ± 0.62	0.77 ± 0.10	1.55 ± 0.09	0.98 ± 0.36	3.09 ± 0.45	1.86 ± 0.38
18:4w1	0.16 ± 0.01	0.34 ± 0.04	0.06 ± 0.02	0.12 ± 0.01	0.06 ± 0.02	0.25 ± 0.06	0.08 ± 0.00

…continued

TABLE 19.4 (continued).

	Chaetognath (*n* = 5)	Copepod (*n* =7)	Euphausiid (*n* = 5)	Fish (*n* = 5)	Gammarid amphipod (*n* = 2)	Hyperiid amphipod (*n* = 6)	Mysid (*n* = 2)
20:0	0.00 ± 0.00	0.01 ± 0.01	0.03 ± 0.01	0.02 ± 0.01	0.00 ± 0.00	0.02 ± 0.01	0.01 ± 0.00
20:1w11	0.16 ± 0.01	0.41 ± 0.07	0.14 ± 0.02	0.13 ± 0.02	0.83 ± 0.08	0.48 ± 0.05	0.19 ± 0.04
20:1w9	3.42 ± 0.28	6.06 ± 0.35	2.51 ± 0.95	4.26 ± 1.46	5.22 ± 0.74	4.52 ± 0.72	1.80 ± 0.06
20:1w7	0.47 ± 0.03	1.75 ± 0.25	0.64 ± 0.12	0.44 ± 0.02	1.22 ± 0.31	0.80 ± 0.13	0.46 ± 0.03
20:2w9	0.55 ± 0.07	0.10 ± 0.01	0.06 ± 0.02	0.13 ± 0.02	0.08 ± 0.02	0.11 ± 0.01	0.03 ± 0.01
20:2w6	0.08 ± 0.01	0.11 ± 0.04	0.16 ± 0.02	0.15 ± 0.03	0.08 ± 0.02	0.14 ± 0.01	0.22 ± 0.02
20:3w6	0.04 ± 0.00	0.06 ± 0.00	0.03 ± 0.00	0.05 ± 0.01	0.10 ± 0.02	0.04 ± 0.01	0.06 ± 0.01
20:4w6	0.25 ± 0.01	0.22 ± 0.02	0.31 ± 0.05	0.29 ± 0.05	0.55 ± 0.28	0.18 ± 0.02	0.72 ± 0.32
20:3w3	0.04 ± 0.01	0.10 ± 0.07	0.06 ± 0.01	0.08 ± 0.02	0.03 ± 0.01	0.13 ± 0.02	0.07 ± 0.01
20:4w3	0.52 ± 0.05	0.63 ± 0.07	0.23 ± 0.03	0.48 ± 0.06	0.23 ± 0.02	0.64 ± 0.11	0.32 ± 0.04
20:5w3	17.05 ± 0.64	15.88 ± 1.94	15.22 ± 1.60	13.59 ± 1.77	9.01 ± 1.66	13.53 ± 1.56	14.31 ± 0.51
22:1w11	2.15 ± 0.22	4.75 ± 0.26	2.66 ± 1.40	2.12 ± 1.16	2.18 ± 0.82	2.52 ± 0.60	0.81 ± 0.02
22:1w9	0.47 ± 0.03	1.49 ± 0.22	0.57 ± 0.17	0.43 ± 0.13	0.65 ± 0.28	0.74 ± 0.20	0.24 ± 0.02
22:1w7	0.30 ± 0.01	0.42 ± 0.06	0.22 ± 0.06	0.15 ± 0.04	0.17 ± 0.09	0.19 ± 0.03	0.08 ± 0.01
22:2w6	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
21:5w3	0.28 ± 0.03	0.13 ± 0.01	0.19 ± 0.02	0.21 ± 0.02	0.10 ± 0.01	0.29 ± 0.05	0.22 ± 0.02
22:4w6	0.01 ± 0.01	0.02 ± 0.02	0.01 ± 0.01	0.02 ± 0.01	0.05 ± 0.03	0.01 ± 0.01	0.05 ± 0.01
22:5w6	0.10 ± 0.01	0.11 ± 0.05	0.07 ± 0.01	0.10 ± 0.01	0.04 ± 0.00	0.11 ± 0.02	0.08 ± 0.00
22:4w3	0.05 ± 0.01	0.17 ± 0.13	0.01 ± 0.01	0.06 ± 0.01	0.04 ± 0.01	0.08 ± 0.02	0.02 ± 0.01
22:5w3	0.71 ± 0.02	1.21 ± 0.12	0.40 ± 0.06	0.90 ± 0.14	0.25 ± 0.05	0.60 ± 0.07	0.41 ± 0.12
22:6w3	12.85 ± 0.57	5.61 ± 0.39	6.57 ± 1.04	12.78 ± 2.11	3.41 ± 1.43	7.60 ± 0.76	6.86 ± 0.85
24:1w9	1.55 ± 0.09	0.52 ± 0.04	0.23 ± 0.06	0.68 ± 0.09	0.03 ± 0.01	0.23 ± 0.02	0.17 ± 0.05

Although seven general categories of zooplankton represented by a total of 32 samples is a very limited prey database, we used these data and the QFASA model to derive a preliminary estimate of bowhead diets. This analysis took into account our current estimates of fat content in each prey type (Table 19.4). We ran several variations of the model, including separate runs for whales harvested at Kaktovik in late summer/fall, Barrow in fall, and Barrow in spring. In all cases the predominant prey were estimated to be euphausiids and copepods, with also some evidence of fish in the diet (Fig. 19.12). These preliminary results indicate that euphausiids were generally the prevalent prey. However, depending on the model variation used, copepods made up a high proportion of the diets of some individuals. These results are generally consistent with the stomach contents data obtained by Lowry and Sheffield (Chapter 18). For instance, the recent diet of bowhead 99K2 was estimated by QFASA to contain almost 100% copepods, and was found to have 100% copepods in its stomach when it was harvested near Kaktovik (see Fig. 18.3 in Lowry and Sheffield, Chapter 18). Nevertheless, even if based on larger sample sizes, we would not necessarily expect an exact match between QFASA and stomach contents results. Diet estimates from fatty acid signatures represent an integration of diet over a longer time interval (likely weeks or even months) and thus over larger geographic areas than are the snapshots of diets represented in stomach contents.

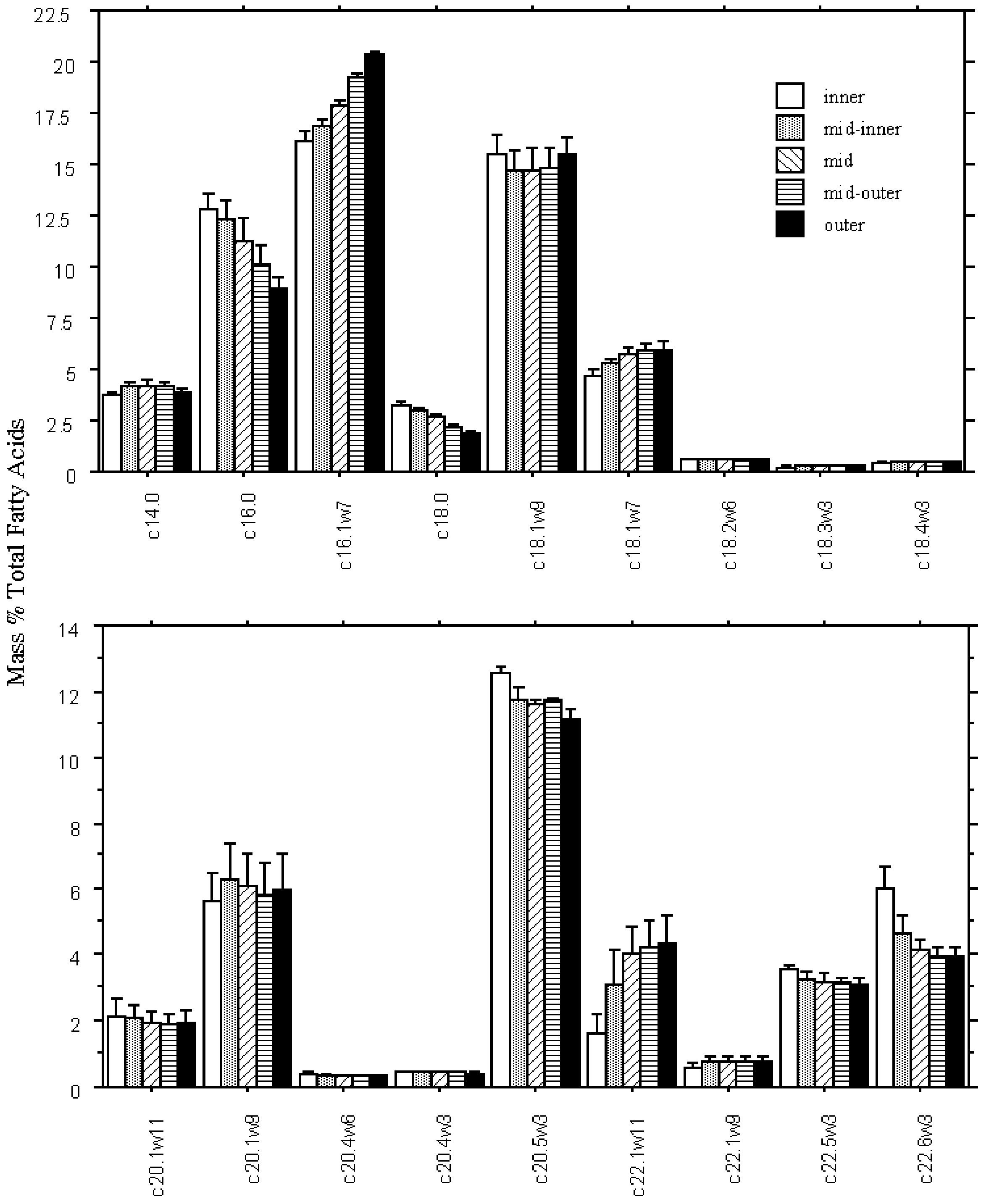

FIGURE 19.1. Limited stratification of fatty acids throughout the blubber of bowhead whales (n = 3). Blubber cores were taken through the full blubber layer and divided into five equal sections extending from the one closest to the skin ("outer") to the one nearest the body core ("inner").

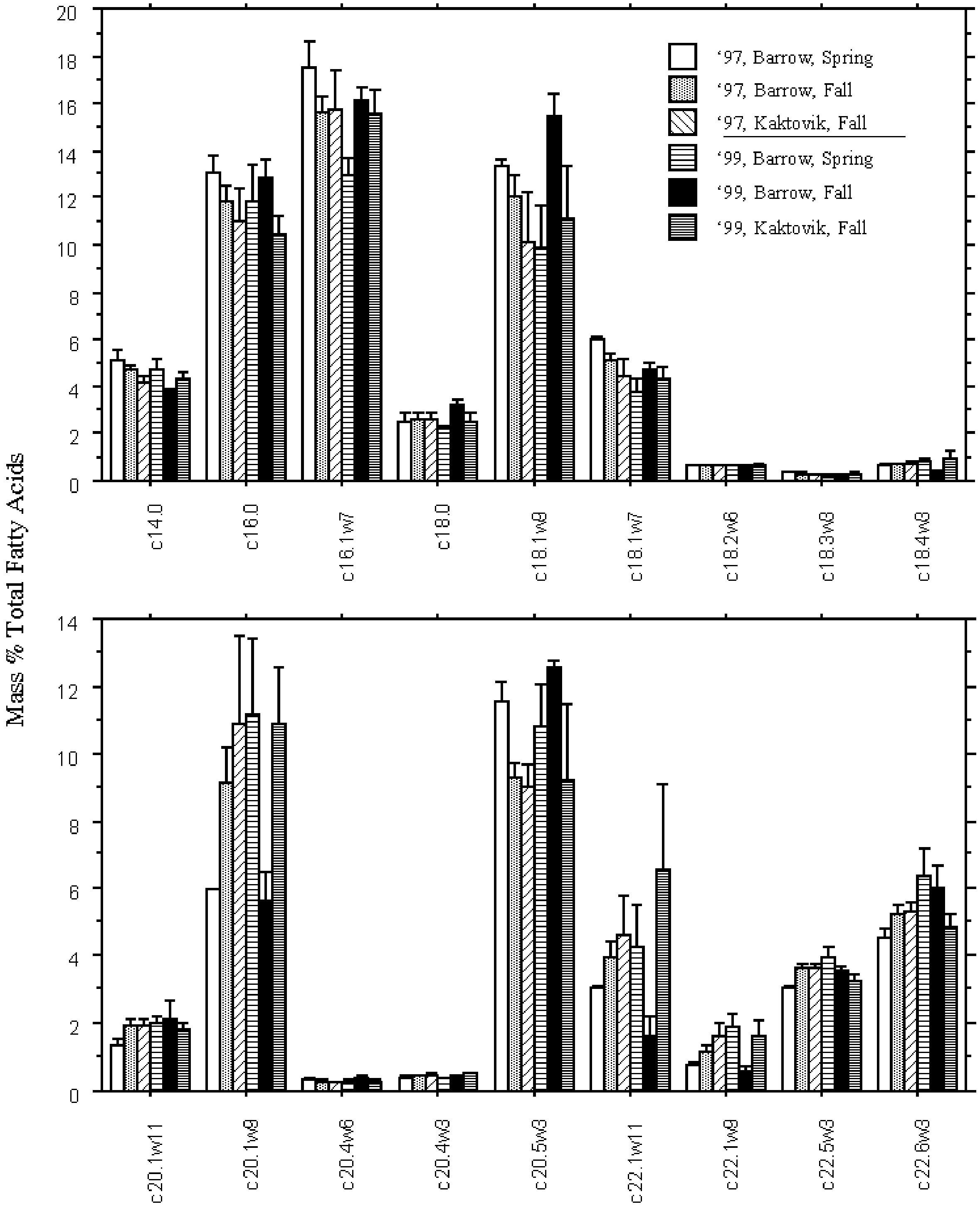

FIGURE 19.2. Fatty acid patterns in inner blubber of bowhead whales (*n* = 28) by collection location and season in 1997 and 1999. See Table 19.1 for sample sizes.

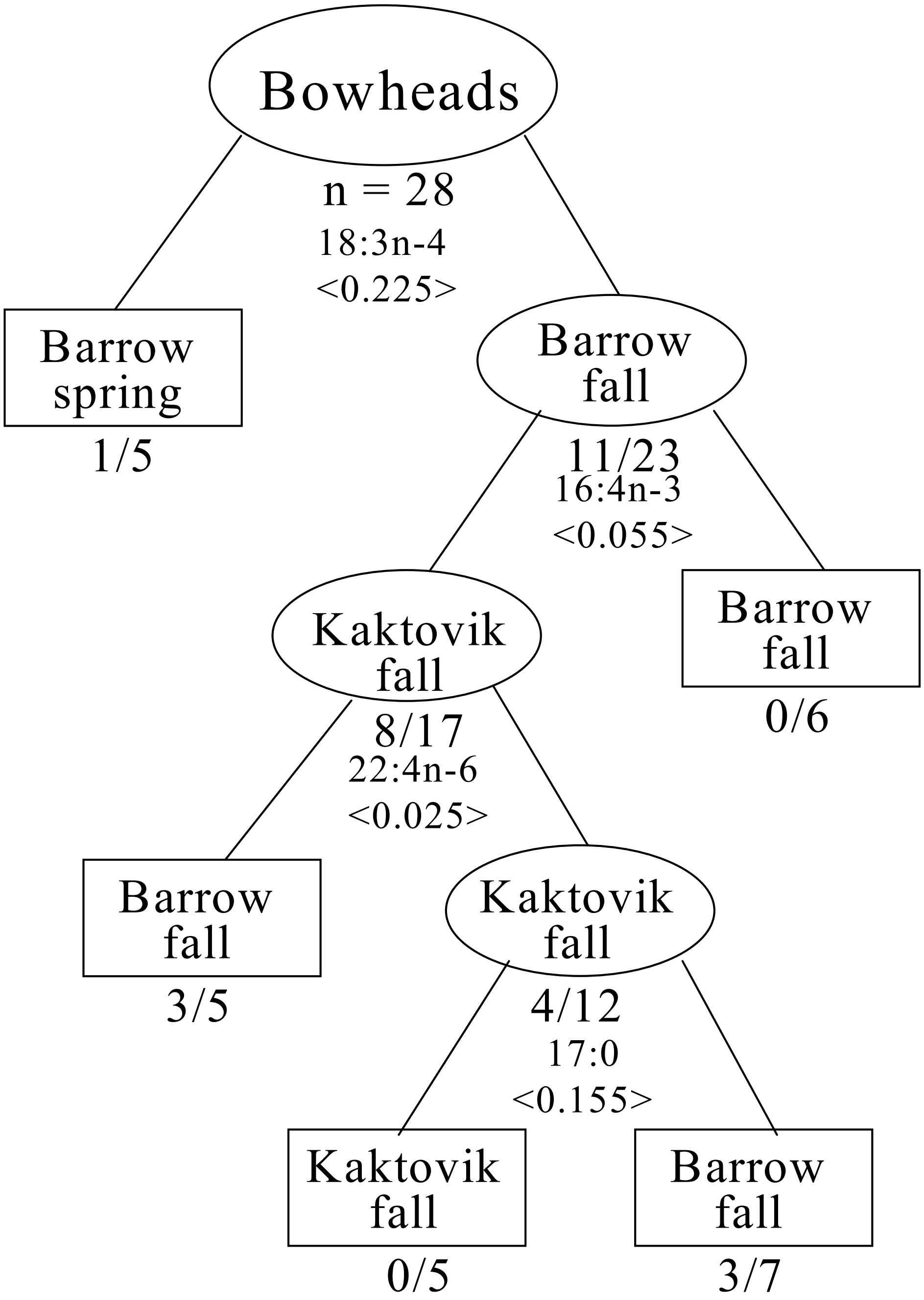

FIGURE 19.3. Classification and Regression Tree (CART) analysis of inner blubber of bowhead whales (*n* = 28) by collection location and season. See Table 19.1 for sample sizes. Ellipses represent intermediate nodes and rectangles represent terminal nodes; labels within an ellipse or rectangle indicate the classification at that node as represented by the largest number of observations in that node. The fatty acid listed at each split is the variable chosen by the algorithm to create the split, with < and > values indicating the optimal splitting level (weight %) of that fatty acid. Fractions under each intermediate and terminal node indicate the number of misclassifications over the total number of observations in that node. See Smith et al. (1997) for further explanation of CART analysis.

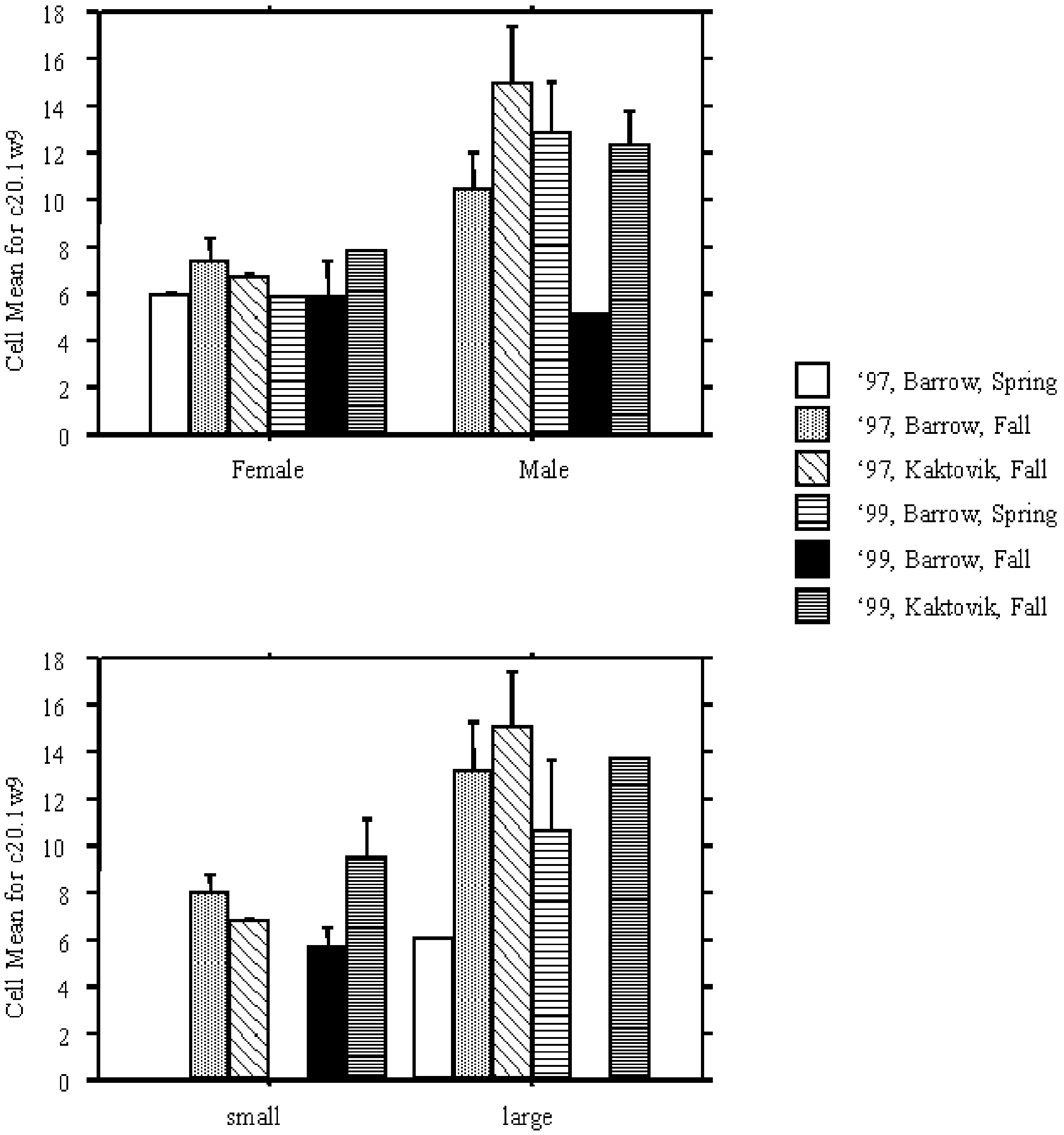

FIGURE 19.4. Relative levels of dietary fatty acid 20:1w9 in inner blubber of bowhead whales (*n* = 28) by sex (above) or body size class (below—cutpoint 12 m) depending on collection location, season, and year (1997 and 1999). Data from 1998 are not shown in this graph due to small sample size (*n* = 3).

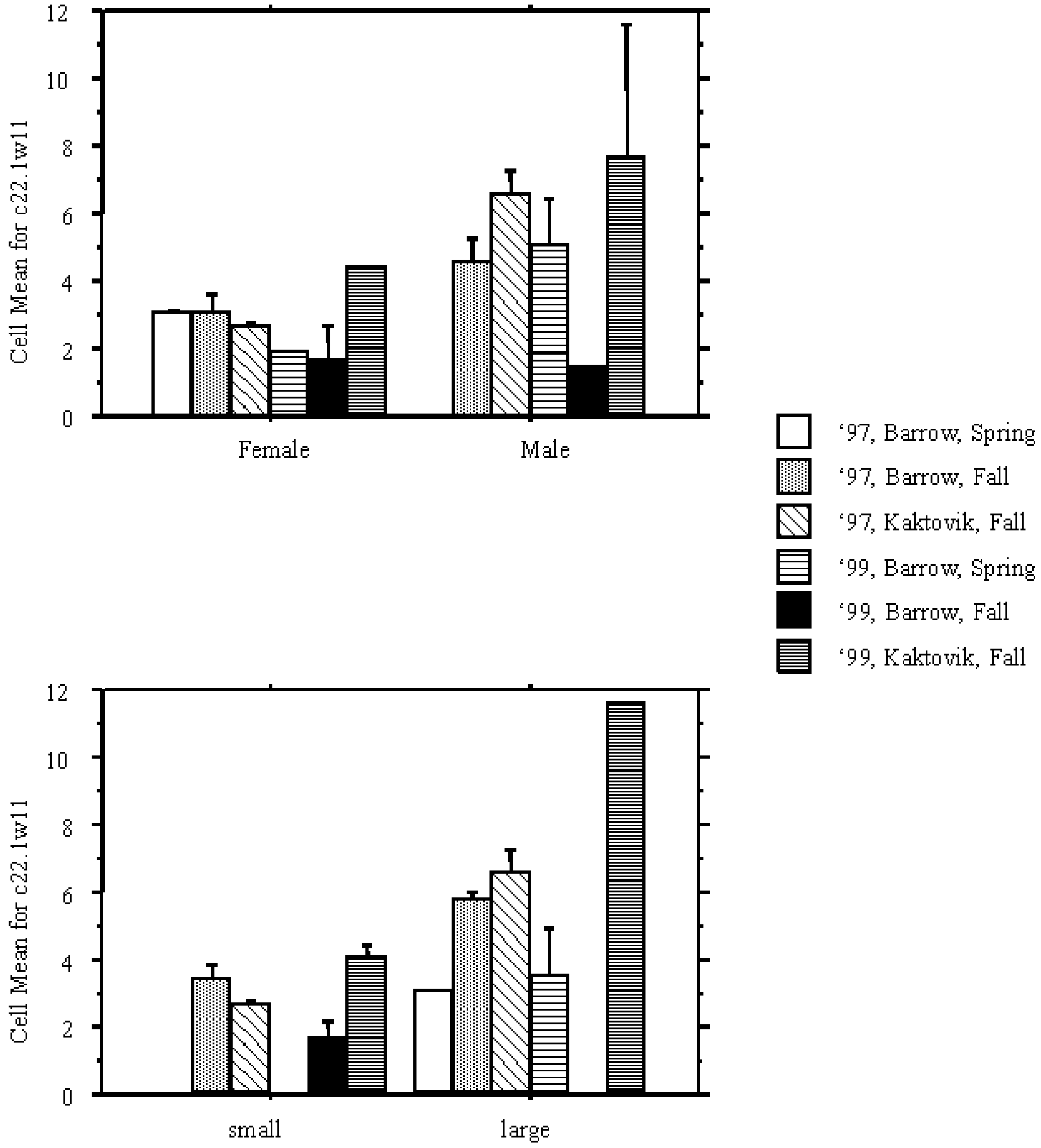

FIGURE 19.5. Relative levels of dietary fatty acid 22:1w11 in inner blubber of bowhead whales (n = 28) by sex (above) or body size class (below—cutpoint 12 m) depending on collection location, season, and year (1997 and 1999). Data from 1998 are not shown this graph due to small sample size (n = 3).

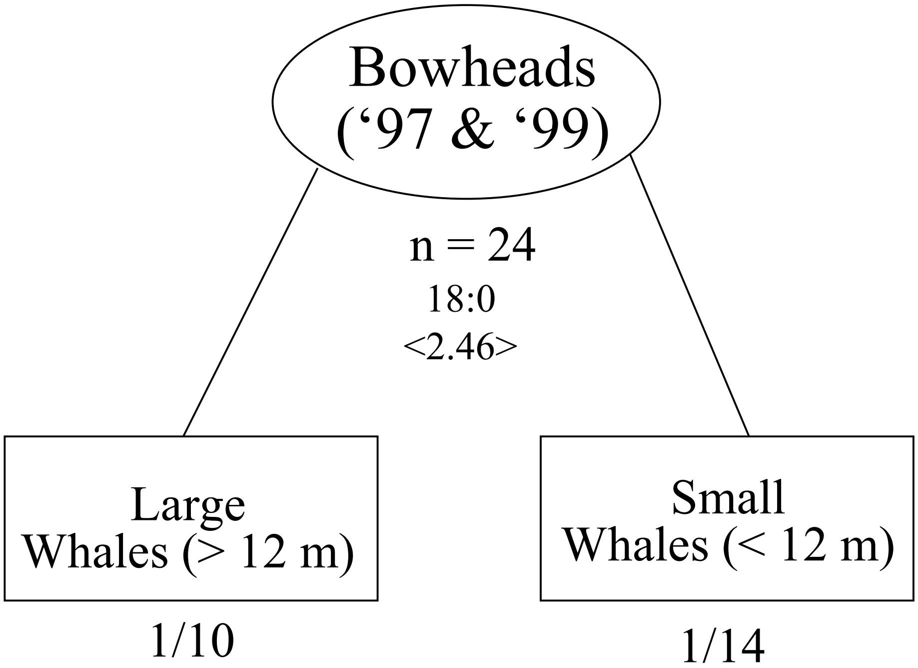

FIGURE 19.6. CART analysis of inner blubber of bowhead whales in 1997 and 1999 (*n* = 24) by whale size group. See Fig. 19.3 for explanation of tree.

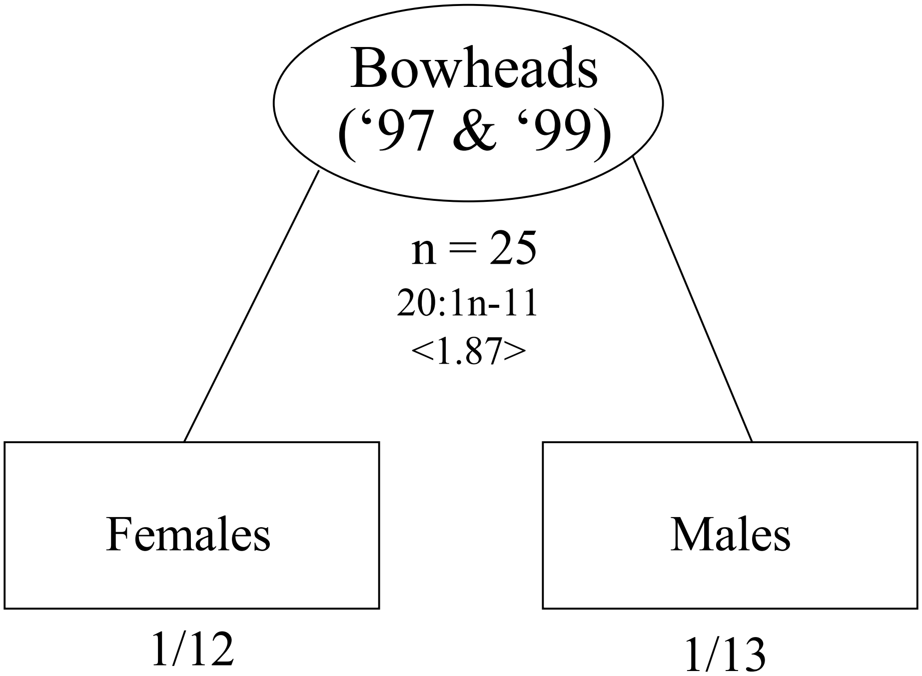

FIGURE 19.7. CART analysis of inner blubber of bowhead whales in 1997 and 1999 (*n* = 24) by whale sex. See Fig. 19.3 for explanation of tree.

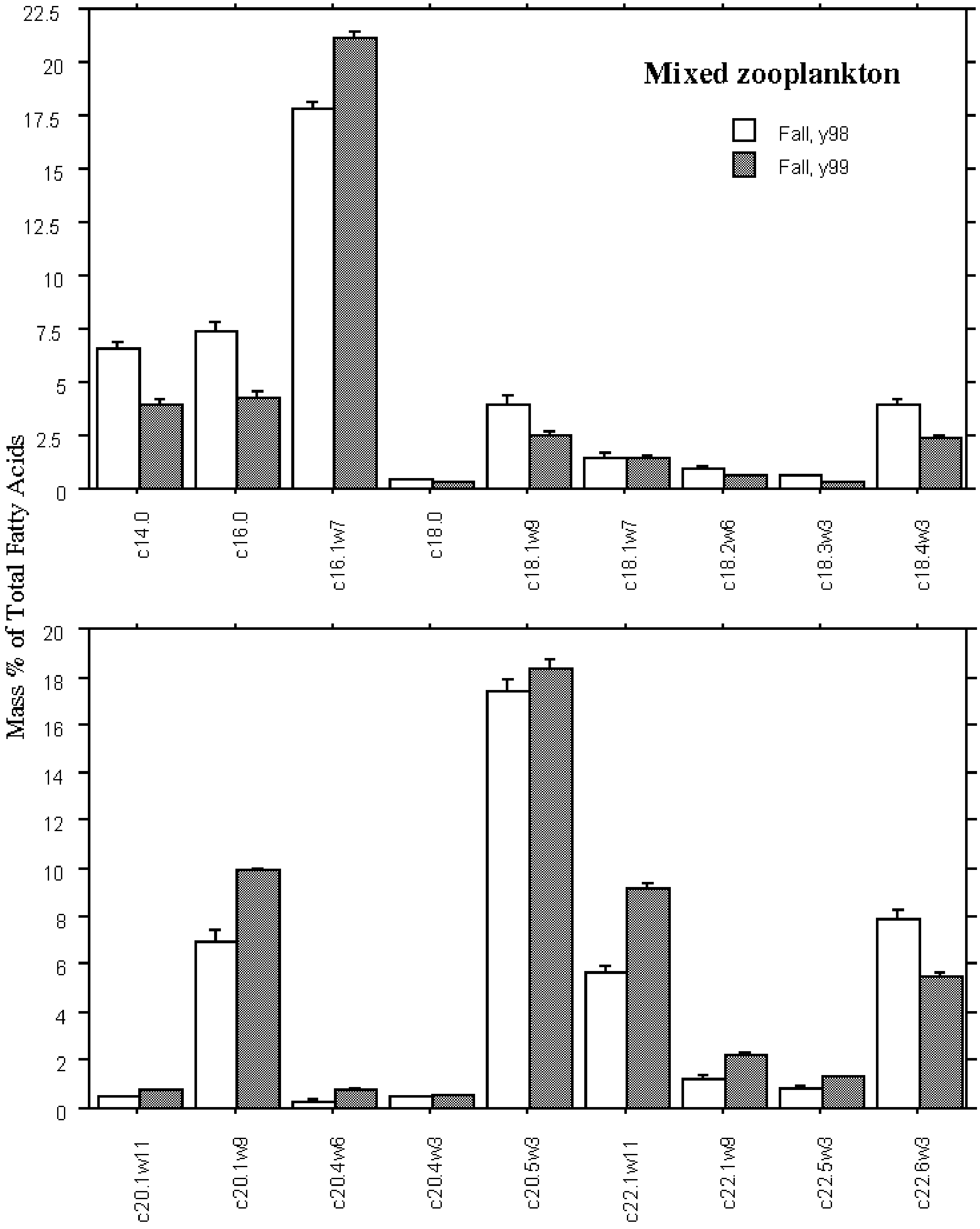

FIGURE 19.8. Fatty acid patterns in mixed zooplankton samples collected in the late summer/fall of 1998 (*n* = 23) and 1999 (*n* = 10) from the Eastern Alaskan Beaufort Sea.

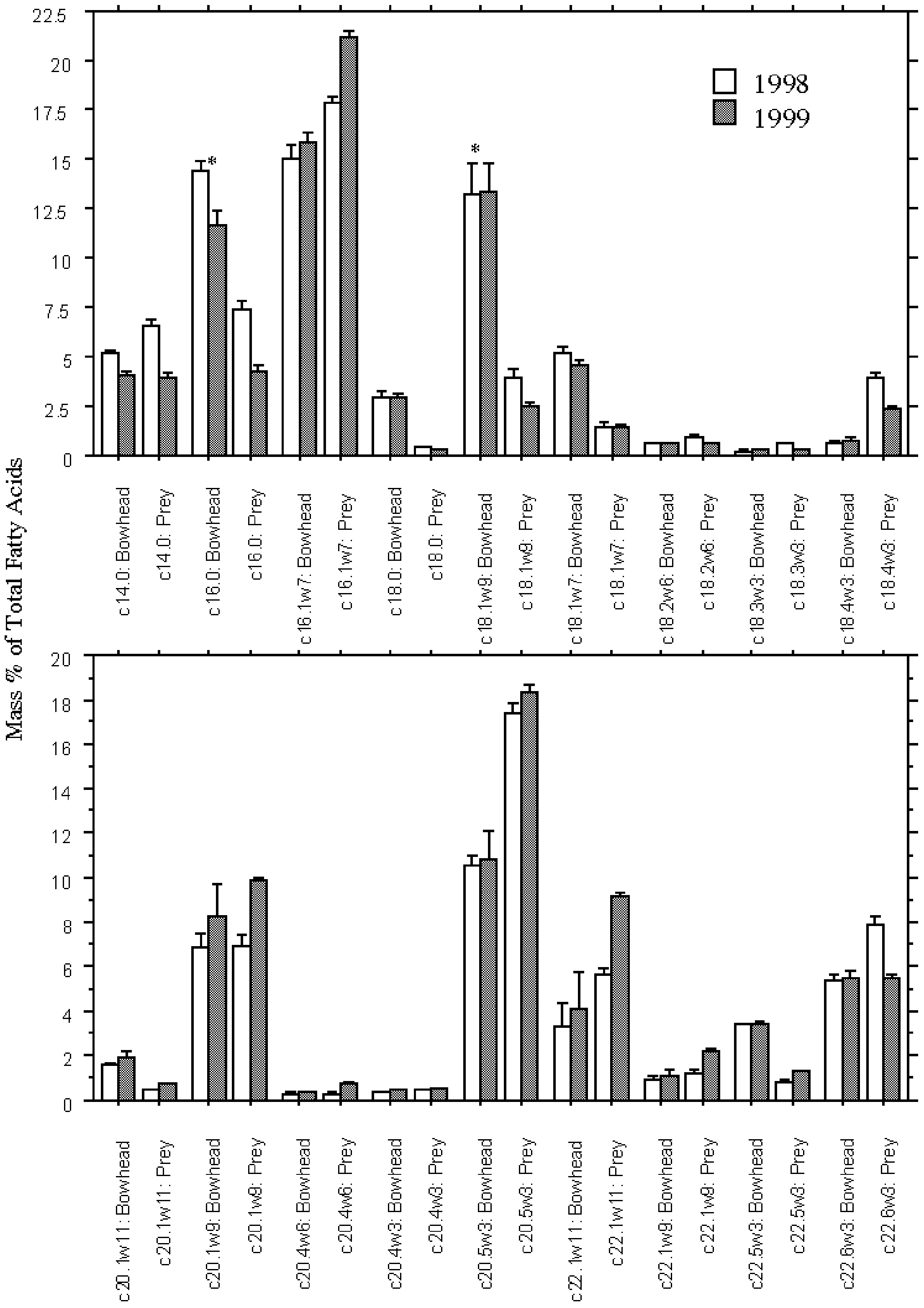

FIGURE 19.9. Fatty acid patterns in bowhead whales and mixed zooplankton samples collected in the late summer/fall of 1998 and 1999. * denotes commonly biosynthesized fatty acids, disregarded in diet analysis.

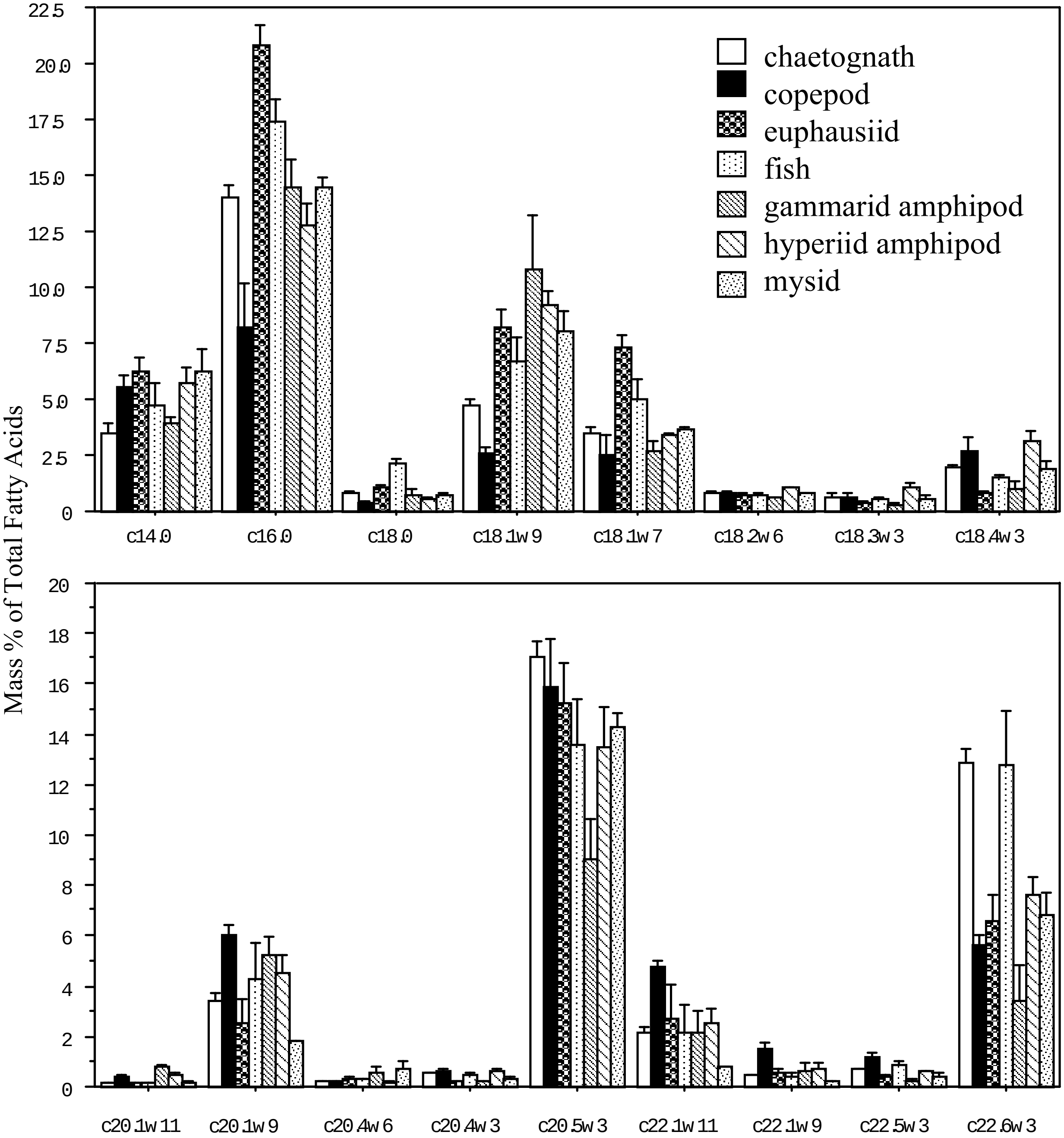

FIGURE 19.10. Fatty acid patterns in sorted zooplankton samples collected in September 2000 from the Eastern Alaskan Beaufort Sea. See Table 19.4 for sample sizes.

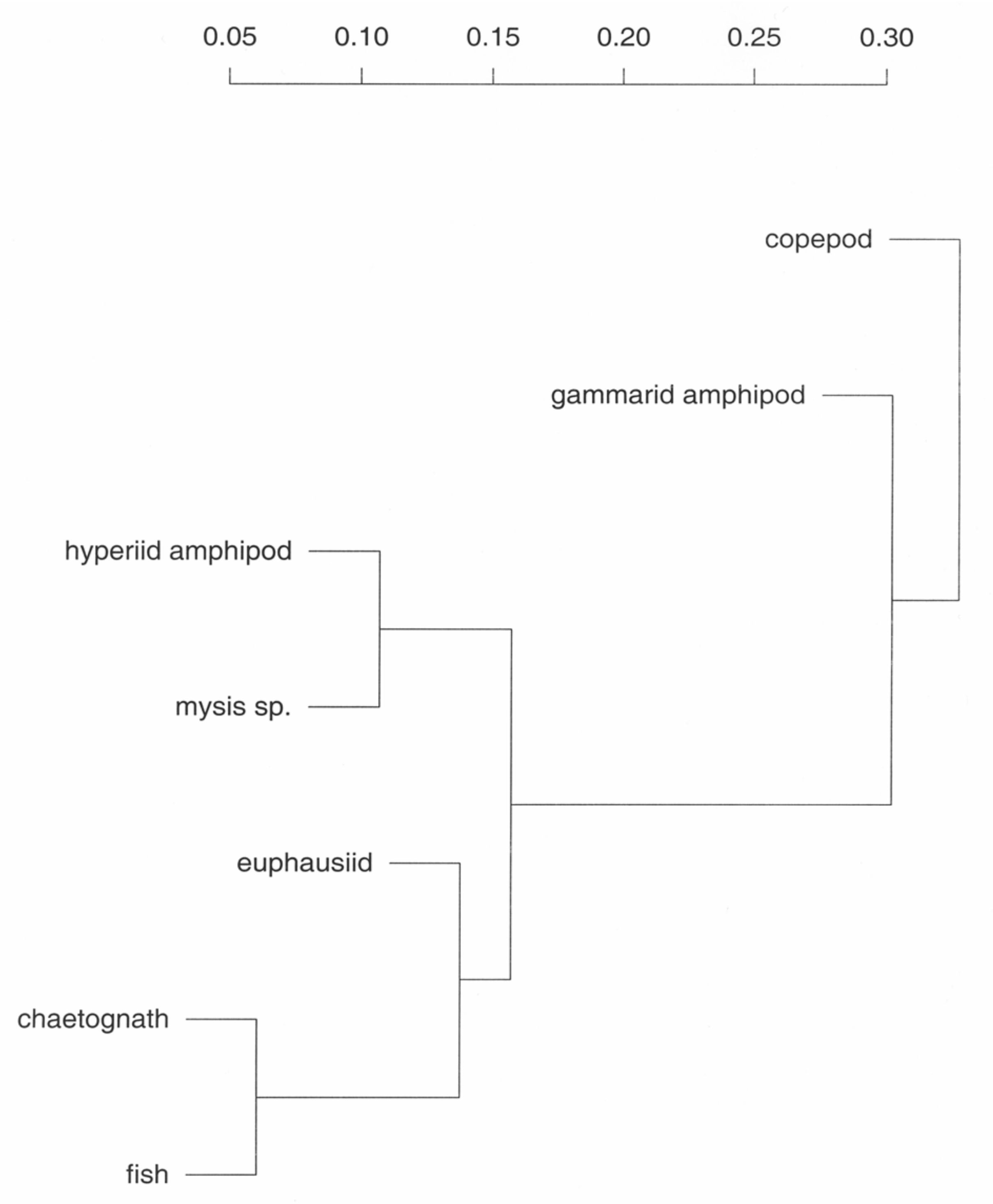

FIGURE 19.11. Hierarchical cluster analysis on the mean fatty acid patterns of major zooplankton groups from the Eastern Alaskan Beaufort Sea. The KL–distance measure was used to determine how similar two taxa were with respect to their fatty acid signatures. The average linkage method was used, which tends to identify spherical clusters.

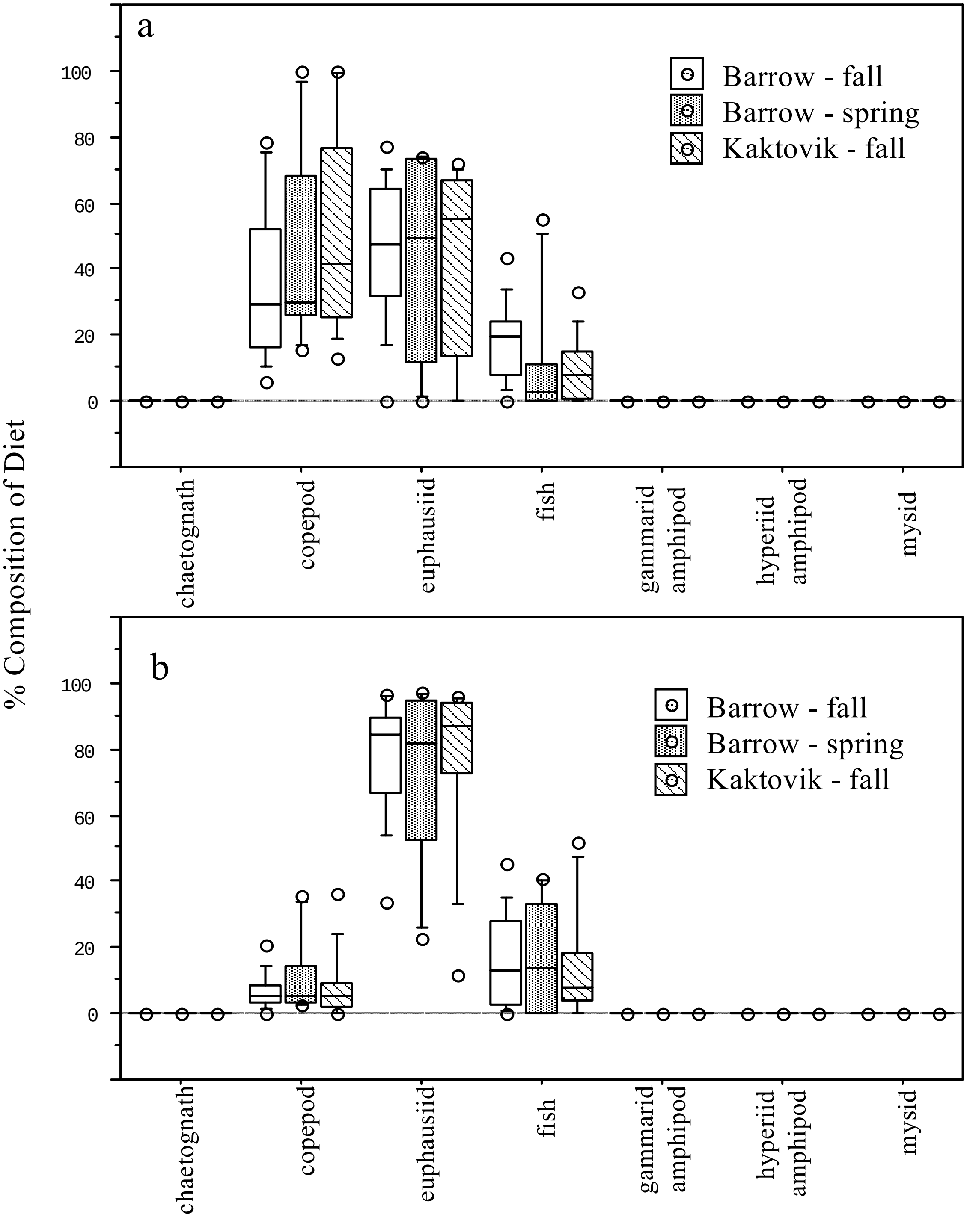

FIGURE 19.12. Percent composition of diets of bowhead whales estimated with the limited available data on fatty acids in bowheads and zooplankton groups, performed two ways: ***(A)*** Modeled using an average composite for each prey species, and ***(B)*** modeled on each individual prey sample analyzed. Modeling on individual prey as in (B) allows full assessment of individual variability within prey species, and thus may provide better estimates of diets. In Box plots, horizontal lines are the 10th, 25th, 50th (median), 75th and 90th percentiles of the data. Values outside the 10th–90th percentile range are plotted as dots.

Summary

Fatty acids, the dominant constituent of lipids, are often deposited in animal tissue with minimal modification from those in the diet. Lipids in the marine food web are exceptionally complex and diverse. We undertook a pilot study to assess whether analysis of fatty acid signatures in bowheads and their potential prey (zooplankton) would be a useful tool for better understanding the foraging ecology and diets of bowheads in Alaskan waters. We identified and measured the fatty acids in samples of blubber from 28 bowheads harvested at Kaktovik (fall) and Barrow (spring and fall); 33 samples of mixed zooplankton from the eastern Alaskan Beaufort Sea; and 32 samples of zooplankton that had been sorted into seven major prey groups (copepods, euphausiids, etc.).

This preliminary study indicates that fatty acid signature analysis could be a very useful tool in better understanding the foraging ecology and diets of bowheads in Alaskan waters. We are currently limited in the inferences we can make due to small sample sizes of whales and potential prey, and lack of data on fatty acid profiles in individual species of prey. However, there are indications that fatty acid analyses may show differences in diets of whales of different sexes and size classes; such differences have not been clearly detectable from stomach contents analyses. We analyzed samples of mixed zooplankton from two years, and the fatty acids of the zooplankton are consistent with them being bowhead diet items. Additionally, although we have very limited data on fatty acid patterns in potential prey, preliminary results from our QFASA (Quantitative Fatty Acid Signature Analysis) model indicate that fatty acid patterns of the inner blubber, presumably indicative of recent diet, are consistent with general diet data obtained from stomach contents analyses. The high fat content of these prey, especially copepods, also suggests high dietary intakes of fat. With further and more extensive sampling and analysis, the taxonomic composition of bowhead prey could likely be better assessed using the quantitative tools now being developed. Fatty acid signatures are expected to represent the integrated diet over weeks or possibly months, and thus over larger geographic areas, than are the stomach contents of harvested whales.

Acknowledgements

We thank the many whaling captains from Kaktovik and Barrow who made bowhead blubber samples available for analysis. Personnel from the North Slope Borough Department of Wildlife Management, particularly Craig George and Todd O'Hara, as well as Tami Mau from the University of Alaska Fairbanks, were instrumental in sample collection. Bill Griffiths of LGL provided zooplankton samples. Shelley Lang conducted laboratory analysis of specimens. Funding for this study was provided by the U.S. Minerals Management Service through a contract awarded to LGL Ecological Research Associates Inc. and a subcontract from LGL to ADF&G. Specimen collection was done under NMFS Scientific Research Permits 797 and 481–1464 (Kaktovik) and 932–1489–90 (Barrow).

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20. REGIONAL AND SEASONAL FEEDING BY BOWHEAD WHALES AS INDICATED BY STABLE ISOTOPE RATIOS

Sang Heon Lee and Donald M. Schell [1]

Introduction

The bowhead whale (*Balaena mysticetus*) is a large baleen whale that historically was abundant in northern circumpolar waters. Commercial whaling over three centuries reduced the numbers in the Atlantic Ocean to small remnants (Ross 1993). The Pacific populations were also reduced to small fractions of their original numbers (Bockstoce and Burns 1993). The largest remaining stock is the Bering–Chukchi–Beaufort stock, which numbered about 8200 animals in 1993, when it was increasing at about 3.2 % per year (Ferrero et al. 2000). This population overwinters in the sea ice of the northern Bering Sea and then moves northeastward in the spring, entering the Beaufort Sea in April–June. Much of the population is in the eastern Beaufort Sea from June through the summer, with most individuals departing westward in September and early October (Braham et al. 1980; Fig. 20.1). The whales return to the Bering Sea by way of northern Alaska and (in at least some cases) northeastern Russia. Feeding has been observed in the Canadian Beaufort Sea in summer and in both the Alaskan Beaufort Sea and near the Russian coast of the Chukchi Sea during autumn. Over the past three decades, offshore oil exploration and developmental activities have occurred in some parts of the summer and autumn range in the Canadian and Alaskan Beaufort Sea (Richardson et al. 1987; USACE 1999), and waters off northeastern Alaska may be of interest to the oil industry in future.

The feeding habitats of the whales during the summer and fall migration are generally known, but the relative amounts of food consumed from various regions along the migration route are poorly understood. This study attempts to quantify the relative importance of the eastern Beaufort Sea (including the eastern Alaskan Beaufort and Canadian Beaufort Seas) as a feeding habitat for the Bering–Chukchi–Beaufort stock of bowhead whales. It also compares feeding strategies of subadult and adult whales in the Bering, Chukchi, and Beaufort Seas.

Various methods can provide information about the feeding habitats and amounts of food consumed by populations of whales, including observations of feeding behavior, stomach contents, energy reserves during different seasons, and stable isotopes. Each method provides a limited perspective, but the results from different methods are often complementary. • *Behavioral observations* can show the manner and location of feeding, and how much time is devoted to feeding, but yield little information as to how much food the animal consumes in a given feeding location. Furthermore, feeding behavior may at times be confused with other behavior, especially in pelagic marine mammals, which are especially difficult to observe in extensively ice-covered areas (Moore and Reeves 1993). However, Würsig et al. (1985, 1989) and Würsig and Clark (1993) have provided fairly detailed descriptions of feeding behavior as observed in the Beaufort Sea (see also Chapter 12). • *Stomach content analysis* shows whether feeding has occurred recently, what the animal has most recently eaten, and what quantity is present in the stom-

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[1] Institute of Marine Science, University of Alaska Fairbanks, Fairbanks, AK 99775. *Phone (DMS)*: 907-474-7210*; e-mail:* ffdms1@uaf.edu

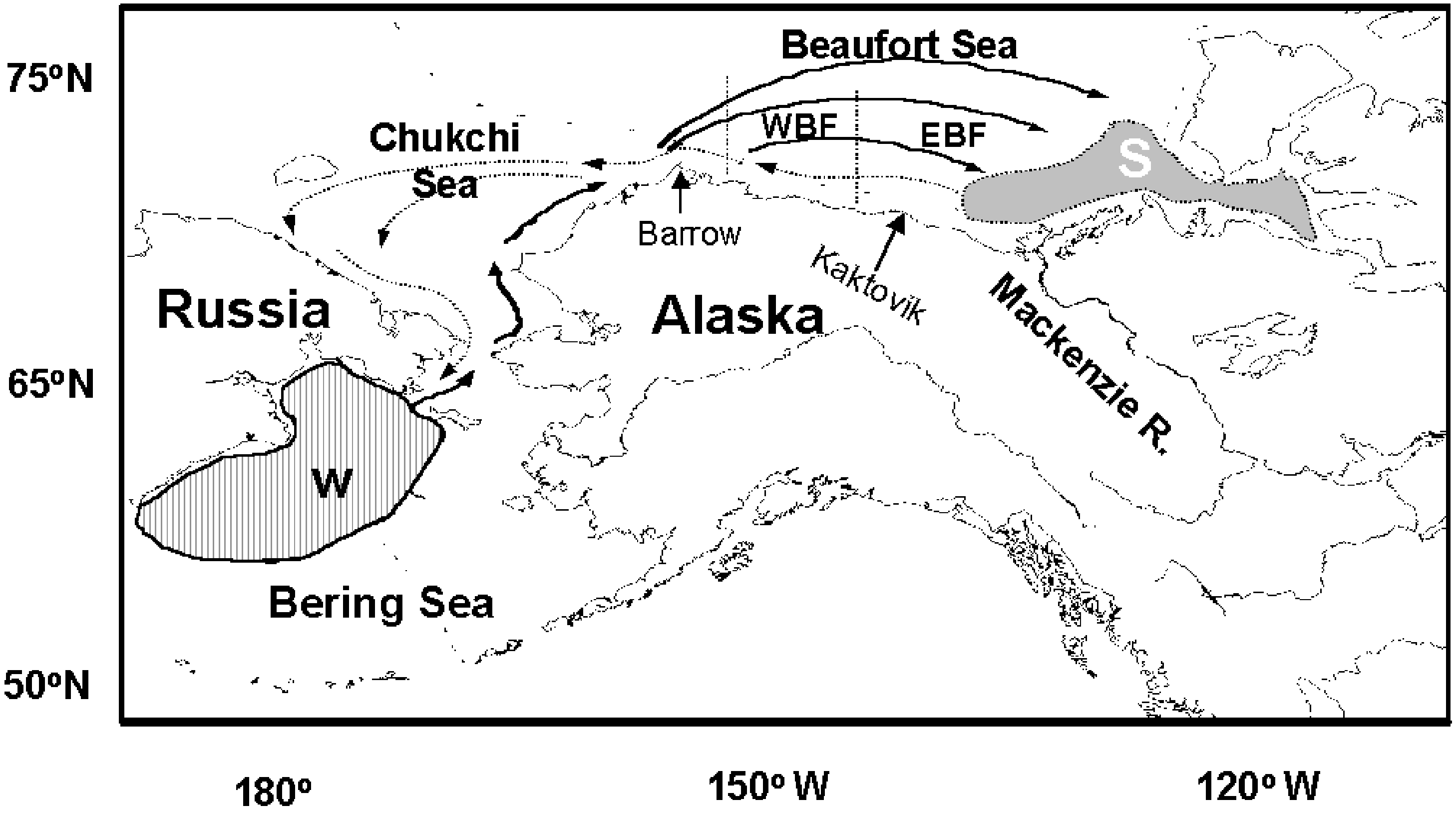


FIGURE 20.1. Bowhead whale migration routes (from Schell et al. 1989). S = summering ground; W = wintering ground; WBF = western Beaufort Sea; EBF = eastern Beaufort Sea.

ach. These estimates can be compared for whales examined in specific regions and seasons (Lowry 1993; see Chapter 18). However, this method represents only the feeding that occurred close to the sampling site(s) during a short interval of time prior to sampling (Hobson and Clark 1992; Hobson et al. 1996). It is also complicated when there is significant delay between the time of the whale is killed and the time when the stomach contents can be sampled. • *Energy reserves* as measured by blubber thickness or other parameters during different seasons have provided data on seasonal feeding in other baleen whales (e.g., Lockyer 1981; Víkingsson 1990), and are now being applied in bowhead whales (see Chapter 22).

Stable isotope ratios provide an alternative approach that may enable the determination of important feeding habitats for migratory animals (Fry 1981; Schell 1987; Schell et al. 1989). Animals acquire a natural isotopic tag from their diet (Fry 1981). If the stable isotope ratios in the food are sufficiently different in specific parts of the annual range where feeding occurs, and if these differences are transferred conservatively and predictably to the animals, the relative importance of the different feeding areas can be determined (Schell and Saupe 1993).

Fry (1981) used stable carbon isotope analysis to trace shrimp movements by matching the $\delta^{13}C$ values of migrating shrimp with the $\delta^{13}C$ values of resident shrimp living in specific habitats. Schell et al. (1989) reported annual oscillations of $\delta^{13}C$ and $\delta^{15}N$ along the length of bowhead baleen plates. These oscillations apparently resulted from annual migrations of the whales from summering grounds in the eastern Beaufort Sea (where food sources are relatively depleted of ^{13}C) to late autumn feeding areas and wintering grounds in the Chukchi and Bering seas (where the food contains relatively more ^{13}C). The previous studies of isotopic composition of bowheads have provided new insight into their feeding habitats in a remote area (Schell and Saupe 1993). Their isotope results, combined with data on seasonal and geographic patterns in zooplankton production, suggested that most annual feeding occurs in late summer and fall during the return migration from the western Beaufort Sea through the Chukchi Sea and into the Bering Sea. The large concentrations of zooplankton that mature over the summer in the northern Bering Sea are carried northward by flow through the Bering Strait (Springer et al. 1989) into the Chukchi Sea, and have been observed being preyed upon heavily by the returning whales (Moore et al. 1995).

Increased interest in the eastern Alaskan Arctic has led us to re-examine the feeding scenarios for these whales in more detail. Our primary objective was to use stable isotope methods to assess the relative amounts of feeding in the eastern Beaufort Sea vs. the Bering and Chukchi Seas, including a comparison of feeding strategies by adult vs. subadult bowhead whales. Also, we were interested in comparing feeding strategies in recent vs. earlier years. Recent evidence that the productivity of the Bering and Chukchi seas may have declined suggested that feeding in the eastern Beaufort Sea might be more important to bowhead whales now than in previous decades (Schell 2000, 2001). As in previous related studies, our approach is based on the fact that samples of bowhead tissues can be obtained in northern Alaska during the spring and autumn migrations, when bowhead whales are harvested by Inupiat hunters (Stoker and Krupnik 1993; see also Chapter 2).

After the draft of this chapter was completed, Hoekstra et al. (2002) published data from a closely-related stable-isotope study of bowhead whale feeding, including measurements from some of the same individual whales studied here. The data of Hoekstra et al. are discussed in this updated chapter.

The main topic of this overall report is feeding by bowhead whales in the *eastern Alaskan* Beaufort Sea, which is a minority of the eastern Beaufort Sea. The isotopic method, as now available, does not permit us to discriminate food acquired in the Canadian vs. eastern Alaskan Beaufort Sea (see Schell et al. 1998). Nonetheless, it is of interest to investigate what proportion of their annual food the Bering–Chukchi–Beaufort stock of bowheads acquires in the eastern Beaufort Sea as a whole. That sets an upper limit on the amount that might be obtained in the eastern Alaskan Beaufort Sea. Other chapters of this report provide data on relative food availability (Chapters 5, 6), residence times (Chapter 11), and proportion of time spent feeding (Chapter 12) in the Canadian vs. eastern Alaskan Beaufort Sea.

Methods

We obtained one of the longest baleen plates from 4 of the whales killed at Barrow and all 10 of the whales landed at Kaktovik during 1997–99; 13 of 14 were killed in autumn (Table 20.1). Additional comparative data were obtained from baleen collected in past studies during both spring (predominantly) and autumn (Table 20.2). Plates were cleaned of adhered gum tissue at the proximal end and then scrubbed with steel wool to remove surface layers of foreign matter such as diatoms and whale oil. Each plate was labeled along its length with adhesive tape and marked at 1-cm intervals. From 0 cm to 100 cm from the proximal end, samples were taken at 1-cm intervals using a flexible-shaft engraving tool. Beyond 100 cm, plates were sampled at 2-cm intervals. These samples allowed us to determine isotopic ratios along the entire temporal span of each plate, with particularly high temporal resolution within the most recently-grown (proximal) baleen. As an example, the ^{13}C data obtained from whale 97KK2 are shown in Figure 20.2.

TABLE 20.1. Bowhead whale samples collected during 1997–99. Baleen samples were obtained from the whales for which baleen length is listed. Muscle samples were obtained from all listed whales except for 97B8, 97B11 and 97B12.

Whale	Date Landed	Village	Whale Length (m)	Baleen Length (m)	Sex	Age Class
97B8	15 May 97	Barrow	13.6	2.54	F	adult
97B11	11 Sept 97	Barrow	13.6	3.00	M	adult
97B12	12 Sept 97	Barrow	15.3	3.12	M	adult
97B14	20 Sept 97	Barrow	8.6		F	subadult
97B16	20 Sept 97	Barrow	8.3		F	subadult
97B18	22 Sept 97	Barrow	10.8		M	subadult
97B20	26 Sept 97	Barrow	8.6		M	subadult
97B21	27 Sept 97	Barrow	9.2		F	subadult
97B22	27 Sept 97	Barrow	9.4		F	subadult
97B23	27 Sept 97	Barrow	10.3		M	subadult
97B24	28 Sept 97	Barrow	8.6		F	subadult
97B25	28 Sept 97	Barrow	11.7	2.08	M	subadult
97B26	29 Sept 97	Barrow	13.5		M	adult
97B27	2 Oct 97	Barrow	9.5		M	subadult
97B28	2 Oct 97	Barrow	8.4		M	subadult
97B29	17 Oct 97	Barrow	8.5		M	subadult
97B30	18 Oct 97	Barrow	8.0		F	subadult
97KK1	3 Sept 97	Kaktovik	8.7	1.50	F	subadult
97KK2	6 Sept 97	Kaktovik	13.2	2.50	M	subadult
97KK3	11 Sept 97	Kaktovik	8.3	1.32	F	subadult
97KK4	27 Sept 97	Kaktovik	14.6	3.06	M	adult
98KK1	4 Sept 98	Kaktovik	10.4	1.92	M	subadult
98KK2	10 Sept 98	Kaktovik	8.9	1.44	F	subadult
98KK3	14 Sept 98	Kaktovik	9.2	1.70	M	subadult
99KK1	11 Sept 99	Kaktovik	7.7	0.86	F	subadult
99KK2	12 Sept 99	Kaktovik	12.9	2.44	M	subadult
99KK3	16 Sept 99	Kaktovik	8.3	1.32	M	subadult

TABLE 20.2. Bowhead whale samples collected during 1986–88 (Schell 1992). Baleen samples were obtained from the whales for which baleen length is listed. Muscle samples were obtained from the whales marked *.

Whale	Date Landed	Village	Whale Length (m)	Baleen Length (m)	Sex	Age Class
86B1	27 Apr 86	Barrow	8.2		M	subadult*
86B2	27 Apr 86	Barrow	8.7		M	subadult*
86B3	3 Apr 86	Barrow	8.9	1.60	F	subadult*
86B4	1 May 86	Barrow	8.9	1.30	M	subadult*
86B5	4 May 86	Barrow	8.1	0.85	M	subadult*
86B6	5 May 86	Barrow	12.3		F	subadult*
86B7	6 May 86	Barrow	10.7	2.01	M	subadult*
86KK1	10 Sept 86	Kaktovik	7.6		F	subadult*
86KK2	17 Sept 86	Kaktovik	17.1	3.80	F	adult*
86KK3	26 Sept 86	Kaktovik	10.4	1.85	M	subadult*
86WW1	5 May 86	Wainwright	15.9	2.69	M	adult*
86WW2	10 May 86	Wainwright	17.7	3.10	F	adult*
87B1	1 May 87	Barrow	9.3	1.68	M	subadult
87B2	2 May 87	Barrow	8.9	1.50	F	subadult
87B3-A	4 May 87	Barrow	11.0	1.95	M	subadult
87B4	2 May 87	Barrow	16.8	2.95	F	adult
87B5	15 June 97	Barrow	15.7	3.00	F	adult*
87B6	22 Oct 87	Barrow	15.7	3.15	F	adult*
87B7	29 Oct 87	Barrow	8.5		M	subadult*
87G2	24 Apr 87	Gambell	16.8	3.45	F	adult
87N1	5 Oct 87	Nuiqsut	15.2	3.30	F	adult*
87WW2	8 May 87	Wainwright	13.5	2.15	M	adult
88B1	24 Apr 88	Barrow	8.9	0.98	M	subadult*
88B2	25 Apr 88	Barrow	8.8		M	subadult*
88B3	25 Apr 88	Barrow	7.8		F	subadult*
88B4	25 Apr 88	Barrow	9.0		F	subadult*
88B5	25 Apr 88	Barrow	8.9		M	subadult*
88B6	2 May 88	Barrow	8.4		F	subadult*
88B7	5 May 88	Barrow	8.2		F	subadult*
88B8	6 May 88	Barrow	7.5		F	subadult*
88B9	15 Sept 88	Barrow	14.6	2.57	M	adult
88B10	17 Sept 88	Barrow	15.1	3.02	M	adult
88G2	25 Apr 88	Gambell	15.3		F	adult*
88KK1	24 Sept 88	Kaktovik	14.9	2.97	F	adult

Muscle samples were obtained from 14 whales harvested at Barrow and 10 whales harvested at Kaktovik during the autumns of 1997–99. These muscle samples provided data on isotope ratios resulting from relatively recent feeding. Approximately 5 g of muscle was collected from each whale by personnel from the Alaska Department of Fish & Game or the North Slope Borough Dept. of Wildlife Management. Subsamples were dried at 65°C for 2 days to constant weight. Muscle samples from 25 additional whales taken in 1986–88, mainly in spring, were used in comparisons (Table 20.2).

The finely powdered baleen and muscle were weighed into cups (0.8–1.0 mg) and the isotope ratios analyzed using a Europa continuous-flow isotope-ratio mass spectrometer. All $\delta^{13}C$ and $\delta^{15}N$ isotope values are reported against, respectively, PDB and air standards as $\delta^{13}C_{PDB}$ (‰) or $\delta^{15}N_{air}$ (‰):

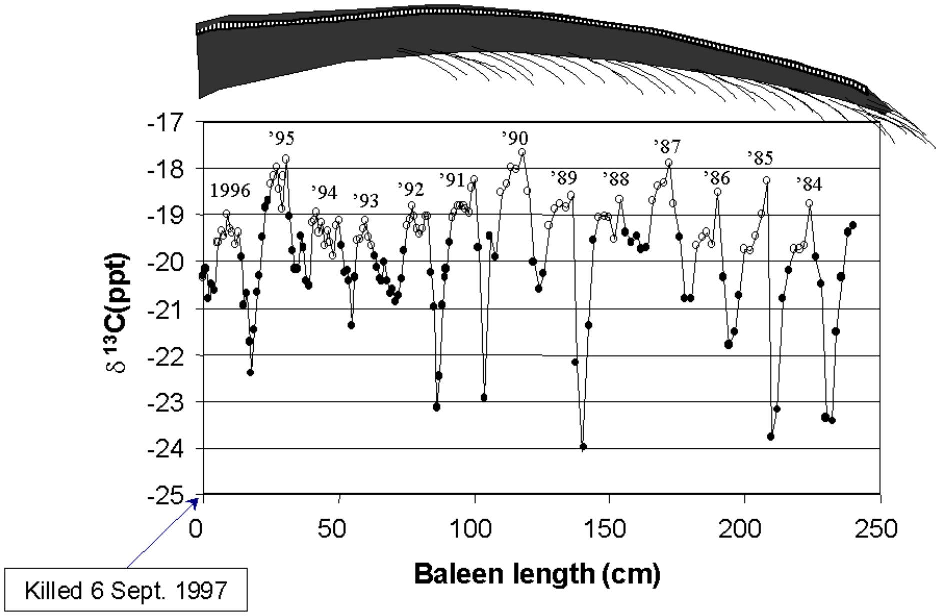


FIGURE 20.2. Carbon isotope ratios along a baleen plate from bowhead whale 97KK2, a 13.2 m male taken at Kaktovik, Alaska, by Herman Aishanna and his crew on 6 Sept 1997. Each oscillation is one year of growth. The most recently formed baleen is at left. Open circles indicate feeding on Bering/ Chukchi prey and filled circles indicate a contribution of Beaufort Sea carbon.

$$\delta = \frac{R_{\text{sample}} - R_{\text{standard}}}{R_{\text{standard}}} \times 1000$$

where R is the ratio $^{13}C : {}^{12}C$ or $^{15}N : {}^{14}N$.

Student's *t*-test was used to identify significant differences between the adult and subadult whales for the years 1986–88 and 1997–99.

Use of $\delta^{13}C$ in Baleen to Assess Feeding

To estimate feeding activity in regions represented by the isotope ratios along the baleen plates, the approximate dietary composition (Table 20.3) and stable isotope values for various components of the diet (Table 20.4) were defined for the eastern Beaufort and for the Bering+Chukchi regions. Because the average isotope ratios of prey from these areas are quite distinct, and because these regions are the geographic extremes of the range of this bowhead population, these two regions were used as end members. Zooplankton from the central and western Beaufort Sea have intermediate $\delta^{13}C$ values (Saupe et al. 1989). Although active feeding has been observed in the western Beaufort Sea during autumn (e.g., Lowry 1993; Landino et al. 1994; Treacy in prep.), it is probably on Chukchi Sea zooplankton that have been advected into the Beaufort Sea.

Specific data on diet composition are available only from locations where bowhead whales are harvested and where their stomach contents have been examined. Stomach contents of bowheads harvested at Kaktovik in September provide data on diet composition in that area and season. Use of those data to represent dietary proportions throughout the eastern Beaufort Sea in summer is subject to various criticisms, including concerns about local and temporal variations, differential digestion, etc. However,

TABLE 20.3. Approximate composition of bowhead whale diets (from Lowry and Sheffield, Chapter 18).

	Copepods	Euphausiids	Mysids	Amphipods
Eastern Beaufort [a]	61 %	22 %	6 %	5 %
Bering + Chukchi [b]	28 %	61 %	1 %	4 %

[a] Based on stomach contents at Kaktovik in fall. [b] Based on stomach contents at Barrow in spring.

TABLE 20.4. Approximate average values of $\delta^{13}C$ and $\delta^{15}N$ (ppt) for main prey taxa from 1985 and 1994, calculated from Schell et al. (1998) and Schell (1992).

	Copepods		Euphausiids		Mysids		Amphipods	
	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
Eastern Beaufort	-25.6	10.4	-23.7	9.2	-23.6	8.5	-23.9	8.2
Bering + Chukchi	-22.2	10.5	-20.8	10.13				

the net tow data from Saupe et al. (1989), Chapters 5 and 6 of this report, and other sources, indicate that the zooplankton of the eastern Beaufort Sea is dominated by calanoid copepods with few euphausiids, generally consistent with prey in the bowhead stomachs examined at Kaktovik. The reverse is true for bowheads harvested near Barrow, where euphausiids have dominated the stomach contents in fall and, in recent years, spring (Lowry 1993; Chapter 18). It is uncertain how representative this is of the actual composition of the bowhead diet in the Bering–Chukchi diet region (including western Beaufort waters).

The tendency for more depleted $\delta^{13}C$ values in copepods relative to euphausiids (difference ~1.1 ‰), combined with the geographic difference in diet (more strongly dependent on copepods in the eastern Beaufort), increases the overall isotopic gradient in the available food and in the diet across the migratory range. If the diet were entirely euphausiids when in the Bering/Chukchi region, and entirely copepods in the eastern Beaufort, the geographic and seasonal shift in the carbon isotope ratio in the diet would be ~4.8 ‰. With the opposite scenario of all copepods in the Bering/Chukchi and all euphausiids in the eastern Beaufort Sea, the difference would be only 1.5 ‰. Net tow data on zooplankton abundance and stomach content data on bowhead diet at Kaktovik and Barrow both suggest that the former scenario is much closer to reality (Saupe et al. 1989). Nevertheless, the relative abundances of prey taxa may change substantially from year to year across the range. Large inter-year variations in taxon abundances in a given region, as shown for the eastern Alaskan study area in Chapter 5, are also expected to be common. Whether the whales target specific taxa preferentially, as opposed to feeding on the most abundant available taxon, is also unknown.

The data on isotope ratios in zooplankton from different parts of the bowhead range are the result of many years of sampling in many locations. The areas of most intense coverage include the eastern Beaufort Sea in both nearshore and offshore waters, and the Bering Sea. The sampling coverage is shown in Schell et al. (1998), with the exception that additional samples were taken in the eastern Alaskan Beaufort Sea during the present study (Table 20.5). The observed geographic patterns in isotope ratios have remained consistent across the years.

Anticipated $\delta^{13}C$ and $\delta^{15}N$ values for the total consumed prey from each end-member region were calculated by calculating a weighted average of the taxon $\delta^{13}C$ values from Table 20.4, using the dietary proportions from Table 20.3 as the weighting factors. We considered only copepods and euphausiids, the dominant prey items (Saupe et al. 1989; Lowry 1993, Chapter 18). For the eastern Beaufort Sea,

TABLE 20.5. Average zooplankton isotope ratios (± standard deviation and number of samples) for the Eastern Alaskan Beaufort Sea in 1998–99 (this study), compared with data of Schell et al. (1998) for the eastern Beaufort Sea as a whole.

	$\delta^{13}C$	s.d.	*n*	$\delta^{15}N$	s.d.	*n*
1999						
Copepods	-25.6	0.59	33	10.3	0.56	33
Euphausiids	-24.2	0.85	5	11.0	0.29	5
Chaetognaths	-23.5	0.18	4	12.3	0.75	4
1998						
Copepods	-24.7	0.37	30	10.8	0.99	30
Euphausiids	-23.1	1.18	5	11.2	0.71	5
Chaetognaths	-23.2	0.32	11	12.8	0.81	11
Schell et al. (1998)						
Copepods	-25.7	0.20	57	10.8	0.19	45
Euphausiids	-23.7	0.32	21	9.2	0.57	18
Chaetognaths	-23.4	0.33	5	13.5	0.60	5

$\delta^{13}C$ = (average $\delta^{13}C$ of copepods × prop'n of copepods in bowhead diets) + (average $\delta^{13}C$ of euphausiids × prop'n of euphausiids) = –25.10 ‰

$\delta^{15}N$ = 10.08 ‰, based on a calculation parallel to the above, but for $\delta^{15}N$.

In the Bering and Chukchi seas,

$\delta^{13}C$ = (average $\delta^{13}C$ of copepods × prop'n of copepods in bowhead diets) + (average $\delta^{13}C$ of euphausiids × prop'n of euphausiids) = –21.24 ‰

$\delta^{15}N$ = 10.25 ‰, based on a calculation parallel to the above, but for $\delta^{15}N$.

These values are the anticipated average isotopic composition of the prey consumed in each region. The difference in $\delta^{13}C$ between the assumed diets during summer and early autumn in the eastern Beaufort Sea as compared with late autumn and winter in Bering–Chukchi waters, including the western Beaufort, is 3.86 ‰. The eastern Beaufort Sea could not be further divided into Alaskan and Canadian sectors due to the lack of significant differences in $\delta^{13}C$ and $\delta^{15}N$ values for zooplankton from the two regions (Schell et al. 1998). Hence, the eastern Beaufort Sea end member includes both sectors. For simple mixing models, use of $\delta^{13}C$ is more practical than $\delta^{15}N$ because a much larger gradient in $\delta^{13}C$ is present in progressing from the Bering and Chukchi seas to the eastern Beaufort region.

The $\delta^{13}C$ values at locations 0 to 50 cm from the basal end of the baleen, representing the most recent 2 or 3 years of baleen growth, were used to illustrate the amount of feeding in each isotopic regime. [The baleen growth rate is 16 to 25 cm/year (Schell and Saupe 1993).] The baleen is also assumed to grow at a constant rate whether the whales are actively feeding or not. Comparison of plates from whales taken in spring and fall showed similar growth rates during summer and winter (Schell et al. 1989). It is also assumed that baleen reflects immediate diet during periods of active feeding and average body protein composition during periods of fasting (Best and Schell 1996). In the latter case overall baleen isotope ratios would tend to reflect primary food sources year round and show only small seasonal shifts if the whales moved into regions of differing prey isotope ratios where they did not acquire significant quantities of food. Many adult bowhead whales exhibit this type of isotopic trace.

The intermediate $\delta^{13}C$ values between –18.8 and –22.0 ‰ evident in parts of the baleen are assumed to arise when the whale moves from one isotopic regime into the other of the two end members (Bering/Chukchi and eastern Beaufort) during migration. Shifts in isotope ratios along the baleen indicate that feeding was occurring as the baleen was deposited, but do not give quantitative information as to the amount of food consumed. However, the amplitude of the annual isotopic cycle provides some information. It is reasonable to assume that large amplitudes in isotopic ratios reflect substantial feeding from each of the two regimes whereas a small amplitude implies that most of the food was from one region. This interpretation also requires the assumption that the zooplankton in the two regions retains the same difference in isotope ratios from year to year. As such, the baleen isotopic data are useful only as a relative indicator of feeding activity, and when comparing whales taken during periods with little year-to-year change in isotope ratios.

Correction for Changing $\delta^{13}C$ and $\delta^{15}N$ in the Bering and Chukchi Seas Biota

An additional correction is also needed in using our data on isotope ratios to assess regional feeding. Carbon isotope ratios in parts of the baleen laid down in the Bering and Chukchi seas have shown an overall 0.81‰ decrease over the years 1994–98 compared to 1983–87 (Schell 2000, 2001; Fig. 20.3). For both carbon and nitrogen, there has been a pronounced decline in isotope ratios in the baleen laid down over the past several decades, presumably representing a corresponding decline in the isotope ratios in the prey. The average $\delta^{13}C$ decreased by approximately 2.7 ‰ between 1965 and 1998. The average $\delta^{15}N$ decreased by about 1.3 ‰ between 1953 and 1998. This decline has been ascribed to a progressive decline in primary productivity in the Bering Sea, although other mechanisms may be contributing (see Schell 2000, 2001; also comment by Cullen et al. 2001). Considering the extensive regions in the Bering and Chukchi seas in which the bowhead whales can feed, the consistency in isotope ratios between whales for a given year is remarkable (Schell and Saupe 1993). The premise that the isotopic record is environmental in origin and not due to physiological responses in the whales is supported by the close agreement in isotope ratios among multiple whales, adults and subadults, for a given year.

To compensate for this long-term trend, an additional 1.0 ‰ was added to the average $\delta^{13}C$ values measured in the parts of the baleen representing feeding on Bering/Chukchi zooplankton during 1997–99. This allows direct comparisons of data from baleen laid down in the late 1990s vs. the 1980s, and comparisons with the regional zooplankton data from the 1980s (Table 20.4). For this study, it was assumed that the carbon isotope ratios in the zooplankton of the eastern Beaufort Sea did not change between 1983–87 and 1994–98 (Table 20.5).

In many whales, the baleen deposited during summer shows only very small depressions in isotope ratios, not representative of isotope ratios in prey from the eastern Beaufort Sea. Also, $\delta^{13}C$ and $\delta^{15}N$ values from summer baleen do not match between whales. Thus, it is not possible to determine if a significant shift has occurred in the isotope ratios within baleen deposited in the Beaufort Sea over past decades.

Results

Zooplankton Isotope Ratios in the Eastern Beaufort Sea

The carbon and nitrogen isotope ratios found for the major taxonomic groups of zooplankton during 1998–99 were very similar to those reported by Schell et al. (1998) for 1985–95. Table 20.5 lists the recently acquired carbon and nitrogen isotope ratios for copepods, euphausiids and chaetognaths, and those from previous work. The 1998–99 data are based on a limited number of stations in the eastern Alaskan Beaufort Sea; the earlier data include samples from the Canadian as well as eastern Alaskan

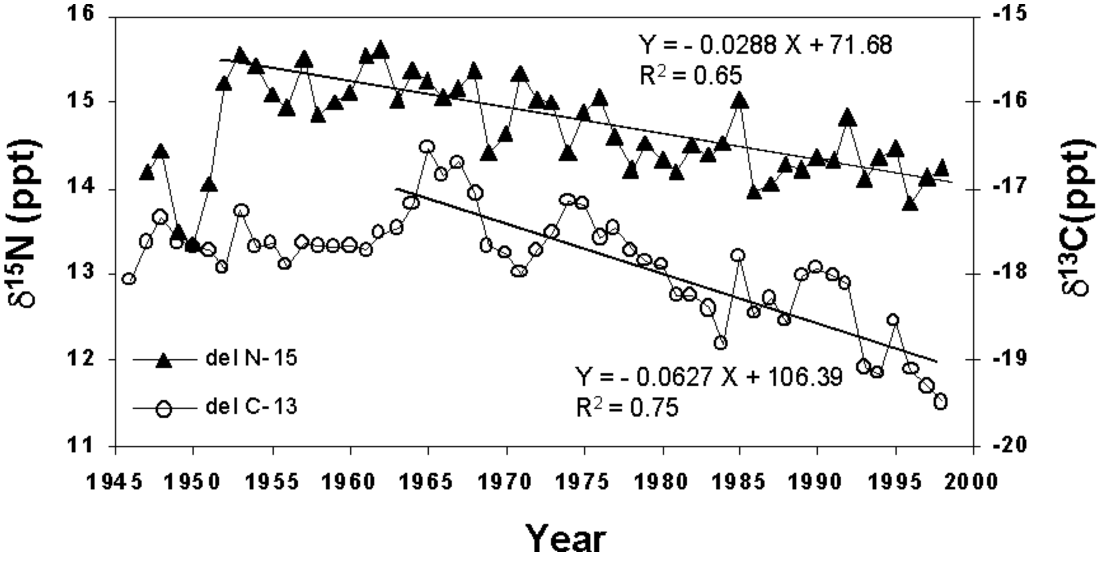


FIGURE 20.3. Average carbon and nitrogen isotope ratios in the portions of 39 bowhead whale baleen plates laid down during feeding in the Bering and Chukchi seas each year over the past five decades. Standard deviations around each point are approximately ±0.5 ppt for carbon and ±0.6 ppt for nitrogen. Straight lines are least-squares linear fits from 1965 to 1998 for carbon and from 1952 to 1998 for nitrogen (from Schell 2000, 2001).

Beaufort Sea, in both coastal and offshore waters. Based on the new data we assumed, when calculating food sources, that the carbon isotope ratios in the zooplankton of the Beaufort Sea during the 1990s were similar to those reported in Schell et al. (1998).

Seasonal Isotope Ratios in Muscle

Muscle tissues of 24 whales harvested in autumn 1997–99 were analyzed. The isotope ratio data are listed in Table 20.6, along with results reported by Schell (1992) for 19 whales harvested in spring (and 6 in autumn) of 1986–88. No muscle samples were obtained by us in spring during 1997–99. Thus we were constrained to using spring whale muscle data from Schell (1992) for comparison of fall vs. spring.

***$\delta^{13}C$ in Bowhead Muscle*.—**Fall muscle for 1997–99 exhibited a unimodal distribution of δ^{13}C with a range from –22 to –19.5 ‰, centered about a mode of –20.5 to –21 ‰. By comparison, the spring muscle for 1986–88 fell between –21 and –18.5 ‰ with a mode at –19 to –19.5 ‰ (Fig. 20.4). The average δ^{13}C values differed by 1.1 ‰ : –20.72 ‰ ± s.d. 0.56 ‰ for fall 1997–99 and –19.58 ‰ ± 0.47 ‰ for spring 1986–88 (Student's $t = 7.11$, df = 41, $P < 0.001$).

There are two possible reasons for lower δ^{13}C values in whales killed in fall 1997–99 than in spring 1986–88. This difference might mean the whales feed to a significant extent during summer in the eastern Beaufort Sea. Alternatively, if most feeding is in the Bering/Chukchi area, a difference of about 1 ‰ would be expected based on the year-to-year decrease in average δ^{13}C values in Bering/Chukchi biota noted above (Fig. 20.3). The latter explanation is believed to be the major factor. The average uncorrected δ^{13}C value for the muscle from six fall-killed 1986–87 whales is –20.47 ‰ ± s.d. 1.05 ‰,

TABLE 20.6. δ^{13}C and δ^{15}N values for bowhead muscle tissues from 1997–99 whales (this study) and 1986–88 whales (Schell 1992). All 1997–99 muscle tissue was collected from fall-killed whales. The muscle samples for 1986–88 were from spring-killed animals, except for six fall-killed whales noted with an asterisk. Muscle samples were not collected from whales 97B8, 97B11, and 97B12. Data have not been corrected for the decreasing decadal trends in δ^{13}C and δ^{15}N in the Bering/Chukchi seas (Schell 2000, 2001).

Whale	Whale Length(m)	δ^{13}C (‰)	δ^{15}N (‰)	Whale	Whale Length (m)	δ^{13}C (‰)	δ^{15}N (‰)
97B8	13.6	NA	NA	86B1	8.2	-19.43	15.24
97B11	13.6	NA	NA	86B2	8.7	-20.10	14.63
97B12	15.3	NA	NA	86B3	8.9	-20.56	12.64
97B14	8.6	-19.87	13.65	86B4	8.9	-19.55	15.56
97B16	8.3	-20.80	14.91	86B5	8.1	-19.10	14.42
97B18	10.8	-20.83	12.85	86B6	12.3	-19.73	13.30
97B20	8.6	-20.62	13.00	86B7	10.7	-20.11	15.56
97B21	9.2	-20.98	12.31	*86KK1	7.6	-21.45	13.91
97B22	9.4	-21.38	12.68	*86KK2	17.1	-19.12	13.86
97B23	10.3	-20.46	12.58	*86KK3	10.4	-21.38	14.97
97B24	8.6	-20.70	12.91	86WW1	15.9	-18.84	14.38
97B25	11.7	-21.37	12.97	86WW2	17.7	-19.35	13.62
97B26	13.5	-21.41	12.80	87B5	15.7	-18.94	14.23
97B27	9.5	-21.53	12.64	*87B6	15.7	-19.20	13.27
97B28	8.4	-19.99	13.78	*87B7	8.5	-20.83	13.85
97B29	8.5	-20.00	13.46	*87N1	16.8	-20.85	12.89
97B30	8.0	-21.78	14.45	88B1	8.9	-20.16	14.55
97KK1	8.7	-20.79	12.85	88B2	8.8	-19.43	14.80
97KK2	13.2	-20.42	12.94	88B3	7.8	-19.24	
97KK3	8.3	-20.44	14.67	88B4	9.0	-19.28	14.54
97KK4	14.6	-20.01	13.62	88B5	8.9	-19.43	13.80
98KK1	10.4	-20.47	12.40	88B6	8.3	-19.94	14.30
98KK2	8.9	-19.80	12.84	88B7	8.2	-20.30	14.43
98KK3	9.2	-21.30	12.54	88B8	7.5	-19.52	13.97
99KK1	7.7	-20.91	13.72	88G2	15.3	-19.06	13.90
99KK2	12.9	-20.49	12.60				
99KK3	8.3	-20.87	12.66				

and closer to the average for fall-killed 1997–99 whales than to the average for spring killed 1986–88 whales. However, the δ^{13}C values in all fall muscle (including 6 fall-killed 1986–88 whales) are not significantly different from those in the spring muscle after adjustment for the 1 ‰ long-term decline observed in Bering–Chukchi isotopic averages over the past 10 years.

δ^{15}N in Bowhead Muscle.—Whales taken in fall 1997–99 have muscle with a mean δ^{15}N value of 13.16 ‰ ± s.d. 0.72 ‰ (Fig. 20.5), whereas spring muscle samples for 1986–88 have an average δ^{15}N of 14.32 ‰ ± 0.76 ‰ or an enrichment of 1.2‰. The average δ^{15}N value for the six autumn-killed whales from the 1986–87 (13.79 ± 0.71 ‰) was intermediate between spring whales in the '80s and fall whales in the '90s. The δ^{15}N values in fall muscle (including 6 fall-killed 1986–88 whales) are significantly different from those in the spring muscle (t-test, 2 tails, $P < 0.001$), although the δ^{15}N values of the main

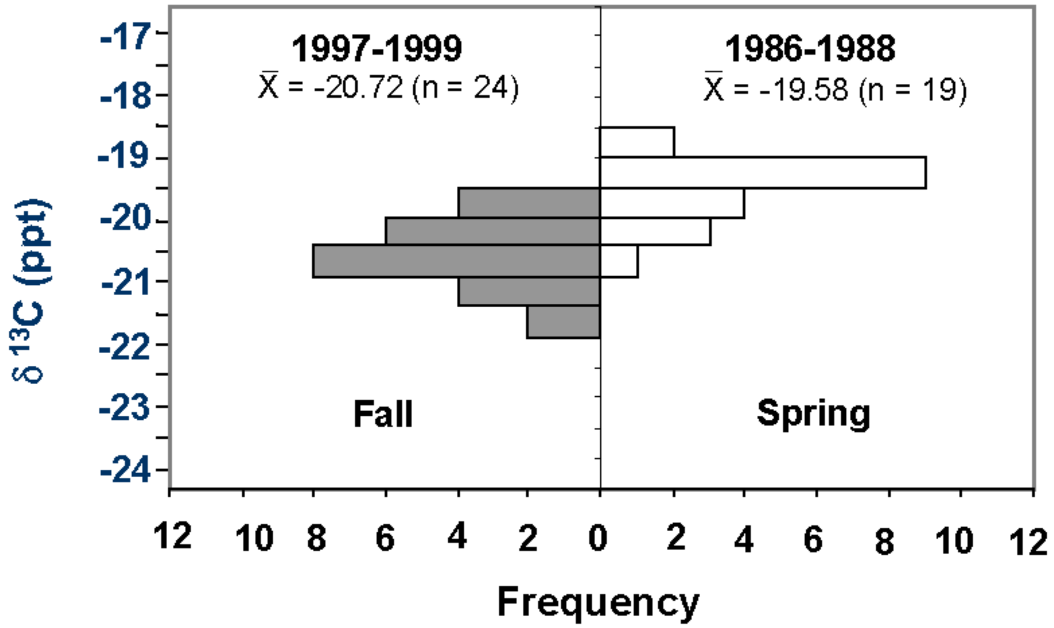


FIGURE 20.4. δ^{13}C values in bowhead whale muscle tissue taken in fall 1997–99 as compared to spring 1986–88. Values are as measured, not adjusted for decadal trend.

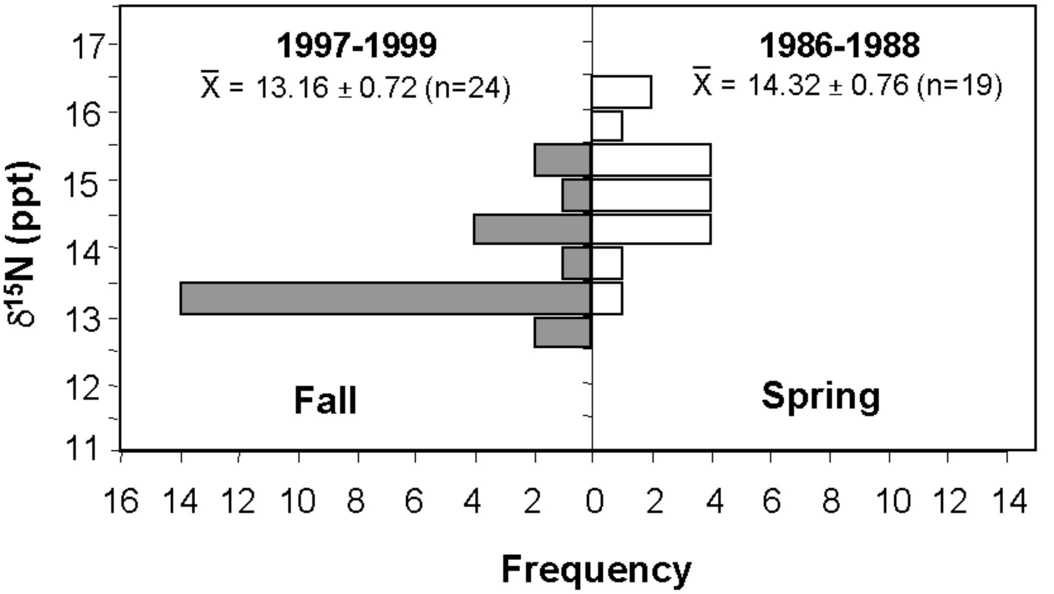


FIGURE 20.5. δ^{15}N values in bowhead whale muscle tissue taken in fall 1997–99 as compared to spring 1986–88. Values are as measured, not adjusted for decadal trend.

prey groups do not differ significantly between summer and winter feeding grounds. $\delta^{15}N$ as well as $\delta^{13}C$ values in muscle have decreased in the past decade, apparently in response (at least in part) to long-term decreases in isotope values in the Bering/Chukchi environment (Fig. 20.3). This may account for the difference in $\delta^{15}N$ of muscle shown in Figure 20.5, although the $\delta^{15}N$ values in baleen deposited in 1986–88 and 1997–99 did not show a significant change (Fig. 20.3).

Isotope Ratio Patterns of Subadult vs. Adult Whales

***Muscle*.—**To assess the extent to which subadults and adults feed differently, all muscle data for $\delta^{13}C$ and $\delta^{15}N$ are plotted against whale length in Figure 20.6 and 20.7. Subadults were separated by body length (<13.5 m) from adults (≥13.5 m). The 13.5 m cutpoint is appropriate for bowhead whales that have been stretched when towed out of the water. No significant differences were noted in $\delta^{13}C$ or $\delta^{15}N$ in subadult vs. adult whale muscle.

***Baleen*.—**Figure 20.8 shows $\delta^{13}C$ and $\delta^{15}N$ values for each point within parts of the baleen formed during the most recent 2 or 3 years, distinguishing adults (n = 9 + 4, Fig. 20.8A) and subadults (n = 9 + 8, Fig. 20.8B). Results for 1997–99 and 1986–88 are plotted separately. The range in $\delta^{13}C$ values is greater in subadults than in adults for both time periods (Fig. 20.8). The range of $\delta^{13}C$ for adults is –20 to –17 ‰ for 1986–88 and –21 to –17.5 ‰ for 1997. By comparison, $\delta^{13}C$ values of subadults range from –23 to –17.5‰ for both 1986–88 and 1997–99. $\delta^{15}N$ values in recently-grown baleen also span a slightly wider range for subadults than for adults (Fig. 20.8). The range of $\delta^{15}N$ in adults is from 12.5 to 16 ‰ for both periods, whereas the range in subadults is 12.5 to 17 ‰ for 1986–88 and 11 to 16 ‰ for 1997–99.

Discussion

Muscle tissue $\delta^{13}C$ values provide a good overall indication of the bulk food sources that the whales have consumed over the seasonal feeding cycle. George et al. (1988) estimated that muscle tissue comprises approximately 19 % of the total body mass with blubber comprising the other large fraction. The estimated $\delta^{13}C$ values for total consumed prey are significantly different between the eastern Beaufort Sea and the Bering and Chukchi Seas (see Methods). Therefore, muscle tissue should change appreciably in $\delta^{13}C$ between spring–summer and fall–winter seasons if whales feed to a significant extent in each region and if the overall composition of the diets for bowhead whales, as listed in Table 20.3, are approximately representative. However, the $\delta^{13}C$ values in fall muscle in the late 1990s were not significantly different from those in the spring muscle from the 1980s after adjustment for the 1 ‰ long-term decline observed in Bering/ Chukchi isotopic averages over the intervening 10 years. This indicates that almost all food for the whales came from the Bering and Chukchi seas.

Appendix 20.1 calculates the estimated turnover in muscle carbon attributable to feeding in the eastern Beaufort sea, based on the data from whales harvested at Barrow in spring of 1986–88 (n = 16) and at Kaktovik in autumn of 1986 and 1997–99 (n =13). This calculation included an adjustment for the long-term trend in Bering/Chukchi isotopic averages, and included derivation of confidence limits. The observed zooplankton fractions in stomach contents of bowhead whales were used as weighting factors in calculating the average $\delta^{13}C$ values for zooplankton food from the Bering/Chukchi vs. Beaufort; they differ by 3.86 ‰ (see Methods). This assumes a dietary composition of 61 % copepods and 22 % euphausiids in the E. Beaufort Sea, vs. 28 % copepods and 61 % euphausiids in Bering/Chukchi waters. As noted earlier, there are questions as to how representative these dietary data may be. However, the similarity in taxonomic composition of stomach contents and samples from net tows (Saupe et al. 1989; Schell et al. 1998; Chapter 5 vs. 18) gives some indication that the approximations are reasonable.

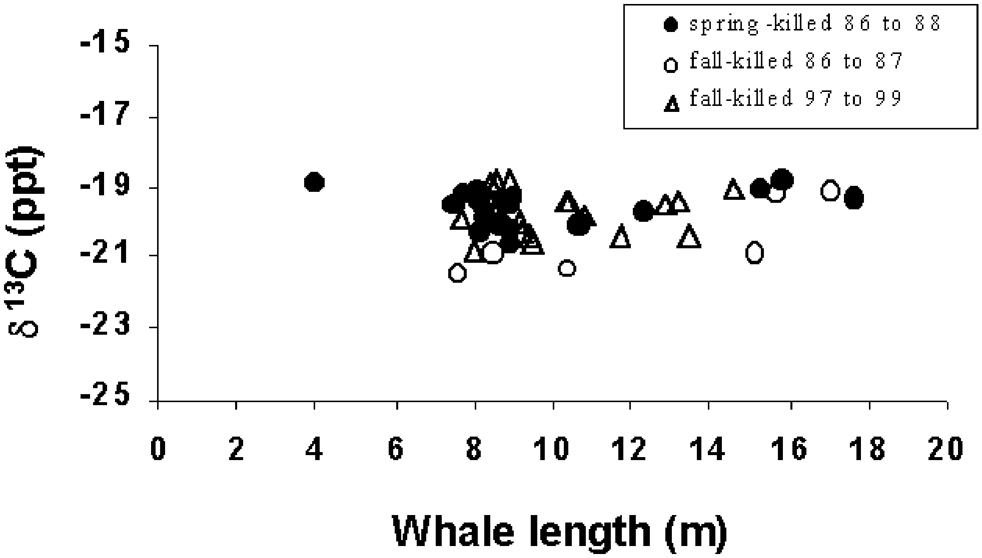


FIGURE 20.6. Carbon isotope ratios in whale muscle versus whale length. Whales >13.5 m in body length were assumed to be adults (sexually mature). Data from 1997–99 have been adjusted upward to allow for the decadal decline in average carbon isotope ratios (1 ‰).

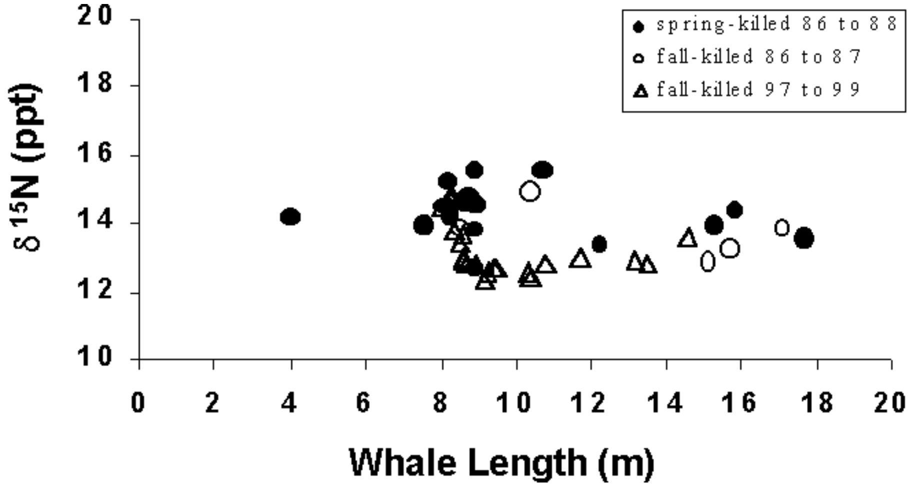


FIGURE 20.7. Nitrogen isotope ratios in whale muscle versus whale length. Whales >13.5 m in body length were assumed to be adults (sexually mature). Values were not adjusted for any decadal trend.

Assuming a 3.86 ‰ difference in the isotopic composition of the prey in the two regions, and the (adjusted) seasonal difference in the muscle as documented in this study, **10 %** of the muscle carbon has turned over during the course of summer feeding, with 95% confidence interval of 0 % to 23 %. Considering subadult whales only, the estimated turnover was 14 % with 95% confidence interval 4 % to 23 %. Considering adults only (for which the data are very limited), the estimated turnover was 5 % with 95% confidence interval 0 % to 30 % (see Appendix 20.1 for details).

The major assumption and weakness of the preceding analysis arises from the need to compare seasonal isotope ratios in whales that were harvested approximately 10 years apart. The changing isotope ratios in zooplankton of the Bering and Chukchi seas (and perhaps the Beaufort Sea) introduce an uncertainty in the feeding estimates that is difficult to quantify, notwithstanding the procedures used in Appendix 20.1.

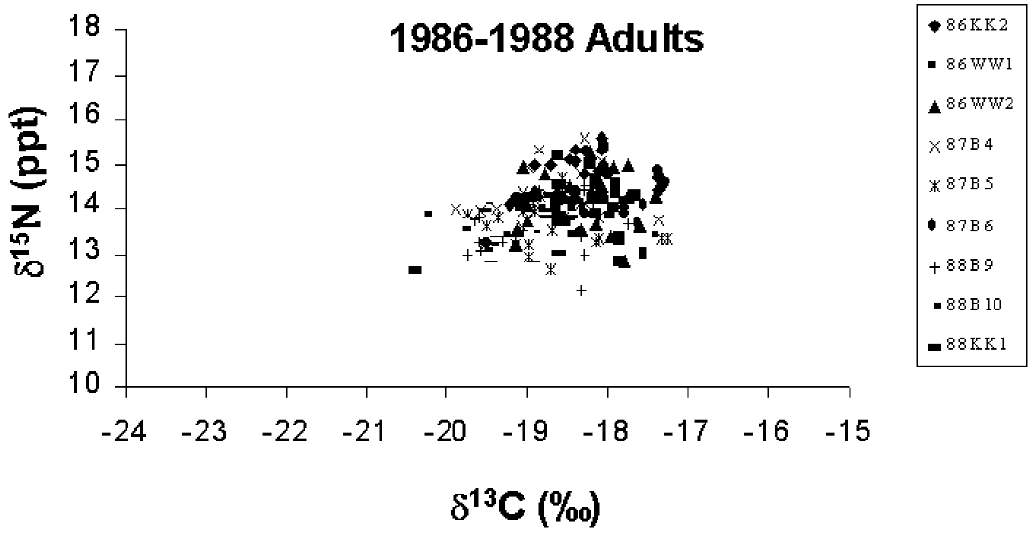
Estimation of Feeding Activity Using Same-Year Data

A recent paper by Hoekstra et al. (2002) contrasts isotope ratios of bowhead whales taken within the same years in spring and fall. This allows a more direct approach to estimation of feeding, as evidenced by the turnover of carbon in muscle tissue. Hoekstra et al. determined that 10 whales taken in fall at Kaktovik during 1997–99 (the years of our sampling) had an average muscle $\delta^{13}C$ of –21.6 ‰ and that 28 whales taken in spring at Barrow during 1998–2000 averaged –19.9 ‰, for a seasonal shift of –1.72 ‰ . The samples taken were lumbar muscle, which would be anticipated to show relatively rapid turnover as it is the primary locomotive muscle. If the zooplankton food end-members are assigned $\delta^{13}C$ values of –20.88 ‰ for the Bering/Chukchi waters and –25.49 ‰ for the Beaufort Sea (Schell et al. 1998), this implies a muscle carbon turnover of 1.7/4.6 or **37 %**. Alternatively, assuming a 3.86 ‰ difference in the isotopic composition of the prey in the two regions (see above), and the 1.72 ‰ seasonal difference in the muscle as observed by Hoekstra et al. (2002), approximately **45 %** of the muscle carbon has turned over during the course of summer feeding.

The above estimates of summer feeding, based on the data of Hoekstra et al. (2002), are much higher than those determined by us based on either the analysis with allowance for long term trend (see above) or additional analyses of same-year data, described here.

We found an average muscle $\delta^{13}C$ of –20.7‰ in Kaktovik whales during the autumns of 1997–99, or –0.8 ‰ as compared with the spring values from Barrow during similar years, as obtained by Hoekstra et al. (2002). This translates into **17.4 %** turnover of muscle carbon during summer feeding based on the assumed 4.6 ‰ difference in the isotopic composition of zooplankton in the two regions, or **20.8 %** if the weighted value (3.86 ‰) based on stomach contents is used. Comparing our average muscle values for Kaktovik in autumn (–20.7 ‰) and theirs for Barrow in autumn (–20.9 ‰), we find a small and non-significant depletion in the muscle $\delta^{13}C$ of the whales while traveling westward, in contrast to their data. Hoekstra et al. (2002) found an average increase in autumn $\delta^{13}C$ values of 0.7 ‰ between Kaktovik and Barrow, equivalent to a muscle turnover of 15–18 percent.

This discrepancy is critical in assessing the importance of feeding in the Eastern Beaufort Sea. The source of this apparent discrepancy arises from differences in the results for the Kaktovik whale muscle samples. Hoekstra et al. (2002) found an average muscle value of –21.6 ‰ in 1997–99, whereas we obtained an average value of –20.7‰ *from the same whales*. We have repeated our isotopic analyses on additional subsamples from the same Kaktovik whales, with the same results as we obtained initially. The reason for the discrepancy between our data from Kaktovik and those of Hoekstra et al. is still uncertain. We have analyzed the isotope ratios for muscle taken from 14 fall Barrow whales taken in



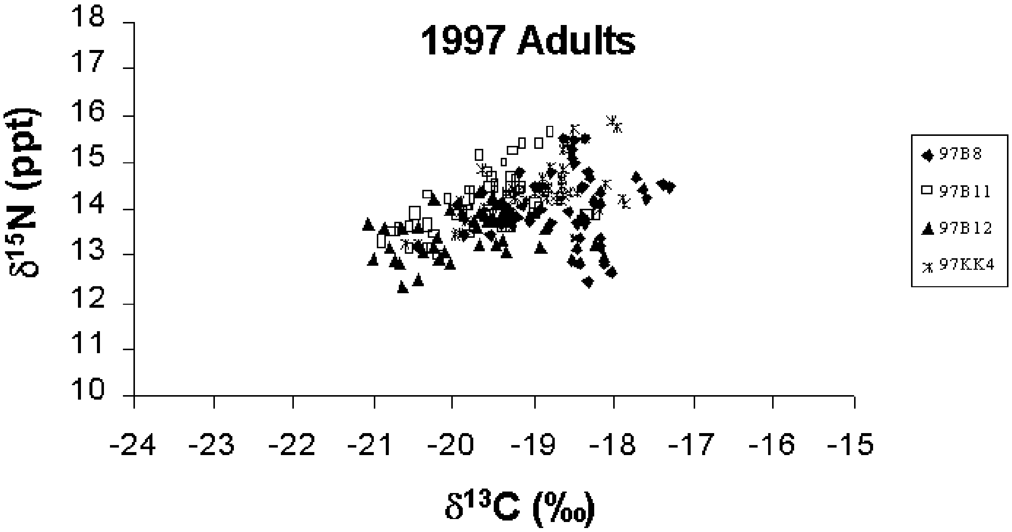


FIGURE 20.8A. $\delta^{13}C$ and $\delta^{15}N$ values from recently-deposited baleen of adult bowhead whales. Each point represents a sample taken 0 to 50 cm from the base of a baleen plate from an adult whale harvested in 1986–88 and 1997. Values have not been adjusted for any decadal trend.

1997 and obtained an average of –20.84 ± s.d. 0.61 ‰. This matches closely the average value of –21.1 ± 95 % CI 0.2 ‰ obtained by Hoekstra et al. for 21 whales harvested at Barrow in fall 1997. We also analyzed three types of muscle from one 1997 Kaktovik whale, including lumbar muscle, and found no significant difference among tissues. This suggests that differences in the types of muscle samples analyzed probably were not important.

In view of the above, we applied this approach to data collected in 1986–87 by Schell (1992), and the results are similar, but based on smaller numbers of whales. Seven whales taken in spring at Barrow had average $\delta^{13}C$ values of –19.6 ‰ for muscle and –24.9 ‰ for visceral fat. Three whales taken at Kaktovik in fall 1986 had average $\delta^{13}C$ values of –20.6 ‰ for muscle and –26.3 ‰ for visceral fat. Thus, the

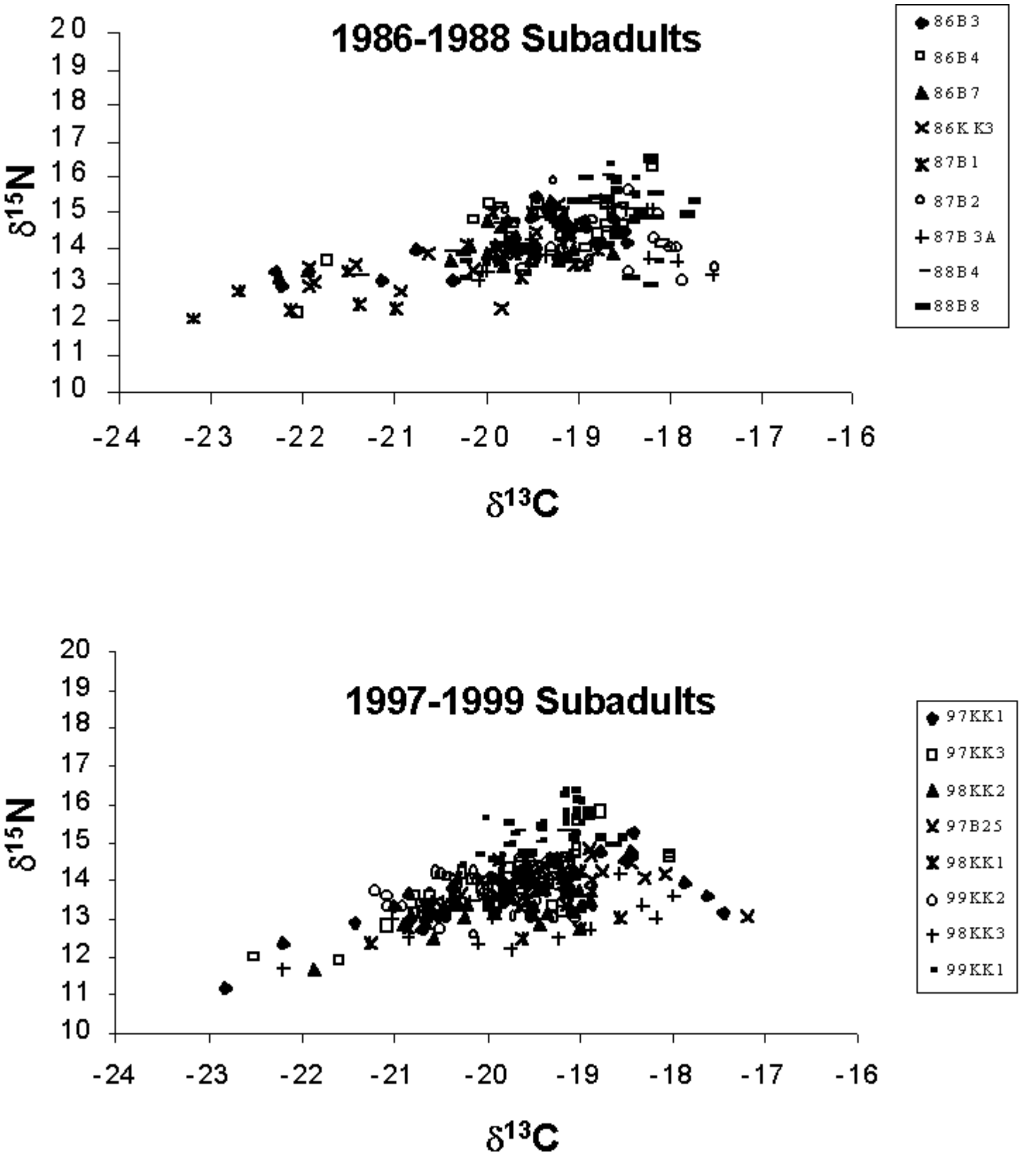


FIGURE 20.8B. $\delta^{13}C$ and $\delta^{15}N$ values from recently-deposited baleen of subadult bowhead whales. Each point represents a sample taken 0 to 50 cm from the base of a baleen plate from a subadult whale harvested in1986–1988 and 1997–99. Values have not been adjusted for any decadal trend.

seasonal change was 1.0 ‰ in muscle and 1.3 ‰ in visceral fat. Again, assuming an end-member difference of 4.61 ‰ , this implies a replacement of about **22 %** of muscle carbon and **28 %** of visceral fat. If the stomach content data of Lowry are used with an end-member difference of 3.86 ‰, the carbon replaced is **26 %** for muscle and **34 %** for visceral fat.

In contrast to the relatively rapid turnover rates of visceral fat and muscle, the blubber lipids showed very little change. Two whales taken at Barrow in 1986 each had blubber $\delta^{13}C$ values of –25.8 ‰ and the three whales from Kaktovik averaged –26.0 ‰ or a change of only 0.2 ‰ over the summer. This implies a turnover of only about **4–5 %**, depending upon the choice of end-member differences. The carbon isotope ratio in lipids is typically depleted by 5–6 ‰ from that in the diet, so the measured values in blubber closely match expected values from feeding on Bering/Chukchi zooplankton.

Our same-year estimates of changes of **17–26** percent in muscle tissue and **28–34** percent for visceral fat are low considering that the whales had been in the ^{13}C-depleted regime of the Eastern Beaufort Sea for approximately four months. Muscle amino acid turnover in terrestrial mammals, as measured using stable and radio-isotope measurements, ranges from 1.2 to 3 percent $\cdot$ day^{-1} for healthy adult humans and dogs, leading to an expected complete replacement time of 33–80 days (Fischman et al. 1998). The low isotopic replacements observed in this study indicate that the metabolic rates of the bowhead whale are slow or that very little food is acquired from the Beaufort Sea. The latter scenario is supported by the very small seasonal isotopic changes observed in blubber tissue in the 1980s.

Isotope ratios in the blubber of bowhead whales landed at Barrow and Kaktovik have not been determined during either the present study nor that of Hoekstra et al. (Paul Hoekstra, pers. comm.). This information would be valuable in estimating the percent of total annual carbon intake derived from the winter versus summer habitats. Blubber comprises approximately 40 % of bowhead body mass and is the major energy store for the whales (George et al. 1988).

Bowhead Whale Feeding Scenario

To assess the contribution of food from Beaufort Sea habitats in meeting the annual energy requirements of the Bering–Chukchi–Beaufort stock of bowheads, it is important to take account of time and resource availability as well as direct evidence of feeding, such as stomach contents and observed feeding behavior. The following feeding scenario is based upon several realistic assumptions concerning food availability and mammalian metabolism:

- Bowhead whales feed seasonally in response to food abundance. Feeding is minimal during the northeastward transit in the Arctic Ocean to summer grounds.
- Zooplankton abundance is proportional to ecosystem primary productivity.
- Zooplankton abundance peaks in the late summer–fall season.
- Zooplankton composition is weighted to euphausiids in the western region and to copepods in the eastern Beaufort Sea.
- Isotope ratios in the whales respond to feeding in the different regimes only if sufficient food is acquired to replace body carbon. Otherwise the whale relies on internal stores and the isotope ratios of the muscle do not change.

This scenario assumes that the whales begin their northward migration in early spring when zooplankton stocks are at an annual minimum and this condition persists during their passage through the Chukchi Sea and into the Arctic Ocean. The whales arrive in the eastern Beaufort Sea after approximately 2–3 months of traveling, with minimal feeding having occurred along the migration route. Bowheads harvested at Barrow in spring often contain some prey, but on average their stomachs contain less food than those harvested in autumn (Chapter 18). Also feeding is much less commonly seen during spring migration than during summer and autumn (Chapter 12). More intensive feeding commences upon arrival on the summering grounds, and with the appearance of growing populations of large copepods and amphipods. Nevertheless, zooplankton patch densities in the Beaufort Sea are constrained by the relatively low primary productivity rates of that area. Primary production estimates are typically in the range of 20–50 gC $\cdot$ m^{-2} in offshore regions of the Beaufort Sea, with the higher values in zones of upwelling associated with offshore winds and open polynyas (Macdonald et al. 1987, 1998; Macdonald and Carmack 1991). Zooplankton biomass and whale feeding would be anticipated to increase at the end of summer.

Most whales begin their fall migration out of the Beaufort Sea in September, feeding intermittently as they travel. On average, they cross into the areas where the zooplankton has higher isotope ratios (west of Harrison Bay) in late September and early October (see Moore and Reeves 1993; also Chapter 9). Here they feed on zooplankton advected from the Chukchi Sea associated with the Beaufort Sea undercurrent. As the fall progresses the whales move into the Chukchi Sea and across to the Chukotka Peninsula region of Russia (Fig. 20.1), in the highly productive waters of the Anadyr current. Primary productivity estimates for this region range from 150 $gC \cdot m^{-2}$ in the coastal waters to over 800 $gC \cdot m^{-2}$ in the center of the Anadyr flow, or approximately 5–10 times estimates for the eastern Beaufort Sea (Springer et al. 1996). This flow carries immense quantities of euphausiids and large oceanic copepods and is known to be prime whale habitat. Thus the whales enter the Chukchi Sea in the fall coincident with maximum annual food supply and are assumed to feed upon these resources. Secondary production of zooplankton is proportional to the primary productivity, but not linear, with increasing trophic efficiency occurring with higher primary production. Thus, the feeding opportunities for the whales would be maximized in this region. Niebauer and Schell (1993) quote whaler observations describing the southern Chukchi Sea as the "cow yard" where the very largest and most oil-rich bowheads were taken. Feeding in reasonably dense concentrations of zooplankton could continue in late autumn/early winter as the whales move into the northwest Bering Sea.

Assuming that the high zooplankton densities persist at least into the early winter, the fall migration past Point Barrow would correspond to the onset of the optimum feeding period for the whales. Although energy-rich zooplankton tend to descend to deep depths in autumn, the Chukchi Sea is generally shallow. This would prevent zooplankton from descending to depths below the diving range of bowheads. If feeding in the Bering/Chukchi system persists until late autumn or early winter, when growing ice cover forces the whales into the Bering Sea, their period of autumn/early winter residence in the Chukchi Sea, and perhaps the northwest Bering Sea, may be the period of maximum energy acquisition and storage. The observation that the nine blubber samples from whales taken in 1986–87 all have similar $\delta^{13}C$ values near –25.8 ‰ supports this conclusion. As noted above, lipids are typically depleted by 5–6 ‰ relative to diet, and this –25.8 ‰ value closely matches expected values from feeding on Bering/Chukchi zooplankton.

Nitrogen Isotope Data

The $\delta^{15}N$ values in fall muscle are significantly different from those in the spring muscle. The nitrogen isotope ratio is often an indicator of nutritional status (e.g., Gannes et al. 1997), but the specific reason for the observed difference is uncertain. One possibility is that it results from the same decadal decline in environmental isotope ratios as noted for carbon. The spring whales were all taken in the 1980s whereas the fall whales were mainly from the late 1990s. The long-term trend noted for both elemental isotope ratios (based on baleen deposited in the Bering/Chukchi region) is of the same magnitude as the difference between the spring muscle from the 1980s vs. the fall muscle from the 1990s. However, the nitrogen isotope data evident in baleen laid down in the specific years of capture in the '80s and '90s are similar (Fig. 20.3). This tends to discount the possibility that a decadal-decline was the cause of the spring–fall difference in the muscle $\delta^{15}N$ values. A second possibility is that summer fasting produced a shift toward higher $\delta^{15}N$ values (Hobson et al. 1993, 1996; Best and Schell 1996). The seasonal change in $\delta^{15}N$ is unlikely to arise from summer feeding as the carbon isotope ratios in muscle would be expected to show a larger effect if a significant amount of food was consumed in summer.

Additionally, the $\delta^{15}N$ values in the assumed main prey taxa are not significantly different between summer and winter feeding grounds, so summer feeding alone would not affect $\delta^{15}N$ values.

Feeding by Subadult vs. Adult Bowheads

The carbon turnover calculations in Appendix 20.1 suggest that subadult bowheads may obtain slightly more of their prey in the Beaufort Sea than do adults, but the best estimates for both groups are low, and there is wide overlap in the 95% confidence intervals.

The average $\delta^{13}C$ value for the muscle from six whales killed in the fall during 1986–87 is closer to the average for fall-killed 1997–99 whales than to the average for spring killed 1986–88 whales. This indicates that these whales may have fed in the eastern Beaufort Sea to a greater extent. Three of the 1986–87 fall whales were subadults, and subadults have often been observed feeding in the eastern Beaufort Sea (Würsig et al. 1989; Chapter 12).

Younger whales have often been observed feeding in nearshore waters of the eastern Beaufort Sea (Würsig et al. 1989; Chapter 12), whereas adults observed feeding in the Beaufort tend to be in deeper water (Chapters 10, 12). It is possible that feeding patterns, as represented by isotope ratios, would be related to age. However, $\delta^{13}C$ values in muscle are similar in adults and subadults, suggesting no major age-related shift in the relative importance of feeding in the eastern Beaufort Sea vs. elsewhere.

In contrast to the muscle data, $\delta^{13}C$ values in the baleen plates do show considerable age-related differences, indicating some variation in feeding patterns between subadult and adult (Fig. 20.8). Each point along the plates records the isotopic value of the circulating baleen precursors at the time of baleen formation, whereas muscle shows bulk isotopic composition of whales integrated over an extended (but uncertain) period. Why there was an age effect on isotope ratios in baleen but not in muscle is not clear. However, it is apparent that the feeding patterns of adults and subadults are quite different. The lack of low $\delta^{13}C$ values in either baleen or muscle of adult bowheads suggests that they feed intensively in the Bering and Chukchi seas and the observed feeding in the eastern Beaufort Sea during summer and early fall must be less intensive. In contrast, the wider range in baleen isotope ratios in subadults suggests that they apparently feed continuously while they are migrating across regions of different isotope ratios. The tendency of the average muscle and baleen $\delta^{13}C$ values in both subadults and adults to match prey from the Bering and Chukchi seas also suggests that feeding is more successful there, which may, in turn, reflect the higher primary and secondary productivity of the Bering–Chukchi region.

In addition, recent measurements of blubber composition of bowhead whales showed lower lipid contents in longer, and presumably older, whales in fall 1998 than those in small whales (Michael Castellini, pers. comm.). These observations are in general agreement with the lack of summer feeding activity of adults indicated in the baleen isotopic ratios.

The consumption of different prey by adults versus subadults in summer could also account for the different isotopic compositions. However, no major differences between the diet of small and large whales were evident from stomach content samples collected from Kaktovik and Barrow over many years (Chapter 18). Both adults and subadults probably feed on any species of zooplankton that is sufficiently concentrated to provide a reasonable energy source (Bradstreet et al. 1987; Chapter 6). However, differences in the locations and water depths where subadult and adult bowheads tend to concentrate may be associated with differences in prey. Subadult bowheads commonly feed in nearshore waters along the Yukon and eastern Alaskan coast at locations and times when the small copepod *Limnocalanus* is concentrated (Chapter 6). Adult bowheads tend to feed farther offshore, in areas without *Limnocalanus*.

In conclusion, the utilization of feeding habitats appears to be more diverse for subadult than adult bowheads, as indicated by the larger range in isotope ratios. The isotopic evidence indicates that the eastern Beaufort Sea is not an important feeding habitat for adult bowhead whales, but may be more important for subadults. However, the Bering and Chukchi regions are the predominant feeding areas for both adults and subadults, based on isotopic values in both bulk body tissues and the baleen plates. The specific estimates of the percent of the feeding that occurs in the eastern Beaufort Sea are subject to a variety of assumptions. However, the strong Bering–Chukchi isotopic signature in the muscle and baleen, as compared with the much more limited eastern Beaufort signature, indicates that only a minority of the feeding by either subadults or (especially) adults is on prey from the eastern Beaufort region.

Although zooplankton prey samples have been collected from almost all of the range of this population of bowhead whales, muscle samples have only been available and analyzed for selected locations and seasons. No muscle samples from whales harvested along the Chukotsk Peninsula (southwestern Chukchi Sea) or at St. Lawrence Island (Bering Sea) have been analyzed. Also, in the absence of regular bowhead harvests in the Canadian Beaufort Sea, muscle samples from that area have not been available for analysis. The baleen, however, grows continuously and reflects the isotopic composition of the food recently consumed. Additional analyses of the isotope composition of baleen could be useful. For example, by analyzing the isotope ratios of individual amino acids in the baleen and comparing them with the same amino acids from prey, many of the uncertainties noted above probably could be better addressed. Similarly, the analysis of oxygen isotope ratios in baleen and prey should allow resolution of offshore versus inshore feeding in the eastern Beaufort Sea, where the influence of the Mackenzie River is pronounced. Isotopic signatures and compositional changes in fatty acids (see Chapter 19) may also provide additional insight into feeding regimes.

Summary

$\delta^{13}C$ and $\delta^{15}N$ ratios in muscle and baleen from harvested bowhead whales were used to estimate the relative amounts of food acquired from the eastern Beaufort Sea (summer and early autumn range) versus the Bering and Chukchi seas — the two regions previously proposed as major feeding grounds. This analysis was based on the fact that isotope ratios in the zooplankton prey of bowheads are different in the two regions. Isotope ratios in prey are reflected in the predators. When isotope ratios differ regionally, this provides a basis for determining the main area(s) where the predators feed.

Samples obtained from whales harvested in autumn of 1997–99 and spring of 1986–88 were compared. Both $\delta^{13}C$ and $\delta^{15}N$ values in the whales have decreased in recent years in response to a long term decreasing trend in isotope ratios in the Bering–Chukchi food chain. The whale samples collected ~10 yr apart were normalized to allow direct comparison.

For all whales, the $\delta^{13}C$ values in muscle sampled in fall were not significantly different from the muscle sampled in spring. Muscle $\delta^{13}C$ during both seasons closely matched the isotope ratios of zooplankton from Bering and Chukchi water, indicating that most of the annual food requirement of adults and subadults is met from that portion of their range. Isotope data from baleen showed, however, different feeding strategies by adult and subadult whales. Subadults acquired sufficient food in the eastern Beaufort Sea to alter the carbon isotope ratios in baleen deposited there relative to baleen representing feeding in Bering and Chukchi water. Baleen plates from subadults showed a wider range in isotope ratios than those from adults, suggesting active feeding by subadults over all parts of their range. A simple approximation based upon observed seasonal shifts in muscle isotope ratios indicates that between 10 and 26 percent of the muscle carbon is replaced over the summer, depending on the method of calculation. A sensitivity analysis that allowed for variability in each factor involved in the calculation indicated that the true percentage probably did not exceed 23 %. Limited data on blubber indicates an even smaller percentage. Although these specific estimates are subject to a variety of assumptions, the isotopic evidence indicates that only a minority of the feeding by either subadults or (especially) adults is in the eastern Beaufort Sea.

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APPENDIX 20.1. VARIANCE OF BOWHEAD FEEDING FRACTION BASED ON STABLE ISOTOPE ANALYSIS

Trent L. McDonald [2]

The bowhead whales under study typically spend the winter months in the Bering Sea, migrate northward through the Bering Strait in spring, travel northeast past Barrow, and then east across the Beaufort Sea to their summering areas. Those summering areas are in the Eastern Beaufort Sea, including waters near the Mackenzie River Delta and Banks Island. In fall, they return west and south and arrive in the Bering Sea in early winter. Bowheads are known to feed, to varying degrees, during both the spring and fall migrations and during summer; there are no specific data for winter.

This migration pattern allows whalers to take bowheads near Barrow, Alaska, in spring soon after the whales exit their winter habitat in the Bering Sea. During the return migration in early autumn, whalers take bowheads near Kaktovik, Alaska, as they exit their summer habitat in the Eastern Beaufort Sea. Bowheads are harvested elsewhere, and in particular at Barrow in autumn, but those data were not considered here.

In the Chukchi and Bering seas during late fall and perhaps winter, feeding bowheads consume zooplankton and other food with a specific ratio of carbon-13 to carbon-12 isotopes ($\delta^{13}C$). In summer habitat of the Eastern Beaufort Sea, feeding bowheads consume food with a different carbon isotope ratio. Because a gradient in $\delta^{13}C$ exists between the Bering and Eastern Beaufort seas, it is possible to measure $\delta^{13}C$ in whales soon after exit from each area and, under certain assumptions, estimate the proportion of annual food consumed in each area. $\delta^{13}C$ ratios can be measured in a variety of whale tissues, including baleen, blubber and muscle. Muscle tissue $\delta^{13}C$ ratios have been used in Chapter 20 to estimate the proportion of food consumed in each area.

The question addressed in this Appendix is the uncertainty in the estimated proportion of food consumed in the Eastern Beaufort and Chukchi Sea. Chapter 20 provides various point estimates of this proportion based on average isotope ratios in samples of bowhead tissue and zooplankton prey tissue. However, there is variability in each value used in the calculations, and as a result there is uncertainty in the calculated feeding proportion. This uncertainty is estimated below based on the procedures described in the next section.

Methods

The proportion of total annual food consumption occurring in the Eastern Beaufort Sea was calculated as the difference in $\delta^{13}C$ ratios in muscle samples collected at Kaktovik in fall vs. Barrow in spring, divided by the difference in $\delta^{13}C$ ratios of dietary components between the Eastern Beaufort and Bering Sea. In equation form, the proportion of food consumed in the Eastern Beaufort Sea was calculated as

$$f = \frac{R_{Kak} - R_{Barrow}}{R_{EBF} - R_{BER}}$$

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[2] Western EcoSystems Technology Inc., 2003 Central Ave., Cheyenne, WY 82001. *Phone*: 307-634-1756; *e-mail*: tmcdonald@west-inc.com

where R_{Kak} was the average muscle $\delta^{13}C$ ratio in whales taken at Kaktovik (fall), R_{Barrow} was the average muscle $\delta^{13}C$ ratio in whales taken at Barrow (spring), R_{EBF} was the average $\delta^{13}C$ ratio of zooplankton collected in the Eastern Beaufort Sea, and R_{BER} was the average $\delta^{13}C$ ratio of zooplankton collected in the Bering Sea. Under the assumption that the difference between R_{Kak} and R_{Barrow} would equal the difference between R_{EBF} and R_{BER} if whales were feeding in the Eastern Beaufort Sea to such an extent that the carbon in muscle turned over each season, f can be interpreted as the proportion of annual food consumption occurring in the Eastern Beaufort Sea. This method does not require estimation of or allowance for the metabolic fractionation of $\delta^{13}C$ in muscle tissue of the whale.

Since 1965, $\delta^{13}C$ ratios in the Bering/Chukchi seas have been declining (Schell 2000). Because our muscle samples were taken at various times between the mid 1980s and late 1990s, an adjustment was made for overall decline when estimating R_{Barrow} and R_{Kak}. All $\delta^{13}C$ ratios in R_{Barrow} and R_{Kak} were adjusted to 1999 values by fitting a linear regression to the post-1965 values in Schell (2000, Table 1; see also Fig. 20.3) and subtracting an appropriate amount based on the slope of this regression and the difference in years between the sampling date and 1999. For example, if the regression of values in Schell (2000) estimated a decline in $\delta^{13}C$ ratios of –0.063 per year, a $\delta^{13}C$ ratio measured in 1987 would be adjusted by $-0.063(1999 - 1987) = -0.756$. A $\delta^{13}C$ ratio measured in 1998 would be adjusted by $-0.063(1999 - 1998) = -0.063$. A $\delta^{13}C$ ratio measured in 1999 would not be adjusted. Standard error of the decline was estimated by the standard error of the slope of the regression. It should be noted that the year to which the standardization is done (here 1999) has no influence on the final results concerning estimated proportion of food consumption occurring in the Eastern Beaufort Sea.

After adjustment of individual $\delta^{13}C$ ratios for the long-term decline, R_{Barrow} and R_{Kak} were calculated as simple arithmetic averages. Because there was an overall decline in $\delta^{13}C$ ratios during the study period, uncertainty in R_{Barrow} and R_{Kak} was estimated by calculating yearly variances, then calculating a weighted average of yearly variances. Weights used in the weighted average were yearly sample sizes. This method of calculating variance removed the overall trend.

Average $\delta^{13}C$ in bowhead whale diets (i.e., R_{EBS} and R_{BER}) were derived from values in Table 20.4, and diet composition values in Table 20.3, considering only the two dominant taxa, copepods and euphausiids. For example, R_{BER} was the weighted average of copepod and euphausiid $\delta^{13}C$ ratios equal to $[(28\%)(-22.2) + (61\%)(-20.8)]/(89\%) = -21.24$. Similarly, R_{EBS} was calculated as $[(61\%)(-25.6) + (22\%)(-23.7)]/(83\%) = -25.10$ Standard errors were also calculated as weighted averages. Standard errors for $\delta^{13}C$ ratios in food components were calculated by averaging the standard errors from certain geographic regions found in Table 1 of Schell et al. (1998):

- Standard errors for copepods and euphausiids in the Bering Sea were calculated as the average of standard errors in the East Bering, Central Bering, and West Bering of Schell et al.
- Standard errors for copepods and euphausiids in the Beaufort Sea were calculated as the average of standard errors in the Canadian Beaufort and East Alaskan Beaufort of Schell et al.
- Because they were not reported in Schell et al., standard errors for $\delta^{13}C$ in mysids and amphipods were assumed to equal the standard error of $\delta^{13}C$ in euphausiids. The standard error of $\delta^{13}C$ in euphausiids was the highest observed standard error in any dietary component.

The square root of average standard errors, weighted by the square of percent composition, was taken to estimate the standard error of R_{EBS} and R_{BER}. For example, the standard error of $\delta^{13}C$ in copepods of the Bering Sea was 0.16 and that in euphausiids of the Bering Sea was 0.21 (Schell et al. 1998, Table 1). The standard error of R_{BER} was calculated as $[(28\%)^2(0.16)^2 + (61\%)^2(0.21)^2]^{0.5}/(89\%) = 0.152$.

To calculate a 95% confidence interval for *f,* a Monte Carlo simulation was implemented wherein random deviates from a normal distribution with mean 0 and appropriate standard deviation were repeatedly generated and added to the data comprising each component of *f.* For example, values for R_{BER} were generated as –21.23 + *e* for each iteration of the Monte Carlo simulation, where *e* was a normal random deviate with mean 0 and standard deviation 0.152. Values for R_{Kak} and R_{Barrow} were generated in four steps: ***(1)*** Random normal deviates with mean 0 and appropriate standard deviation were added to the underlying muscle carbon values found in Table 20.6. ***(2)*** A random value for the slope of the long-term decline in δ^{13}C ratios was generated as –0.0629 + *e*, where *e* was a normal random variable with mean 0 and standard deviation 0.00648. ***(3)*** Randomly-generated muscle δ^{13}C ratios from step 1 were corrected for long-term trend using the randomly generated slope from step 2. ***(4)*** The corrected sums were averaged. After Monte Carlo generation of R_{Kak}, R_{Barrow}, R_{EBS}, and R_{BER}, *f* was recalculated and stored. Generation of R_{Kak}, R_{Barrow}, R_{EBS}, and R_{BER} was repeated 1000 times, yielding 1000 random values of *f* from its assumed distribution. The lower limit of the 95% confidence interval for *f* was the 0.025th percentile of the 1000 generated values of *f.* The upper limit of the 95% confidence interval for *f* was the 0.975th percentile of the 1000 generated values of *f.* If the lower limit of the 95% confidence interval for *f* was negative, the lower endpoint was truncated and set equal to 0.

Estimation of *f* was performed for adult and sub-adult whales separately. Whales greater than 13.3 m in length were defined to be adults. Whales less than 13.3 m were defined to be sub-adults. Upon inspection of the data, it was found that samples from adults taken in the spring at Barrow were not available. Because no spring adult samples were available, δ^{13}C values from two adults taken at Wainwright in the spring of 1986 and one adult taken at Gambell in the spring of 1988 were used to calculate R_{Barrow} for the adult analysis. For completeness, sub-adult and adult data were combined and a separate estimate of *f* was made for all whales. The three whales taken at Wainwright and Gambell were not included in this "all whale" analysis, and consequently only 2 adults were added to the sub-adult analysis for the all whale analysis.

Results

In 1986–88, a total of 16 muscle tissue samples were obtained from whales taken in the spring at Barrow (7 in 1986, 1 in 1987, 8 in 1988). In 1986 and 1997–1999, a total of 13 muscle tissue samples were obtained from whales taken in the fall at Kaktovik (3 in 1986, 4 in 1997, 3 in 1998, 3 in 1999). All 16 whales sampled at Barrow were sub-adults. Of the 10 whales taken at Kaktovik, 2 were adults and 11 were sub-adults.

Estimates and standard errors of R_{EBS}, R_{BER}, R_{Barrow}, R_{Kak}, and of the long-term trend in δ^{13}C ratios appear in Table 20.7. Assuming each component of *f* followed a normal distribution with mean and standard error as listed in Table 20.7, the proportion of diet consumed in the Eastern Beaufort Sea by sub-adult bowhead whales was 13.7 % with 95 % confidence interval of 4.3 % to 23.3 %. The estimated proportion of diet consumed in the Eastern Beaufort Sea by adults was 4.6 % with 95 % confidence interval of 0 % to 30.0 %. Combining age classes, the estimated proportion of diet consumed in the Eastern Beaufort Sea was 10.0 % with 95 % confidence interval of 0 % to 22.6 %.

TABLE 20.7: Estimates and standard errors of $\delta^{13}C$ ratios used in calculation of *f*. Mean $\delta^{13}C$ values in sub-adult and adult whale tissue have been adjusted to 1999 values based on long-term trend.

Age Class	Statistic	Estimate	Standard Error	*n*
Sub-adult	R_{kak}	-20.96	0.128	11
	R_{Barrow}	-20.43	0.109	16
Adult	R_{kak}	-20.03	0.445	2
	R_{Barrow}	-19.85	0.170	3*
All	R_{kak}	-20.81	0.211	13
	R_{Barrow}	-20.43	0.109	16
-	R_{EBS}	-25.10	0.151	-
-	R_{BER}	-21.24	0.152	-
-	Trend	-0.0629	0.00648	-

*Two whales taken at Wainwright, one taken at Gambell. These three whales were not included in the 'all' whale analysis.

References

Schell, D.M. 2000. Declining carrying capacity in the Bering Sea: isotopic evidence from whale baleen. **Limnol. Oceanogr**. 45(2):459-462.

Schell, D.M., B.A. Barnett and K. Vinette. 1998. Carbon and nitrogen isotope ratios in zooplankton of the Bering, Chukchi and Beaufort Seas. **Marine Ecol. Progr. Ser.** 162:11-23.

21. DIET AND REGIONAL OCCURRENCE OF FEEDING: SUMMARY AND CONCLUSIONS

Denis H. Thomson and W. John Richardson[1]

This component of the study sought to determine ***(1)*** what types of prey bowhead whales of the Bering–Chukchi–Beaufort (BCB) stock eat, and ***(2)*** what parts of their seasonal range provide the predominant part of this food. The principal and most direct method for determining what bowheads eat was analysis of the stomach contents of bowheads harvested by Inupiat whalers (Chapter 18). The project also included a pilot study of the fatty acid composition of bowhead blubber in relation to the fatty acid composition of potential zooplankton prey (Chapter 19). It was hoped that this approach might, when further developed, provide a method for assessing food consumption over a longer period (and larger geographic area) than can be assessed from stomach contents. To assess the proportion of the food consumed in different parts of the seasonal range, the carbon and nitrogen isotope ratios in bowhead tissues were compared with those in the prey from the eastern Beaufort Sea vs. the Bering–Chukchi area (Chapter 20). Several of the earlier chapters also provide information directly or indirectly relevant to "Diet and Regional Occurrence of Feeding".

Much of the interest in this general topic focuses on the relative importance of feeding in the Bering–Chukchi region vs. the Beaufort Sea. The latter area includes the summering grounds of the BCB bowheads in the Canadian Beaufort Sea as well as the Alaskan waters that are occupied mainly in late summer and fall. The isotope composition of zooplankton in the Canadian and eastern Alaskan parts of the Beaufort Sea is not distinguishable based on methods used to date. Thus, carbon and nitrogen in bowhead tissues cannot be ascribed specifically to food from the Canadian vs. the eastern Alaskan parts of the Beaufort Sea. The central question that this study is designed to address concerns the importance of the eastern Alaskan Beaufort Sea to feeding bowhead whales. Nonetheless, information about the importance of feeding in the eastern Beaufort Sea as a whole is still relevant. If it were concluded that relatively little of the annual food requirement was met in the overall eastern Beaufort Sea, this would mean that the "eastern Alaskan Beaufort Sea" must contribute an even smaller portion of the annual food intake.

The following three subsections are near-verbatim copies of the summaries of Chapters 18 to 20. Those summaries are followed by a short concluding section, primarily dealing with the evidence in Chapter 20 (Stable Isotopes) vs. various other chapters regarding the importance of feeding in the eastern Beaufort Sea.

Stomach Contents of Bowhead Whales

This component of the study, by L.F. Lowry and G. Sheffield of Alaska Department of Fish & Game (Chapter 18), documents bowhead whale feeding in the Alaskan Beaufort Sea based on stomach contents of whales harvested by Alaska Natives. They examined field records and archived data from previous studies of bowhead stomach contents, and analyzed similar samples from 85 additional bowhead whales harvested during 1986–2000 near Kaktovik, Barrow, and Cross Island. All available data from bowheads harvested near those locations were used to characterize and compare diet by harvest location and season (i.e., Kaktovik fall; Barrow fall; Barrow spring), and by whale size and sex.

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[1] LGL Ltd., environmental research associates, 22 Fisher St., POB 280, King City, Ont. L7B 1A6. *Phone:* 905-833-1244; *e-mail:* dthomson@lgl.com, wjr@lgl.com

Thirty-two bowheads harvested near Kaktovik during fall 1979–2000 have been examined for evidence of feeding. Of 29 whales whose feeding status could be classified as "feeding" or "not feeding", at least 83% had been feeding prior to death. Copepods, most commonly *Calanus hyperboreus* and *C. glacialis*, were the most important prey; copepods occurred in all 21 stomachs with food and were the dominant prey by volume in 62% of the samples. Euphausiids, mainly *Thysanoessa raschii,* were also an important food item. Estimated volume of stomach contents was as much as 150 liters, and in 7 of 18 cases was greater than 20 liters.

Four of five bowheads harvested near Cross Island during 1987–2000 were recorded as having been feeding. Copepods were the main prey in the three stomach contents samples examined.

Stomachs of 106 bowheads harvested in fall near Barrow during 1976–2000 were examined. Of the 103 "non-calf" whales that could be classified as "feeding" or "not feeding", at least 75% had been feeding prior to death. Euphausiids were the most important prey; they occurred in 94% of the stomachs with food and were the dominant prey by volume in 88%. Estimated volumes of stomach contents were as much as 189 liters, and in many cases were recorded as ≥100 liters or "full".

Stomachs of 100 bowheads harvested in spring near Barrow during 1969–2000 were examined. Of the 90 whales that could be classified as "feeding" or "not feeding", at least 33% had been feeding prior to death. Euphausiids occurred in 93% of the samples and were the dominant prey in 61%. Copepods were also an important diet item, especially in samples collected before the 1990s. Estimated volumes of stomach contents were smaller than for whales taken in fall, and never exceeded 60 liters.

There was no significant difference in the proportion of bowheads that had been feeding in the fall near Kaktovik and Barrow. However, there was a significant difference in composition of the fall diet at these locations. Copepods occurred more often and were more frequently the dominant prey by volume in whales from Kaktovik. Euphausiids occurred more often and were more frequently the dominant prey by volume in whales from Barrow.

At Barrow, the frequency of feeding in harvested bowheads was significantly greater in the fall than in the spring. Copepods occurred significantly more often in whales harvested near Barrow in the spring than in the fall.

Male and female bowheads ate essentially the same food items. The data suggest the possibility of a slight difference in the prey eaten by small (<13 m) and larger (≥13 m) whales. There was no difference in the frequency of feeding of small versus large whales.

Preliminary estimates of the overall bowhead diet composition by location/season were as follows: Kaktovik fall, 61–62% copepod, 22–24% euphausiid, 15–17% other prey; Barrow fall, 5% copepod, 84–88% euphausiid, 7–11% other prey; and Barrow spring, 27–28% copepod, 61–63% euphausiid, and 10–11% other prey.

Lowry and Sheffield conclude that coastal waters of the Alaskan Beaufort Sea should be considered as part of the bowheads' normal summer–fall feeding range. During spring, feeding by bowheads near Barrow is more common than previously thought, but the frequency and apparent intensity of feeding is less in spring than in the fall.

Fatty Acids in Bowhead Whales and Potential Prey

Fatty acids, the dominant constituent of lipids, are often deposited in animal tissue with minimal modification from those in the diet. Lipids in the marine food web are exceptionally complex and diverse. Dr. S.J. Iverson et al. (Chapter 19) undertook a pilot study to assess whether analysis of fatty acid signatures in bowheads and their potential prey (zooplankton) would be a useful tool for better understanding the foraging ecology and diets of bowheads in Alaskan waters. They identified and measured the fatty acids in samples of blubber from 28 bowheads harvested at Kaktovik (fall) and Barrow (spring and fall); 33 samples of mixed zooplankton from the eastern Alaskan Beaufort Sea; and 32 samples of zooplankton that had been sorted into seven major prey groups (copepods, euphausiids, etc.).

This preliminary study indicates that fatty acid signature analysis could be a very useful tool in better understanding the foraging ecology and diets of bowheads in Alaskan waters. The inferences that can be made now are limited because of small sample sizes of whales and potential prey, and lack of data on fatty acid profiles in individual species of prey. However, there are indications that fatty acid analyses may show differences in diets of whales of different sexes and size classes; such differences have not been clearly detectable from stomach contents analyses. Iverson et al. analyzed samples of mixed zooplankton from two years, and the fatty acids of the zooplankton are consistent with them being bowhead diet items. Additionally, although there are very limited data on fatty acid patterns in potential prey, preliminary results from a QFASA (Quantitative Fatty Acid Signature Analysis) model indicate that fatty acid patterns of the inner blubber, presumably indicative of recent diet, are consistent with general diet data obtained from stomach contents analyses. The high fat content of these prey, especially copepods, also suggests high dietary intakes of fat. With further and more extensive sampling and analysis, the taxonomic composition of bowhead prey could likely be better assessed using the quantitative tools now being developed. Fatty acid signatures are expected to represent the integrated diet over weeks or possibly months, and thus over larger geographic areas, than are the stomach contents of harvested whales.

Regional and Seasonal Feeding as Indicated by Stable Isotope Ratios

This part of the work (Chapter 20) was done by Sang Heon Lee and Dr. D.M. Schell of University of Alaska Fairbanks, with assistance from Dr. Trent McDonald of WEST Inc. $\delta^{13}C$ and $\delta^{15}N$ ratios in muscle and baleen from harvested bowhead whales were used to estimate the relative amounts of food acquired from the eastern Beaufort Sea (summer and early autumn range) versus the Bering and Chukchi seas—the two regions previously proposed as major feeding grounds. This analysis was based on the fact that isotope ratios in the zooplankton prey of bowheads are different in the two regions. Isotope ratios in prey are reflected in the predators. When isotope ratios differ regionally, this provides a basis for determining the main area(s) where the predators feed.

Samples obtained from whales harvested in autumn of 1997–99 and spring of 1986–88 were compared. Both $\delta^{13}C$ and $\delta^{15}N$ values in the whales have decreased in recent years in response to a long term decreasing trend in isotope ratios in the Bering–Chukchi food chain. The whale samples collected ~10 yr apart were normalized to allow direct comparison.

For all whales, the $\delta^{13}C$ values in muscle sampled in fall were not significantly different from the muscle sampled in spring. Muscle $\delta^{13}C$ during both seasons closely matched the isotope ratios of zooplankton from Bering and Chukchi water, indicating that most of the annual food requirement of adults and subadults is met from that portion of their range. Isotope data from baleen showed, however, different feeding strategies by adult and subadult whales. Subadults acquired sufficient food in the eastern Beaufort Sea to alter the carbon isotope ratios in baleen deposited there relative to baleen representing feeding in Bering and Chukchi water. Baleen plates from subadults showed a wider range in isotope ratios than those from adults, suggesting active feeding by subadults over all parts of their range. A simple approximation based upon observed seasonal shifts in muscle isotope ratios indicates that between 10 and 26 percent of the muscle carbon is replaced over the summer, depending on the method of calculation. A sensitivity analysis that allowed for variability in each factor involved in the calculation indicated that the true percentage probably did not exceed 23 %. Limited data on blubber indicates an even smaller percentage. Although these specific estimates are subject to a variety of assumptions, the isotopic evidence indicates that only a minority of the feeding by either subadults or (especially) adults is in the eastern Beaufort Sea.

Conclusions

At least at first glance, there seems to be an inconsistency between isotopic evidence (Chapter 20) and other evidence concerning the importance of feeding in the eastern Beaufort Sea. The isotope record in bowhead muscle, blubber, and baleen seems to indicate that bowheads (especially adults) feed mainly on prey from the Bering and/or Chukchi Seas. However, behavioral, aerial-survey, and stomach-content data show that bowheads also feed widely across the eastern and central Beaufort Sea in summer and fall.

There is certainly no doubt that bowhead whales feed on prey from the Bering/Chukchi system. Bowheads are commonly observed to feed in the western Beaufort Sea in fall, and much of the prey consumed there may have been advected northeastwards from the Bering/Chukchi system and be of the Bering/Chukchi type. Bowheads also feed in the western Chukchi Sea (off Chukotka) in fall, in highly productive waters moving north from the Bering Sea (Chapter 20). There have been no systematic observations of bowhead activities in the Bering Sea in late fall or winter, and the only stomach content data from the Bering Sea concern bowheads harvested near St. Lawrence Island in spring. Most of those whales have little or no food in their stomachs (Table 21.1). There is some feeding in the Chukchi Sea during the spring migration. However, stomach-content data and behavioral data both indicate that feeding in spring, at least near Barrow, is less frequent than feeding in the Beaufort and Chukchi seas in summer or fall. Thus, available evidence indicates that bowheads may feed heavily in the Bering/Chukchi system in fall, but probably feed much less when in Bering/Chukchi waters during winter and spring.

Behavioral, aerial-survey, and stomach-content data show that bowheads also feed widely across the eastern and central Beaufort Sea in summer and fall. Behavioral data show that bowheads spend most of their time feeding while on the summer range and much of their time feeding during autumn (Chapter 12). Zooplankton sampling near bowhead whales in the Canadian and eastern Alaskan Beaufort Sea during summer and early fall shows that feeding bowheads tend to occur at locations where the biomass of zooplankton is considerably higher than average (Chapter 6). Most of the stomachs of bowheads harvested in the Alaskan Beaufort Sea during late summer and fall contain food, which indicates that the whales had been feeding shortly before being struck. Stomachs of both adult and subadult bowheads harvested during autumn in the Alaskan Beaufort Sea usually contain food.

Behavioral and stomach content data do not directly show how much food is consumed in the eastern Beaufort Sea as compared with the Bering/Chukchi system. One could hypothesize that bowhead feeding in the Beaufort Sea might be frequent, as shown by behavioral and stomach-content data, but not very efficient. Behavioral and stomach content results might be reconcilable with isotopic data if prey availability to bowheads were notably better in Chukchi and/or Bering water than in the eastern Beaufort Sea. This hypothesis would be consistent with the known high productivity of the Bering Sea and of water from the Bering Sea that is transported north into the Chukchi (Chapter 20). However, if feeding in the Beaufort Sea were not important to bowhead whales, it is difficult to understand why bowheads would spend so much time feeding there, and why they would adapt their movements and local distribution to prey concentrations. Indeed, it is difficult to understand why bowheads would migrate from the Bering–Chukchi area to the Beaufort Sea if feeding in the Beaufort Sea were unimportant.

TABLE 21.1. Stomach content records from St. Lawrence Island, Bering Sea. A total of 79 records (not the originals) from 1974–2000 were examined. Notes regarding the condition of the stomach were found for 17 animals. Data courtesy of North Slope Borough Dept of Wildlife Management, compiled by G. Sheffield of ADF&G.

ID	Sex	Location	Total Length (m)	Est. Stomach Vol. (L)	Harvest Date	St. Lawrence Island - Notes
78S1	M	SAVOONGA	10.9	---	16-Apr-78	Stomach almost empty; contained afew "euphausiid like" creatures.
80S2	F	SAVOONGA	10.73	---	20-Apr-80	Stomach full of blood and gas - Empty
81S1	F	SAVOONGA	16.8	---	14-Apr-81	Examined; Empty
81S2	F	SAVOONGA	14.2	---	21-Apr-81	Stomach contents collected in ethanol - Sample LOST
90S1	F	SAVOONGA	10.7	---	7-Apr-90	Stomach empty
90S2	F	SAVOONGA	7.9	---	9-Apr-90	Stomach empty; ingutuk
90S3	F	SAVOONGA	12.2	---	10-Apr-90	Stomach empty
92S2	F	SAVOONGA	10.1	---	18-Apr-92	Stomach empty
94S1	F	SAVOONGA	11	---	22-Apr-94	Stomach empty
81G1	F	GAMBELL	15.5	---	14-Apr-81	Stomach contents collected in ethanol - Sample LOST
82G2	F	GAMBELL	8.8	20-40	30-Apr-82	Full stomach - Hazard and Lowry (1984)*
82G1	M	GAMBELL	7.92	---	1-May-82	Stomach empty
83G1	M	GAMBELL	15.7	---	17-Apr-83	Bile only
85G1	F	GAMBELL	9.3	---	21-Apr-85	Stomach empty
86G3	F	GAMBELL	14	---	11-Apr-86	Stomach empty
90G1	F	GAMBELL	9.14	---	7-Apr-90	Stomach empty
91G1	M	GAMBELL	9.5	---	17-Apr-91	Two gallons of fluid in stomach - described by resident

* Hazard, K.W. and L.F. Lowry. 1984. Benthic prey in a bowhead whale from the northern Bering Sea. **Arctic** 37(2):166-168. The stomach contents of whale 82G2 were principally gammarid amphipods and secondarily cumaceans.

Chapter 22 summarizes additional types of more direct evidence suggesting that feeding in the Beaufort Sea does provide an important contribution to the annual energy intake of the BCB population of bowhead whales. Measurements by J.C. George[2] (North Slope Borough Dept of Wildlife Management) of bowheads harvested at Barrow in spring and fall, and measurements by LGL of bowhead images on aerial photographs taken in spring and late summer/early fall, show that subadult bowheads (and perhaps adults as well) gain weight in summer and loose weight in "winter" (Chapter 22). By "summer", we mean from the time they enter the Beaufort Sea in April–June until either photographed in August–September, or until they pass Barrow when leaving the Beaufort in fall (girth data). By "winter", we mean the reciprocal of the above just-mentioned periods, i.e., while not in the eastern Beaufort Sea. In addition, data from T. Mau[2] (UAF) indicate that the lipid content of blubber in subadult bowheads appears to be lower in spring than in fall. Both of these types of evidence indicate that there is a net reduction in stored energy reserves over the late-fall, winter and early-spring period, and an increase over summer.

If all of these types of evidence are accepted as reliable, then the one feeding scenario that could (perhaps) be consistent with all the data is as follows: Feeding occurs commonly in the eastern Beaufort Sea in summer and early autumn. Bowheads gain energy stores and their girth increases from feeding in that area. However, zooplankton availability is not as high in the Beaufort Sea in summer as in the Chukchi Sea and northwest Bering Sea during autumn, given the much higher productivity of the Bering/Chukchi system. Also, feeding in the western Beaufort in autumn may effectively be on Chukchi prey advected into the western Beaufort. Thus, bowheads might acquire more energy from Chukchi (and Bering?) prey in autumn than from eastern and central Beaufort prey in summer/early autumn. Given this, plus an assumed low turnover rate of body components, their overall body composition may be dominated by carbon (and other components) from the Bering/Chukchi system even at the end of the summer when leaving the Beaufort. Energy gained in both the Beaufort and Chukchi seas during summer and fall feeding is presumably used during winter when food availability is low, resulting in reduced girth and energy stores when returning to the Beaufort in spring than when leaving the Beaufort in autumn.

The above scenario is unlikely to be fully or immediately accepted by proponents of either the "traditional" view, i.e., that most feeding is in the Beaufort; or the isotope-based view, i.e., that most feeding is on prey from the Bering/Chukchi system. Those who have documented the strong Bering/Chukchi component in the isotope signatures of bowheads, even at the end of the summer, emphasize that this can only be explained if relatively little feeding occurs in the eastern and central Beaufort Sea. Those who have studied feeding behavior of bowheads in the Beaufort Sea, or the prey concentrations there, or the prey in bowhead stomachs, or spring–fall changes in body composition, find it difficult to accept that the summer and early-fall feeding in the Beaufort Sea contributes relatively little to the annual diet. Likewise, hunters and others who reside along the coast of the Beaufort Sea, and who have observed bowheads in their areas over the years, are convinced that these areas are important to the bowheads for feeding.

Although these groups of people have different perspectives on the probable importance of feeding in the eastern Beaufort vs. the Bering–Chukchi waters, the feeding scenario described above is at least generally consistent with all of the types of data and observations that they cite. We are not aware of any other hypothesis that is not directly contradicted by some key type of data. Furthermore, the above scenario is helpful in identifying key data gaps that warrant further research (see next subsection).

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[2] Unpublished data of J.C. George and Tamara Mau are cited with their permission, and are not to be used or cited elsewhere without their permission. Contact cgeorge@co.north-slope.ak.us; tmau@ims.uaf.edu

The evidence concerning the importance of summer feeding is discussed further in Chapters 22 and 23. Those chapters also address the annual energetic requirements of bowhead whales, and how much of those requirements might be met by feeding on the concentrations of prey observed in the eastern Beaufort Sea. That comparison suggests that bowheads may need to acquire a substantial proportion of their annual diet elsewhere, consistent with the feeding scenario described above. However, many questions about regional feeding dependencies remain open, given • the minimal data available about feeding in areas other than the Canadian and eastern Alaskan Beaufort Sea, and • concerns about the accuracy of present estimates of zooplankton biomass available to bowheads feeding on concentrated patches of prey.

Recommended Research

Additional data on the stomach contents of BCB bowhead whales, especially from areas where few such data have been acquired previously, would be helpful in characterizing the frequency and intensity of feeding in different locations and seasons, the types of prey consumed, and any long-term trends in feeding activity. Areas and seasons where such data would be most valuable include the Chukotsk coast, the northern Bering Sea in winter/early spring, and the west coast of Alaska in spring. Such sampling must necessarily be done in a cooperative manner with local hunters. Wide-ranging collection of stomach-content samples was beyond the scope of the present study (Chapter 18). However, to understand the importance of feeding in one region and season, it is important to have at least a basic understanding of the amount of feeding, and the types of prey, at other locations and seasons. Information about prey types, during all seasons, is relevant in interpreting the stable-isotope composition of whale tissues, and probably the fatty acid composition as well (see following recommendations). Because relatively few whales are harvested at most communities each year, and only a fraction of these provide meaningful data on feeding, collection of stomach-content data and samples is a slow process requiring long-term effort. Once collected, the stomach-content samples need to be analyzed and the results need to be compiled, along with results from previous stomach-content samples.

While stomach-content samples are being obtained from harvested bowheads, tissue samples and measurements needed for other relevant studies should also be obtained. For example, tissue samples should be acquired for any fatty acid or stable-isotope studies that are underway or planned (see below). Girth (vs. length) measurements should be obtained when possible.

Analyses of the fatty acid composition of bowhead blubber sampled at different geographic locations and seasons, along with corresponding analyses of potential prey items, have the potential to provide a different perspective on prey consumption by bowhead whales. Although fatty-acid techniques have not yet been fully developed for use in trophic studies of bowheads, the pilot study conducted during the present project (Chapter 19), plus related studies on other marine mammals, are promising. Data on the fatty acid profiles of individual taxa of prey will be required in order to take full advantage of the technique. Results are expected to provide a somewhat longer-term and geographically-broader perspective on feeding than can be obtained from stomach-content samples. It may be possible to acquire blubber samples by biopsy methods from free-ranging bowhead whales, thus providing the possibility of studying their diet in areas where there is no native harvest of bowheads, and thus no access to stomach-content samples.

Stable-isotope data, principally concerning the ratio of ^{13}C to ^{12}C, have provided much information about various aspects of the biology of bowhead whales, including growth rates, ages, and feeding ecology. Much of this information, when first acquired, was contrary to then-prevailing thinking, but has been corroborated by other techniques and has come to be accepted. These stable-isotope data have been of much value in elucidating life-history parameters and other aspects of bowhead biology.

Available data on stable isotope composition of bowhead muscle in spring and autumn are important in assessing the amount of feeding in the eastern Beaufort Sea. However, the data obtained in this study are somewhat confounded by the fact that the spring and autumn measurements generally did not come from the same years (see Chapter 20). The complementary study by Hoekstra et al. (2002, *Can. J. Zool.* 80:223-231) did obtain same-year spring vs. fall data, but there are apparent discrepancies in the results of the two studies that are not presently explainable. *It would be desirable to compare stable isotope composition of additional samples of bowhead muscle from spring and fall, collecting these samples in the same years and processing them in strictly standardized ways.* This could provide more definitive information on carbon turnover in muscle during the period of residence in the Beaufort Sea.

During the present study, emphasis was placed on documenting the isotopic composition of muscle and baleen. Although there are some data on stable isotope composition of bowhead blubber and visceral fat in spring and fall, those data are limited. *Additional data on the stable-isotope composition of the blubber (and visceral fat) at various times of year would be useful in assessing seasonal turnover and the importance of feeding in different parts of the annual range*.

Presently-available isotope-based data on regional feeding dependencies of bowhead whales suggest that conventional thinking about the importance of summer feeding in baleen whales may not apply directly to BCB bowheads. *There are many questions about the nature and extent of feeding in some areas outside the eastern Beaufort Sea, most notably the western Alaskan Beaufort Sea in autumn, the southwestern Chukchi Sea in late autumn, and the Bering Sea in winter. To assess feeding activity in those areas, a wide variety of study approaches could be valuable, including not only isotopic methods, but also most or all of the other methods used in the present study.*

- W***estern Alaskan Beaufort Sea in fall****:* A key question is whether feeding here is effectively on Bering/Chukchi prey advected into the area. That could be determined from isotopes in prey. Other types of data on prey availability, feeding behavior, residence times, etc., are also needed.
- ***Chukotsk coast of Russia****:* Data from this area are needed to evaluate the feeding scenario suggested above. A wide variety of study approaches would be again valuable, including collection of data on prey abundance, isotopic and energy content of the prey, and energy gain by bowheads during feeding in the area. Although it is not likely that many tissue samples from harvested whales will be available from this area in late fall, any such samples would be very useful for analyses of isotopic, fatty acid, and energy content. Bowhead girth vs. length measurements would also be valuable, either from direct measurements of harvested whales or (perhaps more practical) via photogrammetry. Data showing whether girth of bowheads increases appreciably while they feed off the Chukotsk Peninsula during late fall would very relevant in assessing the importance of that area vs. other areas for feeding.
- ***Northern Bering Sea in early spring****:* Data on stable isotope (and potentially fatty acid) composition of tissue from bowheads harvested here would allow assessment of nutritional status at the end of the winter. Girth and other measures of energy stores would also be very useful. The annual feeding scenario summarized in the preceding section assumes that bowheads utilize stored energy for much of the winter. In understanding overall annual energy balance, it would be important to have data on condition of bowheads at the end of the winter.

The "Discussion" section of Chapter 20 identifies additional types of isotope analyses that might be helpful in understanding various finer-scale questions about the locations and timing of feeding, and the predominant sources of nutrition for bowhead whales of the Bering–Chukchi–Beaufort stock.

22. ENERGETICS OF BOWHEAD WHALES

Denis H. Thomson [1]

Introduction

An estimate of the importance of the eastern Alaskan Beaufort Sea to feeding bowheads requires that their daily and annual food requirements be estimated and then used to determine what proportion of their annual requirements could be obtained in the study area. Large whales cannot be kept in captivity, so direct measurements of their energetic requirements cannot be made. Researchers have used several different approaches to estimate energetic requirements of large whales. These include heat loss (Folkow and Blix 1992), respiration (Blix and Folkow 1995), and comparing theoretical metabolic rates with those extrapolated from small animals (Lavigne et al. 1986).

Thomson and Martin (1984) and Thomson (1987) estimated the theoretical energetic requirements of gray and bowhead whales and compared these to observed feeding rates in nature. This is the approach that is used here. This chapter updates the earlier estimates with recent information about, or relevant to, the energetics of bowhead whales and other species.

This chapter first describes the size, growth, and reproduction of bowhead whales and the related physical attributes needed for the estimation of energetic requirements. This is followed by a description and discussion of several approaches to the estimation of the metabolic rate of bowheads. These are compared to estimates of the amount of food consumed by bowhead whales as determined through observations of behavior, swimming speed, and amount of food found near feeding whales. There are numerous data gaps and there is much variability (year-to-year and otherwise) in the data. Sensitivity analysis techniques have been used to assess the effects of this uncertainty and variability on estimates of the dietary contribution of food from the eastern Alaskan Beaufort Sea. Results of the sensitivity analysis are included in Chapter 23, “Integration and Conclusions”.

Size and Other Physical Attributes of Bowhead Whales

Energetic calculations require some basic information about the size and composition of the animals, growth rates, details of the reproductive cycle, and the annual cycle of weight gain and loss, if any.

Scoresby (1820) believed that the largest bowhead whale that he personally saw was 18.3 m in length, and that a whale of 19.8 m in length was rarely encountered. The largest he actually measured was 17.7 m long. As of spring 2001, the lengths of 3854 whales of the Bering–Chukchi–Beaufort (BCB) population had been measured by calibrated photogrammetric methods applied to aerial photographs taken by LGL and the National Marine Mammal Laboratory. Only 9 of these measured whales were 17 m or more in length. The largest was 17.7 m in length.

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[1] LGL Ltd., environmental research associates, 22 Fisher St., POB 280, King City, Ont. L7B 1A6. *Phone:* 905-833-1244. *E-mail:* dthomson@lgl.com

Length and Weight

Weights and lengths of bowheads were estimated using measurements made from known-scale aerial photographs. Twenty six vertical photographs of 24 different whales, as photographed in August and September 1981–86 by Davis et al. (1982, 1983, 1986a,b), Richardson et al. (1987) and the present study (Chapter 10), showed good definition of both sides of the whale as well as its length. Techniques used to measure lengths of whales are described in Koski et al. (1992) and Chapter 10. Whales were assumed to be circular in cross section and were divided into five truncated cones. Photographs showed that the head is somewhat conical in shape (Fig. 22.1). It was assumed to be conical from the blowhole to the snout. The length of each segment, its diameter at each end, and total length of the whale image were measured from photographic prints or scanned images. These measurements were compared to total whale length (in m) as determined photogrammetrically in order to obtain actual measurements of the "segments" in meters. As a check on accuracy, fluke width was estimated from the prints by the same method, and compared to previous photogrammetric measurements of the same parameter. The error in our measurements from prints as compared to earlier photogrammetric results was 1.03 % ± s.d. 1.49 %. This imprecision is additional to inherent uncertainty in the photographic technique, which was ~2 % (Koski et al. 1992). The lengths and maximum girths of an additional 13 whales photographed in August and September of 1982–2000 and 27 photographed in late April and May 1986–92 were measured from photographs.

The maximum girth–length relationship as measured on photographs was compared to the maximum girth–length relationship measured from 11 whales harvested in Kaktovik in fall 1997 through 2000 and measured by Lowry and Sheffield (Chapter 18). Ingutuks, which are short, fat and possibly recently-weaned whales, were not included. J.C. George (pers. comm.[2]) measured lengths of whales in the water and after being hauled up onto land and found that they stretched an average of 8.2 % in the process. The measured lengths of the whales harvested at Kaktovik were adjusted downward to allow for this stretching. Scatter plots of the data and fitted regression lines showed that a simple linear relationship best described these data.

Analysis of covariance showed that slopes of girth–length regression lines based on photographs and measured whales were similar (ANCOVA $F = 1.9$, $P = 0.17$, df = 1,44), as were adjusted mean group maximum girths (ANCOVA $F = 0.073$, $P = 0.79$, df = 1,45). Thus maximum girths and, presumably, the other diameters measured from photographs appear to be an accurate representation of actual dimensions.

The weights of the 24 bowheads measured on photographs were estimated by summing the calculated volumes of the truncated cones. Density was assumed to be 1 kg/L, i.e., similar to water. Weights were expressed in metric tonnes (MT), which equal 1000 kg.

Length–weight relationships of photographed whales as estimated with the volumetric method were compared with those of five sub-adults harvested in fall (lengths 7.5–12.9 m) whose weights were measured directly by George et al. (1990, 1992). The lengths of the five measured and weighed subadults were adjusted for stretching. All weights were plotted against whale length and curves were fitted by regression. Analysis of scatter plots and residuals indicated, as expected, that power curves ($\text{weight} = a \times \text{length}^b$) best described the length–weight relationship.

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[2] Data provided by Craig George from a work in progress are not to be cited without written permission of Craig George, Department of Wildlife Management, North Slope Borough, Barrow, AK. cgeorge@co.north-slope.ak.us

FIGURE 22.1. Photograph of a bowhead whale on its side.

The regression equations for whale length vs. actual measured weight of 5 harvested subadults and length vs. weight as calculated by the volumetric method were not significantly different. The slopes were similar (ANCOVA $F = 0.06$, $P = 0.80$, df 1,25) and the difference in adjusted group weight was not significant (ANCOVA $F = 0.09$, $P = 0.77$, df = 1,26). Thus, the two datasets were merged (Fig. 22.2). The length–weight relationship of all 29 whales in fall was best described by the equation

(1) $\text{Weight (MT)} = 0.047 \times \text{Whale Length (m)}^{2.58}$; $r = 0.98$, $P < 0.001$

For a given length, bowheads weigh about the same as North Pacific right whales and humpback whales (*cf.* Lockyer 1976; Fig. 22.3). However, different techniques were used to estimate the length–weight relationships of the different species, so caution is necessary in interpreting these results. For a given length, bowheads are much heavier than fin, blue or sei whales (Fig. 22.3).

Lockyer estimated that the bone weight of North Pacific right whales is 13 % of body weight, and that the weight of viscera is also 13 % of body weight. We assume that these values apply to bowheads.

Quantity of Blubber

The bowhead whale has the thickest blubber of any cetacean (George et al. 1999). Thus, much of the weight of the animals, in a metabolic sense, is relatively inert. From 1997 to 2000, inclusive, standard measurement were made by ADF&G personnel of 13 whales landed during the subsistence hunt at Kaktovik in September (Chapter 18); measurement procedures followed those of the North Slope Borough Dept of Wildlife Management. Blubber thickness as used here is the average of dorsal measurement made 1 m behind the blowhole and ventral measurement between the flippers. There was a significant linear relationship between length and blubber thickness for the 13 whales landed at Kaktovik in 1997–2000:

(2) $\text{Blubber Thickness (m)} = 0.085 + 0.014 \times \text{Whale length (m)}$; $r = 0.79$; $P = 0.003$

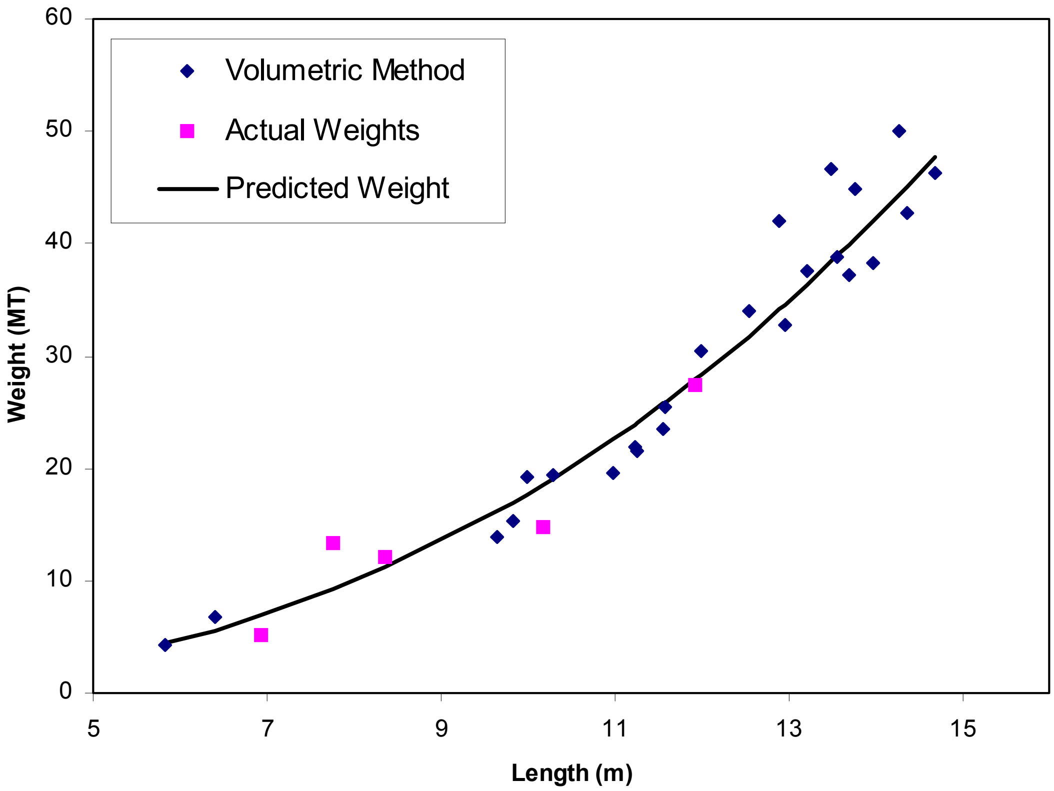

FIGURE 22.2. Length–weight relationship of bowhead whales derived through the estimation of volumes of photographed whales and actual weights of whales recorded by George et al. (1990, 1992). The solid curved line is the fitted least-squares regression based on the natural logs of weight and length.

The blubber thickness for each photographed whale was estimated using the above equation and subtracted from the overall body dimensions described above to estimate the weight of the core and head minus the blubber. The weight of the blubber was estimated by subtracting the weight of the core plus head minus blubber from the total weight. For the 24 photographed whales, weight of blubber in MT estimated in this manner was related to body length in m as follows:

(3) $\text{Blubber (MT)} = 0.027 \times \text{Length (m)}^{2.403}$; $r = 0.99$, $P < 0.001$

Weight of blubber was also estimated from data collected by the whaling ships *Cumbrian* in 1823 and *Arctic* in 1873 as reported in Lubbock (1937):

- Data collected by Markham (1874, *in* Lubbock 1937) during a cruise of the *Arctic* in 1873 contained measurements of maximum baleen length and yield of oil for 28 bowhead whales. Whale length was not measured. After 1870, 1 ton of whale oil was composed of 20 hundredweight, i.e., 20 × 112 pounds or 2240 pounds (Lubbock 1937), = 1016 kg. Prior to that, 1 ton was 877.1 kg (Scoresby 1820; Lindquist 1992). Oil was converted to blubber using Scoresby's (1820) estimate that 4 tons of blubber yielded three tons of oil.

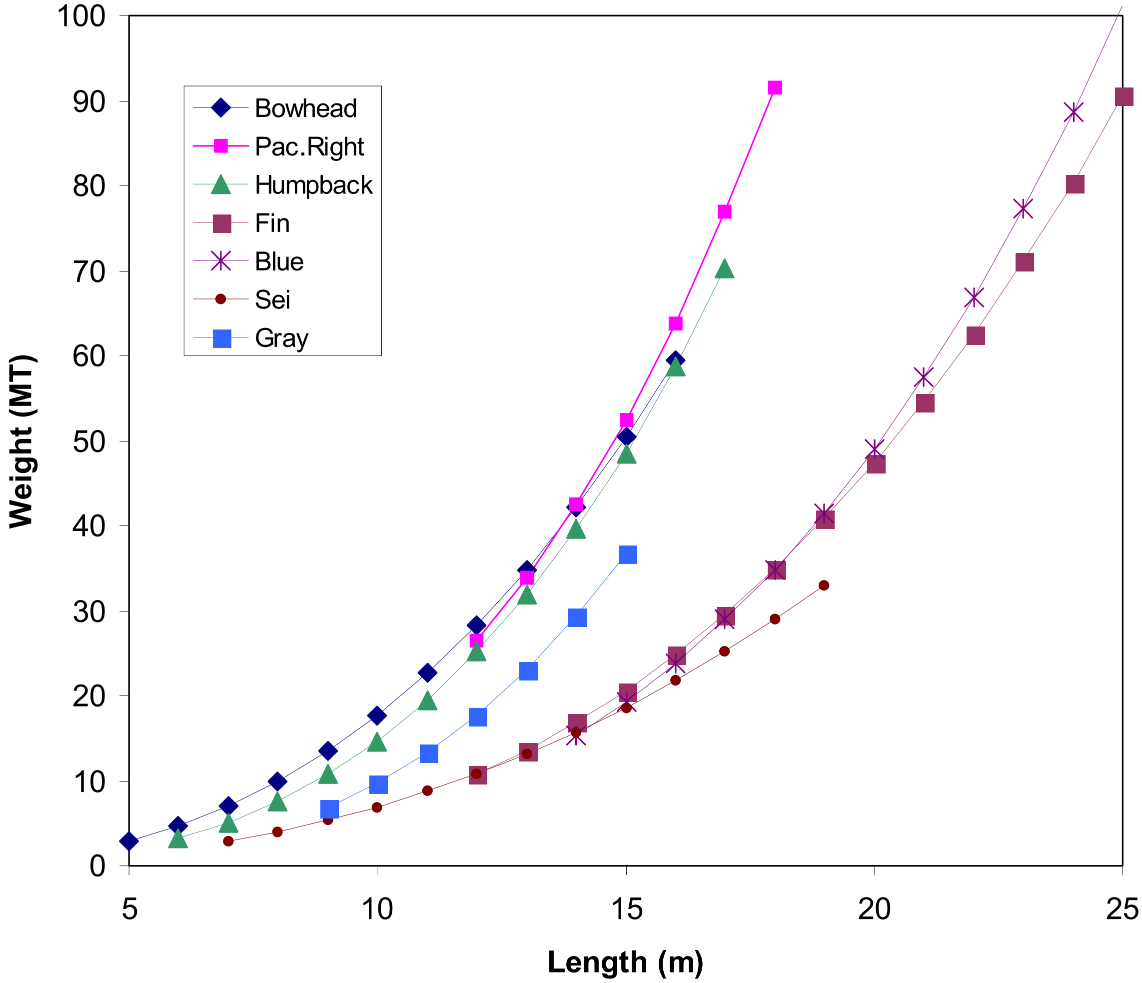

FIGURE 22.3. Length–weight relationship for bowhead whales, from equation (1), compared to relationships for other species of whale, from Lockyer (1976). The lines are fitted least-squares regressions based on the natural logs of weight and length.

- In 1823, the *Cumbrian* collected data on maximum baleen length and whale length for 23 whales. Alaska Department of Fish and Game collected similar data at Kaktovik (n = 13 whales) from 1997 to 2000, as an adjunct to the work described in Chapter 18. There were only marginal differences in the relationship between natural log of body length (in m) and maximum baleen length (in m) for data collected by the *Cumbrian* vs. ADF&G. The slopes were similar (ANCOVA $F = 2.8$, df 1,32, $P = 0.10$) and adjusted group mean baleen lengths of 2.32 m for the ADF&G data and 2.47 m for the Cumbrian data were only marginally different (ANCOVA $F = 3.5$, df = 1,33, $P = 0.07$). The data from these 36 whales, plus 2 measurements in Scammon (1874), were merged to estimate body length from maximum baleen length for a greater range of whale lengths than would have been available for any one data set:

(4) $$\log_e \text{Whale Length (m)} = 1.609 + 0.355 \times \text{Max. Baleen Length (m)};\quad r = 0.97,\ P < 0.001$$

Equation (4) was used to substitute whale length for maximum baleen length in the *Arctic* data ($n = 28$). The relationship between whale length in m and weight of blubber in MT was best explained by the equation

(5) $$\text{Blubber (MT)} = 0.052 \times \text{Length (m)}^{2.186};\quad r = 0.95,\ P < 0.001$$

The slope of the length to blubber weight relationship derived from the volumetric method (equation 3) was not significantly different from that derived using the old whaling data (equation 5) (F = 0.13, df = 1,47, P = 0.43). However, on average, whales collected by the *Arctic* had 0.9 MT more blubber than those for which blubber mass was estimated by the volumetric method (adjusted group means F = 5, df = 1,48, P = 0.3). Data collected by Scoresby (1820) on average oil yield for whales with 12 equally-spaced baleen lengths, from shortest to longest, were converted to whale length and blubber weight as shown above. However, the slope of the whale length to blubber weight relationship derived from the volumetric method (equation 3) was significantly different from that derived from Scoresby's data (F = 11.7 df = 1,32, P = 0.002). For whales > 9 m in length, blubber content of whales taken by Scoresby was lower than for whales taken by the *Arctic* or estimated using the volumetric method (Fig. 22.4). One reason for the higher weights found in the *Arctic* data is that whalers extracted oil from the bones and other body parts.

Blubber weights for two whales measured by George et al. (1987) are also plotted on Figure 22.4. Those weights are similar to those derived from the data of Scoresby for whales of comparable length. Blubber weights predicted by the volumetric method were intermediate between the other estimates. The blubber thickness from the volumetric method appears to be a good approximation of average blubber thickness of the core of the body.

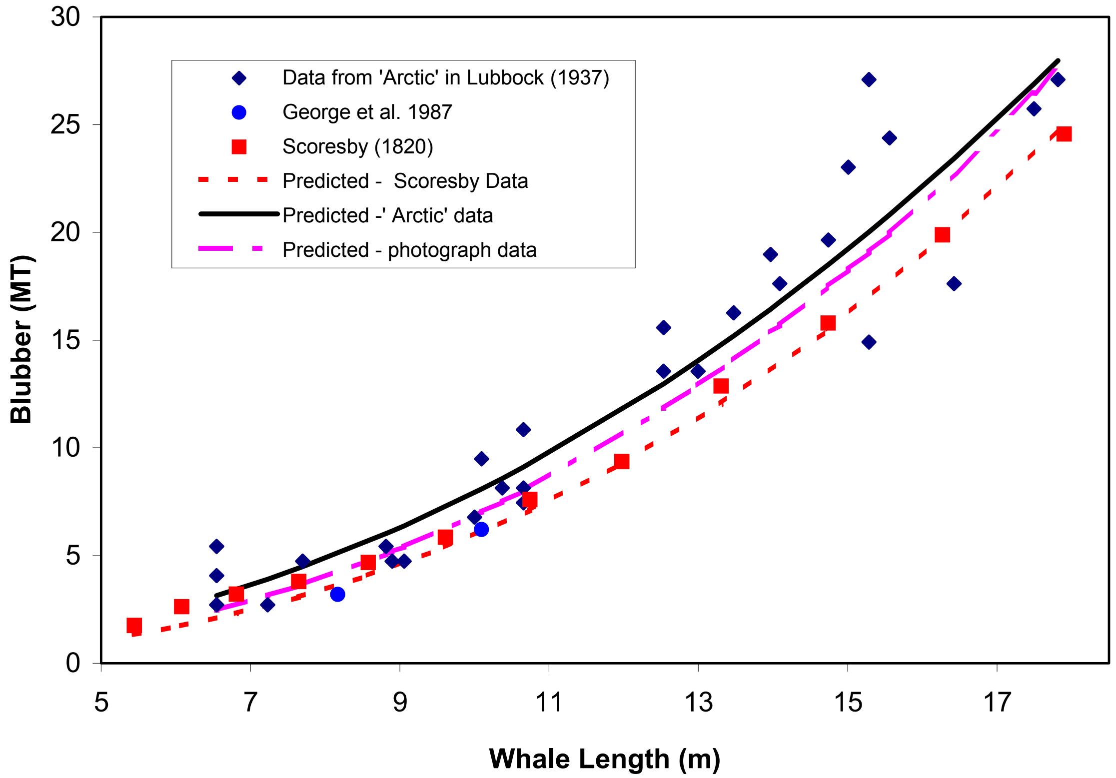

FIGURE 22.4. Weight of blubber vs. whale length, based on old whaling records (Scoresby 1820; Lubbock 1937), the volumetric method applied to aerial photographs, and actual weights from George et al. (1987). Curved lines are fitted least-squares regressions of natural logs of blubber weight and length.

The length–weight and length–blubber weight equations (equations 1 and 5) predict that a 9 m subadult whale will contain ~39 % blubber by weight, and that a 13.5 m adult will contain ~37 % blubber. This is about the same as found in the North Pacific right whale and higher than in any other species of whale (Lockyer 1976).

Surface Area

The metabolically active surface area is the surface area of muscle (Brodie 1981). The region posterior to the blowhole was taken to be the body core. Its volume was calculated from aerial photographs, considering the diameters of the truncated cones posterior to the blowhole minus the blubber thickness. Surface area was calculated in a corresponding way. The truncated cones were also used to calculate total surface area of the animal. The weight of muscle and viscera was calculated assuming a density of 1 kg/L. Analysis of scatter plots of the data and residuals showed that power curves of the form $y = aX^b$ best fit the relationship between each of whale surface area, fluke surface area, and the weight of the metabolically active core vs. whale length (Table 22.1).

TABLE 22.1. Relationship between whale length and whale surface area, weight of the metabolic core, and other parameters. Curves of the form $Y = a \cdot \text{length (m)}^b$ were fitted by regression analysis.

Parameter/ units		**a**	**b**	***R***	***P***
Total surface area	m^2	0.54	1.85	0.99	< 0.001
Weight of metabolic core	MT	0.03	2.53	0.97	< 0.001
Fluke area	m^2	0.012	1.94	0.92	< 0.001
Surface area of metabolic core	m^2	0.49	1.70	0.97	< 0.001

Growth and Reproduction

Growth in the first five years may be very slow and is quite variable (Schell et al. 1989; Koski et al. 1993; George et al. 1999). After this time, bowheads grow slowly (Koski et al 1993; George et al. 1999). Based on aerial photographic measurements of lengths of females with calves, Koski et al. (1993) estimated that most females become sexually mature at a length of 13 to 13.5 m. Koski et al. estimated that most males mature at a length of 12–13 m. [See also O’Hara et al. (2002).] There are seasonal variations in isotopic content of baleen plates that can be used to age young animals (Schell et al. 1989). Schell et al. (1989) and Schell and Saupe (1993) estimated that bowheads mature at an age of 17 to 20 years. Koski et al. (1993) used lengths of whales re-identified from aerial photographs to estimate growth rates as a function of length. They estimated that bowhead females that matured at 13 m were in their late teens to early twenties. They estimated that males grew more slowly and that males and females combined reached 13 m at an age of 22 to 31 years, and most likely at the upper end of that range. Recently, aspartic acid racemization analysis of bowhead eye globes has confirmed a very slow growth rate (George et al. 1999). They estimate that sexual maturity is reached when bowheads are in their mid-twenties. It will be assumed that male bowheads mature at age 25 when they are 12.5 m in length and weigh 31 MT, and that females mature at age 27 when they are 13.5 m in length and weigh 38 MT.

The growth equation presented in George et al. (1999) was combined with the length–weight equation (1) to estimate weights and annual weight gain for whales of various ages and lengths (Table 22.2). When just mature, bowheads gain about 0.7 to 0.8 MT per year. Older animals gain much less.

TABLE 22.2. Estimated annual weight gain for bowhead whales of various ages estimated from the age–length equations developed by George et al. (1999) and the length–weight relationship shown in equation (1).

	Male			**Female**		
Age (yr)	**Length (m)**	**Weight (MT)**	**Annual Gain (MT)**	**Length (m)**	**Weight (MT)**	**Annual Gain (MT)**
3	8.9	13.1	0.9	9.4	15.3	1.0
6	9.5	15.7	0.9	10.1	18.3	1.0
9	10.1	18.3	0.9	10.8	21.4	1.0
12	10.7	21.0	0.9	11.3	24.5	1.0
15	11.2	23.5	0.8	11.9	27.5	1.0
20	11.9	27.6	0.8	12.6	32.3	0.9
25	12.5	31.4	0.7	13.3	36.7	0.9
27	12.7	32.9	0.7	13.5	38.4	0.8
35	13.5	38.1	0.6	14.3	44.5	0.7
49	14.4	45.2	0.4	15.3	52.8	0.5
50	14.4	45.6	0.4	15.3	53.3	0.5
75	15.3	53.1	0.2	16.3	62.1	0.2

The total energetic cost of gestation is equivalent to about twice the basal metabolic rate of the foetus as predicted from Kleiber's equation (Lavigne et al. 1982). Assuming a 13.5 month gestation period (Tarpley and Stott 1994) and a birth weight of 1000 kg for a bowhead, total metabolizable cost of pregnancy would be about 220 x 10^5 kJ. Not included is the calorific value of the foetus itself, about 136 x 10^5 kJ at birth.

Most calves are born in April, May and early June (Koski et al. 1993). At birth calves may be about 3.6 to >4.5 m in length, with most being >4.0 m (Koski et al. 1993). A 4 m calf would weight 1 MT (George et al. 1992). An average calf that was 4.75 to 5 m in length in late May would be 6.25 to 6.5 m long in late summer (Koski et al. 1993). Yearlings may be 7 to 8.7 m in length (Koski et al. 1993). Calves are weaned at about 12 months and a length of 6.6 to 8.2 m. An estimate of 7.2 m will be used here. At weaning, whales are short and fat. Three of five sub-adults harvested in fall (lengths 7.5–12.9 m) whose weights were measured directly by George et al. (1990, 1992) were 2 to 3 MT heavier than their predicted weight. At an average length at weaning of 7.2 m, the length–weight equation (1) predicts a weight of 8 MT. If a newly weaned whale is 2 MT heavier than predicted, then it would weight 10 MT at weaning and would have gained 9 MT during one year of lactation. Mature females may produce a calf every 3 to 4 years (reviewed in Koski et al. 1993). For this analysis, the metabolic cost of pregnancy and lactation is averaged over 4 years.

Assimilation efficiency for milk is about 90 % and cetacean milk contains about 18,000 kJ/kg (4300 kcal/kg) wet weight (Lockyer 1981; Gaskin 1982). Sei and fin whale muscle has an energetic value of about 6300 to 10,900 (mean 7950) kJ/kg wet weight (Lockyer et al. 1985). Blubber is about 80 % oil and wax with a mean energetic content of 22,190 kJ/kg wet weight (Lockyer et al. 1985). Neonates would require 1365 x 10^5 kJ for growth and 810 x 10^5 kJ for metabolism. This is based on their daily basal metabolic rate in relation to their weight on that day, x1.5 to allow for the extra energy required over and above BMR, and summed for the year. About 12 MT of milk would be required.

Weight Gain During Summer/Loss During Fall–Winter

Photographic Data.—Measurements of aerial photographs of bowheads showed weight gain in summer and net weight loss over the fall–winter. The lengths and girths were measured from photographs taken in April, May and June during spring migration near Barrow, Alaska (27 bowheads), and in August and September in the Beaufort Sea (37 whales). Linear equations provided the best fit to the length–girth data. The regression equations of length vs. girth for whales photographed in spring and fall were compared with analysis of covariance. The slopes of the regression equations were not significantly different (ANCOVA $F = 0.093$, df = 1,60, $P < 0.8$). Whales photographed in spring were significantly thinner than animals photographed in fall (ANCOVA, $F = 7.7$, df = 1,61, $P = 0.007$; Fig. 22.5). J.C. George (pers. comm.[3]) has derived an equation relating actual measured weight of bowheads to length and girth: Weight (kg) = 38.28 × Girth (m)^2 × length (m). The regression parameters and estimated weights of whales in spring and fall are shown in Table 22.3. Because the equation relating length and girth to weight was based on stretched animals, the lengths in Table 22.3 were adjusted for 8.2 % stretching. The equations predict that a 9 m whale would gain about 2 MT over the summer, a 12.5 m whale would gain about 3 MT, and a 16 m whale would gain about 4 MT.

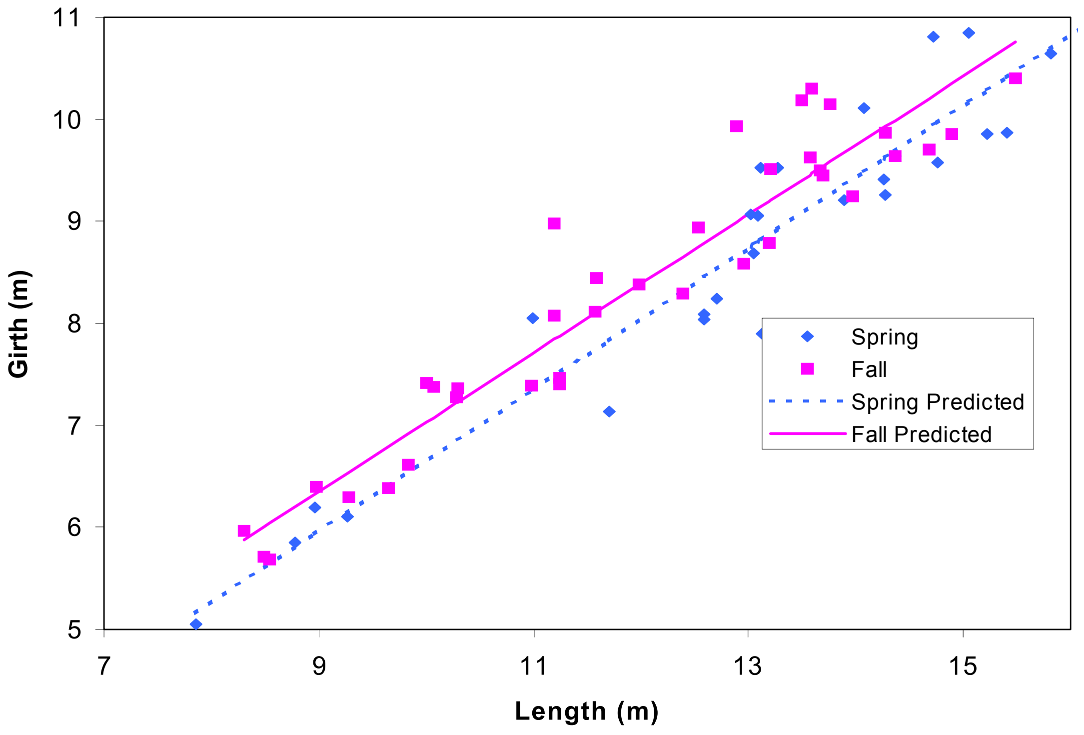

FIGURE 22.5. Maximum girth as a function of length as estimated from aerial photographs of bowhead whales in spring (near Barrow, AK) and in late summer/early fall (Beaufort Sea). The lines are the fitted least-squares linear regressions of girth vs. length for the two seasons.

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TABLE 22.3. Regression parameters for the linear equations of the form girth (m) = a + b x length (m) for bowhead whales photographed in spring (near Barrow, AK) and in late summer/early fall (Beaufort Sea). Also shown are the adjusted group mean girths and the estimated weights, during spring and late summer/early fall, of animals of four specific lengths adjusted for 8 % stretching.

	Regression Parameters					**Weight (MT) vs. Length/Adj. Length (m)**			
Season	**a**	**B**	***r***	***P***	**Mean Girth**	**11/11.9 m**	**12.5/13.5**	**13.5/14.6**	**14.5/15.7**
Spring	-0.292	0.695	0.96	< 0.001	8.338	24.64	36.50	46.22	57.52
Early Fall	0.253	0.678	0.95	<0.001	8.672	27.10	39.45	49.48	61.09
Difference					0.334	2.46	2.95	3.26	3.56

Note that the August–September measurements were obtained before the period of feeding that occurs in fall in the western Beaufort Sea and Chukchi Sea. It is suspected that this autumn feeding is in areas where the zooplankton is abundant and energy-rich (see Chapter 20, 21, 23). Thus, there is probably additional gain in girth and weight subsequent to the dates when the late summer/early fall photographs were taken. If so, the reduction in girth and weight during winter must be larger than shown by the measurements in Figure 22.5.

Other Data.—J.C. George (pers. comm.[4]) measured girths and lengths of whales harvested at Barrow. He found that subadult bowheads had larger girths in fall than in spring, but he found little seasonal difference in the girths of large adults. In contrast, the photographic data indicate that the seasonal difference is evident in adults as well as subadults (Fig. 22.5). The discrepancy between the results obtained from photographs and those of whales measured by George could be an artifact of stretching. Whales were measured after being hauled up onto the ice or shore. George has shown that the animals are stretched when this occurs. In spring, whales are hauled up onto the ice whereas in fall they are hauled up onto the beach; there could be a difference in the amount of stretching in spring vs. fall. In any event, at least for subadults, direct measurements of girth vs. length in spring and fall are consistent with the photographic data in showing that the whales gain girth (and thus weight) while in the Beaufort Sea.

In addition to the seasonal change in girth, with animals being thinner in spring than in fall, there is evidence that some lipid is lost from the blubber during winter. Lipid content in the blubber of subadults harvested in fall was about 80 % (T. Mau, pers. comm.[5]). In spring, lipid content of the inner 20 % of the blubber in subadults was about 70 %; lipid content in the next 20 % of the blubber was less than 80 % but not as low as 70 %. Lipid content in the outer 60 % of the blubber layer was unchanged from fall. An 11 m subadult bowhead contains about 9.8 MT of blubber. Based on the data of T. Mau quoted above, seasonal loss of lipid would amount to about 0.3 MT. It appears that only subadults lose this percentage of lipid over the winter (Chapter 20).

Inupiat on the North Slope have noticed these seasonal changes. Hunters have told us that bowheads caught in spring and fall taste different. Also, Vincent Nageak stated that "When the whales come this way from the east they don't travel fast, they often become fatter and their meat is even

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[5] Data provided by T. Mau, from a work in progress, are not to be cited without written permission of Tamara Mau, University of Alaska Fairbanks, Institute of Marine Science, 245 O'Neill Bldg., Fairbanks, AK 99775-7220. tmau@ims.uaf.edu

different." (Chapter 2; Kisautaq 1981:296). In fall, blubber appears to be dripping with fat and this is different from the condition of the blubber in spring (J.C. George, pers. comm.[6]).

As discussed elsewhere in this report, it is difficult to reconcile these and other data indicative of feeding and weight gain during summer in the eastern and central Beaufort Sea with stable isotope data indicating that bowheads derive most of their food from Bering/Chukchi water (Chapter 20).[7] However, one scenario has been suggested (see Chapters 20, 21, 23) that could be at least generally consistent with all data. This scenario acknowledges that bowheads feed and gain weight both in the Beaufort Sea in summer and (more intensively) in Bering/Chukchi waters in autumn. (Feeding in the western Beaufort in autumn may effectively be in Bering/Chukchi waters.) Under this scenario, weight gain must be assumed to be greater in the highly productive Bering/Chukchi waters in autumn than in the less productive eastern and central Beaufort Sea in summer/early autumn. This assumption is necessary to account for the predominantly Bering/Chukchi isotope signature in bowhead tissue, as documented by Lee and Schell (Chapter 20; *cf.* Hoekstra et al. 2002). Aside from the isotope data, there are no other specific data on weight gain in the Chukchi in autumn—a significant data gap. Under this scenario, bowheads are assumed to subsist mainly on stored energy over winter and early spring, to the point that they are leaner when returning to the Beaufort Sea in spring than when they moved from the Beaufort Sea into the Chukchi Sea in fall.

Theoretical Energetic Requirements

The theoretical energetic requirements of bowhead whales were estimated based on the estimated basal metabolism, cost of swimming, heat loss, and respiration. These estimates were compared to one another and with an estimate of feeding rates in nature.

Time Budgets

During spring migration, bowheads socialize, rest and feed as well as migrate (Carroll and Smithhisler 1980; Rugh and Cubbage 1980; Carroll et al. 1987; Richardson et al. 1995a). Feeding was not common in the area northeast of Barrow during spring migration in 1989–91 and 1994; whales spent only an estimated 1 % of their time feeding (Table 22.4), based on Richardson et al. (1995a) and Chapter 12. However, feeding was commonly seen southwest of Barrow during the 1978 and 1985 spring migrations (Carroll and Smithhisler 1980; Carroll et al. 1987). It is possible that, in spring, feeding is more common in Chukchi waters near and southwest of Barrow than in Beaufort waters northeast of Barrow (where the 1 % figure was obtained). Stomach content data from bowheads harvested at Barrow in spring indicate that they feed less in spring than in fall. None of the 100 bowhead stomachs examined in spring at Barrow were full, whereas about 27 of 106 stomachs examined at Barrow in fall may have been full (Appendices 18.4, 18.5). About 33 % of the bowheads landed at Barrow in spring were classified as

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[7] The independent isotope data of Hoekstra et al. (2002) suggest that that feeding in the eastern and central Beaufort Sea vs. Bering/Chukchi waters may be about equally important. However, as discussed in Chapter 20, additional investigation is needed to resolve the reasons for differences between the data of Hoekstra et al. (2002) and those of Lee and Schell (Chapter 20).

TABLE 22.4. Observed or assumed proportion of time when bowhead whales are engaged in various activities during different seasons.

	Observed or Assumed Percent of Time				
Activity	**Spring**[a]	**Summer**[b]	**Fall Beaufort**[b]	**Fall Chukchi**[c]	**Winter**[d]
Travel	75	7	31	7	7
Feed	8	73	47	73	0
Social	7	15	17	15	0
Other/Unknown	10	5	5	5	93
No. of Obs. Sessions	*(54)*	*(85)*	*(80)*		

[a] From field observations summarized in Chapter 12, but with % time feeding adjusted upward (from observed 1 %) based on a speculative assessment of the frequency and quantity of food in stomachs of hales harvested in spring off Barrow vs. fall off Kaktovik (see text).

[b] From field observations summarized in Chapter 12.

[c] Includes Bering Strait; activities in fall in the Chukchi Sea and Bering Strait area are assumed similar to those in summer in the eastern Beaufort.

[d] No data for winter; assumed to be negligible feeding and same amount of travelling as during summer.

feeding, with an average quantity of ~14 L for the 17 whales where quantity could be estimated (Lowry and Sheffield, Chapter 18 Appendix 18.5). In contrast, of the whales landed at Kaktovik in fall, 83 % were classified as feeding, and average content was 34 L for the 18 whales where quantity could be estimated (Appendix 18.3). The percent of time spent feeding in the latter area in fall was 47 % (Chapter 12). An alternative estimate of the percentage of time spent feeding in spring was obtained by applying the percentage of stomachs with food in spring at Barrow vs. fall at Kaktovik (33 % / 83 %) and their average contents in spring vs. fall (14 L / 34 L) to the percent of time spent feeding in the Kaktovik area in fall (47 %, from Chapter 12). The time spent feeding in spring estimated in this speculative manner was 8 %, as compared with the 1 % estimate based on direct observation northeast of Barrow.

Bowhead whales summering in the Canadian Beaufort Sea were observed to be feeding 71 % of the time, based on data of Würsig et al. (1985, 1989) and Dorsey et al. (1989) as re-examined in Chapter 12 (Table 22.4). Results of photoidentification and satellite-linked tagging studies show that there can also be much local movement of bowheads in late summer while in the Canadian Beaufort Sea (Koski et al. 1988; Mate et al. 2000). During summer, bowheads of the Hudson Bay stock spend about 74 % of their time feeding (Thomas 1999), consistent with the results from BCB bowheads in the Canadian Beaufort Sea.

Fall migrants appear to spend a considerable proportion of their time feeding while in the eastern Alaskan Beaufort Sea (Table 22.4, based on Chapter 12). Of 29 whales landed at Kaktovik in fall whose feeding status could be classified, 83 % had been feeding shortly before being struck (Chapter 18). Migrating bowheads also feed at least occasionally in the central Alaskan Beaufort, and sometimes feed heavily in the western Beaufort east of Barrow. Four of five bowheads landed at Cross Island and 77 of 103 bowheads landed at Barrow in late summer and fall had been feeding shortly before being struck (Lowry and Sheffield, Chapter 18).

There have been no systematic observations of bowhead whale behavior in winter. Chapter 20 indicates, via indirect evidence, that BCB bowheads feed mainly during autumn and/or winter while in Bering/Chukchi waters. [Hoekstra et al. (2002) suggest, also based on isotopic data, that both the Beaufort Sea and Bering/Chukchi Sea are important feeding grounds. Further investigation is needed to resolve differences in some of the isotopic data.] The isotopic methods used in Chapter 20 and by Hoekstra et al. cannot distinguish feeding in the Bering Sea from that in the Chukchi Sea. Bowhead whales appear to lose weight during winter, i.e., from the time they depart the Beaufort Sea in fall until the time they return in spring. Thus, most food that bears a Bering/Chukchi isotopic signature probably is consumed in the Chukchi Sea, and to some extent the western Beaufort Sea or northwest Bering Sea, in fall. Time spent feeding in winter is assumed to be zero. It is assumed that, as in summer, wintering bowheads spent ~7 % of their time traveling, and the remainder of their time doing unknown activities.

Primary and secondary productivity in the Chukchi Sea may be highest in the southern and southwestern part (Truett 1984). Abundance of zooplankton in the SE Chukchi Sea is higher south of Cape Lisburne than north of it (Wing 1974). There is a very high biomass of zooplankton in the southern Chukchi Sea. Average summer zooplankton biomass in 145 vertical zooplankton tows taken in the SE Chukchi Sea between Cape Lisburne and the Bering Strait was about 1700 mg/m^3 (English 1966). By comparison, average biomass in vertical tows in the eastern Alaskan and Canadian parts of the Beaufort Sea is about 230 mg/m^3 (Chapter 6). Bowhead whales are known to feed in the SW Chukchi Sea during autumn (Moore et al. 1995). In October 1993, they saw 11 bowheads feeding in a 5 m × 8 km patch of euphausiids located at depths of 25 to 30 m. The high productivity of invertebrates in the SW Chukchi Sea may be the result of advection of organic carbon and zooplankton from the Bering Strait and Bering Sea (Springer et al. 1984). Zooplankton biomass in the Bering Strait and coastal waters to the south and west are very high—higher than those in the central Bering Sea (Coyle et al. 1996). Biomass may remain high there until early November, which is the end of "biological fall" in the Bering Sea. Intensive feeding may continue into November as bowheads move into the northern Bering.

Thus, the autumn can be divided into two periods: ***(1)*** migration across the Alaskan North Slope, including some feeding, and ***(2)*** feeding in the Chukchi Sea and (presumably) coastal waters of the Bering Strait area. Autumn feeding in the western Beaufort Sea, just east of Barrow, is probably of a transitional type, in terms of both the likely zooplankton biomasses (probably higher than in eastern Beaufort but lower than in the SW Chukchi) and the probable isotopic signature of the prey. Average residence time in the area from Herschel Island to Flaxman Island was 5.1 d (Chapter 11). That area is 270 km in width. Net westward speed would thus average 2.2 km/h (270 km in 122 h). Whales spend 47 % of their time feeding while in that study area. If the whales maintain this speed, they would arrive the southern and western Chukchi Sea in another 19.4 d. Total migration time across all of the Alaskan Beaufort Sea and part of the Chukchi Sea would be ~24.6 d. This would leave ~52 d to feed in the zooplankton-rich southern and western Chukchi Sea, the Bering Strait, and areas immediately to the south. It will be assumed that whales spend the same proportion of time feeding (73 %) when in these areas as observed in the Canadian Beaufort Sea in summer.

Respiration Method

Energy requirements can be estimated by calculating oxygen consumption of the animals (Sumich 1983; Folkow and Blix 1992). Estimates of oxygen consumption are based on the observed breathing rate for various activities, the percentage of time spent doing the activities, and estimates of the size of the lungs, tidal volume, and oxygen utilization.

Blow Rates.—Observed blow rates, along with some assumptions and approximations, can be used to estimate the total number of blows in a year by various categories of whales. In the southeastern Beaufort Sea in summer, mean blow rate for all non-calves (all activities combined) was 0.77 blows/min (Table 22.5). Overall, blow rate is lower for feeding, migrating and traveling whales than for socializing whales. Blow rates for feeding, socializing, and traveling whales for each season (from Table 22.5) were scaled using blow rates by size category and activity based on data in Table 22.6. The blow rates based

TABLE 22.5. Respiration rates of undisturbed bowhead whales in various areas under various circumstances.

	Blows/Surfacing			**At Surface (min)**			**Minutes Diving**			**Blows/**	
Location/ Activity	**Mean**	**± s.d.**	**n**	**Mean**	**± s.d.**	**n**	**Mean**	**± s.d.**	**n**	**Min**	**Reference**
Spring Migration											
Barrow Area											
Traveling	6.5	2.8	41	1.5	-	31	15.6	5.0	63	0.38	Carroll and Smithhisler 1980
Traveling	6.5	2.6	78	1.6	0.5	19	11.7	5.3	156	0.49	Carroll et al. 1987
Traveling	7.4	3.0	184	1.3	0.6	184	9.9	5.2	41	0.66	Zeh et al. 1993
Traveling*	5.0	3.3	355	1.4	1.0	367	6.6	6.3	244	0.63	Chapter 13
Traveling + socializing*	4.8	3.6	70	1.0	1.0	80	3.2	3.6	38	1.14	Richardson et al. 1995a
Feeding*	12.6	2.2	37	2.3	0.6	39	14.7	6.5	16	0.74	Carroll et al. 1987
Summer											
Canadian Beaufort Sea											
All non-calves, all activities	4.3	3.3	626	1.2	1.1	715	4.4	6.3	333	0.77	Dorsey et al. 1989
Calves	2.6	2.5	41	1.1	1.1	51	5.0	5.4	45	0.43	Dorsey et al. 1989
Adult with calf	5.1	4.2	38	1.7	1.4	47	8.2	6.5	39	0.51	Dorsey et al. 1989
Feeding Shallow	3.9	3.1	145	1.2	1.7	185	2.9	4.4	99	0.96	Chapter 13
Feeding Deep	3.7	2.7	114	0.9	0.7	118	3.8	4.2	34	0.79	Chapter 13
Weighted Mean Feeding*	3.8		259	1.1		303	3.1		133	0.91	From Above
All Social*	4.2	2.9	230	1.1	0.8	261	2.8	3.6	83	1.08	Chapter 13
No forward speed	5.1	2.9	75	1.4	0.7	91	6.5	7.4	37	0.65	Dorsey et al. 1989
Swimming , slow speed	5.4	3.0	100	1.2	0.7	111	5.5	6.5	45	0.80	Dorsey et al. 1989
Swimming, moderate speed*	5.3	3.6	100	1.3	1.2	116	4.9	6.9	59	0.85	Dorsey et al. 1989
Swimming, Fast	4.7	3.9	10	1.0	0.8	10	4.9	6.1	3	0.80	
8 Subadults	4.5	1.1	8				10.4	2.4	8	0.43	Krutzikowsky and Mate 2000
Foxe Basin, E. Arctic											
Feeding	10.2	4.2	30	1.4	0.8	67	11.1	5.1	31	0.82	Thomas 1999
Traveling	5.1	2.5	25	1.1	0.7	40	4.1	2.7	25	0.98	Thomas 1999
Isabella Bay, E. Arctic											
Feeding >50m	17.3	6.7	23	4.7	1.8	46	15.8	7.1	29	0.84	Chapter 13
Traveling	6.0	3.5	76	1.5	0.9	91	9.4	5.7	82	0.55	Chapter 13
Socializing	2.1	2.9	35	1.2	1.8	78	1.6	1.7	45	0.74	Chapter 13
Fall Migration											
Alaska North Slope											
Migrating	9.2	2.5	10	1.8	0.8	13	17.9	5.0	10	0.47	Ljungblad et al. 1988
Migrating	8.5	2.3	8	1.8	0.6	8	17.8	11.7	4	0.43	Ljungblad et al. 1988
Migrating	3.8	2.0	19	1.1	0.6	21	14.2	10.5	6	0.25	Ljungblad et al. 1988
Migrating	8.0	2.1	24	2.0	0.6	25	16.2	11.5	4	0.44	Ljungblad et al. 1988
Weighted Mean	7.0		61	1.6		67	16.7		24	0.38	Ljungblad et al. 1988
Traveling*	6.1	3.3	68	1.6	1.0	75	14.0	8.1	66	0.39	Chapter 13
Feeding*	5.9	3.6	123	1.3	0.7	157	8.9	7.1	63	0.58	Chapter 13
All Social*	6.1	3.8	108	1.3	0.7	149	5.7	5.3	26	0.89	Chapter 13

*means that these data were used in the computation of annual breathing rates.

TABLE 22.6. Average respiration rates (blows/min) of bowhead whales in relation to whale status and whale activity (from Table 14.2).

Activity	Subadult	Adult	Mother
Traveling	0.92	0.53	0.55
Feeding	0.64	0.53	0.31
Socializing	0.59	1.04	0.52
Unknown[a]	0.77	0.77	0.77

[a] Listed value for "Activity = Unknown" is the overall average for all non-calves and all activities in summer (Table 22.5; Dorsey et al. 1989).

on the largest samples (Table 22.5) were used; these data were also collected in a similar fashion. The resulting estimates of blow rates by season, whale status, and whale activity are shown in Table 22.7. No data on blow rates in winter were available. In the absence of other data, the results from summer were, as a first approximation, assumed to apply to winter (Table 22.7). An example calculation follows. The overall blow rate for traveling in spring, 0.63 blows/min (Table 22.5), was used as the traveling rate for subadults because the blow rate for traveling was the highest of all subadult activities (Table 22.6). The overall blow rate for feeding in spring, 0.74 blows/min (Table 22.5), was scaled to the ratio of the blow rate of feeding vs. traveling subadults (0.64/0.92; Table 22.6) to yield a blow rate of 0.51 blows per minute for feeding subadults in spring (Table 22.7). Similar calculations were performed for each age category, activity type, and season shown in Table 22.7.

Blow rate estimates in Table 22.7 were applied to the time budgets in Table 22.4 to estimate annual number of blows in a year (Table 22.8). The assumed seasonal timing for bowhead activities, for a typical individual, is according to Moore and Reeves (1993). In assessing the assumed seasonal timing, note that the total number of days is fixed at 365. Minor re-allocation of days from one column to another would have little effect on overall estimated number of blows per year for a given category of whale. Total number of blows per year is estimated to be on the order of 300,000 to 350,000 for an average bowhead whale.

TABLE 22.7. Estimated average respiration rates (blows/min) of bowhead whales by season, whale status, and whale activity. Derived from data in Tables 22.5 and 22.6 as described in text.[a]

	Spring	Summer	Fall	Winter
Subadult				
Traveling	0.63	0.85	0.39	0.85
Feeding	0.51	0.63	0.40	0.63
Socializing	0.73	0.70	0.57	0.70
Unknown	0.77	0.77	0.77	0.77
Adult				
Traveling	0.32	0.43	0.20	0.43
Feeding	0.38	0.47	0.30	0.47
Socializing	1.14	1.08	0.89	1.08
Unknown	0.77	0.77	0.77	0.77
Mother				
Traveling	0.63	0.85	0.39	0.85
Feeding	0.42	0.52	0.33	0.52
Socializing	1.08	1.03	0.84	1.03
Unknown	0.77	0.77	0.77	0.77

[a] No winter data are available; summer data assumed to apply.

TABLE 22.8. Number of times an average bowhead breathes during a year. Based on blow rates from Table 22.7 and time budget from Table 22.4. Seasonal timing from Moore and Reeves (1993). Fall-1 and Fall-2 refer to periods when whales are (1) migrating across the Alaskan Beaufort and Chukchi Seas (with some feeding), and (2) feeding in the SW Chukchi Sea and Bering Strait area, respectively.

Category of Whale and Whale Activity	Spring April-May	Summer June-15 Sep	Fall-1 16 Sep-9 Oct	Fall-2 10 Oct-Nov	Winter Dec-Mar	
Days→	61	107	24	52	121	Blows/year
Subadult						
Traveling	41,443	9,441	4,229	2,066	10,310	
Feeding	3,654	71,148	6,436	21,892	-	
Socializing	4,517	16,027	3,435	6,385	-	
Unknown	6,733	5,559	1,325	2,702	124,204	341,506
Adult						
Traveling	21,236	4,838	2,167	1,059	5,283	
Feeding	2,701	52,596	4,758	16,184	-	
Socializing	6,985	24,782	5,311	9,873	-	
Unknown	6,733	5,559	1,325	2,702	124,204	298,294
Mother (nursing)						
Traveling	41,443	9,441	4,229	2,066	10,310	
Feeding	3,009	58,583	5,300	18,026	-	
Socializing	6,654	23,606	5,059	9,405	-	
Unknown	6,733	5,559	1,325	2,702	124,204	337,652

Blow rate data used here were collected in different years and with varying sampling strategies. Calculated blow rates depend strongly on the mean dive durations, which can be biased by observational problems. Also, some assumptions and approximations had to be applied to estimate blow rates for certain combinations of season, whale status, and whale activity. Values for winter are speculative. Thus, mean values in Table 22.8 are approximate. Apparent differences should be treated with caution.

Lung and Heart Size.—Henry et al. (1983) measured the dimensions of one preserved lung from each of five bowhead whales. Volumes that we calculated from their measurements were used to estimate the total volume of the preserved and collapsed lungs. Only three lungs were actually weighed. The collapsed volumes and weights were as follows:

Vol (L)	Weight (kg)	Weight/Vol
30.5	33.2	1.09
26.5	30.0	1.13
32.0	33.8	1.06

Based on this, we assumed that collapsed lung weight (in kg) is closely approximated by 1.09 x volume (in L), i.e., that the density of the preserved and collapsed lungs was 1.09 kg/L.

The estimated weights of bowhead lungs (as calculated from volume) are about 0.65 % of body weight (Table 22.9) and are smaller than those found in other whales. For minke, right, sei, fin and blue whales, lung weight is 0.65 to 0.85 % (mean 0.76 %) of body weight (Lockyer 1981; Lockyer and Waters 1986). In blue and fin whales, total lung capacity in liters is 2.5 to 2.8 % of body weight in kg (Lockyer

TABLE 22.9. Lung size of five bowhead whales, based on measurements by Henry et al. (1983).

Measured Length (m)	Adjusted Length[a] (m)	Weight[b] (MT)	Measured Dimension of Collapsed Lung (cm)[c]	Estimated Weight of Lungs (kg)[d]		Lung Weight as a % of Total Weight
10.9	10.1	18.0	12 x 72 x 42	79	(L)[e]	0.44 %
10.8	10	17.6	13 x 77 x 50	109	(R)	0.62 %
10	9.2	14.4	13 x 77 x 41	90	(L)	0.62 %
8.7	8	10.1	12 x 72 x 36	68	(R)	0.67 %
8.7	8	10.8	11 x 87 x 42	88	(R)	0.87 %
				Mean ± s.d.		0.65 ± 0.15 %

[a] Adjusted for 8.2 % stretching.
[b] Estimated from equation (1) for adjusted length
[c] Thickness x mean length x mean width.
[d] Estimated from calculated volume assuming tissue density of 1 kg/L.
[e] L = left; R = right—indicates which lung was used for the estimate.

1981) and in the smaller minke whales it is 7 % (Folkow and Blix 1992). If we assume that total lung capacity is proportional to lung weight, then total lung volume in L is about 2.25 % body weight in kg. This value is close to actual measured values (J.C. George pers. comm.[8]). Lung volume in bowheads is low when compared to that of other species.

The small lung size of bowhead whales may also be reflected in small heart size. Only a portion of one heart has been weighed. Seventy-five percent of the heart of a 12.7 m whale was reported to weigh 80 kg (Jones and Tarpley 1981). The entire weight would have been roughly 107 kg. Adjusted for stretching, this 11.7 m bowhead would weigh about 30 MT. According to Lockyer (1981), heart weight of a whale is approximated by the equation Heart weight = 0.00588 Body weight$^{0.984.}$ Thus, for a 30 MT whale, the heart is expected to weigh about 148 kg. Thus, based on the meager available evidence, bowhead heart weight ($n < 1$!) is about 70 % of predicted weight, and the lungs ($n = 5$) are about 80 % of the weight of those of other whales of comparable size. The relatively small heart and lung sizes indicate a relatively low metabolic rate.

An average non-calf bowhead, which is about 12.5 m in length (Angliss et al. 1995) and weighs about 31 MT (equation 1), would have a lung capacity of about 708 L. Tidal volume is about 60 % of lung capacity (Blix and Folkow 1995). Average oxygen utilization, i.e., the proportion of the oxygen in each breath that is extracted, may be about 8.7–9.6 % (Sumich 1994). However, this value, which is the one used by Blix and Folkow (1995) for minke whales, is based on oxygen utilization of a gray whale calf with surfacing-dive cycles of duration <1 min. Bowhead surfacing-dive cycles are >1 min in duration (Table 22.5), so this may be a source of error in the calculations. One liter of O_2 consumed corresponds to 20.09 kJ (McNab 1988). Using data in Table 22.4 and 22.8, the average energy expended by an average 12.5 m bowhead respiring at this rate is 6.4 x 10^5 kJ/d.

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Basal Metabolic Rate

The basal metabolic rate (BMR) is the metabolic rate measured at a metabolically indifferent temperature at rest or without abnormal activity (Kleiber 1961). It can be estimated from Kleiber's formula:

$$\text{BMR} = 70.5\ W^{0.7325} \qquad (6)$$

W is weight in kg and BMR is basal metabolic rate in Kcal/d. This formula was derived from measurements of the metabolism of resting terrestrial mammals, but it also applies to marine mammals (Lavigne et al. 1986). Based on this formula, basal metabolic rate for a 12.5 m bowhead whale is 5.8×10^5 kJ/d.

About 36 to 39 % of the weight of a bowhead is blubber. By comparison blubber only accounts for 17 % of the body mass in minke whales, 24 to 26 % in Antarctic fin whales, and 17 to 21 % in Icelandic fin whales (Lockyer and Waters 1986). The blubber may be largely inert from a metabolic perspective. It is used for insulation and energy storage and the outside layers are cold. BMR for a 12.5 m whale, excluding the weight of the blubber, would be 4.1×10^5 kJ/d.

Standard Metabolism

This rate includes basal rate plus the cost of maintaining buoyancy and warming the air and food (Brodie 1975, 1981). During this project, an attempt was made to use a forward-looking infrared sensor (FLIR) to detect bowheads. (This test was made possible by ARCO Alaska and Mark Major.) The flukes were not visible on FLIR imagery (W.R. Koski, LGL Ltd., pers. comm.), i.e., there was no observable heat loss through them. However, George (pers. comm.[9]) found that the rate of heat loss through the flukes was higher than elsewhere on the animal; in contrast, he found no measurable heat loss through the flippers.

Thus, heat loss through the layer of blubber on the core and flukes needs to be considered. The heat conductivity of minke whale blubber is 0.25 W/m/°C (Kvadsheim et al. 1996), a figure that is higher than previously believed (Folkow and Blix 1992; Ryg et al. 1993) and higher than that of seals (Kvadsheim et al. 1997). Body core temperature of a bowhead whale is about 33 to 34°C and temperature of the core of the flukes is about 15°C (J.C. George, pers. comm.[9]). Water temperature is -1.8°C in winter and 0 to about 5°C in summer. Heat loss (H) in Watts can be expressed as

$$H = \frac{k \cdot A \cdot \Delta t}{d} \qquad (7)$$

(Kvadsheim et al. 1996), where A is surface area (m^2), d is depth of blubber, Δt is temperature difference between body core and water (°C), and k is thermal conductivity of blubber (0.25 W/m/°C). The blubber around the body of a 12.5 m bowhead averages 0.266 m in thickness (eq'n 2). The blubber layer on the flukes is about 1.5 cm in thickness and the thermal conductivity of the flukes is about 0.2 W/m/°C (J.C. George, pers. comm.[9]). Total heat loss computed in this manner would be 2.15×10^5 kJ/d.

To this must be added energy that heats expired air and ingested food. Heat loss through respiration was computed as 0.00187 kJ/L/s from data in Folkow and Blix (1992). On average, a 12.5 m adult bowhead breathes 817 times a day (from Table 22.8) and a 12.5 m bowhead would have a tidal volume of 425 L. Total energy required to warm the air is about 0.4×10^5 kJ/d. Given the amount of

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food consumed, as computed below, an additional 0.3 kJ/d (approximately) would be required to warm food. Heat loss though the tongue while feeding may be negligible because bowhead whales possess a very effective heat exchange mechanism in the tongue, which conserves heat (J.C. George, pers. comm.[10]). This mechanism is similar to one found in gray whales (Heyning and Mead 1997).

Overall, standard metabolic rate computed from these heat-loss estimates is about 2.8 x 10^5 kJ/d for a 12.5 m bowhead whale.

Bowheads are very efficient at conserving heat. Total metabolic rate computed through heat loss calculations is very low—lower than theoretical BMR. When very active, bowheads would need a cooling mechanism. George (pers. comm.[10]) has shown that bowheads may use a vascular heat exchanger in the tongue and flippers to dump excess heat in these situations. The amount of heat lost in this manner cannot be calculated. The cost of locomotion can be estimated and needs to be added to heat loss to estimate total energetic requirements.

Energetic Cost of Swimming

Swimming Speeds.—Data on swimming speeds of bowheads are a useful indicator of the animal's level of activity. Traveling speeds of bowhead whales have been measured in several areas and are summarized in Table 22.10. Fall and spring migrants may travel at about 4.5 to 5 km/h. However, over long periods of time animals stop in various areas, engage in other activities and the average speed may be about 3.7 km/h (Mate et al. 2000). When using photographic re-sightings to estimate speed, the time interval between re-sightings is a critical factor in estimating speed (Fig. 11.4 *in* Chapter 11). Net swim-speeds become slower as time between sightings increases. Swim speeds estimated from sightings <1 h apart are similar to those derived by direct observation (Table 22.10; see also Chapter 11).

Finley et al. (1986) used a shore-based theodolite to measure swimming speeds of bowheads feeding in deep water near Baffin Island. Whales feeding at a specific location showed little horizontal movement from one surfacing to the next. It is not known how far or fast they traveled while under water. A whale feeding near the surface along a windrow visible at the surface traveled at 2.1 to 5.2 km/h over the 5 h that it was tracked. Rate of movement slowed and dive duration increased where the windrow was most prominent (Finley et al. 1986).

Mate et al. (2000) tracked the movements and swimming speeds of 8 subadult bowheads tagged (with satellite-linked tags) in the Canadian Beaufort Sea. Whale movements were not coordinated and whales swam at different speeds. Average speed of all whales was 3.7 km/h. These are net (minimum) speeds, assuming straight-line travel between detection locations. There was some indication that swimming speeds while in the Canadian Beaufort Sea were similar to those of migrating whales (Mate et al. 2000). A whale that was tracked while migrating from the Canadian Beaufort Sea to Siberia averaged 5 km/h.

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[10] Data provided by C. George from a work in progress are not to be cited without written permission of Craig George, Department of Wildlife Management, North Slope Borough, Barrow, AK. cgeorge@co.north-slope.ak.us

TABLE 22.10. Swimming speeds of undisturbed bowhead whales recorded in various locations and circumstances.

	Speed km/h					
Location & Activity	**Mean**	**±s.d.**	**Sample Size**		**Method**	**Reference**
Eastern Arctic						
Fall Migration	5.1	0.3	(s.e)	22	Theodolite	Richardson et al. (1995b)
Fall Migration	4.7	0.5	(s.e.)	10	Theodolite & aerial	Richardson et al. (1995b)
Western Arctic						
Spring Migration	4.7	0.6	9		Theodolite	Rugh and Cubbage (1980)
Spring Migration	4.1	1.1	18 (cow-calf pairs)		Theodolite	George and Carroll (1987)
Spring Migration	5.1	2.5	49 (< 1 h apart)		Photo resighting	Rugh (1987)
Spring Migration	2.6	2.3	14 (1 – 10 h apart)		Photo resighting	Rugh (1987)
Spring Migration	1.2	1.0	14 (> 10 h apart)		Photo resighting	Rugh (1987)
Fall Migration	5	2.0	5		Aerial	Ljungblad et al. (1984)
Fall Migration	4.3		1 Group of 10		Aerial	Ljungblad et al. (1984)
Fall Migration	8.5		1 Group of 10		Aerial	Ljungblad et al. (1984)
Fall - Traveling	4.5	1.2	72		Behavior	Chapter 11
Fall - Travel + Feed	3.3	1.6	19		Behavior	Chapter 11
Fall - Feeding	1.5	1.2	37		Behavior	Chapter 11
Fall Migration	2.8	1.8	294		Photo re-sighting	Chapter 11
Summer/Fall Migr.	3.7		8 (9820 km, 111.1 d)		Satellite tag	Mate et al. (2000)
Summer	5.1	2.9	18 (at surface)		Theodolite	Würsig et al. (1982)
Summer	4.3	0.8	4 (below surface)		Theodolite	Würsig et al. (1982)
Summer	2.3	1.26	1 (at surface)		Theodolite	Würsig et al. (1982)
Summer	8.9	5.6	1 (calf)		Theodolite	Würsig et al. (1982)

The above represent the speeds of actively moving animals. At some times, bowheads (including migrating animals) mill around and do not move very quickly, and may reverse direction and swim to various parts of the same area (Koski et al. 1988; Zeh et al. 1993; Mate et al. 2000; Chapter 11). Two of Mate et al.'s tagged animals that remained in the Canadian Beaufort Sea for 16 to 24 d averaged 1.1 and 2.8 k/h. However, mean speeds for five other whales in that area averaged 3.5 to 5.8 km/h

Power Output.—For Antarctic rorquals engaged in feeding and other activities at speeds of 5.5 km/h, Lockyer (1981) estimated that power output is about 0.0001 hp/lb (1.64×10^6 ergs/s/kg). This power output is equivalent to 14.2 kJ/d/kg of muscle. Only one-half the muscle is used at any one time (Lockyer 1981). The average 12.5 m, 31 MT sub-adult whale contains about 15.3 MT in the metabolically active core, including 2 MT for organs and 2 MT for bones (see "Size of Bowhead Whales" subsection). Thus, the musculature operative at any one time is about half of 11,300 kg, i.e., 5750 kg. During this level of activity about 0.8×10^5 kJ/d would be required just for motion .

Cost of Motion.—Although measured swimming speeds of both spring and fall migrants are about 4 to 5 km/h, blow rates are quite different (Table 22.7). Blow rates for traveling whales are about 0.6 blows/ min during spring migration and about 0.4 blows/min in fall. The cost of motion through the water can be computed through hydrodynamic considerations. The cost of transport is

$$P = 0.5 \cdot \rho \cdot Ct \cdot Sw \cdot V^3 \qquad (8)$$

where P = power requirement in dyne · cm/s, ρ = density of water in g/cm^3, Sw = surface area (cm^2), V = swimming speed (cm/s), and Ct = coefficient of drag (Sumich 1983).

Sumich (1983) computed a coefficient of drag of 0.06 for a 15 MT gray whale migrating at about 7 km/h. The estimate of power requirement (P) was based on breathing rates and lung capacity. He extrapolated lung volume of a young gray whale to the adult, assuming that tidal volume in liters equals 3.5 % of body weight in kg. However, in the gray whale, lung capacity as a percentage of body weight appears to decrease with increasing size. In the gray whale foetus, total lung weight is 2.5 % of total body weight (Blokhin 1984). Lung weight in a 31,460 kg (not including blood) female was 333 kg (Yablokov and Bogoslovskaya 1984). Adding 6 % to the body weight for blood loss (Lockyer 1981), the lung weight of this adult was 0.99 % of body weight. Most other species of whales also have a lung weight ~1 % of body weight, and a total lung capacity (in L) of 2.5 to 2.8 % of body weight in kg (Lockyer 1981). The volume of inspired air (tidal capacity) is about 80 % of total lung capacity. Based on the higher figure for total lung capacity (2.8 %) and a tidal volume of 80 %, tidal volume in L = 2.2 % of body weight in kg. Based on this 2.2 % figure and the cost of transport equation (8) given above, cost of transport for a gray whale would be 2.85 kJ/kg/km and the drag coefficient would be 0.04.

The above calculations of cost of transport and drag coefficient for a gray whale are based on an energy utilization figure that includes basal metabolism. The values cited in the preceding paragraph were used in the equation to derive a cost of transport that excluded basal metabolism (P minus basal metabolism). Excluding basal metabolism, the coefficient of drag for a gray whale is 0.02 and cost of transport is 1.51 kJ/kg/km. This drag coefficient will be used to approximate the drag coefficient of a bowhead. It takes into account only the power, over and above basal metabolism, required to move the animal through the water.

For an average 12.5 m bowhead whale moving at 5 km/h (139 cm/s) and with total surface area of 58 m^2 (from Table 22.1), cost of transport, excluding basal metabolism, would be 0.63×10^{10} dyne · cm/s, or about 0.55×10^5 kJ/d.

Feeding Rates in Nature

Bowhead whales feed on zooplankton. In this section, an estimate is made of potential feeding rates in nature using the size of the mouth opening, swimming speed while feeding, time spent feeding, and quantity of zooplankton found near feeding whales.

Feeding Mechanism and Mouth Opening

Bowheads filter zooplankton by swimming with their mouths open (Scoresby 1820; Pivorunas 1979). Similarly, North Atlantic right whales have been observed and photographed feeding near the surface with their mouths open widely (Watkins and Schevill 1976, 1982). Although bowheads and right whales feed in a similar manner, bowheads of a given length have longer baleen than do right whales (Pivorunas 1979). In order to estimate potential feeding rates of bowheads, it is necessary to know the size of the mouth opening. The mouth area of a bowhead can be calculated from the length of the baleen, width of the head, and mouth gape.

The maximum length of baleen and whale length are available for 23 whales taken by the *Cumbrian* in 1823 (Lubbock 1937), 13 whales measured be Sheffield (this study), and two measured by Scammon (1874). These maximum baleen lengths were plotted against whale length and curves were fitted by regression. The following equation best described this relationship:

$$(9)\qquad \text{Max. Baleen Length (m)} = -2.107 + 0.537\ \text{Length (m)} - 0.012\ \text{Length}^2;\ r = 0.97,\ P < 0.001$$

The mouth is narrow at the anterior end and becomes progressively wider toward the back. When open, the anterior baleen plates are not in contact with the lips (Fig. 22.6). The lengths of the first 60 plates increase rapidly toward the rear, lengths of lamellae increase more slowly from lamellae 60 to 120, and maximum lengths are found at lamellae 120 to 250 (Haldiman and Tarpley 1993). Thus, long baleen begins one third of the distance from the forward end of the baleen rack. The baleen is attached to the narrow upper jaw in such a way that, at the top of the mouth, there is very little space between the right and left racks. The area of the mouth opening can be approximated as triangular. Its width at ~1/3rd the distance between the tip of the rostrum and the rear corner of the mouth would be the width measured on vertical photographs minus the thickness of the lips. We have assumed that the lips are the thickness of the blubber. The width of the mouth, along with total whale length, was measured from vertical photographs of 22 whales that were not calves. The inner width of the mouth and maximum baleen length (from eq'n 9) were used to compute the area of the mouth opening. The relationship between whale length and mouth opening at the 1/3rd-distance location was best described by a linear function (Fig. 22.7):

(10) $$\text{Mouth Opening (m}^2\text{)} = -2.15 + 0.312 \times \text{Length (m)}, \quad r = 0.93, \quad P < 0.001$$

The morphology of the mouth, baleen, tongue, and lower lips of the bowhead whale are well adapted to feeding on small copepods, larger fast-moving euphausiids, and continuous feeding as opposed to the gulping method used by some other baleen whales (Lambertsen et al. 1989; Haldiman and Tarpley 1993). A rack of baleen contains about 324 lamellae. The topology of the inner surface of the rack is complex. The shape of the forward part of the rack suggests that it is specialized for seawater channeling and flow acceleration, and the shape of its rear section increases the filtering area for concentrated prey (Lambertsen et al. 1989). The shape of the rear portion of the rack and the tongue may create turbulence that may prevent prey buildup on the baleen and increase efficiency (Lambertsen et al. 1989).

The outer surface of the baleen rack is convex. The lower jaw is articulated and, when feeding, rotates outward forming a channel between the outer surface of the baleen and the lower lip (Lambertsen et al. 1989). Thus, all of the rack can be used as a filtering surface while being held in place by the massive lower lip. Lambertsen et al. (1989) believe that feeding is accomplished by hydrodynamic as well as hydrostatic pressures. The baleen racks from a 7.5 m whale have a combined surface area of 3.5 m^2 (Lambertsen et al. 1989). Water entering the mouth would be reduced in velocity quickly, thereby reducing the pressure wave in front of the mouth and allowing the bowhead to capture fast moving prey such as euphausiids (Lambertsen et al. 1989). Photographed whales that have their mouths completely shut appear to have narrower heads than those with their mouths slightly open. The lower lips seem to bulge out when the mouth is open and jets of water are often seen emanating from the rear corners of the mouth.

Aerial photographs (Fig. 22.6) and observations of whales by ourselves and others (e.g., Scoresby 1820; Würsig et al. 1985) show that, at least when surface feeding, the mouth opening may be quite large. Because the lower lip holds the baleen in place when the mouth is open, bowheads could feed with their mouths open very wide. Therefore, we estimated the relationship between whale length and maximum mouth opening. This was best described by a linear function (Fig. 22.7):

(11) $$\text{Maximum mouth opening (m}^2\text{)} = -2.03 + 0.342 \text{ Length (m)}; \quad r = 0.94, \quad P < 0.001$$

FIGURE 22.6. Photograph of a bowhead whale on its side with mouth open.

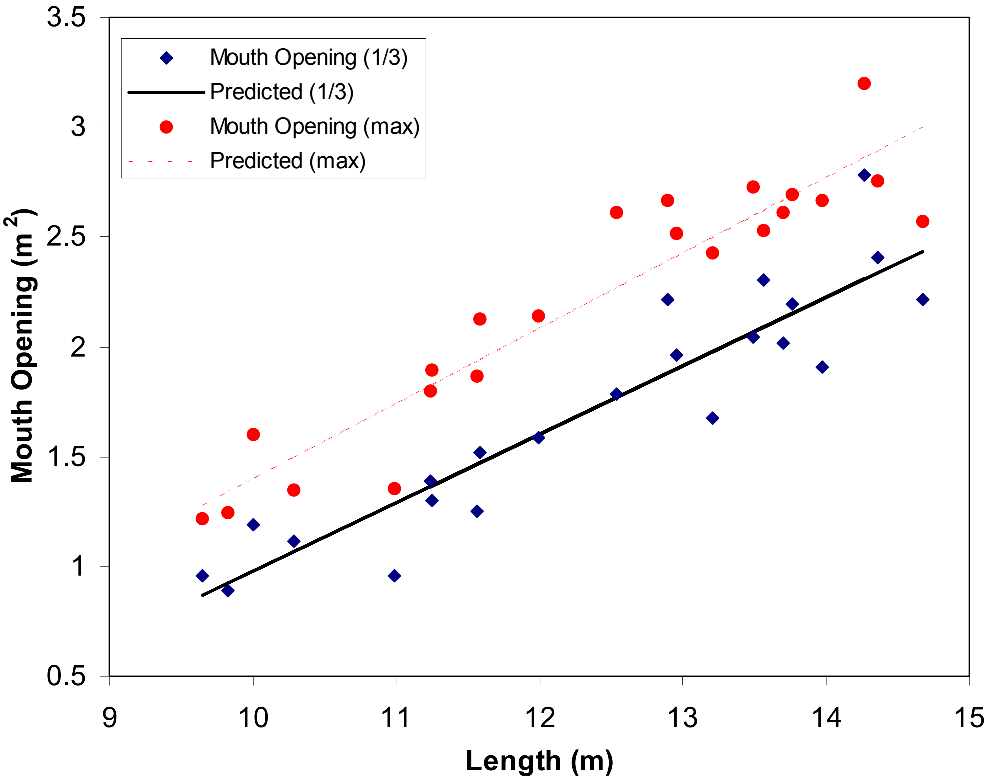

FIGURE 22.7. Relationship between whale length and area of the mouth opening estimated from baleen length and width of the head 1/3rd the distance from the rostrum to the rear of the mouth, and at the maximum width, as measured from aerial photographs. The lines are the fitted least-squares regressions of mouth opening vs. whale length.

The difference in mouth opening as computed with equations (10) and (11) is 0.4 m^2 for a whale 10 m long, i.e., 1 m^2 vs. 1.4 m^2, and 0.5 m^2 for a whale 13.5 m long. The maximum mouth opening was used in subsequent calculations of potential filtering capacity.

Habits and Nutritive Value of Potential Food Species and Their Relationship to Bowhead Energetics

Bowhead whales eat predominantly copepods and euphausiids (Lowry and Sheffield, Chapter 18). Stomach contents and the species composition of zooplankton found near feeding whales (Chapter 6) indicate that copepods are the primary prey species in the Canadian and eastern Alaskan Beaufort Sea. Euphausiids are the primary prey near Barrow in fall and (recently) in spring as well (Chapter 18).

The caloric content of various zooplankton taxa collected in the Alaskan and Canadian Beaufort Sea, and lipid content of zooplankton from the Canadian Beaufort, were measured in samples taken and frozen during field work described in Chapter 5. Each species or life stage subsample was blended and dried to constant weight at 70°C for about 18 h. Caloric content was estimated with a Parr high-pressure oxygen bomb calorimeter. Lipids were extracted following methods of Bligh and Dyer (1959). An aliquot of extract was then dried to constant mass at 40 to 50°C, and used to estimate the percentage of the dry weight that was lipid. Copepods and euphausiids contain much energy per gram of tissue (Table 22.11).

We hypothesize that bowhead whales obtain much of their energy intake, at least in summer and fall, by extracting the lipid from their prey without digesting most of the remaining prey tissue. The stomach of a 9–m subadult bowhead whale can hold about 100 L of food (Haldiman and Tarpley 1993). A whale this size weighs about 13.5 MT and its maximum mouth opening is about 1 m^2. During periods of substantial feeding, a bowhead whale needs to process several hundred kg of food per day (see below). This is several times the stomach volume. The lipid and caloric content of bowhead food is very high (Tables 22.11, 22.12), and extraction of the lipid from the prey would provide a rich source of energy for bowheads. Copepods are readily identifiable in bowhead feces. During two years of studies of bowheads in Baffin Bay, Finley (1990) and Finley et al. (1994) report that northern fulmars (seabirds) fed on bowhead feces, and in those years the feces had an oily quality. During other years, fulmars did not feed on the feces and the oily quality was not present.

TABLE 22.11. Energy content of zooplankton (J/g dry weight) collected on the continental shelf in the Canadian and eastern Alaskan Beaufort Sea in 1985 and 1986, expressed as mean ± s.d (sample size).

	Canadian Beaufort Sea		**Alaskan Beaufort Sea**		
Species	**23 - 30 Aug 1985**	**27 Aug - 8 Sept 86**	**September 1985**	**September 1986**	**October 1986**
Copepods (all)	28,615 ± - (14)	20,996 ± 2943 (64)	29,662 ± 2337 (27)	26,323 ± 2588 (47)	19,722 ± 1468 (13)
<1.8 mm	28,591 ± 681 (11)	19,696 ± 3804 (10)	27,732 ± 2018 (10)	-	-
>1.8 mm	28,704 ± 447 (3)	21,234 ± 2730 (54)	30,797 ± 1699 (17)	-	-
Euphausiids	21,502 ± 293 (3)	21,811 ± 3779 (8)	21,611 ± 732 (3)	21,289 ± 1437 (25)	21,321 ± 1437 (25)
Mysids	22,442 ± 318 (4)	18,894 ± 3001 (16)	21,425 ± 2556 (3)	-	-
Amphipods	25,197 ± 414 (3)	20,599 ± 1463 (10)	26,907 ± 3682 (9)	28,382 ± 3118 (10)	-
Decapods	-	17,205 ± 1676 (9)	17,613 ± 1669 (3)	-	-
Fish larvae	-	19,320 ± 1701 (20)	20,224 ± 1828 (5)	21,705 ± 235 (3)	16,637 ± 374 (5)
Pteropods	-	18,726 ± 6634 (9)	18,948 ± 95 (2)	-	-
Chaetognaths	-	18,421 ± 3085 (8)	-	17,576 ± 531 (4)	17,576 ± 531 (4)
Hydrozoans	24,177 ± 523 (3)	8084 ± 1572 (14)	-	20,344 ± 3101 (8)	3352 ± 911 (7)
Ctenophores	-	8536 ± 2688 (8)	-	8,571 ± 2875 (7)	8571 ± 2875 (7)

TABLE 22.12. Energy content, lipid content, and energetic value of lipids in zooplankton collected in the Canadian Beaufort Sea in late August 1985 and late August/early September 1986. Wet weight to dry weight conversion was based on data shown in Table 22.13.

	J/g Dry Weight			Lipids/g Dry Wt.				% Energy
Species	Mean	± s.d.	*n*	Mean %	± s.d.	mg/g	J/g	in Lipids
1985								
Copepods (all)	28,615		14	37.3	8.9	373	14,723	51.5 %
1986								
Copepods (all)	20,996	2943	64	30.9	16.4	309	12,206	58.1 %
< 1.8 mm	19,696	3804	10	40.8	22.1	408	16,116	81.8 %
1.8 - 4 mm	21,076	2579	31	27.4	13.5	274	10,823	51.4 %
> 4 mm	21,452	2968	23	33.0	18.0	330	13,035	60.8 %
Euphausiids	21,811	3779	8	25.0	11.3	250	9875	45.3 %
Mysids	18,894	3001	16	12.9	8.7	129	5096	27.0 %
Amphipods	20,599	1463	10	25.4	9.8	254	10,033	48.7 %
Decapods	17,205	1676	9	19.3	15.2	193	7624	44.3 %
Fish larvae	19,320	1701	20	18.3	16.5	183	7229	37.4 %
Pteropods	18,726	6634	9	9.4	7.2	94	3713	19.8 %
Chaetognaths	18,421	3085	8	18.5	11.4	185	7308	39.7 %
Hydrozoans	8,084	1572	14	6.9	5.5	69	2726	33.7 %
Ctenophores	8,536	2688	8	19.9	20.9	199	7861	92.1 %

TABLE 22.13. Dry weight as a percentage of wet weight for various species of zooplankton collected during late August and early September 1986 in the eastern Alaskan Beaufort Sea.

	Mean	s.d.	*n*
Copepods	18.3	1.1	5
Euphausiids	19.8	1.6	5
Mysids	20.1	1.2	5
Hyperiids	16.6	2.5	5
Chaetognaths	6.6	0.6	5
Hydrozoans	11.4	2.2	5
Ctenophores	9.8	1.8	5
Decapod larvae	13.4	1.3	5
Fish larvae	16.8	1.4	5

These observations, the small size of the bowhead stomach, the large quantity of food that a bowhead needs to process, and the high lipid content in bowhead food are all consistent with a hypothesis that, when food is abundant, bowheads process food quickly and extract only the easily extractable lipids. The chitinous exoskeletons are indigestible by most animals. Even if chitin could be digested, it would be inefficient to digest it when richer food is abundant in summer and fall. Digesting the muscle tissue within the exoskeleton would also be inefficient when food is abundant. In extracting only the lipids, bowheads could assimilate 50 to 80 % of the energetic value of their summer prey efficiently and quickly. The extraction of the lipid may occur in the bowhead fore-stomach. The fore-stomach has no digestive glands and does have muscles. Haldiman and Tarpley (1993) speculate that it may be a churning vat for mixing ingesta with refluxed digestive enzymes. It could be used for extracting lipid from zooplankton. This would require little effort. For example, a layer of fat quickly develops on the surface of the water–preservative mixture when copepods are placed in a jar with preservative. When bowheads are feeding in areas with limited food availability, they might digest additional components of the prey.

Assimilation Efficiency

Approximately 75 % of the prey eaten by carnivores is assimilated (Lockyer 1981); for a grazer (cow) about 53 % of the food is assimilated (Kleiber 1961). Lockyer (1981) derived an assimilation efficiency of 87 % for pregnant or lactating female rorquals. This value is higher than the 77 to 79 % estimated for males, subadults, and nonreproductive females (Lockyer 1981). These figures are clearly an oversimplification; they leads to a lower predicted energy requirement for a pregnant than for a nonreproductive female—an unrealistic result. Rorquals engulf large quantities of prey whereas bowheads, which commonly feed on more thinly-distributed prey, typically eat a smaller amount of prey at one time. In our subsequent calculations, we assume that bowheads extract only the lipids from their prey and do so with 90 % efficiency. In summer, copepods contain 24,800 J/g dry weight and euphausiids 21,650 J/g dry weight (average of August 1985 and Aug./Sept. 1986 data in Table 22.11). The energy in lipids represents about 20 to 82 % of the total energy in zooplankton, depending on the major group of zooplankton (Table 22.12). We assume here that, in summer and early fall, bowheads eat mainly copepods (75 %) and euphausiids (20 %), with 5 % of other prey types. In summer, the energetic value of the lipids in this mixture (excluding other components) would be about 12,396 J/g dry weight based on the data in Table 22.12, or about 2283 J/g wet weight (wet/dry ratios from Table 22.13). The lipids represent about 502 % of total energetic content of this prey mixture. Lipid content of arctic copepods is highest in summer and decreases over winter when they metabolize their stored lipid (Lee 1974):

Month	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Lipid (µg/individual)	800	800	700	600	400	900	1700	2100	1300	1200	900
Lipid (% dry wt.)	42	44	38	37	29	52	74	66	64	62	51

Spring values would be about 36 % of those in summer. Bowheads apparently feed less intensively in spring than in summer or early autumn (Table 22.4; Chapter 18). Measured fall values would be about 95 % of summer values or about 2165 J/g assuming a diet of 50 % euphausiids, 45 % copepods, and 5 % other. Winter energetic values of potential prey would be about 50 % of summer values or about 1450 J/g, assuming 75 % copepods, 20 % euphausiids, and 5 % other. However, as noted earlier, we assume that there is little feeding in winter.

Right whales, and presumably bowheads, are very efficient at filtering zooplankton. The filtering efficiency of North Atlantic right whales depends on prey size, but they retain 95 % of the available energetic value of their prey (Mayo et al. 2001). Right whales prey mainly on *Calanus finmarchicus*, which are >2 mm in length (Woodley and Gaskin 1996). Arctic zooplankters are generally larger than are temperate species. An exception is *Limnocalanus macrurus*, which has commonly been found in abundance near feeding bowheads (Chapter 6); it is <2 mm in length (Bradstreet et al. 1986). However, this species has many spines, which cause the animals to clump together when collected by a plankton net, and presumably by baleen. They could be easily filtered from the water by bowheads.

Time Spent Feeding

The number of days that BCB bowheads may spend feeding, by season, are estimated in Table 22.14 based on their seasonal distribution and activities, the proportion of time spent feeding (Table 22.4), and other factors. Bowheads do not feed constantly during the time they are classified as “feeding”. Whales feeding at depth need to surface to breath. Whales feeding at depths >50 m spend about a quarter of their time at the surface (Table 22.5). Whales “skim-feeding” at or near the surface spend more time at the surface than at depth (Table 22.5). We assume that, overall, the proportion of time spent feeding should be reduced by 30 % to account for time spent at the surface breathing, cleaning the baleen, and engaged in other non-feeding behaviors. (It is uncertain whether bowheads require a specific allocation of time to clean the baleen.) Based on the available data, total time spent actively feeding may be the equivalent of about 93 d/yr (Table 22.14).

TABLE 22.14. Number of days bowheads may spend feeding per year (calculated from Table 22.4 as described in text). Feeding days have been decreased by 30 % to account for time at the surface, cleaning food off the baleen, and engaged in other activities interspersed with feeding.

	Spring: April–May	**Summer: June–15 Sep**	**Fall-1: North Slope[a]**	**Fall-2: Chukchi/ Bering**	**Winter: Dec – March**	**Total Annual**
Calendar days	61	107	24	52	121	365
Prop’n of time feeding	0.08	0.73	0.47	0.73	0.00	
Effective days feeding	5	78	11	38	0	119
Days feeding – 30 %	3	55	8	27	0	93

[a] Includes time spent traveling across Chukchi Sea.

Feeding Rate

The feeding rate is a function of the mouth opening, swimming speed while feeding, quantity of food available, and assimilation efficiency. The mouth opening can be computed from equation (11). Griffiths et al. (Chapter 6) estimated that the average biomass of zooplankton near bowhead whales feeding in the Canadian and eastern Alaskan Beaufort Sea was 1800 mg/m^3 (wet weight). This is the average found by echosounder-guided horizontal tows at the depth of maximum biomass. As shown above, a wet-weight of 1800 mg/m^3 may contain about 2069 J/g in the lipids alone, which we assume to be assimilated with an efficiency of 90 %. The overall assimilation efficiency for zooplankton would be quite low at about 50 %. The estimated number of feeding days per year is shown in Table 22.14. Average swimming speed while presumably feeding under water between surfacings has been estimated at about 1.54 km/h (Koski et al., Chapter 11). However, this may be an underestimate because it does not account for changes in swimming direction while underwater. A swimming speed of 2.5 km/h while feeding may be more realistic. Right whales may feed at a speed of 5.5 km/h (Kenney et al. 1986). However, right whale baleen is shorter than that of bowhead whales, and right whales tend to be smaller.

A 12.5 m bowhead whale with maximum mouth opening 2.25 m^2, from eq’n (11), traveling at 2.5 km/h while feeding, could consume 244 kg wet-weight during 24 h of continuous feeding at locations and depths with average zooplankton biomass 1800 mg/m^3 wet weight. This estimate of plankton available to bowhead whales at feeding locations in the eastern and central Beaufort Sea (1800 mg/m^3) may only apply to subadult animals because sampling of prey availability was conducted only near subadults (Chapter 6). Average annual daily food consumption was estimated as follows. The estimate of 244 kg/d of food consumed during a day of continuous food consumption was converted to an energetic equivalent using a seasonally-adjusted energetic content of zooplankton. This was then multiplied by the effective number of feeding days per year less 30 %, from Table 22.14. The total annual energetic consumption was then divided by 365 d. A 12.5 m bowhead could consume 1.4 x 10^5 kJ/d averaged over the year on this basis.

Zooplankton biomass available to bowheads during autumn feeding near Barrow, Alaska, or in the southwest Chukchi and Bering Strait, is expected to exceed that in the Canadian Beaufort Sea in summer or the eastern Alaskan Beaufort in later summer/early autumn. The productivity of the Bering/Chukchi water found in the southwest Chukchi Sea (and, to some extent, near Barrow) is considerably higher than that of the eastern Beaufort Sea (see Chapters 20 and 23). Conversely, the limited feeding in spring may be primarily at locations where food availability is less than 1800 mg/m^3.

Comparison of Estimates for Bowheads and Other Whales

Several different methods have been used to compute the energetic requirements of an average 12.5-m bowhead whale weighing an estimated 31 MT (Table 22.15).

TABLE 22.15. Average daily energetic requirements of a 12.5-m bowhead whale weighing 31 MT, estimated based on several different methods. Energy requirement for growth is shown as a separate item.

Method of Estimation	**kJ/d x 10^5**
Standard metabolism	2.8
Standard metabolism + swimming	3.4
Basal metabolic rate	5.8
Basal metabolic rate of core only	4.1
Power output + BMR	6.6
Cost of swimming +BMR	6.4
Core BMR + Cost of swimming	4.7
Respiration	6.4
Feeding in nature (2.5 km/h, 1.8 g plankton/m^3	1.4
Feeding in nature (5 km/h, 4 g zooplankton/m^3	6.0
Growth/Food Storage for Winter	1.4

The energetic requirements of traveling as computed from power output and hydrodynamic considerations are close to one another and higher than standard metabolism plus the cost of motion. Basal metabolism is higher than standard metabolism. However, basal metabolism for the weight minus the blubber is about the same as standard metabolism.

Using empirical evidence, Lavigne et al. (1986) found that basal energetic requirements of marine mammals are well described by Kleiber's equation, which was derived for terrestrial mammals. The active metabolic rates for gray whales (food removal method), blue whales, and fin whales have been estimated to be two to three times the basal metabolic rate (Lockyer 1981; Thomson and Martin 1984). However, Hinga (1979) found evidence that large whales have average annual metabolic rates that are only about 1.5 times the basal rate. Folkow and Blix (1992) estimated that the active metabolic rate of minke whales was about 1.2 times BMR. Results from Brodie and Paasche (1985) are also consistent with the idea that active metabolic rates of large whales are low. Brodie and Paasche found that the body core temperatures of large whales were lower than those of other mammals, and there was a gradient of decreasing temperature from the core to the muscle/blubber interface. They also found that body temperature did not rise after exertion (pursuit), and they speculate that whales are hydrodynamically and biomechanically very efficient. Thus, available data for large whales indicate that active metabolism is about 1.5 times basal metabolism.

One question that remains unanswered is "how is BMR to be calculated for a bowhead whale"? Blubber is presumed to be essentially inert. It does not require as much energy for maintenance as do other tissues. The bowhead has the largest blubber content of any whale on a percentage of body mass basis (George et al. 1999). The bowhead is very well adapted for conserving heat. It grows very slowly, requires many years to reach sexual maturity, and reproduces only once every 3 or 4 years (Miller et al. 1992; George et al. 1999). Its heart and lungs are relatively small compared to other animals. Heart size is related to body mass (Innes et al. 1986). However, for a specific animal size, animals with higher metabolic rates will have larger hearts than those with low metabolic rates (Ridgway and Kohn 1995). Thus, metabolic rates of bowhead whales may be quite low for their size. The evidence tends to support a low estimate based on BMR calculated from the core weight not including blubber, plus a small but unknown amount for maintenance of blubber. BMR calculated in this manner for a 12.5 m whale is 4.1×10^5 kJ/d, similar to standard metabolism plus cost of locomotion (3.41×10^5 kJ/d).

This estimate is much higher than suggested by feeding rates in nature, 1.4×10^5 kJ/d estimated using average zooplankton concentrations near feeding whales in summer and early autumn (1800 mg/m^3, wet weight) and an average swimming speed while feeding of 2.5 km/h. Subadults and adult males would need to feed on average concentrations of 4000 mg/m^3 at an average speed of 5 km/h to meet energetic requirements as calculated by the feeding rate method. Right whales feed at speeds 4.8 km/h (Mayo et al. 2001). A speed of 5 km/h for feeding bowheads is perhaps possible, though it is at the high end of observed speeds while feeding (Table 22.10). Zooplankton concentrations of 4 g/m^3 are at the upper end of the values found near feeding whales in the Canadian and eastern Alaskan Beaufort Sea (Chapter 6). Sampling was conducted near feeding bowheads or in areas where bowheads were feeding, using echosounder guidance to the depth of maximum zooplankton biomass. However, sampling was not necessarily in the exact three-dimensional location where bowheads were feeding. Bowheads are probably adept at finding highly concentrated food patches within areas with a higher than average biomass of zooplankton. Average prey biomass at precise sites of summer/early fall feeding probably exceeds 1800 mg/m^3 by some unknown amount.

Bowheads may feed, on occasion, in extremely dense patches of zooplankton that could meet a substantial percentage of annual requirements within a short time. North Atlantic right whales occasionally do so (Beardsley et al. 1996). Given the limited number of locations and times when we sampled near feeding bowheads (Chapter 6), we very likely did not encounter a location with maximum biomass. Also, our sampling probably underestimated the biomass present at certain times and places, especially when fast-moving prey such as euphausiids were dominant. Perhaps most importantly, all of our zooplankton sampling near bowheads was in summer and early-autumn in the Canadian and eastern Alaskan Beaufort Sea. There are no specific data on prey availability at locations where bowheads often feed just east of Barrow, or in the southwest Chukchi Sea. Those locations are likely to have higher zooplankton abundance than the eastern Beaufort Sea given the high productivity of the Bering/Chukchi water present in those areas. Bowheads feeding in those more westerly areas during autumn may have access to zooplankton with average wet-weight biomass well above the 1800 mg/m^3 found in the eastern and central Beaufort Sea.

Food Requirements of Different Segments of the Population

The energetic requirements of subadults, adult males, and adult females calculated by different methods are shown in Table 22.16. Bowheads grow very slowly, and little energy is required for growth and food storage (Table 22.16). Bowheads feed in summer and fall, and to a lesser degree in spring (Chapters 12, 18, 20). Winter feeding has not been documented, and the loss of girth over the winter

TABLE 22.16. Theoretical energetic requirements of various categories of bowhead whales estimated from respiration, heat loss, cost of motion, and basal metabolic rate. Estimates of the cost of growth, reproduction, and weight loss over winter are included.

	Units	Sub-adult Male	Sub-adult Female	Adult Male at Puberty	Adult Female at Puberty	Older Adult Male	Older Adult Female
Mean Length	m	11	11	12.5	13.5	13.5	14.75
Age	yr	14	10	25	27	35	41
Weight	MT	22.6	22.6	31.5	38.4	38.4	48.3
Weight of Blubber	MT	8.6	8.6	11.7	14.0	14.0	17.3
Blubber thickness	m	0.24	0.24	0.265	0.28	0.28	0.30
Surface Area of flukes	m^2	2.49	2.49	3.19	3.70	3.70	4.40
Total surface area	m^2	46.1	46.1	58.4	67.3	67.3	79.3
Metabolically active core	MT	11.1	11.1	15.4	18.7	18.7	23.4
Respiration							
Lung Volume (2.25 % kg body wt)	l	509	509	708	864	864	1085
Tidal Volume (60 % of lung volume)	l	306	306	425	518	518	651
Oxygen used (9.15 % of tidal volume)	l/blow	28	28	39	47	47	60
Energy (kJ/d x 10^5)	kJ x 10^5/d	5.3	5.3	6.4	8.0	7.8	10.1
Basal Metabolism (BMR; Kleiber 1961)	kJ x 10^5/d	4.6	4.6	5.8	6.7	6.7	7.9
Basal Metabolism (Body Core only)	kJ x 10^5/d	3.2	3.2	4.1	4.8	4.8	5.7
Standard Metabolism (heat loss)							
Through body surface (Folkow and Blix 1992)	kJ x 10^5/d	1.4	1.4	1.6	1.7	1.7	1.9
Through flukes (Folkow and Blix 1992)		0.4	0.4	0.6	0.6	0.6	0.8
Total Heat Loss		1.8	1.8	2.1	2.4	2.4	2.7
Warming air (Folkow and Blix 1992)	kJ x 10^5/d	0.3	0.3	0.4	0.5	0.5	0.6
Heat loss warming food	kJ x 10^5/d	0.3	0.3	0.3	0.5	0.3	0.5
Total	kJ x 10^5/d	2.4	2.4	2.8	3.3	3.2	3.8
Power Output							
Power Output (no BMR; Lockyer 1981)	kJ x 10^5/d	0.6	0.6	0.8	1.0	1.0	1.2
Cost of swimming (no BMR; Sumich 1983)	kJ x 10^5/d	0.4	0.4	0.5	0.6	0.6	0.7
Standard Metabolism + Swimming	kJ x 10^5/d	2.8	2.8	3.4	4.0	3.8	4.6
Growth and Reproduction							
Growth (40 % lipid 60 % Muscle)	MT	0.86	1.02	0.74	0.83	0.61	0.62
Weight Loss over Winter	MT	2.55	2.55	3.02	3.32	3.32	3.66
Lipid loss over winter	MT	0.29	0.29				
Total	MT	3.69	3.86	3.76	4.15	3.93	4.27
Total	kJ x 10^5/d	1.45	1.51	1.41	1.55	1.47	1.60
Foetal growth and metabolism (/4 years)	kJ x 10^5/d				0.24		0.24
Neonate growth and /4 years)	kJ x 10^5/d				1.55		1.55
Total Growth + Reproduction	kJ x 10^5/d	1.45	1.51	1.41	3.35	1.47	3.39
Basal Metabolism	kJ x 10^5/d	4.56	4.56	5.81	6.72	6.72	7.94
Core BMR+ Motion + Growth + Reproduction	kJ x 10^5/d	5.10	5.17	6.10	8.80	6.92	9.87
Respiration + Growth + Reproduction	kJ x 10^5/d	6.70	6.77	7.79	11.39	9.25	13.50
Std. Metabolism + Motion+Growth +Reprod.	kJ x 10^5/d	4.28	4.34	4.80	7.32	5.30	7.95

suggests that there must be little feeding in winter. However, the relative amounts of feeding in different seasons and regions are controversial. Isotopic evidence in Chapter 20 suggests that feeding is predominantly in Bering/Chukchi waters, presumably mainly in fall, but with a minority of the feeding in the eastern and central Beaufort Sea. Other evidence shows that feeding occurs very frequently in summer and early fall in the Beaufort Sea, but does not specifically show how much food is acquired there as compared with other areas and seasons. As shown above, bowheads lose weight over winter.

Females of reproductive age require the most energy. However, the full reproductive cycle requires three or four years and, as a result, annual requirements for reproduction are not as large as those of some other species of baleen whales that give birth at shorter intervals. The total cost of reproduction is about 1.8 × 10^5 kJ/d averaged over a 4-year reproductive cycle. The estimates of theoretical energetic requirements range from 4.6 to 9.25 × 10^5 kJ/d for non-reproductive individuals, and from 6.7 to 13.5 × 10^5 kJ/d for females of reproductive age. Differences among the various theoretical estimates of food requirements are not large, given all the uncertainties associated with the derivation of these estimates, and they can essentially be considered equal.

Bowheads cannot satisfy even the low theoretical estimate of energy and food requirements by feeding on average concentrations of zooplankton found near whales feeding in the eastern and central Beaufort Sea (Table 22.17). The estimated average of 1.8 g/m^3 of zooplankton (wet weight) found near feeding subadults is not enough to meet energetic requirements, given our assumptions about amount of feeding during each season. Bowheads apparently need to feed in average concentrations of about 4 g/m^3 at a speed of 5 km/h to meet energetic requirements (Table 22.17). Such swimming speeds and zooplankton concentrations have occasionally been observed, but these values are near the upper limits of the observed speeds and zooplankton concentrations, and are well above the averages observed in the eastern and central Beaufort Sea.

TABLE 22.17. Estimates of energy consumed by various categories of bowhead whales through consideration of the size of the mouth opening, time spent feeding, and energetic value of food compared to the theoretical estimates derived in Table 22.16.[a,b,c]

	Units	Sub-adult Male	Sub-adult Female	Adult Male at Puberty	Adult Female at Puberty	Older Adult Male	Older Adult Female
Mean Length	m	11	11	12.5	13.5	13.5	14.75
Mean Weight	MT	23	23	31	38	38	48
Total Theoretical Requirements							
Respiration + Growth							
Average Requirements/d	kJ x 10^5/d	6.7	6.8	7.8	11.4	9.3	13.5
Annual requirements/yr	kJ x 10^5/yr	2447	2470	2843	4157	3377	4927
Annual food requirements	kg/yr	111,435	112,483	129,467	189,313	153,782	224,349
Average food per feeding day[a]	kJ x 10^5/d	26.40	26.65	30.67	44.85	36.43	53.15
Average food per feeding day[a]	kg/d	1202	1213	1397	2042	1659	2420
Standard Metabolism, Swimming, Growth							
Average Daily Requirements	kJ x 10^5/d	4.28	4.34	4.80	7.32	5.30	7.95
Annual requirements	KJx10^5/yr	1561	1586	1751	2673	1934	2903
Annual food requirements	kg /yr	71,080	72,200	79,722	121,721	88,046	132,181
Average food per feeding day[a]	kJ x 10^5/d	16.84	17.10	18.89	28.83	20.86	31.31
Average food per feeding day[a]	kg/d	767	779	860	1313	950	1421
Food Consumption Method							
Mouth opening	m^2	1.7	1.7	2.3	2.6	2.6	3.0
Feeding distance (at 5 km/h)	m/d	120,000	120,000	120,000	120,000	120,000	120,000
Volume filtered/feeding day	m^3/d	209,136	209,136	270,827	311,955	311,955	363,365
Consumption per Feeding Day[b]	kg/d	837	837	1083	1248	1248	1453
Annual Food consumption[c]							
Summer consumption (55 d)	kJ x 10^5	1046	1046	1355	1560	1560	1818
Fall consumption (35 d)	kJ x 10^5	624	624	808	931	931	1084
Spring consumption (3 d)	kJ x 10^5	33	33	43	49	49	57
Total Annual Food Consumption	kJ x 10^5/yr	1703	1703	2205	2540	2540	2959
Average Annual consumption/d	kJ x 10^5/d	4.7	4.7	6.0	7.0	7.0	8.1

[a] Assumes ninety-three 24-hour feeding days/year and seasonally weighted annual energetic content for zooplankton.

[b] Assumes zooplankton concentrations of 4 g/m^3 and swimming speed 5 km/h while feeding.

[c] Adjusted for seasonal changes in energetic content of zooplankton.

This chapter has derived point estimates for many parameters. It has not attempted to assess the uncertainty in estimates that are based on various other estimates, each of which is itself somewhat uncertain. Chapter 23 includes sensitivity analyses of some of the key calculations and estimates. The overall purpose of the sensitivity analysis was to place confidence intervals around the estimated percent of annual food requirements that bowheads consume in the eastern Alaskan Beaufort Sea.

Summary and Conclusions

An estimate of the importance of the eastern Alaskan Beaufort Sea to feeding bowheads requires that their daily and annual food requirements be estimated and then used to determine what proportion of their annual requirements could be obtained in the study area. The "energetics" chapter first describes the size, growth and reproduction of bowhead whales and the related physical attributes needed for the estimation of energetic requirements. This is followed by several approaches to the estimation of the metabolic rate of bowheads. These are compared to estimates of the amount of food consumed by bowhead whales as determined through observations of behavior, swimming speed, and amount of food found near feeding whales. The only specific data on the amount of food near feeding whales come from the Canadian and eastern Alaskan Beaufort Sea. There are numerous other data gaps where it has been necessary to make assumptions. Identification of these data gaps is useful in showing topics on which additional research would be desirable.

The sizes of bowhead whales and their blubber content can be estimated using known-scale vertical aerial photographs. The results are in agreement with blubber content as estimated from old whaling records and weights of a few whales harvested at Barrow. Baleen length was estimated as a function of whale length using data from whales harvested at Kaktovik and from data in old whaling records. Important relationships needed for energetic calculations are summarized below, where "a" and "b" are the coefficients for an equation of the form $y = a \times (\text{body length in meters})^b$, *r* is the correlation coefficient, and *P* denotes the significance level of the correlation:

Parameter/ units [a]		**a**	**b**	***r***	***P***
Whale Weight	MT[b]	0.047	2.58	0.98	< 0.001
Blubber Weight	MT	0.052	2.19	0.95	< 0.001
Total surface area	m^2	0.54	1.85	0.99	< 0.001
Surface area of fluke	m^2	0.012	1.94	0.92	< 0.001
Weight of metabolic core	MT	0.03	2.53	0.97	< 0.001
Surface area of metabolic core	m^2	0.49	1.70	0.97	< 0.001

[a] Equation form: $y = a \times \text{body length (m)}^b$. [b] 1 MT (metric tonne) = 1000 kg.

Theoretical energetic requirements were calculated for a 12.5 m whale that weighs 31 MT, taking account of the available data on whale physiology and bowhead dimensions, seasonal activities, swimming speeds, and surfacing–respiration–dive cycles. The energetic requirements of bowhead whales, as estimated using the respiration method, are higher than estimates based on calculated power output or hydrodynamic considerations plus the standard metabolism approach, which is based on heat loss.

The theoretical energy requirements of bowheads appear to be quite low and are in keeping with the adaptations that bowheads possess for living in a cold environment where food is relatively scarce compared to some other marine waters. These adaptations include

- A very slow maturation rate where males mature when 12 to 13 m long at an age of ~25 years, and females at a length of 13 to 13.5 m when ~27 years old.

- Very slow growth rates: after weaning, subadults initially show little growth and an average subadult gains only about 0.8 to 1MT/yr; adults gain 0.2–0.9 MT/yr.
- The highest blubber content on a percentage basis of any species of whale.
- The longest baleen of any species of whale.
- A long reproductive cycle which spreads the energetic cost of reproduction over about four years.

Potential feeding rates in nature were computed from the area of the mouth opening, speed while swimming, and quantity of food available to bowheads in the eastern and central Beaufort Sea. The mouth opening computed from width of the mouth at ~1/3 the distance between the tip of the rostrum and the rear corner of the mouth, as a function of body length, was estimated as

$$\text{Mouth Opening (m}^2\text{)} = -2.15 + 0.312 \times \text{Length (m)}; \quad r = 0.93, \; P < 0.001$$

Because the lower lip holds the baleen in place when the mouth is open, bowheads could feed with their mouths open very wide. The relationship between whale length in m and maximum mouth opening in m^2 was best described as

$$\text{Maximum mouth opening (m}^2\text{)} = -2.03 + 0.342 \text{ Length (m)}; \quad r = 0.94, \; P < 0.001$$

Bowheads feed on zooplankters that have a high lipid content. The small size of the bowhead stomach and observations of bowhead feces are consistent with a hypothesis that bowheads extract only the lipids from their prey, at least when feeding in areas with much zooplankton. Zooplankton concentrations near feeding subadult bowheads in the Canadian and eastern Alaskan Beaufort Sea average 1.8 g/m^3 on a wet weight basis, based on echosounder-guided net sampling. This corresponds to an energetic value of about 2069 J/g wet weight considering only the lipid content of the prey. Observations of behavior indicate that bowheads may feed an equivalent of ninety-three 24-hour-days per year. This estimate has wide uncertainty given the lack of specific time-budget data for the western Chukchi Sea and Bering Strait in fall (where we assume intensive feeding) or the central Bering Sea in winter (where we assume no feeding). Assuming 93 days of feeding/yr and a swimming speed of 2.5 km/h while feeding, a 12.5 m whale feeding at locations with average prey biomass of 1.8 g/m^3 could consume 1.4×10^5 kJ/d, averaged over the year and adjusted for annual differences in lipid content. For comparison, the calculated value assuming a swimming speed while feeding of 5 km/h and prey density 4 g/m^3 was 6.0×10^5 kJ/d,

Several different methods have been used to compute the energetic requirements of an average 12.5-m bowhead whale weighing 31 MT:

	kJ/d x 10^5
Standard metabolism	2.8
Standard metabolism + swimming	3.4
Basal metabolic rate	5.8
Basal metabolic rate of core only	4.1
Power output + BMR	6.6
Cost of swimming +BMR	6.437
Core BMR + Cost of swimming	4.7
Respiration	6.4
Feeding in nature (2.5 km/h, 1.8 g plankton/m^3	1.4
Feeding in nature (5 km/h, 4 g zooplankton/m^3	6.0
Growth/Food Storage for Winter	1.4

Estimated basal metabolism is higher than standard metabolism computed through consideration of heat loss. However, estimated basal metabolism for the core weight (excluding blubber) is about the same as standard metabolism. The metabolic rate of bowhead whales may be quite low for their size. The evidence tends to support a low estimate based on BMR calculated from the core weight not including blubber, plus some small but unknown amount for maintenance of the blubber layer. The cost of locomotion derived through consideration of power output and cost of swimming were also computed, and added to standard and basal metabolism.

About 1.4×10^5 kJ/d needs to be added to the above estimates to account for growth and food storage, and $\sim 1.8 \times 10^5$ kJ/d need to be added to adult female requirements for the cost of reproduction averaged over a 4-year reproductive cycle. When these amounts are added to the two theoretical estimates, the difference between those estimates and the lower "feeding in nature" estimate becomes even greater.

One major uncertainty affecting the energetic analysis is the unknown amount of feeding in the Chukchi Sea and Bering Strait in fall, and the Bering Sea in winter. Isotopic results suggest that most feeding by both subadult and (especially) adult bowheads occurs outside the Canadian and eastern Alaskan Beaufort Sea. However, feeding is commonly observed in those areas, most whales harvested at Kaktovik have food in their stomachs, and subadult bowheads harvested in fall are heavier and have a higher lipid content in their blubber than do spring harvested animals. Measurements of length and girth from known-scale aerial photographs confirm some loss of girth (and thus weight) in winter. Available data indicate that the net loss of weight from the time bowheads leave the Beaufort in fall until they return in spring may be on the order of 2.5 to 3.6 MT for an 11 m subadult and a 14.5 m adult. Actual weight loss in winter is probably greater, assuming there is further weight gain in the Chukchi Sea and Bering Strait in late autumn before the (presumed) period of winter fasting and weight loss begins.

Sampling of food available at places where bowheads were observed feeding has only been conducted near subadults feeding in summer and early fall. These data came from feeding sites in the Canadian and eastern Alaskan Beaufort Sea. The average prey availability at the depth of maximum prey biomass at these sites was measured as 1.8 g/m^3 on a wet weight basis. Estimated prey consumption by subadults feeding in such locations is only about half that required by even the lower of the estimates of theoretical energetic requirements if average food availability in other feeding locations is similar. Subadults and adults would need to feed in higher concentrations of zooplankton. The quantity of prey available at specific locations where adult bowheads feed is unknown. Given our assumptions about the number of days of feeding in various seasons, subadults and adult males would, over the course of the year, need to feed on average concentrations of 4 g/m^3 at an average speed of 5 km/h to meet energetic requirements. A swimming speed of 5 km/h while feeding, and zooplankton concentrations of 4 g/m^3 near feeding whales, are at the upper ends of the observed ranges of values in the Beaufort Sea, and above the average observed values for that area.

The estimate of energetic requirements derived through consideration of respiration is at the high end of the range of estimates derived here. It is based on weights of only 5 lungs and assumptions about the undocumented relationship (for bowheads) between weight of lungs and their volume. Tidal volume and oxygen consumption of bowheads are unknown, as are breathing rates in winter.

The estimate derived through consideration of heat loss and cost of motion is an intermediate estimate relative to other methods. This intermediate estimate may represent the best available estimate of the energetic requirements of bowhead whales. It is consistent with adaptation to a cold environment with relatively low food availability, and with the morphology and physiology of the animal.

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23. INTEGRATION AND CONCLUSIONS

Denis H. Thomson, William R. Koski, and W. John Richardson [1]

Introduction

The purpose of the project, as defined by the Minerals Management Service, was to compile and integrate existing traditional and scientific knowledge about the importance of the eastern Alaskan Beaufort Sea for feeding by bowhead whales; to build consensus on the need for and approach to fieldwork to augment this knowledge; to conduct the field studies and to analyze the results; to integrate them with existing traditional and scientific knowledge; and to report on and publish the results.

The essential questions to be answered by the study were ***(1)*** what proportion of their annual food requirements does the ***population*** of bowhead whales derive from the study area, and ***(2)*** how important is the study area to ***individual*** bowhead whales that may linger in the study area. A multidisciplinary effort was launched to answer the questions. Early in the project, as part of the planning process, interviews were conducted with whaling captains and other knowledgeable individuals from Kaktovik to develop and synthesize traditional knowledge of bowhead biology and use of the study area by bowhead whales. The field studies included studies of zooplankton distribution and abundance, the nature of zooplankton near feeding whales, the distribution and abundance of bowhead whales in the study area, their activities and specific behaviors, and their rates of movement and residence times. In addition, the stomach contents of bowheads harvested in the Beaufort Sea were analyzed to document the diet, and a pilot study of fatty acids in bowhead blubber and bowhead prey was done to test the usefulness of that method in studying bowhead diet. Stable isotopes in bowhead tissues and prey were studied to help assess what portion of the food for adult and subadult bowheads is obtained in the eastern Beaufort Sea as a whole. Most field work for this specific project was conducted in 1998, 1999, and 2000. Corresponding types of data collected during a similar study 1985 and 1986 were also used, thus providing data from five field seasons. In addition, data collected during 1979–2000 during other studies in and adjacent to our study area were used as appropriate. This chapter attempts to integrate information produced by each discipline to answer the key questions.

Study Area and Period

The study area for the 1985–86 project extended from eastern Camden Bay, just west of Kaktovik (144°W), to the Alaska–Canada border as defined by the U.S., which intersects the coastline at 141°W (Fig. 23.1). The study area for the 1985–86 project extended from the coast offshore to the 200 m contour (intensive effort) and beyond (aerial surveys only). Based on a data review, advice from Kaktovik whalers (see Chapter 2), and advice from the project's Scientific Review Board (SRB), the primary study area for the 1998–2000 fieldwork was extended west to the middle of Camden Bay (145°; Fig. 23.1). At this latitude, 1° of longitude equals about 20 n.mi. or 37 km, so efforts extended about 37 km farther west in 1998–2000 than in 1985–86. During the 1998–2000 study, boat-based zooplankton sampling was limited to areas from the shore to the 50 m contour (vs. shore to 200 m contour in 1985–86). However, our standard aerial survey coverage in 1998–2000 extended to the 200 m contour. Less intensive aerial survey coverage was again obtained farther offshore by ourselves and as part of the broad-scale aerial survey program conducted by MMS (Treacy 2000, 2002).

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[1] LGL Ltd., environmental research associates, 22 Fisher St., POB 280, King City, Ont. L7B 1A6. *Phone:* 905-833-1244. *E-mail:* dthomson@lgl.com

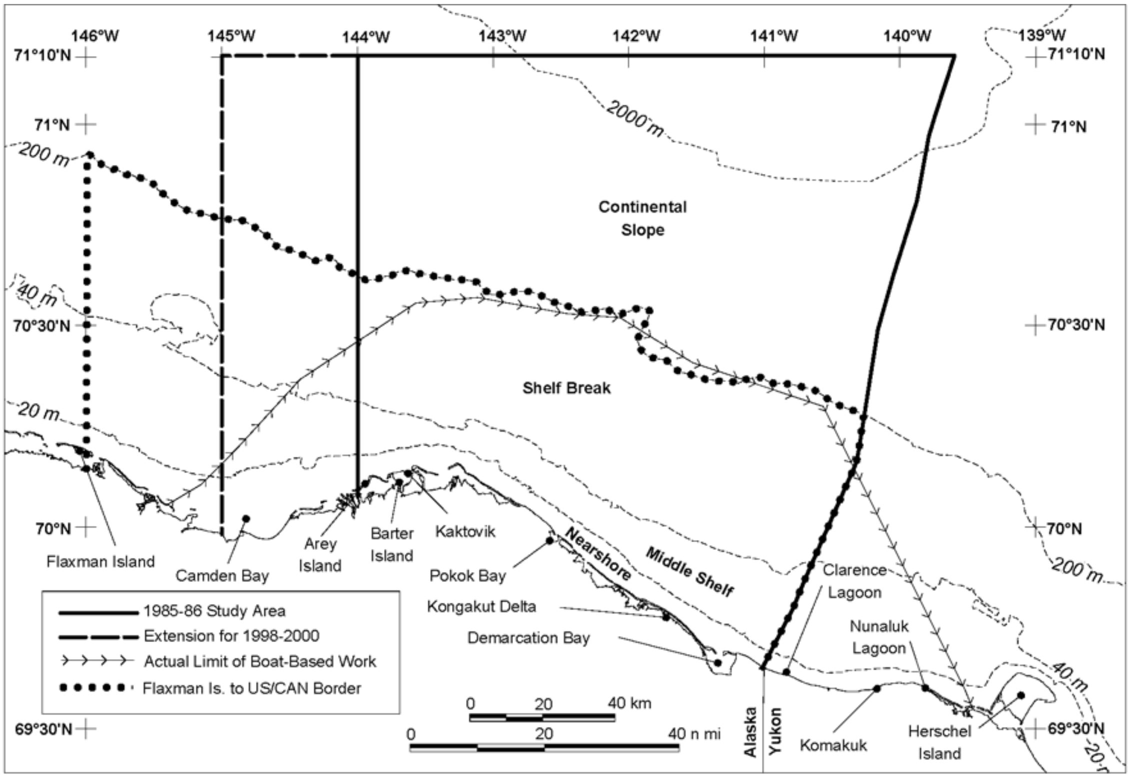

FIGURE 23.1. Map of the eastern Alaskan Beaufort Sea showing study area boundaries as defined for different purposes. The heavy dotted line outlines the area to which whale-days estimates and energetic calculations in Tables 23.8–23.11 apply. That area extends from Flaxman Isl. to the Alaska/Yukon border, and from the shore seaward to the 200 m contour.

Although our focus during fieldwork was on areas from 144ºW (1988–86) or 145ºW (1998–2000) to the Alaska-Canada border, and from shore to the 200 m contour, relevant data of various types were obtained from adjacent areas to the north, east, and west: ***(1) North*** – The one type of information available from areas north of the 200 m contour was aerial survey information. ***(2) East*** – From the outset, it was recognized that there could be times within our study periods when feeding bowhead whales might be scarce or absent from the study area, but present just to the east in Canadian waters. Project plans and permits included provision to observe bowheads and to sample their prey in Canadian waters as far east as Herschel Island (139ºW) when there were no opportunities to study feeding bowheads in the "official" eastern-Alaskan study area. Aerial data (aerial surveys, behavioral observations, photography) were sometimes obtained in Canadian waters, mainly in 1985–86, and zooplankton near feeding bowheads was studied there on two dates in 1986. ***(3) West*** – Aerial data, including aerial surveys, behavioral observations and aerial photographs, were often available (mainly from other projects) as far west as 146ºW (Flaxman Island), i.e., an additional 37 km farther west than the western boundary of the study area as officially defined for 1998–2000.

Limits of data collected and used in each major part of this study, and the associated data collection periods, are summarized in Table 23.1. The overall approach was to make use of relevant data from other projects when appropriate, thereby expanding the available data temporally and spatially, and strengthening the conclusions that can be drawn. Analyses based on aerial data, including estimates of numbers of

TABLE 23.1. Study area boundaries and timing of data collection for each type of data collected during the bowhead feeding studies in 1985–86 and 1998–2000.

	Study Area Boundaries			
Types of Data	West	East	North	Sampling Dates
Zooplankton Distribution and Abundance	Camden Bay	Border	70°30’	4 – 22 Sept
Zooplankton Near Feeding Whales	Camden Bay	Herschel Isl.[a]	70°20’	4 – 22 Sept
Stomach Contents	Camden Bay	Pokok Bay	70°20’	2 Sept – 11 Oct[b]
Aerial Surveys (abundance, whale days)	Flaxman Isl.[c]	Border[d]	71°10’	1 Aug – 28 Oct[e]
Aerial Photography	Flaxman Isl.	Herschel Isl.	70°30’	16 Aug – 3 Oct
Aerial Observations of Behavior	Flaxman Isl.	Herschel Isl.	70°30’	3 Sept – 6 Oct
Residence Times	Flaxman Isl.	Herschel Isl.	71°10’	16 Aug – 6 Oct

[a] Only 2 whale feeding stations were east of border.

[b] Harvest dates of bowheads landed at Kaktovik in 1979–2000 whose stomachs were examined (Appendix 18.3).

[c] MMS-BWASP project provided data west to Flaxman Isl., 146ºW. The feeding project *per se* provided aerial survey data west to 144ºW (1985–86) or 145ºW (1998–2000).

[d] MMS-BWASP project provided survey data east to 140ºW (37 km into Canada at coastline); the feeding project *per se* provided data east to the border. Estimates of numbers of whales, and of whale-days, exclude data east of border.

[e] Date range is that for all aerial surveys, with the earliest and latest surveys being from the MMS-BWASP project. The feeding project *per se* provided data from 4 to 27 Sept.

whales present, whale residence times, and behavioral analyses (see Chapters 9–14), were based on data collected from 146ºW east to Herschel Isl. (139ºW). However, in analyzing the importance of the eastern Alaskan Beaufort Sea to bowhead whales in this chapter, we have generally excluded the data obtained east of the Alaska–Canada border. The analyses in this chapter consider the western edge of the study area to be 146ºW, i.e., near Flaxman Island (Fig. 23.1).

The selection of the study period for this project was discussed in Chapter 1. The primary field periods for the feeding study *per se* were in September, during the time of peak occurrence of bowheads in the study area. Some bowheads are in the area earlier and later in the season, and their occurrence has been documented by aerial surveys (Chapter 9) and the observations of local residents (Chapter 2). We acknowledge that the intensive feeding study work did not extend through the full period while bowhead whales are present in the eastern Alaskan Beaufort Sea. However, it did occur during the time of peak utilization of that area by bowhead whales. It would be interesting to have specific information about food availability and whale feeding during the early and late parts of the late summer/autumn season. However, we believe that the various sources of data, in combination, provide a reasonable basis for assessing the overall importance of the study area for feeding in late summer and autumn. The available aerial survey data from August to October, as well as local and traditional information, are of particular importance in understanding the general utilization of the study area throughout the late summer and autumn period.

Questions

Questions were developed to address the study objectives and the study design was based on these questions. These questions were worded as “hypotheses” at some stages in the project. However, a consensus developed late in the project that they should be considered to be research questions that were addressed by the project rather than formal hypotheses to be tested (see Chapter 1 and SRB report in Annex A).

The overall question to be addressed during this study was as follows:

> *Question (1). In an average year, how important is the eastern Alaskan Beaufort Sea for bowhead whales; what percentage of the population’s annual energetic requirements is derived from the area?*

This overall question was addressed by considering many different types of data acquired or assembled during the project (see Chapters 2 – 22), integrated by means of an energetic model (Chapter 22 and below). For each question, the project aimed to estimate a measure of study area utilization, rather than simply determine whether utilization is above or below some specified threshold or cutpoint. However, for Questions 2 – 6, the cutpoints included in the (former) hypotheses were retained when the hypotheses were reformulated as questions. We consider these cutpoints to represent levels of feeding activity that, if exceeded, would indicate substantial feeding in the area. The following are the specific questions:

> *Question (2). How much of its annual food requirements does the Bering–Chukchi–Beaufort (BCB) population of bowhead whales derive in the eastern and central Beaufort Sea? At least 10 percent?*
>
> *Question (3a). Of the bowheads that travel through the eastern Alaskan Beaufort Sea, how long does an average whale spend there? At least 7 days?*
>
> *Question (3b). Of the individual bowheads that travel through the eastern Alaskan Beaufort Sea, how long do some individuals spend there? At least 7 days?*
>
> *Question (4). What percentage of the bowheads that pass through the eastern Alaskan Beaufort Sea feed there? At least 10 percent?*
>
> *Question (5). What percentage of the geographic area within the study area is suitable as feeding habitat in different years? Is at least 1 % of the study area suitable in some years?*
>
> *Question (6). During migration through the eastern Alaskan Beaufort Sea, how often are bowheads observed to feed while they are traveling? Is feeding while traveling evident more than 10 % of the time while traveling?*

Background

The bowhead whale population occupying the Bering, Chukchi and Beaufort seas was estimated, as of 1993, to contain about 8200 animals with upper and lower 95 % confidence intervals of 7200 to 9400 animals (Zeh et al. 1996; Ferrero et al. 2000). As of 1993, the population was believed to be increasing at a rate of about 3.2 % per year (or possibly somewhat less—Punt and Butterworth 1999) despite annual subsistence harvests of 14 to 74 bowheads from 1973 to 1996 (Suydam et al. 1995). If a 3.2 % rate of increase has continued to the present day, the best estimate for the summer of 2000 would be about 10,223 animals. Preliminary results from the 2001 bowhead census, the first successful census since 1993, confirm that the current population is indeed near 10,000 whales and continuing to increase (George et al. 2002). Thus, the population size in 2000 was probably lower than the pre-exploitation population, which is estimated to have been 10,400–23,000 bowhead whales (Woodby and Botkin 1993). The large increases in population estimates that occurred from the late 1970s to today are partly a result of actual population growth, but are also (in substantial part) attributable to better census techniques (Zeh et al. 1993). The bowhead population is currently listed as endangered under the Endangered Species Act and is classified as a strategic stock by the National Marine Fisheries Service (Ferrero et al. 2000).

Bowhead whales of the Bering–Chukchi–Beaufort (BCB) stock winter in the central and western Bering Sea and most of them summer in the Canadian Beaufort Sea and Amundsen Gulf (Moore and Reeves 1993). Spring migration starts in late March and whales follow a prominent nearshore lead along the eastern side of the Chukchi Sea northeastward to Point Barrow (Fig. 23.2). From there, they migrate

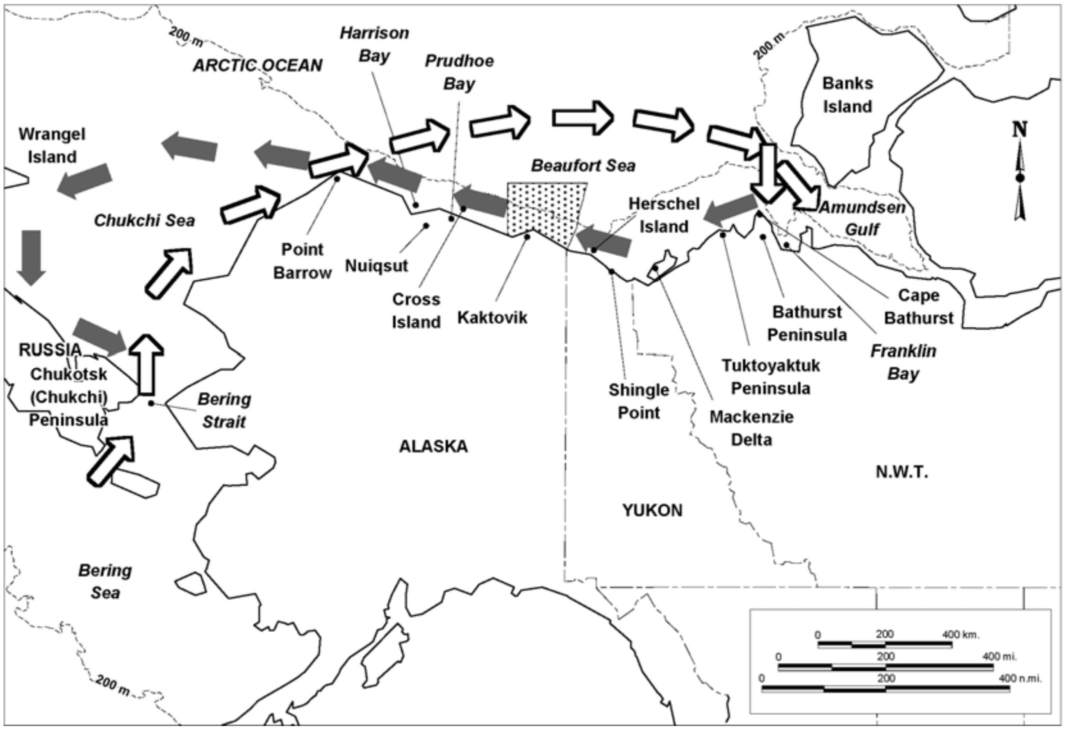

FIGURE 23.2. Schematic depiction of the seasonal migration of the Bering–Chukchi–Beaufort stock of bowhead whales, and locations mentioned in text. The "eastern Alaskan Beaufort Sea" is shaded.

through the Western Beaufort Sea through offshore ice leads, generally from mid-April to mid-June (Braham et al. 1984; Moore and Reeves 1993). East of Point Barrow, the lead systems divide into numerous branches that vary from year-to-year in location and extent, but are typically located well offshore. In the western part of the Alaskan Beaufort Sea, the route follows a corridor centered at about 71°30'N latitude, and broadly occurring between latitudes 71°20'N and 71°45'N. Bowheads are not seen in spring by Kaktovik residents (Chapter 2; Annex B). This report assumes that bowhead whales do not "utilize" continental shelf portions of the eastern Alaskan Beaufort Sea during spring.

A few bowheads arrive in coastal areas of the eastern (Canadian) Beaufort Sea and Amundsen Gulf in late May and June but most whales apparently remain in offshore waters (>200 m deep) among the pack ice until mid-summer. Little is known about bowhead activities in early summer. In August of most years, subadult whales move into nearshore and shelf waters (<100 m deep) along the Yukon coast and Mackenzie Delta, and off the Tuktoyaktuk Peninsula. In some years, adults whales also move toward the coast from offshore waters but adults normally remain in waters >40 m deep during summer.

After feeding in the Canadian Beaufort Sea and Amundsen Gulf, most bowheads begin migrating west in late August to early October. Autumn migration into Alaskan waters is primarily during September and October and primarily through waters 15–100 m deep (Wartzok et al. 1989, 1990; Moore and Reeves 1993; Miller et al. 1999; Mate et al. 2000; Treacy 2000). However, in some years local residents see a few bowhead whales off Kaktovik in late July, and some bowheads occur near Kaktovik in August (Chapters 2, 9; Annex B). In rare years, a few bowheads may occur almost as far west as Barrow during mid-August (Moore 1992). It is not known if these early sightings represent early autumn migrants, or whales that summered in Alaskan waters. It has been suggested that, as the BCB bowhead population has recovered from commercial whaling, some bowheads may be summering in areas that they have not occupied for many decades (i.e., the Alaskan Beaufort and Chukchi seas) and that autumn migration may be starting earlier. Consistent with this, the Kaktovik and Nuiqsut whalers have stated that the earliest-arriving bowheads reach the Kaktovik and Cross Island areas earlier in recent years than formerly (Chapter 2; T. Napageak, pers. comm.). Most bowheads from the Beaufort Sea arrive in the northeastern Chukchi Sea near Point Barrow in mid-September to early October (Moore and Reeves 1993). However, some bowheads continue to migrate past Kaktovik as late as mid-October (Chapters 2, 9; Annex B).

Evidence from several sources suggests that bowheads travel generally west or southwest from Point Barrow to the Russian coast off the Chukotsk Peninsula. Bowheads are known to feed in this area (Moore et al. 1995) before migrating southeastward along the Chukotsk coast to the Bering Strait. The latter migration continues through November (Moore and Reeves (1993). The peak of migration through Bering Strait, at the southern extremity of the Chukchi Sea, is during the last 10 days of October and the first 10 days of November. Bowheads are seen in the Bering Strait and coastal areas to the southwest through November (Moore and Reeves 1993).

Feeding activities and associated behaviors of BCB bowhead whales have been described for summer by Würsig et al. (1984, 1985, 1989) and Dorsey et al. (1989), and for late summer/early autumn in Chapters 12–14 of this report. Three modes of feeding have been described: ***(1)*** During ***near-surface feeding***, bowheads move forward with mouths open at or just under the surface. Most often these whales are alone but in some cases up to 14 whales have been observed feeding side-by-side in echelon formation. ***(2)*** Whales are assumed to be ***water-column feeding*** when they exhibit some or all of the following: • dive and surface in the same general area for prolonged periods, • orient in variable directions from one surfacing to the next, • remain stationary or move slowly at the surface between dives, and • dive steeply, often with flukes out. ***(3)*** Whales are assumed to be ***bottom feeding*** when they come to the surface with mud on parts of the body or with mud streaming behind them.

Bowhead Feeding Areas Across the Arctic

Lee and Schell (Chapter 20) have analyzed carbon isotope ratios in bowhead muscle, baleen, and fat, and in bowhead food organisms. Isotopic signatures in zooplankton from Bering and Chukchi waters, which sometimes extend into the western Beaufort Sea, are similar and cannot be differentiated. Zooplankton from the eastern Beaufort Sea has an isotopic signature quite distinct from that in Bering/Chukchi zooplankton. Lee and Schell compared isotopic signatures in bowhead tissues vs. zooplankton. From this comparison, they estimate that 10 to 26 % of the annual feeding activity was in the eastern and central Beaufort Sea waters, roughly east of Prudhoe Bay (Chapter 20). The 10 to 26 % range of estimates reflects different methods of calculation, and all of those estimates are uncertain given the assumptions, variability in the data, etc. [One set of data, those of Hoekstra et al. (2002), suggest that the percentage could be on the order of 37–45 %, but some of the data used to derive those percentages are inconsistent with replicated measurements obtained by Lee and Schell from the same individual whales (Chapter 20).] There was an indication, both from muscle and baleen, that subadult bowheads may feed somewhat more than adults in the eastern Beaufort Sea. Evidence discussed in Chapter 20 and below suggests that the Bering/Chukchi signature in bowhead isotope ratios is mainly derived from feeding in mid- to late fall in the Chukchi Sea and probably also, to some extent, the western Beaufort Sea and northern Bering Sea.

The low estimates of summer feeding, as evident from the isotope data of Lee and Schell (Chapter 20), are difficult to reconcile with other data: behavioral observations showing frequent feeding in the eastern Beaufort Sea during summer and early autumn, frequent occurrence of food in stomachs of bowheads harvested in the Alaskan Beaufort during late summer and autumn, and increases in girth and energy content over the summer. However, as noted in Chapters 20–22 and below, those data on summer/early fall feeding do not specifically show what fraction of the annual feeding occurs in the eastern and central Beaufort Sea. No comparable data on feeding, girth, or energy content have been obtained during and after the whales feed in the Chukchi Sea in mid- to late fall. Perhaps more feeding and energy accumulation occurs there in fall than in the Beaufort Sea in summer. If so, the evidence of feeding in the Beaufort might be reconcilable with the strong Bering/Chukchi isotope signature in bowhead tissues.

Distributional and Behavioral Observations

Direct observations of bowhead behavior show that bowheads spend most of their time (~73 %) feeding while summering in the Canadian Beaufort Sea and Amundsen Gulf, and somewhat less time feeding (~47 %) when in the eastern Alaskan Beaufort Sea during late summer and early autumn. There are no quantitative data concerning bowhead activities in the Chukchi Sea during autumn, where feeding is known to occur, or in the Bering Sea in winter, where bowhead activities are undocumented. In spring, the percentage of time spent feeding is low, at least in the area northeast of Barrow (see Chapter 12). Feeding in various parts of the annual range is discussed further in the paragraphs that follow.

Canadian Beaufort Sea and Amundsen Gulf.—Feeding areas and activities of bowhead whales have been relatively well documented for late July through mid-September, but have not been studied for June and most of July. Also, the majority of the information for late July to mid-September concerns subadult bowheads, with the distribution of adults being less well known. Feeding ecology of bowhead whales in the Canadian Beaufort Sea has been studied by Bradstreet et al. (1987) and others, using some of the same techniques applied in the present eastern Alaskan study.

The area most consistently used for feeding by small subadult whales (<10 m long), during August and September, was the waters <50 m deep along the Yukon coast from Herschel Island to Shingle Point (Koski et al. 1988). In some years, small subadult bowheads were also found along the Yukon coast in shallow waters west of Herschel Island (Davis et al. 1986a) and in shallow waters off the Mackenzie Delta and Tuktoyaktuk Peninsula (Renaud and Davis 1981). Large subadult whales were found in and adjacent to the areas used by small subadults, but they generally were found slightly farther offshore and in slightly deeper water than small subadults. In many years, large subadult bowheads were common in shelf waters east, northeast and north of Herschel Island where steep gradients cause upwelling.

Adult bowheads generally were found in shelf and offshore waters from 126° to 133°W during late July to early September. Of the known feeding areas for adults, the most commonly used are in the easternmost part of the Canadian Beaufort Sea: shelf waters northwest of Cape Bathurst, and shelf and shelf break waters east of the Bathurst Peninsula as far south as southern Franklin Bay (Harwood and Borstad 1985; Davis et al. 1983, 1986a,b; Duval 1986; Ford et al. 1987). Adult bowheads were rarely found feeding in shelf or offshore waters north or west of Tuktoyaktuk (~133°W) before late August (Koski et al. 1988). However, during their westward migration, which starts in late August and continues through September, many adult bowheads moved through shelf waters and some interrupted migration to feed. 1982 was an exception, and moderate numbers of adult whales were seen and photographed throughout August in shelf waters northeast of Herschel Island and near the 200 m depth contour north of Shingle Point (Davis et al. 1983). In general, knowledge of the summer distribution of adults is incomplete, and there may be additional areas that are important for feeding by adults in summer.

Eastern Alaskan Beaufort Sea.—Bowhead whales have been seen feeding at several locations from the Alaska–Yukon border to Camden Bay. In 1985 and 1986, small subadult whales were seen feeding in shallow nearshore waters near and west of Demarcation Bay. In 1998, small and large subadults were feeding as they traveled in shelf waters north and west of Kaktovik. In 1999, adult and some large subadult bowheads fed in shelf waters from north of Demarcation Bay to just east of Kaktovik. In 2000, bowheads moved through the study area rapidly and little feeding was observed. Thus the size classes of whales feeding in the eastern Alaskan Beaufort Sea, the areas used for feeding, and the amount of feeding all varied among years. Despite this variation in use of the study area among the five field seasons of this study, the areas used agree with data from other sources as to the types of areas that tend to be important for feeding bowhead whales. Use of shelf and nearshore waters near Demarcation Bay and Icy Reef by feeding bowheads has also been documented in other years, including 1982 and 1984 (Johnson 1984; Davis et al. 1986a; see also Chapter 2). Nearshore and shelf waters near Kaktovik and in Camden Bay, e.g., near Arey Island, have also been reported to be important to bowheads during other years (Moore et al. 1989; Chapter 2).

Western Beaufort Sea.—Moore and Clarke (1993) and Moore and Reeves (1993) have documented that bowheads are more abundant in the area east of Point Barrow during late summer and autumn than they are in other parts of the Alaskan Beaufort Sea, apparently including our study area. Of the bowheads harvested near Barrow in fall, 75 % were categorized as "feeding" based on the food found in their stomachs (Chapter 18). Other studies have documented feeding near Point Barrow during autumn of different years (Braham et al. 1984; Ljungblad et al. 1986; Landino et al. 1994; Treacy 1998, in prep.), further suggesting that the area is used frequently by feeding bowheads. Bowhead whales occasionally have been seen feeding in other areas in the western Beaufort Sea (Miller et al. 1998; Treacy 1998, in prep.), and the few stomach contents samples from the Cross Island area (near Prudhoe Bay) suggest that feeding may be common near there. However, feeding has been seen more frequently in the area just east of Point Barrow than in parts of the Alaskan Beaufort Sea from western Harrison Bay eastward (Treacy in prep.). There has been no specific study of bowhead feeding ecology in the area just east of Barrow.

Chukchi Sea.—The routes and timing of migration through the Chukchi Sea, the amount of feeding that occurs there, and the nature of that feeding, are not as well documented as for the Beaufort Sea. Most bowheads of the BCB stock arrive in the northeast Chukchi Sea in late September to mid-October (Moore and Reeves 1993). Aerial surveys indicate that most bowheads travel west and southwest through this area, moving toward Russia (Moore and Clarke 1992, 1993). During extensive cruises in the central and western Chukchi Sea during late September and early October 1992–93, few bowheads were seen except off the Chukotsk Peninsula south and southeast of Wrangel Island. Some feeding occurs there (Moore et al. 1995). The southwest Chukchi Sea is highly productive, and it is probable that dense concentrations of zooplankton are available to bowhead whales in that area during late autumn (Chapter 20; see also Niebauer and Schell 1993). From there, bowheads follow the Chukotsk Peninsula southeast to the Bering Strait.

The timing of the passage through the Bering Strait in autumn is variable and not well documented. Some bowheads arrive at the Bering Strait as early as 20-21 September (Moore et al. 1995) and others as late as late November (Moore and Reeves 1993). Most bowheads leave the Chukchi Sea through the Bering Strait during 21 October to 10 November (Moore and Reeves 1993). Given that most bowheads arrive in the northeast Chukchi Sea near Point Barrow in mid-September to early October (Moore and Reeves 1993), an average bowhead may spend about a month in the Chukchi Sea. Some may be there for considerably longer. Thereafter bowheads are found in the Bering Strait and coastal areas to the southwest through November (Moore and Reeves 1993). The waters of the Bering Strait and coastal areas to the southwest contain a high biomass of zooplankton through November (Coyle et al. 1996).

Seasonal Time Budgets

As noted above, direct observations of bowhead behavior show that bowheads spend an estimated 73 % of their time feeding while summering in the Canadian Beaufort Sea and Amundsen Gulf (Table 23.2; Chapter 12). The time spent feeding decreases to about 47 % for bowheads in the eastern Alaskan Beaufort Sea during late summer and early autumn. There are no quantitative data concerning bowhead activities in the Chukchi Sea during autumn, where feeding is known to occur. There are no data on activities in the productive northern Bering Sea in late fall, or in the Bering Sea in winter. In spring, the percentage of time spent feeding has been determined in only one area, just northeast of Barrow (see Chapter 12).

For purposes of energetic and related calculations, there was a need for estimates of the amount of time that might be spent feeding in each season, including seasons for which quantitative data are lacking. Chapter 22 describes our basis for estimating the percent of time that might be spent feeding during late fall in the Chukchi Sea, Bering Strait, and northwestern Bering Sea; during winter in the Bering Sea; and during spring migration. The results are summarized in Table 23.2.

TABLE 23.2. Observed or assumed proportion of time when bowhead whales are engaged in various activities during different seasons (from Chapters 12 and 22).

	Observed or Assumed Percent of Time				
Activity	**Spring**[a]	**Summer**[b]	**Fall Beaufort**[b]	**Fall Chukchi**[c]	**Winter**[d]
Travel	75	7	31	7	7
Feed	8	73	47	73	0
Social	7	15	17	15	0
Other/Unknown	10	5	5	5	93
No. of Obs. Sessions	*(54)*	*(85)*	*(80)*		

[a] From field observations summarized in Chapter 12, but with % time feeding adjusted upward (from observed 1 %) based on a speculative assessment of stomach contents (see Chapter 22).

[b] From field observations summarized in Chapter 12.

[c] Includes Bering Strait and coastal NW Bering Sea as well as southwest Chukchi Sea; activities in fall in these areas are assumed to be similar to those in summer in the eastern Beaufort.

[d] No data for winter; assumed to be negligible feeding. Travel assumed to be as in summer.

Stomach Contents

Most bowheads harvested during their autumn migration across the Alaskan Beaufort Sea, and some of those harvested during spring migration near Barrow, have food in their stomachs (Chapter 18). In this study, all whales recorded as having at least 10 prey items or 1 L of prey in their stomachs were classified as feeding. There is a large difference between a stomach with that small amount of prey and one that is full. The frequency and amount of food present are not necessarily direct measures of feeding intensity. However, food is present in a higher proportion of the whales taken at Kaktovik and Barrow in fall than of those taken at Barrow in spring. Also, the amount of food in the stomachs tends to be higher in fall. Only a few stomach content data are available from Cross Island (near Prudhoe Bay), but those few data suggest that feeding is also common there in fall.

Weight Loss in Winter/Gain in Summer

Inupiat on the North Slope have noticed that bowheads caught in spring and fall taste different, and one hunter mentioned that they are fatter in fall (Chapter 2; Kisautaq 1981:296). Similarly, three independent studies provide evidence that bowhead whales lose weight in winter and gain weight in summer/early autumn (see Chapter 22 for details). By winter, we mean the interval between departure from the Beaufort Sea in fall and return to the Beaufort Sea in spring: ***(1)*** J.C. George (pers. comm.[2]) measured whales harvested near Barrow and found that the girths of subadult bowheads were larger in autumn than in spring. He determined that subadult bowheads were significantly heavier in autumn than in spring, but found little seasonal difference in weights of large adults. George (pers. comm.[2]) found no change in the thickness of blubber between autumn and spring harvested animals. ***(2)*** Lipid content in the blubber of subadults harvested in fall was about 80 % (T. Mau pers. comm.[3]). In spring, lipid content of the inner 20 % of the blubber in subadults was about 70 %; lipid content in the next 20 % of the blubber was 70–80 %. Lipid content in the outer 60 % of the blubber layer was similar in spring and autumn. ***(3)*** Thomson (Chapter 22), based on length and girth measurements from aerial photographs of bowheads, showed that bowheads gained weight during summer in the Beaufort Sea, and lost weight in winter. Thomson's equations predict that a bowhead whale 9 m long would gain ~2 MT over the summer. A 16–m whale would gain ~4 MT.

One probable reason for the difference between results of George vs. Thomson for adult bowheads is that George used a constant value to account for stretching of animals (based on a sample size of 3) that were hauled up prior to measurement. More measurements of stretching of animals hauled up onto ice (spring) and land (fall) are needed to quantify stretching in relation to length, weight, and substrate. However, it is notable that George's results are consistent with indications, from isotope techniques, that adults feed less than subadults during summer in the Beaufort Sea (*cf.* Chapter 20).

Weight loss in winter was probably greater than apparent from the girth measurements by George and Thomson. Their data concern the difference between the girths before or as bowheads leave the Beaufort in autumn as compared with girths when bowheads enter the Beaufort in spring. Bowheads presumably gain additional girth and weight during late-autumn feeding in the southwest Chukchi Sea, and possibly also in the coastal northern Bering Sea, after the time when the "fall" measurements quoted above were taken. Thus, weight loss from the time of peak weight in late fall (in the southwest Chukchi or northern Bering) until spring presumably exceeds that measured by George and Thomson.

Potential Prey Consumption in Summer and Autumn

Griffiths et al. (Chapter 6) found an average zooplankton biomass of 1.8 g/m^3 near bowheads feeding in the Canadian Beaufort Sea and eastern Alaskan Beaufort Sea during summer and early autumn. From this, Thomson (Chapter 22) estimated that a 12.5 m bowhead whale, traveling at 2.5 km/h while feeding, could consume 244 kg wet-weight during 24 h of continuous feeding at locations and depths with average zooplankton biomass 1.8 g/m^3 wet weight. This estimate of plankton available to bowhead whales at feeding locations in the eastern and central Beaufort Sea (1.8 g/m^3) may only apply to subadult animals because sampling of prey availability was conducted only near subadults (Chapter 6). If the estimate of 244 kg/d is multiplied by the assumed number of effective days of continuous feeding per season (see Table 22.14), adjusted for seasonal variations in lipid content of zooplankton, and then divided by 365 d, a 12.5 m bowhead could consume an average of 1.3 x 10^5 kJ/d. This represents only ~30 % of annual requirements as estimated though consideration of theoretical energetic requirements (Chapter 22).

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[2] Data provided by J.C. George from a work in progress are not to be cited without written permission of Craig George, Department of Wildlife Management, North Slope Borough, Barrow, AK. cgeorge@co.north-slope.ak.us

[3] Data provided by T. Mau from a work in progress are not to be cited without written permission of Tamara Mau, University of Alaska Fairbanks, Institute of Marine Science, 245 O'Neill Bldg., Fairbanks, AK 99775-7220, tmau@ims.uaf.edu

To meet estimated energetic requirements, subadults and adult males would need to feed on average concentrations of 4 g/m^3 at an average speed of 5 km/h. A speed of 5 km/h is possible, but is at the upper end of the range of speeds observed during feeding in the eastern Beaufort Sea (Chapter 22; Table 22.10). Zooplankton concentrations of 4 g/m^3 are also at the upper end of the concentrations found near feeding whales in the eastern Beaufort Sea (Chapter 6).

We may have underestimated prey availability in the Beaufort Sea. Sampling was conducted near feeding bowheads, but not necessarily in the exact locations where bowheads were feeding. Bowheads are probably adept at finding highly concentrated food patches within areas with a higher than average biomass of zooplankton. Right whales occasionally feed on very dense patches of zooplankton that could supply, in a fairly short time, much of the annual energetic requirement (Beardsley et al. 1996). Bowheads may also feed in extremely dense patches of zooplankton that could meet a high percentage of annual requirements. We probably did not sample in the densest patches of prey available in the eastern Beaufort Sea, and we probably underestimated the biomass available in some patches where we did sample. However, underestimation of prey availability in the Beaufort cannot explain the strong Bering/Chukchi isotope signature in bowhead tissue. That requires intensive feeding in Bering/Chukchi waters. Perhaps bowheads feeding in the western Beaufort and southwest Chukchi/northern Bering Sea in autumn have access to zooplankton with average biomass well above 1.8 g/m^3, thus increasing average prey availability at all feeding sites used during the year to >1.8 g/m^3 wet weight. This could account for both ***(1)*** the thriving bowhead population despite the apparent inability to ingest sufficient food if average prey availability were only 1.8 g/m^3, and ***(2)*** the strong Bering/Chukchi signature in bowhead tissue.

An Interpretation of the Isotope Data

If the types of evidence described above are accepted as reliable, then the one feeding scenario that could (perhaps) be consistent with all the data is as follows: Feeding occurs commonly in the eastern Beaufort Sea in summer and early autumn. Bowheads gain energy stores and their girth increases from feeding in that area. However, zooplankton availability is not as high in the Beaufort Sea during summer as in the Chukchi Sea and nearshore northern Bering Sea during autumn, given the much higher productivity of the Bering/Chukchi system. Also, feeding in the western Beaufort in autumn may effectively be on Chukchi prey advected into the western Beaufort (Chapter 20; see also Niebauer and Schell 1993). Thus, bowheads might acquire more energy from Bering/Chukchi prey in autumn than from eastern and central Beaufort prey in summer/early autumn. Given this, plus an assumed low turnover rate of body components, their overall body composition may be dominated by carbon (and other components) from the Bering/Chukchi system even at the end of the summer when leaving the Beaufort. Energy gained in the Beaufort and Chukchi seas during summer and fall, and possibly the northern Bering Sea during late fall, is presumably used during winter when food availability is low. This would result in reduced girth and energy stores when returning to the Beaufort Sea in spring than when leaving the Beaufort in autumn.

The above scenario is unlikely to be fully or immediately accepted by proponents of either the “traditional” view, i.e., that most feeding is in the Beaufort, or the isotope-based view, i.e., that most feeding is on prey from the Bering/Chukchi system. However, we are not aware of any other hypothesis that is not directly contradicted by some key type of data.

Percentage of Diet from Eastern and Central Beaufort Sea

The first of the key questions identified in Chapter 1 concerned the importance of food from the eastern Alaskan Beaufort Sea to the bowhead population. That is the central question to be addressed in this study. Question (1) is addressed near the end of this chapter, after the more specific questions have been discussed.

The second of the questions identified in Chapter 1, and repeated above, was as follows:

> *Question (2). How much of its annual food requirements does the Bering–Chukchi–Beaufort (BCB) population of bowhead whales derive in the eastern and central Beaufort Sea? At least 10 percent?*

Note that this question pertains to the eastern and central Beaufort Sea as a whole, not just the eastern Alaskan Beaufort Sea.

Chapter 20 provides various isotope-based estimates. The specific value depends on which group of whales is being considered, assumptions about the isotopic composition of their prey, and the tissue being considered (muscle, blubber, visceral fat). The most comprehensive data are available for muscle. When whales sampled in spring and fall of the same years are considered, estimates of the food acquired in the eastern Beaufort Sea range from 17 to 26 % of the annual total, with one outlying value of 37–45 % derived from the data of Hoekstra et al. (2002). When whales sampled in both the 1980s and the 1990s are considered, with allowance for a long-term trend in the isotope composition of prey in the Bering/Chukchi system, the overall estimate is 10 % with a 95 % confidence interval of 0 % to 23 % (see Appendix 20.1 in Chapter 20). Based on the data from both the 1980s and the 1990s, the overall estimate for subadults is 14 % with 95 % confidence interval of 4 % to 23 %. The corresponding estimate for adults was 5 % with 95 % confidence interval of 0 % to 30 %. The greater uncertainty in the adult estimate is associated with lower sample size and other limitations of the data for adults.

Thus, based on isotope evidence, it is likely that subadults derive >10 % of annual food requirements in the eastern and central Beaufort Sea, although the 95 % confidence interval extends below 10 %. The best estimate for adults is below 10 %, but the data are very uncertain and the 95 % confidence interval extends well above 10 %. Behavioral observations and stomach contents of whales harvested at Kaktovik indicate that adults as well as subadults spend much of their time feeding in summer while in the eastern and central Beaufort Sea. Adults either gain weight or at least maintain weight between the time they enter the Beaufort Sea in spring and the time they depart in autumn (see above). If adults derived 10 % or less of their food in the Beaufort Sea, they would lose weight over the summer, which is not the case. Therefore, adults as well as subadults probably gain >10 % of their food in the eastern Beaufort Sea. However, for adults, the isotope evidence alone would support an answer of <10 %. Further investigation is needed to resolve this uncertainty, and broader concerns as to whether the percentage of food acquired in the eastern Beaufort is actually as low as these isotope data suggest. To summarize the conclusions with respect to Question (2),

***Answer (2)**:* Based on stable-isotope evidence, bowhead whales likely consume only 10 to 26 % of their food in the eastern and central Beaufort Sea. Subadult bowheads appear to derive >10 % of annual food requirements there, although the 95 % confidence interval extends below 10 %. It is also probable that adults gain >10 % of their food in that area, but for adults the isotope evidence considered in isolation would support an answer of <10 %.

Local and traditional knowledge (LTK) at Kaktovik does not specifically address the amount of feeding in the eastern and central Beaufort Sea as a whole. However, Kaktovik residents consider that overall region to be an important feeding area for bowhead whales. They, along with most biologists who have studied bowheads in the eastern and central Beaufort Sea, would expect the area to provide a substantially higher proportion of the total annual food requirements than is evident from the isotope data.

Amount of Time that Bowheads Spend in the Study Area

The third question was in two parts, to address the fact that there are distinct questions about the importance of the study area to certain individual whales vs. the population as a whole:

> *Question (3a). Of the bowheads that travel through the eastern Alaskan Beaufort Sea, how long does an* <u>*average*</u> *whale spend there? At least 7 days?*
>
> *Question (3b). Of the* <u>*individual*</u> *bowheads that travel through the eastern Alaskan Beaufort Sea, how long do some individuals spend there? At least 7 days?*

Data on residence times (Chapter 11) can be used to address these questions.

Population as a Whole

Many of the BCB bowhead whales pass through the eastern Alaskan study area during their autumn migration to over-wintering areas. (A minority of the population migrates west through offshore waters north of the study area.) Koski et al. (Chapter 11) used various methods and sources of data to estimate the residence times of bowheads in a study area from Flaxman to Herschel islands (146ºW to 139ºW, Fig. 23.1). This area is about 1.32 times wider than the specific study area of relevance to MMS, i.e., from Flaxman Island to the Alaska-Yukon border. Thus the residence times estimated in Chapter 11 and summarized in Table 23.3 should be divided by 1.32 to estimate the time spent in the area from Flaxman Island to the border. It is acknowledged that this approach is an approximation. It assumes that the rate of travel across the excluded area (border–to–Herschel Isl.) is similar to that across the area relevant here (Flaxman Isl.–to–border). If there is any difference in these rates, it is probable that whales have more tendency to linger in the "border–to–Herschel" area, which is an area where some bowheads are known to linger during late summer of some years. Thus, average residence times in the "Flaxman–to–border" area may be somewhat lower than estimated by the "divide by 1.32" procedure.

The "best estimates" of residence time derived in Chapter 11 for the "Flaxman–to–Herschel" area and summarized in Table 23.3 appear to be those based on • intervals between photographic resightings, • "stop-over duration analysis" (SODA) using best-fit models, • aerial survey estimates of whale-days in the study area, and • telemetry. The various methods that were used have differing biases, and some procedures are clearly more reliable than others. This is discussed by Koski et al. in Chapter 11. Estimates of residence time based on speeds as evident from behavioral observations, photogrammetry, or telemetry are highly variable. This variability probably arises from variable activities of the whales among years or among parts of the study area, difficulties in obtaining unbiased estimates of the proportion of the whales engaged in these activities over the study area as a whole in each year, and (sometimes) low sample sizes (Chapter 11). The variability is assessed in Appendix 23.1 taking account of the mean and standard error of each estimate for each year. The procedure and results are described in Appendix 23.1, and the resulting confidence limits are listed in Table 23.3.

Considering various specific years and methods of calculation, the mean residence times for the "Flaxman–to–Herschel" area vary from 1 day, an implausibly low value based on the interval between photographic resightings in 1998; to 16 days, based on aerial survey whale-days in 1999. Average annual estimates varied from 2 to 8 d, or 3 to 8 d if the aforementioned implausible value is excluded, and averaged 5 d (Table 23.3). The corresponding annual figures for the "Flaxman–to–border" area would be 2.5 to 6.3 d (avg 4 d), based on the "divide by 1.32" method. A steadily traveling whale would take 2.4 d to travel from the Alaska/Yukon border to Flaxman Isl., based on the 3.67 km/h net westward speed

TABLE 23.3. Summary of estimates of mean residence times of bowhead whales in the "Flaxman Island to Herschel Island" area during late summer and autumn, by year (1985–2000). For approximate estimates of average residence times in the "Flaxman Island to Alaska/Canada border" area, divide all values by 1.32. All values except confidence limits are from Table 11.6. Estimates considered to be unreliable are not included. See Chapter 11 for explanation, qualifications, and discussion of reliability. Derivation of confidence limits by Dr. B.F.J. Manly (WEST Inc.) is described in Appendix 23.1.

	Year								
Method	**1985**	**1986**	**1988**	**1989**	**1992**	**1998**	**1999**	**2000**	**All**
Photos: Intervals Between Resightings	8.13	4.18				1.00	4.10	-	
Photos: Intervals Between Resightings + Travel	11.24	7.12				3.38	6.90	3.07	
Photos: Stop-over Duration, Best Fit	5.30	3.81				-	4.36	-	
Behavior: Overall Speeds		4.42				7.35	9.38	3.87	
Aerial Survey: Whale Days	3.03	4.40	0.84			5.31	16.62	2.96	
Telemetry Data[a]			3.40	4.38	6.45				
Mean	6.92	4.79	2.12	4.38	6.45	4.26	8.27	3.30	5.06
Lower 95 % confidence limit	4.64	3.25	0.75	2.52	4.60	2.86	5.68	2.57	4.22
Upper 95% confidence limit	10.32	7.06	5.99	7.61	9.04	6.34	12.05	5.78	6.07

[a] Telemetry data from Wartzok et al. (1989, 1990); Mate et al. (2000)

documented for traveling bowheads by Koski et al. (Chapter 11). Thus, in years with minimum residence times, such as 2000, it appears that most if not all whales traveled steadily across the study area without lingering to feed or for other purposes.

No useful telemetry data, either radio- or satellite-linked, were obtained during the present project, but relevant telemetry data were obtained in three years by other investigators. In 1988, a radio-tagged whale apparently traversed the study area without lingering (Wartzok et al. 1989). In 1989, Wartzok et al. (1990) tracked four subadult whales (9.5–12.5 m in length) through our study area during the 21–29 September period. The estimated average residence time of these whales in the "Flaxman–to–Herschel" area, based on locations at intervals of 1–5 days, was 4.4 days. This would represent an average of ~3.3 d in the "Flaxman–to–border" area. Mate et al. (2000) deployed satellite-linked transmitters on 12 bowhead whales in the Canadian Beaufort Sea during early September 1992. Five of these whales were tracked in the present study area. Minimum residence times in the "Flaxman–to–Herschel" area during the late summer/autumn period was 6.45 d, or ~4.9 d in the "Flaxman–to–border" area. The mean residence times of all the radio-tagged whales in the respective two regions were ~4.7 d and ~3.6 d, similar to the mean residence times of 5.1 d or 3.8 d calculated from all data.

For the overall population, the mean residence time in the "Flaxman–to–Herschel" area was 5 days (± 95 % CI 4.2 – 6.1), based on the mean of six approaches over all 8 years with data (Table 23.3). The means for the 8 individual years ranged from 2.1 to 8.3 d with the upper 95 % confidence limit ranging from 5.8 to 12.1 d. For the "Flaxman–to–border" area, the overall mean was ~3.8 d, with means for the individual years ranging from 2.5 to 6.3 d, assuming that the "divide by 1.32" method is appropriate. On this basis, the mean residence time in the "Flaxman–to–border" area did not exceed 7 days in any of the 8 years considered. The 95 % confidence bounds have not been calculated explicitly for the reduced estimates of residence time in the "Flaxman–to–border" area. However, when divided by 1.32, the upper confidence bound exceeded 7 d in two years: 1985 and 1999. Thus, although the estimated mean residence time in the "Flaxman–to–border" area averaged less than 7 days in each of the 8 years considered, it is possible that it might exceed 7 days in a small minority of the years.

Individual Bowheads

Question (3b), above, dealt with the residence times of individual bowheads. As shown above, an average BCB bowhead spends ~5.1 d in the "Flaxman–to–Herschel" area, or ~3.8 d in the "Flaxman–to–border" area, during late summer and autumn. However, in 1999 the average whale spent 8.3 d and 6.3 d in those areas. For the "Flaxman–to–border" area, the upper confidence bound probably exceeded 7 d in 2 of the 8 years. In addition, photographic resighting data show that some individual bowheads spent substantially more than 7 d in the "Flaxman–to–Herschel" study area (Table 23.4). The maximum recorded residence time in that area was 16 days, and there were 5 records of residence times ≥10 d. This suggests that some whales were likely to spend more than 7 d in the smaller "Flaxman–to–border" area, as one would expect with a mean of ~6.3 d in one year (1999).

Summary re Residence Times

Answer (3a)*:* An average bowhead spends ~3.8 days in the area from Flaxman Island to the Alaska/Canada border during the late summer/autumn period, or ~1.4 d longer than expected for a whale that swims steadily across that area. Averages in various years ranged from ~2.5 to 6.3 d. Although the average was <7 d in all years studied, it might exceed 7 days in a small minority of the years, based on the calculated upper 95 % confidence bounds.

Answer (3b)*:* Of the individual bowheads that travel through the eastern Alaskan Beaufort Sea, some spend at least 7 days between Flaxman Island and the Alaska/Canada border during late summer and autumn.

These conclusions are based on analysis of photoidentification data collected from mid-August to early October, including much (but not all) of the late summer/autumn migration period of bowhead whales through the central Beaufort Sea. The results have been scaled to estimate residence times in the "Flaxman–to–border" area, but they are actually based on data collected in the larger "Flaxman–to–Herschel" zone. Some bowheads are known to linger in the "border–to–Herschel" zone. Therefore, the estimates for the "Flaxman–to–border" area, of primary interest in this study, are more likely to be overestimates than to be underestimates.

Observations by local residents are generally consistent with these conclusions. However, their observations do not provide specific evidence on these questions because bowhead whales generally are not individually recognizable to observers in a small boat or on shore. Kaktovik residents sometimes see bowheads in a given area for 1–2 weeks or more (Chapter 2 and Annex B). One such area is between Icy Reef and Demarcation Bay, within the southeast part of the "Flaxman-to-border" area. However, it is uncertain from the hunters' observations whether the same individual whales remain for that long. One hunter indicated that bowheads tend to remain longer when the water is open than when ice is present.

Feeding in the Study Area

Two of the questions listed in Chapter 1 and repeated above concerned the frequency of feeding in the eastern Alaskan study area:

> *Question (4). What percentage of the bowheads that pass through the eastern Alaskan Beaufort Sea feed there? At least 10 percent?*
>
> *Question (6). During migration through the eastern Alaskan Beaufort Sea, how often are bowheads observed to feed while they are traveling? Is feeding while traveling evident more than 10 % of the time while traveling?*

TABLE 23.4. Within-year resighting intervals of bowhead whales in the "Flaxman Isl. to Herschel Isl." area of the Beaufort Sea, late summer to early autumn of 1985-2000 (from Chapter 11). Photographs were not taken on each day; therefore resighting intervals do not have equal probability of being recorded even if individual whales remained in the survey area. Only the first and last sighting of each whale in each year is included.

Zone	Unique Whales	Span of	Number of Resightings at Interval 1-21 days																							
Year	Photographed	Study (d)[a]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Mean	s.d.	*n*
"Flaxman Isl. to Herschel Isl." [b]																										
1985	177	33	0	1	2	0	1	0	0	0	0	0	2	0	0	1	0	1	-	0	-	-	0	8.13	5.51	8
1986	267	31	4	3	0	1	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	4.18	4.45	11
1998	141	9	1	0	0	0	0	0	-	0	X[c]	X	X	X	X	X	X	X	X	X	X	X	X	1.00	-	1
1999	397	21	2	1	1	2	1	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	X	4.10	2.51	10
2000	33	9	0	0	0	0	0	0	0	0	X	X	X	X	X	X	X	X	X	X	X	X	X	-	-	0
All years																								5.10	4.46	30
Average of means for "Eastern Alaska" in each year																								4.35		4

[a] Span includes both the first and last days with photographs in the area. Maximum resighting interval is one day less than the span.

[b] Includes Yukon west of Herschel Island (Fig. 11.1).

[c] "X" indicates that resighting intervals of this length would have been beyond the span of the study.

Numbers of Whales that Feed

On average, bowhead whales spent 3.8 days in the "Flaxman-to-border" area during late summer and autumn in the eight years listed in Table 23.3, based on the ÷1.32 factor previously discussed. On average, these whales spent 47 % of their time feeding (Table 23.2). Estimates of "proportion of time feeding" for each of the five years of the study are shown in Table 23.5. In 4 of 5 years, bowheads fed for ≥38 % of their time in the study area during late summer/autumn (Table 23.5). A considerable proportion of the observed feeding was simultaneous with travel. Of 581 surfacings involving feeding, 158 (27 %) also involved travel. Also, of 369 surfacings by traveling whales, 158 (43 %) also involved feeding (from Table 12.3A in Chapter 12).

TABLE 23.5. Proportion of the time spent feeding during each year of the study, based on behavioral observations (Chapter 12).

	1985	1986	1998	1999	2000	Overall
Proportion of time feeding	0.39	0.58	0.38	0.66	0.09	0.47

Of the 29 whales harvested at Kaktovik and characterized as either feeding or not feeding based on stomach contents, 24 of 29 (83 %) were classified as feeding, including 7 of 9 adults and 17 of 20 subadults (Chapter 18). Of the 18 whales landed at Kaktovik for which volume of stomach contents was noted, eight (39 %) had ≥20 L of stomach contents (Table 18.5).

***Answer (4)**:* Based on stomach content data, supplemented by behavioral evidence, far more than 10 % of the bowheads that pass through the eastern Alaskan Beaufort Sea during late summer and autumn feed there. Of the whales harvested at Kaktovik, 83 % had food in their stomachs, and 39 % had ≥20 L of stomach contents.

***Answer (6)**:* Bowheads fed for an average of 47 % of their time in the eastern Alaskan Beaufort Sea during late summer and autumn. A substantial minority of the feeding occurred during travel. Among traveling whales, feeding as well as travel was occurring during a substantial percentage of the time, on the order of 43 %.

The answer to Question (4) is based mainly on stomach content data from whales harvested at Kaktovik, and thus is to some extent specific to the fraction of the eastern Alaskan Beaufort Sea where hunters from Kaktovik harvest whales. That area extends to ~40 km east, 25 km north, and 25 km west of Kaktovik (Kaleak 1996). However, behavioral observations relevant to Questions (4) and (6) indicate that feeding is common across the larger area from central Camden Bay to the Alaska/Canada border and beyond (Fig. 12.5 in Chapter 12; see also Treacy in prep.). Both stomach content and behavioral data extend from early September to early October (Table 23.1).

Our conclusion concerning Question (4) is consistent with local knowledge. Whale hunters and other residents of Kaktovik know that the stomachs of most bowheads harvested near Kaktovik contain zooplankton, and believe that the area near Kaktovik is important for feeding (Chapter 2; Annex B). Local residents and hunters have no real opportunity to provide information relevant to Question (6). Most local residents report that they rarely can distinguish feeding from other activities when they see whales at sea. This is not surprising, given the low vantage points, and the fact that bowheads seen from a moving boat are likely to be avoiding the boat even if they were originally feeding before the boat approached (Richardson and Malme 1993).

Food Availability to Feeding Whales

Zooplankton sampling near bowheads found that average zooplankton biomass near whales was very much higher than that in the water generally. Also, the mean zooplankton biomass in these concentrations varied from year to year. Copepods were the dominant organisms, on a biomass basis, in our samples from the eastern Alaskan (and Canadian) Beaufort Sea. Euphausiids contributed a much lower proportion of the biomass in the net samples, and we did not collect high biomasses of euphausiids during our zooplankton sampling. However, euphausiids are commonly eaten by bowheads landed at Kaktovik (Chapter 18; Chapter 2), and concentrations of euphausiids were found in Camden Bay by Wartzok et al. (1990; Chapter 6).

Question (5) concerned the fraction of the study area that contained concentrations of zooplankton sufficiently dense to allow economical feeding by bowhead whales:

> *Question (5). What percentage of the geographic area within the study area is suitable as feeding habitat in different years? Is at least 1 % of the study area suitable in some years?*

This type of question can be addressed based on the quantitative echosounder surveys conducted during the project.

To address this question it is first necessary to determine what constitutes suitable feeding habitat. Horizontal plankton tows guided to layers of concentrated zooplankton by an echosounder have been made at 17 locations where bowheads were observed <1 km from the sampling boat (Chapter 6). These locations were in the Canadian Beaufort Sea in 1981, 1985 and 1986 (n = 13), and in the eastern Alaskan Beaufort Sea in 1986 and 1999 (n = 4). The lowest biomass in these tows was 545 mg/m^3. For 4 of 17 stations, the highest biomass measured was 771–807 mg/m^3, and for 11 of 17 stations the highest value was ~1000 mg/m^3. Biomasses of ~800 mg/m^3 may represent the feeding threshold for bowhead whales, i.e., the minimum biomass for economical feeding. A comparison of the maximum biomass in net tows with the maximum biomass estimate derived by echosounder at these stations suggests that the net did sample within the layer of highest zooplankton biomass (Chapter 6). Mean biomass in the water column at 173 stations where whales were not observed from the boat in the Canadian Beaufort Sea and Eastern Alaskan Beaufort Sea in 1980, 1981, 1985, 1986, 1998 and 1999 was 230 ± s.d. 173 mg/m^3.

Griffiths et al. (Chapter 6) conducted echosounder surveys to determine the nature and extent of zooplankton patches within the eastern Alaskan study area. Relationships between "acoustic biomass" as measured by the echosounder and net biomass of zooplankton as determined by horizontal tows had been developed by Johnson and Griffiths (1990) and Griffiths (Chapter 4). These acoustic biomass vs. net biomass regressions were used to convert results from echosounder surveys over broad geographical areas to estimates of zooplankton biomass present at each depth along the echosounder transects. During four years of sampling, biomass was recorded for a total of 1860 two-minute transect segments, each spanning a horizontal distance of ~240 m (Table 23.6). When these same 2-min segments were subdivided into 1- or 2-m depth intervals, there were 53,399 such 2-min (~240 m) by 1- or 2-m depth intervals (Table 23.7).

Averaged over four years, 25 % of the surveyed area contained a zooplankton biomass ≥800 mg/m^3, the presumed feeding threshold for bowhead whales, at some depth below the surface (Table 23.6). During each year of sampling there were many segments that contained a biomass >800 mg/m^3 (Tables 23.6 and 23.7). At least 7 % of the surveyed area had ≥800 mg/m^3 at some depth during all four years with effective echosounder surveys. The presumed 800 mg/m^3 threshold was exceeded in 2.2 % of the total volume of water sampled (Table 23.7).

TABLE 23.6. Number and percent of total 2-min (~240 m) horizontal segments that contained zooplankton biomass ≥800 mg/m^3 in one or more 2-m (1985–86) or 1-m (1999–2000) depth intervals. Sampling was conducted in the Alaskan Beaufort Sea (Camden Bay to Alaska/ Canada border) with a 200 kHz echosounder in 1985–86, and a 430 kHz echosounder in 1999–2000.

	2 minute (~240 m) horizontal segments		
Year	Number	≥800 mg /m^3	Percent
2000	512	50	10 %
1999	370	25	7 %
1985	330	108	33 %
1986	648	280	43 %
Total	1860	463	25 %

TABLE 23.7. Number of sampling cells, and percent of total volume of water sampled, that contained zooplankton biomass ≥800 mg/m^3. Sampling cells were 2-min (~240 m) in horizontal extent by 2-m (1985–86) or 1-m (1999–2000) depth intervals. Otherwise as in Table 23.6.

	2–min. x 1 or 2 m depth Intervals		
Year	Number	≥800 mg /m^3	Percent
2000	14,167	83	0.6 %
1999	10,931	25	0.2 %
1985	5163	157	3.0 %
1986	23,138	902	3.9 %
Total	53,399	1167	2.2 %

***Answer (5)**:* The percentage of the study area suitable as feeding habitat, i.e., with ≥800 mg/m^3 zooplankton at some depth, averaged 25 % over four years with effective echosounder sampling, and varied from 7 % to 43 % in individual years.

The echosounder data used to address Question (5) came from continental shelf waters (0 to 200 m deep in 1985–86; 0–50 m deep in 1998–2000) between central Camden Bay and the Alaska/Canada border during the period of peak bowhead abundance in early–mid September (2–22 Sept.). The assumed feeding threshold of ≥800 mg/m^3 is based on sampling near feeding whales both in that area and in the Canadian Beaufort Sea, including data from mid-August to 22 September.

Question (5) can only be addressed through specialized zooplankton sampling procedures. Thus, there is no specific local knowledge relevant to this point. However, residents of Kaktovik mentioned that they sometimes see concentrations of "krill" in or on the water, and that amounts of krill vary from year to year (Chapter 2; Annex B).

Food Consumed in the Study Area by the Population and by Individual Whales

The overall purpose of the project, as defined by the Minerals Management Service and quoted at the start of this chapter, included a number of interrelated components: to compile and integrate existing traditional and scientific knowledge about the importance of the eastern Alaskan Beaufort Sea for feeding by bowhead whales; to build consensus on the need for and approach to fieldwork to augment this knowledge; to conduct the field studies and to analyze the results; to integrate them with existing traditional and scientific knowledge; and to report on and publish the results. Although the overall purpose was fairly broad, the central question to be addressed during this study has been phrased as follows:

> *Question (1). In an average year, how important is the eastern Alaskan Beaufort Sea for bowhead whales; what percentage of the population's annual energetic requirements is derived from the area?*

In this subsection, we attempt to estimate that percentage, recognizing that this percentage represents only one of many possible descriptors of the importance of the study area to bowhead whales.

Thomson (Chapter 22) estimated the food requirements of various size/age/reproductive categories of bowhead whales. The estimate of energy requirements derived through consideration of heat loss plus the costs of motion, growth and reproduction will be used in the calculations in this section. Food requirements per feeding day are computed based on the theoretical total annual food requirements divided by the estimate of ninety-three 24–hour days of feeding per year, as calculated in Chapter 22. (Feeding occurs on many more than 93 calendar days, but not for 24 hours on any one day.) Appendix 23.2 also describes the calculation procedure. The following analysis is mainly concerned with the proportion of food obtained in the study area relative to other areas and so is insensitive to the estimated rate of consumption. In estimating the proportion of total annual diet that is consumed in the eastern Alaskan study area, we consider the area from Flaxman Island to the Alaska/Yukon border, and from the shore to the 200 m depth contour, as outlined by the heavily-dotted line in Figure 23.1.

Based on the population census taken at Barrow in 1993 (Zeh et al. 1996), and the estimated rate of increase of the population (Punt and Butterworth 1999), the BCB population is estimated to consist of 10,223 bowheads in 2000 (see "Background", above). Angliss et al. (1995) estimated that 41.1 % of the population were adults ≥13 m in length, 53.7 % were subadults, and 5.2 % were calves. It will be assumed that the ratio of adult males to females is 1 : 1.

Use of the Area by Feeding Whales

Whale-days of use of the study area during the late summer and autumn period were estimated in Chapter 9, separately by year (see Table 23.8). These estimates pertain to the specific area considered here, i.e., from Flaxman Island to the Alaska/Canada border, and from the shore to the 200 m depth contour. The estimates were based on aerial survey results analyzed by line-transect methods and adjusted using various correction factors. These correction factors, derived in Chapter 15, allowed for whales present but missed by aerial surveyors. Chapter 9 applies the correction factors to the aerial survey data. In each year, there were 5 to 11 days with sufficient aerial survey coverage for a direct estimate of total numbers present on that day or an adjacent pair of days. Numbers present on days with no coverage were estimated based on these direct estimates and the seasonal pattern of densities (see Chapter 9). Results were summed for the 7 August to 27 October period. Because there is considerable variation in these data and because whale-days is one of the most critical numbers used in estimating amount of food consumed in the study area, whale-days of use were included in the sensitivity analysis described below and in Appendix 23.2.

Whale-days for each year were multiplied by the proportion of time spent feeding for each year (from Chapter 12) to derive the estimated feeding-days of use for each year (Table 23.8).

TABLE 23.8. Estimated numbers of whale days of use of the "Flaxman-to-border" area (from Chapter 9), proportion of time spent feeding (from Chapter 12), and feeding days of use per year and for all years combined. The estimates include calves. The "Proportion of time feeding" and "Feeding-Days of Use" include time at the surface between feeding dives, plus time engaged in other activities that were interspersed with active feeding and not distinguished from feeding.

Fall Study area	1985	1986	1998	1999	2000	Avg./yr
Number of whale-days of use	11,937	17,899	31,507	101,850	18,727	36,384
Proportion of time feeding	0.39	0.57	0.38	0.67	0.09	0.47
Feeding-Days of Use	4,643	10,228	11,915	67,900	1,702	16,953

Amount of Food Consumed in the Study Area

In this subsection we estimate the proportion of annual energetic requirements consumed in the study area by the Bering–Chukchi–Beaufort population of bowhead whales. The amount of food consumed in the study area was estimated separately for each year, and these estimates were compared to annual consumption by the entire population.

Energetic and food requirements of bowheads were estimated in Chapter 22. The estimates of total annual and daily food requirements of individuals, by size class, were based on the estimated standard metabolism (heat loss) plus the energetic cost of swimming, weight gain (growth), and reproduction. Bowheads do not feed continuously, so a feeding rate per unit of time spent feeding needed to be computed. Based on behavioral observations and an assumption that bowheads do not feed in winter, bowhead whales may feed for the equivalent of ~93 days of continuous 24-hour feeding per year (see Chapter 22). Thus, the feeding rate per feeding-day, based on calculated annual requirements divided by 93 feeding-days, is 773 kg/d for an average subadult, 905 kg/d for an average adult male, and 1421 kg/d for an average adult female (Table 23.9A).

Because the population of bowheads increased during the course of the study, population size was estimated separately for each year of the study (from Appendix 9.2 in Chapter 9). For each year, the population was apportioned as numbers of subadults, adult males, and adult females according to Angliss et al. (1995). Calves were not included in Table 23.9, as their energy requirements are included in those of their mothers. Hence, the numbers of whales considered for each year add up to slightly less than 100% of the total population size.

Annual food consumption in the study area for each year of the study was estimated through consideration of several factors: estimated whale days in the study area, their size class composition, the percent of time spent feeding, and the average amount of food that must be consumed per day to meet annual energetic requirements. The factors and calculations are summarized in Table 23.9B. Whale days for each year were apportioned to subadults, adult males, and adult females according to their proportional presence in the study area that year, as determined via aerial photogrammetric methods (Chapter 11). Calves were not considered, so the total number of whale days per year, as shown in Table 23.9B, is lower than shown in Table 23.8. The number of whale days was multiplied by the proportion of time spent feeding for each year of the study (Table 23.5) to obtain whale feeding days by size category. The estimate of feeding days was not reduced to account for the time bowheads spend at the surface breathing, or (perhaps) cleaning baleen, or for the time engaged in other activities that were not distinguished from "feeding". Thus, feeding time is overestimated by this procedure. Whale feeding days for each size category were multiplied by the estimated average daily food requirement per feeding day for that size category (from Table 23.9A), and summed across size categories to determine total food consumption in the study area.

TABLE 23.9. Theoretical energetic requirements of the entire BCB bowhead whale population and proportion of the total food requirements that could have been obtained in the eastern Alaskan study area (Flaxman Isl. to Alaska/Canada border) in 1985, 1986, 1998, 1999, and 2000.

	Units	Subadults	Adult Males	Adult Females	Total
A. Food Requirements of the Population					
% of Population[a,b]		54%	20.6%	20.6%	94.8%
Individual requirements[c]	kJ x 10^5/yr	1573	1934	2903	
	kg/yr	71,640	88,046	132,181	
Food Requirements/Feeding Day/animal[d]	kJ x 10^5/d	16.97	20.86	31.31	
	kg/d	773	950	1,421	
B. Food Consumed in the Study Area					
1985 Number of Animals = 6373[e]		3,422	1,313	1,313	6,042
Population Requirements	kg /yr	245,173,741	115,590,284	173,532,615	534,296,640
Proportion of Study-Area Population [f]		0.833	0.072	0.072	0.978
Whale Feeding Days in Study Area [g]		3,869	335	335	4,540
Zooplankton Consumption	kg	2,990,116	318,489	476,625	3,785,230
Percent of Annual Consumption		1.2%	0.3%	0.3%	0.7%
1986 Number of Animals = 6577[e]		3,532	1,355	1,355	6,235
Population Requirements	kg/yr	253,021,763	119,290,334	179,087,402	551,399,498
Proportion of Study-Area Population [f]		0.665	0.115	0.115	0.895
Whale Feeding Days in Study Area [g]		6,802	1,174	1,174	9,151
Zooplankton Consumption	kg	5,256,625	1,115,470	1,669,322	8,041,416
Percent of Annual Consumption		2.1%	0.9%	0.9%	1.5%
1998 Number of Animals = 9599[e]		5,155	1,977	1,977	9,100
Population Requirements	kg/yr	369,280,204	174,101,857	261,374,482	804,756,543
Proportion of Study-Area Population [f]		0.811	0.081	0.081	0.973
Whale Feeding Days in Study Area [g]		9,660	966	966	11,593
Zooplankton Consumption	kg	7,465,305	917,491	1,373,043	9,755,840
Percent of Annual Consumption		2.0%	0.5%	0.5%	1.2%
1999 Number of Animals = 9906[e]		5,320	2,041	2,041	9,391
Population Requirements	kg/yr	381,090,707	179,670,069	269,733,891	830,494,667
Proportion of Study-Area Population [f]		0.453	0.242	0.242	0.936
Whale Feeding Days in Study Area [g]		30,751	16,407	16,407	63,566
Zooplankton Consumption	kg	23,763,438	15,582,767	23,319,904	62,666,108
Percent of Annual Consumption		6.2%	8.7%	8.6%	7.5%
2000 Number of Animals = 10,223[e]		5,490	2,106	2,106	9,691
Population Requirements	kg/yr	393,285,917	185,419,657	278,365,593	857,071,167
Proportion of Study-Area Population [f]		0.593	0.148	0.148	0.889
Whale Feeding Days in Study Area [g]		1,009	252	252	1,513
Zooplankton Consumption	kg	779,602	239,534	358,467	1,377,603
Percent of Annual Consumption		0.2%	0.1%	0.1%	0.2%
1985 - 2000 Average Pop. Requirements	kg/yr	328,370,466	154,814,440	232,418,797	715,603,703
Zooplankton Consumption	kg	8,051,017	3,634,750	5,439,472	17,125,239
Percent of Annual Consumption		2.5%	2.3%	2.3%	2.4%

[a] From Angliss et al. (1995).

[b] Does not include calves whose energy is derived from lactating females.

[c] From Chapter 22; standard metabolism + cost of motion + growth; assumes average adult is 14.5 m in length.

[d] Assumes 93 feeding days per year and the “individual requirements” values quoted above.

[e] Total bowhead population size from Appendix 9.2 (in Chapter 9); breakdown by age and status is from Angliss et al. (1995) and total does not include calves.

[f] From Chapter 10; total does not include calves.

[g] From Table 9.3 (in Chapter 9) and Table 23.8, adjusted to exclude calves.

[h] Assumes late summer/autumn energy content of zooplankton (Chapter 22)

Food Consumed in Study Area vs. Overall Annual Diet

Estimated food consumption by bowheads in the eastern Alaskan study area (Flaxman Isl. to Alaska/Canada border) was expressed as a percentage of total annual consumption by the population. This was done separately for each year of the study, and averaged for the five years of the study (Table 23.9B).

Based on this approach, in an average year the population of bowhead whales is estimated to consume about 2.4 % of its annual energetic requirements in the study area (Table 23.9B). In one of 5 years (1999), the population of bowheads may have derived about 7.5% of annual energetic requirements there. In all other years, estimated consumption in the study area was <2 %. On average, feeding in the eastern Alaskan Beaufort Sea was apparently of similar importance to subadults and adults (Table 23.9B).

The substantially higher estimate of food consumption in the study area in 1999 than in other years is a result of the markedly higher estimate of "whale-days in the study area" for 1999 (Table 23.9). Other measures of utilization of the study area do not show such a large difference in use between 1999 and the other four years of detailed study (Table 23.3). It is possible that we have overestimated whale-days in the study area during 1999, and thus food consumption in the area in that year.

Many assumptions are involved in this analysis, and there is considerable uncertainty in many of the estimates used in the calculations. However, the estimated mean consumption in the study area (2.4 % of annual requirements) is quite low. Even if mean consumption were substantially underestimated for some unknown reason, it is implausible that the population would consume more than a few percent of its annual food requirements in the study area in an average year (see below).

Uncertainties and Potential Errors in the Estimate

The estimate that an average bowhead whale consumes ~2.4 % of annual energetic requirements in the study area is independent of the manner in which energetic requirements are calculated. If our estimates of the relative food requirements of subadults, adult males, and adult females are approximately correct, then the estimated percent of annual food requirements obtained in the study area is independent of the actual feeding rate. Even if identical feeding rates were assumed for the three size/sex classes, the final result would differ by only 0.01 % (i.e., 2.39 % vs. 2.40 %).

The estimated percent of annual consumption that occurs in the study area is sensitive to the estimated number of whale-days in the study area, the proportion of time spent feeding, number of feeding days per year, and size and makeup of the entire population. All factors used to estimate percent of food consumed in the study area, including daily energetic requirements, were included in a sensitivity analysis (Appendix 23.2). The main data used in the simulation were whale days, proportion of whales in the study area by age class, proportion of time spent feeding, total population size, and proportional composition of the population by age and reproductive class. Standard errors of these and other variables were computed from the original data, derived from the literature, or otherwise approximated, as described in Appendix 23.2. Although the sensitivity analysis is complex and allows for many sources of variability, it necessarily involves many assumptions and approximations. Nonetheless, it provides useful guidance concerning the uncertainty in the estimated proportion of the diet obtained in the study area.

The 95 % confidence limits of the percent of food consumed in the study area are shown in Table 23.10, based on Appendix 23.2. In 4 of 5 years, the upper bound of the 95 % confidence interval was below 5 %. If the high whale-days estimates for 1999 are correct, then consumption in the study area during that "high-utilization" year, estimated in Table 23.9 as 7.5 % of annual population requirements, might have been even higher if other parts of the calculation were underestimated. The upper 95 % confidence interval for

TABLE 23.10. Estimated proportion of the total annual food requirement of the BCB bowhead population that could have been obtained in the eastern Alaskan study area (Flaxman Isl. to Alaska/Canada border) in each of the five study years, and its 95 % confidence limits (from Appendix 23.2).

	Estimated	95% Confidence Limits	
Year	**% of Food**	**Lower**	**Upper**
1985	0.7	0.2	3.0
1986	1.5	0.6	3.6
1998	1.2	0.4	3.4
1999	7.5	3.4	16.5
2000	0.2	0.0	0.9

1999 is 16.5 % of total food consumed by the population, given the various assumptions and the observed variability in data. However, we suspect that the whale-days figure for 1999 was overestimated, and that the 16.5 % upper confidence bound is unrealistically high. In any event, it is possible that consumption in the study area during a high-utilization year might exceed 5 % of annual population requirements. All lines of evidence indicate that utilization of the study area varies widely in space and time, depending on zooplankton availability and other factors.

This estimation process assumes that average prey availability is the same in all areas where bowhead whales feed. However, average prey availability at bowhead feeding locations is suspected to be higher at autumn feeding sites in the western Beaufort Sea, southwest Chukchi Sea, and (perhaps) northwest Bering Sea, than in the summer/early fall feeding areas in the eastern and central Beaufort Sea. If so, the bowhead population probably obtains a lower percentage of its annual diet in the present study area than calculated here, and a higher percentage in the late-autumn feeding areas farther west. The presumed lower prey availability in winter and spring do not offset the presumed higher prey availability in late fall. Our calculations assume that bowheads spend no time feeding in winter, and little time feeding in spring. Thus, low prey abundances in winter and spring would have little downward effect on the proportion of annual requirements met in those seasons. In contrast, a high prey abundance in Bering/Chukchi waters in late fall would allow bowheads to acquire more of their annual diet in late fall, thus reducing the proportion likely obtained in the present study area.

As noted earlier, the estimation process did not make any downward adjustment to the feeding time to allow for time spent at the surface or otherwise “not feeding” during periods when whale activities were classified as “feeding”. This is likely to result in an overestimate of food consumption. Given this factor, plus the effects of the presumed higher prey abundance in the Bering/Chukchi system where bowheads feed in autumn (see above), our estimates of the percent of the annual dietary requirements acquired in the eastern Alaskan Beaufort Sea are more likely to be overestimates than underestimates.

Summary of Food Consumed

Bowhead whales do not spend enough time in the study area to consume more than a small fraction of annual requirements. However, in the occasional year when utilization of the study area by feeding bowhead whales is considerably higher than average, it is possible that the population may derive 5 % or more of its annual energetic requirements from the area.

***Answer (1)**: In an average year, the population of bowhead whales derives an estimated 2.4 % of annual energetic requirements in the eastern Alaskan Beaufort Sea. In 1 of 5 years of study, the population may have derived 7.5 % or more of annual energetic requirements from the area. Utilization of the study area varies widely in time and space depending on zooplankton availability and other factors.*

These estimates are based on many different types of data collected at varying locations within and near the study area in varying parts of the late summer/early autumn period, along with general analyses of bowhead energetics. Specific sources of data, uncertainties, and potential biases are documented throughout this report, including Appendix 23.2. In general, we believe that the resulting values are reasonable estimates for the eastern Alaskan study area (Flaxman Island to the Alaska/Canada border; from shore to the 200 m contour). If anything, the estimates are likely to overstate the actual proportion of the diet acquired in this area, for reasons mentioned in the preceding subsection.

Some reviewers have noted that the eastern Alaskan Beaufort Sea is only a small proportion of the Beaufort Sea, and an even smaller proportion of the area where BCB bowhead whales are known to feed. Also, it is common knowledge, further documented in this study, that the study area is occupied by large numbers of bowheads for only a relatively small part of the year. Given this, it would be very surprising if the present study area did provide a high proportion of the population's annual food requirements. Based on this rationale, some reviewers have commented that it is unreasonable to judge the importance of the eastern Alaskan Beaufort Sea based simply on the percentage of the annual food requirements that it provides to BCB bowheads. They note that it would also be important to know how much food is obtained in the present study area as compared with other areas of comparable size. Specific studies of feeding in other areas were outside the scope of the present project.

Whale hunters and other residents of Kaktovik know that bowheads feed near Kaktovik because they see food in the mouths and stomachs of the whales, and they sometimes see whales feeding on prey concentrations. They believe that the area near Kaktovik, and the Beaufort Sea generally, is important for feeding (Chapter 2; Annex B). Bowhead whales are of great cultural importance to the Inupiat and are a major source of food. Thus, any area used by bowheads, especially when it is also a hunting area, is considered important. No matter what percentage of the annual food requirement is derived from the eastern Alaskan Beaufort Sea, local residents will continue to view their hunting grounds as an important area for bowhead whales.

Individual Bowhead Requirements

Given the energetic requirements of individual whales discussed above, an assumption that bowheads feed (intermittently) for a total of ninety-three 24-hour days per year, and evidence that bowheads feed during 47 % of their time in the eastern Alaskan Beaufort Sea, individual whales would need to spend ~10 days in the area in order to consume 5 % of annual food requirements (Table 23.11). They would need to spend ~20 days in the area to consume 10 % of annual requirements. Over the five years of our study, the average whale spent ~4 days in the eastern Alaskan area from Flaxman Island to the Alaska/Canada border. If a whale spent 4 d in the study area, it could consume about 2.5 % of annual requirements. This is close to the 2.4 % of annual requirements computed in Table 23.9 based on a different approach starting from estimated whale-days of use and other factors.

For the overall population, the mean residence times in the "Flaxman–to–border" area during individual years of study ranged from 2.5 to 6.3 d. These figures are based on the "Flaxman–to–Herschel" data in Table 23.3 divided by 1.32 to estimate averages for the "Flaxman–to–border" area. If the 1.32 factor is applied to the 95 % confidence bounds, the (adjusted) upper bound for mean residence time in the "Flaxman–to–border" area

TABLE 23.11. Percent of annual requirements potentially consumed in the eastern Alaskan Beaufort Sea by individual whales that might remain in that area over the specified periods of time. Energetic requirements are based on standard metabolism plus the cost of transport, feeding for the equivalent of 93 days per year (24 hours per day), and feeding for 47 % of their time in the eastern Alaskan Beaufort Sea.

	Units	Subadults	Adult Males	Adult Females
Annual Requirements	kJ x 10^5/yr	1724	2270	3269
Daily Requirements/Feeding Day	kJ x 10^5/d	20.77	27.35	39.38
Days in Study Area				
1	kJ x 10^5	0.5 %	0.5 %	0.5 %
5	kJ x 10^5	2.5 %	2.5 %	2.5 %
10	kJ x 10^5	5.0 %	5.0 %	5.0 %
15	kJ x 10^5	7.5 %	7.5 %	7.5 %
20	kJ x 10^5	10.1 %	10.1 %	10.1 %
30	kJ x 10^5	15.1 %	15.1 %	15.1 %

exceeds 7 d in two years, 1985 and 1999 (7.8 and 9.1 d, respectively). Although these mean residence time estimates do not pertain directly to individual whales, they imply that a minority of the individuals would be present in the study area for 10+ d, especially in years when mean residence time is higher than average. Individuals that spend 10 days in the eastern Alaskan Beaufort Sea could obtain ~5 % of their individual annual food requirements in the study area.

A few bowhead whales have been documented to remain for at least 11–16 days in the larger "Flaxman–to–Herschel" area (Table 23.4). Documented resighting-intervals of this type often underestimate residence times (see Chapter 11). Hence, a few whales probably remain in the "Flaxman–to–Herschel" area for 20+ days. However, it is not known whether any remain in the smaller "Flaxman–to–border" area (i.e., the eastern Alaskan Beaufort Sea proper) for the 20 days required to obtain ~10 % of their individual annual food requirements. If so, the numbers of individuals that do so must be small.

Recommended Research

This study has assembled much information, including both scientific results and traditional knowledge, concerning bowhead whale feeding, particularly in the eastern Alaskan Beaufort Sea. However, as is inevitable even after such a study, various questions about bowhead feeding dependencies remain unanswered or only incompletely answered. This section lists the additional research that has been recommended in Chapters 7, 16 and 21 concerning, respectively, • zooplankton; • bowhead distribution, numbers and activities; and • bowhead diet and regional feeding. Those three chapters include additional rationale and details concerning the recommendations on those topics. Also, this section includes a fourth subsection concerning recommended research relating to additional topics discussed in Chapters 22 and 23. No specific attempt has been made to assign priority rankings to research topics, and the sequence is not intended to imply any such ranking.

Zooplankton

1. *More precise estimates of food availability to bowheads in the eastern Alaskan Beaufort Sea would be possible if zooplankton sampling there could be extended to include the full period when bowheads use the area, or at least the main period of use from mid-August to mid-October.*

2. *To understand the relative importance of autumn feeding areas west of the present eastern-Alaskan area, studies of zooplankton availability in the more westerly areas during autumn would be useful.*

3. *Any follow-up study of zooplankton availability in different months or in different areas should be planned for a duration of at least 3 years if at all possible.*

4. *Any future bowhead feeding study needs to include guidance by aerial observers (or some other means, e.g., telemetry) to locations of feeding whales.*

5. *Within the eastern Alaskan Beaufort Sea, it would be desirable to obtain additional data on food availability and associated aspects of bowhead feeding in deeper waters*

6. *It will be desirable, in any similar future study of zooplankton availability to bowhead whales, to develop and use improved field and analysis methods that will provide more reliable and better-correlated net-sampling and echosounder results.*

7. *It would also be desirable to consider the suitability of improved or new types of zooplankton sampling gear that might be available (and practical) by the time a future study is being planned, e.g., opening-and-closing nets; video plankton recorder; specialized echosounder gear.*

8. *Data on day–night differences, if any, in the vertical distribution of zooplankton in areas and seasons where bowheads feed would be helpful in assessing food availability to bowheads.*

Bowhead Distribution, Numbers and Activities

9. *More data on distribution, activities, size segregation, and residence times of bowhead whales in the eastern Alaskan Beaufort Sea during the early and late parts of the season, e.g., July-August and October, would be helpful in better understanding the importance of the area to bowheads.*

10. *To understand the relative importance of autumn feeding areas west of the present eastern-Alaskan area, studies of bowhead activities, size segregation, and residence times in the more westerly areas during autumn would be useful.*

11. *Any follow-up study of bowhead utilization in different months or in different areas should be planned for a duration of at least 3 years if at all possible.*

12. *Within the eastern Alaskan Beaufort Sea, it would be desirable to obtain additional data on bowhead utilization of deeper waters throughout the summer and autumn*

13. *New technology has considerable potential to provide additional data concerning bowhead utilization of various parts of the Beaufort Sea and other areas:*

    (a) Satellite-linked and VHF (or UHF) radio tags could provide new levels of detail concerning distribution, movements, residence times, behavior, and disturbance responses.

    (b) The possibility of day–night differences in bowhead activities deserves further study, perhaps via VHF or UHF telemetry, as well as expanded use of satellite telemetry.

    (c) Passive acoustic detection, localization, and (occasionally) tracking of bowheads could also provide data on seasonal distribution, movements, and disturbance responses during autumn migration, although it is doubtful whether passive acoustic data could be related specifically to feeding whales.

Bowhead Diet and Regional Feeding

14. *Additional data on the stomach contents of BCB bowhead whales, especially from areas where few such data have been acquired previously, would be helpful in characterizing the frequency and intensity of feeding in different locations and seasons, the types of prey consumed, and any long-term trends in feeding activity. Areas and seasons where such data would be most valuable include the Chukotsk coast, the northern Bering Sea in winter/early spring, and the west coast of Alaska in spring.*
15. *While stomach-content samples are being obtained from harvested bowheads, tissue samples and measurements needed for other relevant studies should also be obtained, e.g., for fatty acid and stable-isotope studies; girth (vs. length) measurements.*
16. *Analyses of the fatty acid composition of bowhead blubber sampled at different geographic locations and seasons, along with corresponding analyses of potential prey items, have the potential to provide a different perspective on prey consumption by bowhead whales.*
17. *It would be desirable to compare stable isotope composition of additional samples of bowhead muscle from spring and fall, collecting these samples in the same years and processing them in strictly standardized ways.*
18. *Additional data on the stable-isotope composition of the blubber (and visceral fat) at various times of year would be useful in assessing seasonal turnover and the importance of feeding in different parts of the annual range.*
19. *There are many questions about the nature and extent of feeding in some areas outside the eastern Beaufort Sea, most notably the western Alaskan Beaufort Sea in autumn, the southwestern Chukchi Sea in late autumn, and the Bering Sea in winter. To assess feeding activity in those areas, a wide variety of study approaches could be valuable, including not only isotopic methods, but also most or all of the other methods used in the present study.*

Bowhead Energetics and Other

The research recommendations listed above have been described in more detail in chapters 7, 16 and 21, but the following recommendations related to bowhead energetics and other topics have not been described previously. Therefore, each of the following recommendations has a preamble outlining the rationale.

One major uncertainty affecting the energetic analysis is the unknown amount of feeding in winter. Isotopic results suggest that most feeding by both subadults and (especially) adults occurs outside the Beaufort Sea (Chapter 20). However, subadult bowheads harvested leaving the Beaufort Sea in fall are heavier and have a higher lipid content in their blubber than do subadults returning to the Beaufort Sea in spring. Measurements of length and girth from known scale aerial photographs confirm some weight loss in winter and some weight gain in the Beaufort Sea during summer (Chapter 22).

20. *More girth measurements are needed from harvested and/or photographed animals to accurately determine seasonal weight loss/gain by size category. Crucial to these measurements is an estimate of the amount of stretching that occurs when whales of varying sizes are hauled up on land vs. ice. Data on girths vs. lengths of whales in late autumn, after feeding in the southwest Chukchi Sea, would be of great value.*

Many of the morphometric and physiological data used to compute theoretical energetic requirements of bowhead whales have been derived for other species of whales in the absence of needed data from bowheads. The following is a list of some key parameters where presently-available data for bowhead whales are inadequate or lacking. Some of the needed data are being collected in an ongoing project by J.C. George, NSB-DWM. Data gaps should be re-evaluated when his work is completed.

21. *Data needed to estimate theoretical energetic requirements of bowhead whales include total lung volume, tidal lung volume, temperature of expired air, thermal conductivity of blubber, heat loss through the mouth, amount of heat dumped by the whales when they overheat, coefficient of drag, size of mouth opening, and swimming speed while submerged and feeding.*

Sampling of food available at places where bowheads were observed feeding has only been conducted near subadult bowheads feeding in late summer and early fall. These data came from feeding sites in the Canadian and eastern Alaskan Beaufort Sea. At these sites, the average prey availability measured at the depth of maximum prey biomass was 1.8 g/m^3 on a wet weight basis (Chapter 6). Estimated prey consumption by subadults feeding in such locations is only about half that required by even the low estimate of theoretical energetic requirements (Chapter 22). Bowhead whales may derive much of their energy by feeding in the densest patches of zooplankton in the Beaufort Sea (denser than most or all of those sampled to date), and by feeding in the Bering/Chukchi system. To better document the extent to which bowheads locate and feed in dense patches of zooplankton, more zooplankton sampling near bowhead whales is needed, preferably with improvements in matching precise sampling locations/depths with feeding locations/depths. In particular,

22. *To obtain a comprehensive understanding of the annual feeding ecology of bowhead whales, zooplankton sampling should be attempted near adult bowheads feeding in summer in the Beaufort Sea, and near bowheads feeding in fall in the western Beaufort and southwest Chukchi seas.*

Bowhead whale distribution in the study area (and elsewhere) is closely related to the distribution of zooplankton concentrations (Chapter 6). However, factors controlling zooplankton biomass and composition at specific locations and times are not well understood for the Beaufort Sea.

23. *Physical and biological oceanographic studies designed specifically to better understand the productivity and local distribution of zooplankton in the Beaufort Sea would be helpful in understanding the feeding ecology of bowhead whales.*

Summary

The purpose of the project, as defined by the Minerals Management Service, was to compile and integrate existing traditional and scientific knowledge about the importance of the eastern Alaskan Beaufort Sea for feeding by bowhead whales; to build consensus on the need for and approach to fieldwork to augment this knowledge; to conduct the field studies and to analyze the results; to integrate them with existing traditional and scientific knowledge; and to report on and publish the results. Preceding chapters have described the variety of studies included in the project, efforts to coordinate the work with local residents, and incorporation of local knowledge of bowhead whales into the project. This chapter draws the various lines of evidence together in order to address several key questions regarding the importance of the study area for feeding by bowhead whales. In this final chapter, the study area is considered to extend from Flaxman Island to the Alaska/Canada border (a distance of ~205 km), and from the shore to the 200 m depth contour.

The activities of bowhead whales throughout the year need to be considered when assessing the importance of feeding in the eastern Alaskan Beaufort Sea during late summer and autumn. Bowhead whales are known to feed in the Canadian Beaufort Sea in summer/early fall, and during westward migration across the Alaskan Beaufort Sea during late summer and fall. At least some of the bowheads also feed in the southwest Chukchi Sea in mid- to late fall. Bowhead activities in the Bering Sea during winter have not been studied. There is some feeding, probably quite limited, during spring migration around western Alaska. Although behavioral observations and stomach contents provide some data on feeding intensity during spring, summer, and early fall, such data are lacking for late fall in the Chukchi Sea, and from winter. It is unclear, from the available data of those types, what fraction of the annual feeding occurs in any one part of the annual range.

A comparison of carbon isotope ratios in bowhead muscle and baleen with those in the main food organisms suggests that bowhead whales consume only a minority of their food in the eastern and central Beaufort Sea, including Canadian as well as eastern Alaskan waters:

- Based on stable-isotope evidence, bowhead whales likely consume only 10 to 26 % of their food in the eastern and central Beaufort Sea. Subadult bowheads appear to derive >10 % of annual food requirements there, although the 95 % confidence interval extends below 10 %. It is also probable that adults gain >10 % of their food in that area, but for adults the isotope evidence considered in isolation would support an answer of <10 %.

The isotope results are surprising in relation to several other types of evidence that show considerable feeding by bowheads in the eastern and central Beaufort Sea during summer and early autumn: • Behavioral observations show that bowheads spend much of their time feeding while in those areas. • Zooplankton sampling near bowheads feeding in those areas shows that whales concentrate their feeding at locations with much higher than average biomasses of zooplankton. • Stomach contents of bowheads harvested during late summer and autumn at three locations in the Alaskan Beaufort Sea (including Kaktovik, within the eastern Alaskan Beaufort) show that most bowheads, both subadult and adult, had been feeding shortly prior to death. • Length–girth relationships show that subadult bowheads, and possibly adults, gain weight while in the Beaufort Sea in summer, and lose weight while elsewhere. • Lipid content of blubber, at least of subadults, is higher when they leave the Beaufort in fall than when they return in spring. Although some of this evidence is preliminary and based on small sample sizes, this evidence suggests the importance of feeding in the Beaufort Sea during summer and early autumn.

A feeding scenario that might be consistent with all these data is as follows: Feeding occurs commonly in the Beaufort Sea in summer and early autumn, and bowheads gain energy stores while feeding there. However, zooplankton availability is not as high in the Beaufort Sea during summer as in the Chukchi and northern Bering seas during autumn. Also, feeding in the western Beaufort in autumn may effectively be on Chukchi prey advected to that area. Thus, bowheads might acquire more energy from Bering/Chukchi prey in autumn than from eastern and central Beaufort prey in summer/early autumn. Given this, plus an assumed low turnover rate of body components, the overall body composition of bowheads may be dominated by components from the Bering/Chukchi system even at the end of the summer when leaving the Beaufort. Energy gained in the Beaufort and Chukchi seas during summer and fall is presumably used during winter when food availability is low, resulting in reduced girth and energy stores when returning to the Beaufort Sea in spring than when leaving in autumn. Several aspects of this scenario are speculative, thus pointing toward topics warranting further research.

Although various types of evidence (with the exception of isotope ratios) indicate that the eastern Beaufort Sea as a whole, including the Canadian Beaufort, is important to bowhead whales for feeding, the eastern Alaskan Beaufort Sea is only a small fraction of that area. It was of interest to know how much time an average whale, and some individual whales, spend in the specific eastern Alaskan Beaufort

Sea. Was there evidence of average or individual residence times of at least 7 days? Analysis of several types of data resulted in the following conclusions:

- An average bowhead spends ~3.8 days in the area from Flaxman Island to the Alaska/Canada border during the late summer/autumn period, or ~1.4 d longer than expected for a whale that swims steadily across that area. Averages in various years ranged from ~2.5 to 6.3 d. Although the average was <7 d in all years studied, it might exceed 7 days in a small minority of the years, based on the calculated upper 95 % confidence bounds.
- Of the individual bowheads that travel through the eastern Alaskan Beaufort Sea, some spend at least 7 days between the Alaska/Canada border and Flaxman Island during late summer and autumn.

What percentage of the geographic area within the eastern Alaskan study area is suitable as feeding habitat? At least 1 % in some years? At whale feeding locations in the Canadian and eastern Alaskan Beaufort Sea, zooplankton biomass at the depth of maximum biomass, where bowheads presumably fed, averaged 1.8 g/m^3 and was usually ≥800 mg/m^3. The latter was assumed to be the minimum biomass that was sufficient for economical feeding by bowheads.

- The percentage of the study area suitable as feeding habitat, i.e., with ≥800 mg/m^3 zooplankton at some depth, averaged 25 % over four years with effective echosounder sampling, and varied from 7 % to 43 % in individual years.

Two additional questions of interest concerned the proportion of bowheads that feed while in the eastern Alaskan Beaufort Sea, and the frequency with which they feed while actively traveling:

- Based on stomach content data, supplemented by behavioral evidence, far more than 10 % of the bowheads that pass through the eastern Alaskan Beaufort Sea during late summer and autumn feed there. Of the whales harvested at Kaktovik, 83 % had food in their stomachs, and 39 % had ≥20 L of stomach contents.
- Bowheads fed for an average of 47 % of their time in the eastern Alaskan Beaufort Sea during late summer and autumn. A substantial minority of the feeding occurred during travel. Among traveling whales, feeding as well as travel was occurring during a substantial percentage of the time, on the order of 43 %.

A key objective for this study was to estimate what percentage of the bowhead population's annual energetic requirements might be derived from the study area. The estimated number of whale-days in the study area during August–October averaged ~16,953 /yr across the five study years, but varied widely from year to year. Whale-days estimates were based on aerial survey data adjusted to allow for whales missed by the surveyors. Based on the whale-days estimates, and the fact that bowheads in the study area were observed to feed for 47 % of the time (9 to 67 % in different years), we estimated the number of effective feeding-days in the study area each year. Given this, the bowhead energetics model developed in the preceding chapter, and various assumptions, it was possible to estimate the fraction of the population's annual dietary requirements that might be derived from the eastern Alaskan study area:

- In an average year, the population of bowhead whales derives an estimated 2.4 % of annual energetic requirements in the eastern Alaskan Beaufort Sea. In 1 of 5 years of study, the population may have derived 7.5 % or more of annual energetic requirements from the area.

Utilization of the study area varies widely in time and space depending on zooplankton availability and other factors.

In 4 of 5 study years, the bowhead population was estimated to consume <2 % of its annual requirements within the eastern Alaskan Beaufort Sea during late summer and autumn. A sensitivity analysis by Dr. B.F.J. Manly indicated that, in those four years, the upper bound of the 95 % confidence interval was below 5 %. However in 1999, when the best estimate was 7.5 %, the upper bound was 16.5 %. We suspect that the whale-days figure for 1999 was overestimated, and that the 16.5 % upper bound is unrealistically high. However, consumption in the study area during a high-utilization year might exceed 5 % of annual population requirements. Given some of the approximations that were made, these estimates are more likely to be over- than underestimates. It is implausible that the population would consume more than a few percent of its annual food requirements in the study area in an average year.

A related analysis showed that an individual whale would need to spend 10 days in the eastern Alaskan Beaufort Sea in order to consume 5 % of annual food requirements. A small (but uncertain) fraction of the individuals spend 10 days there in late summer/autumn. Few if any individuals spend 20 days in the area, which would be required to obtain 10 % of their individual annual food requirements there.

Overall, the results show that the eastern Alaskan Beaufort Sea is used for feeding to widely varying degrees depending on the year and on the individual bowhead. It is not surprising that the average contribution to the annual diet is apparently rather small: Most individual bowheads remain in that area for only a rather short period in late summer/fall, averaging ~4 days. That is too little time to allow an average bowhead to consume more than a small fraction of its annual dietary intake. Also, the eastern Alaskan study area is rather small in comparison to the overall area in the Beaufort and Chukchi seas where bowheads are known to feed. It would be unreasonable to expect that a high percentage of the annual diet would be acquired during a short stay in one small area. However, it was beyond the scope of this study to assess the importance (for feeding) of the present study area as compared to other similar-sized areas.

Bowhead whales are of great cultural importance to the Inupiat and are a major source of food. Thus, any area used by bowheads, especially when it is also a hunting area, is considered important by the local residents. No matter what percentage of the annual food requirement is derived from the eastern Alaskan Beaufort Sea, local residents will continue to view their hunting grounds as an important area for bowhead whales.

This study has devoted much effort to the integration of existing and new scientific knowledge with local and traditional knowledge. It has provided many new data concerning bowhead feeding ecology and related aspects of bowhead biology, especially in the eastern Alaskan Beaufort Sea. However, there are still numerous approximations, assumptions, data gaps, and variations of opinion regarding interpretation of data. This is inevitable in dealing with such a complex topic, especially in an environment where field studies must cope with severe logistical difficulties. We do not claim that the project has resolved all uncertainty about the importance of the eastern Alaskan Beaufort Sea for feeding by bowhead whales—only that much progress has been made, and that the range of uncertainty has been narrowed. One result of the project has been to better identify the major questions that remain to be answered. A list of potential research topics is included in the “Integration and Conclusions” chapter of the final report.

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APPENDIX 23.1

SENSITIVITY ANALYSIS FOR ESTIMATED AVERAGE DAYS SPENT BY BOWHEAD WHALES IN THE FLAXMAN ISL. TO HERSCHEL ISL. AREA

Bryan F.J. Manly[4]

Calculation of the Statistic of Interest

The statistic of interest is the average number of days spent by bowhead whales in the study area. The residence time data acquired in this study pertain to the area from Flaxman Island to Herschel Island (146º to 139ºW). That area includes Canadian waters between the Alaska/Canada border (141ºW at the coastline) and Herschel Isl. (see Fig. 23.1). Probable residence times in the smaller area from Flaxman Isl. to the Alaska/Canada border (146º to ~141ºW) are discussed in Chapter 23.

Ten possible methods have been considered for calculating the average residence time for each of the years 1985, 1986, 1988, 1989, 1992, 1998, 1999 and 2000, although each method of calculation can only be used for some of the years (see Koski et al., Chapter 11). Furthermore, only some of the methods available for use in a particular year are considered to be reliable. Table 23.12 shows the estimates that are considered to be suitable for use.

The goal for the sensitivity analysis was to calculate 95 % confidence limits for the true values of the means that are shown in the last column of Table 23.12. This was done by assessing the sampling errors in the estimated means for each of the methods, simulating this variation in Resampling Stats for Excel (Blank 2001), and hence generating distributions for the means, from which the variance can be estimated.

TABLE 23.12. Summary of reliable estimates of the average number of days bowhead whales spent in the "Flaxman-to-Herschel" area.

	Method of Estimation*						
Year	1	2	3	6	9	10	Mean
1985	8.13	11.24	5.30		3.03		6.92
1986	4.18	7.12	3.81	4.42	4.40		4.79
1988					0.84	3.40	2.12
1989						4.38	4.38
1992						6.45	6.45
1998	1.00	3.38		7.35	5.31		4.26
1999	4.10	6.90	4.36	9.38	16.62		8.27
2000		3.07		3.87	2.96		3.30
						Mean	5.07

*Methods of estimation are (1) photo intervals between resightings; (2) photo intervals plus travel time; (3) photos stop-over duration best fits; (6) behavior overall speeds; (9) whale days from aerial surveys; and (10) telemetry resightings.

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[4] Western EcoSystems Technology Inc., 2003 Central Ave., Cheyenne, WY 82001. *Phone:* 307-634-1756; *e-mail:* bmanly@west-inc.com

Assessing the Variances of Estimates

Each of the methods of estimation shown in Table 23.12 is based on a different principle. These methods therefore need to be considered one by one in terms of sampling errors. In many cases log-normal distributions are used to approximate the distributions of sample estimates because these estimates must be positive.

Method 1: Photo Intervals Between Resightings

If an individual whale is sighted in the study area, and then resighted at a later date still in the study area, then the times between these resightings are the minimum time that the whale remained in the study area (ignoring the possibility that the whale went outside and then returned). The estimated residence time for Method 1 for a year is the mean of these observations. The same observations are used with Method 2. Hence the modeling of sampling errors must be done for Methods 1 and 2 at the same time.

Method 2: Photo Intervals Plus Travel Time

This is a simple extension of Method 1. If the east-west distance between the resightings of a whale is d, then the whale must travel (270 - d) km west in the study area to reach the initial sighting location, and to move from the resighting location to the western boundary of the study area (which is 270 km wide). The time required for the whale to move through the study area is therefore estimated as the time between sightings, plus the time required to move (270 - d) km, at the assumed speed of 3.67 km/hour. Note that d will be negative if the whale moves east between the sighting and resighting.

A complication is that the time between locations of a whale (t) and the distance moved (d) can be expected to be positively correlated, which needs to be taken into account for the modeling of sampling errors. It was allowed for by a bootstrap resampling procedure (Manly 1997), with the following steps:

(1) The sample mean values were calculated for the years where data for t and v values are available. There were eight (t,d) observations for 1985, eleven (t,d) observations for 1986, one (t,d) observation for 1998, and ten (t,d) observations for 1999, giving 30 observations in total.

(2) The residuals (r_t,r_d) for (t,d) observations were calculated for each year, by subtracting the yearly means from the (t,d) values, e.g., r_t = t - Yearly Mean.

(3) The residuals were bootstrap resampled (i.e., resampled with replacement) to produce new residuals (r_{tb},r_{db}) for each of the original observations. New observations for each year were then generated by adding the bootstrap residuals to the yearly means for t and d.

(4) As the minimum possible time between a sighting and resighting is one day, any values of t less than one were made equal to one.

(5) The Method 1 and Method 2 estimates of mean residence time in the study area were calculated.

(6) Steps (3) and (4) were repeated 10,000 times to generate the distribution of estimates for Methods 1 and 2.

Method 3: Photos Stop-Over Duration Best Fits

Method 3 uses the Schaub et al. (2001) mark-recapture method to estimate the residence time of whales in the study region for the years 1985, 1986, and 1999. Bootstrap resampling of the capture histories of individual whales was used to approximate the standard errors of these estimates. The estimates (with standard errors in parentheses) are as follows: *1985*, 5.30 (4.90); *1986*, 3.81 (3.73); and *1999*, 4.36 (2.62).

To simulate sampling errors in the estimated mean residence times, the distributions of these estimates were assumed to be log-normally distributed with their means and standard deviations set equal to the estimated values. A total of 10,000 sets of estimates from these distributions were generated simultaneously with the generation of bootstrap data for Methods 1 and 2.

Method 6: Behavior Overall Speeds

For method 6, westward speeds estimated from the observations of individual whales were used. For each of the years 1985, 1986, 1998, 1999 and 2000, there is a sample of observed speeds, so the mean can be estimated with a standard error. Sample sizes are 4, 20, 37, 27 and 37 for the years in order. Because of the small sample size in 1985, the estimate was not used for this year. The estimates for the other years (with standard errors in parentheses) are as follows: *1986*, 3.06 (0.60); *1998*, 1.31 (0.46); *1999*, 0.85 (0.40); and *2000*, 2.54 (2.21).

To model sampling errors, sample mean values for 1986, 1998, 1999 and 2000 were generated from log-normal distributions with means and standard deviations equal to the sample means and standard errors. The mean residence times in days were then estimated as 270/[(24)•(S)], where S is the mean speed in km/hour. A total of 10,000 sets of estimates were generated simultaneously with the 10,000 sets of data for each of the other estimates.

Method 9: Whale Days from Aerial Surveys

Aerial surveys enable estimation of the number of whale days in the study area for each of the years 1985, 1986, 1988, 1998, 1999 and 2000, with standard errors. These estimates (with standard errors in parentheses) are as follows: *1985*, 11,937 (9634); *1986*, 17,899 (7639); *1988*, 3638 (2306); *1998*, 31,507 (14,920), *1999*, 101,850 (38,692); and *2000*, 18,727 (12,209). Log-normal distributions with these means and standard deviations were used to approximate sampling distributions.

The mean time spent in the study area is estimated for each year by dividing by the total number of whales in the population during the year in question. This total number of whales in year i is given by $N_i = N_{1993}(1 + G)^{i - 1993}$, where N_{1993} is the number in 1993, and G is the yearly growth rate. The estimated value of N_{1993} is 8200 with a standard error of 566, while the estimated growth rate is 0.0320, with standard error 0.0093. Sampling errors in these estimates are approximated by assuming log-normal distributions for the estimates with the estimated means and standard errors.

The residence time per whale in the study area is estimated for each year by the whale days divided by the population size. However, two adjustments are needed with this method. First, the population sizes are multiplied by 0.814 to give the numbers passing south of the 200 m depth line, which is the area for which the whale days are estimated. Second, the width of the area used for estimating whale days is 76 % of the width of the study area of interest. Therefore, the residence time in the study area of interest is estimated by multiplying the estimate from whale days by 1.316 = 1.00/0.76.

To account for sampling errors in the mean residence times from whale days, random values from the log-normal distributions mentioned above were generated and used to produce simulated mean residence time estimates for each of the years 1985, 1986, 1988, 1998, 1999 and 2000. This was repeated 10,000 times simultaneously with the generation of estimates from the other methods.

Method 10: Telemetry Resightings

Information is available on residence times in the study area for one whale in 1988, four whales in 1989, and five whales in 1992, based on telemetry data. Because of the small sample sizes, the pooled within-sample standard deviation of 2.50 was used to estimate the standard errors of the yearly means.

The estimated mean residence times with standard errors in parentheses were then found to be as follows: *1988*, 3.40 (2.50); *1989*, 4.38 (1.25); and *1992*, 6.45 (1.12).

Sampling errors in these estimated mean values were simulated by generating random values from log-normal distributions with means and standard deviations equal to the observed means and standard errors. This provided new values for 1988, 1989 and 1992. This process was repeated 10,000 times simultaneously with the generation of estimates from the other methods.

Results

The generation of simulated data from each of the methods 10,000 times produced the equivalent of 10,000 tables like Table 23.12. The estimates of mean values that were produced had skewed distributions, but in all except one case (year 2000) the logarithms of the estimates were approximately normally distributed (Fig. 23.3). For the year 2000 the method of generating random sets of data meant that the value for method 2 was always 3.07. Taking this into account, it was found that for this year the variable

$$\log_e[\log_e\{\text{Mean} - 3.07/3\}]$$

has an approximately normal distribution (Fig. 23.4). Based on the assumed normal distributions, confidence limits for the true values of the yearly means and the overall mean were as shown in Table 23.13.

The calculated 95 % confidence limits for the mean days of whale residence in the study area for the various years are therefore as follows: *1985,* 4.6 to 10.3 d; *1986,* 3.3 to 7.1 d; *1988,* 0.8 to 6.0 d; *1989,* 2.5 to 7.6 d; *1992,* 4.6 to 9.0 d; *1998,* 2.9 to 6.3 d; *1999*, 5.7 to 12.1 d; and *2000,* 2.6 to 5.8 d. The confidence interval for the mean of all years is 4.2 to 6.1 days.

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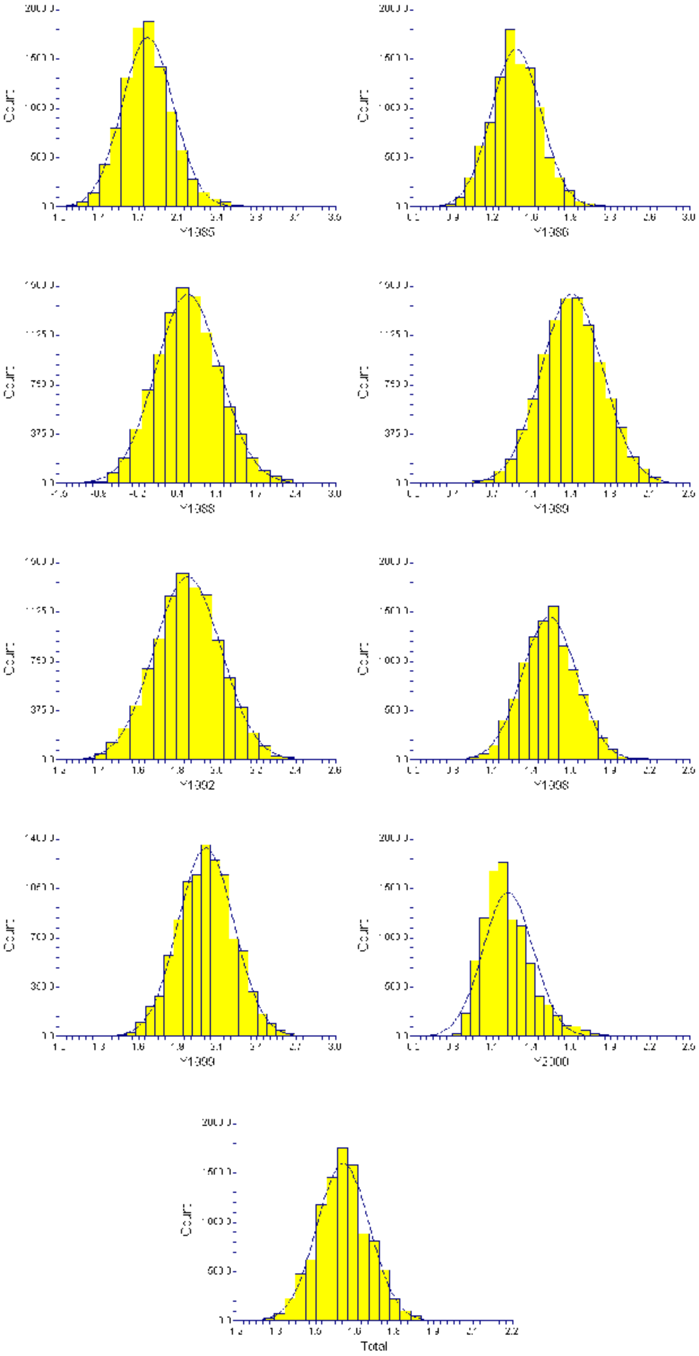

FIGURE 23.3. Distributions of logarithms of simulated mean values for the years 1985 (Y1985), 1986 (Y1986), ..., 2000 (Y2000), and for the overall mean, with fitted normal distributions shown.

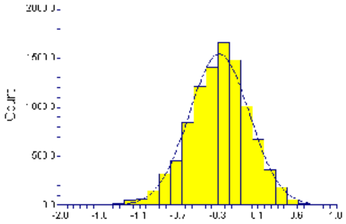

FIGURE 23.4. The distribution of $\log_e[\log_e\{\text{Mean} - 3.07/3\}]$ for year 2000, with a fitted normal distribution shown.

TABLE 23.13. Estimated mean days that whales spend in the "Flaxman–to–Herschel" area, with simulated standard errors, and 95 % confidence limits based on the assumption that transformed estimates are normally distributed.

Year	Estimated Mean Days Residence[1]	Simulated Std. Err.[2]	Transformed Estimate[3]	Simulated Std. Err.[2]	Transformed Confidence Limits[4]		Confidence Limits for Mean Days Residence[5]	
					Lower	Upper	Lower	Upper
1985	6.92	1.55	1.934	0.204	1.535	2.334	4.64	10.32
1986	4.79	1.02	1.567	0.198	1.178	1.955	3.25	7.06
1988	2.12	1.30	0.751	0.530	-0.287	1.790	0.75	5.99
1989	4.38	1.25	1.477	0.282	0.924	2.030	2.52	7.61
1992	6.45	1.12	1.864	0.172	1.527	2.201	4.60	9.04
1998	4.26	0.98	1.449	0.203	1.051	1.847	2.86	6.34
1999	8.27	1.67	2.113	0.192	1.736	2.489	5.68	12.05
2000	3.30	0.66	-0.195	0.326	-0.834	0.444	2.57	5.78
Mean	5.06	0.48	1.621	0.093	1.439	1.804	4.22	6.07

[1] From Table 23.12.
[2] From the 10,000 generated sets of data.
[3] Using the natural logarithm transformation except for year 2000 (see main text).
[4] The transformed estimate plus and minus 1.96 standard errors, assuming normal distributions.
[5] The transformed limits untransformed back to days, e.g. 4.64 = Exp(1.535).

APPPENDIX 23.2

SENSITIVITY ANALYSIS FOR ESTIMATED PROPORTION OF FOOD TAKEN BY BOWHEAD WHALES IN THE EASTERN ALASKAN BEAUFORT SEA

Bryan F.J. Manly[5]

Calculation of the Statistic of Interest

The statistic of interest is the proportion of the annual food consumption of bowhead whales that is consumed in the eastern Alaskan Beaufort Sea (Flaxman Island to Alaska/Canada border). This has been estimated for sub-adults, adult males, adult females, and all whales, for the years 1985, 1986, 1998, 1999 and 2000.

For the sub-adults in one year the statistic is given by

$$P_{sa} = FSA_{sa} / TAF_{sa},$$

where FSA_{sa} is the kg of plankton consumed in the study area, and TAF_{sa} is the total annual plankton consumption for the sub-adults. Similarly, for adult males and adult females there are the feeding proportions

$$P_m = FSA_m / TAF_m,$$

and

$$P_f = FSA_f / TAF_f,$$

while for the entire population the feeding proportion is

$$P_t = (FSA_{sa} + FSA_m + FSA_f)/(TAF_{sa} + TAF_m + TAF_f).$$

To estimate the food consumed in the study area it is necessary to take into account the number of whale-days for the year (the average number of whales in the area per day times the number of days when they may be present), the fraction of the whale-days for the group of interest (sub-adults, adult males, or adult females), the proportion of time spent feeding, and the feeding rate (kg per day) for the group. For example, the food consumed by sub-adults in the study area is estimated by

$$FSA_{sa} = (WD)\cdot(PW_{sa})\cdot(PTF)\cdot(FR_{sa}),$$

where WD is the total number of whale days in the study area for the entire population, PW_{sa} is the proportion of the whales that are sub-adults, PTF is the proportion of time spent feeding, and FR_{sa} is the feeding rate in kg per day of sub-adults, whilst feeding.

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[5] Western EcoSystems Technology Inc., 2003 Central Ave., Cheyenne, WY 82001. *Phone:* 307-634-1756; *e-mail:* bmanly@west-inc.com

The estimation of the total annual consumption involves taking into account the population size, the proportion of the population in the group of interest (sub-adults, adult males or adult females), and the feeding rate necessary for this group. Thus, for example,

$$TAF_{sa} = (N)\cdot(PP_{sa})\cdot(93)\cdot(FR_{sa}),$$

where N is the total population size, PP_{sa} is the proportion of the population that are sub-adults, 93 is the total number of feeding days in a year, and FR_{sa} is the daily feeding rate defined above.

Daily Feeding Rates

The daily feeding rates are based on the energetics requirements of the whales, for which the components are the heat loss from the body, the heat loss from the flukes, the heat loss from warming air in breathing, the heat loss from warming food, the energy required for motion, the energy required for growth, and the energy required by females for reproduction. Each of these components is a function of other variables, some of which depend upon the type of whale (sub-adult male, sub-adult female, etc.), and some of which are assumed to be the same for all whales.

The heat loss from the body for a sub-adult male (kJ/day) is given by

$$HLB_{sam} = (KB)\cdot(SAB_{sam})\cdot(\Delta TB)/DB_{sam},$$

where KB is the thermal conductivity of blubber (watts/m/°C), SAB_{sam} is the surface area of the body (m^2), ΔTB is the temperature difference between the body core and the water (°C), and DB_{sam} is the depth of the blubber (m). Similarly, the heat loss from the flukes is given by

$$HLF_{sam} = (KF)\cdot(SAF_{sam})\cdot (\Delta TF)/DF,$$

where KF is the thermal conductivity of the fluke blubber, SAF_{sam} is the surface area of the flukes, ΔTF is the temperature difference between the fluke core and the water, and DF is the depth of the fluke blubber. Similar equations are available for sub-adult females, males at puberty, females at puberty, average adult males, and average adult females, with the subscripts on variables changed to saf, mp, fp, am or af, respectively. The variables without subscripts are the ones that are assumed to be the same for all whales.

The heat loss from breathing for a sub-adult male (kJ/day) is given by

$$HLBR_{sam} = (BY_{sam}/525600)\cdot(LVPW)\cdot(1000WT_{sam})\cdot(TVP)\cdot(WLM)\cdot(86400/1000),$$

where BY_{sam} is the number of blows per year, 525600 is the number of minutes in a year (365x24x60), LVPW is the lung volume as a proportion of the total body weight, WT_{sam} is the total weight in tonnes, so that $1000WT_{sam}$ is the total weight in kg, TVP is the tidal volume as a proportion of the total lung volume, WLM is the watts per liter per minute, 86400 is the number of seconds in a day (60x60x24), and the factor of 1000 is to make the units for heat loss kilojoules per day. Similar equations apply for sub-adult females, males at puberty, etc.

The heat loss due to warming food for a sub-adult male (kj/day) is given by

$$HLWF_{sam} = (AFC_{sam}/365)\cdot(CPG)\cdot(\Delta DW)\cdot(4.1868),$$

where AFC_{sam} is the annual food consumption (kg), CPG is the heat in calories needed to raise one gram by one degree Celsius, ΔDW is the degrees of warming required, and 4.1868 is the factor for converting calories to joules. Similar equations apply to sub-adult females, males at puberty, etc.

The energy required for motion for a sub-adult male (kJ/day) is given by

$$EM_{sam} = (0.5)\cdot(CD)\cdot(SAB_{sam}/10000)\cdot(V^3)\cdot(8.64\text{x}10^{-6}),$$

where CD is the coefficient of drag, SAB_{sam} is the area of the body in square meters (already used above), so that $AB_{sam}/10000$ is the area in square centimeters, V is the average swimming velocity (cm/sec), and $8.64\text{x}10^{-6}$ is the factor required to convert from dynes times centimeters per second to kilojoules per day. Similar equations apply to sub-adult females, males at puberty, etc.

The energy needed for growth for a sub-adult male (kJ/day) is given by

$$EG_{sam} = (37394.4)\cdot(WG_{sam} + WGS_{sam}) + (60794.6)\cdot(LG_{sam}),$$

where WG_{sam} is the annual weight gain through normal growth, WGS_{sam} is the extra weight gain in the summer to compensate for the loss of weight over winter, and LG_{sam} is the extra lipid gain per year for sub-adult males, all measured in tonnes. The constant 37394.4 is the conversion factor from tonnes weight per year to kilojoules of energy per day, assuming that normal weight gain is 40 % blubber and 60 % muscle. The constant 60794.6 is the conversion factor from tonnes weight to kilojoules of energy per day for blubber. A similar equation applies for sub-adult females. For older males and females there is no allowance of extra lipid gain.

The final component of the energetics model is the cost of reproduction (kJ/day) for adult females at puberty and average adult females. For females at puberty this is

$$CR_{fp} = CP_{fp} + CL_{fp},$$

where CP_{fp} is the average cost of pregnancy (kJ/day), and CL_{fp} is the average cost of lactation (kJ/day). A similar equation applies for average adult females.

Adding up the components described above gives the total energy requirements for a sub-adult male in units of kilojoules per day. This is converted to kilojoules per feeding day by multiplying by 365/93 = 3.925, assuming 93 feeding days per year. It is then converted to kilograms of food per feeding day by multiplying by $4.5524 \text{ x } 10^{-4}$, based on an assumed energy content of zooplankton. The result is that the food requirement in kilograms per feeding day for a sub-adult male is assumed to be given by

$$FR_{sam} = 3.925\text{x}4.5524\text{x}10^{-4}(HLB_{sam} + HLF_{sam} + HLBR_{sam} + HLWF_{sam} + EM_{sam} + EG_{sam}).$$

Similarly, for sub-adult females, males at puberty and average adult males the food requirements are given by

$$FR_{saf} = 3.925\text{x}4.5524\text{x}10^{-4}(HLB_{saf} + HLF_{saf} + HLBR_{saf} + HLWF_{saf} + EM_{saf} + EG_{saf}),$$

$$FR_{mp} = 3.925\text{x}4.5524\text{x}10^{-4}(HLB_{mp} + HLF_{mp} + HLBR_{mp} + HLWF_{mp} + EM_{mp} + EG_{mp}),$$

and

$$FR_{am} = 3.925\text{x}4.5524\text{x}10^{-4}(HLB_{am} + HLF_{am} + HLBR_{am} + HLWF_{am} + EM_{am} + EG_{am}),$$

respectively, while for adult females at puberty and average adult females the food requirements are

$$FR_{fp} = 3.925\text{x}4.5524\text{x}10^{-4}(HLB_{fp} + HLF_{fp} + HLBR_{fp} + HLWF_{fp} + EM_{fp} + EG_{fp} + CR_{fp}),$$

and

$$FR_{af} = 3.925\text{x}4.5524\text{x}10^{-4}(HLB_{af} + HLF_{af} + HLBR_{af} + HLWF_{af} + EM_{af} + EG_{af} + CR_{af}),$$

respectively.

For the purpose of calculating the fraction of food consumed in the study area, the average feeding rate

$$FR_{sa} = (FR_{sam} + FR_{saf})/2$$

is used for sub-adults. Similarly, for adult males and females the averages

$$FR_{m} = (FR_{mp} + FR_{am})/2,$$

and

$$FR_{f} = (FR_{fp} + FR_{af})/2,$$

are used.

Assessing the Variances of Estimates

The main estimates of interest are for the proportions of the annual food requirements that are obtained in the "Flaxman–to–border" area, for the years 1985, 1986, 1998, 1999 and 2000. The main question for the sensitivity analysis therefore concerns the likely distribution of sampling errors for these estimates and, in particular, the biases (if any) and the variances that are associated with these estimates.

Because the estimated feeding rates per day are based on a complicated energetics equation, the distribution of sampling errors in these estimates was considered first. The method employed was a Monte Carlo simulation, using Resampling Stats for Excel (Blank 2001) to do the calculations. Basically, what was done was to consider each of the many variables that are used to calculate the estimated feeding rates, and where possible give each variable the distribution that is expected because of how it is obtained.

For example, the heat loss from the body of whales is a function of the blubber thickness, and the average value of this thickness is estimated from a regression of blubber thickness on whale length for a sample of 11 whales. Because the estimated regression equation will be subject to sampling errors, so will the estimated thickness of blubber for whales of a given length. An average adult male is considered to have a length of 13.5 meters, which gives a mean blubber thickness of 0.254 m based on the regression equation. To model the potential sampling error in this estimated blubber thickness, the observed blubber thicknesses of the 11 males used in the regression are replaced by their expected values plus a normally distributed random error with a mean of zero and a standard deviation equal to the estimated error standard deviation for the regression equation. The regression equation is then refitted, and the blubber thickness for an 13.5 meter whale is re-estimated. This then simulates the blubber thicknesses that the 11 whales might have had, with the corresponding mean thickness for a 13.5 meter whale. By repeating the simulation many times, a distribution of blubber thicknesses is obtained.

By generating random variation in all variables where this is possible and calculating the corresponding proportions of food obtained in the study area, it is possible to estimate the sampling variance in these estimated proportions. Confidence limits for the true proportions can also be obtained, subject to some necessary assumptions.

Table 23.14 shows how random variation was introduced for the variables involved in the calculation of the feeding rates per day for different groups of whales. For all of these variables, it is assumed that the sampling distributions are the same for all calendar years.

TABLE 23.14. Random variation assumed for variables involved in calculating feeding rates per day.

Variable	Notation	Nature of Random Variation
Thermal Conductivity of blubber (w/m/°C).	KB	Assumed normally distributed with a mean of 0.25 and a standard deviation of 0.03. The same values for all whales.
Surface area of body (m^2).	SAB	Estimated from a regression of log(SAB) against log(Length) for 24 whales, using the lengths 11.0 m for subadults, 12.5 m for a male at puberty, 13.5 m for an average male and adult female at puberty, and 14.75 m for an average adult female. Random variation simulated by giving the 24 whales in the regression new log(SAB) values equal to the expected values from the regression plus normally distributed random errors with a variance equal to the estimated regression error variance, and refitting the regression. Estimated SAB varies for different lengths of whale.
Temperature difference between body core and water (°C).	ΔTB	Assumed constant at 33.5°.
Depth of blubber (m).	DB	Estimated from a regression of blubber thickness against length for 11 whales. Random variation introduced into the results from the regression in the same way as for SAB. Estimated DB varies for different lengths of whale.
Thermal conductivity of flukes (w/m/°C).	KF	Assumed constant at 0.20.
Surface area of flukes (m^2).	SAF	Estimated from a regression of log(SAF) against log(Length) for 21 whales. Random variation introduced into the results from the regression in the same way as for SAB. Estimated SAF varies for different lengths of whale.
Temperature difference between the fluke core and water (°C).	ΔTF	Assumed constant at 15°.
Depth of fluke blubber (m).	DF	Assumed constant at 0.015 m.
Blows per year.	BY	Estimated blow rates are based on sample observations, with sample means and variances available. Sample means were assumed to be normally distributed with means equal to the observed values and standard errors equal to standard deviations divided by square roots of sample sizes. A separate simulation with 10,000 randomly generated sets of data was then used to estimate standard deviations for BY. Random values for BY were then chosen from normal distributions, with means (M) and standard deviations (SD) as follows: sub-adults M = 341528, SD = 36407; adult male M = 29824, SD = 29633; adult female M = 308141, SD = 25879.
Lung volume as a proportion of total body weight in kg.	LVPW	Assumed normally distributed with a mean of 0.0225 and a standard deviation of 0.0054. The same value used for all whales.

…continued

Total weight (tonnes).	WT	Estimated from a regression of log(WT) against log(Length) for 29 whales. Random variation introduced into the results from the regression in the same way as for SAB. Estimated WT varies for different lengths of whale.
Tidal volume as proportion of the lung volume.	TVP	Assumed constant for all whales at 0.60.
Watts per liter of air per minute.	WLM	Assumed normally distributed with a mean of 1.8700 and a standard deviation of 0.0373, the same for all whales.
Food consumed in a year (kg).	AFC	This is the food consumption per feeding day (FR) multiplied by 93, which is the assumed feeding days per year. As FR is what is estimated from the energetics equation, it was necessary to iterate this equation so that AFC/93 equals FR for all sizes of whale. Three iterations were found to be sufficient for this purpose, and these iterations were incorporated for all sets of simulated data.
Calories per gram of food per degree of heating.	CPG	Assumed equal to 1.0 for all whales and all food.
Degrees of warming required for food (°C).	ΔDW	Assumed constant at 33.5.
Coefficient of drag.	CD	Assumed constant at 0.02.
Average velocity of movement (cm/sec).	V	Assumed constant at 102.78.
Annual weight gain through normal growth (tonnes).	WG	Estimated by assuming that the lengths of a male at ages 3, 13, 25, 35 and 45 are 8.89, 11.00, 12.50, 13.50 and 14.16 meters, respectively, and that the lengths of a female at ages 3, 10, 27, 41 and 50 are 9.44, 11.00, 13.50, 14.75 and 15.33 meters, respectively. The corresponding weights can then be determined from the regression of log(weight) against log(length) used for the variable WT. Hence average annual weight gains can be calculated for sub-adult males, sub-adult females, etc. Random variation is introduced through the regression equation as is done for WT. Expected annual weight gains are 0.84, 0.72, 0.56, 0.96, 0.83, and 0.65 tonnes, for sub-adult males, males at puberty, average adult males, sub-adult females, females at puberty, and average adult females, respectively.
Weight gain over the summer (tonnes).	WGS	The weight gain over the summer is calculated based on regressions of circumference against length for whales measured in spring and fall. For a whale of a given length L and circumference C (both in meters), it is assumed that the weight is $W = 38.29\ C^2\ (1.082L)$ kilograms. The factor of 1.082 is introduced because the regression equations are estimated on "stretched" whales. Random variation is allowed for in the estimation of WGS by simulating new data for the regression equations, in the same way as described for SAB. The weight – circumference relationship is assumed to be exact as no data are available for the fitting of this.
Cost of pregnancy (kj/day).	CP	Assumed constant at 24458.9 for females at puberty and average adult females.
Cost of lactation (kg/day).	CL	Assumed constant at 155118.8 for females at puberty and average adult females.

By applying the random variation described in Table 23.14 and the equations given in Section 2, it is possible to derive distributions for the daily feeding rates of sub-adults, adult males, and adult females (FR_{sa}, FR_m, and FR_f). These daily feeding rates can be expected to be correlated because they are calculated from related variables. For this reason, the distribution of daily feeding rates was described by generating 1000 values of the triplet (FR_{sa},FR_m,FR_f) and randomly resampling these to get simulated data for deriving the distribution of the proportion of the yearly food requirements obtained from the study area. The distributions used for the other variables involved in calculating these proportions are described in Table 23.15.

TABLE 23.15. The distributions assumed for other variables used in the calculation of proportions of food consumed in the study area (Flaxman Isl. to Alaska/Canada border).

Variable	Notation	Nature of Random Variation
Whale days	WD	Standard errors are available from the program DISTANCE used to analyze line-transect sampling data. Using these, it is possible to derive a standard error for the estimated number of whale days. For the years being considered this results in the following estimated whale days (Est) and standard errors (SE): *1985*, Est = 11936.8, SE = 9634.6; *1986*, Est = 17898.9, SE = 7639.0; *1998*, Est = 31507.4, SE = 14919.5; *1999*, Est = 101849.5, SE = 38691.7; and *2000*, Est = 18726.6, SE = 12208.8. To model sampling variation, the whale day estimates were assumed to be log-normally distributed with these means and standard deviations.
Proportion of the whales in the study area in an age class.	PW	In each year of interest there is a sample of whales in the study area from which the proportions of sub-adults, adult males and adult females are estimated. To simulate sampling variation, the numbers in different age classes are assumed to have Poisson distributions, with mean values equal to the observed counts.
Proportion of time spent feeding.	PTF	Sample estimates of the proportion of time spent feeding are available, with standard errors, for each of the years of interest. These estimates are assumed to have log-normal distributions, with these means and standard deviations.
Total population size.	N	An estimate of the total population size in 1993 is 8200, with a standard error of 566. There is also an estimate of the growth rate of 3.2 % per year, with a standard error of about 0.93 %. These two estimates were combined to produce population estimates (Est) and standard errors (SE): *1985*, Est = 6373, SE = 634; *1986*, Est = 6577, SE = 613; *1998*, Est = 9599, SE = 790; *1999*, Est = 9906, SE = 867; and *2000*, Est = 10223, SE = 953. The standard errors were determined using a Taylor series approximation. Sampling error in N was simulated by assuming that the estimate for a year is a random value from a log-normal distribution with a mean equal to the estimated size and a standard deviation equal to the estimated standard error.
Proportion of the population in a group.	PP	Population samples are available for the years 1985, 1986, 1989, 1990, 1991 and 1992, from which the proportion of calves, sub-adults and adults in the whole population can be estimated. It is assumed that these proportions change little over time, but the sample proportions are highly significantly different. It was therefore concluded that the yearly samples are more like cluster samples than random samples. Based on the year to year variation it was concluded that these samples are approximately equivalent to a single random sample of size 230, consisting of 12 calves, 230 sub-adults, and 95 adults. Random sampling variation was therefore simulated by drawing new samples with the numbers of calves, sub-adults and adults being randomly selected from Poisson distributions with means equal to 12, 230 and 95, respectively.

Results

Figure 23.5 shows the distributions obtained for daily feeding rates of sub-adults, adult males, and adult females. These are the distributions that were resampled as part of the simulation of the proportions of food consumed in the “Flaxman–to–border” study area. The correlation between the estimated feeding rates is quite high, particularly for adult males and females. This is allowed for in the simulation of the proportion of food consumed in the study area.

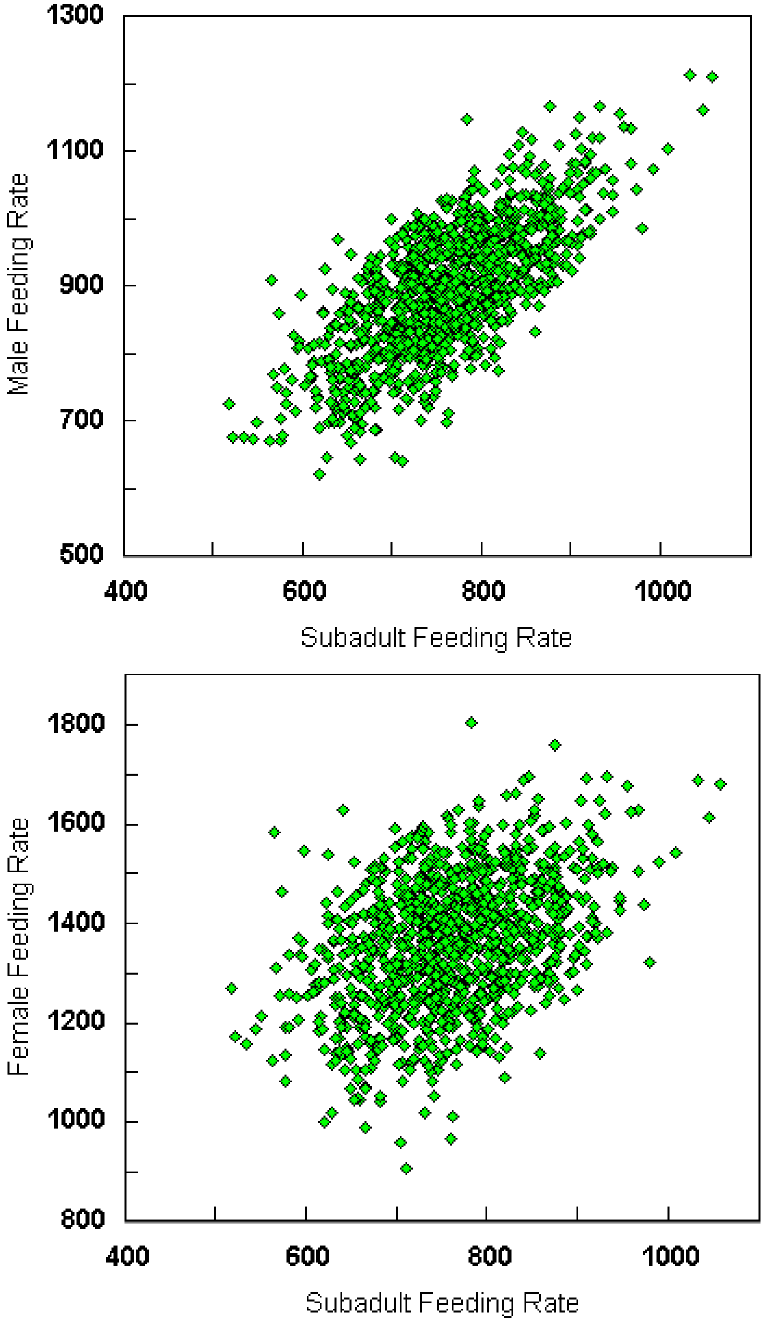


FIGURE 23.5. Variation in the estimated feeding rates (kg/day) as determined from the variation in the components of the energetics calculation.

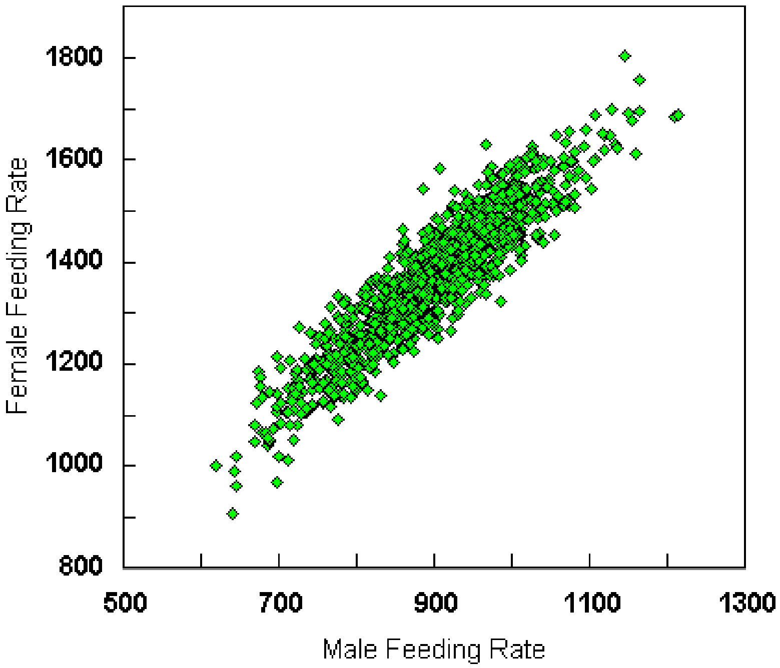


FIGURE 23.5. Continued.

The main simulation to determine the effects of sampling errors on the estimates of the percentages of food consumed in the "Flaxman–to–border" area was run with 10,000 generated sets of data. The distributions of estimates were clearly non-normal, but became close to normal after taking logarithms, as shown in Figure 23.6. It was therefore concluded that it is appropriate to assume that the estimated percentages are log-normally distributed, and to calculate 95 % confidence limits for the true population proportions on this basis. The calculations are as follows:

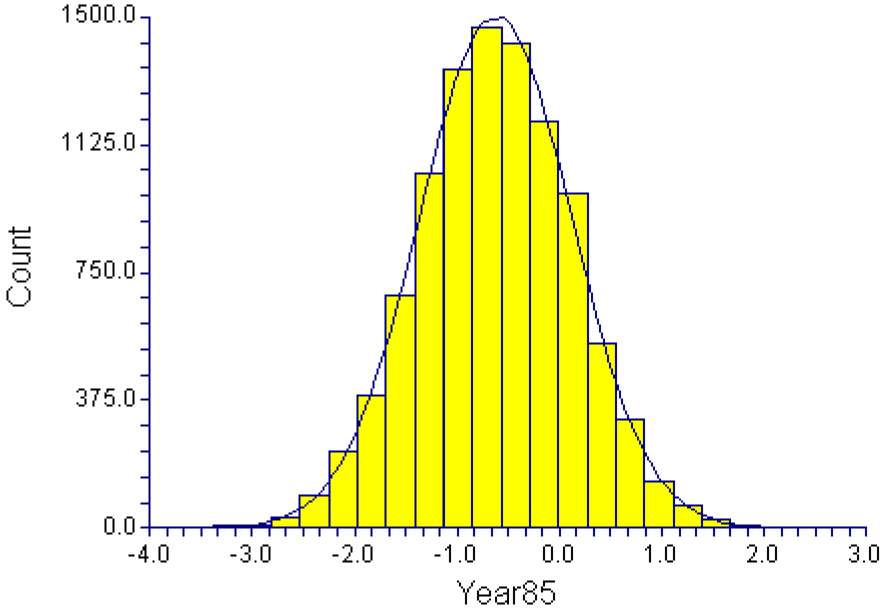
				95 % Confidence Limits			
	Estimated	Natural	Simulated	On Logarithms		On Percentages[3]	
Year	% of Food	Logarithm	Std Err	Lower[1]	Upper[2]	Lower	Upper
1985	0.71	-0.348	0.743	-1.804	1.109	0.16	3.03
1986	1.45	0.374	0.458	-0.523	1.271	0.59	3.56
1998	1.21	0.189	0.520	-0.830	1.208	0.44	3.35
1999	7.53	2.019	0.401	1.234	2.805	3.43	16.53
2000	0.16	-1.829	0.869	-3.533	-0.126	0.03	0.88

[1] Estimate - 1.96(Standard Error).
[2] Estimate + 1.96(Standard Error).
[3] Values are Exp(Values for logarithms).

The confidence limits for the proportion of food consumed in the "Flaxman–to–border" area for the five years are therefore as follows: *1985,* 0.16 to 3.03 %; *1986,* 0.59 to 3.56 %; *1998,* 0.44 to 3.53 %; *1999,* 3.43 to 16.53 %; and *2000,* 0.03 to 0.88 %.

References

Blank, S. 2001. Resampling stats for Excel. Available from Resampling Stats, Inc., at the web site www.resample.com.



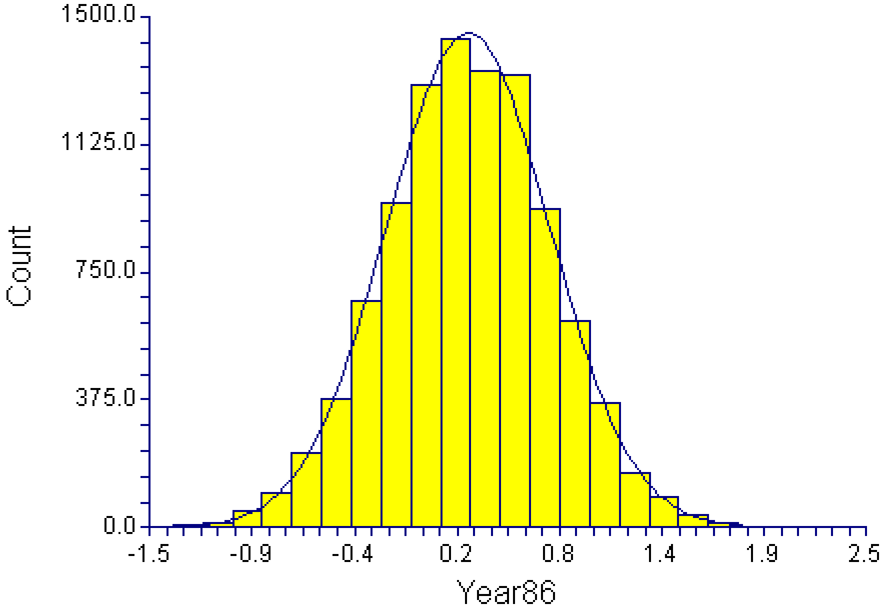
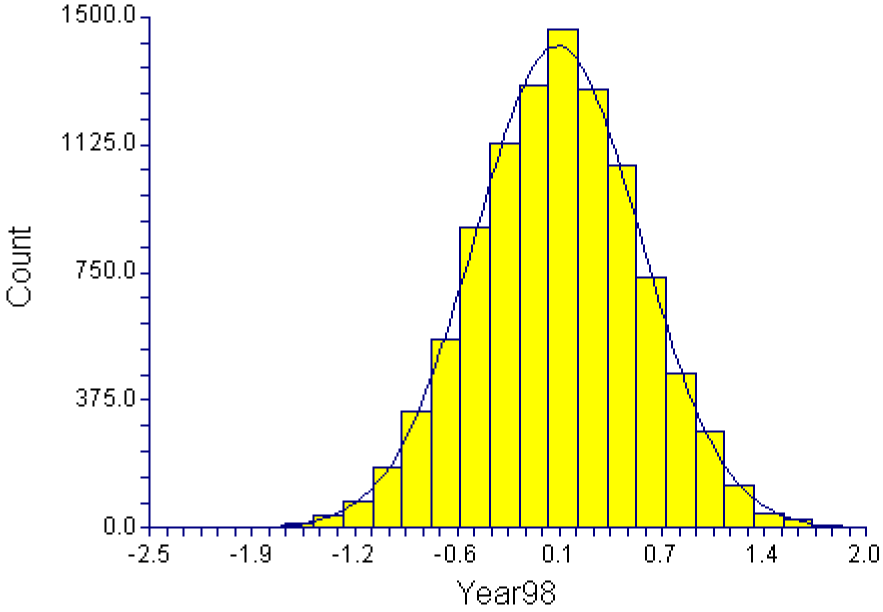


FIGURE 23.6. The simulated distributions for the natural logarithms of the estimated proportions of food consumed in the study area for years 1985 (Year85), 1986 (Year86), 1998 (Year98), 1999 (Year99) and 2000 (Year00).



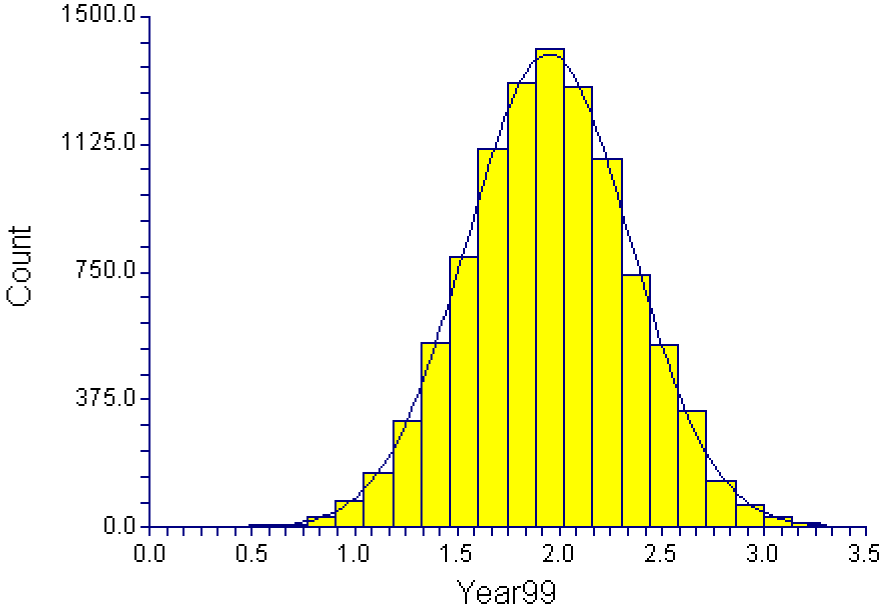


FIGURE 23.6. Continued, for 1998 and 1999.

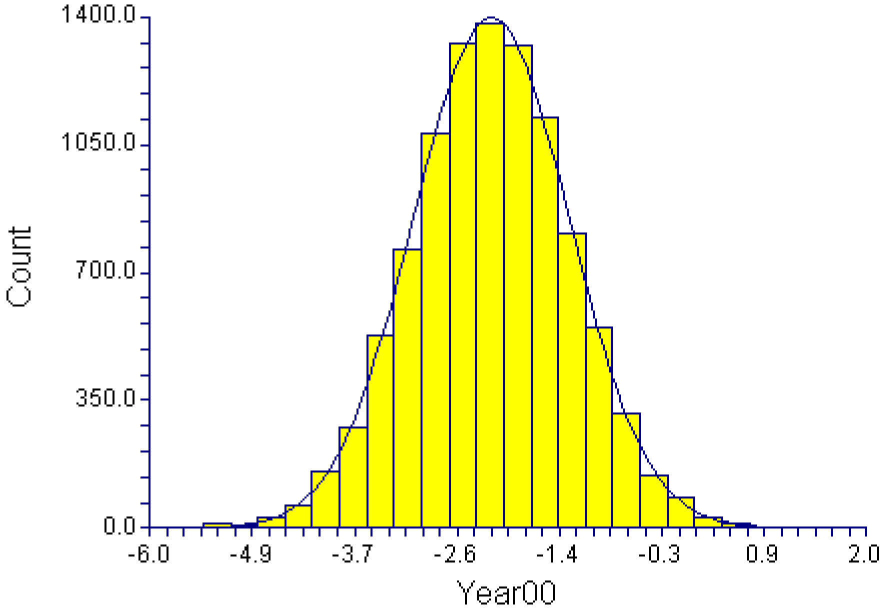


FIGURE 23.6. Continued, for 2000.

ANNEX A: FINAL REPORT OF THE SCIENTIFIC REVIEW BOARD (SRB), WITH LGL RESPONSES

> ***Note:*** *The plain text that follows is a verbatim, unedited copy [except for a few corrected typos] of the report prepared by the project's SRB in February 2002 following its final meeting on 28-29 Jan 2002. At that meeting the SRB discussed the draft final report that had been circulated before the meeting. Unless noted as "[now…]", Page, Figure and Table numbers mentioned in the SRB's comments refer to the draft report, and are not always the same in the final report.*
>
> *"Boxed italic" text appearing after some SRB statements represents a response by LGL or other project participants. Page, Figure and Table numbers quoted in "Responses" refer to the final report.*
>
> *LGL is grateful to all SRB members for their extensive review efforts at various stages of the project, and for valuable guidance and comments provided to the project team by SRB members collectively and individually. We are especially grateful to Dr. Steven L. Swartz, chair of the SRB, for his lead role at SRB meetings, in preparing this and earlier SRB reports, and for participating in a workshop in Kaktovik on 31 January 2002.— W.J. Richardson, LGL Ltd.*

The third and final meeting of the Scientific Review Board (SRB) for this study was convened in Anchorage, Alaska on 28-29 January 2002. SRB members in attendance were: Steven L. Swartz, Ph.D. (NMFS-SEFSC & Chair), Robert Kenney, Ph.D. (University of Rhode Island), Judy Zeh, Ph.D. (University of Washington), Mr. Craig George (NSB-DWM), Ms. Maggie Ahmaogak (AEWC), Mr. Joe Kaleak (KWCA), Mr. Thomas Napageak (AEWC), Mr. Mark Major (ARCO), Ray Jakubczak, Ph.D. (BP Exploration), and Mr. Brad Smith (NMFS-Anchorage). W. John Richardson, Ph.D., Mr. William Griffiths, Mr. William Koski, Ms. Gay Sheffield, Mr. Sang Heon Lee, and Mr. Michael Galginaitis represented the contractor, LGL Limited (LGL). Mr. Steve Treacy represented the Minerals Management Service, Anchorage office. Mr. George Ahmaogak, Mayor NSB also attended the meeting.

The purpose of this third and final SRB meeting was to review the findings and conclusions of the project as presented in the draft final report for Minerals Management Service (MMS) sponsored project "Bowhead Whale Feeding in the Eastern Alaskan Beaufort Sea: Update of Scientific and Traditional Information, Volumes 1 and 2." The draft final report of the bowhead whale feeding study contained a great deal of information in 23 Chapters in two volumes which were provided to the SRB for review barely two weeks before their meeting in Anchorage. While the SRB members were able to review most of this material before the meeting, and it was able to get through discussions of each chapter at that meeting, there was insufficient time to completely evaluate and analyze the contents of each chapter in detail…

> *Response: More specifically, the draft final report was sent to SRB members in two volumes, with Chapters 1-16 being sent on 31 Dec 2001 and Chapters 17-23 on 21 Jan 2002, in both cases by overnight delivery. The SRB meeting was on 28-29 Jan 2002.*

The SRB acknowledged that the contractor (LGL) made a effort to produce the extensive draft report in time for the SRB meeting, but in doing so it was clear that many of the chapters could have been more effectively integrated and cross referenced if more time had been available. The SRB **expects** that a more complete integration of the information in each chapter will be appearing in the final report of the feeding study. The

SRB **believes** that the final report would greatly benefit if the study's findings were presented in the context of the bowhead whales' life history, annual migratory cycle, and natural history…

> *Response: An introductory section on the biology of the bowhead whale has been added at the start of Chapter 1 of the final report (pages 1-1 to 1-3). Additional discussion and integration has been added to Chapter 23, "Integration and Conclusions", and to some extent in some other chapters.*

The SRB spent the time available on the last day of the meeting formulating views and conclusions on the overall study approach, the findings, and conclusions, and evaluating whether those conclusions were supported by the findings of the study. In addition to the general comments on the overall study, the SRB provides additional comments on specific chapters it had the opportunity to concentrate on during the meeting.

The SRB's comments and findings are as follows:

General Comments

Project Limitations

The SRB reaffirmed its view as expressed at its 1999 meeting, that *"the overall project was well founded and represented needed research to better understand the use and importance of the coastal habitat of the eastern Alaskan Beaufort Sea as a feeding habitat by bowhead whales. The SRB noted again, however, that the magnitude of the questions being asked far outstripped the resources and time available (two-three weeks in each year) to fully address the issue of the importance of this region to bowhead whales."* The SRB welcomed LGL's decision to limit the study's focus to key activities that were most likely to provide substantive reliable results that add to and complement previous research efforts. However, the SRB was disappointed that its previous recommendations to employ the use of statistical power analyses to evaluate the potential outcome of specific study projects given the limited resources and effort available was not followed, as this approach might have improved the outcome of the study's individual projects in key areas…

> *Response: At the 1999 SRB meeting, the SRB recommended that power analyses be performed, especially of the various aircraft-based tasks, to determine the level of effort required to obtain statistically meaningful results. After that meeting, LGL worked with SRB member Dr. Judy Zeh of the University of Washington Dept of Statistics on this power analysis. This interaction provided useful guidance regarding the statistical power of some individual data collection efforts in addressing specific questions. However, it did not prove possible to conduct an overall power analysis of the type originally envisaged by the SRB. The results of the effort to perform a power analysis were given in two sections of the Study Plan for Year 3 (Thomson and Richardson 1999, LGL Rep. TA2196-3): the section on "Aircraft-Based Field Work", and in Appendix B. The results are summarized in the last 5 paragraphs of Chapter 8 in both the draft and the final report, starting on page 8-4.*

Using these results, the final report should present an assessment of the overall characteristics of the study area, appropriately qualified, as feeding habitat by bowhead whales.

> *Response: Chapters 5-7 of the final (and draft) report address this topic, with further discussion in Chapter 23.*

The SRB noted that the information obtained in this study re-affirmed some existing knowledge and contributed new findings to the overall body of information on bowhead whale feeding in this region. However, the project was constrained (1) geographically, (2) temporally, and (3) financially. Regarding (1), only a portion of the bowhead's feeding and migratory range around Barter Island was included as the primary study area (see Figure 9.1 on page 9-3), while it is known that the whales utilize the entire Eastern Alaskan Beaufort Sea during the summer and fall seasons…

> *Response: Intensive fieldwork extended from the center of Camden Bay (longitude 145ºW) to the Alaska-Yukon border, and from the shore to the 200 m depth contour (see Fig. 1.2). This is a reasonable representation of the "eastern Alaskan Beaufort Sea", and is the study area that was agreed to by the SRB and local stakeholders early in the 1998-2000 project. Aerial surveys in fact extended farther north, west, and east, providing additional perspective. A section on the definition of the study area has been added to Chapter 1 of the final report (pages 1-5 to 1-7).*

With regard to (2), to accommodate the Kaktovik whaling season and conform to the prevailing fall weather, the study could only be conducted during the last 2-3 weeks of September each year, while it is clear from the whalers' local knowledge and from previous studies that bowhead whales are found in and pass through the study area as early as July and as late as October each year (also noted in the 1999 SRB report)...

> *Response: Intensive boat-based work was conducted for 2-3 weeks, and intensive aerial work for 3-4 weeks, during each of the five years of feeding study; almost all work was indeed in September. Dates when this work was done varied among years, providing some coverage throughout September. Additional relevant aerial work was done in August of some years and October of most years during other projects conducted by MMS, LGL, and others; all available aerial data (1979-2000) are used in the analysis. These aerial results provide additional perspective on use of the area throughout the period when many bowheads are present. A section on the study period has been added to Chapter 1 of the final report (pages 1-7 to 1-9). Local knowledge concerning occasional sightings of bowheads in the study area during July is now mentioned more frequently, in Chapter 9 and elsewhere.*

Finally, regarding (3), while the SRB recognizes the limited funding available from the Minerals Management Service (MMS) for this study, it notes again that oceanographic studies of productivity and prey species for whales are necessarily expensive and extensive investigations owing to the magnitude of effort required to obtain sufficient data to be meaningful. The SRB **believes** that this study can be best viewed as the beginning of a bowhead whale prey study that provides initial information that should be built upon by future investigations that are broader in scope.

Given these limitation the SRB recognizes the need for the report of the findings of this study to be specific and to address the results in the context of the study's limitations. For the example, the title of the draft final report implies that the scope of the study was broader than it was. The SRB **recommends** that the title of the final report be changed to accurately reflect what was done; something like:

"**Bowhead Whale Feeding in <u>a Portion of</u> the Eastern Alaskan Beaufort Sea <u>Around Barter Island During the Mid-September Migration</u>: Update of Scientific <u>Information</u> and Traditional Knowledge <u>for this Region</u>.**"

> *Response: Underlining has been added above to show the additional words that the SRB suggests. The title of the draft final report was the title that was assigned to the 1998–2000 feeding study by MMS in the "Request for Proposals" (April 1997) and in the contract:*
>
> *"Bowhead whale feeding in the eastern Alaskan Beaufort Sea: Update of scientific and traditional information"*
>
> *We believe this is a reasonable title for the project and the report. As noted in an earlier response, "eastern Alaskan Beaufort Sea" is an appropriate description of the study area. Work was not limited*

to waters near Barter Island. Also, although the most intensive work was in early-mid September (zooplankton sampling) or early-late September (aircraft-based work), aerial survey data from August and October were also used. Furthermore, it has been argued in the past that describing the study period as the migration period is an oversimplification, as some bowheads interrupt their migration to feed for extended periods.

Regarding addition of "information" and "...for this region" to the 2nd clause, the added words would not convey additional information. The first clause already defines the region under consideration.

Any attempt to develop a title more specific than that assigned in 1997 by MMS seems to lead inevitably to problems of these types, along with an increasingly long and cumbersome title. The original title seems to us to be accurate and to identify the key topics, as well as being consistent with the historical development of the project. We have retained it as the title of the final report.

Use of Local Traditional Knowledge

The SRB welcomed the inclusion of *"local traditional knowledge"* (LTK) in the report of the study as it previously recommended. The SRB commented that this was an extremely valuable addition to the report of this study, as well as a significant contribution to the documentation of the cultural tradition of native of whaling for bowheads in the Arctic. However, it was the view of the SRB that the LTK presented in the draft report could be more effectively utilized by more completely incorporating relevant information into the various report chapters, as appropriate. For example, the LTK presented in the draft report indicates that bowhead whales occur in the primary study area off Barter Island as early as "*July*", however, in several report chapters the draft final report refers to "*August*" as the earliest that whales move into the region. The SRB also noted that results of interviews with Kaktovik whalers yielded "*little information on whale feeding*" in the region, while discussions at the SRB meeting and at the meeting with Kaktovik whaler's and community members following the SRB meeting yielded additional information relevant to bowhead feeding that should be incorporated into the final study report. In this regard, the SRB **recommends** that complete summaries of LTK relevant to bowhead feeding be incorporated into **all** of the appropriate chapters of the final report, and that **complete transcripts** of the interviews with whalers be reproduced as a separate appendix or volume to the final report of the feeding study.

Response: Additional references to LTK (including the comments about some whales occasionally being seen in July) have been added to several chapters, and some previously-included references to LTK have been made more prominent. New LTK mentioned during the SRB meeting (28-29 Jan 2002) and the 31 Jan 2002 Kaktovik meeting has been added to Chapter 2. The complete transcripts of the interviews with local residents are included in the report (volume 2) as Annex B.

Program Hypotheses

The SRB previously noted in 1999 that "*the hypotheses to be addressed with this feeding study are overly ambitious given the available time for the field work to be completed, the limitations of the level of funding of the research...*" The SRB considered whether or not sufficient data could be obtained in future seasons to adequately address the hypotheses and concluded at that time the data likely to be obtained in 1999 and 2000 field seasons "*would not be sufficient to accept or reject the hypotheses as written*." The SRB previously recommended that a quantified basis be developed for general questions and that "*the text of the study report be revised to reflect specifically what information will be required to test a specific hypothesis or other conclusive statement or finding*" based on the results of statistical power analyses.

The SRB commends the LGL for attempting to develop quantifiable terms (e.g., < 5%, <10%, etc.), however, the findings as presented do not indicate that they were based on statistical power analyses nor do they lend themselves to hypotheses testing in a statistical sense. As such, the SRB notes that the hypotheses as re-formulated by LGL represent general questions that were used to direct the various component research activities that made up the feeding study. As such, these hypotheses are not testable in a scientific sense. As an alternative, the SRB **recommends** that the final report re-phrase the existing draft hypotheses as research questions, and present the relevant findings that address these questions at face value and not as "testable hypotheses" in the appropriate chapters of the final report.

Response: The original general hypotheses were revised to include quantitative cutpoints based on recommendations of the SRB's 1999 meeting. See the earlier response regarding the attempted use of power analysis in this process. In theory, the hypotheses formulated with cutpoints (rather than in more conventional null/alternate format) could be tested statistically. However, as the SRB indicates, this was in fact not done in the draft final report. As all concerned now agree that the best approach is to present the (former) hypotheses as research questions rather than formal hypotheses, they have been reworded as questions in Chapter 1 (pages 1-9 to 1-11) and Chapter 23.

Overall Null Hypothesis

Overall null hypothesis No. 1: the null hypothesis addresses whether or not the Eastern Alaskan Beaufort Sea is or is not a major feeding area for Bowhead whales from which they derive very little (<5%) or a significant (>5%) portion of their annual energetic requirements. The draft final report concludes that the overall null hypothesis is supported by the findings of the study: that *"...the eastern Alaskan Beaufort Sea is not a major feeding area for bowhead whales; the population derives less than 5 percent of its annual energetic requirements from the area"* despite findings of previous studies that suggest whales do feed in the primary study area and throughout the Alaskan Beaufort Sea during their summer and fall migration, and despite the findings of this study that strongly support the suggestion that bowhead whales do utilize the eastern Alaskan Beaufort Sea including the primary study area for feeding.

The conclusion that the primary study area does not represent a major feeding area for bowhead whales is largely based on the findings reported in Chapter 22 on the Energetics of Bowhead Whales. In that Chapter and in Chapter 23 the authors develop a "*theoretical annual energy requirement*" for bowhead whales, an estimate of the seasonal prey intake of an individual whale, and extrapolated these to the population. Then, from these "approximations", an estimated residence time in the primary study area and a migration timetable, the authors estimate that the *"...average bowhead whale consumes 1.2% of annual energetic requirements in the study area...*" The SRB notes and is concerned about numerous inconsistencies and unresolved uncertainties with the methods, information, and logic used in Chapters 22 and 23 to formulate analyses and conclusions. The SRB suggests that, if these uncertainties are taken into account, the findings of this study may not support the overall null hypothesis (see discussion of Chapters 22 and 23 below).

Response: The "overall null hypothesis" has been reworded as "Question 1" rather than a formal hypothesis, as discussed earlier. The specific concerns alluded to above have been addressed in finalizing various chapters; we are grateful for the SRB's guidance in finding and resolving these discrepancies. These revisions have resulted in generally-small changes in the resultant estimates of residence times, proportional food consumption in different regions, etc. The calculations in Chapters 22 and 23 of the final report have been updated (relative to the draft reviewed by the SRB) to take account of the revisions in various estimates. Also, sensitivity analyses have been added to Chapters 20 and 23 to assess how much overall uncertainty there is in some of the key results given

> *the uncertainties in the various estimates used in deriving those key results. After these changes, the conclusion with respect to null hypothesis no. 1 (now "Question 1") remains essentially unchanged.*

The SRB further notes from the findings presented in several chapters of the draft final report (e.g., the Chapter 2 on LTK, Chapters 3-7 on zooplankton, Chapters 17 and 21 on diet and regional occurrence of feeding, etc.) that the observed annual variability in distribution and abundance of the prey species and the numbers of bowhead whales observed annually in the Eastern Alaskan Beaufort Sea and the primary study area suggests that the degree to which this region provides prey for Bowhead whales may vary greatly from year to year. It is clear that the distribution of bowhead whale prey is dynamic and variable in space and time, and that bowhead whales have evolved a foraging strategy to optimize the available prey. The SRB repeats its 1999 suggestion that the importance of the eastern Alaskan Beaufort Sea, and particularly the primary study area off Barter Island, as a feeding area "*...may be a temporal variable and on average could represent an important portion of the bowhead whales' feeding range with the significance of its contribution to the Bowhead whale population's food needs varying in any given year*."…

> *Response: We concur that the importance of the eastern Alaskan Beaufort Sea varies from year to year, no doubt in large part because prey availability varies from year to year. This was discussed in the draft report as well as the final report. However, the analyses described in Chapters 22 and 23 (after updating for the final report) continue to show that the eastern Alaskan study area rarely if ever provides more than a small portion of the total annual energetic requirements of the BCB bowhead population. It may be important for some individual whales that linger in the area longer than average.*

Noting that only a small portion of the Eastern Alaskan Beaufort Sea was included in this study, the SRB believes that the information obtained in this study is insufficient to conclude that the Eastern Alaskan Beaufort Sea or any portion thereof is any more or less important than any other portion as a feeding area for bowhead whales.

> *Response: We do not agree that only a small portion of the Eastern Alaskan Beaufort Sea was included in this study (see earlier discussion). Also, this study was not asked to determine whether the Eastern Alaskan study area is more or less important for feeding than other similar-sized areas, and this question is not addressed specifically in the report. It is likely that the present study area is more important for feeding than some similar-sized areas where feeding has not been seen very often, e.g., the central Alaskan Beaufort Sea. (However, no specific study of feeding has been done in the latter area, and some feeding does occur there—see Chapter 18.) It is also likely that the Eastern Alaskan study area is, on average, less important for feeding than some other areas where larger numbers of feeding bowheads are known to concentrate for extended periods during certain years (e.g., along the Yukon coast).*

With regard to the overall null hypothesis, the SRB recommends that:

1. The final report be revised to reflect important new findings from this study including: Local Traditional Knowledge confirmed many of the research findings concerning bowhead whales' use of the primary study area; analysis of stomach contents from harvested whales and observations of behavior indicate that bowhead whales do feed in the primary study area in mid-September; more sub-adult whales utilize the near shore portion of the primary study area than do adult whales; and the first ever direct measurement of bowhead whale prey species in mid-September were obtained for the primary study area.

2. Given these findings, the final report be revised to describe the dynamic nature and annual and seasonal variability of bowhead whale prey that occurs in the primary study area and other portions of the Eastern Alaskan Beaufort Sea as revealed in the findings of this study;

Response (re points 1 and 2): The draft report covered all these topics, as does the final report. LTK is mentioned more prominently in several chapters of the final report, and the detailed transcripts of discussions with local residents are now included as Annex B.

3. The final report should clearly state that the findings of the various component projects within the overall study indicate that in any given year the primary study area off Barter Island appears to have the potential to provide at least as much food resources for bowhead whales as does any other portion of the Eastern Alaskan Beaufort Sea, and;

4. The findings of this study, in and of themselves, cannot confirm or conclude that the eastern Alaskan Beaufort Sea or any portion of it is any more or less important than any other portion as a feeding area for bowhead whales in any given year.

Response (re points 3 and 4): The primary study area included the full Eastern Alaskan Beaufort Sea (inshore of the shelf break), not just waters off Barter Island. Some parts of that study area more commonly support concentrations of feeding whales than do other parts, but available evidence suggests that bowheads may at times feed anywhere in the continental shelf portion of the Eastern Alaskan study area. This study was not designed to determine whether the study area is more or less important for feeding than other comparably-sized areas of the Beaufort Sea. However, based on available evidence, one can identify similar-sized areas that, over a number of years, appear to be more important and others that appear less important (see above).

5. Indicate that additional research on the seasonal occurrence and dynamics of bowhead whale prey need to be evaluated in other areas of the Beaufort Sea visited by bowhead whales and at other times (i.e., before and following September) in order to provide a comparative context to evaluate the importance of any single area during any single year.

Response: We concur, and this is mentioned in the "Recommended Studies" sections that have been added to Chapters 7 and 23 of the final report.

The SRB **recommends** that, to provide a context for the contents of the final study report, this report of the SRB's 28-29 January 2002 meeting including the SRB's comments and recommendations on the draft final should be included as a chapter in the final report of this bowhead whale feeding study along with appropriate responses from LGL and MMS. Response: Done – this "Annex".

Finally, the SRB **recommends** that a non-technical summary of the findings of this bowhead whale feeding study be produced in *"layman's language"* and widely distributed as a public information document. Such a document should present the key findings of this study of the area off Barter Island in the overall context of the bowhead whales' natural history and annual migratory cycle, and make full use of LTK and information collected from local people and historical documents and publications that is relevant to bowhead whale feeding behavior and biology.

Individual Chapter Comments

Chapter 2. Kaktovik Whaling - Local Traditional Knowledge

The SRB applauds the incorporation of Local Traditional Knowledge (LTK) into this investigation of bowhead whale feeding biology and behavior. The SRB believes, however, that more LTK relevant to the issue of whale feeding could have been obtained if the questions asked during investigative interviews had been formulated differently. It became clear to the SRB during discussions of this topic that relevant information was often buried in descriptions of other topics or in historical accounts of events not specifically about feeding (e.g., accounts of the hunting of whales). The SRB noted that additional sources of LTK were available and should be more fully utilized in the preparation of this report. For example, G. Sheffield (LGL Sub-Contractor) had acquired detailed information on bowhead whale feeding from her discussions with whalers during the collection of stomach contents from harvested whales and related activities. Similarly, the SRB wonders if additional LTK could be obtained from L. Soloman, the local Kaktovik participant in the small boat surveys? Additional sources of LTK could be obtained from published accounts of life in the Arctic by early explorers and historians (e.g., C. Brower's book "50 years below Zero").

Response: We now include the full transcripts of the individual discussions as Annex B (in volume 2). Also, subsequent to the final SRB meeting we have reviewed those transcripts again and have identified a few additional points relevant to the study. References to that information, and to LTK mentioned during meetings in Kaktovik, have been added or expanded in various locations in the report, including Chapters 2, 6, 9, 10, 11, 12, 22 and 23. In most of these chapters, we have added a paragraph on relevant LTK at the start of the Discussion, along with addition references to LTK at relevant places elsewhere in the chapter. It is quite possible that additional relevant LTK might be found through a more extensive review of published and unpublished sources than was possible here; however, an exhaustive search for such sources was beyond the agreed scope of the study.

With regard to the data on the lengths of harvested whales in Figures 2.6 and 2.7 on page 2-13, the SRB **recommends** that these data be presented by sex of the harvested whales rather than in aggregate, or both ways to be most informative. *Response: Done.*

The SRB notes that the LTK that was obtained during this study could be more completely integrated into the report of the findings and more accurately referenced. For example, the LTK indicates that bowhead whales are seen off Barter Island from July through November, yet in other report chapters the authors refer to "*August*" as being the earliest arrival data of the whales. The SRB **recommends** that: (1) the authors review the existing interviews against the behaviors used to characterize bowhead feeding behavior, as well as other feeding observations, and that any additional relevant information incorporated into the report of the feeding study; *Response: Done.* (2) that rather than isolating the LTK in a single chapter, this information should be fully integrated into all relevant chapters and their discussions; *Response: Done.* and (3) in Chapter 23 summarize for each conclusion the contribution of LTK to that conclusion, be it in agreement or disagreement with that conclusion… *Response: Done.* Given the relevance and cultural importance of the LTK obtained in this study, the SRB further **recommends** that the complete text of the information interviews with whalers and local Kaktovik residents be published in a separate appendix or volume to the final report of this feeding study. *Response: Done – see Annex B.*

Chapters 3-7. Zooplankton Sampling:

While the SRB commends LGL for undertaking zooplankton sampling as part of this study, it recognizes that obtaining samples and information adequate to accurately characterize bowhead whale prey resources is a monumental task that requires a great deal of time, sampling over a wide range of the whales' habitat, and funding that generally outstrips available resources. The vessel utilized for the zooplankton studies was limited in its range and the number of days it could operate within the primary study area due to the conduct of the Kaktovik fall whaling season and prevailing weather conditions. It was also noted that zooplankton distributions change during the night, and that the vessel based sampling occurred only during daylight hours.

Response: The Discussion of Chapter 5 (page 5-37) now addresses the lack of data on diel vertical migration by zooplankton in the Beaufort, and this is also mentioned under "Recommended Studies" (Chapters 7, 23). Most of our sampling (including all of that in 1998–2000) was in places where water depth was sufficiently shallow that we were able to document zooplankton throughout almost all of the water column. Although the measured biomass might have a different vertical distribution at night, the overall average biomass would not be expected to differ appreciably at night.

In their presentation to the SRB, LGL acknowledged that there was generally a poor correlation between the bongo net sampling and estimates of zooplankton density from the hydroacoustic sampling. In response to questions from the SRB, LGL acknowledged that some small plankton may have passed through the nets and escaped as could fast moving prey like euphausiids, but these zooplankton may account for high biomass detection from the hydroacoustic records. These observations suggested that there was a need for improved calibration of these methods. SRB member J. Zeh recommended that the authors should utilize covariates to try to explain some of the variation in the biomass data. Such covariates might include, e.g., some measure of the importance of euphausiids in the net samples for a given year (see below).

Response: Over the five seasons, the correlation between echosounder data and net biomass ranged from weak (1998) to strong (1999). Given the weak relationship in 1998, the 1998 echosounder data were not used to estimate zooplankton biomass. Net avoidance and the possibility of small copepods passing through the mesh are addressed in the Discussion sections of Chapters 4 and 6. No useful covariates were available for re-analysis, but a robust regression method is used in the final report as suggested by the SRB (below). We agree that further research is needed on methods for quantifying zooplankton from echosounder data. Possible approaches for future studies in the Beaufort Sea are discussed in Chapter 4 (page 4-13) and under "Recommended Research" in Chapter 7.

Despite these difficulties, this study obtained new and significant information on the composition and distribution of principal prey species of bowhead whales within the primary study area. These data, however, are insufficient to support statements in the draft final report that characterize the entire eastern Alaskan Beaufort Sea in all seasons when whales are present. The SRB recommends that the final report clearly state that such characterizations are limited to the areas in which the zooplankton samples were obtained (i.e., the primary study area off Barter Island) and specify the time periods during which they were obtained (i.e., mid-September).

Response: See previous responses to SRB comments on the study area and study period, and discussion of these matters that has been added to Chapter 1 (pages 1-7 to 1-9).

The SRB noted that euphausiids may escape the 0.6 m wide plankton nets utilized in this study, and as a result may be under-represented in the samples obtained. This could bias the conclusions concerning the prey types that bowhead whales feed on in the eastern Beaufort Sea compared to the Chukchi and Bering Sea.

The SRB recommends that the final report note this potential bias, and discuss the implications of this bias on conclusions of the prey species bowhead whales exploit in the eastern Alaskan Beaufort Sea.

> *Response: The net-avoidance phenomenon and other known or potential biases were addressed in the Discussion sections of Chapters 4 and 6 of the draft report, and these sections have been refined in the final report.*

The plots of zooplankton biomass provided in Figure 4.2 on page 4-9 present the "best fit" linear relationships between zooplankton biomass in the horizontal net tows and corresponding volume backscatter data. The SRB question why the data for 1999 and 2000 were pooled - presumably to improve the correlation between the horizontal tow data and the corresponding echo-sounder data, when the result of pooling diminished the correlation for 1999 presented in Table 4.3 on page 4-8. The SRB recommends that the data be re-analyzed by not pooling independent years, and utilizing the correlations for each year independently in their analyses. Alternatively, use of covariates with pooled data that would permit a better fit to the data from each of the pooled years might be explored. The SRB further recommends that the final report contain some discussion of the advantages, disadvantages, and effectiveness of both horizontal plankton tows and echo sounding methods to assess zooplankton biomass in the Beaufort Sea.

> *Response: In the final report, separate regression equations for 1999 and 2000 are used throughout. As a result, numerous changes, mostly subtle, have been made to diagrams in Chapters 4, 5 and 6. These changes did not necessitate any notable changes in the interpretation.*

The plots of average biomass in the water column and maximum biomass of zooplankton shown in Figure 5.15 *[now Fig. 5.16]* on page 5-28 truncate the data for maximum biomass at 1,000 mg/m^3. The SRB believes that these maximum values would be instructive, and it recommends that these data be re-plotted to show the peaks of maximum biomass. The SRB also notes that there are instances where maximum zooplankton biomass peaks occur, but are not evident in the corresponding plots of mean water column biomass. The SRB recommends that these differences be explained in the final report, and suggests that LGL investigate alternative analysis methods, such as "robust regression techniques" to evaluate the relationship between horizontal net tows and corresponding echo-sounder data.

> *Response: Done. Graphs showing estimated biomasses >1000 mg/m^3 now show actual best-estimates, without truncation. A cautionary note about the uncertainties has been added to p. 5-25 (footnote). Apparent discrepancies between maximum and mean biomass are to be expected when layers are only 1 or 2 m thick, as now discussed on page 5-25. A robust-regression technique is now used to derive the net biomass vs. acoustic biomass relationships for 1998–2000, as described in the revised Chapter 4 (page 4-7; see also Fig. 4.2).*

In view of the findings of the limited zooplankton sampling conducted the primary study area, the SRB repeats its 1999 view that "the available data suggest that prey availability may be highly variable from year to year in the Eastern Alaskan Beaufort Sea and that in any given year the nature of this variability may result in specific areas of the Beaufort Sea being more or less important as feeding areas. In this regard, the eastern Alaskan Beaufort Sea may be more or less important to bowhead whales in different years. Thus, several years of monitoring of the available prey in the eastern Alaskan Beaufort Sea will be required to assess the overall importance of this area as a source of food for Bowhead whales…

> *Response: We concur that prey availability and importance of the area to bowheads are quite variable from year to year, as now documented over five autumn migration seasons and discussed in the draft and final reports (Chapter 5). However, those data, plus data on bowhead use of the*

> *area (over 21 years), even with allowance for the uncertainties, provide strong evidence that that the present study area provides no more than a small percentage of the food required by the bowhead population – even in years of higher-than-average use by bowheads (see revised Chapter 23, including sensitivity analyses in Appendices 23.1 and 23.2).*

…compared to other areas such as the Chukchi Sea." The SRB therefore recommends that MMS continue to sponsor investigations on the distribution and seasonality of bowhead whale prey species throughout the range of the species for comparison with, and to provide a context for understanding the importance of the eastern Alaskan Beaufort Sea as a feeding habitat for bowhead whales.

> *Response: Many of the same types of data on food availability and bowhead feeding are available for parts of the summer range of bowheads in the Canadian Beaufort Sea. However, few data of these types are available for the western Alaskan Beaufort Sea, or the Chukchi Sea, or other areas within the annual range of BCB bowheads where bowhead feeding is known or suspected to occur. We concur that additional research on food availability and bowhead feeding ecology is desirable in these areas. This is mentioned in the list of recommended research that has been added to Chapters 7 and 23. However, this additional research is unlikely to result in any major change in present understanding of the importance of the eastern Alaskan Beaufort Sea, which has already been studied in considerable detail for the period of peak bowhead occurrence during September.*

Chapter 9. Distribution and Numbers of Bowhead Whales in the Eastern Alaskan Beaufort Sea During Late Summer and Autumn, 1979-2000.

The SRB viewed the results presented in this chapter as informative, except that the distinction between observations from this feeding study relevant to the primary study area and information collected from "*a large number of studies conducted in late-summer and autumn*" in other portions of the Beaufort Sea was not clear, and implied that the information collected in this feeding study was actually more extensive than it is and represented periods of time other than mid-September when the feeding study was conducted. As a result, the reader is lead to believe that all the data presented was collected in and relevant to this primary study area and collected during the 2-2.5 weeks in each September. …

> *Response: The present study was planned from the outset to incorporate all relevant scientific data (and traditional knowledge), not just the "new" data acquired during the specific feeding-study fieldwork in 1998-2000 (or 1985-86 and 1998-2000). Extensive aerial survey data are available from many additional years, and from August and October as well as September. These data complement and extend those from the specific feeding studies, and have been used in Chapter 9 as called for by the project plan. The temporal and geographic extent of the data used are described in detail in the "Methods" of both the draft and final versions.*

… In this regard, Figure 9.1 on page 9-3 was extremely helpful for understanding the location and extent of the primary study area and its relation to the greater eastern Alaskan Beaufort Sea. The SRB **recommends** that figure 9.1 be replicated in appropriate chapters of the report to aid in understanding the distinction between the primary study area within the Beaufort Sea. The SRB also **recommends** that a clear distinction be made between data collected and directly relevant to the primary study area and data collected in other areas and at other times. In this regard, the SRB **recommends** that the authors develop a data/information summary table, that presents all the various data sources from each activity that was a component of the feeding study and the dates when those data were collected. The table could also indicate the sources and dates of collection for data/information that was collected from other studies but included because of its relevance to the feeding study.

> *Response: In the final report, study area maps have been added or clarified in some other chapters (e.g., Chapter 1). The two regions analyzed in Chapter 9 ("extended" and "restricted") are described in that Chapter. Some rewording has been done to help clarify which of these two regions is under consideration in each subsection, Figure and Table. A Table has been added to Chapter 23 (Integration and Conclusions) to summarize the study area and dates for the data assembled on each major topic.*

In Figures 9.10-9.11, 1979-89 are compared with 1990-2000. This is a logical breakpoint given the time span of the studies. However, for some water-depth strata and regions, 1990 is a more appropriate breakpoint in terms of equalizing the number of years with surveys in the early and late periods. It would be useful to examine the sensitivity of summary statistics and conclusions to defining the early period as 1979-90 and the late as 1991-2000. This also applies to the significance tests given on pp. 9-26 and 9-28 of the report.

> *Response: Done, as now noted on pages 9-22, 9-27, and 9-30. There was no effect on conclusions.*

On pp. 9-28 and 9-30 *[now p. 9-29 to 9-31]* the authors present a good discussion of a number of possible reasons for the estimated increase in whale population during the 1990s. However, some further confounding factors should also be discussed. For example, the early period shows higher continental slope values; this may be because it was surveyed in early August only during this period. Effects of changes in survey timing, planes, observers, altitudes, prey availability, and other factors make interpretation of the results difficult even though adjustments were attempted for some of these. Some of these factors, particularly the years in which surveys were conducted in August and October, may have created biases in the 10-d moving averages used in estimating whale-days.

> *Response: The Discussion section of Chapter 9 has been expanded to further address these questions.*
>
> *Additional Note: At the 28-29 Jan. 2002 meeting of the SRB, a question was raised concerning the applicability of line transect procedures to single surveys with few or even zero sightings. This practice is legitimate when the* $f(0)$ *and* $g(0)$ *factors were derived from larger samples combined across days, as here (Buckland et al. 2001, p. 88). This is now noted at the bottom of p. 9-8.*

Chapter 11. Bowheads: Rates of Movement & Residence Times:

In its 1999 report, the SRB noted that "*the requirement of re-sighting of an individual whale for more than 10 days to establish the significance of an individual whale's residency in a feeding area is not feasible due to the limited number of field days available to obtain photographic identification data*." and strongly recommended "*that a power analysis be conducted utilizing the results of the 1995, 1996, and 1998 field season to re-evaluate the effort required to obtain sufficient data to assess whether whales remain in a specific area for prolonged periods of time, and adjust the sampling design accordingly*." The SRB was disappointed that such a power analysis was not included in the draft final report, but believed that LGL did what they could to establish and estimate residence time for an individual whale given the photographic identification and other information that was obtained during this study. …

> *Response: See response to first paragraph of "General Comments", above (p. A-2), regarding power analysis; see also pages 8-4 to 8-5 in Chapter 8. In response to the SRB's 1999 concerns about the level of effort devoted to the residence time question (via photoidentification), we reduced the proportion of the effort devoted to systematic aerial surveys and increased the effort devoted to photoidentification during 1999 and 2000 as compared with 1998.*

The estimates of residence time for migrating and feeding bowhead whales presented in the draft final report appear reasonable for the mid-September time frame, and are consistent with historical information. However, the SRB **recommends** that similar studies be continued in the future for other times of the year and locations, and that these include statistical power analyses to maximize the information return on effort expended and to improve the database for these kinds of analyses.

Response: We concur that additional data on residence times would be very valuable for the present eastern Alaskan study area (where available data are limited in various ways), for more westerly parts of the Alaskan Beaufort Sea, and for the western Chukchi Sea. This is mentioned in the list of recommended research that has been added to Chapters 16 and 23.

Chapter 12. Activities and Behavior of Bowhead Whales in the Eastern Alaskan Beaufort Sea During Late Summer and Autumn.

As with previous chapters that incorporate information obtained from other studies, the SRB **recommends** that a clear distinction be made between data collected in the primary study area during the 2 to 2.5 weeks in September that the feeding study was conducted and data from other studies. In this regard, the SRB **recommends** that the authors develop a data/information summary table, that presents all the various data from each activity that was a component of the feeding study and the dates when those data were collected. The table should also indicate the sources and dates of collection for data/information that was collected from other studies but included because of its relevance to the feeding study.

Response: Page 12-3 now provides a more explicit statement concerning the number of Behavioral Observation Sessions (BOSs) within eastern Alaskan waters vs. waters east of the Alaska/Canada border. Also, BOSs in Canadian waters are now more explicitly identified (boxes) in Appendix 12.1.

Chapter 13. Surfacing, Respiration and Dive Cycles of Bowhead Whales in the Eastern Alaskan Beaufort Sea During Late Summer and Autumn as Related to Whale Activity.

As with previous chapters that incorporate information obtained from other studies, the SRB **recommends** that a clear distinction be made between data collected in the primary study area during the 2 to 2.5 weeks in September that the feeding study was conducted and data from other studies. In this regard, the SRB **recommends** that the authors develop a data/information summary table, that presents all the various data from each activity that was a component of the feeding study and the dates when those data were collected. The table should also indicate the sources and dates of collection for data/information that was collected from other studies but included because of its relevance to the feeding study.

Response: New Table 13.1 added on page 13-2. Table 13.1 and associated text include cross-references to Appendix 12.1a-f and Figure 12.1, which list and map the locations of the individual observation sessions.

The SRB notes that the term "respiration" has a specific meaning in a physiological context and **recommends** that the words "breathing" or "blow rate" be substituted in the title and text of this chapter.

Response: "Respiration" is widely used as a synonym for "blow" or "breath" in the baleen whale literature, and we have retained this usage. Blow rate has a specific meaning (blows per minute). Information about blow rates (and percent of time at surface) has been added to Appendix 13.1.

The SRB assumes that the depth information presented in this chapter was obtained from nautical charts (?), but this is not clear in the text.

Response: Sources of depth information were (and are) stated in Chapter 9 (page 9-7). A cross-reference to this information is now repeated in the Methods of Chapter 13 (p. 13-4).

Additional Note: At the SRB meeting, it was also suggested that information about "blow rates" should be added. Mean blow rates and mean % time at surface are now shown in Appendix 13.1, and some of the key values are mentioned in the Results (p. 13-6 to 13-8, plus 13-11)

Chapter 14. Surfacing, Respiration and Dive Cycles of Bowhead Whales in the Beaufort Sea: Calves, Subadults and Adults.

As with previous chapters that incorporate information obtained from other studies, the SRB **recommends** that a clear distinction be made between data collected in the primary study area during the 2 to 2.5 weeks in September that the feeding study was conducted and data from other studies. In this regard, the SRB **recommends** that the authors develop a data/information summary table, that presents all the various data from each activity that was a component of the feeding study and the dates when those data were collected. The table could also indicate the sources and dates of collection for data/information that was collected from other studies but included because of its relevance to the feeding study.

Response: New Table 14.1 added at start of "Methods" (p. 14-3).

The SRB notes that the term "respiration" has a specific meaning in a physiological context and **recommends** that the word "breathing" be substituted in the title and text of this chapter.

Response: No change; see response to corresponding comment on Chapter 13.

Chapter 18. Diet & Regional Feeding: Stomach Contents:

The SRB recognizes the importance of stomach contents from harvested whales as the most direct evidence of bowhead whale feeding, and **recommends** that the sampling of stomach contents from harvested whales continue and that previously collected samples also be analyzed. The SRB noted that the data in table 18.3 of estimated stomach volumes suggest "feeding bouts" in pockets of high prey density – higher prey density than that indicated in the zooplankton sampling net tows. SRB members R. Kenny and C. George did a "quick calculation" suggesting that for whale 99KK2 to fill its stomach in a "reasonable" amount of time, the prey density would have to be ~ 5 gm/m^3 based on 150 L of prey in the stomach and a 2 m^2 mouth gape, suggesting that the zooplankton net sampling was biased low and did not collect a representative sample of these dense prey pockets. This should be noted in this chapter and in the zooplankton and energetics chapters…

Response: We acknowledge that whales may more adept at finding a high biomass than we are, and that we may at times underestimate the biomass of prey that is present. However, as described in Chapter 6, during 1986 we sampled near one whale where zooplankton biomass was found to be 3.8 g/m^3 and near two other whales where biomass was found to be 3 g/m^3. In 1988 we obtained 5 g/m^3 in a vertical tow near whales in the Canadian Beaufort Sea, and in 1989 Wartzok et al. (1990) found a biomass of euphausiids of 3 g/m^3 in a vertical tow near whales in the Eastern Alaskan Beaufort Sea. If a zooplankton biomass of 5 g/m^3 was present at some depth at a sampling station where echosounder-guided horizontal tows were taken, we would have documented a high biomass.

…The SRB further **recommends** that LGL and MMS work with the AEWC to obtain stomach samples from whales harvested by the native whalers in areas to the west of Kaktovik, particularly attempt to get samples from harvested whales that may have been feeding the Bering and Chukchi Seas in winter (e.g., off St. Lawrence Island).

> *Response: Data from all available stomach-content samples acquired at more westerly locations in the Beaufort Sea, i.e., Cross Island and Barrow, were already included in Chapter 18. ADF&G has provided a Table of information about stomach contents of whales harvested during the spring hunts at St. Lawrence Island; this Table has been added to Chapter 21. The desirability of further sampling in the Bering and Chukchi Seas is noted in the list of "Recommended Research" on diet and regional occurrence of feeding, added to Chapters 21 and 23.*
>
> *Additional Note: At the SRB meeting on 28-29 Jan. 2002, there was a request to document the relationships between individual diet items and the factor scores. This has been added as Appendix 18.6.*

Chapter 19. Fatty Acids in Bowhead Whales and Potential Prey from the Alaskan Beaufort Sea

The SRB welcomed the preliminary fatty acid analyses as a contribution of new information for the study of bowhead whale feeding, recognizing that uncertainties remain in the methodology. The SRB **recommends** that MMS sponsor future research on the application of fatty acid analyses as a component of future bowhead whale feeding studies.

> *Response: LGL concurs, and this is now mentioned in the list of "Recommended Research" on diet and regional occurrence of feeding, added to Chapters 21 and 23.*

Chapter 20. Diet and Regional Feeding: Stable Isotopes

The overall conclusion of this chapter is that bowhead whales obtain the majority of their annual prey intake in the Bering and Chukchi Seas and not in the Eastern Beaufort Sea. The SRB noted that this conclusion is in contrast to the findings presented in other chapters of the draft final report and an overwhelming body of evidence from other studies that suggest that bowhead whales feed continuously during their spring, summer, and fall migrations across the Beaufort Sea, during which time they gain weight and girth as is evident in the analysis of whales harvested by the native whalers and from aerial photography. The SRB recognizes that the isotope analyses "*...are subject to a variety of assumptions...*" that are difficult to test, but none the less, they raise concern about the accuracy of the method and conclusions given other evidence of bowhead whale feeding in the Beaufort Sea as a whole.

> *Response: We agree that the results of Chapter 20 are not easy to reconcile with other data demonstrating the frequent occurrence of feeding in the eastern Beaufort Sea. The final version of Chapter 20 (Discussion section), and also the final version of Chapters 21-23, describe an annual feeding scenario that might be at least generally consistent with all data. It is acknowledged that additional data of numerous types are needed to verify (or otherwise) this possible interpretation of the now-available data. Studies listed under "Recommended Research" in chapters 21 and 23 would provide some of the needed data.*

The SRB noted that an independent review of Chapter 20 was solicited by LGL, but this review was not made available to the SRB at the time of its January 28-29, 2002 meeting in Anchorage. In an e-mail to LGL (W.J. Richardson) the reviewer (K. Hobson) indicated that "*At the very least, much more explanation is required for the method of calculating the percent feeding in the eastern Beaufort",* and that there are likely *"...alternate explanations of the results provided.*" The SRB was disadvantaged when reviewing this chapter owing to a lack of expertise in isotopic analyses within its members. However, the SRB noted similar concerns with the methods and analyses of the information presented in this chapter, and **recommends** that the final report incorporate and address the points and uncertainties raised by the independent reviewer.

> *Response: The comments from Dr. K. Hobson, mentioned above, concerned an earlier draft of Chapter 20, not the one included in the draft final report as reviewed by the SRB. Dr. Hobson provided updated comments (in Feb. 2002) on the draft final version of this chapter, i.e. the version that the SRB reviewed. He noted that "I found this to be a much improved draft…" However, he again expressed concerns about the use of baleen data to estimate the proportion of the diet acquired from the eastern Beaufort. He also recommended a sensitivity analysis to assess how strongly the results depend on various uncertain estimates. Some other reviewers had similar comments. The present final version of Chapter 20 has been substantially modified, and now uses data on isotope ratios in muscle rather than baleen to estimate proportional food intake in the eastern Beaufort Sea. Also, a sensitivity analysis has been added as Appendix 20.1, as suggested by several reviewers.*

The SRB further noted that additional stomach contents from harvested whales were made available to the authors of Chapter 20, but these were not, but should have been, analyzed and included in the analysis…

> *Response: The final version of Chapter 20 takes account of the latest data (from Table 18.7 in Chapter 18) on the proportional composition of the stomach contents of whales harvested at Kaktovik and Barrow (see updated values in Table 20.3). Those data were not yet available at the time when the draft version of Chapter 20 was being prepared. As to the suggestion that isotope composition of stomach contents should have been analyzed, this would not have been helpful given the probable contamination issues. Also, while it would be interesting to confirm the specific isotope composition of prey consumed east of Barrow in fall, the isotope composition of the main types of zooplankton prey has already been determined, from direct zooplankton sampling, for the general areas where stomach content samples have been obtained.*

…The SRB questioned whether the use of the long-term (decadal) correction factor was needed or appropriate

> *Response: For reasons discussed in both the draft and final versions of Chapter 20 (and in papers cited therein), the decadal correction factor seems necessary. However, it is acknowledged that this introduces uncertainty. This uncertainty is dealt with in the final version of Chapter 20 in two ways.* ***(a)*** *Appendix 20.1 estimates the 95% confidence limits for the percent of the food acquired in the eastern Beaufort, including allowance for uncertainty in the slope of the decadal correction factor.* ***(b)*** *The Discussion section of Chapter 20 now discusses, in some detail, the recently published data of Hoekstra et al. (2002,* Can. J. Zool. *80: 223-231), which provide carbon isotope data from bowhead whales harvested in spring and fall of the same years. For these data, no decadal correction is needed. Those data were not available when the draft of Chapter 20 was prepared and submitted.*

…and it questioned the "*isotopic fractionation factor*" assumed for the tissues analyzed.

> *Response: In the final version of Chapter 20, baleen data are no longer used in a quantitative way for estimating proportional feeding in the eastern Beaufort Sea, so the fractionation factor is no longer relevant.*

The SRB is curious why the isotope analysis results are contradictory to other study findings, and **recommends** that a sensitivity analysis of the uncertainty in the calculated proportion of food that bowhead whales might obtain in the eastern Beaufort Sea compared to other areas (e.g., western Beaufort Sea, Bering and Chukchi Seas, etc.) be conducted to test the assumptions that are relevant to the calculations. The most important of these include the value of the isotopic fractionation factor and the assumed diet composition (Tables 20.3 and 20.4). The fractionation factor could have been examined (e.g. by analyzing prey in the stomach and tissue samples from the same whale) but was not. Tables 20.3 and 20.4 should have been, but were not, updated by analyzing samples collected during the present study. Note the discrepancy between Table 20.3 and the summary of the results of the stomach content analyses of the present study on p. 21-2.

> *Response: A sensitivity analysis has been added in Appendix 20.1 of the final report. That Appendix estimates 95% confidence limits for the proportion of the food acquired in the eastern Beaufort Sea. The confidence limits are fairly wide, but are consistent with earlier evidence that prey from the eastern Beaufort Sea provides only a minority of the total food for this stock of bowhead whales. Analyses of isotopic composition of stomach contents would, if they had been done, be subject to concerns about contamination. In any event, the fractionation factor is no longer relevant as baleen data are no longer used quantitatively. Diet composition data in Table 20.3 have been updated as described previously, eliminating the discrepancy relative to p. 21-2, and the updated values are now used for the calculations.*

The SRB further **recommends** that additional samples and data (e.g., prey samples, stomach contents, fatty acid samples, genetic samples, measurements of girth, etc.) should be obtained from whales harvested around St. Lawrence Island for comparison with the results reported in Chapter 20 of the draft final report, in particular to test whether bowhead whales do feed in winter in the Bering and Chukchi seas. The SRB also **recommends** that the final report clearly state that the isotopic composition of bowhead whale tissue and prey tissue "*through the range of the bowhead whale*" was not tested, and that additional prey samples and stomach contents will be required to constitute a comprehensive analysis of all bowhead feeding areas. Future work should also consider the role of the lipid content in late summer and fall prey in building the bowheads' blubber reserves.

> *Response: These recommendations for additional studies have been taken into account in formulating the list of Recommended Research on diet and regional feeding that is included in Chapters 21 and 23. As noted in the Discussion of Chapter 20, isotope composition of zooplankton prey* has *been determined from most of the range of this bowhead population. However, no muscle samples are available from several key areas (Chukotsk Peninsula, Bering Sea, Canadian Beaufort Sea), and only a few data are available on isotope composition of blubber and fat. The importance of the autumn peak in the lipid and energy content of zooplankton is addressed in the Discussion section of Chapter 20, and in other chapters, and is taken into account in energetic calculations in Chapters 22 and 23.*

Chapter 22. Energetics of Bowhead Whales

The SRB found the overall approach to the analyses presented in this chapter appropriate, however, it recognized that there are <u>unquantifiable uncertainties in many of the assumptions</u> that are used to develop values for the various components of the energetic calculations. The SRB notes that the summary tables of values for parameters used in the energetic calculations are "*theoretical energetic requirements*" and "*estimates of energy consumed*" (Tables 22.14 and 22.15, respectively) *[now Tables 22.16 and 22.17]* and that the use of these values in the energetic calculations introduces an unquantifiable level of uncertainty in the analyses. Changing the values within the possible range of these parameters can significantly affect the resulting analyses and, thus, the conclusions based on them. The SRB also noted that the conclusions developed in this chapter have direct and significant implications for the interpretation of the overall null hypothesis for the study - the significance of the primary study area as a feeding habitat for bowhead whales - and in this regard, the SRB **strongly recommends** that the authors include statistical sensitivity analyses, as appropriate, for each component of the energetic analyses that support assumptions and conclusions relevant to bowhead whale energetics. For example, where a range of possible values is available for a specific parameter (e.g., months/days of feeding each year, total caloric intake per whale per day or per year, percent of time spent feeding per day or per season, number of days spend in the primary study area, etc.), the authors should undertake calculations that include the full range of parameter values and present the range of calculation results rather than providing the results of calculations that utilize only a single value from a range of possible values for a given parameter.

Response: A sensitivity analysis was done, taking account of uncertainty in the factors involved in the calculation of the percent of food that might be consumed in the study area (see Appendix 23.2).

The SRB had trouble understanding completely how estimates of "*whale-days*" were developed. Because "*whale-days*" are fundamental to the energetic calculations and the evaluation of the overall null hypothesis of the study, the SRB **recommends** that the authors provide a complete and clear description of how this parameter was estimated and include the equation for calculating "*whale-days*" in the text of the report.

Response: Clarified in revised Chapter 9 (p. 9-9, 9-27) where the whale-days are calculated.

The SRB notes that Table 22.4 "Percentage of time groups of bowhead whales in the Beaufort Sea spent engaged in various activities during spring, summer, and fall" on page 22-11 *[now p. 22-12]* states that whales feed only 1% of the time in the spring. However, the paragraph on page 22-10 states that "*31% of the bowhead whales landed at Barrow in spring had food in their stomachs....*", suggesting that whales are beginning to feed during their spring migration across the Beaufort Sea and brings into question the feeding percentages presented in Table 22.4. In addition, the statement that it is "*assumed*" that winter feeding is equal to that in "*summer*" is not supported by direct observations or other evidence of winter feeding. The SRB questions the validity of the assumption on page 22.11 third paragraph that "*for energetic calculations, we will assume that the time budget [for all behavior including feeding] in winter is similar to that shown in Table 22.4 for summer*" when the authors state, correctly, that there [are] "*no systematic observations of bowhead whale behavior in winter*", and (as previously noted) the SRB questions the findings reported in Chapter 20 suggesting that whales feed extensively in winter.

Response: The 31% figure (representing the percentage of the stomachs containing some food) does not provide direct information as to the percentage of time that whales spend feeding in spring. However, the revised report does acknowledge the possibility that, during spring migration as a whole, bowheads spend more of their time feeding than the 1% observed just northeast of Barrow. The assumed percent of time feeding in spring has been changed from 1% to 8% for purposes of energetic calculations, based on a speculative interpretation of the stomach contents data (see pages 22-11 and 22-12). The time budget in winter is no longer assumed similar to that in summer; we now assume no feeding in winter (see Table 22.4). Wording in Chapter 20 (and elsewhere) has been clarified regarding the assumed feeding in the Bering/Chukchi system; this is assumed to occur mainly in the Chukchi Sea in fall and perhaps the Bering Strait area in late fall, not in the Bering Sea in winter.

The SRB notes the reference to the controversial information presented in Chapter 20 (the isotope analyses) that conflicts with the statement later in the third paragraph on page 22-11 that winter behavior in the eastern Canadian Arctic during winter surveys was "*qualitatively similar*" to summer behavior in the winter Chukchi and Beaufort Seas where no data are available. The SRB believes that such speculation introduces great and unnecessary uncertainty into the analysis and conclusions in this chapter, and believes such discussion go beyond the limits and extent of the data available. The SRB **recommends** that such speculation not be included in this chapter, or any chapters of the report, and that the authors revise this and other chapters to clearly state the actual data and revise the discussion to reflect actual information and not unfounded speculation.

Response: The draft paragraph criticized above has been removed.

While Table 22.12 *[now Table 22.14]* indicates that whales do not feed in the spring, data from 32-34% of the whales harvested off Barrow in spring (Table 18.6 on page 18.15) contained stomach contents clearly indicating that some yet to be quantified feeding occurs during the spring migration. The SRB notes that perhaps some of the most compelling evidence of significant bowhead whale feeding during spring, summer and fall the eastern Alaskan Beaufort, including the primary study area, is presented in Figure 22.5 and Table 22.3 on page 22-9 that shows the maximum girth to length ratios of whales increases in the fall (i.e., they are bigger in the fall compared to spring. These data are contrary to the conclusions in Chapter 20 and suggest that whale are feeding during the spring, summer and fall in the Beaufort Sea.

Response: See earlier response re percent of time spent feeding in spring. We agree that the data in the referenced Figure and Table show conclusively that bowheads feed in summer and early fall; this was emphasized in the draft report and again in the final report.

Further, the information presented in Table 22.12 on page 22-23 *[now Table 22.14 on p. 22-27]* is not intuitive and needs better explanation. There is also an error - there are 121 days in the period from December to March which increases the author's estimate of feeding days from 132 to 139. The SRB **recommends** that this table be revised to include the number of days for each time period and percentages of time whales are estimated to be feeding along with the days feeding. For example:

Table 22.12 Revised

Time Period	Apr-May	Jun-15 Sep	15 Sep-Nov	Dec-Mar	Total
Number of days	61	107	76	121	365
% time feeding	1%	71%	47%	71%	
Days feeding	1	76	36	86	198
Days feeding – 30%	0.7	53	25	60	139

The SRB notes that if Table 22.12 on page 22-23 *[now Table 22.14 on p. 22-27]* is revised to reflect the lack of evidence for winter feeding, the estimated number of days feeding in the eastern Alaskan Beaufort becomes 53 in summer and 25 in fall for a total number of days of 78 days compared to the 132 (139 corrected) feeding days the Authors present. This alternate estimate is better supported by the available data and has implications for all of the calculations used to estimate the amount of feeding whales undertake in the eastern Alaskan Beaufort and the primary study area. Given that bowhead whales do manage to obtain sufficient amounts of prey each year, 78 feeding days could imply that whales are very good at locating rich patches of prey - they optimize the patchy prey resources - , feed continuously on below average prey density during migration, and that estimates of prey density obtained in this study are negatively biased and underestimate actual prey densities, or some combination of these alternatives. The SRB **recommends** that Table 22.12 *[now 22.14]* be revised to include information that is based on observations and data, something like the following:

Alternative Table 22.12:

Time Period	Apr-May	Jun-15 Sep	15 Sep-Nov-	Dec-Mar	Total
Number of days	61	107	76	121	365
% time feeding	31%	71%	47%	0%	
Days feeding	19	76	36	0	131
Days feeding – 30%	13	53	25	0	91

31% from stomach contents of whales harvested off Barrow in spring.

Response: The format of the table (now Table 22.14) has been revised as the SRB suggests. See previous comments regarding assumed percent of time feeding in winter and spring (the suggested 31% for spring is not appropriate). Chapters 22 and 23 now include a better explanation of the procedure for subdividing the year and for estimating the number of days of feeding during each season.

The SRB further **recommends** that the authors revise this section of Chapter 22 to include a statistical sensitivity analysis of Table 22.12 *[now 22.14]* that presents the range of values for various input parameters used to calculate feeding days, and discuss the implications of the range of these values on the following calculations of the percent of prey/ annual energy requirement bowhead whales obtain in the eastern Alaskan Beaufort Sea and the primary study area.

Response: Uncertainty in the parameters used in the energetic calculations has been taken into account in the sensitivity analysis now included as Appendix 23.2. That analysis was used to determine confidence limits on percent of the annual energy requirement that bowhead whales may obtain in the primary study area (see Table 23.10 on p. 23-24).

The statement on page 22-26 *[now p. 22-31]* that “Bowheads cannot satisfy even the low theoretical estimate of energy and food requirements by feeding on average concentrations of zooplankton found near the feeding whales” and the fact that bowhead whales are surviving and even growing during the spring, summer and fall suggests to the SRB that the theoretical estimate of energy and food requirements and/or estimates of zooplankton concentrations presented in the draft report are inaccurate, and/or all of these measurements are biased by some unknown amount.

Response: That paragraph has been revised to acknowledge that bowheads could meet their (low) energetic requirements if average prey concentrations encountered in all feeding areas (both within and outside the Beaufort Sea) are somewhat denser than those documented near feeding whales in the Beaufort Sea in summer/early autumn. As now discussed in Chapters 21-23, the most parsimonious explanation of all data may be as follows: bowheads obtain a minority of their annual needs in the eastern and central Beaufort Sea, sufficient for some increase in girth and energy reserves, but need to feed intensively in late fall on denser zooplankton concentrations in the Bering/Chukchi system in order to meet overall annual requirements.

SRB member C. George believed that that the energetic estimates are probably pretty close but that the prey density estimates are either too low or more likely that the high density prey masses are missed by the zooplankton sampling. He was more comfortable with the idea that important feeding events are relatively rare (see previous SRB comment on whale feeding on dense prey pockets –Chapter 18). Like polar bears finding a stranded whale, a few feeding events could make a huge contribution to their annual or even "multi-annual" nutritional requirements. The bowheads’ unusual reproductive cycle whereby they calve synchronously every 3-5 years could be reflecting these opportunistic feeding events. The energetic requirements based on the "respiration method" are not based on direct measurements of lung volumes. George strongly suggests that the respiration-based measurements be removed from the report but retain the comments about the relatively small lung and heart size. These later observations fit with the bowheads' modest metabolic rates. The SRB concurred with this suggestion.

Response: The respiration method (updated) has been retained in the report based on consideration of J.C. George's unpublished data on bowhead lung volume. Those data show that the volumes obtained via the convoluted method used in the report were, in fact, close to the measured volumes.

SRB member R. Kenny noted that similar calculations and estimates for prey density and energetic requirements for North Atlantic right whales have proven similarly uncertain, suggesting that "*the whales are far better at finding and gathering prey than are scientists*." The SRB concurs with this view, and **recommends** that the authors of Chapter 22 include in their discussion a balanced description of the potential biases in their findings and implications for their conclusions concerning bowhead whale energetic requirements, annual feeding, and the importance of the primary study area to bowhead feeding ecology.

Response: The discussion in Chapter 6 of problems in estimating zooplankton availability to feeding bowheads has been expanded somewhat. This issue is also addressed in Chapters 22 and 23 (p. 22-29 and p. 23-11). The discussion of the importance of the study area in Chapter 23 has been revised and expanded.

The SRB notes apparent discrepancies in Table 22.15 "Estimates of energy consumed..." on page 22-26 *[now Table 22-17 on p. 22-31]* and Figure 22.7 the "Relationship between whale length and mouth opening..." on page 22.19 *[now p. 22-23]*. For example, the size of the mouth opening of an 11-m long whale is given as approximately 1.25-m^2 in Figure 22.7, but is indicated as 3.2 m^2 in Table 22.15. Values for mouth size for other lengths of whales also do not agree with the values in Figure 22.7. The SRB recommends that the authors carefully cross-check other values in the table and figures and correct these as appropriate.

Response: Discrepancies have been corrected and related results in different Tables and Figures have been further cross-checked.

The SRB notes the discussion on page 22-29 *[now p. 22-34]* that states, among other things, that "*If zooplankton abundance at sub-adult feeding sites in the Canadian and eastern Alaskan Beaufort Sea are indicative of prey availability at all feeding sites used throughout the year, annual food intake would be insufficient to meet the theoretical estimates of energy requirement given present assumptions about amount of time spent feeding in different seasons.*" Given that bowhead whales do gain weight during the spring, summer, and early fall and given that the population is growing and reproducing, it is quite clear to the SRB that the "*assumptions*" about prey availability, time spent feeding, and estimated energy requirements are inaccurate and should be interpreted with great caution. Given the great degree of uncertainty with numerous aspects of the information presented in this chapter, the SRB **recommends** that the analyses and conclusions presented in the energetics chapter be revisited and revised by the authors taking into account the numerous uncertainties inherent with the information utilized to develop them, and that the implications for the overall null hypothesis of the study be revisited in light of these uncertainties

*Response: The assumptions about seasonal feeding have been revised in the final report as previously noted, but this does not change the results very much. The fact that bowheads gain weight while in the eastern and central Beaufort Sea during summer and early fall does **not** prove that the rate of weight gain in summer (if continued during other feeding periods) would be sufficient to*

> *sustain the whales through periods when they do not feed. In the final report, Chapters 20-23 have all been revised to discuss this issue in greater detail, and to suggest a feeding scenario that could be consistent with all data. This scenario assumes that prey availability is higher in the western Beaufort Sea, the southwest Chukchi Sea, and possibly the Bering Strait area in autumn than in the Beaufort Sea in summer/early autumn, and that bowheads feed intensively in those areas during autumn. Whatever its merits or failings, this scenario is useful in identifying data gaps deserving of additional research.*

The statement on page 22-15 *[now p. 22-18]* that "no measurable heat loss through the flippers and flukes" [was] attributed to SRB member C. George. While true for the flippers, this is NOT what he found for the flukes, in fact he found the opposite. George is not sure how this statement got reversed! The heat flux rate through the flukes is higher than anywhere else on the animal - mainly because the blubber is so thin there (1.5 cm). Thomson should use a mean core fluke temperature of roughly 15 C, a blubber thickness (flukes) of 1.5 cm, and a thermal conductivity of ~0.2 W/mK for his heat loss calculation for the flukes. This will boost the BMR estimate somewhat. George used three "zones" for the flukes but this is not really needed…

> *Response: Corrected and revised as suggested.*

…He also suggest giving the energy output in Watts in a couple places in the text (and the conversion for KJ/day to Watts somewhere in the text or footnotes).

SRB member C. George also noted on page 22-24 *[now p. 22-29]* that the statement that BMR [is] consistent with standard metabolism plus the cost of locomotion (4.4 x 10^5kJ/d) in Table 22.14 *[now Table 22.16]* cannot be verified. The SRB suggests that this section, like other chapters, require a careful proof reading of the figures in the text with those in the tables for the final report.

> *Response: "Consistent" changed to "similar". Numbers checked and verified.*

Chapter 23 Integration and Conclusions

The discussion of the discrepancy between estimates of significant bowhead feeding in the Bering and Chukchi Seas compared to the Eastern Alaskan Beaufort Sea in Chapter 20 and information in other chapters could be aided by references to information on advection of Bering-Chukchi water and its plankton into the Beaufort in summer…

> *Response: Discussion of the hydrographic regime in the Chukchi Sea has been added to Chapter 20 (p. 20-19).*

…Except for the stomach contents of whales harvested off Barrow in the spring, it should also be noted that there is almost no information on where bowheads are feeding in June and July.

> *Response: This was noted on p. 23-5 of the draft report (now p. 23-7).*

The SRB has concerns for the basis of the conclusions presented on pages 23-13 to 23-15 *[now p. 23-19 to 23-26]* concerning the "*energetic requirements of individual whales and the population*" given the uncertainties in the components that go into these calculations. For example, the authors state on page 23-13 (end elsewhere) that "*Based on behavioral observations and an assumption (per Chapter 20) that bowheads feed extensively in the winter, bowheads may feed for the equivalent of ~132 full days per year (see Chapter 22). Thus, the amount of food needed to meet the average requirements per feeding day was estimated by dividing the annual requirements by 132 days*." Similarly, on page 23-15 the authors' statement that the "*estimate of ...annual energetic requirements...is independent of the manner in which the energetic* *requirements is calculated but is sensitive to the amount of time whales spend in the study area and the proportion of time spent feeding*" tells us that the duration of time spent in the feeding area is a key variable affecting the overall hypothesis, and the SRB notes and commented previously on the uncertainty concerning estimates of residence times presented in the draft report. As noted above, the number of feeding days could be 78 or 91 days if that estimate is based on existing data and observations of spring, summer and fall feeding and not on speculation of winter feeding. Similarly, the conclusions presented in Chapter 20 are suspect given the body of evidence that indicates that bowhead whales do feed extensively in spring, summer and fall, and this would significantly change the estimated 132 feeding days per year. In addition, the calculations that support the estimation of the "*average requirements per feeding day*" and the "*annual [energetic] requirements*" are developed from parameter values with possible ranges of values other than those presented by the authors, and are therefore similarly uncertain. Given the significance of these estimated energetic values and conclusions to the fundamental conclusions concerning the findings of the feeding study, the SRB strongly repeats its recommendation above that the authors undertake statistically based sensitivity analyses that examine the full range of possible values for the component parameters that are used to development estimates of energetic requirements for bowhead whales, and that the full range of results be used when developing conclusions based on the energetic calculations.

Response: All calculations have been redone taking account of the above comments and other refinements, resulting in an updated estimate that, in an "average" year, the average bowhead whale consumes ~2.4 % of annual energetic requirements in the study area (Table 23.7). This estimate is independent of the manner in which energetic requirements are calculated if the ratios among feeding rates of subadults, adult males, and adult females remain constant.

Sensitivity analyses were performed, as described in Appendix 23.1 for residence times, and Appendix 23.2 for percent of diet acquired in study area. The latter estimate is most sensitive to the estimates of whale-days in the study area, but is also affected by the uncertainty in various other parameters, as addressed in Appendix 23.2. Even so, in 4 of 5 years, the upper limit of the calculated 95% confidence interval for percent of diet acquired in the study area was <4 %. In one year it is possible that bowheads acquired more than 5% of their annual food requirements in the study area, assuming that the (high) estimate of the number of "whale-days" in the study area that year was realistic.

The SRB questions the choice of "*reliable approaches*" used to estimate "*mean residence times*" presented in Tables 23.2 and 23.3 *[now Tables 23.3 and 23.4]* on page 23-9. First, dividing the residence values presented in Table 11.6 on page 11-19 *[now p. 11-20]* by 1.32 assumes a linear relationship of whale density between the primary study area and other portions of the eastern Alaskan Beaufort Sea. The SRB finds no reason or support for this assumption. Further, the authors indicate their preference for the residence time values calculated using the SODA program from photographic re-capture data, while no details of the SODA program are presented, nor are reasons provided for not using only the "*unbiased*" estimates developed by methods No. 3 "Photos: Stop-over Duration, Best Fit" or No. 9 "Aerial Survey: Whale Days." Instead, the authors employ the mean residence time estimated from methods Nos.1, 2, 3, and 9 without any justification for pooling these data. The SRB was not entirely convinced by the arguments for dismissing the estimates based on large sample sizes as unreliable, particularly No. 6 "Behavior: Overall Speeds." That method was apparently dismissed because of a single unusually large value to which observations from outside the study area made a major contribution.

The SRB notes that the most reliable estimate of residence time comes from radio tagging telemetry studies. The SRB recommends that the authors provide a complete explanation for their preference of the method used to estimate residence times and provide confidence intervals for each method for comparison. The SRB also recommends that MMS sponsor additional studies of whale residence times that employ methods that are more reliable than photographic identification, such as VHF and satellite radio tagging (see research recommendations below).

> *Response: • We acknowledge that the "divide by 1.32" method for obtaining residence time estimates for the "Flaxman–to–border" area is approximate. If anything, it is likely to overestimate residence times in that area, given the tendency of whales to linger in the "border–to–Herschel" area. This is now noted on p. 23-13 and 23-15. • The estimates that have been considered more reliable vs. less reliable have been revised in Chapter 11 (and Chapter 23) taking account of the SRB's comments. • The telemetry data are now included in the averaging process rather than being treated separately as they were in Chapter 11 (and 23) of the draft report. It should be noted, however, that the available telemetry data have their own limitations given the low sample sizes and (often) wide spatial and temporal gaps between detections. • The suggested sensitivity analysis has been done (Appendix 23.1), providing 95% confidence limits for the estimated residence times.*

Given the uncertainties inherent in the data and other information used to develop the information presented in Table 23.7 *[now Table 23.9]* on the "Theoretical energetic requirements for the entire BCB whale population", the values for "Percent of Annual Consumption" for the years 1985, 1986, 1998, 1999, and 2000 attributed to the study area range from a low of 0.3% to a high of 5.2%. The SRB notes this range of values (not their actual magnitudes) is consistent with the overall picture of the dynamic and annual variation of prey availability in the eastern Alaskan Beaufort Sea and the primary study area supported by the available data and LTK. This observation further supports the SRB's view that the apparent variability in space and time of the resources available to bowhead whales in the Beaufort Sea is truly characteristic of the region, and prevents ranking any one portion of the region above or below any other in importance to bowhead whales in any given year.

> *Response: The updated annual estimates range from 0.2% to 7.5%, with 95% confidence intervals ranging from a low of 0.0% in 2000 to a high of 16.5% in 1999 (Tables 23.9, 23.10). We concur that the project has shown wide spatial and temporal variability in zooplankton availability within the eastern Alaskan study area, and in use of that resource by bowhead whales. This was described and discussed in many chapters of the draft report, and again in the final report. To highlight this point, it is now mentioned in Chapter 23 as part of the answer to "Question (1)" concerning the overall importance of the study area (p. 23-25).*

Future Research Needs and Recommendations

Radio-Tagging: The SRB recognizes the value of radio and satellite tagging to the estimation of migration movement, rates of travel, and distribution which are fundamental to projects like this feeding study. The SRB **recommends** that, rather than including a radio tagging activity in the feeding study, MMS sponsor an independent directed bowhead whale tagging research program and that the results of this program be integrated into the findings of the feeding studies and other relevant research on bowhead whales in the Western Arctic.

Acoustic Monitoring: Technologies for passive acoustic monitoring have and continue to improve since the bowhead whale feeding study was initiated. Such devices mounted on the sea floor can record whale calls over long periods of time and can transmit their information to an aircraft or satellite, thereby eliminating the need to recover the device. This would be an advantage in the arctic when weather and ice conditions often hinder field research on the water. The SRB **recommends** that MMS look into sponsoring programs that will use passive acoustic methods to gather information on seasonal occurrence and absence of bowhead whales across their range, particularly during the spring and winter where information on bowhead whale presence, distribution, and movements are poorly known.

> *Response: We concur that radio-tagging and passive acoustics have much potential in further documenting the utilization of the Beaufort Sea (and other waters) for feeding and other activities by bowheads. This is noted in the "Recommended Research" sections in Chapters 16 and 23. The utility of satellite telemetry in autumn, and of acoustic monitoring in spring and autumn, has already been demonstrated in the field. It should be noted, however, that telemetry of acoustic data to an aircraft or satellite as suggested above is problematic because of the large volumes of data involved. Before this will be practical, it will likely be necessary to develop the capability to process and compress the acoustical data aboard the tagged whale prior to data transmission. However, other types of acoustic localization methods have proven successful in monitoring bowhead whale migration in spring at Barrow and in autumn in the Prudhoe Bay region.*

Stomach Contents Analyses: The SRB encourages the continued collection and analysis of stomach contents from harvested whales, particularly from areas where no such data have been collected, to provide a broader base of the range of prey species, times, and locations at which bowhead whales feed.

Oceanographic data: The SRB notes the value and need to continue to gather oceanographic data that would be helpful in better understanding the productivity and prey species available in the Beaufort Sea, and while recognizing the cost of such research, encourages the MMS to undertake such studies as resources are available.

Fatty Acid Research: The SRB recognizes the potential for fatty acid analyses to contribute new information for the study of bowhead whale feeding, recognizing that uncertainties remain in the methodology. The SRB **recommends** that MMS sponsor future research on the application of fatty acid analyses as a component of future bowhead whale feeding studies.

> *Response: We concur with the preceding three SRB recommendations, and have included them in the lists of "Recommended Research" in Chapter 21 (stomach contents; fatty acids) and Chapter 23 (all 3 topics).*

Local Traditional Knowledge: Future studies of bowhead feeding seeking to incorporate LTK would do well to have a biologist familiar with the community involved in designing questions in a way that would be effective in eliciting LTK. It would also be beneficial to collect LTK while whaling is occurring, since much discussion of observations related to bowhead feeding takes place then.

> *Response: We agree that future studies of this type should follow (or include) these practices, as did the present study insofar as practical. The individual discussions conducted early in the present study (Annex B) were conducted jointly by two people: a sociocultural specialist with much previous experience in Kaktovik, and an LGL biologist who is also an Inupiat. LTK was also collected during the local-boat surveys just before the whaling season, as described in Chapter 2. We concur that there could be additional opportunities to collect LTK during the whaling season itself. In the present study we purposefully avoided formalized efforts to collect LTK during the whaling season to reduce concerns about interference in the hunt by the project. However, the ADF&G biologist involved in sampling the harvested bowheads (Chapter 18) interacted with the whalers on an informal basis during each hunting season from 1997 to 2000.*

Agenda, Bowhead Feeding Study: 2002 SRB Meeting

Project: Bowhead Whale Feeding in the Eastern Alaskan Beaufort Sea: Update of Scientific and Traditional Information: Draft Final Report

Contractor: LGL Ltd, environmental research associates, 22 Fisher St., POB 280, King City, Ont. L7B 1A6, Canada, and LGL Ecological Research Associates, Inc., 1410 Cavitt St., Bryan, TX 77801, U.S.A.

Funding Agency: Department of the Interior, Minerals Management Service, Anchorage, AK
MMS Contract 1435-01-97-CT-30842.

Meeting Date and Location: 28-29 January 2002, Anchorage Hilton Hotel, 500 West 3rd Avenue, Anchorage, AK. Ph. 907-272-7411; Fax 907 265-7140.

Contact: John Richardson, LGL Ltd., phone 905-833-1244, Fax 905-833-1255; e-mail: wjr@lgl.com

Attendees:

SRB Members or Alternates

Dr. Steve Swartz, NMFS SEFSC (Chair)
Dr. Judy Zeh, Univ. Washington
Ms. Maggie Ahmaogak, AEWC
Mr. Thomas Napageak, AEWC
Dr. Ray Jakubczak, BP Explor. (Alaska) Inc.
Dr. Robert Kenney, Univ. Rhode Isl.
Mr. Craig George, NSB-DWM
Mr. Joe Kaleak, KWCA
Mr. Mark Major, Phillips Alaska Inc.
Mr. Brad Smith, NMFS Anchorage

Other Attendees

Mr. Steve Treacy, MMS Anchorage
Mr. George Ahmaogak, Mayor NSB

LGL and subcontractors

Dr. W. John Richardson, LGL
Mr. William Koski, LGL
Mr. William Griffiths, LGL
Ms. Gay Sheffield, ADF&G
Mr. Michael Galginaitis, Appl. Sociocult. Res.
Mr. Sang Heon Lee, UAF

Monday 28 January 2002

08:00 Coffee/tea/pastries available
08:30 Meeting begins
- Introductions
- Revisions to Agenda

08:40 Opening comments by
- MMS -- Mr. Steve Treacy
- Chair -- Dr. Steven Swartz charge to the SRB
- LGL -- Dr. John Richardson on behalf of study team
- Other -- Mr. George Ahmaogak, Mayor NSB

08:50 Chapter 1. Introduction -- background, objectives, hypotheses, study components, local coordination
- Brief overview by John Richardson
- SRB comments and discussion

09:20 Chapter 2. Kaktovikmiut Whaling
- Brief overview by Michael Galginaitis (LTK) and Bill Koski (data from harvested whales)
- SRB comments and discussion

09:50 Break

Zooplankton Chapters

10:00 Chapters 3. Introduction to Zooplankton Components, and 4, Acoustic vs. Net Biomass
- Brief overview by Bill Griffiths
- SRB comments and discussion

10:30 Chapter 5. Zooplankton - Species Composition, Biomass & Distribution -- as above
11:00 Chapter 6. Zooplankton - Characteristics of Bowhead Feeding Areas -- as above
11:30 Chapter 7. Zooplankton - Summary & Conclusions -- as above

Bowhead Whale Distribution, Numbers and Activities

11:45 Chapter 8. Introduction to Bowhead Whale Distribution, Numbers & Activities Components of Study
  - Brief overview by John Richardson
  - SRB comments and discussion
12:00 Lunch served in the meeting room.
13:00 Chapter 9. Bowheads: Distribution & Abundance
  - Brief overview by Bill Koski
  - SRB comments & discussion
13:30 Chapter 10. Bowheads: Habitat Use by Size Class -- as above
14:00 Chapter 11. Bowheads: Rates of Movement & Residence Times -- as above
14:30 Chapter 12. Bowheads: Activities & Behavior -- as above
15:00 Break
15:15 Chapter 13. Bowheads: Surfacing, Respiration & Dive Cycles vs. Whale Activity
  - Brief overview by John Richardson
  - SRB comments & discussion
15:40 Chapter 14: Bowheads: Surfacing, Respiration & Dive Cycles vs. Age -- as above
16:00 Chapter 15: Bowheads: Correction Factors for Aerial Surveys -- as above
16:30 Chapter 16: Bowheads: Summary & Conclusions -- as above
17:00 General discussion; any other concerns about chapters 1-16 (Volume 1)
17:30 Adjourn for the day

Tuesday 29 January 2002

08:00 Coffee/tea/pastries available
08:30 Meeting begins

Diet & Regional Occurrence of Feeding

08:30 Chapter 17. Introduction to Diet & Regional Occurrence of Feeding
  - Brief overview by John Richardson
  - SRB comments and discussion
08:45 Chapter 18. Diet & Regional Feeding: Stomach Contents
  - Brief overview by Gay Sheffield
  - SRB comments and discussion
09:15 Chapter 19. Diet & Regional Feeding: Fatty Acids -- Pilot Study
  - Brief overview by John Richardson
  - SRB comments and discussion
09:35 Chapter 20. Diet & Regional Feeding: Stable Isotopes
  - Overview by Sang Heon Lee
  - SRB comments and discussion
10:15 Break
10:30 Chapter 21. Diet & Regional Feeding: Summary & Conclusions
  - Overview by John Richardson
  - SRB comments and discussion

Energetics, Integration, Conclusions

10:45 Chapter 22. Energetics of Bowhead Whales -- as above
11:15 Chapter 23. Integration and Conclusions -- as above
12:00 General discussion regarding any substantive concerns
13:30 Lunch on your own (no pre-arrangements made)

SRB Executive Session

14:30 SRB meets without project or MMS personnel to formulate recommendations
19:00 Adjourn

ANNEX B: KAKTOVIK INTERVIEW TRANSCRIPTS [1]

by

Thomas Agiak
Bert Akootchook and George Kaleak
Daniel and Lillian Akootchook
Isaac Akootchook
Charles Brower
Joe Kaleak

compiled by

Michael S. Galginaitis
Applied Sociocultural Research [2]

for

U.S. Department of the Interior
Minerals Management Service
Alaska Outer Continental Shelf Region

MMS Contract 1435-01-97-CT-30842

October 2002

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[1] Annex B *in* W.J. Richardson and D.H. Thomson (eds.), *Bowhead Whale Feeding in the Eastern Alaskan Beaufort Sea: Update of scientific and traditional information*. OCS Study MMS 2002-012; LGL Rep. TA2196-7. Rep. from LGL Ltd., King City, Ont., for U.S. Minerals Manage. Serv., Herndon, VA.

[2] 608 West 4th Ave., Suite 31, POB 101352, Anchorage, AK 99510-1352. *Phone:* 907-272-6811; *e-mail:* msgalginaitis@gci.net

Introduction

Individual discussions were held with several Kaktovik whaling captains and other residents during and shortly after the first project workshop, conducted in January 1998. These discussions were held to seek additional information about utilization of the study area by bowhead whales, and particularly by feeding bowhead whales. Kaktovik residents know a great deal about the occurrence of bowheads in their area and their behavior, but in most cases say that they cannot determine whether the whales that they see are feeding as opposed to migrating or engaged in some other activity. Nonetheless, much local information on whale occurrence and behavior exists and can be elicited through interviews.

A total of eight interviews were conducted for this limited effort. We restricted the number of interviews because the project had neither the time nor resources to prepare a formal survey instrument for formal review by the Office of Management and Budget (OMB). OMB regulations stipulate that no more than nine interviews asking the same questions can be conducted without such review. Six of the eight interviews were recorded on tape cassettes. With one exception, the interviews were conducted in Kaktovik on 16–19 January 1998 by Steven MacLean, a staff biologist (and Inupiat) at LGL Alaska (Anchorage), and by Michael Galginaitis of Applied Sociocultural Research (Anchorage). Herman Aishanna was contacted by phone in Barrow on 20 January 1998, and hence his interview was not recorded. Archie Brower was interviewed in his home, but background noise precluded recording this session. Transcripts of the six recorded interviews constitute the text of this Annex. Copies of original tapes and draft transcripts were sent to each person interviewed, for their review. Copies of the tapes and draft transcripts were also sent to the AEWC for review. One of the interviewers (MSG) made several subsequent trips to Kaktovik during which he discussed the transcripts with the people interviewed. MMS will distribute copies of these tapes and transcripts to the appropriate repositories (AEWC, IHLC, KWCA), in addition to their inclusion in this document.

It is important to recognize the limitations of the interviews and transcripts. The interviews were focussed on a very narrow range of information, and were primarily intended to determine if a concise, concrete body of Inupiut knowledge related to the feeding behavior of bowhead whales in the eastern Beaufort Sea of Alaska could be elicited in a short period of time. Such a body of knowledge was not documented. While the Inupiat possess a wide and deep knowledge of bowhead whale behavior, this knowledge is embedded in a rich experiential context, and such a focussed interview methodology is ill-suited to document that knowledge or to tease out a specific sub-component of it. Much more time and effort would need to be devoted to such a task.

The transcripts are also very limited in scope. They are, for the most part, literal transcriptions of what people actually said, with no attempt to represent the non-verbal aspects of the interviews or verbal expressions with no meaning (“um” and so on). No attempt has been made to complete sentences or thoughts or otherwise “clean up” what was said to us, as in many cases the meaning is embedded in the way an idea or experience is related. Parts of transcripts are also unclear due to the poor quality of the recording. This poor quality was due in part to the short period of time available for the interviews and the locations where many of the interviews took place. While many of the transcripts would benefit from explanatory glosses, these have not been provided except for information directly related to whale feeding behavior, due to limited resources.

Nonetheless, even with their defects, the transcripts represent an important source of information for an understanding of whaling in Kaktovik. A general study of whaling was not a component of this study, but knowledge of whaling is vital for an understanding of the importance of this study for the people of Kaktovik (and the North Slope in general). Thus, the transcripts supplement and expand the summary treatment of whaling in Kaktovik that is provided in Chapter 2 of this report.

Thomas Agiak

MG Basically, what we're, what we're interested in really is what you can tell us about whale behavior in the Kaktovik area. [unclear sentence]. What you can tell us about where you see whales, you know, if they're big ones or small ones, what time of year you see them [?], and tell us what they are doing [unclear].

TA Well, all the, all the time I'm growing up I'd say I seen them right around this area and early. August.

?? [faint brief comment on tape, may be background noise]

MG Early August when you see them there?

TA Yup, early August. At one time, I'm, when I was young, in my, me and my dad, we -- just right off the shore up in there, toward the part of the one island.

MG So off of west, west part of Barter Island.

TA Early August, that's where I've seen them, right around in this area here. I'm, know I ah, most of the time, anyway. On our map we hardly catch any this far. I think we got some right around here. All of, every time we go out we catch them right off here.

MG So right off Bernard Spit?

TA [affirmative]. At one time I, right close to the surf here, a hundred yards off from the shore there, where, I ran into some few of 'em right around, right around in there. But when they get that close to the shore, there, they, ah, they spook pretty easy. Once you get close to them they take off. You can follow them in that shallow water where they swim along and ... knock bubbles.

MG [affirmative]. They, do they hit bottom, or make sort of bubbles?

TA They make bubbles. They make that dirt around on theirs. They make a, right middle of brown bubbles when they swim in the shallow waters, but you can't, ah. When you get 'em that close to the shore then spook pretty easy. Harder to catch them. [Pause] Right over here, on the beach, up on the lands, when I was growing up one year ...

SM Oh yeah?

TA ... we could hardly, ah, whalebones over there now. Arey Island right there. And last fall I was walking on the beach there and I found a stone, about that big. Burton [?] Rexford said they used that long time ago before they get any, any other kind of bombs, and that's what they usually hunt whale with over there.

SM Harpoon tip, you said?

TA [affirmative]

MG So you think they whaled from Arey Island, or they bring whales back at least?

TA I don't know, that's ah, we see you when I come up, we see some few of 'em on this artifacts right there, but, not as much as we do over here on that Arey Island. [Pause] [short unclear phrase]. Let's see, I find a whalebones back over here too ... not as much as we see 'em over here at Arey Island there.

MG [? ?] Spit too.

TA Yeah, that sand spit.

MG When you say that you catch most of your whales here, that's September then, right?

TA Yeah, September.

MG But you first see them August, around in here?

TA Yep.

MG And you, you don't bother them when they're there?

TA No

MG Are these moving or are they just sort of, hanging around.

TA I don't know. Or, I never really ah, pay much attention to 'em when I go fishing over there, it usually blows out there quite a few time. And my brother, when, when he go hunting over in Camden Bay area, he been seeing some, early August or July, over that way. In middle of the, August that's when maybe see 'em close to the Arey Island over there, feeding there pretty good that time. Quite a few blows over that way. [Pause] We never, we catch our whales right out here too, not, we got, most of our whales we catches just right in there. Then they catch him half a mile out from ...

MG When, you say when they're close there are harder to catch, that's cause they spook

TA That's shallow water, yeah, shallow water. Spook easier.

MG Will they stay close to shore after they spook?

TA I don't know. I never ... when I'm hunting out there we usually come out there, and just [unclear], that time we, spot him. Sometimes we go over that way and chances come. Just right in this area.

MG That's Arey Island, ah, Jago Spit. And, when you're, when you're in this area looking for whales, are the whales moving?

TA Yeah, seems to be swimming towards westly, going up. I don't know, theys, they just going each different direction, also, they.

MG Oh, so sometimes you'll see whales going the other way?

TA Yeah. Also as they go up and down the [eastern sea a way?] they swim different directions there. At one time, when we last, ah, struck a whale and when, I went out and looked for it, I got in the middle of them right there -- just swam all the way around it. Just sit. It was sideways [or that ways?]. And just sit that paper straight up and just sit there [?]. [Pause] So anyway, I think that was the last whale we struck [that year], the last quota we had. We went out and looked for it and couldn't find it. And I got in the middle of them whales out there, they just swam around, all the way around my boat, they, clumps of them. [Pause]

MG Then, did you find the whale, after a while?

TA No

MG Never found it?

TA Never found it. [Pause] I don't know, some years there are more whales over there than right down here [unclear] year or two, probably depend on the current there.

MG Current different from year to year?

TA [faint affirmative]

MG The whales, do they stay near currents, or do they like currents?

TA I think when you see them, ah, there they feed, tends to feed more, by the currents there.

MG But the currents change year, every year?

TA Yeah, there are different currents out there. Sometimes when you see water, it goes out, and some of 'em goes east and west, some of 'em north and south. Different patterns of water, it just, aren't going around [?]

MG And some of the, the people at the workshop, they were talking about rivers flowing from the land, too. Do the whales like that kind of water?

TA Not probably. I don't know. I never really studied much, um, they stay out, out here too, mainly. Most of them are out here. We never go, in last ten years or so, we never go beyond the, down below here over that way or, never go much beyond, down below Jago.

?? Just head straight out.

MG How far out will you go, to look for whales?

TA About 10, 15, 20 miles.

MG And the, of course the further you go out the longer it takes to bring the whale back?

TA Yeah, anyways, [?] and I scout around out there, sometimes I just barely can see the mountains on the top of the ocean, when I scout around out there. [Pause] I haven't been out in a long, long time, there. When they was doing seismic I had to go quite a ways out, just see the top of the mountains here, then try to see some whales out there. I nev, we never strike any whales that, that far out.

MG Do you, every year, do you always go out and scout before you go out and whale?

TA No, I just go, always go to here, or just go straight out of Barter Island about ten miles and, sit around out there. You see them blow out there. That's what they did last fall, anyway. They went, in a two or, this way a little bit thick. And first day, they was ... the first time we were out we got it. In the morning.

MG Quick.

TA When it's clear they catch 'em, but last fall we hadda lot of fog out there and we couldn't. We go too far out sometime we see 'em closer to the island and then we go back up and clears up [PHONE RING] ... each time it clears up a little bit they see a whale, it [PHONE RING].

MG Yeah, people said [PHONE RING] it was very foggy last year.

TA Yeah, it was.

MG Is that [PHONE RING] ... how, how do you communicate with the other boats, can you still keep in contact with [PHONE RING]...

TA CB

MG CB all right?

TA Yeah, when they want to find out [PHONE RING] where all the, each boat is [?], CB is on a, land too [PHONE RING] ... find us pretty fast that time [PHONE RING] get on GPS, I suppose. Before we got GPS I used to [PHONE RING] go out with compass.

MG And how do you find the whales when it's foggy?

TA It's a, sometimes when they blow, you can see a, lotta dark ... bolts coming outa clouds there, most always. Most of the time when I'm going out in that really low fog out there, you can see the dark marks going up ... that's whale blows. Can see it in a real low fog. Just gotta [?]. Find 'em pretty easy, like that out there. A couple of times, I think, me and my brother, spot whales like that, when, when it's started to get a little foggy down there in the, ocean there and you can see the dark marks going up.

MG Do you ever see what the whales are, are looking .. feeding on? Or do you see little things in the water?

TA No, there, never. We just concentrate on going out and catching 'em.

MG Uh hum

TA Find a whale we going to be, when the captains find a whale, they ever found a boat can stick it, we stick together over here in Kaktovik. When those captains find a whale we all go out. And when captains start to whale that’s when we concentrate on killing it and taking it home. All the boats get together once again when we strike a whale.

MG When you say when you go out you just stay within this area, uh, different times of the year are there different numbers of whales here? Like early in the season, is it different then later?

TA Ah, I don’t know.

MG Or when do you first see whales? You said you saw them in August here?

TA Yeah. When we go fishing over there, snow machine ... you can see blows right off of there.

MG Uh hum. And you don’t see so many over in this area then?

TA Not as much. You see them over on this area, early in August.

MG And then later in September, are there more closer to Bernard Spit?

TA Uh huh. They’re out this way.

MG Can you tell, are, are they just, are they staying there, or are they moving to the east.

TA Sometimes when they’re ... ones I’ve seen right up in there they just go back and forth.

MG Uh hum. So in September they just seem to be staying there.

TA Uh huh

MG And how late do you see whales?

TA When you can boat out there, ah, tend to see them in October, second week of October. When I went out, when I went out after we finish our quota one year I went out in a, Trailbusher [?] here and I was going out, and I went out through here and I was going straight over to that point there, and I seen three whales feeding there.

MG Well, that's still in, uh, October -- the same place you saw them in August then. Maybe different whales, but the same place.

TA Yeah, the same place. You know, one year I took my daughter, daughter-in-law, down. We spot a whale right in here [name or phrase in Inupiaq?]. Just playing around out there, and seen him standing straight up like that. I don't know how they do that, I don't know whether they are just playing around or feeding.

MG If you just ... If they were just hanging around, do you think and they're small ones, real small ones?

TA Yeah, real small ones.

MG When do the big whales go by?

TA Umm. I think they go by early in August. They say you see most of the whales feeding over in this way in ...

MG And are there any big whales in September, uh

TA Oh yeah

MG So they don't all go by at the beginning

TA Yeah, we see big whales out there too [when they are whaling], mixed in with small ones. There's a whole bunch of whales out there. ... First time when I become a captain, ah, first time I was a captain back in '82, I got, I got my whale there, around here, about fifteen miles out. And it was too big. I got fined.

MG By the whaling captains association?

TA No, by the lawyers down in Washington DC. I had to go to court in Barrow ... Alaska Eskimo Whaling Commission. My whale was too big. It was fifty two and a half foot. I got him September twenty seventh. My first year was lucky, back in '82.

MG Hmm.

TA That time we couldn't catch ... no, no bigger than forty six [two or three unknown words], and no smaller than thirty five.

MG What's the size limit now? Do they restrict it, no restrictions?

TA No restrictions. But that first time when I ... we start studying the whales there, the Alaska Eskimo Whaling Commission just come out, ah, once had a big construction here [?] one time, you know, [word or two ?] Alaska.

MG Yeah, not very many back then.

TA No. I'm sure now that they're start getting help from scientists and, ah, Dr. [Thomas] Albert and Craig [George], they come in and [they didn't know, there were more than, they didn't have to go out UNCLEAR ?]

MG What kind of whale do you look for now when you go out?

TA By-and-large its just bowhead. I have, I never see any gray whales. Only one time I've seen that kind of ... come up, come up to a gray whale, and then we ... That's the only time I've seen a gray whale out there.

MG Do you look for a medium size whale, or a small whale?

TA Small whale.

MG How long would, how long ... if, if you had your choice, what how long a whale would you look for?

TA Over a thirty footer

MG And most other captains, same way?

TA Yeah. I get, ah, thirty six. If we get them over thirty six, thirty, thirty six, they can catch up early in the morning and butcher it in the afternoon, divide it up in the [evening time ?-- sound of door closing] and get ready for the next whale.

MG Uh hmm.

TA One year they catch a whale in the morning, and they were done in ... they cut up that whale in three hours ... and then in the evening they divided the [unclear ?]. [First full ray ?], get up, that way divide it up before we go out to catch another one. First strike, first crew [get ?] in the fall time. ... PAUSE ... Ah, one year, when I -- I can remember they -- that was before they get the quota system, they catch five whales in one week. [Unclear phrases], cut 'em up.

MG Most of those were small whales, though?

TA Small, small

MG That's still a lot of whales

TA That's good [? Said faintly, as an aside]. Small whale, they done[?][laughs], pretty big, all right, but they, ah, divide 'em up they take [laughs], get a little piece

MG Um hmm. Some people tell us, you said whales were, lived here, were here in August. Some people say whales are, you know, in the area as early as July?

TA Yeah. I think on my brother was out hunting over that way, toward Camden Bay, they, they spotted some over that way. Feeding around over there, I don't know what area. Last summer I didn't do much boating, I, I went back to work for a couple months there. Didn't do too much boating [around/out there ?]. End of August I quit, middle of August I quit working. And the rest of us to go hunt caribou [UNCLEAR ?].

MG Would that be just a few whales that were you see over there?

TA I think when they were setting up that, uh, drill rig over there over by Camden Bay area, and I said I seen some whales over there when I was setting up. About a hundred twenty-five blows they spotted over that way, before it was started.

MG Yeah, I guess that's what they said. We'll have to ask him and see, if we can get records of how many whales they saw and when they saw them there. I guess one thing we're interested in is, if you can tell us anything about the migration, you know, if it -- what time it occurs during, and whether there're more whales at one time of it than another.

TA The last three years have been, we've been -- I actually like to go in the middle of September, but the last three years they've been coming up earlier. It depends on different years. Last year we could have got done in first week of September if it wasn't foggy. And all the whales, I must start whaling the fifth till right around the middle of, almost the last, end of September. There're not big, all those whales, they're a little kind of big then. Forty eight footers. Forty seven, forty three footer.

MG At the end?

TA End of September, there're like that, too [unclear phrase ?].

MG So there're bigger whales at the end, it sounds like.

TA [unclear]. The first of September you can sometimes they go by with, small whales are there with 'em. Those are the ones we don't come close to.

MG You don't go after those ones?

TA I don't think so. I see a whale, a small whale right alongside of it, we don't dare go near. Too danger [unclear at the end -- lower voice ?].

MG You said you like to, you would like to go out middle of September?

TA I think it's a lot cooler, but, you know, the last three years have been starting right at the first of September.

MG And that's something all the captains decide together, when to go out ...

TA We have a meeting, ah, before September. We set up date to, the captains can go out, after that date they can go out. All the captains meet together down here before whaling starting, set up a date, to tell them when you can go out. All of us have to go together, if they want to go out. No captain goes out before that day, hah?

? Uh huh

TA I've traveled quite a bit over that west of that way, in August. I never see any whales over that way, over to Herschel [Island, in the Canadian Beaufort Sea]. I've seen 'em, I've seen quite a few of 'em when I coming home from, ah ... Running [placename unclear on tape] River or , ah, Shingle Point over there, from ah King Point area right around there where the Canadians do their whaling over there.

MG I guess we could look at that map if you want.

TA I don't think you can go that far over.

MG Well, this one maybe goes that far over [sound of unrolling and moving map]

TA It doesn't go that far over. Here.

MG First line

TA First line. All the way down here.

MG Oh. Way down there. Right at [Hersey Bay farm?]. But, but you don't see whales in here when you go hunting?

TA No, I never go any hunting, over there to [see or visit] my relatives over there. Visit them over there.

MG You do go visit them?

TA Yeah. The only place I've seen real close to the shore is right off King Point. From King Point out, on the ... the area here [unclear ?]

MG But even in here, no whales?

TA No. I never ... I've boated quite a few times over there, and I never see any of 'em.

MG What, what time of year would that be?

TA August, and July

MG Yeah, that's pretty early, I would think ... though you say August there are already whales up here

TA Yeah ... that time around I travel with a boat out this way I never see any, ah. And one year, a couple years ago, I went back across here three or four times, with a boat and with Albert [last part unclear ?].

MG And you never see whales over here?

TA No

MG But you do right around Kaktovik?

TA Yeah

MG And maybe over here?

TA When I snow machine over there, do a lot of fishing over there in that channel over there, when that was open. [Sound of maps to find the place referred to] When this channel was open there, they do a lot of fishing -- my wife likes to go over there, Honda over there. Go char fishing over there. It's a good, pretty good size fish. And now she goes all the way over, over that way.

MG Do you need the open channel for the water going through?

TA Catch a lot of fish there. See, it's all closed right there now, you got so much in, all the way, on that island over there, all summer long. They, ah, fish over there in the fish creek by the end of, end of July. July, hard to catch. They're running, but they're really hard to catch. [unclear word or phrase]. PAUSE

MG Do you think, are the whales, do they like the, the current too, do you think?

TA Probably. You got rivers going off from the, along the shore over there, and, coming up, you have a pretty strong current going through there.

MG But you don't use the current when you are looking for whales or when you are hunting them?

TA No, no. All we do is look for blows.

MG Is this just because there are usually so many whales you don't need to ... do that?

TA No [faintly, and then a pause]. They see 'em right out here before we once start whaling.

MG I guess some people say that, you know, there is a pattern to the migration.

TA Sometimes they come out early, sometimes they come out late. For some reason, I don't know. Some years you don't see any whales ... over here. Some years you have to go look for 'em out there. [Find the whales -- a faint inaudible word or phrase ?]

MG Some years there aren't many whales? Hard to see, or ...?

TA Hard to see or sometimes they just get swimming out there, they go by and the wind is blowing. You see more whales in there [? unclear] and the wind is blowing out there. And then clear up and they disappear [laughs].

MG So, so years when you don't get whales, there are still whales out there, you just ... either can't get out or don't see them?

TA Yeah, and that's really been a hard time start whaling, when we don't like to go out [?], and there are whales out there. Especially when there's no ice, the waves gets pretty high. [Pause]. And [nowadays ?] I went with my brother [name ?] to the whale and my brother strike it, and went over it. Waves, ... [Inaudible faint sentence], messed up. I seen this whale coming up. And I was too high on the whale, you know [? tape somewhat unclear], to pass it up. That whale is right there. Missed the whole thing [laughs].

MG You say you, you, you got your first whale in '82?

TA Yeah, first time I was a captain.

MG When, when did you start going out whaling?

TA Oh, no -- was before I was ever captain, I went out with my brother a long time ago. Early '60s, when we came up here, there wasn't going to hunt [?], start whaling around here.

MG In the early '60s? But you always whaled in Kaktovik?

TA When I was growing up here, you seen whales right off the [name ?] in August ... every year, you don't see 'em every year out here, early years. [sound very muddy]

MG I guess that's one reason why they want to do the, the whale feeding study, because every year is different. They want to see what they can find out about whales in the area, I guess, from year to year. To see if the things that the whales are looking for are different from year to year

TA That current's changing quite a bit out there during the year.

MG But it does sound like you've been very successful catching whales in this [?] area.

TA [unclear]. We never go beyond this point here, over here [name or phrase?]. And actually they almost, pretty swim about, about ten miles out. [Pause] One year they caught a mile and a half out here.

MG Real close

TA Yeah

MG Do you always take your whales to the same place?

TA Used to go straight in, one time, now we gotta use channel. Channel water goes quite a ways out. You gotta go over this way, you gotta ... A long time ago they say they used to [kunuk ?unclear], went through over there, [kuva ? unclear] went through there, back up.

SM Through the lagoon

TA Through the lagoon

MG Too shallow now?

TA Too shallow now.

MG Be a longer way to tow too, I guess.

TA While they were doing seismic out there, they had that drill site out there, we were quite a ways out, [before they turn away, catch out there quit -- ? unclear part of statement]. And it was quite a ways from [name ? unclear] -- twenty five to thirty miles out. And they quit doing the seismic and that much start to go out next day, we never go further out.

MG So you think, uh, noise affects the, uh ...

TA What affects?

SM and other faint and confused voices

TA When they were doing that well over that way, too ... I wanted to cross [?] up close to a whale but I couldn't. I couldn't, I couldn't do it, get the strength, I, I just couldn't ... get 'em, couldn't be catching up to 'em. [PAUSE] One year they were doing seismic and they had some ice out there, [unclear phrase ?], turn around, never see 'em again.

MG Why do you think they spook so easy?

TA I don't know. Too much noise out there or something. They were doing some seismic in that area, and that could be why ... [continues to talk but becomes very faint]. Have to go quite a way out to see any whales. And the drill rig was sitting out there a couple of, two years ago, [?] -- had to go quite a ways out. When there is no noise, [very unclear phrase] quick, and we go out there and get 'em pretty close. I even got a new update, ah, map last night ... [some of the guys went to Anchorage ? unclear]. [At this point we are looking at the old map of Kaktovik whale strike locations in the DMS break room. TA making some comments about it].

MG Ah, old map [TA comments on map too faint to make out]

TA That's the [agvik ? Unclear]

MG Is that one that somebody struck here ...

TA Nope.

MG ... or came from somewhere else?

TA Died of natural causes. Had a big black clot on the undersides, on the end of it. About eighteen feet, I think. Dr. Albert, he looked at almost every inch of the whale and he couldn't find any bomb holes or nothing ... [rest of sentence inaudible. Next sentence also not understandable ?] It just died of natural causes. First one I've ever.

MG You took the muktuk and the meat? It look all right?

TA I take most of it here, but when I cut those off him, in places [hard to understand] -- some bacteria that's what makes him stomach ache and ... diarrhea. That's what ... [very faint]. That Dr. Albert, he always [very faint]. I thought we would find a bomb or a bomb hole in that one, but ... that was it, nothing.

MG And that's the only one that you've seen like this, died by itself?

TA And without a hole in the agvik too.

MG [to SM] I don't know if you have any questions you want to ask -- things we may have missed

SM You've covered most of it.

MG Things we may have missed.

SM What kinds of whales do you see closest to shore?

TA Small whales

SM Small whales closest to shore?

TA I say no. Sometimes we see a pretty good size whales over this way in August. There are some big ones out there, early in the, um, late '60s. [Unclear phrase or sentence ?]. Quite a few of them, I see big whales and small pairs out there in August, now [unclear word or two ?]. You can tell the difference between the blow and the, the blows of the small ones. For the big ones only, they blow pretty high. The small ones they blow just a little bit. I don't know, it's the last ??? ...

I heard it, and it sounds like it's quite a ways out, but it was a hundred yards away. It was [?] run over just between the house, and that guy was [?],.. Sound different

MG But that whale, that you got, after you heard it, how did you get up to it, so you could strike?

TA [Laughs]I give up. ... between the ice pack. I harpoon it. And it took a couple of days ...

[Some unclear sentences here]

MG So the next day, the next day you could find it.

TA Yeah, it was nice out there, we can ... [?] ... from the boat out there ... [?] ... go thirty miles out... [?]

MG You say that one took several days before it could bring it in?

TA ... [?] Got too dark on us and I hadda, hadda send everybody home. Come back the next day and pick up our buoy.

MG forty-eight foot whale, that's a pretty good whale.

MG Can we share the information that you've given us?

TA [faint affirmative]

MG You know, talk to other people about it? And if you would be willing to I would like you to sign a form that says that, you know, we can share this information with other people,

TA Yeah

MG and that way then what ... makes it easier for us to do that. If I can find where I put those now ... You can tell I'm not always very organized ... [tape ends]

Bert Akootchook and George Kaleak

Tape was not started at the very beginning, as we had to ask them if we could tape. When we came in there was also a larger group of people just socializing. We waited until the break was over and people resumed work (or went out) before asking BA and GK if we could talk to them a bit more. Joe Kaleak and others had suggested them as good people to talk with, and they had expressed interest at the earlier workshop.

BA When they get them arthropods, and they just pull them up at, cause they did, and they get some arthropods right on, right from the bottom. They make [???] waiting for the whalers.

MG So are they in the boat or on the ice when they are doing that?

BA On the ice, while we're waiting for whales, and when we're on the ice, and

SM Springtime?

BA That's in the fall time

GK That way you can, you can, you can, ah hear, or listen -- listen for the whale, cause they got a big blow, you know, and you hear a tremendous amount of blow and then you know where to go. [pause] Lot of times...

BA [???] about that long.

GK we look in the water also, you know, you can know when -- when you're, like, krill -- out in the water you just look down and you can see all that.

MG Do you always see krill when you go out whaling?

GK Not always, but a lot of the times, you know, you can see it, some of them floating at the top and, even under the water a little ways, you know, as far as you can see them -- some years there'll be lots and you know some years like this year seem like there was some hardly any.

MG But you got lots of whales this year, you saw lots of whales.

GK Yeah, yes -- quite a few whales out there.

BA Even after they were done whaling they were still sticking around down here.

SM Hanging out near the island?

BA Right after that last whale.

GK Especially after they're struck seem like they, they know when to come out, you know. Every time, seems like almost every time a whale is struck and we start towing all the whales start showing.

BA Sometimes right through October too, you see them, going down to the airport, you'll see whale blows. That's not too far.

MG Can you see them from the airstrip?

BA No -- from the land, from the road [which is elevated or higher up].

GK They don't go very far, I mean, a lot of 'em even, you know, they come real close to shore. Like, like the one this year, one of the first whales, we wound up chasing -- we were, we -- was foggy and we followed the trail. Because, you know, you know when the whale hits bottom and its, its got brown murky water, you know, you know a whale trail's right there so we started following it. Sure enough, there was a whale nearby.

BA Pretty near everybody find a whale by, just by listening. Last year best way -- its foggy most of the time

GK Yeah. I think the three whales was pretty foggy. The last whale it was kind of snowing, a little bit, with a little fog here and there.

MG So you found your whales by listening mostly?

GK By listening, you know

BA That was last year.

MG How do you decide where, where to listen from, where are you?

BA You find out how many miles you go and people just pretty much spread out since they had the GPS and learn how to use them.

GK And that's pretty much how everybody finds each other is by coordinates. We give 'em the coordinates and they know if they are drifting away or coming closer by trying to match the numbers of the coordinates so they can get as close as possible to where they can see us -- and it worked out pretty good this year, you know, I, this is, uh, actually the first year I had to use my GPS and say "Man, this really works, you know." It's pretty amazing.

MG Does it make whaling easier, then, the GPS?

GK Oh yeah. The more boats around the better, you know, once we spot a whale, the more eyes, the more eyes around the whaling area is a lot better than just with one boat.

[some pause or side discussion]

MG You said that the whales just hung around this year?

GK Oh, pretty much. I mean they were, seemed like they were sticking around.

MG Is that normal, is that what they normally do?

GK Oh yeah, I mean

BA Yeah, how many times we see them

GK They're always, they're always around

BA You'll see them right out there

MG What I mean, the way, the way I think of it the whales are coming from Canada and they go, you know, past Barrow, but you say they hang around in this area for ...

BA Just for a while, yeah

GK Yeah, I mean, seem like its -- its to feed or something

?? Remember that one year, that down by Jago, every boat saw a whale

GK Yeah, that was awesome, when we ...

?? Every boat was chasing a big whale.

GK It was, it was so hard to decide which whale to go after they were so many, and, and ...

?? We got [???] whales enough [more than one person talking]

GK They're, they're not even a mile from, from shore either, you know. [pause] These guys got, Akootchook's crew got piggy-backed by a whale, and I don't even think they realized it because they were right, right on top of the whale and, he was right in line with it.

?? [????] flip the boat

MG Did, did, did they flip over?

?? No, no -- he just ride on top of it, [??] put back by itself [and quite a few voices]

SM I heard about that, a couple of years ago, huh?

GK Yeah, a couple years ago. I thought, the ah, whale was going to feel the boat and, and let its flipper, you know, go wild and flip them over or something, but it didn't even, didn't even do that. That was awesome. I was right behind them when I seen that.

MG Just sort of lift up a little and then down?

BA Real pretty much, yeah -- just lifted up and slide back ...

GK The whole boat was out of the water, yeah.

BA First time I ever done that before [laughing]. All of us was just [???] on the boat, its [???] all of us to keep it moving. Just watching [?]

GK You don't ever begin to think about being scared out there, when, when its our livelihood and when the people out there depend on us to bring 'em food, you know, you, we, we don't ever tend to think about being scared cause the old folks, you know, they, they taught us, scared you know, you probably either get hurt or get in trouble or -- so, me, myself, I don't ever think about being scared, no matter what.

MG You think that's pretty true for all whalers?

GK Oh yes -- you always gotta listen to your Elders. They know best.

?? Pop -- you want some pop?

MG Well, I have coffee here.

?? Right around, right after I got out of school in 64 I [???], just a few of us. We didn't have a crew that time, we just tagged along. And then we ... Vernon [?], we were just learning, help, just learning anyway.

MG And you said that you just tagged along ...

?? Just with a boat, go out with a crew, and just the two of us -- boy, there was that, lot of muktuk just, just the two of us -- just for tagging along and helping to pull the whale [laugh]. That was before the season's came around.

MG Is there any, any one crew that you helped more than others, or

?? Pretty much all worked together

MG Everybody stays together then?

?? But they always tell us to have another boat, if another boat goes a different direction he always ask for another partner to go with him, just in case something happens.

MG So boats still partner up?

GK Yeah, always travel in pairs, you know. Never, never go alone. You never know when the wind's going to come or ... but now with the communications system [???] Prudhoe Bay [loud noise from DMS building machinery]

...

?? there's another way we find out about a wind is [unclear] Rexford, she's an Elder, she must about, close to eighty years old. And she would read her barometer and when the barometer moves telling that we were going to have a strong west wind she'd call us ahead of time, just by checking the barometer. And that's the only people we used to [???]

?? That was another way we find out when wind change.

GK Now with our VHF, you know, the communication system with Prudhoe Bay radio they, they get the weather report every day, you know, every how many hours they get the weather report and, we, we request for weather report and they give it to us, you know. Sometimes, its true but you can never predict, because that's ... down there.

MG I was going to ask, is the weather report always right?

BA Sometimes they're wrong

GK Sometimes they're wrong, you know. They may say the wind, the winds going to pick up to like 25 miles an hour and it don't even come close to that -- calm

BA That's the [????] probably north side of Cross Island. Course I know one time when we were hunting on this side, on the east side, it was [?] rough. The weather would be really calm.

GK So the weather report is not always right.

MG You said the whales often -- you can see whales in October still?

?? Yeah

GK Probably late, late, late ones that, you know, that, that pass on by, they might be the big ones, I don't know. Probably the late comers. You know not all whales travel together. [noise revs up, then down]

MG So you think [??] are sort of by themselves or are they, they're a bunch of them together

GK Some of them, you know, go in schools, but not all of them

BA Probably towards end of the year. Last year and a couple years ago there was a whole bunch of them north side right down by [Inupiaq place name], some of them were even very close, right by the beach. Lot of whales. We see a whole bunch of them there.

?? But we didn't go after them because we were looking for the whale they had struck the day before.

?? The weather was [?], afterwards was looking for the one they already had struck.

?? The day after, two days after, we can't find it ... we decided try and find another one.

MG Did you find the one that you had struck?

?? Most of the time we do but when the wind is strong, and the wind is blowing strongly, with the storm tides maybe a couple of days later with the bloat, it is all aired up, floats. That way it would probably float, after a couple days.

GK Very rare though. I mean, most of the whales I think are landed. There's -- I know of one stinker I remember in my lifetime that you see the whale so bloated up you know over half of it is exposed in the water, out of the water. That's unreal. Still, we take that whale, we bring it back and gather up all the muktuk and the baleen and, the meat's already spoiled so we can't touch that. And we just leave the rest for the polar bears and foxes.

MG If we showed up some, some maps, some nautical maps, could you show us where currents are in the areas where you've been?

?? Currents?

MG Currents, you know

GK Yes

MG Where the water flows most of the time or where you can predict where water's going to be flowing?

GK Pretty hard to tell, I mean -- like, go out a little bit, it'll be flowing that way and you go out further and it'll be going this way. I know when I go out, you know, oogruk [bearded seal] hunting, you notice that. All of a sudden you see an ice going this way and further back over there it's going this way like its going in a circle.

?? Sometimes you can't even see the currents in the bottom.

GK You have to be out there to, you know, experience that, for to see it -- it might be different closer to shore, further out. You know, there's all sorts of different currents over here.

MG After you see currents in an area, and you go back, are they the same? do you learn where, where they are?

GK No, it all depends on weather too, you know. Like, going since when the tide start coming in, you know, we, we're, we're gonna, we're gonna get west wind, that's another way they decide that we're going to get west wind, is by when the tide comes up. Usually when we get west wind the tide comes in and when the east wind start coming around the tide goes down. That's one thing I've learned being in Kaktovik, it's ah, it's the tide, and the weather change, sure enough. You know, you got west wind. Even when it first freezes, you know its, all that ice -- it's setting. Then all of a sudden there's water on top of the ice because the tide's coming up and pretty soon we should have west wind and sure enough west wind comes around.

[long pause]

MG How late do you see whales -- what's the latest that you see whales?

BA October, last time we ... couldn't find one -- was a little, little hard. We were seeing whales, and it was right out here. Lotta ice though. You had to break through, almost [?] the boat. Kinda hard on the boat.

GK Yeah.

BA [?] they had to, they go out October, middle part of October.

MG Do you still whale sometimes in October?

GK Just so long as the water's open. There's, there's enough room to maneuver around ices, so, by golly, we'll be out there.

MG It's harder conditions, though, I guess.

GK Yeah, it's more challenge. As to suppose that you had no ice and nothing to get in your way. Whole different story. Going around ice and chasing whales is like playing cat and mouse. Cause you know them, them whales know the ice is around and they're going to use it to their advantage.

[Pause]

[To a co-worker] Open the top Norman [laugh]. You never put enough, hey!

?? Open the top?

GK Open the top. Lift it. [laughing again]

Every summer almost, you know, when we travel over toward Canada, we ... we almost always see whale all the time.

MG What time of the year do you go usually?

GK July

MG Any particular place you see whales, or just any ... ?

GK Mainly around that Kay Point and Shingle Point area, from there ... Herschel Island. From Herschel Island to Shingle Point I'd say mostly, but seem like they mostly hang around ah, Kay Point area where it's real deep, near the, near the shore.

MG Can you think of any reasons they, they stay there?

GK I don't know, it might be feeding. There again, you never know, it playing. Or, or like some Elders say, you know, they, they like congregate together or something and start playing.

MG But you don't, you don't hunt them in July.

GK No, no. That's. ah, Canadian waters where we're not allowed.

MK In the spring, do you ever see them Kaktovik?

BA No, we never see them, because ice always packed.

GK We don't, we don't have no open lead around here, in the springtime ...

MG So they're always ...

GK Maybe a crack here and there, but ...

MG So where do the whales go by in the springtime?

BOTH Probably further north.

MG Way out there.

GK Yeah

BA Where the Barrow current is mostly -- you know where Barrow is?

MG Yeah

GK I imagine about, 50 to 100 miles, maybe

MG And when does, when does the uh, ice open up enough, so that maybe ...

GK If it, if it ever -- sometime, I mean. There's some years where the ice hardly ever leaves.

MG So some years you may not see whales at all? Or whaling

GK [To BA] Some years, yeah?

BA Couple years that we, two, three years ago, we had very cold weather. The ice was ... around. Stayed around here, the ice. That time we just got, they got only one. [cough in background] two years ago?

GK I know two years ago we were the only one that brought a whale in because of ice, and cold weather.

?? [? remark that draws a chuckle from people -- maybe about a cold foot?]

GK Besides that, you know, in .. the whole summer all that ice stuck around. It, it never went anywhere. It might have broken up, but it, it didn't go out in the ocean.

MG Other crews went out that year though, to whale?

GK Yeah

BA Almost every crew

MG But just -- were there, were there a lot of whales?

GK Not that many, I mean, you couldn't spot them because there was so much ice. We practically, how many, 20 miles out before we spot a whale.

BA And that's normal [I believe that is what he said, meaning that this is normal for those conditions -- that is, during heavy or pervasive ice years].

GK And that's, um, trying to find a way to get to the, where the open water was, you know, a big pool of water anyway. But, but near the shore it was, it was hard. We had to try to go find other source of water.

MG Did you have to take your boat out over the ice?

GK Not over, around, maneuvering, you know. Some places was closed -- you can't get through, so you had to try and find your way.

BA What really happened we were getting south wind from the, um, during August, and when's the wind blowing south it probably hits, the waves hit the uh, northern ice and moves the current, move the ice towards the land, and it, other time it freeze up, it just stuck around.

GK Yeah

BA [?] current pretty strong, I guess, depending on which way the wind is blowing. Seem like you have something blocking one way, the waves hit it and you just get the bounce back.

MG You said last year whales were all close and this year they were all further out?

GK Oh no, close this year.

BA I know, when was it, three, three years ago, it was 50 degrees and [? ?] whole bunches -- whole bunch of whales all over. That was, uh, 20th of September. 50 degrees, unbelievable.

GK And it was, too ... still too warm ...

BA No ice

GK Usually we try to wait for cold weather, you know, so we can preserve the meat and the muktuk so it don't spoil, and that year you was talking about it was 50 degrees, when how many crews landed a whale and ... you know, the muktuk and meat spoiled. Not so much as the muktuk but the meat, you know, it just got stink because of warm weather. So we learned from our mistakes in the past, and we, we try and wait for cooler weather so we can preserve the meat and the muktuk. Cause that's a lot of meat wasted, you know, that's how many tons a square foot. Depending on the size of the whale, and, most of them whales caught this year were no more than 40, with the exception of the last one.

MG Do you, do you go after a certain size of whale?

GK Yeah, we always try to go after the smaller whales. Because their, their muktuk is softer. Their meat also. Besides 3 or 4 small whales is just right for this village -- enough for everybody, no complaints.

?? [?] 49-footer. [?]

GK Even that they was happy with. Our catch, last year in 96, fall of 96 was the only whale landed. They may look small in the water but as soon as you put them on ground they become big. So you can never know the actual size of a whale. See, some of them can be so fat -- you know, we call them fatso [Inupiaq word]. That's the one, the real ones they try to go after too, because even those ones are real soft.

MG Even if they're big.

GK Right. This way, not length-wise, but round.

[some shop talk]

BA Yeah, last year was big, also ...

GK They call them num-num. Our Elders like uh, fat, round whales.

BA Their tails are shorter than [?] whales.

?? Their tails are shorter than ... ordinary, the bigger whales

MG If you go for the, the smaller-sized whales, are those, do they come any special time of the year? I mean, are they the early whales, or late whales, or in the middle?

GK Well, I want to say, I mean, depends on what whales they are traveling with, I guess. Not every small whale travels together or passes first -- you can't say that.

MG So they can be any time.

Gk So they can be any time.

BA [?] ... most of them are with their mother whales [?]

GK Some of them, you'll, you'll see like ... well one is that we saw one that might have been less than 20 feet that just was born, you know, probably that year. And it, and it wasn't even black, it was grey. Darker than a beluga though. But, we never go after the one that are paired up, especially if there is a mother and a cub, just born, because they can be very dangerous.

BA If they get one with a baby by accident, the mother would drag it out away, drag it away

GK Yeah, and lead it away from trouble, being us.

BA Holding on to it

GK Holding on to it, so ...

BA Pretty quick can't find 'em

GK ... we have no choice but to let it go even though it has a harpoon stuck in it. Because we're not about to fight a battle with a mother whale. Just leave it in. You know, it's protective over its young. Yeah, I remember how many years back, that's what happened, happened to us, we had to let it go, no matter how much we wanted to go after it, the mother was there, protecting it, you know, leading it away. And there's no way I'm, I would ever try to jeopardize my crew by going after a whale.

[pause]

MG How far out do you normally have to go out for a whale?

BA Don't we have a map, over here?

GK We got a map in there that shows where all our catches are [meaning in the break room -- so we went there and looked at it -- left the tape running so you can hear walking sounds and such]

BA This is an old one

GK This is 92, its been updated. last update. [Unintelligible for a bit] 96, 97. And all of these ones here are the whales landed, or where they all died. All the numbers indicate who caught the whale, and there's a scale to see how far they, they all were. Some of them were catched, you know, quite a ways out there, at least 20 miles [?], some of them. Some could be at least 30 miles, number 28, Nolan Solomon.

MG Can you tell ... last year's [?], were they, they were pretty close, weren't they?

BA Oh yeah ... even all three of them probably

GK You know, almost all three of them was in this area, eh?

BA Yeah, two, about two hours pulling, in less than two hours.

GK That's for 3 to 5 miles an hour. [?] GPS will tell us how much, how fast we're traveling, what, what time we'll get there. Some of them are even real close to shore, you know -- real close.

SM When they are close to shore are they usually the small ones, or big ones?

GK No, some of them big too. I wish they would have put, you know, the, the length of them [on the whale harvest location map] that way could tell.

BA Right around here in July, last part of July [then too faint to hear clearly]

?? [too faint -- seems to be an Inupiaq name]

GK That's where they, ah ...

BA [Inupiaq name] Point Anderson

GK Warthog was all last year, and they, they spotted whales out there and they said to have eight of 'em just south of 'em, but they only know of one passing through. All the rest came back out in, around. We have a drill rig over here too, one time, somewhere back here.

[phone rings, obliterates other sound on tape]

GK ... out here, and hardly any whales, cause activity was going on. Also seismic activity. And it showed in their study, when we was in Prudhoe, that when, every time they, you know they were using that air hammer to detect the seismic activity below it there was no whales spotted -- very little. Then after, after they shut down the numbers were like in the hundreds, that they had spotted. And it, and they told them that, yeah, no whales are going to go around a seismic boat or vessel.

BA They always tell us that [?oil rigs will drill for?] twenty years.

MG How long ago was the test well -- that activity over there?

BA 85, 86, somewhere around there.

GK Somewhere around there, 'cause we have to go way, way ...

BA [can't hear, talking at same time] whales

GK ... that's one of the rare times we have to go, you know, way out, [pause], and, and you can spot a whale. It was, it was pitiful. And we know it was due to that seismic activity going on.

MG 85. No whales in 85 [looking at map].

GK Yeah. 81, no whales in 81 [looking at map]. This might have been 87 -- they didn't know the, the date [a point on the map with no date]. [?]

[some interchange here too faint to hear on tape]

MG Trying to see of there were certain years that you would have to go further out than usual. These ones that are further out in [?] years.

GK You see how far Nuiqsut has to go at some years?

MG That was their first year.

GK There's ah, number 101 in 1973. They're usually hunting Cross Island. And, and that's in our waters, I mean, that's in our neighborhood. Imagine how long it would take them ... days, weeks [soft laugh].

[another soft interchange too soft to hear]

GK Even, even some years some years, like -- in POW-D area they have to cut a whale in the water

BA [Just a little too faint]

GK [Just a little too faint]

BA [Just a little too faint]

GK [Just a little too faint]

BA ... in fact, I was working at Prudhoe that time, [?], that's when I came back from Prudhoe I, got out on a boat, and then they told me that they got a whale [and faint again]

GK That was one year when we caught two whales [may mean Kaleak boat got two whales, or maybe Kaktovik as a whole] -- same year

BA Yeah -- [?] time we got five, 77

GK Yeah, or 78. Or five in 77, yeah, but 78 my dad, my dad caught two in one year.

BA So we may have to request for a new update [map]

GK [?]. See, a lot of these, a lot of these they, they, they guess because we didn't have GPSs in them years

BA [?]

GK I'd say all of these are guesses, because ...

BA [Just a little too faint]

GK [Just a little too faint]

BA [something on report on harvest, including location of strike and kill]

MG You say when you go out whaling you sort of, do you have a formation. Do you ever just go out on icebergs and, and watch the whales from there?

GK Yeah, we let them know, you know -- probably, maybe lunch time, you know. "Go to have lunch time, on the ice, listen for whales." Only thing [?] they bother us sometimes [unclear phrase].

BA People would carry hook so they could hook what they caught.

GK Lot of Tom Cod

?? [too faint]

GK Like a [?] head, and sink it all the way down, and bring up whatever is on the [?] head.

BA Arthropod, yes, was there some kind of arthropod [then some faint sentences]. It was long way down to the bottom.

?? [faint]

MG Do you ever see differences in the water when you are out there?

BA Sometimes its dirty, and sometimes its clear. One time I saw something [eating?] a small octopus [? and then faint? Something about starfish in there]

GK I know there are starfish, too, cause my kids beach combing, you know, they find starfish, little tiny crabs, here and there.

BA Before you remove the de, before you even move -- fall whaling, we used to live right around the beach here, before they moved us here [where the new site of Kaktovik now is]. As we were growing up we used to dig up all kinds of stuff -- there was crab, put them in the pot, cut their legs off, and see if they will grow again [laugh] [then faint -- seems to talk of storms putting stuff on the beaches].

END OF SIDE ONE

SIDE TWO

lost some content when turning tape over -- may not know how much

GK ... when it's windy we don't go out there. We wait for calm weather. I don't, I don't think whales are affected by weather. I mean, there're in the water all the time anyway.

BA I remember one time they were waiting right there, it dying down [?] that if the wind don't [could not make it out for a while] over nothing -- but this part right here, number one at the end of it, the others had followed and stayed, had lunch. We spotted the whale, we pack up and [?].

GK We tried to go out but the waves were too big for our boat so we [?] turning back. [A further sentence not understandable]

BA But now the other, the other boats were waiting here, and we just stayed over here ourselves, watching polar bears. Heh heh. While we were having lunch.

GK Always strong currents in here too. In springtime, you go duck hunting. Lotta times that will be open, and you never travel by channel, channeled areas.

BA Gotta good current right here too.

GK And over here.

MG Let's see, can we look at our maps? Maybe we can mark those on our maps.

BA This is [Inupiaq name]

GK Arey Island

BA Arey Island [as confirmation]

GK This is now connected, this is a whole thing, this, Barter Island, is now connected to Arey Island. It never used to be.

BA But this part right here is opened up.

GK And yeah it created another channel.

BA Where that channel is it caused another strong current, too.

GK Same thing with our, this -- behind the hanger -- the channel is moving, this way. It, it's coming out, because, you can know when the wind's coming around it gets longer and, and you know where the shallow spot is. So, that in the future might connect with Barter Island also.

MG I guess it's always changing.

GK Oh yeah. Mother Nature does its worst [?].

[A part of the tape that does not appear to have much on it -- maybe some internal discussion, and then a period of the tape with too much outside noise to be listenable]

GK This is using our long-time [LOUD PHONE RING][CRASHING NOISE] for, for their leaving [?]

MG [?]

some other unintelligible conversation, and another loud noise

SM [some question on fish]

?? [LOUD whistle]

GK One of them first whales I get, you know they used to have, ah, whale bombs, or anything like that. Lances, [?], like Archie Brower, he used a 50-caliber, that come out of a, a tanker. Don't have to to shoot that caliber [?].

?? [can't make it out] a wooden boat.

[Section of unintelligible interchange here]

BA One [?] we caught that whale when it was dark, it was close to darkness. Possible to just happen to look down in the spots of open water and we see our whale, cause it was real clear that, that side's hurt.

GK People were going, "neat"

BA And yet if they looked down and that whale was at the bottom of the [?]

?? What the other [? loud noise]

[SHOP NOISE and conversation -- rather extended period]

GK Yeah, even some, some years, like, normal was unlikely to see a Orca whale follow the [? loud shop noise] ship.

?? We saw a gray whale last year [rest of phrase unclear]

[unclear shop noise]

GK We say they may have think they seen a narwhal.

SM [totally unclear]

rest of tape pretty unusable, most of side not recorded

Daniel and Lillian Akootchook

MG My name is -- I'm Mike Galginaitis

LA Okay, let's just talk first, okay, a little bit

[tape break while we talk about the overall project and how what they tell us will be used]

DA Vincent Nageak is the one that he taught me, even taught me how to shoot -- give me that whale up there, hump whale [pause while we look at a whale carved from a piece of baleen]. He let me draw a whale in the piece of paper. I told him, very first time I shot with that shooting iron [not really sure of those words], with a shoulder gun, I thought it uh, it's heart was way over here, somewhere around here [pointing out a location on the baleen whale model he is using -- then a pause]. No. His heart is right [laughing] over here, front of ??? ???, so then he said that the target is right here where the heart is, back of the eye.

LA You go out hunting, whaling [addressed to Steve MacLean]?

[talking over each other, SML says yes, tells of crew, LA says is a good tradition]

SM Yeah, I'm learning

DA Also, he's telling me to put your harpoon or anything when he's starting to going down -- he's open his -- it's going to go right, right into the spine. One shot. Any how, he got the whale without shooting any, anything with it, except ...

MG Just a lance?

DA Yeah

LA Harpoon

DA I got one, I got one outside, like, like the one he killed the whale with.

LA [to SML] You know my brother, Ralph Akiviak -- that's my brother -- he go on top of the, I heard many time, my brother, Ralph Akiviak, he always go on top of the whale, and go like that [making motion as with a lance], kill it, and jump off again [laughs]

MG Have to be quick

LA Yeah, when he was younger I guess he was really fast. Many times he just jump on it and he kill it like that. Real fast. He, you, when you go, when you, notice when you go you gotta be really physical fit, you know -- you can't just be slugging around, you gotta be worker. [some softer talk here, and a pause]

DA Yeah, when the whalers ???, we got ??? ??? on the boat, every boat has CB. When you don't, um, look at them, just look at them -- they just slowly coming back this way, in the way, from way over in POW-D. They coming back that way, all here [looking at map?] -- just going back and forth over here, especially over at, ah

LA *Naalagiagvik*

DA *Naalagiagvik* Arey Island

LA You probably seen the ???

DA You know, what's out in the front of the rivers, maybe that's what all the good eating sometimes

MG You think whales are in front of rivers mostly?

DA You harmonize on a mention about a current that go, um, just like a trail, You see, when you, when it's nice, waters are calm, and you could see that the water is really moving, and that's a pretty good spot. And you see lots of little birds feeding in there.

LA You could see, you could see sometime a top, you know, that, dirt like you know, and you notice that the birds always feed on those, at the current. What do they call it in Inupiaq? [addressing DA -- a short interchange in Inupiaq with no apparent resolution]

DA Well, ??? mention it. Some kind of a name, yes, but, um [at a loss for the name]

LA [suggests a name in Inupiaq -- not confirmed by DA]

MG Does that current, does it always stay in the same place?

LA No.

MG So that's different too

LA Once in a while ??? and seagulls always feeding on that, you know

MG So there's food in there for them

LA Something in there they eat

MG Can you find whales there too, or, sometimes

LA You just see whale anyplace

MG When you go out hunting, do you look for whales in certain places?

LA [starts to answer, but defers to DA]

DA We have about ten boats. Before we spot any whales we just separate, up by maybe five miles

LA Two by two

DA apart

LA two by two

DA From here, go that way about maybe fifteen, twenty mile that way, that way

MG So, both ways -- east, east, west

LA And they spot one, you know ...

DA [taking over from LA] You know, soon as somebody spot one, they get [makes noise like shot]

LA Yeah -- whale. Whale come up there, you know -- Oh [sentence or phrase in Inupiaq] B they say that going [katok ? Inupiaq word?] -- boat drivers go like crazy people [everyone laughs]. You remind me of Bob ??, Bob ?? -- you met Papadiak (?), Apachook (?)?

MG No

LA Okay, he [laughs], he finish school and he harpoon two ????? -- how old was he, about sixteen, first time, when he harpoon, and then this year.

DA How old is Burdell?

LA He's eighteen

DA Eighteen?

LA Yeah, he must be sixteen when he first harpooned a whale, his grandpa -- like this year too, end up eighteen. Just neat kid, you know [laughs]. [Pause] So, okay -- so they feed most mainly [Inupiaq aside or question to DA]

DA I, and that, over that way [pause] -- drag(?) over here. This is where, the further of the far we go is up to here [location on map].

LA Is that Pokok?

DA, LA some repetition and then agreement on the name and location

LA Yeah

both Down there -- we'll go that way, and then slowly and slowly we just go, maybe not even, slow, go way over there, back and back, ???, go that way. Sometime whaling, kind of bad weather, we get into those sand spits. Talk and talk and watch and look [pause]

MG How long do you stay out when you go out?

LA Let's see, we [DA cuts in]

DA Soon as -- we station in the morning, when the weather, depending on the weather, soon as the daylights come up.

LA Seven o'clock, seven I guess, seven thirty

DA And then, two hours before the daylight would give out because if we started to ? after the whale, just for, two hours before the kick in the weather happens, the daylight down, and we had a chance to lose the whale. Sometimes it take us quite a while to get the whale.

LA To their limit, they try to set five o'clock, you know, that way, it takes a long time to try to kill it, cause you know, like in morning, ten o'clock, sometime they put the buoy out or [Inupiaq?] and we follow it all day long, you know, so, so that five o'clock in the evening, and they lose, a couple of times, ??? to that, you know, going to five o'clock they

DA But we learn, we talk, before we go out hunting, go after whaling, we get together and talk -- once ??? start talking about how it faster or how we will be doing, if we just spot a whale. We get to one whale, even though there's a whale over here, over there -- go for ONE whale [emphasis on the ”one” meaning that they single out one whale for all the boats to try for].

LA Yeah, one that put buoy on, you know, we go after that one with one buoy. Whales all over all right, look good [laughing]

MG How do you pick the whale?

LA Oh, whoever, whoever first strike, first got there and then just put the buoy on, so that's where -- good job! They put buoy on, you know, that's it -- sometimes they name them [say what crew struck the whale], sometimes they just say they put buoy on, so we just quit looking at that whale [a whale that their boat may have been following] and go after that one [go and help with the whale already struck by another crew].

DA The person who, who, who puts the harpoon first -- kill him [and some unintelligible/inaudible]

MG I can, I can imagine. I don't know ...

DA No, never can tell if the whale is cold or winded, you get sweat [laughs]

LA How long you been here?

MG Been in Kaktovik?

LA No, in North Slope

MG Well, I live in Anchorage, but I -- first time I visited the North Slope was in 1982, Nuiqsut. Yeah, I spent -- I don't know, I've never lived full-time on the slope, but in Nuiqsut, like, I was there 8 months. I spent about 8 months in Point Lay ...

LA It was different Nuiqsut than here, you know, you have to travel long way, long way. You been there [directed to SM]?

SM Nuiqsut? Uh-huh [affirmative]

LA That long way, that was scary, bad enough we just jump in the boat and take off.

MG Real close here, then in Nuiqsut

LA Yes, just thankful. Boy, I don't know how they can do that, that lotta ...

MG Lot of hard work and, and the river there too, it's not even easy to get out in a boat sometimes

LA Yeah, it's shallow, huh. [Pause] So mainly was you just interested in feeding area, huh?

MG Well, feeding areas, and then since we know it's hard to tell feeding from non-feeding, just where you see whales, and what different kinds of -- are bigger whales in different places than little whales?

LA Um [then in Inupiaq, to DA -- translation of question, probably]

DA Inupiaq answer to her

LA The first one

DA The scout

LA The scout, they

DA Scouting, in July sometime they shows up -- before they talks to each other, by telephone or ...

LA [laughs] Yeah, they do

DA or they could talk in hundreds of miles away.

LA I notice that they see whales not too far from right here, you know, in July -- not too far, you know, and I notice that every time they follow the first one. He made a trail, you know.

DA The very first one we see a whale, just trying to remember we isn't hunting, being taught -- don't bother the first -- ?? ?? the caribou. Don't bother the very first caribou that goes that far. If you do, you have a hard time -- bad luck. So the feeding area, we don't really go way up far -- the farthest we go is up to Anderson Point sometime, right here [locates on map]. The furthest that we ...

LA [Inupiaq]

DA Anderson Point ...

LA Oh, [?] and POW-D, right there, yeah -- right there

DA yeah, up to here [pointing at map], I think. The further we go is up to HERE, Pokok. When we don't see [pause] ... and seems to me there's a whale here feeding there nows

MG Do they stay around a while?

DA They stay around two weeks.

MG Same whale?

DA Same -- I don't know, all kinds of whales.

MG All kinds

LA I notice that just once, you know ...

DA big, small

LA big

DA big go that way, swimming that way ... before we get our opening, opening season to go out to whale is September 1. Before that, in August, we just go down there and look at them just play around. They just, when you pass by them, they just, if you don't go after them, you just move along along with them. They don't seem to have [can't understand the phrase] any sound or anything, they just -- feeding -- that way, good, going around that way, getting into it, that way.

LA I notice that, um, they kill one in August and the meat spoiled -- it spoiled, so after that they have, they start having meetings. September 1 we go out, so the meat won't spoil -- something just right.

DA Some time in August the water come to ????

MG Yeah, warm water

DA That -- it doesn't take long for the whale meat to spoil, if you don't butcher in the right ???.

MG Some people have told us that they see whales in July too, sometimes.

DA Yes, yes -- whale what are they, scouting area and then reporting to, whatever -- a whale is coming. "Okay, you guys -- clear." [laugh] "Lot of food to eat!" [laughing]

MG So that's a real early whale.

LA No, they are just scouting, they just scouting -- and I don't know how, you talk to people to Nuiqsut?

MG No, people here have told us they see whales in July sometimes.

LA Oh yeah, no -- in Nuiqsut, you know, they usually don't try to go down

MG Right, they don't go down this far at all. No, I, I have talked to them about whaling, but not about down here. Up where they whale.

[Pause]

Is the scouting whale, is that any special kind of whale? Is it a big one or a small one or ...?

LA No, it's just a whale, you know.

DA Well, if nobody tried to figure out how, well we don't carry measurement ...

MG Right

DA [Laughs]. They just telling by how hard a blow, how high the noise goes up, some people knows how many signs

LA Yeah, they know. The old people, you know, they know.

MG And whales, do they come in spurts or waves ... or pulses, like, do a lot of whales come at once?

LA Sometime they do [then some in Inupiaq]. Whole bunch of times, I remember, you know, whale all over. Yeah, they do.

DA How many years ago did Isaac get a whale? Two years ago?

LA Yeah

DA Three years ago?

LA Two

DA Two years ago. Boy, there was a lot of whales. When they report, "Isaac got a whale" we were all going after a whale down THAT way ... but we had to quit, quit following the other whales to go go to, go to them, where they were going out, over the waves When we take off way over there, whales were all over ... right along side us, everywhere.

LA And last year too, after we all got ... Eddie Rexford take movie and there was whales all over ... long ones, big ones

MG When do, when are, when do all the whales go by? When are there no more whales?

LA I think October, you know, first part of

DA October

LA First part of

DA ????

LA I don't know [to DA]. I notice that when it ices quick, you know, I mean, you know, it start icing and then we still see some in October but nobody dare to go down there because it kind of slush, you know.

MG And so you can't really see anymore, so there could still be whales out there still.

LA Yeah

DA In order to be a good whaler, you got to be, ah, you know, keep together, with everybody ...

LA One mind, one spirit

DA don't talk about this other motor[?] not too good, we not doing very well, now don't talk about what he does, but, counsel him more -- tell him. This is how you are supposed to do. Help each other. When you, when you, when you have a happy crew, you see ????. Happy crew, that means the whale is not going to be very far. There he goes. Also, for other captains. Head of the ship. But, is the general, is the wife of the captain [laughs].

LA They always say that, you heard that, huh?

DA Ever since I could remember, you tell that the wife of a captain is the boss of every whaling captain, whaling crew ..

LA And me, you know, I could strike out (?) people, but dreams, I see whales, that's when I try and shut my mouth and try to be humble.

DA And that body been told not to talk about other, other whalers or try to be brag about did you do now -- not that kind of talk, humble. Humble, you had to be humble. Don't argue with no other whaler or other wife of other whaler. Be just listen.

LA Ruth Nukapigak, you probably met her? [MG indicates yes] Okay. First thing, she came over for something, you know, first thing she talked to me, she was the Elder, you know, and I listened to her. She said, you know, when you're whaling, people, ah, when you get a whale people like to have clean meat, you know, clean stuff. Make sure you clean your whale real good and show them, you know, that is what she told me. I never forget that. [then speaks Inupiaq to DA].

DA And you have to have a clean cellar, where you put the whale. And some people make a story of a whale. Talk about it, before they start coming. For that way, way over there, they meet each other too and talk about it. "Well we're going up that way again. I remember one guy back ... very kind, he treated us really good. We're going to visit him again."

LA "Clean house" you say. "Clean cellar, they welcome me, I feel at home" you know this whale was talking. "I going to go to that person's camp, so that person, same person, get a whale again.

DA My sister make mistake one time, my oldest sister. Maryaq [?], he usually get whale all the time, very first person get whale. Every year. The captain could say anything he want and tell other guys not to

LA He could cuss at them or swear at them, but then not the woman [laugh]. Got to keep quiet and humble.

DA But my sister say something like, you know, she don't want to get first, very first, how do you say

LA He don't want it, he don't want to be first, you know, the crew don't want to be first to get the whale [Inupiaq to DA]

DA She don't want to be first no more. That's what she said, and not supposed to say anything about that kind of talk. After that, they never came no whale.

LA You guys want 7-up or root beer or ...

SM I'm okay

DA We got pop. Give me hot coffee.

LA You want hot coffee?

MG Sure, I'll have a little bit.

DA I made that one for you guys, here, here's my cup and ??? over here.

SM I'll have coffee.

DA Oh, I never even open it yet. Sugar? Cream?

MG Thank you

DA Cream? Sugar over there.

LA Sugar?

SM No, just black

LA Just black

DA Maybe him

MG Yeah, I'm a .. I need sweet in my coffee

DA [Laughs] I use this one. [Stirs coffee] There are all kinds of stories about whalers. We been told, I been told, to follow. When you follow them, everything fine -- no problem. [Pause] They really say truth about whales -- they listening, they listen, and they can hear. I got ear. [DA gets up and brings us whale ears to see]

LA It was small, but [something about size of] ear.

DA This a bomb

LA 90 and 91 I think, it was [the years he took the whales whose ear drums he is showing us]

SM 92

DA 92

MG Yeah, this one is 91

DA What year?

MG 91

LA First year, we got that one first time.

DA I did it before I retired.

LA I told, ... we were just three of us, he [Daniel] got sick, you know, he had a cold sore, all three of us, my son-in-law, and Eddie Rexford and me, went out and here I was telling sonny, you know, that [Inupiaq word], you know that [], you know that float, I said, this is light, I could throw it out. You harpooned it, I could throw it out, you know. So Eddie raised him up and son-in-law, I guess he forgot to take the pin off and he harpooned it and that thing just shook and I looked at it and I forgot all about, I had that ball in my hand, and I forgot, I look at the whale I forgot about to see "Turn around and throw it over" [laughs]. Soon as it over, that when I start ???? That was fun, that was first time. And he was sick, he was listening to CB, you know. What do you do when them, that we got a whale?

DA PRAISE THE LORD!!! [laughing]

LA And they come over trying to get buckets and stuff, and they look at him -- "Wrong, wrong person is in house -- he supposed to be down there [in the boat] and

MG Right, and you supposed to be up here

LA And I'm supposed to be up there [in town] to get everything, pots and pans, ready ... That was good, you know. It's, You can't explain it, the joy you get from that animal, or something. It do something, make you humble or something, you know, just really good feeling, to feed all the people. First time, you know, to feed all the people. In fact we had that flag up there how many years, I mean couple days, you know, we forgot to -- "You still have your flag up there, we can still eat" she said. [laugh] That year we the only one catch a whale, you know.

MG Ah, that would be special.

DA Not very far from here, THAT way, east, northeast -- they got a whale. They got, they killed a whale before it swallowed the ... the one that put it in his mouth. Didn't have a chance to swallow them, and he died, and he was mouth closed, I think, all the way to the beach. And then, when they stopped pulling it the mouth opened wide (or twice) [noise]. Chance of something coming out, man there were some of them that were still alive.

LA What do you call those?

SM Arthropods -- little toe biters.

LA [Unclear]

DA Hundreds and hundreds and hundreds of them. They kept coming out [side of tape ends]

Side two

MG ... their mouth open and take in a lot and.

SM How big were those arthropods?

LA Big, you know ...

SM A couple of inches

LA Uh-huh, a couple inches

DA There's a little shrimp we got in the beach, about that size

SM About one inch

DA And the further you go, sometime we down, go down there 20 mile, sometime and stop, they ??? ??? lot of ice, you know, and some people start hooking them little fish and then they put something .. hard, or something, to put a big chunk of meat and let it go down to the bottom of the ocean, so many feet, way down. Let it stay there and almost time to go and pull him up and LOT of shrimp in there. Then, the further you go the bigger you get.

MG And, they're real good?

DA [Unintelligible]. The shrimp? I can't eat them [?] They get bigger.

LA She'll eat them, you know. I remember. She'll eat them. And I remember my dad and them. When they get a seal they tie that seal gut, that stomach, and they cook it, and they usually put shrimp in there. We don't do that no more -- cook with the guts, you know.

DA Everybody eat Tunik food now [laughs].

MG Do you ever go catch the shrimp like this and eat them by themselves?

LA No, uh-huh, and we know we got them flounders too, you know -- those black

SM flounder

DA Look like, uh [various unintelligible, maybe several people at once] ... halibut -- THAT kind. Maybe they're down there because halibut ?? big, the deeper you go the bigger they get. [Unintelligible sentence -- everyone laughs]. Nobody ever really look for them, you know.

LA Well

MG I, I didn't bring my papers with me today, but I guess, we have to ask, can we share what you've told us with other people?

LA Yeah, yes [and DA signifies affirmation as well]

MG I mean, we want to be able to, you know, to share it with people in Kaktovik but also with North Slope Borough and Minerals Management Service, too.

DA I tell you the same thing

MG Well, I think you tell us a lot more. I think you know more than a lot of other people, certainly more than Minerals Management Service, but North Slope Borough I think will be interested people, at the Inupiat History, Language, and Culture Center, Commission, and I'd like to make a tape of this for them so that they can have it.

LA What little we know we'd like to share it.

MG Well, I'm glad you ...

DA I'm glad to help, along with. That's why I visit, glad to have a visitor.

Isaac Akootchook

IA [tape stated late] ... some of the whales,[several indistinct words], because um, if we start whaling [indistinct phrase], here and there, sometime -- if we ever spot the whale, and we go there sometimes he moved, he ... either way, you know. [Sentence very fast and unclear] almost always, feeding.

MG And I guess ...

IA Our knowledge, but, ah, maybe different from the other guys, too. That'd be good

MG You say, you always go back and forth?

IA Yeah, might be over here. This Kaktovik over there? [looking at and referring to map]

MG Kaktovik's right here.

IA Oh right here, this, a, that's ... oh, okay.

MG Yeah, ah Barrow ...

IA Sometime they, we usually whaling here down here anyway.

Mg Uh huh

IA We not ... one time we go farther, out of town here somewhere, we never start to whale so far

MG [some sound]

IA for many many years.

[faint phrase in background]

IA If we were lucky here, we do it around here

MG I guess we have a bigger map over here, too.

IA Yeah, that's the one

MG Is this the area you use then, or would it be a little further south?

IA No, we use this over, over here.

MG Right here, mostly?

IA Yeah, mostly. Yeah, we have been lucky, with a using down here.

SM So right on Barter Island?

IA Yeah, right on Barter Island ... and we, they have a map. And [unclear phrase], you know, and ah, [faint, talking while referring to map on wall of the room]

MG [faint, talking while referring to map on wall of the room]

IA [faint, talking while referring to map on wall of the room]

Unknown number of interchanges

MG The whales that you get here, are they moving?

IA Yeah, sometimes they move moving in down here, yeah [unclear]. How many people you have already now? [that is, how many whalers have we talked with?] Yes.

MG Talk to you?

IA Yeah

MG I guess we talked to Daniel [Akootchook] last night, and we talked to George Kaleak and I think ah, maybe, Bert Akootchook

IA Ah, this is my son ... Bert, my son [further faint remark]. Whatever, that's all I gotta say, and I feel that I don't much farther [?]

MG Have you ever seen whale feeding that you know of?

IA You know, ah, early -- early, before we, ah, got, before we whaling.

MG [affirmative noise]

IA And ah the first time we spot, ah they spot the whale, [?] round here. And we seen it down here. They never move, you know, before we got, before we start whaling, whale, whaling

MG And so they ...

IA And that one around about maybe, what? Fifty, fifty-nine or fifty-three, whatever [referring to years]. You know, a long long time before we got, we start whaling [whaling was resumed in Kaktovik in 1964]. They spot the whale before that. And, ah, again, its um our parents and um uncles who always spot the whales right on here

MG Right off the island ...?

IA Yeah, right on here and here, and, and Arey Island.

MG Here?

IA Yeah, west of Barter. Right here, at that place, yeah. That was always is, ah, telling us is, she's, ah, the whale feeding, I've, I heard that. That's where we have [finding/fighting?] for those, ah, people try to find out, you know, that's why we always asking about, who always ask. We have interview, who is our interview anyway? But, this is good, you know. Not only one person, take it, so ...

MG Right

IA [not clear]

MG And, are there, currents in here that, that are, where you find ...

IA Yeah, current is always is, pretty clear sometimes. You know, these, ah, the current is as, not only one, maybe always have three, a little farther out, too. When there's [phrase?]. Just, just like a river. And, ah, maybe you, boating on the river is just, ah, there's shallow one is always black, right? You have a current that's just, and a clear one is down here. Just like that, it's always happening. Clear, and the one side is always red and it usually turns a lot of, muddy or something like that, so that's, ah, I think that's what he's, whale is feeding, too. They have a lot of seagulls around here. Got the seagull always eating something, too, you know. So [?unclear?], crap.

MG [Unclear] parallel to the coast?

IA Yeah, Uh huh, you could. Sometime they have, ah, maybe about three or four miles, five miles, and ah sometimes they a little farther out, maybe about twelve miles. And some then these coming close to um, down here. Way down here. Mostly we go that far as we always go. Sometime we, one time we got down here, because we never start to whale much, and we moved [word?], first we look at it back here, Arey Island. This is Arey Island, we always, very important ...

MG [talking over IA] Arey, Arey Island is a big old spit [?]

IA ... maybe a little farther out too, but, I'm not saying that, ah, we, just when we use this, we use this ...

MG Right

IA ... all the boat

MG Use, use as much as you need to, right?

IA Right, ah huh -- we just lucky we use about here [?place name?], every time we start whaling. This is what, about, I don't know how ... What, what's this number system, I don't know.

MG That's supposed to be how deep it is

SM Water depth

IA Oh, how ... oh, deep it is. Oh, I see, yeah. Twenty feet, forty eight feet ...

MG Soundings are in feet

IA [statement or two too faint to hear] ... must be a current or something, I don't know. I don't know about it.

MG It says, ah, territorial sea. I think that means that's three miles.

IA Three mile's limit.

MG Yeah.

IA That's a [?word?] for the federal? [laughs] Federal water, whatever.

MG That means it's state, I guess, and this is federal water here.

IA And what else is there?

MG Do you notice currents in between these islands ... or ?

IA Yeah, they haven't, not, they never stop this current is cut, back and forth, you know, over her in the channel, all the time. These channels, that's where these always current ... always open in [opening?]. But this one is this map is been here for a long time. There haven't already ...

MG This is closed?

IA Closed. This is closed. And, this open it down here.

? That one is closed already, now.

IA And again, this is, ah, ... [?word or two] Kaktovik. It just come down the shallow water, come down here.

[? Several voices at once -- faint and confused -- Come down the, ah, shallow water down here, ... ?]

? We seen it in the wake

? Just washed up down there

IA Every time we get a, ... drag the whale, we gotta go a little farther down there and come back that ways, you know. Go around that ways.

MG So you still, you still butcher the whale over in here?

IA Yeah, ah huh, right down to here about, Right behind the village. That way's a house down there, used for cooking, have a coffee break, ... We usually [or "used to"] use the tent, but its [?] now, whale camp. [Further sentence or two very faint]. Well?

MG Do you notice, does do the, how much the river flows, does that affect how many whales there are or where they stay?

IA I don't know the lagoon, they never go through the lagoon. No, not up here, just stay in the ocean. Maybe, um, this is pretty shallow up here, you know, and ah ... muddy, ah ... early, early long, long time, that, that we see a lotta bones down here. Here, and Arey Island, and ah the people who used to whaling up here, many many years and years [?unclear words?] whaling captain [?unclear phrase?], I don't' know how many years [unclear again]. I remember my brother here, Daniel, have a cabin down here, this summer, go to hunt, go to get something to eat. He found a bones down here, whale bone.

? Eih

IA But I don't know how long [unclear]. If you let 'em quite a few around, still go sideways [?].

For people, ah, that have a house, along here, just like a, he talk about the Arey Island. Same, same thing, you know.

? Yeah, this [quite unclear] down here, before they U.S. get the Navy boundary, you know [?]. Nineteen ... forties, four-forties -- it was that long. It was ... come over? Thirty, thirty-five years ago? [faint and unclear]

IA We never know about [unclear] at that time, but is today, after I heard [this part of the tape very faint and difficult to understand] ... Anyway, and ah, we, we got to this ah, Air Force was coming in here 1948. That's when we gotta leave. Both sides, hunting [?]. Some of them is still around, right on the corner, around here [becomes faint]. Who, who's usually picking up something -- oak[?], bones[?], stones[?], stuff like that.

MG And is this eroding any now?

IA This one?

MG Yeah

IA A little bit. And then down here he, he may go down, usually have right down here, especially right in here, you know? Early on, early ah thirties, ah twenties. Before the twenties there was filling over here -- usually it just here, but it started over here, this, this one over here, it's already here. They, they have more on the other side, maybe he started more over here to seen it in the summer time. They're erosion [?], and um, at some of them it, they come up, and this one is channel. There supposed to be cut down here somewhere too, you got a channel over here somewhere. Yeah, open here some where. Yeah, that's why we maybe gone through further up higher, I don't know. PAUSE

IA This one? But I never go boating, there're, there're usually open, that over here too. But maybe some people more in boat out here. But I usually boating up here, right over here [faint here]. [Faint sentences]

MG When do you think the last time you went, went out there in ...?

IA About a two years ago, I go with them. But I usually go with 'em, but this, ah, too many. My grandsons and grandkids. Friends who want to come along, you know, my brother George like to come over and ah, you have about five people in a boat is, is enough. Sometime you don't like to overload the boat, stuff like that, you know. And George and them, they get him out, we'll be going out. But, ah, that's why ah, we have a first-time my grandsons is, where they'll get a, harpoon a whale. [Next statement very faint] Yeah, we were happy about that [laughs] At that [?word?] Yeah, that's a, that's the way we been [trails off, a few faint words] ... That ways Bert is always real close because that ah he's the harpooner. [two or three other statements too faint to understand, may be different people speaking]. Joe, and me, myself, I still, I used to steering, the boat. And ah, the Rexford crew, Herman Rexford, ah, whaling, we used, ah, we worked together, Herman and, and our family, together, still. I was steering the boat all the time, after me and Albert[?], Bert was always behind us, as I was steering the boat all the time. [Next several sentences unclear -- too faint to really understand what was said] Some of them would stay in the boat, too. Kept, they got harpoon and the float all the time too. As soon as they see that, harpoon and float over sides, float up [then unclear]. Everybody learn from that old timers -- talk about it

? [Seems to be a faint question].

IA [faint response]

MG Who decides where to look for whales?

IA Well, ah, people used to go hunting. Seal hunting, ougruk hunting in spring time, when we find ah, for the winter. Make some seal oils, then we often hunt.

MG [Affirmative noise]

IA But this, ah, they always find it. They not really look at it, but, ah, we spot the whale. We always [unclear word] 'em. But it's ah, and it is ah, people use boat out, for boating. And make sure its, ah something in the village. I don't know anybody who says he's going to look around, you know, he always ,he always [becomes faint]. Before we start whaling we always spot whales, because we already know that whales is coming. And we always ah, are telling 'em not fail, scare them something's wrong. Because if, if you [?unclear?] come early, just, just to bother them, check, check them out ... we never know if maybe they might [unclear words -- worried about disturbing whales]. If they have a migration [unclear], it happens, they don't always turn around and go back, go a little farther out. That's what you're supposed to, you know everybody, ask the Elders that talk talk last night. The leaders is always is just coming toward through here, but it's, how much we gonna make it for us, if they haven't already had leaders go through here, they always go right by. They always follow that trail, just like caribou. We ah, make this ... [cabin?] if you really want to [fill?] people, down in here. How we got a lot of caribou ...

MG Right.

IA that about [word] 19th. Then when the whales, ah comes and put 'em ... [stops speaking]

MG So when they know, when the whales are coming, but is there any one, one place that you look, when you know whales are ...

IA Not really. They always move them. But mostly ah, people always a spotted at, over here -- and um, and ah, and down here, and down here in the Arey Island side. People always going out, if we decide to go whaling, they goes out straight drive [?], about three miles maybe, [faint phrase]. And ah, some of the people always going up this way. [Unclear phrase] They always is going "I gotta go, I gotta go west for a little bit," you know, some of them people coming this way. And and either way they always spot it over here, sometime they spot it, whale, down here. They are [name -- Unaparak?], it's always slowly going up east all the time, and there's some people always take that Arey Island perch before they go, go farther east. They not seen it over there, always coming behind us, see, behind this, ah, boat [faint, maybe point?]. [Unclear phrase]. Sometime we not started over here, um uh, down here, you know, mostly, uh, started down here too, you know, we're whaling down here. That's where they saw ... [name? -- karak].

[Eight seconds or so very faint and unclear on tape -- may have been looking at map to see location -- not really sentences -- check maps]

IA This is important waters down here, all the way from here, all the way down to ... Camden Bay. We're lucky ah for a couple, three years and we always go whaling, not too far. But if, about a couple years ago, we got one whale, still got one whale, because of, ah, ice. Too many ice. Ah, too many ice, and ah, [PHONE RINGS]

MG When there's ice, does that affect how many whales [PHONE RINGS] , or just ...

IA Well, not really, not really. There, there, uh, uh, if they have a lotta ices around, yeah [PHONE RINGS], that brings always problems, they don't have a migration, 'cause they always go out [too faint to understand]. [PHONE RINGS] They not stopping. If there's a lot of open lead around ... [PHONE RINGS] that where those, that where we always sits, we gotta get them. If they hadn't [PHONE RINGS] cleared out a lotta ice, we gotta look for open water somewhere. [PHONE RINGS PHONE RINGS PHONE RINGS]

MG Think, think we should answer?

IA No, I don't think so [PHONE RINGS]. It could be [word], I don't know.

MG No, I don't think so.

IA don't think so. Somebody going to be answer it, somebody always answers. [PHONE RINGS PHONE RINGS]

MG Do you, do you ever notice what the whales are feeding on, do you ever [PHONE RINGS] see little shrimps or anything like that ...?

IA Um, if you go down to whaling [goes/crews ?], a little fences [?] around the small one?

MG Yeah

IA And, ah, you go down to floating on the water, you see there's a lot of right on the water. Just, just floating. And that ways ah, the old people, and ah, telling us about the [word?], that's the whale, food. That's what he is always eating on. But, we never, we never study it but we seen it -- anywhere, anywhere you travel, there's a real bubble like this, you know. They are in the water. They are right on the water. All kinds a, and ah, little, to little things [faint word].

MG And you've seen them all, all the time ...?

IA Yeah ...

MG Or just sometimes ...?

IA I'm, ah mostly all the time here, sometimes in the harvesting [?] too. You haven't seen a lot of them around until [pause and then faint]. At, we always try to look and stop and look down, water you know. The water's always clear, [faint phrase]. Just, must be the wonderful, water.

MG So that you can see that in July sometimes? July, June, August -- all of them?

IA Summer. Maybe that's why you ah, got to more inspect 'em, you know, since summer they ah, ah, haven't [fast faint phrase]. AMS, you know, got a little more [faint and hard to understand] three seconds. That's why I'm I'm always, my mind, if I'm going down to ocean, have to look for, you know, what I see in that water. 'Cause it's really important to ah [then becomes too soft and faint]. [short unclear phrase] I, I'm always tell my family all the time,"Toova, gotta check that water. See that [word] look like these. But ah, maybe ah, my [word?] told me, "Get something and drag him up here." Then, pick him up, make sure [unclear], bring it up. See what is [unclear -- in his stomach?]. Check that. Make sure [unclear middle] animal. See you. See you have to have ah, have food, have ougruk and food, not only a whale, you know, but all kinds of ... fish come out from our boat [last phrase not all that clear].

MG Do people still go hunting for seals and ougruk quite a bit?

IA Yeah, ah ... just only, quite a bit of ougruk, you know. We hunt seal once in a while, just down [or a place name ?], here. We have, we have dogs ... we have a lot of need for the, for, for the quota [unclear remark -- we have a lotta meat for the ___ ?]. We not usually hunt too much seal because we not really use it. Because ah, we ... sometimes we get it for ... cook [unclear sentences]. Food seal, they cook, [uclear continuation]. Get up [unclear]. Last fall we shot about two or three. People out there eat them [Unclear remark].

MG When you hunt beluga, do you, do you hunt ...

IA Yeah, usually they want to, they want ... a lot of people on that hunt. [Unclear last sentence or two]

MG I know in Point Lay they ...

IA Yeah

MG they hunt together, with, with many boats at once. Do you do that here too?

IA [Not clear on tape -- started answer during question]

MG Right

IA Just like, ah, [?], right on the ... ah, what do you call it, that place sticking out for ... hunting ... beluga [and then too faint to hear]

MG But here do, do just people go out in single boats for beluga?

IA Just some of them always do, the people, people in boats, [?]. If they've started to surface call [?] , then people would like to go hunt them. [further unclear remarks]

PAUSE

MG Do you know, do ... Just ... Are some whales close to the shore and others further away? I mean, on their size or ...

IA Yeah, [on that one we do ?].And ah, those is always spot a, spotted from here. Some of them is close to the shore, boat is down here some ... more than, a little farther out, but it's always [?]ing for them ... About a mile and a half, two miles [?], you know? [unclear for a bit] a little farther out, sometimes. Mostly, as I was saying, right two or three hours [?] right on the middle.

[Some faint discussion here -- not clear]

IA And early on, a couple years we have lucky. Every time that he went out for early in the morning, his [unclear statement and further, several sentences]. Yeah. Early in the morning, he's always "You strike that one."

MG But most of the time you go for a smaller whale?

IA That one [answer not really clear -- too faint]. Try to get the smaller.

You know, ah, early ah, 80, 87 -- I have ah, a big one we have at that time. [unclear for several sentences]. After that, everybody "You take the small one." [Laughs] Lot of people worked hard, especially [?] family [some more that is unclear].

MG Are the big whales, are they further out, in the ocean?

IA They always go through close, some of them. Some of them are farther out, some of them. [unclear][several sentences]

MG [?] too big?

IA Yeah, too big is a lot of work, but is good though [and then unclear]

MG What, what kind of year ... is there a time of year when you don't see any whales at all out there?

IA One time, I have a real, really down [?] year, something [unclear]. Last year we never did get a whale. Not only that, but they don/'t have any ah, [?] around here some years with [?], price of, ah, water. I don't know, whatever, you know [and following is unclear]

MG Was it, was there a lot of ice that year? Was it open water?

IA Open water, all the way.

MG Just couldn't see any whales.

IA [unclear]. You know, in the old ... story, going to talk about the whaling, this is mine, I know what, I know how to hunt. Don't thinks nothing until you see him [?] doing something else. Whale is his hearing. [unclear] That's why you think you hear, but sometimes you have to say something earlier, you know, because people always come to [phrase] to do something. Whale always know about it, and you [?]. The whale and God appear is over there ....[unclear]

IA You know, ah, before that, we have a lot of ice. Before that, a lot of ice, [?], we didn't get any whales, because of a lot of ice and hardly see 'em. They around all right, but, it is hard to find them, hard to spot 'em. Next year, our ice is gone. And that year we didn't get any. And that the people started comment on it. "Well, maybe we'll get a, we're going to get a whale this year, no ice at all." But, no ice means the whale is ... [?] seen that whale. Just comes down there, just see him. [unclear] We find out [unclear]. We always say something about [?], but we can't always, you know, talking about and screw it up . You know these, you know, this, this is really important, for the [unclear], about the whale. Whale is [inaudible]. You know, [inaudible].

MG Yeah, I think that's, that's why it's important, too, for ...

IA Right, yeah

MG ... for MMS, they have to know that too...

IA That's what I telling them, [unclear] and, um, it gotta be asked God for this, before we start to do something, and that way/why we always [unclear]. [?] God always answer.

? May be some remark or question in here, but if so is very faint

IA 'Cause they are free, all of them, animals, use 'em, the land, use it well freely, you should follow. Disappear, give thanks that because we not doing it without him [?]. [word?]. Sometimes we make a plan, to do this, [unclear phrase]. Not to talk about [unclear]. [several unclear sentences]

MG I don't know, I guess that's really what we wanted to know ...

IA Uh hmm

MG ... was where, where whales were ...

SM [Unclear]

MG ... how, how you went about going after them. Some people say that when the whales come from the east, the west, that sometimes they come in groups, you know, there's groups that ...

IA Yes, they are always group. Sometime that we go whaling, you know, they probably down here, and seeing a lot of 'em. Lot of 'em together. Nothing we ah, no. Ah, sometime we have to use this whale, and we start to take it, the whale never stop. It always "Hey, look at the whale down here." "Hey, Look at that down here, too." Blows, you know. They awful many, many of them. Never stop. Not there, maybe later on the ... sometimes they have a slow down, after time. About after later on he come back, they the same place. Moving [unclear phrase]. We never, never really strike that all of 'em. That would be something just completely [very faint]. Strike 'em, the other have problems. [several unclear statements -- very faint]

MG So each whale is ... pretty much any time, must be.

IA Yeah, must be, ah. Yeah, anytime, come in ... July. In a week or two, we ... we have our, we always spot the whale, [unclear]. [Last sentence unclear]. We ah, I don't know, we can't tell if just feeding around here somewhere, just like it, see it in the waters.

MG Do you catch some of those whales, or ...

IA Migrating

MG Migrating [unclear]?

IA [Response is too faint to understand]

MG [unclear]

IA And after we get finished Prudhoe bay, a lot of guys going out with the boats [uclear finish]. "Hay, look at that spouter!" "Huh?"

MG Yah, I guess a lot of open water in [?]

IA [unclear]

MG So are the whales ... [?] a lot smaller than the last half week [?]

IA [response too faint]

MG Do you think maybe sometime you'll wail till October to whale?

IA Well, that we usually that ah, we not gonna wait till October. That's ah, the last month that we like to go hunt [unclear]. [Further remarks too faint on tape]. And there a lotta, lotta people who usually go hunting in July. [Some other faint remarks on tape]. After the whaling, it always boating [unclear]. PAUSE Well, I think that's about all ...

MG Yeah, that's pretty good. Can, can we share the information that's you gave with other people?

IA Sure, I like to. This time, it's good. Maybe um, maybe after you writing together, maybe ah, I'll want the paper, you know.

MG Yeah, then I'll, I'll we'll give it back, show you a copy so you can look and see what you said.

IA Yeah, I like that one. [unclear remark]

MG And I guess what I have here is a paper that says that we talked to you, and that you uh, you will agree to share this, and what I'll -- down here is that you want us to write, we'll give you a copy of everything so that you can see what you are saying.

IA [last remarks too faint]

MG And, and what I'll do is I'll ...

IA I sign it here?

MG Yeah, I'll give you my card and that way you'll know who I was and, I'll put Steve's name on here I guess.

IA Yeah, let me have a copy if you have the time [and faint after that for a bit] ... my box is 139 [?], Kaktovik

MG Well, it, it won't be before we leave, but what I'll do is next week when I get back in Anchorage I'll make, make copies of everything and send it back to you.

IA Good [and then faint]

MG You know, if you have any questions for us, we'd be glad to answer them.

IA [to SM] You always been to Barrow or Anchorage?

SM I live in Anchorage, and my mom [end of tape]

Charles Brower

MSG Don't bother calling Hagland.

CB Yeah.

MSG But anyway, that's sort of what we'd like to talk about with you. We did bring some maps, if you want to look at maps to show us specific areas and things like that.

CB I know places where we used to go see whales would be like around Arey Island on that one bend.

MSG Uhm-hm (affirmative).

CB That's usually where they hang around.

MSG Any special time of year, or just all summer?

CB Well, during whaling time, that's -- when we can't see whales anywhere close by, that's usually the first place we go to then, then we started heading eastward.

MSG And whaling time, that's the beginning of September?

CB Yeah.

MSG Is there any -- big ones, small ones, all kinds?

CB Oh, I'd say about medium size.

MSG And are they migrating then or are they hanging around?

CB They used to hang around right around that area, few days around -- around there.

MSG And other people, they've said, you know, when they -- before whaling, sometimes they go out hunting, different parts.

CB Uhm-hm (affirmative).

MSG And they see whales in other areas. Has that been your experience too, when you go out there you see whales

________?

CB Once we saw some over by the Jago entrance.

MSG Uhm-hm (affirmative).

CB Just a small one over that area.

MSG And that's still pretty close to shore. What time of year was that?

CB This was like in mid-August.

MSG Uhm-hm (affirmative). So -- and other people say they go over to Canada, some by boat, some on snowmachine, and of course, snowmachine, I guess you don't see too many whales. But by boat -- some people say they don't see too many whales over that way, really. I don't know, have you gone over there by boat.

CB Oh, I go over there a lot, used to go over there a lot.

MSG Uhm-hm (affirmative).

CB Right around that, uh, Komakuk Bay, that's where we used to start really meeting up with them.

MSG Komakuk Bay?

CB BAR-1, Komakuk Bay.

MSG BAR-1, okay. That's when you start to meet them?

CB Uhm-hm (affirmative).

MSG And are -- what time do you generally travel over to Canada, what time of year would that be?

CB We usually go -- we used to go in, like early August, try to be back before whaling time. And some years we'd go in July, see them around Ptarmigan Bay area.

MSG And once, once you'd seen them at Komakuk Bay, do you see them all the way then into Canada, all the rest of the way?

CB Pretty much, but there's not so many like -- between Komakuk and Herschel Island, in that area.

MSG Uhm-hm (affirmative).

CB But once you get past Herschel Island, then there's quite a bit right around that, ah, Ptarmigan Bay area.

MSG That's not the study area, but I think that they'll be real interested to know that, and -- but you say there are whales out here already, early August too?

CB Uhm-hm (affirmative). Yeah, my wife's from Herschel Island, born and raised over there. I go visit over there sometimes and just watch the whales just swimming around, around Herschel Island, kind of a bay area.

MSG So they stay around there for -- I guess those are the -- some of the summer feeding grounds, probably.

CB Yeah.

MSG Then how late do whales go by here, by Kaktovik?

CB You mean heading back?

MSG Yeah. Right here.

CB I know it's sometime in October. One year we were catching whales, like the 8th, 10th, and 12th of October. That's when there was not much ice.

MSG Just scared somebody, I think. {Child had peeked around the doorway, but then jerked back behind it]

CB Hey, my baby. Archie Robert -- where are you?

MSG But you have whales as late as that?

CB Oh, yeah.

MSG Do you notice any difference where big whales go and where big -- small whales go?

CB Not -- I know they travel at different times. The little whales, usually by the time we start whaling, usually go in too, and then a little later in the season the big ones start.

MSG And before you start whaling, is there any special kind of whale that goes then?

CB I don't know [too faint].

MSG But the little ones do go beginning of September, then the -- sort of big ones at the end?

CB Yeah.

MSG People too have told us that you usually don't have to go too far to whale.

CB Always --

MSG Pretty close to --

CB -- to -- just right off -- not too far offshore. You know, two or three miles at a time.

MSG Do people ever take boat trips further to the west for other things?

CB Well, caribou hunting and all that, they usually go up to -- first, I know they go up to, like, Brownlow Point.

MSG Uhm-hm (affirmative).

CB Some people used to go to Flaxman Island, but I don't know if they really go that way anymore.

MSG Don't they ever talk about seeing whales over that way, or pretty much just --

CB I -- I don't -- they're just mostly looking for caribou. That's all we ever hear about. That and beluga whales.

MSG Yeah, they probably see them and they just probably won't talk about it. They do look for beluga too?

CB Oh, yeah. I don't know if they look for them, but they'll run into them and --

MSG Uhm-hm (affirmative).

CB -- and you hear them on the CB, “beluga's over there”.

MSG Guess we should have asked you how long you've been whaling, when you started whaling, what sort of experience you grew up with.

CB I started the year I graduated, like 1978.

MSG Uhm-hm (affirmative).

(Background remarks - indiscernible). And then I took over my dad’s crew [too faint]

MSG And does he still give advice and --

CB Oh, yeah.

MSG -- pretty much things like that?

CB We try to take him out when he's not too busy working.

MSG Crew is how many -- five in the boat, pretty much?

CB Oh, sometimes we got a whole bunch. But we usually use one of them sea dories. I'd say we average about eight.

MSG That's a big crew.

CB Uhm-hm (affirmative).

MSG And I guess everybody -- all the crews are coordinated, so -- that's a whole lot of people out there at one time.

CB Yeah.

MSG Do you notice anything -- people tell us there are a lot of currents out there too. Do whales and currents, do they occur together? Do whales --

CB Sometimes.

MSG -- like currents?

CB Yeah. There's one time we were out whaling, we saw -- you know, where the current is and it's got stuff floating around?

MSG Uhm-hm (affirmative).

CB There was a whole bunch of them black seabirds sitting around there. We just thought those were ducks, and we looked them a little closer, and there was a whale floating around with the ducks too. And so some people started calling them whale ducks or whale birds.

SM Do you see that often, the whales hanging out where the birds are?

CB Not very much. It's once in a while you'll se it.

MSG So sometimes you'll see the birds but no whales?

CB Uhm-hm (affirmative).

MSG And do you see the -- I don't know what -- little whale food, I guess what they call them, copepods, all that stuff? Do you see that in the water very often?

CB Never really looked for them [and then very faint].

MSG I guess I've heard some people say they see a mass of red stuff, but not very often. But unless it's that vivid, probably, it's not really necessary, they [faint].

CB Yeah, during whale divings, you can just looking for blows until looking in the water, by the time you're looking at the horizon.

MSG So there really are -- there are enough whales out there, you just need to -- for the blows, you don't have to worry about?

CB Uhm-hm (affirmative).

MSG If they're there, you'll see them?

CB Oh, yeah.

MSG Some years you don't see many whales, though?

CB Yeah. Especially on warm weather, it's pretty hard to see the blows too. You have to look kinda [?], keep an eye on 'em.

MSG In years when you don't get whales, why do you think that is?

CB Mostly ice conditions [faint].

MSG Just too much ice, too many chunks --

CB Yeah.

SM -- what have you?

CB Sometimes we'll see them and we'll try to go after them, but then we have to try to go around ice and all that, and just gets to be too much.

MSG Uhm-hm (affirmative). Guess they can dodge around the ice better than you can.

CB Uhm-hm (affirmative).

MSG Let's see. What else can we ask about whale behavior?

SM Do you see a -- different kind of whales closer to the shore or farther away from the shore? Smaller whales, _______________?

CB Smaller whales usually are closer -- closer to the shore, yeah.

SM Smaller whales are closer.

MSG Do you ever see whales inside the Barrier Islands?

CB Not really, no.

MSG How about whales that bring up mud or seem to hit the bottom? I don't know if they're feeding or doing something else, but do ever -- do they ever bring up mud?

CB I haven't really noticed that, actually. Some people talk about it, they say they've been chasing them and see a brown spout.

MSG Uhm-hm (affirmative).

SM Some people said that whales like to -- some whales like to hang out where the rivers --

CB Uhm-hm (affirmative).

MSG -- come into the water? Do you see that?

CB That one around Jago that was -- that's right around near that river. And I think the ones at Arey Island part, that's where -- where -- where it comes out to.

MSG Uhm-hm (affirmative).

CB So right around the Two (ph) -- Two River area.

MSG But again, that's just where you find whales, so --

CB Uhm-hm (affirmative).

MSG -- you don't know if that's because of the rivers, but that's where they --

CB Yeah.

(Background remarks - indiscernible)

MSG Have you seen whaling change at all while you -- you said you started in '78? Has it been pretty much the same or --

CB [faint -- other voices].

MSG Have you seen whaling change, the way that people whale here?

CB No, it really been about the same. See, I know when they first started -- when I first started in, it used to, sometimes they'd shoot the whale before they put the harpoon on it.

MSG Uhm-hm (affirmative).

CB They'd get away with that and start putting the harpoon and floats on before they'd start trying to shoot the -- they cut down on the lost whales.

MSG And they'd do this for any special kind of whale?

CB Just the small ones.

MSG Okay.

CB That's what it -- try to stay away from the big ones. They try to. And some years they just have pretty big ones.

MSG And what do you think is a small whale? What's the kind that you like?

CB I'd say about, between ... 30- to 40-footers.

MSG And that's something that the whaling captains association, they sort of say that's what people should try to be looking for?

CB I think it's just whalers consult with this [consensus?], they just like that smaller, not so hard muktuk.

MSG I guess we should ask if you can -- can you tell a feeding whale from a whale that's just not feeding? Is there any way to tell?

CB I really don't know.

SM What's the earliest you've ever seen whales?

CB There was one year we saw one, like in late July.

SM Where did you see that one?

CB Right around by Jago area.

SM Was it a small one or a big one, do you know?

CB I couldn't really tell. We were, like inside the sand spit there, and could see the blow on the outside, so --

MSG Uhm-hm (affirmative).

CB -- we never really tried to go out after it.

MSG That's unusual to see them that early?

CB Well, they see them once in a while, but not very often.

MSG I don't know; when you see one that early, does it get people excited, or is it just --

CB Well, everybody's thinking about caribou hunting and all that. They -- never mind.

MSG Has to get towards late August --

CB Uhm-hm (affirmative).

MSG -- I guess. (Pause) I don't know, I guess that pretty much answers the questions we want to try to get at, which is where whales are seen, distribution, and that. Is there anything you think we should know about whales or whaling in Kaktovik that the study needs to be aware of that we may not be right now?

CB No, I don't know [faint].

MSG Okay. I think that's good enough for this recording, anyway.

(End of interview)

Joe Kaleak

JK What -- really want me to talk anyway? What's the --

MSG Well, if you can tell us anything specific about where whales are or -- you know, everybody said that they really couldn't tell if whales were feeding when you were out there.

JK Well, we don't really pay attention for -- on the, ah, feedings for whales, so when we're -- when we're out whaling, we just go, ah, look for some whales, you know. So we don't really pay attention whether -- where the feeding areas are.

MSG Uhm-hm (affirmative).

JK But I know they've got feeding area at the east side of us, right -- right by -- right around the -- between Demarcation and Icy Reef, right between there -- between there.

MSG Uhm-hm (affirmative).

JK And I just find out not too long ago, there's another feeding area on the west side of us. So, ah -- gee -- yeah, oh, did you -- did anybody mention about this map here? [indicating the NSB map of Kaktovik whale strike locations]

MSG Yeah, the map.

Several talking at once, not understandable

JK Yeah, okay. So this is the -- no, that's the -- the other one we got, it was just about everything [an updated version of the map which JK has received]. This is -- we got to catch up on this map here, so we never --

UNIDENTIFIED Did -- do you know how many whales now we're behind to -- we got to put it on that map.

JK So -- yeah. See --

MSG This one is -- this map is just around the Barter--

JK Right.

MSG -- island area.

JK Uhm-hm (affirmative). Uhm-hm (affirmative). Okay. Now, where is Barter Island -- oh, way back over here, okay. Okay. See, let's see, what’s this here. This is Barter here. Okay.

MSG This is Arey Island here.

JK Right. Right, Arey Island right here, see. And, ah, they probably -- they probably have some feeding -- feeding areas somewhere around this area too, sometimes. But they come up from -- from Demarcation Bay some --

? We have a bigger map out here

MSG This one has Demarcation Bay, Barter Island ...

JK [Makes affirmative sounds]. That’s, that’s where, that’s where probably feeding areas start off from here, all the way to Icy Reef some place. Where’s that Icy Reef?

MSG Icy Reef...

JK Icy Reef. Someplace around here, so --

SM Right here, Icy Reef.

JK Yeah, right. It's right -- right between there, there's some -- there's, its a feeding, feeding, ah, area, right -- right around those -- right around that area.

MSG Demarcation _______________.

JK Right. Right. Icy Reef and Demarcation. Right, between there. So we don't really go check all those feeding areas when we're going out whaling in the fall time. When we take out from Barter Island, we go out about -- we go north, straight down about 10 miles or more --

MSG Uhm-hm (affirmative).

JK -- sometimes. When it's -- when it's really calm weather -- calm and clear and no ice, and we always thought going out north about 10 to 12 miles out, of course, and start traveling slowly, straight east to try to meet whales, you know. So sometimes when we are trying to meet whales here, if we didn't see any whales for about three or four days straight, and next -- next day, next three or four days after, when we start going out west from Barter, from Barter to the Arey Island. So that's the only place we go for in fall whaling time. Because when you never see any whales in,-- around this area, right around this area, anyway, for three or four days when we don't see no whales, if it's clear, calm, no ice, and next -- next day we start heading toward the -- toward west, going down about same -- about -- it's about same thing, eight, ten miles out west. And sometimes we see some whales right close to the Arey Island. I think they always trying to feed themselves right close to the -- right close to the Arey Island too.

MSG You mean Arey Island here?

JK Right, right. Right.

MSG You never go past Camden Bay, though?

JK No. We don't -- no, we don't -- we don't pass the Camden Bay. Sometimes when we have a -- a really bad ice condition in fall time.

MSG Uhm-hm (affirmative).

JK Sometime we go down -- down straight to Camden Bay, maybe, about 10, 12 miles out _______________.

MSG So if there's bad ice, you won't go down here?

JK Right. Sometimes when there's bad ice around here, but we may have open lead, down side of the ice, if you can't go through going to the other open lead, you try to go west, it used to be open, open by -- by -- goes to Camden Bay. That -- we'd go there how many -- how many times, more than once. What, at least good, clear -- at least good, clear or calm weather, no ice, we just keep going from here on out this way and going straight down. Sometimes we just go straight down, about four or five miles out, we spot some whales. And we don't watch the whales, we go to at the Griffin Point -- there's Griffin Point here, that's a fishing camp. And we go -- and we go down. And we always find some whales around -- around this area too. So that's the only place we're going out -- going out for hunting in fall time. It only is a problem when there's bad ice conditions. When this is bad, we can't go out to other lead. This Camden Bay always have open, you know.

SM To get to the lead?

JK Right, to -- to get to the lead. This one always too -- too tight, but this one always kind of open, you know, loose. And we go out. And after we pass that -- and after we pass that ice, when we go out to the open lead, we start heading toward the east again. And sometimes we spot a whale right down side of the Griffin Point, down the ice -- down side of the ice. We did that a lot of times. So --

MSG When you have to go out that way, do you have to go out further then?

JK Right, further -- further out, yeah. Further out. When we -- when we have a -- a solid ice on -- on here, right close to the shore, then whales always go down side of the ice, see, north side of this open lead.

MSG Uhm-hm (affirmative). And the easiest way for you to get out is --

JK Right.

MSG -- from Camden Bay then?

JK Right. Right. Uhm-hm (affirmative).

MSG Is it the ice that controls how far the whales are out _______________?

JK Well, it's pretty -- it's -- it's pretty hard, it's really hard to -- when is, when is too much ice, it's really hard to say how far the whales -- on the lead. Sometimes we go down about 15, 20 miles out, straight out, and there's another lead, and this is like -- ice. But we don't really -- they check all those are feeding it. We -- we never go that -- we never go that far to the Demarcation anyway, see.

MSG Right.

JK That's too far, too far out for whales.

MSG At least not for whaling. People tell us that sometimes --

JK Right.

MSG -- they travel to Canada for trips, you know, _______________.

JK Right. I go there -- I -- I -- I -- I -- I make a trip every summer. And there's Herschel here, right? Okay.

MSG Yeah.

JK When I -- when I travel, I stay -- start out July, middle part of July. When I -- heading to Canada, I always meet -- meet some whales right at the -- what's that come about -- far away. That's Herschel here. This is -- what's this, Demarcation area?

MSG It's Demarcation, yeah.

JK Okay. Someplace -- someplace -- some -- some -- someplace right here, always meets -- meets whales, going -- going west, and this side of Herschel. Right -- right around there, right -- this is really deep, ah, ocean here, on the Canadian sides.

MSG Really, right there, right --

JK Right -- yeah, past --

MSG -- close to shore?

JK No, past -- past -- past this one. There's a Kay Point -- there's a -- it -- got another map?

MSG No.

JK That's how far you go, okay.

MSG No, that's as far as it --

JK Yeah, there's another Kay Point way back this way a little bit, got a south point. That's where all the whales always -- that's where they are for feeding -- feeding area between Canadian waters. I go there every summer for 17 years now. So I always meet whales right around past Komakuk (ph) and the either side of Komakuk, west side, right close to shore.

MSG Uhm-hm (affirmative). You meet them starting here --

JK Right.

MSG -- and then they're feeding right down there?

JK Right, uh-huh (affirmative). Right, uh-huh (affirmative). I -- I go there every summer myself, take my family over -- family relations over there, uncles and cousins, you know -- family.

MSG Are those small whales or big whales or --

JK Yeah, small -- yeah, mostly all small -- small whales. Them -- yeah, them small whales, we always let the first -- first whale past, the first one we let them pass, so -- we used to hunt them first when we -- when we went out early, in August middle part sometime we go out, but it's too early to go out in August, it’s too warm. And -- and -- and -- and we're out about 15, 20 miles out from Barter, and we struck a whale, and we can't tow it -- we can't tow it back when it's warm, it'd take us about 12 hours sometimes.

MSG Oh.

JK So kind of spoiled the meat, too warm. Yeah, but in fall, in early, first of September, it's nice and cool, and when we get the whale, we save all the meat. That's where we -- we used to get out early before. So we hold the hunting to after Labor Day or September, it's cool.

MSG When do you come back from Canada _______________?

JK About the last part of August.

MSG So in time for whaling?

JK Right, just before whaling, about two weeks' time before whaling.

MSG And on your way back, do you see whales _______________?

JK Yeah, on the -- on the way back, I always see some whales the east side of Herschel. More than once, more than one whale; small ones too.

MSG Uhm-hm (affirmative).

JK Small whales. And when you -- when you go out through here, through this channel here, sometimes we see some whales around -- around -- around this area too. Right around this area, you have small whales, right around there, when you go out to this channel.

MSG But you still don't see any whales over here, or do you?

JK Well -- no, well, it's -- they're traveling pretty slow, you know, they're -- when somebody told us there's some whales at POW-1, Canadian side. Take about week and a half or a week to reach Barter Island, just because they probably always stop on the feeding area for about a week or so, you know.

MSG Uhm-hm (affirmative).

JK So that's how that's -- I've been start -- I've been -- started whaling here in 1972, myself. I settled down here. So I've been whaling since. And so it's really important, so that's why we sure like to go and try to get out those, all feeding areas, so -- so the oil companies don't have to disturb the whales out their feeding area, see.

MSG Yeah, uhm-hm (affirmative). Yeah.

JK So that's real important, so we don't want to damage anything, from the oil companies, where their feeding areas are. So that's --

MSG The whales you run into when you go down there in July, do you think they're just sort of staying in this area, or are they --

JK Yeah, some -- yeah, sometimes they're -- sometimes they're staying right around this pass, on -- on this side, steady or over and forth in about more than two weeks sometimes, just go back and forth.

MSG So east of Herschel Bay they --

JK Right. East of --

MSG -- stay then?

JK -- Herschel, right.

MSG And then the --

JK Over two weeks, yeah.

MSG Then the ones that you run into here, are they --

JK Yeah.

MSG -- traveling, or what?

JK Yeah, yeah. They always traveling -- when I meet some whales here, they're always traveling west, yeah, even on the POW-D leavings [?] right here.

MSG So as early as July it would be --

JK Right.

MSG -- they're coming this way.

JK Right. Right, right, coming that way already in early July.

MSG So there are some whales going by Barter that early?

JK Yeah. Last summer -- last summer they're -- spot a whale the middle part of July right this side of Camden Bay. Early July, middle part.

MSG That's pretty early.

JK Yeah, it's pretty early, yeah. Yeah, them small ones, they were probably traveling early, you know, so it's really hard -- it's really hard, how many whales traveling. They always trying to -- they -- one time they told us to count the whales, how many we seen each day.

MSG Uhm-hm (affirmative).

JK But we -- when we spot a whale, we -- we -- we never thought to put it down how many [?] whales we saw when we were out dazing [?], you know. Lot of whales. Yeah. So that's really important for the subsistence for all the hunters anyway, all the way from St. Lawrence [Island] out to here.

MSG Right. Because it's all --

JK We -- yeah, right.

MSG -- the same whales.

JK We can't -- we can't live without -- without muktuk, ougruk, seal oil, you know, we have to have it.

MSG When, when would you say the big whales come by?

JK Well, the big -- the big whales come by on the last -- last part, you know, them with the baby -- all of them with a baby whale, they'll come last. So they'll travel -- they'll -- sometimes they'll travel till middle of October. One time -- one time we went out whaling. The weather was -- and the ice was bad condition, we went out whaling till October, but it was [unclear ?]. We got to go -- we got to track our boat on towards the Arey Island on this side. This side was already tight.

MSG Uhm-hm (affirmative).

JK We stopped, ice too tight, and we went over -- that's where that -- that's where that -- they had a little open -- open area, you know, loose, so we did that about three or four times.

MSG Over by Arey Island?

JK Yeah.

MSG You had to drag your boat _______________?

JK Yeah, we got -- yeah, we got to -- we got to -- got -- put -- put it on the trailer and drag it all the way to Arey Island.

MSG Oh.

JK Put it on the trailer, yeah. Yeah. So it's really tough sometimes, really hard going out, really -- ice patches, bad. But right now, we're lucky. For -- for about three or four years now, we've been one hundred percent landing, lots of the weather's good, hardly any ice, calm weather. We don't -- we don't go out when it's getting about ten, fifteen knots wind. So we don't like to -- we don't like to lose our quota. So we wait for the good, calm weather, clear weather. We don't like -- don't like to loss, but we have to catch for our community. Sometimes it's tough, sometimes [unclear ?].

MSG And last year, I guess -- people tell us that the trips were short, but they had to wait for a week for the right weather?

JK Yeah, right. Yeah -- yeah, right. We got to wait for the good weather, see. If it's -- if it's -- if it's windy, we don't go. But if it's good weather, we go out. Sometimes the good weather for a week, little over a week, we land all three quota, sometimes, less than a week or a little over a week, [PHONE RINGS] eight days _______________. [last sentence too faint to understand]

MSG Do you go out first of September?

JK Yeah, right after Labor Day we go out.

SM This year Labor Day's real late, not till September 7th.

JK Well --

SM Do you still wait for Labor Day?

JK Yeah, we still -- yeah, we still could wait for Labor Day. I like -- the people like to go out their own holidays, go out for -- for different subsistence hunt for caribou, on holiday for their own -- for their own food, for caribous here, so they always wait until after Labor Day. So on their own holidays, they like to go out and do some caribou hunting, take their family out for a long weekend. So we don't go out till after Labor Day. I don't know about this year, but probably going to do the same thing. PAUSE So I'll be -- appreciate if you guys -- you guys going to do some survey for the -- for these feeding areas. They get them all -- they get them all where they're really at and let us know, appreciate. So that's why I want to get some report from them -- soon, I should get a re, [?].

SM Yes, [inaudible for one or two sentences ?], that's why we've got to get the boat out there. [Faint statement].

JK So what we say after we get our two landed, they could go out any time they want to go, you know, for -- to do some more survey on the whale, ah, after we get two landing or between. I hope it's going to be a good weather like --

SM Yeah.

JK I hope it's going to be a good whaling season again this year, like last year. If it's -- if it's -- if it's -- if it's good, they're going to have a lot of time to do some surveying, soon as we get our quota feel free.

MSG Well, to get -- can never tell.

JK Yeah, it's never -- can't never tell, it's hard to tell. Might be -- might be bad weather, might be too much ice. We might even not catch any whales, you mean you can try. Try to the, ah, weather, ice conditions, [unclear word or two ?], can't tell. So it's hard.

MSG You said, you know, the areas down by Demarcation Point especially were feeding areas. Do whales, when they go through here, do they also?

JK I -- I don't know. That's the only place -- that's the only place, right by the Demarcation and this side of Herschel. And right over by the Arey Island toward the Camden Bay, yeah.

MSG And over here?

JK Yeah. See, they're -- they do some surveying there, don't bother us. It's going to be about 30, 40 miles west of us, but Nuiqsut still going to --

MSG Yeah.

JK -- still fight. So that's one that's over [unclear ?]. So you gotta talk to Nuiqsut whalers. They want -- they want to go ahead and do some surveying even in August, early, but -- it's okay with us, but listen, you're going to -- so...

MSG Do you notice the whales, are they just traveling when they go by here, or do some of them stay in this area?

JK Well, they always -- they always stay around right by -- where was that sheet.

MSG Barter, here.

JK Yeah, Barter, sometimes. They always -- yeah, they go -- right. They used to be -- just stick around here too, someplace around this area, go back and forth too, in-out, in-out, all this area, too. See, that's where -- that's where -- always mostly get some whales on almost -- just one -- one area, see. Some --

MSG Yeah.

JK -- some -- some -- some -- somewhere around like here, yeah. They always go fast [?] -- no, they don't -- they -- they always stay there for a few days too.

MSG Do you have any guesses why whales like to stay there?

JK I don't know why, but might be -- might be -- it might be more feeding -- feeding areas may belong there, too. But we don't know, we don't -- yeah, we don't know. They always stick around right there too, for -- for a few days, go back and forth, in and out, you know; sometimes go back and forth. Might be some -- might be some more feed -- feeding area around there, too. But it's hard -- I can't -- it's hard to tell.

MSG When, when you got out and look for whales, are there -- you know, when you went out when, like when they do on Wednesday [?], are there usually so many whales that all you need to do is look for the blows?

JK Yeah, sometimes we got -- sometimes we got to look for blows, yeah. It's really hard. Some -- sometimes whales probably stay in one area someplace roughly -- right between Demarcation and Icy Reef. Maybe always stay there for, for a awhile -- maybe two, two weeks, maybe more. I don't know why. Maybe they have a convention like us, maybe too, see. Yeah.

MSG Have the whale convention.

JK Yeah, yeah. That's how they do in Barrow, so every springtime, they got to wait for other bucks [?] coming in about -- after two weeks sometimes. Same thing right here. Same -- same thing. Then we got to wait two weeks or less, to see any more whales. So sometimes you really -- sometimes when they're traveling, we always spots right around this area. So that's why we don't like to pass this too much, you know, if we don't see about three or four days, we've passed it, and we go all the way to down side of -- what they call that -- Griffin Point.

MSG Oh, yeah.

JK Yeah

JK So since I'm start whaling myself, '72, that's where we -- just about spot whales, where -- where the -- all the whales are. It's really hard for -- to spot a whale sometimes, [Indistinct ?].

MSG Do you know the --

JK They're -- they're not -- they're not that easy to find them, you know, you’ve got to,got to, got to search and try to look. Sometimes you go out 5:00 -- 5:00 o'clock in the morning, soon as it gets daylight, taking off, if it's good weather, don’t wait -- don’t wait for nobody, everybody always with you anyway -- every,every day.

MSG But you don't use currents or anything else to help find whales?

JK No. No. Sometimes we go out for Barter Island, most of the crew go straight out.

MSG Uhm-hm (affirmative).

JK We don't find -- we don't spot any whales for about three or four days. Most the crew went west. We would split sometimes, trying to spot some whales, where the whales are. Sometimes we split in two groups, five on that side, five on that side; split about a quarter-mile apart, you know, if it's good weather. If it's kind of little light, ah, foggy, stick together, not too far apart for -- for, for each other, so we can see each other, too. It's really -- it's not really -- it's not easy to going out for subsistence [fall ?].

MSG And even, even if you've seen whales before, while going up for caribou or something, you can't depend that they'll be in the same places when you go out in September?

JK No, no, no. They -- they don't, no. They're moving, they've moving. They don't stay in one spot unless they have to, for a while, you know. But when -- when we have a real pack [?] ice, all the way from Demarcation, all the way to Barter. They always try to [?] sometimes. If there's an open lead downside, they always stay back for a while until they get the open lead, right, [unclear ?}.

MSG And they say you can't predict that.

JK No, no. No. So far we’re lucky for our whaling season for three, four years now. [Unclear statements in here -- low voice] We used to _______________ three, four years _______________.

MSG Well, I think you've told us pretty much --

JK Yeah.

MSG -- what we wanted to know. I guess a lot of the questions we have are things that just are hard to know, and that’s partly why we’re doing the study.

JK Yeah, that's the -- well, we appreciate it. We just a keep his promise to, ah, give us some report we’ll appreciate it.

MSG Well, we'll make sure that _______________.

JK Yeah.

MSG We'll make sure he remembers what you told him.

JK Yeah.

MSG Now, can we share this information that we -- you've given to us?

JK Yeah, right.

MSG I guess what I have, what I have is a form that they like us to fill out for people we talk to, saying that we asked -- to participate in the -- a study with us and agree to be tape recorded, let you know it's being funded by the Minerals Management Service, and that's where we, for their report, but that we're also going to supply you with information if you want it. And basically, it says you're willing to be tape recorded --

JK Right.

MSG -- that we can share this information with other people, and then I can write down that you want copies of the tapes?

JK Yes. Well -- well, be -- be better, so...

SM That way you can make sure what you're saying?

JK Right. I'll appreciate it.

MSG Then I write this down and what I'll do is, when I get back to Anchorage then, I'll make a copy of the tape and send it back to you with a copy of this.

JK Great. Okay.

MSG So that, you know, you go --

JK And -- and when they're out -- are you going to be one tape, even the other --

MSG No, just your tape. But --

JK Oh. Oh, oh, oh.

MSG -- I'll send other tapes back to the other people too.

JK Oh. Oh, okay. Okay. Good.

MSG And then, you know, all you have to do is sign this, that you have -- that we talked about this --

JK Okay.

MSG -- with you.

JK Okay.

MSG And I'll leave you another one of my cards _______________.

JK Yeah, just in case, yeah. Okay. That's it.

MSG Yeah.

JK [Unclear ?] going to have to [unclear ?] this afternoon. Okay.

MSG I sure do appreciate it.

JK Okay. Have a nice trip. Okay.

MSG Okay.

JK Yeah.

MSG And I'll probably come by and maybe just drink some coffee or something, but we don't have to talk about anything.

JK Well, any time, any time, we'll have coffee, right. Okay.

(End of interview)