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Outer Continental Shelf Environmental Assessment Program

Final Reports of Principal Investigators

Volume 60 February 1989

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Service
Office of Oceanography and Marine Assessment
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U.S. DEPARTMENT OF THE INTERIOR
Minerals Management Service
Alaska OCS Region
OCS Study, MMS 89-0004

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Anchorage, Alaska

The facts, conclusions, and issues appearing in these reports are based on research results of the Outer Continental Shelf Environmental Assessment Program (OCSEAP), which is managed by the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and funded (wholly or in part) by the Minerals Management Service, U.S. Department of the Interior, through an Interagency Agreement.

The content of these reports has not been altered from that submitted by the Principal Investigators. In some instances, grammatical, spelling, and punctuation errors have been corrected to improve readability; some figures and tables have been enhanced to improve clarity in reproduction.

Outer Continental Shelf Environmental Assessment Program

Final Reports of Principal Investigators

VOLUME 60 FEBRUARY 1989

CONTENTS

ENVIRONMENTAL CHARACTERIZATION AND BIOLOGICAL UTILIZATION OF THE NORTH ALEUTIAN SHELF NEARSHORE ZONE

Edited by

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Final Report
Outer Continental Shelf Environmental Assessment Program
Research Unit 658

July 1987

ACKNOWLEDGMENTS

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The financial support of the Minerals Management Service (MMS) of the Department of the Interior is gratefully acknowledged. Individuals of the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce in Anchorage, Alaska, have been supportive and helpful throughout this project. We would particularly like to thank Paul Becker, Lyman Thorsteinson, George Lapiene, and Mike Meyer of NOAA's Anchorage office for their able assistance during the course of the project. Constructive reviews of the project final report were provided by Erdogan Ozturgut (NOAA), Terri Poluszkiewicz (MMS), and others of the staffs of NOAA and MMS.

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In cases where other individuals were especially helpful to specific disciplines, they have been acknowledged in appropriate chapters of this report.

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Section 1

INTRODUCTION

by

Joe C. Truett

Section 1

INTRODUCTION

In March 1982, in anticipation that portions of the southeastern Bering Sea adjacent to the Alaska Peninsula (designated the "North Aleutian Basin") were soon to be leased for petroleum exploration, the National Oceanic and Atmospheric Administration (NOAA) in Alaska convened a meeting to assess the status of environmental knowledge in the area. The synthesis resulting from this meeting was to be used to evaluate the environmental hazards to and potential environmental damages from future activities in the leased areas. In this meeting the participants characterized the ecological processes causing high biological productivity in coastal lagoons and in offshore areas beyond about 5 km. However, the participants could not define what caused the high biological utilization of the nearshore zone within about 5 km of the coast, partly because very little research had been conducted in this nearshore environment.

In March 1983 NOAA initiated a review of available data related to this nearshore environment. This review described, to the extent possible based on the data reviewed, the processes responsible for the observed biotic distributions in the nearshore zone. It identified remaining areas where additional data would be needed to provide an understanding of the important processes in the nearshore zone sufficient to enable managers to predict the ecological effects of man's activities in the area.

In March 1984 NOAA issued a solicitation (Number WASC-83-00-125) for proposals to conduct research to fill the important information gaps identified.

As a result of this solicitation, NOAA in May 1984 awarded LGL Ecological Research Associates, Inc. (LGL) a contract to conduct an environmental characterization and biological utilization study of Alaska's North Aleutian Shelf nearshore zone (Contract No. 84-ABC-00125).

The study resulting from this contract (hereafter called the North Aleutian Shelf study) commenced immediately after contract award. Short reports on the progress of the study were submitted in November 1984 and May 1985. A comprehensive Progress Report was submitted in September 1985. The following report is the Final Report for the project.

1.1 STUDY OBJECTIVES

The North Aleutian Shelf study has four objectives as follows:

1. Test the hypothesis that the nutrients and/or organic materials transported from the lagoons to the adjacent North Aleutian Shelf nearshore zone contribute significantly to nutrient or carbon supplies in that zone and cause heightened utilization of the zone by higher trophic level organisms.
2. Describe the relative roles that zooplankton, epibenthos, infauna and microbiota play in cycling organic material and making it available to higher levels.
3. Determine the manner in which the dominant forage fish, anadromous fish, birds and marine mammals contribute to or utilize the nearshore zone and its organic resources.
4. Determine the vulnerabilities of the dominant ecosystem components, or the processes on which they depend, to increased industrialization, releases of oil or other pollutants, or other environmental changes that might be brought about by OCS oil and gas activities.

Seven tasks have been identified in the contract to be necessary to meet these objectives. The tasks are as follows:

1. Measure carbon and nutrient levels in, and transport mechanisms in and between, the nearshore environment and the adjacent lagoon systems.
2. Determine the importance of lagoon-derived carbon to nearshore biota.
3. Develop a schematic physical model of nutrient and carbon transport.
4. Estimate the standing crop biomass, productivity, and consumption rates of invertebrates.
5. Estimate the distributions, abundances, and diets of fishes.

(6) Estimate the distributions, abundances, and diets of birds and mammals.

(7) Develop a schematic model of energy flow in the nearshore ecosystem.

1.2 STUDY AREA

The contract defines the general "area of interest" to be the nearshore environment shoreward of the 50-m isobath between Unimak Pass and Cape Newenham in the southeastern Bering Sea (Fig. 1.1). The specific area of field research for this study (hereinafter called "study area") is restricted to the nearshore environment between Cape Mordvinof and Cape Seniavin. Special emphasis is placed on the Izembek Lagoon and Port Moller areas. Note that a few samples have been taken seaward of the 50-m depth contour for comparative purposes (Fig. 1.2).

The lagoons themselves are addressed mainly as contributors to the productivity of the nearshore zone outside the lagoons. Biota and food chains more or less restricted to the lagoons have already received a level of investigation (e.g. Tack 1970, Barsdate et al. 1974, Gill et al. 1978, McConnaughey 1978, Petersen 1980, and Smith and Paulson, n.d.) comparable to that of the shelf waters beyond the 50-m isobath, and for that reason are outside the major focus of this study.

1.3 RESEARCH APPROACH

The research approach for the project has been structured on the basis of several constraining factors. First, because the disciplinary scope and depth of investigation required to address the project objectives is relatively great, new research has focused on those issues judged to be most important in terms of oil and gas leasing rather than trying to address all issues. Second, because of the required interdisciplinary interpretations, coordination among participating scientists has been stressed. Third, because of limited time and funding, strong emphasis has been placed on interpreting new data in the context of existing data.

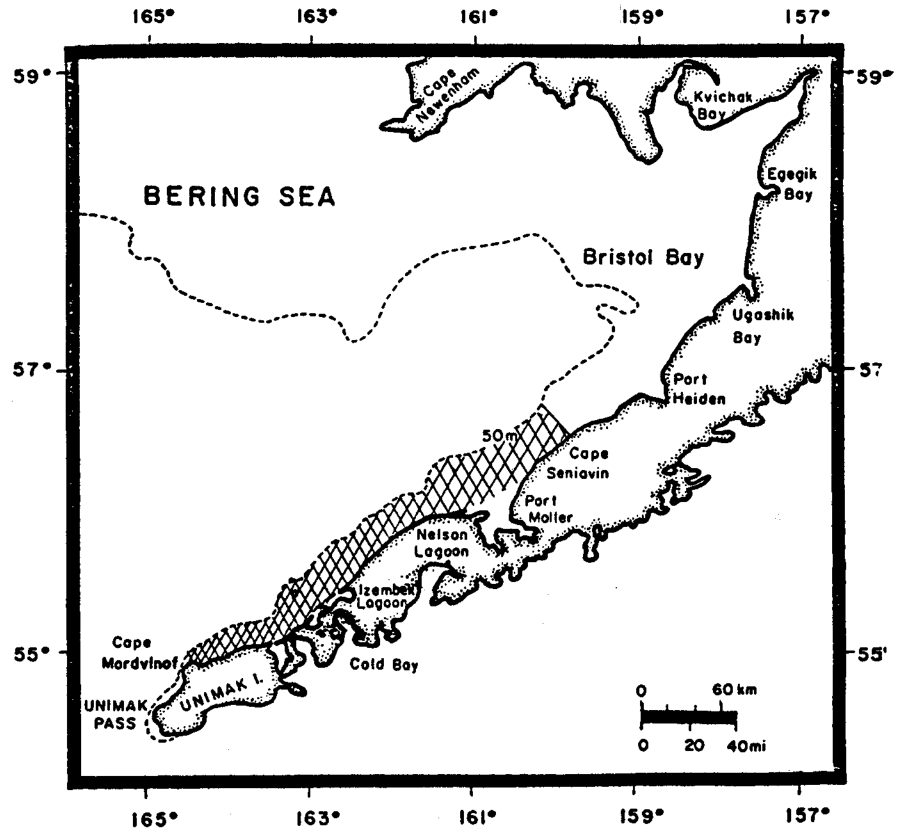

Figure 1.1. The area of research for the North Aleutian Shelf study in the Bering Sea, Alaska. The entire area of interest lies shoreward of the 50-m isobath between Unimak Pass and Cape Newenham; the area of new field research (shaded) is restricted to the nearshore zone north of the Alaska Peninsula.

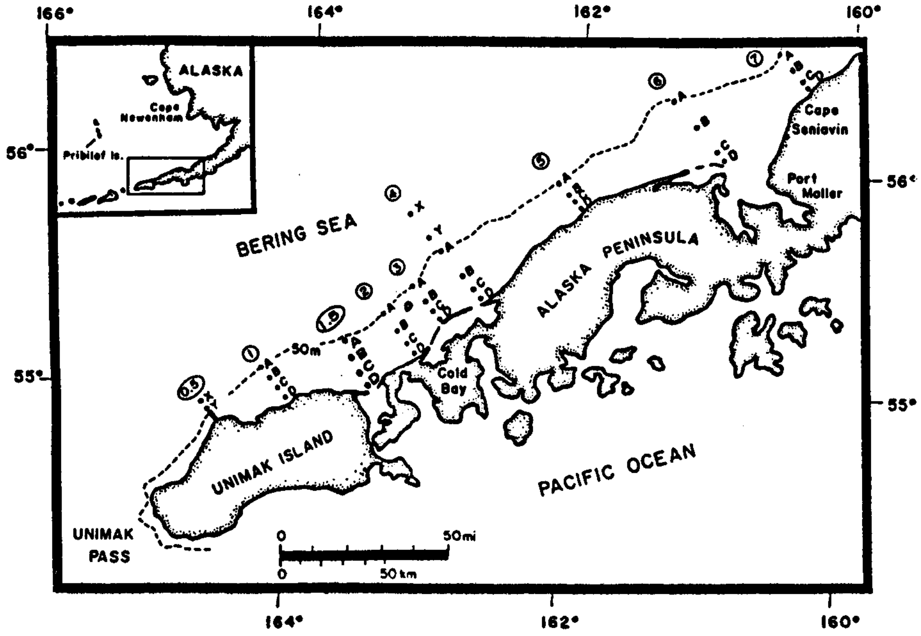

Figure 1.2. North Aleutian Shelf (NAS) study area showing locations of transects and sampling stations. Sampling station depths: X (100 m), Y (75 m), A (50 m), B (35 m), C (20 m), D (3-10 m).

1.4 CONTENT OF REPORT

The following report includes disciplinary sections on physical oceanography, primary production and carbon, invertebrates, fish resources, marine birds, and marine mammals. The most important and/or abundant species and processes have received emphasis. In each of the sections, pertinent background information is discussed, and new data analyzed are presented and compared with this background information. Conclusions and recommended areas of future research emphasis are presented for each of the sections.

A synthesis of information is presented in the final section. It draws upon both existing and new data to discuss the distributions and abundances of important species in the area of study and the physical and trophic factors that appear to influence these distributions and abundances. Vulnerabilities (both direct and indirect via food webs) of the important species to OCS oil and gas activities are addressed, and conclusions with respect to potential effects of OCS activities are drawn.

1.5 LITERATURE CITED

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Section 2

PHYSICAL OCEANOGRAPHY

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Section 2

PHYSICAL OCEANOGRAPHY

2.1 SUMMARY

Wind, current, lagoon, and hydrographic data collected from the NAS during 1984 and 1985 are presented. The wind and current data confirmed the findings of previous investigators, i.e., that the currents are predominantly tidal. The mean flow was toward the north rather than toward the northeast as found by other investigators. This was, however, quite probably due to the short observation period (two to three weeks). Other investigators have observed bursts of off- and onshore flow during isolated periods of similar duration. Izembek Lagoon's effects (localized warming and freshening of surface waters) were limited to those areas immediately adjacent to the lagoon. The hydrographic data, while generally supporting previous characterizations of a well-mixed coastal domain, suggested that occasionally stratification did occur. This vertical stratification was either local and resulting from terrestrial runoff, or extended over the entire NAS study area and was caused by an intrusion of central domain water (typically two-layer structure). Analysis of the field and historical data, incorporated into a conceptual physical model, indicated that: (1) water in the coastal zone was more likely to be dispersively exchanged with central shelf water than to pass to Cape Seniavin; (2) the typical residence time of a water parcel in the coastal domain was 10 to 20 days; (3) 60 to 80% of the water moving alongshore at Cape Seniavin entered the coastal domain by dispersive exchange across the inner front; and (4) with the exception of localized effects, net precipitation and runoff were insignificant in the water and salt balance of the NAS.

2.2 INTRODUCTION

Physical oceanographic and meteorological studies were conducted on the NAS (Fig. 1.2) between May 1984 and July 1985 as part of the Environmental Characterization and Biological Utilization of the North Aleutian Shelf Study. These studies were designed to augment physical oceanographic investigations previously conducted in the Bering Sea, with particular emphasis on the less studied NAS nearshore zone (i.e., that zone lying shoreward of the 50-m isobath and north of the Alaska Peninsula). These physical oceanographic and meteorological studies provided insight into the nearshore zone physical processes and their relationship to the various chemical and biological findings. Of particular interest, with regard to physical processes, was the importance of lagoons in providing nutrients and/or organic material to the nearshore zone, how the physical processes affect the biotic components of the NAS, and how these physical processes might affect offshore oil development impacts.

2.3 CURRENT STATE OF KNOWLEDGE

The current state of knowledge regarding the physical oceanography of the southeastern Bering Sea is thoroughly summarized in "Circulation, Water Masses, and Fluxes on the Southeastern Bering Sea Shelf" (Coachman 1986). No attempt will be made here to repeat the entire scope of this comprehensive article. Instead, a brief overview of southeastern Bering Sea physical oceanography, information specific to the NAS nearshore zone (coastal domain and inner front), and other information that would aid in the interpretation of our data, will be presented.

The eastern Bering Sea shelf, oriented northwest between the Alaska Peninsula and Cape Navarin and extending approximately 500 km seaward of the Alaskan coastline, comprises nearly one-half of the surface area of the Bering Sea (Fig. 2.1). This shelf is the widest continental shelf outside of the Arctic Ocean. The unique physiography of this shelf is responsible for some of the eastern Bering Sea's more distinctive physical oceanographic features (Coachman 1986). One of these features is the existence of hydrographic domains that are separated by quasi-permanent fronts that result (at least in part) from two sea-floor zones where the slope is two to three times greater than the mean slope of the shelf. These two zones of enhanced bottom slope naturally divide the southeastern shelf into three distinct domains (as shown in Fig. 2.2A): coastal (0-50 m), central (50-100 m), and outer [100-150 m (shelf break)]. According to Coachman (1986) this zonation plays a fundamental role in almost all aspects of the physical regime.

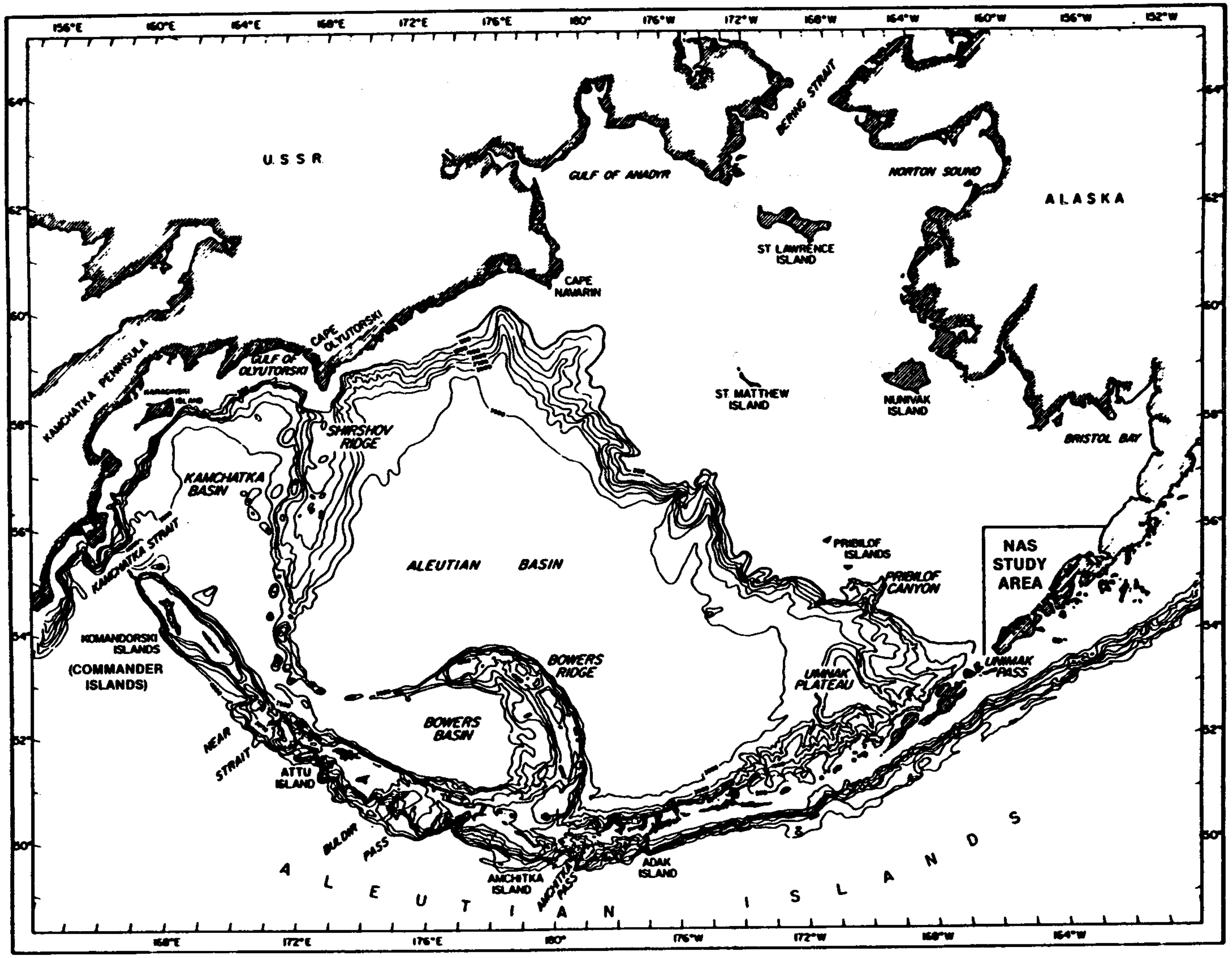

Figure 2.1. The Bering Sea and North Aleutian Shelf (NAS) study area (from Hood and Calder, 1981).

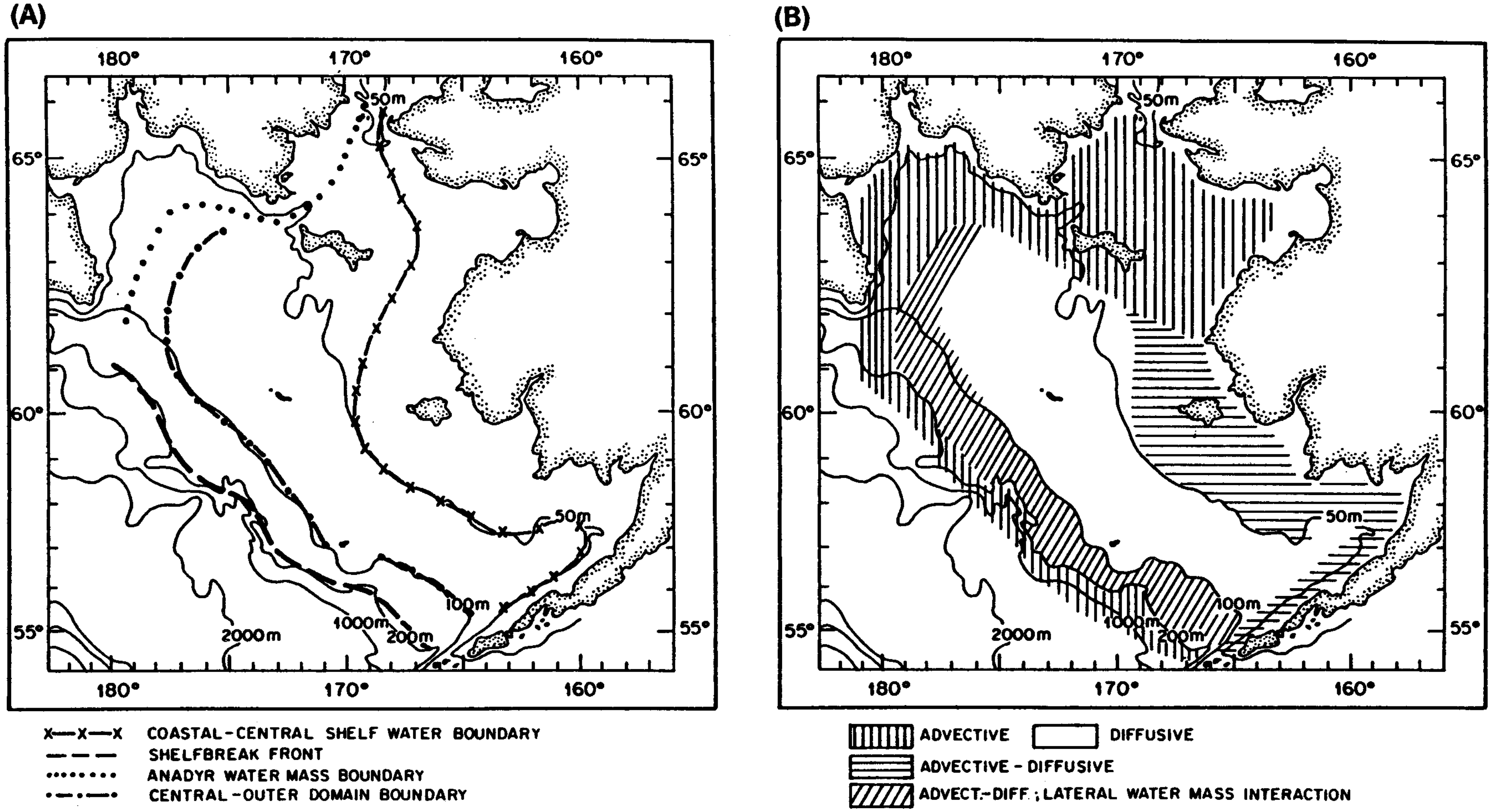

Figure 2.2. Approximate locations of the major hydrographic transition zones (A) and areal arrangement of the four different physical process regimes (B) of the eastern Bering Sea shelf (Coachman, 1986).

Unique physical processes and characteristics are associated with each of the three domains. A summary of these processes and characteristics is presented in Table 2.1 and Figures 2.2B and 2.3; a detailed discussion is presented in Coachman (1986). Our study involves primarily the coastal domain (and inner front) of the NAS, therefore, the following discussion will emphasize the physical processes and characteristics of these regions.

The coastal domain is bounded on the seaward side by the inner front and landward by the coastline and varies in width from 30 km on the NAS to 300 km (as defined by the 50-m isobath) in the vicinity of Nunivak Island. The coastal domain and inner front have been delineated using a variety of schemes. Schumacher et al. (1979) first defined the inner front as a transition zone about 20 km wide approximately following the 50-m isobath across which the two-layered structure of the central domain changes to a nearly homogeneous structure in the shallower coastal domain. These investigators noted, however, that the vertical structure of the inner front did not exist in winter, and during that season the waters were generally well mixed across most of the central domain. More recently, Coachman (1986) has suggested that the Bering Sea fronts may be defined as broad zones, much wider than the sea depth, in which horizontal property gradients are relatively stronger than elsewhere. Coachman (1986) concluded that the front exists year-round and is probably the result of dynamical activity focused near the 50-m isobath.

Seaward of the inner front lies the central domain which, during the summer, may be characterized as having a two-layered structure and dynamic features unique to that domain. The coastal domain lies landward of the inner front. This domain has been characterized as well mixed virtually all year (Coachman 1986, Schumacher and Moen 1983, Kinder and Schumacher 1981a, Ingraham 1981). Nevertheless, Schumacher and Moen (1983) observed vertical stratification within the coastal domain in the vicinity of Port Moller.

Schumacher and Kinder (1983) analyzed the proportional distribution of kinetic energy (KE) within various frequency bands associated with eastern Bering Sea currents. From this analysis they were able to divide the shelf into dynamical regimes that were coincident with the hydrographic domains. Within the coastal and central dynamical regimes,

Table 2.1 Physical process regimes (from Coachman, 1986).

	Outer	Central	Coastal
I. General characterization	Advective–diffusive; with lateral water mass interaction	Diffusive	Advective–diffusive
II. Energy			
A. Kinetic	Tidal ~85% Low. freq. ~10%	Tidal ~95%	Tidal >90% Low freq. ~5%
B. Turbulent for mixing	upper layer, wind mid-layer, none lower layer, tidal	upper layer, wind lower layer, tidal	wind and tidal
III. Property fluxes			
A. Vertical	Enhanced by finestructure ($K_v \sim 5$ cm^2 s^{-1})	Summer: suppressed by pycnocline ($K_V \sim 0.1$ cm^2 s^{-1}) Winter: some vertical convection	Greatly enhanced (large K_V)
B Horizontal			
1. Along-shelf			
surface layers	Wind, advection	Wind	Wind, advection
lower layers	Advection	Diffusion ($K_H \sim 10^6$ cm^2 s^{-1})	
2. Cross-shelf			
surface layer	Wind	Wind	Wind; diffusion ($K_H \sim 0.5 \times 10^6$ cm^2 s^{-1})
mid-layer	Off-shelf with finestructure		
lower layer	Diffusion (on-shelf) ($K_H \sim 10 \times 10^6$ cm^2 s^{-1})	Diffusion ($K_H > 10^6$ cm^2 s^{-1})	
IV. Hydrographic regime			
A. Freshwater	Melting of ice (precipitation)	Melting of ice (precipitation)	Runoff (precipitation)
B. Salt resupply			
upper layer	Up diffusion	Up diffusion	Freezing of ice; advection from near Unimak Pass
lower layers	Shelf basin mixtures; basin water at shelf break	Lateral diffusion across fronts; freezing in polynyas (northern area)	
C. Heating			
upper	Surface exchange	Surface exchange	Surface exchange; vertical mixing
lower	Shelf-basin mixtures; basin water at shelf break	Vertical exchange (very slow)	
D. Cooling	Surface exchange	Surface exchange; ice melting	Surface exchange; ice formation

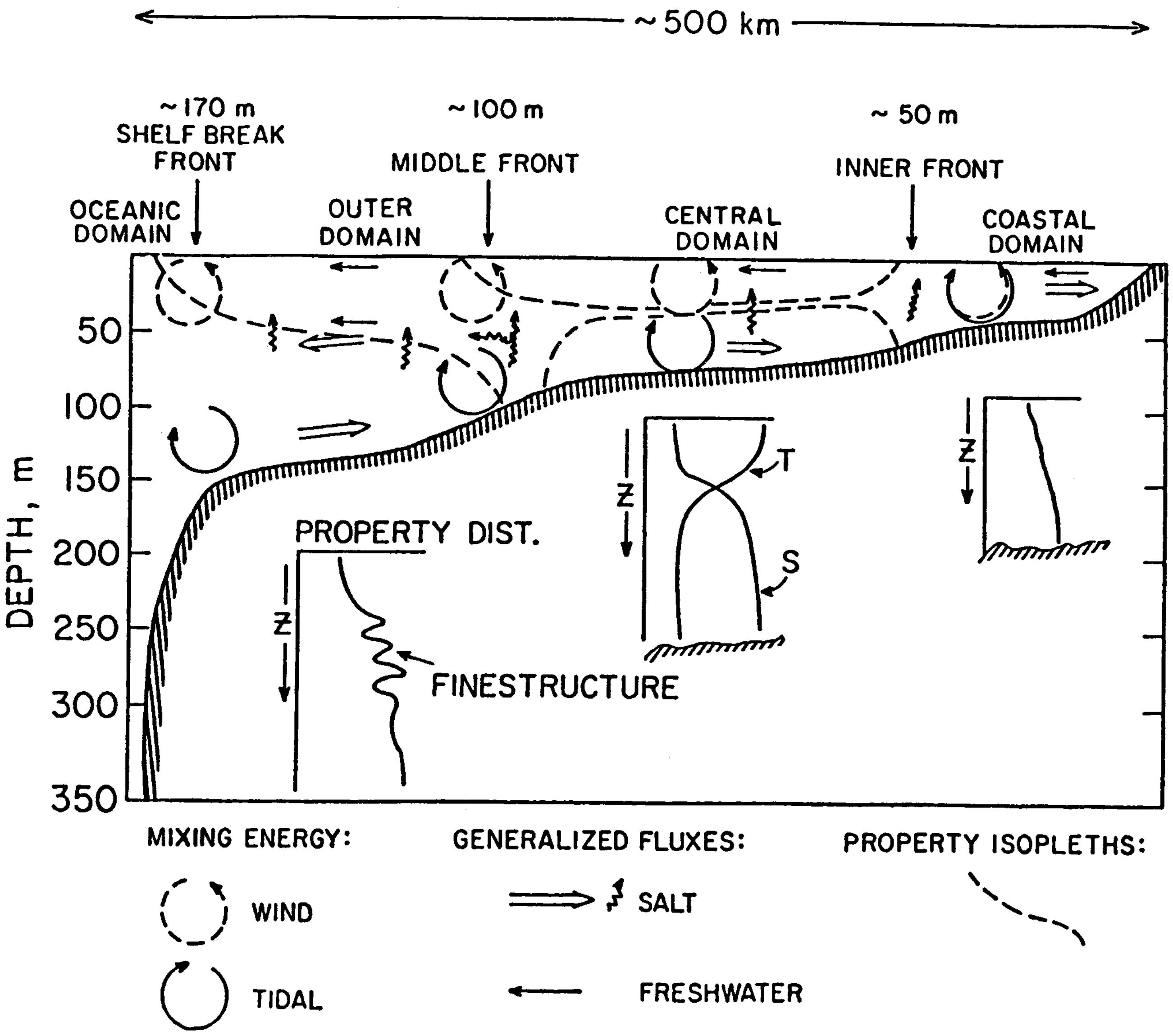

Figure 2.3. **Schematic diagram relating vertical energy distributions to the typical horizontal and vertical property distributions and the fronts, and the inferred freshwater and salt fluxes (Coachman, 1986).**

95% of the total KE was the result of tidal currents, 3% of the KE was associated with weather events with periods of 2 to 10 days, and the remaining 2% were associated with other fluctuating subtidal components (long period fluctuations).

Although the dynamical regimes coincided with the hydrographic domains (and, therefore, the depth zones), the boundaries between dynamical regimes did not precisely match the boundaries between the hydrographic domains. The inner front which separates the central and coastal hydrographic domains is usually about 15 to 20 km wide: the boundary between the central and coastal dynamical regimes, indicated by the distribution of mean flows (Fig. 2.4), is approximately 30 to 40 km wide (Coachman 1986).

The coastal domain differs from the central domain in that there are longer term mean flows of 2 to 5 cm/s parallel to the bathymetry in the coastal domain, whereas the central domain exhibits mean flows of <1 cm/s (Fig. 2.5). The mean flow in the coastal domain is directed northeast into Bristol Bay. The driving forces of this mean flow are: (1) rectification of tidal currents due to interaction with the locally steeper bottom slope near 50-m depth; (2) some baroclinicity due to mass distribution differences between coastal and central shelf waters; (3) some possible rectification along isobaths of storm-generated subtidal components of the flow field; and (4) an influence of a decreasing sea level from Bristol Bay northward to the Bering Strait (Coachman 1986).

Some of the earlier circulation schemes (e.g., Takenouti and Ohtani 1974, Favorite et al. 1976) have some validity, however, tidal diffusion is also an important mechanism for property dispersal in the coastal domain. "A consequence is that freshwater introduced along the land boundary is readily mixed seaward across the domain, but near the inner front it enters the advective regime and is carried northward out of the system without significant amounts egressing seaward into the central domain ..." (Coachman 1986). Therefore, advection and diffusion play a significant role in the coastal domain.

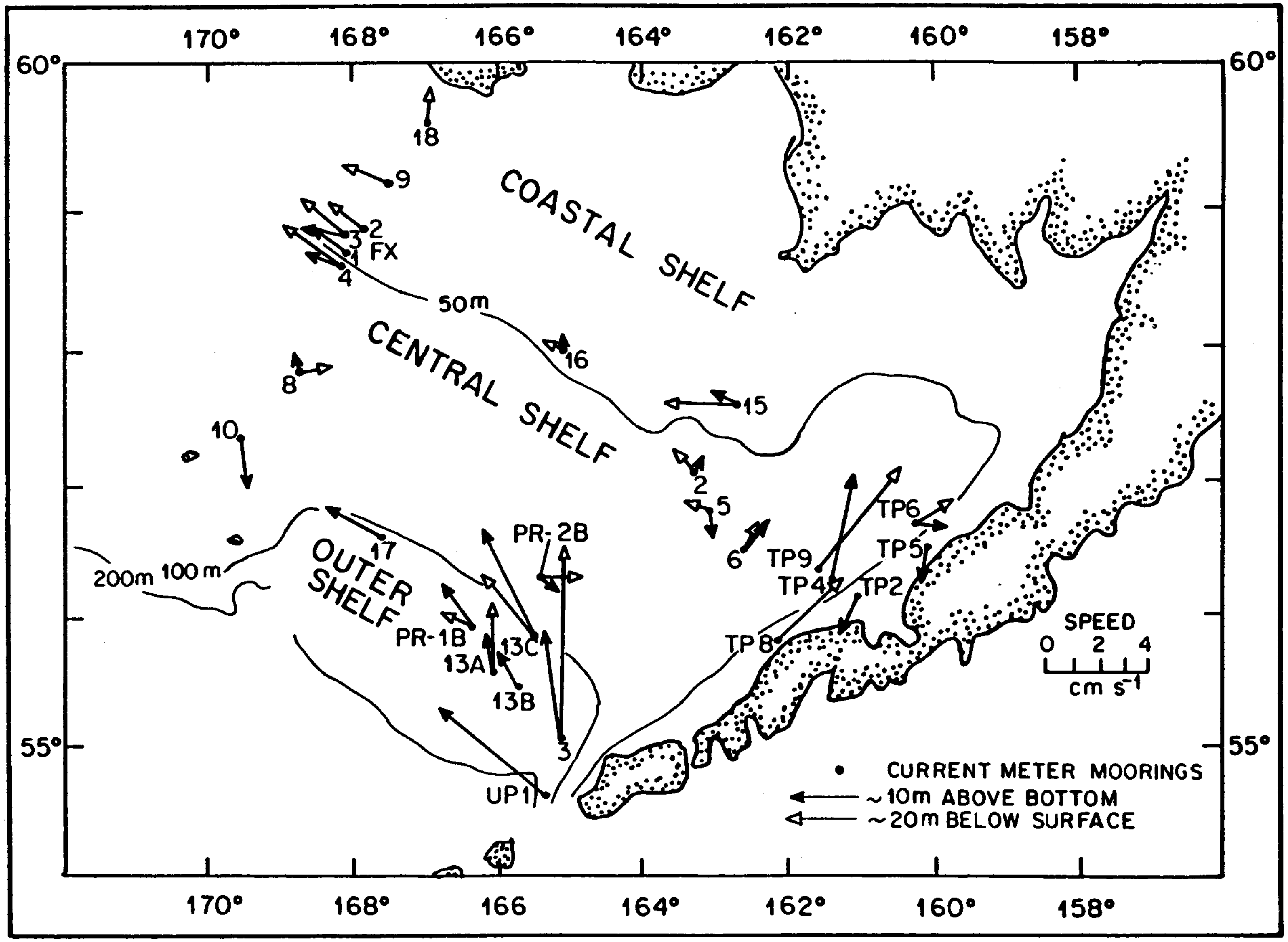

Figure 2.4. Vector-mean flows from long term current data from Schumacher and Kinder (1983).

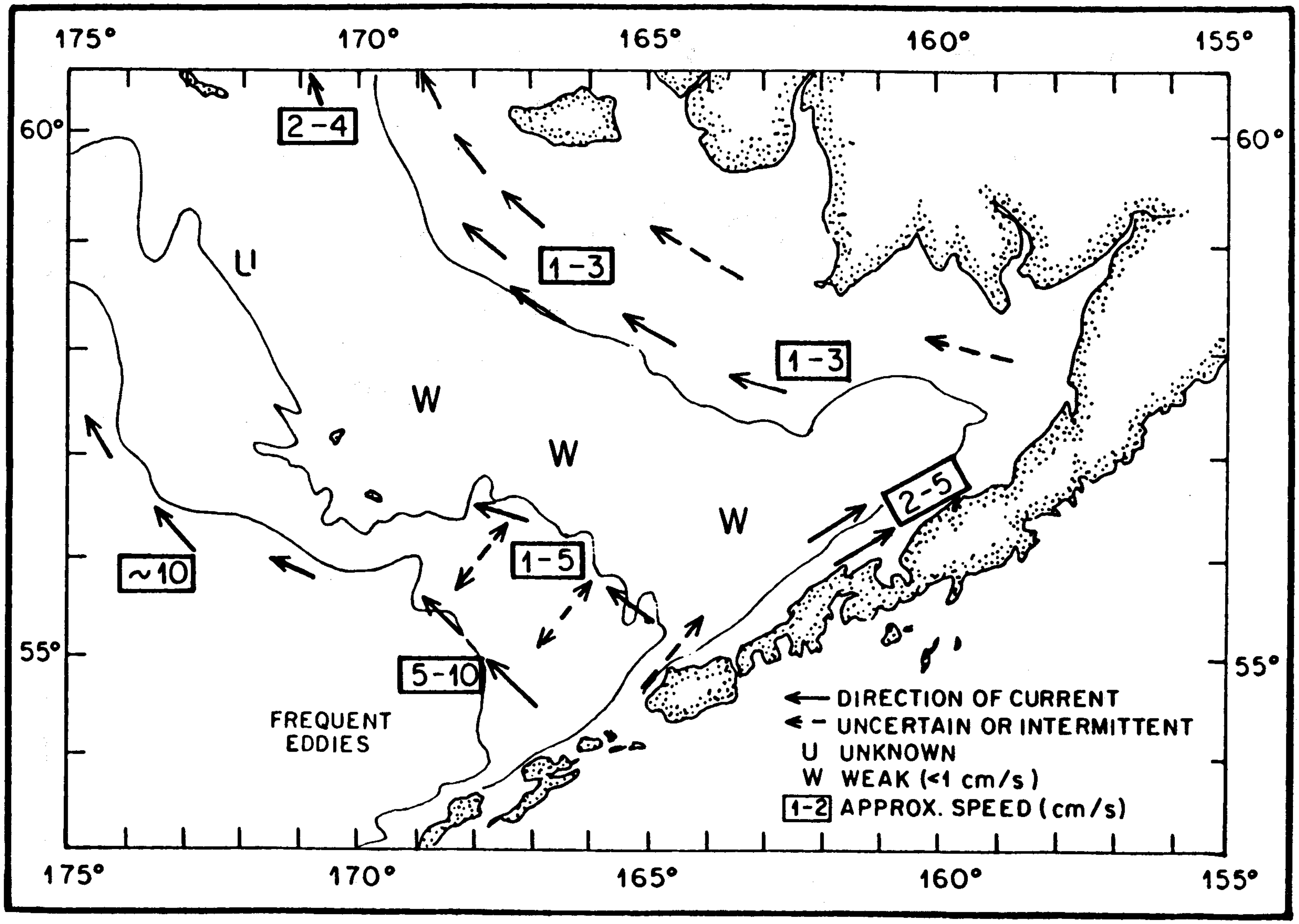

Figure 2.5. **Estimated longer-term (mean) circulation (Coachman, 1986).**

2.4 STUDY AREA

The physical oceanographic and meteorological investigations of the nearshore NAS included the collection of wind, current, tide, bathymetric, and hydrographic data. The field data were collected from numerous nearshore and onshore locations (Fig. 2.6) using various methods. The collection and analytical methods are discussed in subsection 2.5.

Wind velocity and air temperature were continuously monitored at Grant Point from 11 May through 28 May 1984, and from 15 September through 26 September 1984. Current velocity was continuously measured from 12 May through 24 May 1984, and again from 18 September through 8 October 1984. These data were collected at two stations, one located in 20 m of water and the other in 50 m of water. Continuous tide measurements were also taken immediately offshore of Grant Point from 11 May to 25 May 1984; a tide gage failure precluded similar measurements near Cape Glazenap. Additionally, a 24-hr inlet survey was conducted on 18 and 19 May 1984, at the south inlet (Cape Glazenap Inlet) of Izembek Lagoon. As a result of the high tidal current velocities and the inadequacy of the boats available, 24-hr surveys were not conducted at the middle and northern inlets. Nevertheless, bathymetric surveys were conducted at all three inlets, and drogue studies were conducted at both the north and south inlets of Izembek Lagoon (Moffet Point and Cape Glazenap).

A series of CTD hydrographic transects (Fig. 2.6) were sampled by NOAA's R/V Miller Freeman during May and September-October 1984, and January, March, April, and July 1985.

2.5 METHODS

Various methods were used to collect and analyze data for the NAS physical characterization. These methods are presented in the following subsections categorized by data types: meteorology, tides, currents, hydrography, lagoon survey data, and existing data.

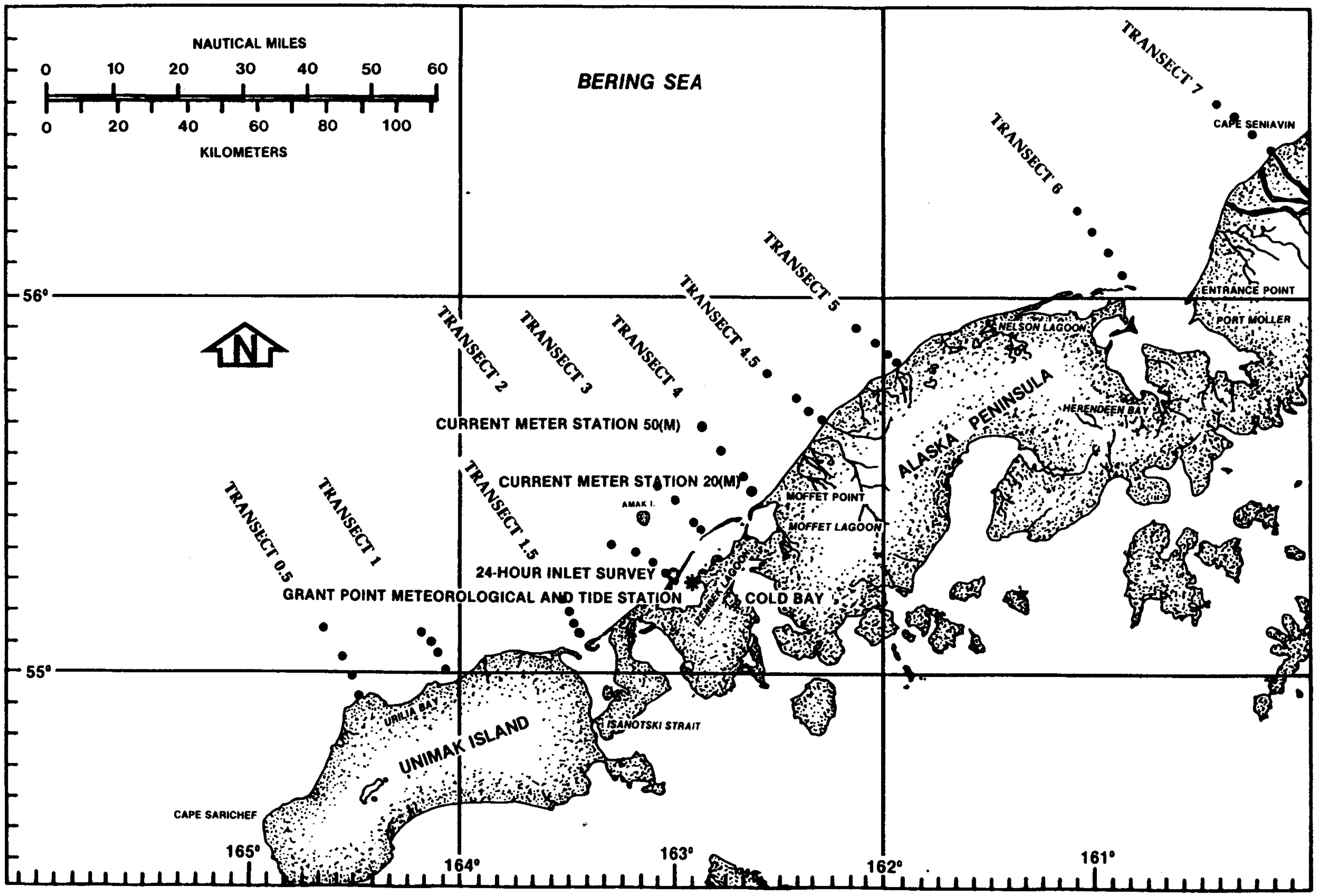

Figure 2.6. Physical investigation station locations.

2.5.1 Meteorology

Meteorological measurements were obtained from a self-contained remote weather station erected approximately 20 m above the sea level on Grant Point in Izembek Lagoon. This station recorded 30-minute average values for air temperature and wind speed and direction. In addition, three-hour averaged barometric pressure, wind speed and direction, and air temperature data were obtained from the National Weather Service (NWS) Cold Bay station. These data were then tabulated and time history plots were prepared. The barometric pressure measurements from May 1984 were used to correct tide gage pressure records for atmospheric pressure fluctuations.

2.5.2 Tides

Tides were measured near Grant Point with a Sea Data TDR-1 pressure gage. Pressure measurements were recorded internally on magnetic tape at 5-minute intervals. Converting pressure data from the tide gage to depth of water was performed in two steps. First, the barometric pressure obtained from the NWS Cold Bay station was subtracted from the total pressure measured by the tide gage. Second, the depth of water over the pressure gage was calculated from an assumed constant density calculated from salinity and temperature measurements in Izembek Lagoon.

The water depths calculated from pressure measurements were referenced to mean lower low water (MLLW) by comparing the difference between measured depths and the corresponding predicted water depths from the NOAA Tide Tables for Grant Point. The mean difference between corresponding observed heights and predicted heights was assumed to be the depth of the tide gage below MLLW. That number was then subtracted from all measured depths to provide water levels relative to MLLW.

Time history plots of measured and predicted tides were produced, and the differences between predicted and observed heights and times of occurrence were calculated and plotted for comparison.

2.5.3 Currents

Current speed and direction were continuously measured at two stations located on a line normal to the shore at Moffet Point at nominal depths of 20 and 50 m. A taut-wire current meter mooring was deployed at each station with a current meter positioned 5 m below the surface and 2 m above the bottom. Two types of current meter were used: the ENDECO Model 105 current meter (CM105) and the EG & G Model CT/3 current meter.

The CM105 is an axial-flow, ducted-impeller instrument specifically designed for use in wave zones. These instruments were calibrated by the manufacturer prior to deployment. The threshold speeds were determined to be between 2 and 3 cm/s; the accuracy of speed measurement was within ±0.6 cm/s of the true speed; and the current direction accuracy was $\pm 5^{\circ}$ at threshold speed, $\pm 3.6^{\circ}$ above threshold speed, and resolvable to $\pm 1.0^{\circ}$. This instrument recorded 30-minute average values of current speed and direction on 16-mm film. These films were digitized and transferred to the computer for analysis.

The CT/3 is an electromagnetic current meter with an internal compass. Digital current speed and direction data are recorded on magnetic tape cassettes. The CT/3 is capable of measuring current speeds from 3 to 300 cm/s with an accuracy of ±1.5 cm/s. Current direction, measured from 0° to 359° is accurate to $\pm 5^{\circ}$. The data recorded on the magnetic tape are transferred to the computer and analyzed.

The current meter data were presented as time history plots, joint frequency tables (JFTs) of current speed and direction, and progressive vector diagrams (PVDs).

Drogue studies (discussed in subsection 2.5.5) were conducted at two of the three entrances to Izembek Lagoon to augment continuous current meter data and evaluate trajectories of suspended materials issuing from the lagoon.

2.5.4 Hydrography

Hydrographic measurements were made along a series of cross-shelf transects extending from approximately the 20-m to beyond the 50-m isobath. These measurements, consisting of conductivity and temperature versus depth, were obtained with the R/V Miller Freeman's Plessey/Grundy Model 9041 CTD. These measurements were made approximately five times per second and recorded on magnetic tape. The values recorded by the CTD were checked against salinity samples obtained from rosette-mounted 5-L Niskin bottles and temperatures obtained from deep sea reversing thermometers mounted on these bottles.

The CTD data tape and calibration and quality control information were sent to the University of Washington for reduction. The resulting product was a tabulation of temperature, salinity, sigma-t, and geopotential anomaly averaged over 1-m intervals. These reduced data were then presented as vertical profile plots of temperature, salinity, and sigma-t. Hydrographic data for the entire study area that were collected within approximately 48 hours were presented as vertical and horizontal contour plots of temperature and salinity.

2.5.5 Lagoon Surveys

Several data collection and analytical methods were used to identify and quantify the effects lagoons might have on the NAS nearshore environment. Rather than attempt to study all of the lagoons or embayments along the Alaska Peninsula in a cursory fashion, efforts concentrated on a single important lagoon, Izembek Lagoon. The methods used to gain insight into the processes and influence of Izembek Lagoon included examination of remote sensing imagery, bathymetric surveys of the lagoon's three entrances, a 24-hour entrance survey of currents and temperature, and current drogue studies conducted at two entrances to Izembek Lagoon.

2.5.5.1 Remote Sensing

Recent information on the morphology and areal extent of Izembek Lagoon was obtained from remote sensing imagery. Satellite imagery (e.g., LANDSAT) was not used because the optimum 80-m resolution was considered inadequate for the purposes of this study. The National Cartographic Information Center (NCIC) was contacted, and a computer search of aerial (aircraft) imagery was instigated. The photographs obtained from NCIC were used to construct photomosaics from which information such as entrance dimensions and areal extent of the lagoon and its drainage channels was determined.

2.5.5.2 Bathymetry

Three transects were run in alternate directions at the north and south entrances (Moffet Point and Cape Glazenap), and two transects were run at the middle entrance. Depth measurements were obtained with a Raytheon 719B Fathometer. During the survey the boat speed and heading were maintained as constant as possible, given the varying current speeds and obstructing shoal areas.

The water depths recorded on the fathometer paper chart were digitized and input to the computer for reduction and analysis. The tides measured at Grant Point were used to correct the depths to MLLW. The widths of the entrances were obtained from the aerial photographs. From these data, cross sections referenced to MLLW were prepared and the cross-sectional area at different stages of the tide were determined.

2.5.5.3 Twenty-four Hour Inlet Survey

The information from the bathymetric surveys was used to determine the optimum location for the 24-hour current and temperature entrance survey. Because 4-knot tidal currents rendered the available Zodiacs inadequate, only a single survey at the south entrance was completed.

During the survey, a boat was anchored for 24 hours at a location in the lagoon entrance deemed most representative of mean flow conditions (based on bathymetry data). An ENDECO Model 110 remote-reading ducted-impeller current meter (capable of measuring current speed and direction, temperature, and depth) was lowered periodically to discrete depths and the data manually recorded. These data were then plotted as a series of vertical profile plots. From these data and from estimates of the tidal prism (obtained from tide data and aerial imagery), tidal flushing rates were calculated for the Cape Glazenap entrance and extrapolated to the middle and northern (Moffet Point) entrances.

2.5.5.4 Drogue Studies

Current drogue studies were conducted in the nearshore water off Izembek Lagoon to evaluate the trajectories of suspended materials leaving the lagoon. Six window-shade drogues were released concurrently from each of the north and south lagoon entrances at hourly intervals during ebb tide. Each drogue consisted of a marker flag, a buoy with identification number, and a polyethylene sail (or window shade). The sail measured 1 m to a side and was suspended directly below the buoy (i.e., there was no tether), therefore the movement of the drogue represented the movement of the top 1.5 m of water. The cross-sectional area of the buoy was less than 10% of the area of the sail to ensure that the movement of the drogue was representative of the water and not the result of the wind acting on the drogue. The decision was made to suspend the sail directly below the buoy, thereby measuring the movement of the top 1.5 m of water, rather than using a tether to observe water movement at deeper depths. This decision was made because of the high probability of the buoy stranding shortly after deployment at the entrances to Izembek Lagoon. The drogues were then tracked for approximately two days with an aircraft equipped with a LORAN C navigation system. This navigation system was checked against known positions at the start of each flight. The drogue position data were hand plotted and velocities were calculated.

2.5.6 Existing Data

In addition to the remote sensing imagery obtained from NCIC and meteorological data from the NWS, other sources of existing data were investigated. The most valuable sources of information were: Dr. J.D. Schumacher of NOAA, who provided published and unpublished information; the very comprehensive "Circulation, Water Masses, and Fluxes on the Southeastern Bering Sea Shelf" (Coachman 1986); and "The Eastern Bering Sea Shelf: Oceanography and Resources" (Hood and Calder 1981).

2.6 RESULTS AND DISCUSSION

Meteorological, tide, current, and hydrographic data were collected as described in previous sections to better understand the physical processes of the nearshore NAS. In addition, the effects lagoons have on the nearshore environment were also studied. The results of these studies are presented and discussed in the following subsections.

2.6.1 Meteorology

2.6.1.1 May 1984 Results

The winds were offshore from the southeast or onshore from the west-northwest approximately 17% of the time from each direction. These winds tended to persist for several days. For example, winds were primarily offshore from 12 to 16 May, and onshore from 18 to 23 May. The strongest winds were offshore from the east-southeast with speeds up to 18 meters per second (m/s). Winds were greater than 5 m/s 60% of the time. The most common speeds ranged between 5 and 7.5 m/s (34%). The air temperature at Grant Point ranged from 0° to 9°C, with a typical diurnal variation of 5°C. Time history plots of wind speed and direction, air temperature and barometric pressure are presented in an appendix (see Section 2.11).

2.6.1.2 September 1984 Results

Winds measured during this period were more frequently onshore with about 26% of the total from the north or north-northwest. The maximum speeds ranged between 15 and 17.5 m/s and were not confined to a particular direction. Winds were greater than 5 m/s 84% of the time with the most common speed range between 10 and 12.5 m/s (24.3%). Air temperatures averaged about 10°C, ranging from approximately 7° to 13°C. Time history plots of wind speed and direction, air temperature, and barometric pressure are presented in an appendix (see Section 2.11).

2.6.1.3 Comparison with Historical Data

Selected meteorological parameters measured at the Cold Bay NWS station during May, September, and October 1984 were compared with Cold Bay historical means for those same months (Table 2.2). This comparison indicates that May 1984 was less windy (6.6 m/s versus 7.2 m/s), drier (3.0 cm versus 6.3 cm), and cooler (3.3°C versus 4.2°C) than average, based on 30 years of data. September was more windy (7.6 m/s versus 7.2 m/s), drier (7.3 cm versus 9.6 cm), and warmer (9.9°C versus 8.4°C). October was slightly drier and warmer than average. The local climatological data for 1984 (LCDs) are presented in an appendix (see Section 2.11).

2.6.2 Tides

The predicted tide and the difference between the predicted and the tide measured in May 1984 at Grant Point are presented in Figure 2.7. The measured tide heights ranged from approximately 0.3 to 0.5 m higher than those predicted. Higher-high water was generally higher than predicted, although the other stages were not consistently high or low.

The times of the high and low water differed from approximately 1.3 hours before to 1 hour after the predicted time. The occurrence of lower-high water was generally later than that predicted (up to 1 hour) and the occurrence of higher-low water was generally earlier than predicted (up to 1.3 hours). Higher-high water and lower-low water usually occurred within 30 minutes of the predicted time with higher-high earlier and lower-low later than predicted.

2.6.3 Currents

Measurements of current speed and direction were collected at the 20- and 50-m isobaths seaward of Moffet Point. Both near-surface (meters 20S and 50S) and near-bottom (20B and 50B) measurements were obtained for 12 through 24 May and 18 September through 8 October 1984, with the exception of 20B in September-October, when a failure of one current meter resulted in no data.

Table 2.2. Comparison of selected Cold Bay, Alaska meteorological parameters with historical mean values* for May, September, and October.

Meteorological Parameter	May		September		October	
	1984	Historical	1984	Historical	1984	Historical
Mean Wind Speed (m/s)	6.6	7.2	7.6	7.2	7.6	7.5
Prevailing Wind Direction	—	SSE	—	SSE	—	WSW
Resultant Wind Speed (m/s)	1.0	—	2.1	—	2.5	—
Resultant Wind Direction (°T)	304	—	154	—	011	—
Barometric Pressure (mb)	1008.5	1003.3	1001.7	1004.2	1003.1	999.7
Precipitation (cm)	3.0	6.3	7.3	9.6	9.2	9.6
Air Temperature (°C)	3.3	4.2	9.8	8.4	4.9	4.2

*Based on 30 years of data.

Source: NCDC, 1984.

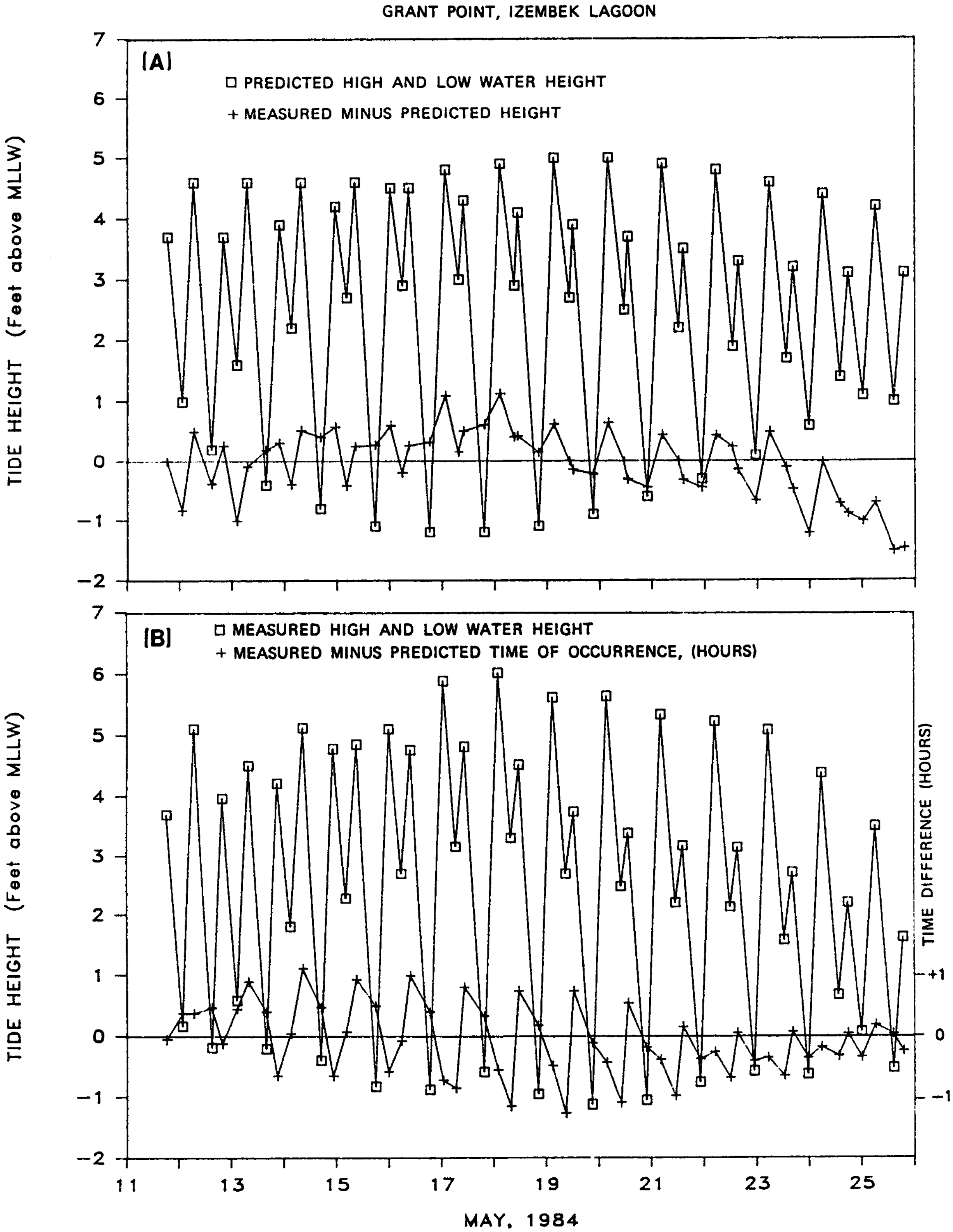

Figure 2.7. Predicted (A) and measured (B) tide heights for Grant Point during May 1984. Difference between measured and predicted tidal heights (A) and time of occurrence (B) are also presented.

2.6.3.1 May 1984 Results

The semidiurnal frequency and nearly rectilinear motion of the NAS currents observed in May 1984 corroborate the conclusions of previous investigators (Coachman 1986, Schumacher and Moen 1983, Kinder and Schumacher 1981b) that tidal currents are predominant on the southeastern Bering Sea shelf. The currents generally set to the northeast and southwest (along the shelf and parallel to the depth contours). There was, however, some variability in current direction and speed between the 20-m and 50-m stations and between the near-surface (5 m below the surface) and near-bottom (2 m above the bottom) currents.

The near-surface currents at the 20-m station set 075°T (relative to true north) and 270°T on the flood tide and ebb tide, respectively. The near-surface average speed was 21 cm/s; the near-bottom currents set 55°T and 255°T with an average speed of 16 cm/s. The current speeds at the 20-m station exceeded 60 cm/s at the surface and 45 cm/s at the bottom less than 1% of the time. A small offshore component was evident at both levels.

Progressive vector diagrams (PVDs) of the near-surface currents (Fig. 2.8) confirmed the semidiurnal tidal current motion and revealed a net transport to the north at 2.9 cm/s. This transport suggests that near-surface water on the shelf can have a significant offshore transport component over periods of one to two weeks. Conversely, near-bottom transport was definitely along the shelf toward the southwest at 1.4 cm/s. The calculated net current of 1.4 cm/s is deceptive: during the first two days the net current speed was 3.5 times greater, then decreased to nearly 0 cm/s for the remaining 10 days. The winds during the first two days were from the southeast in excess of 15 m/s eventually decreasing to below 10 m/s from the northwest. This brief record would suggest that local winds have very little direct effect on NAS nearshore currents.

The current speeds were somewhat greater at the 50-m station with average values of 25 cm/s near the surface (setting 55°T and 280°T on the flood and ebb tide, respectively) and 17 cm/s near the bottom (setting 55° and 250°T). The near-surface current speeds exceeded 75 cm/s less than 1% of the time; the near-bottom speeds exceeded 40 cm/s less than 1% of the

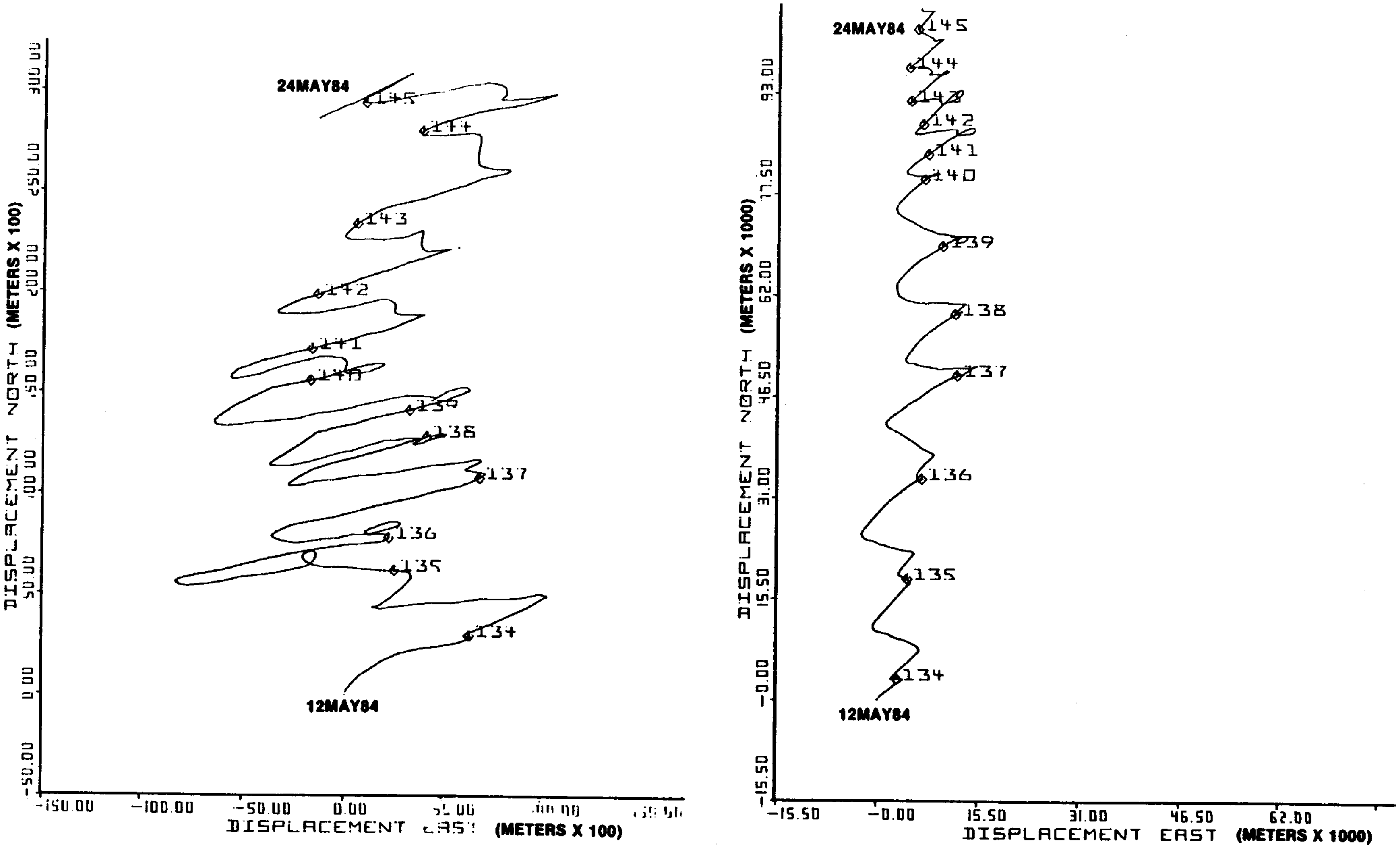

Figure 2.8. Progressive vector plots of current velocity at Station 20S and 50S (5m below surface).

time. Like the 20-m station, currents at the 50-m station revealed an offshore component.

Near-surface net transport at the 50-m station was, like the 20-m station, to the north (Fig. 2.8). The net current speed, however, was 3.5 times greater at the 50-m station (10.1 cm/s). There was virtually no near-bottom net transport; similar to the 20-m station, except that there was no transport even during the initial two days. The predominance of the tidal currents was apparent and, again, there was no obvious direct correlation of the winds and currents.

2.6.3.2 September-October 1984 Results

No near-bottom current data were recovered for the 20-m station during September and October. The near-surface currents set 55°T and 280°T (with a definite offshore component) at an average speed of 22 cm/s. The current speeds exceeded 70 cm/s less than 1% of the time. These currents were similar to those measured in May 1984 at the 20-m station.

The major difference at the 20-m station between the May and September-October period was revealed in the PVDs (Fig. 2.9). The net transport, although still to the north, was 4.4 times greater in September-October (12.8 cm/s) than in May. This was the highest net current speed measured at any of the locations during this study. This record was also unique in that during the last three days the tidal influence was completely masked and on the second to the last day the net transport increased to 46 cm/s to the north. Winds during this period were from the north at about 13 m/s. Winds with speeds in excess of 15 m/s during September had no measurable effect on the currents. These two facts suggest, once again, that the winds have a minimal direct effect on the NAS currents.

The currents measured during September-October, 1984 at the 50-m station differed from the May currents in that the directions had changed by 10° to 20° and the current speeds were somewhat slower in September-October. The near-surface currents set 65°T and 245°T with an average speed of 20 cm/s; the near-bottom currents set 75°T and 225°T with an average speed of 12 cm/s. Tidal currents were, once again, predominant.

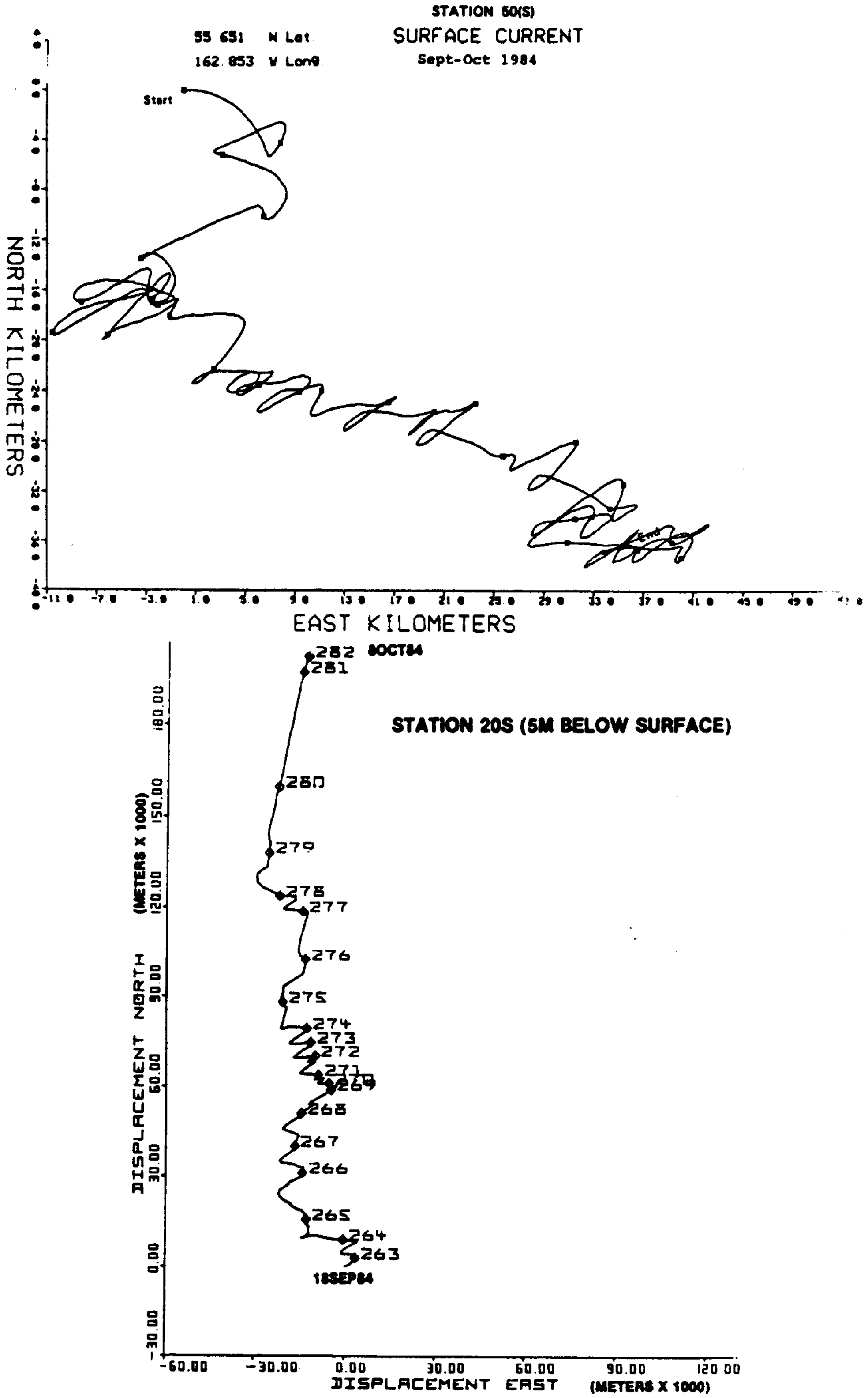

Figure 2.9. Progressive vector plots of current velocity at Stations 20S and 50S (5m below surface).

Net currents at the 50-m station differed significantly from the 20-m station during September-October and from both the 20- and 50-m stations during May 1984. It has been suggested (Ozturgut 1987, pers. comm.) that the difference in net transport (the PVDs presented in Fig. 2.9) between the 20- and 50-m stations occurs because the 50-m mooring may have been within the inner front during this period. The cross-shelf vertical temperature distribution along Transect 4 (Fig. 2.11) and alongshore vertical temperature distribution (Fig. 2.12) may support this suggestion. It is apparent in vertical temperature distribution that Transect 4 lies in a transition zone between two-layered structure (indicative of the middle domain) and vertically well mixed water (indicative of the coastal domain). The near-surface net currents set to the southeast at 3.0 cm/s (Fig. 2.9); the near-bottom net currents to the east-northeast at 1.0 cm/s. This suggests a slight onshore transport at the surface and bottom at the 50-m station. At the other stations and all other times during this study, either offshore or alongshore net transport was observed.

Although both the May and September-October 1984 net current data frequently reveal a definite offshore component, this does not necessarily conflict with the findings of previous investigators. Schumacher and Moen (1983) reported that the long-term net transport was alongshore to the northeast, nevertheless, their current records also revealed short-term offshore transport for periods of two to three weeks. Generally, these data are consistent with previous findings that, although there is some cross-shelf transport, the net transport is alongshore toward the northeast in the NAS nearshore coastal zone.

2.6.4 Hydrography

Cruises to collect hydrographic and chemical oceanographic data were conducted during May and September-October, 1984 and January, April, May, and July, 1985. The results from each of these cruises are discussed individually in the following subsections. Additional data, including maps of temperature and salinity distribution, vertical profile plots, and tabulated data are presented in an appendix (see Section 2.11).

2.6.4.1 May 1984

The near-surface temperatures ranged between 2.4° and 4.5°C and generally decreased offshore; however, a minimum did occur at stations located between the 30- and 40-m isobaths suggesting the possible intrusion and upwelling of central domain water. Vertical stratification of the water was evident in May 1984 temperature distribution. This stratification occurred in those waters adjacent to Izembek Lagoon and Port Moller where the near-surface temperatures were somewhat warmer. Near-bottom temperatures ranged from 2.0° to 3.9°C and decreased with distance offshore. No warming in the vicinity of the lagoons or cooling near the 30- to 40-m isobaths were evident in these near-bottom temperatures.

The near-surface salinities during May 1984 ranged between 30.4 and 31.8 $^{o}/_{oo}$ and generally increased with distance offshore; the near-bottom salinities also increased with distance offshore and ranged from 31.2 to 31.9 $^{o}/_{oo}$. As a result of runoff, the lowest near-surface salinity values (and warmest water) were measured near Cape Seniavin, Moffet Point, and those waters adjacent to Izembek Lagoon. These salinity minima were associated with nearshore vertical stratification evident in the salinity distribution (Fig. 2.10) and concomitant with the temperature maxima. This figure also reinforces the evidence for intrusion of central domain water into the coastal domain.

2.6.4.2 September-October 1984

The near-surface temperatures ranged from 9.1° to 10.5°C and decreased with distance offshore. The greatest temperature difference (approximately 1.1°C) was observed offshore of Cape Seniavin, located at the northeast periphery of the study area. Toward the southwest end of the study area the temperature difference was only about 0.4°C. Generally, the near-surface temperature increased toward the northeast. Because the water was well mixed vertically (Fig. 2.11), the same trends described for the near-surface temperatures were also observed in the near-bottom temperature distribution. The outermost station located on Transect 7 revealed a two-layered stratification typical of central domain

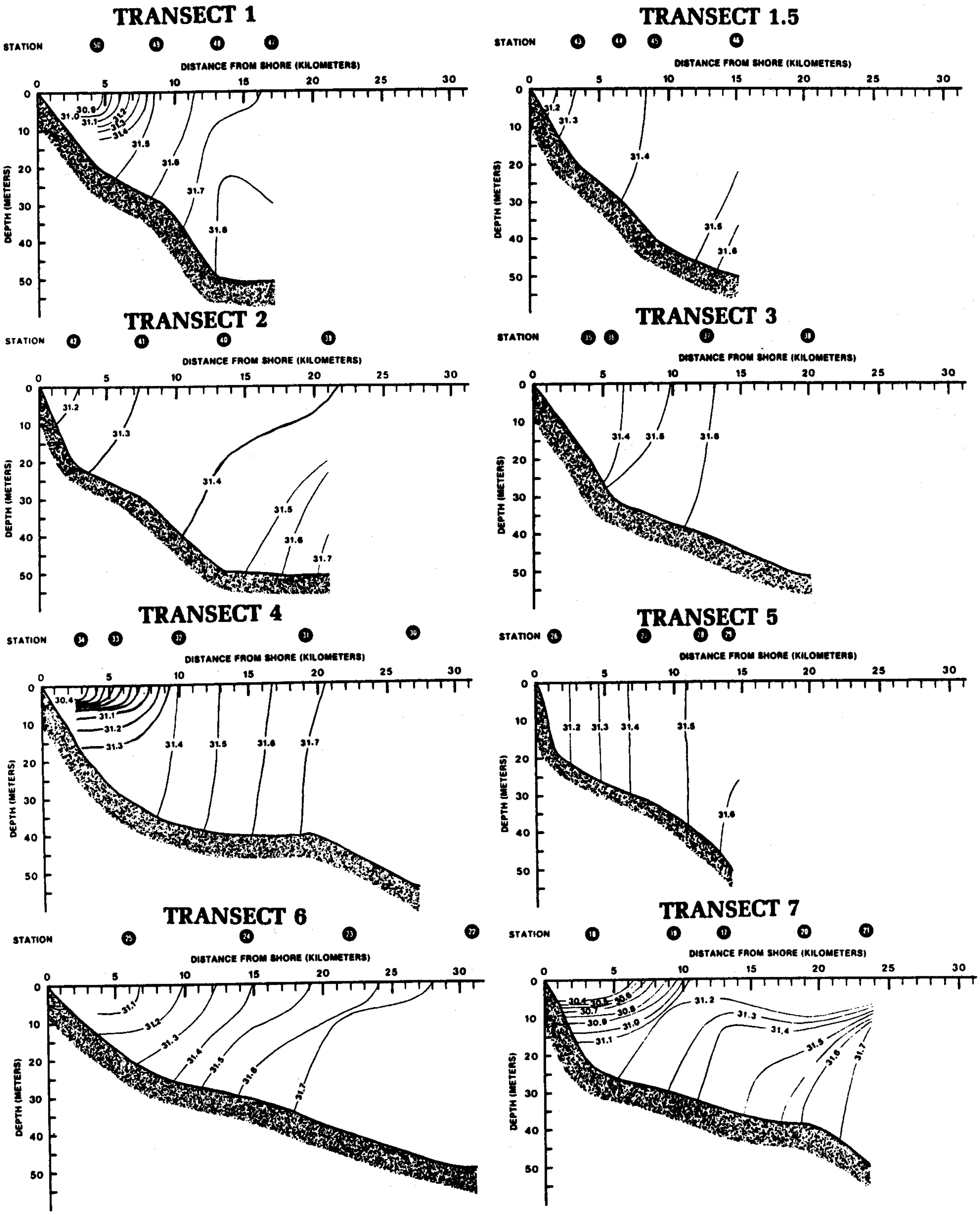

Figure 2.10. Vertical salinity contours for May 1984.

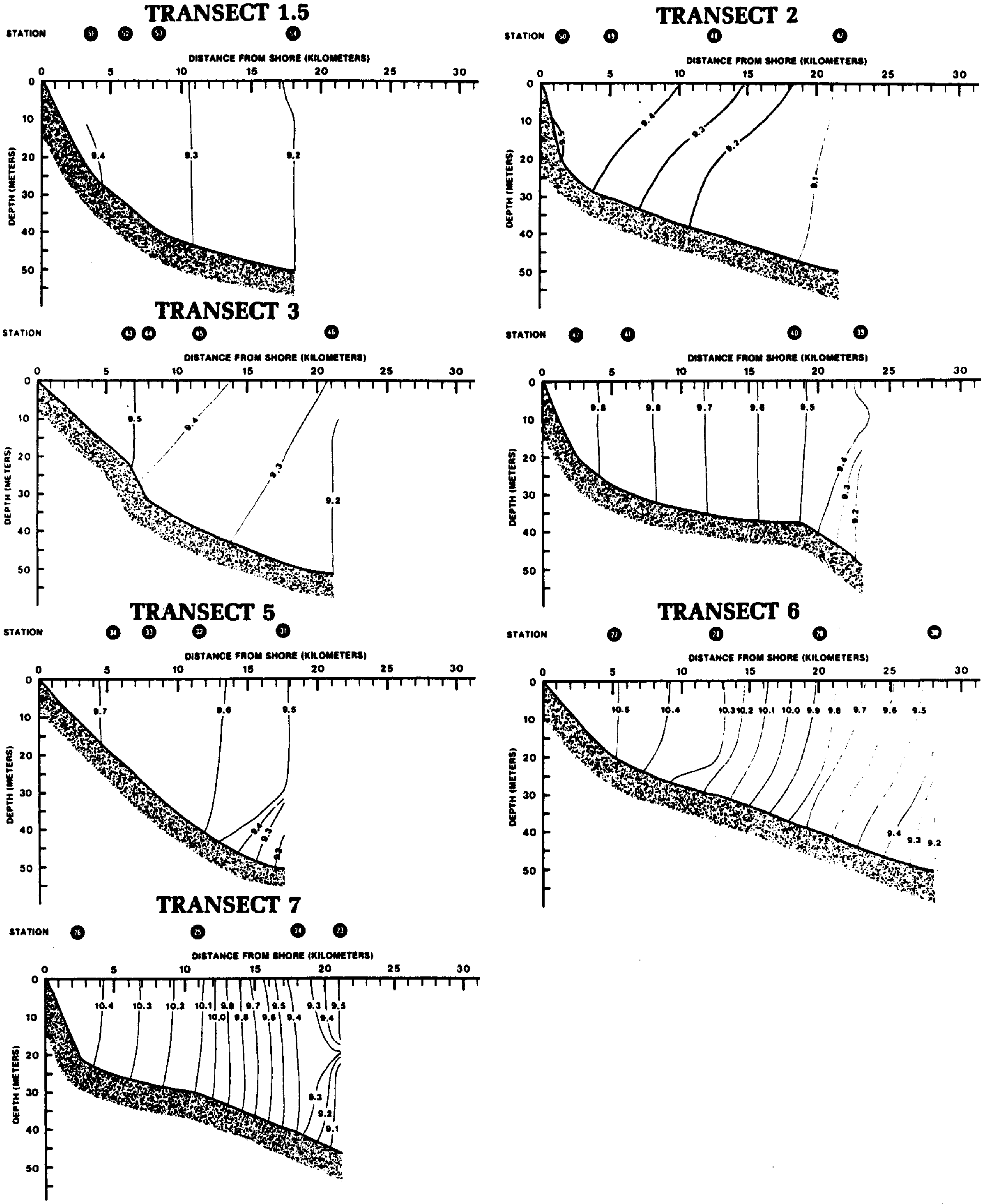

Figure 2.11. **Vertical temperature contours for October 1984.**

water (Kinder and Schumacher 1981a). This transition from the coastal domain across the inner front to the central domain is obvious in the vertical distribution of temperature along the 50-m isobath (Fig. 2.12). The inner front along Transect 7 was only 5 km wide.

The salinity distribution during September-October, like the temperature distribution, reflected the fact that the water was well mixed. The near-surface and near-bottom salinities ranged from 30.9 to 31.9 $^o/_{oo}$ and increased with distance offshore. The lowest salinities were observed in the waters adjacent to Port Moller. There was no typical two-layered structure indicative of the central domain evident in the vertical salinity distribution along Transect 7 or any other transect. This suggests that the central and coastal domain waters during this time differed only in temperature and structure.

2.6.4.3 January 1985

Surface temperature and bottom temperature generally increased with distance offshore during January. The surface temperature ranged from 2.5° to 5.2°C; bottom temperature from 3.0° to 5.2°C. The warmer temperatures were measured at the southwest periphery of the study area (Unimak Island). The distribution of temperature indicated that the water was mixed vertically at nearly every transect.

A notable exception to this generalization occurred along Transect 6 where a near-bottom intrusion of central domain water was evident in both the temperature (Fig. 2.13) and salinity distribution. At all other transects the salinity distribution, like the temperature distribution, indicated that the water was well mixed vertically. Near-surface and near-bottom salinity increased with distance offshore with ranges of 30.6 to 31.8 $^o/_{oo}$ and 30.9 to 32.4 $^o/_{oo}$, respectively. The salinity decreased from southwest to northeast alongshore; the waters adjacent to Port Moller were the freshest (approximately 0.5 $^o/_{oo}$ less than the surrounding water).

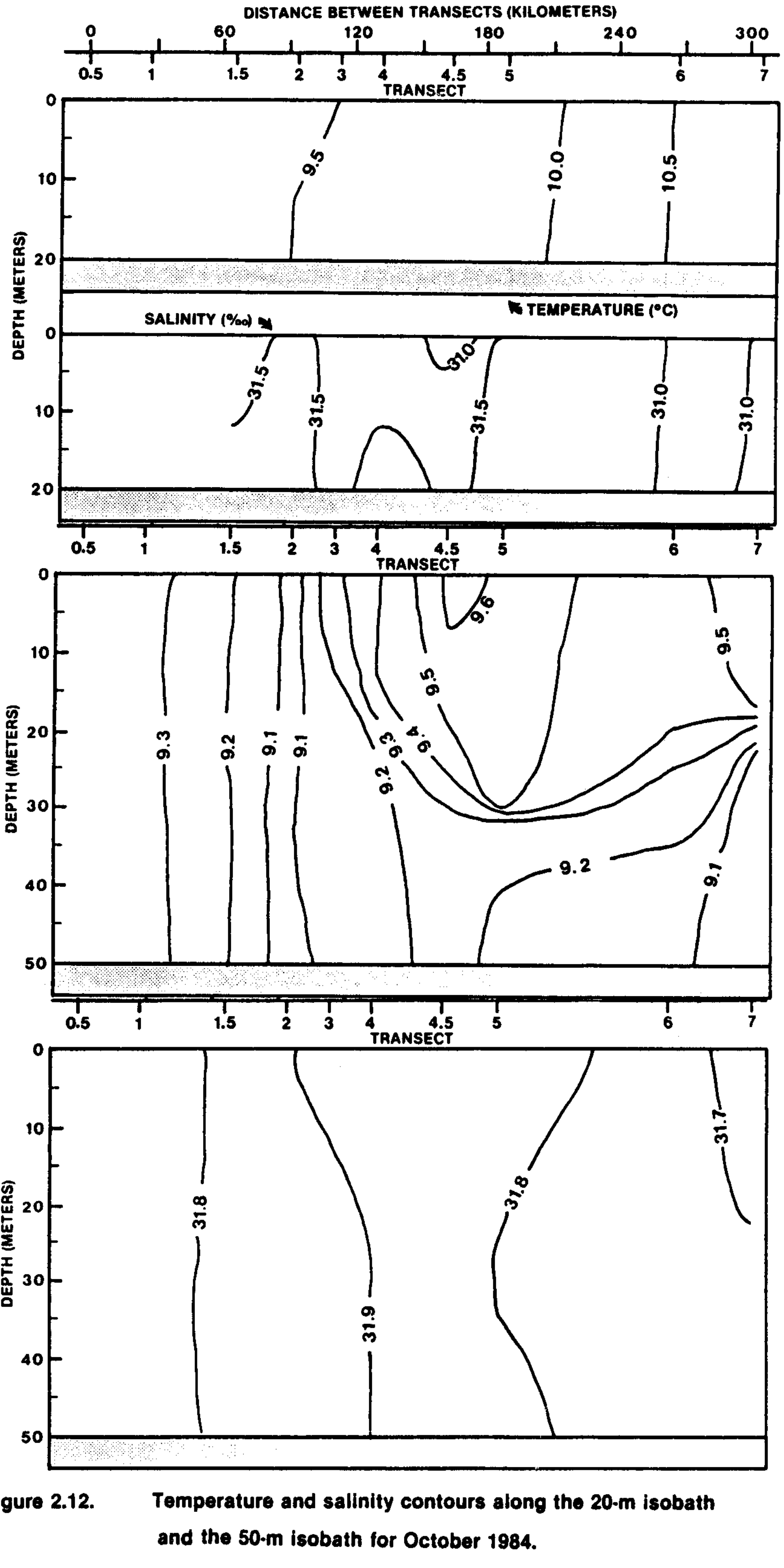

Figure 2.12. Temperature and salinity contours along the 20-m isobath and the 50-m isobath for October 1984.

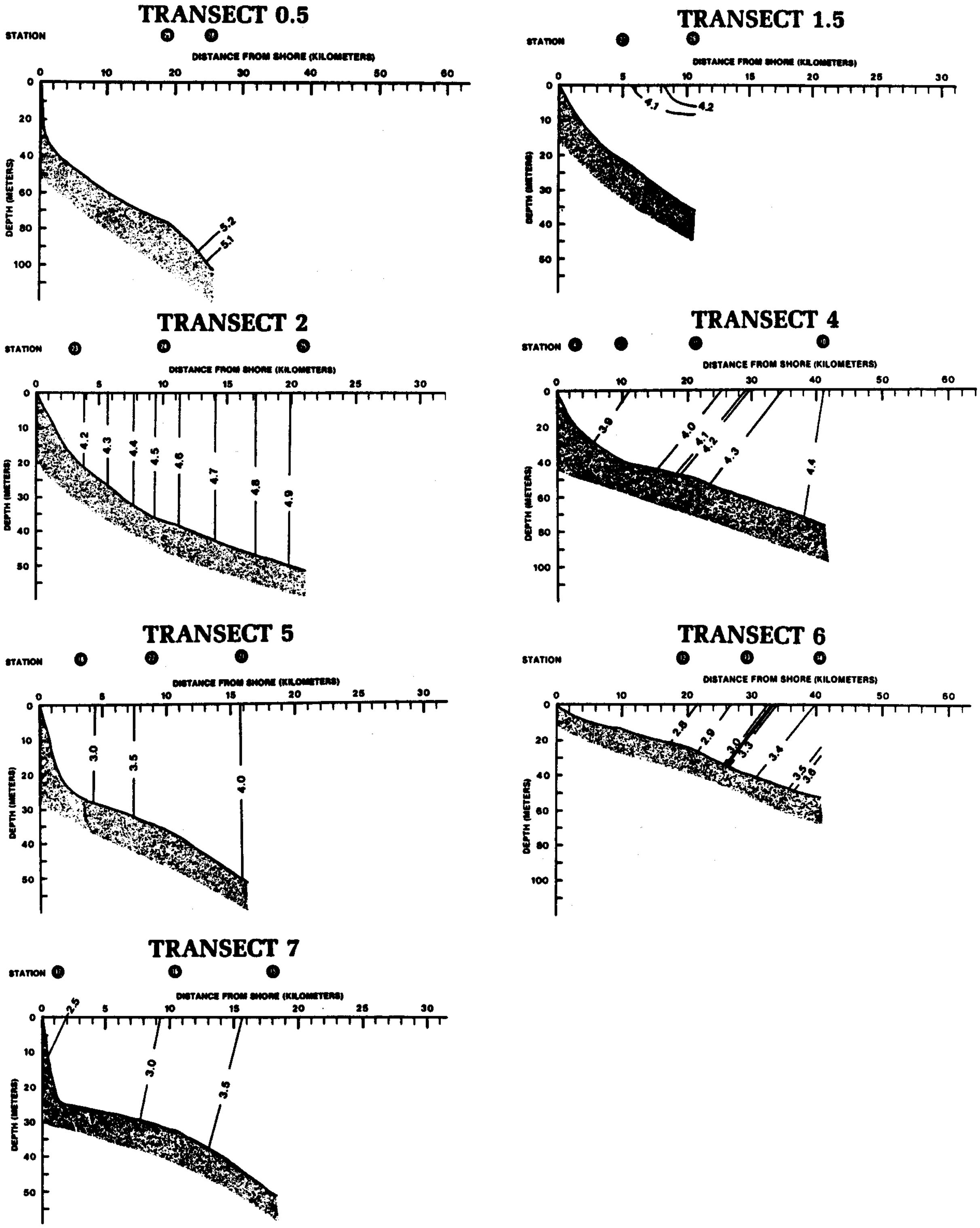

Figure 2.13. Vertical temperature contours for January 1985.

2.6.4.4 April 1985

April near-surface and near-bottom temperatures generally increased with distance offshore. The temperature gradient along Unimak Island northeast of Cape Mordvinof tended to be alongshore and decreased to the northeast. The near-surface temperatures decreased by approximately 2°C from southwest to northeast, ranging between 2.8°C (southwest and offshore) and -0.1°C (northeast and nearshore). This trend was apparent for the near-bottom temperatures as well, with temperatures ranging between 3.0° and -0.2°C. In the vicinity of Izembek Lagoon the cooler temperatures extended further offshore. The distribution of temperature indicated that the water was well-mixed vertically along the entire NAS study area as shown in Figure 2.14.

The vertical distribution of salinity, also shown in Figure 2.14, supports the vertically well-mixed characterization. It is apparent that the coastal domain, as defined by previous investigators, extended to the 50-m isobath. The salinity, like the temperature, generally increased with distance offshore with the near-surface values ranging from 30.7 to 32.1 $^{o}/_{oo}$ and the near-bottom values from 30.9 to 32.3 $^{o}/_{oo}$. The lower salinity values were measured nearshore near the northeast periphery of the study area; the higher values were measured offshore in the southwest.

2.6.4.5 May 1985

The near-surface and near-bottom temperatures generally decreased offshore. This was unlike January and April 1985 but similar to May 1984. The near-surface temperatures ranged from 2.5° to 5.0°C; the near-bottom from 2.0° to 4.5°C. These maximum temperatures were approximately 0.5°C warmer than the maximum temperatures measured in May 1984. The temperature distribution indicated that the water was well mixed vertically from Transect 0.5 up to, but excluding Transect 4 (Moffet Point). From Transect 4 on up to the northeast periphery of the study area and extending at least as far inshore as the 20-m isobath, the water exhibited the two-layered structure typical of the central domain (Fig. 2.15).

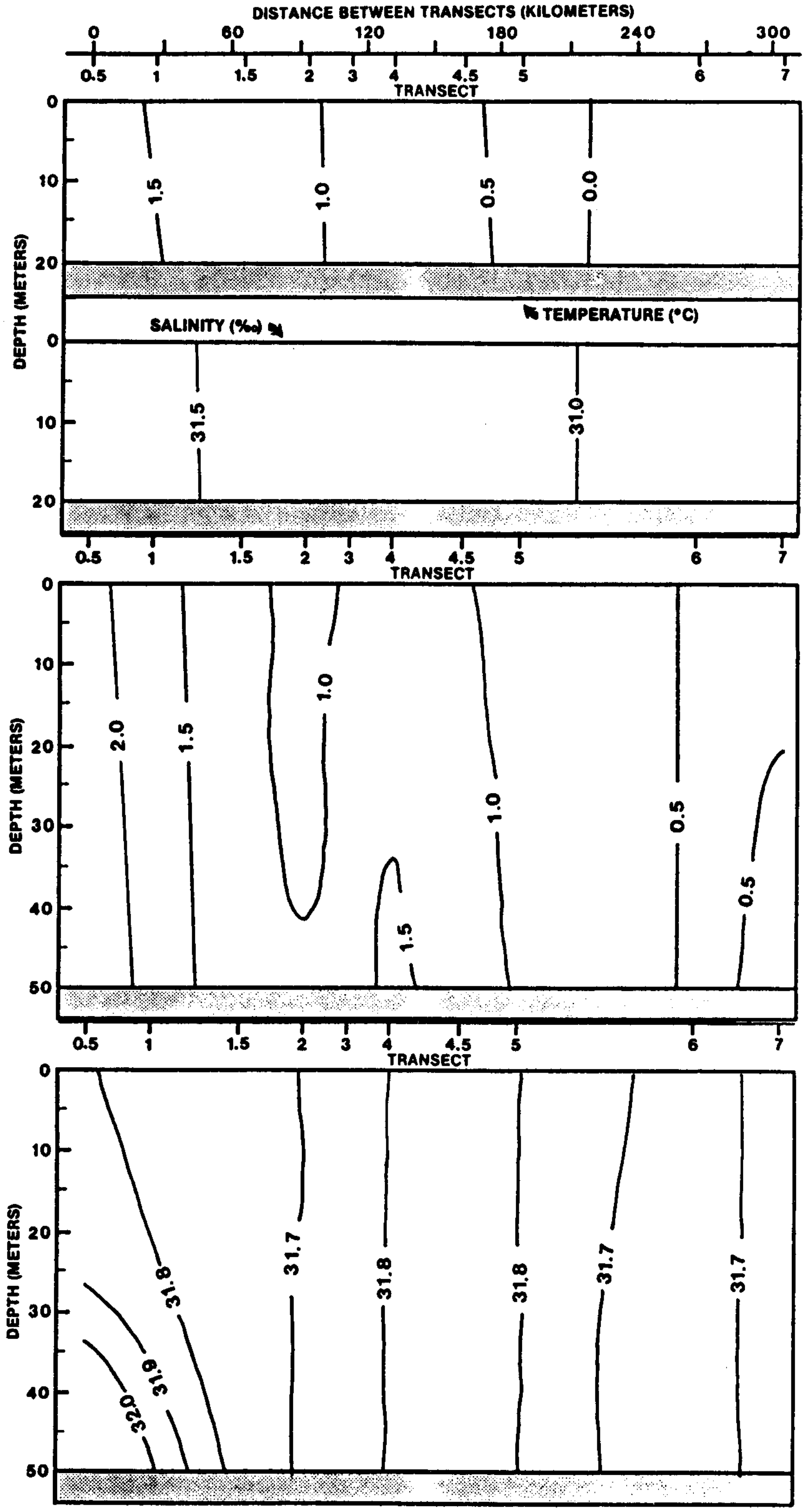

Figure 2.14. Temperature and salinity contours along the 20-m isobath and the 50-m isobath for April 1985.

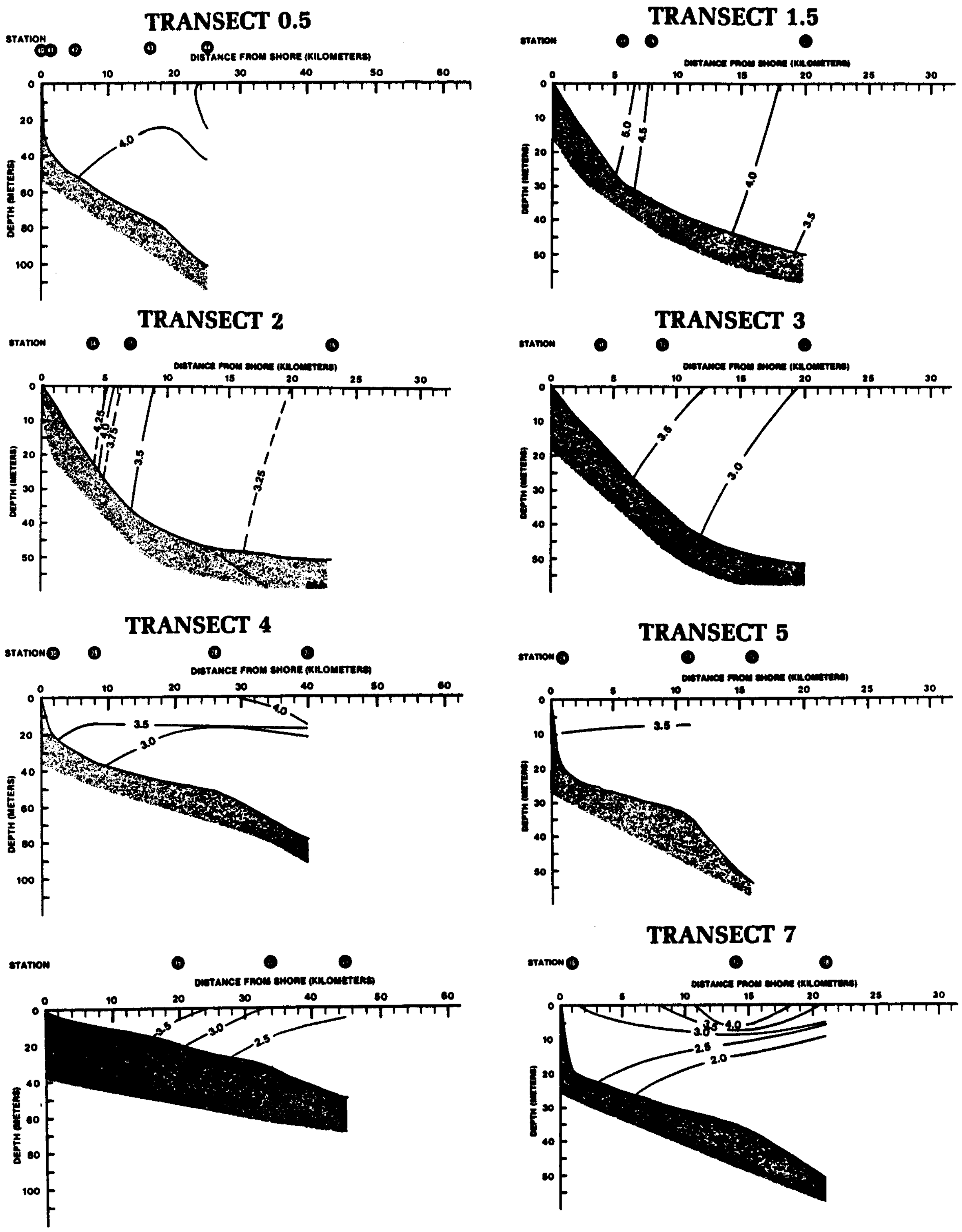

Figure 2.15. Vertical temperature contours for May 1985.

With the exception of Transect 7 (Cape Seniavin), this two-layered structural trend was not reflected in the salinity distribution. Salinity generally increased with distance offshore. The near-surface and near-bottom salinity values ranged from 30.8 to 32.1 $^{o}/_{oo}$ and from 31.0 to 32.6 $^{o}/_{oo}$, respectively. The lower values were measured in the nearshore northeastern periphery of the study area; the higher values were in the offshore southwestern periphery of the study area.

2.6.4.6 July 1985

Near-surface and near-bottom temperature trends were dissimilar during the July cruise. The near-surface temperatures, which ranged from 7.0°C in Unimak Pass to 9.0°C near Izembek Lagoon, generally increased with distance offshore. The near-bottom temperatures, however, decreased with distance offshore, ranging from 3.5°C (offshore southwestern periphery of the study area) to 9.0°C (nearshore northeastern periphery of the study area). The near-surface temperature trend did deviate from the above characterization at two locations: a temperature maximum occurred near the 20-m isobath adjacent to Izembek Lagoon, a temperature minimum was observed near the center of Transect 6. No corresponding temperature maxima or minima were observed near the bottom. In addition, similar to April 1985, the temperature gradient in the vicinity of Unimak Island tended to be alongshore rather than cross-shelf. The vertical temperature distribution (Fig. 2.16) was typical of the two-layered structure found in the central domain during the summer. This two-layered structure extended inshore as far as the 20-m isobath.

The two-layered structure was also evident in the salinity distribution. In fact, the distribution of salinity and temperature almost suggests that the coastal domain, as described by previous investigators, existed only out as far as the 20-m isobath in July. The near-surface salinity generally increased with distance offshore and ranged from 30.2 $^{o}/_{oo}$ in the northeast (nearshore) to 32.7 $^{o}/_{oo}$ offshore of Unimak Island. Directly off of Izembek Lagoon the near-surface salinity contours were normal to the shore rather than alongshore. The near-bottom salinity revealed a slight bulge in the alongshore salinity contours. Near-bottom salinity increased with distance offshore and

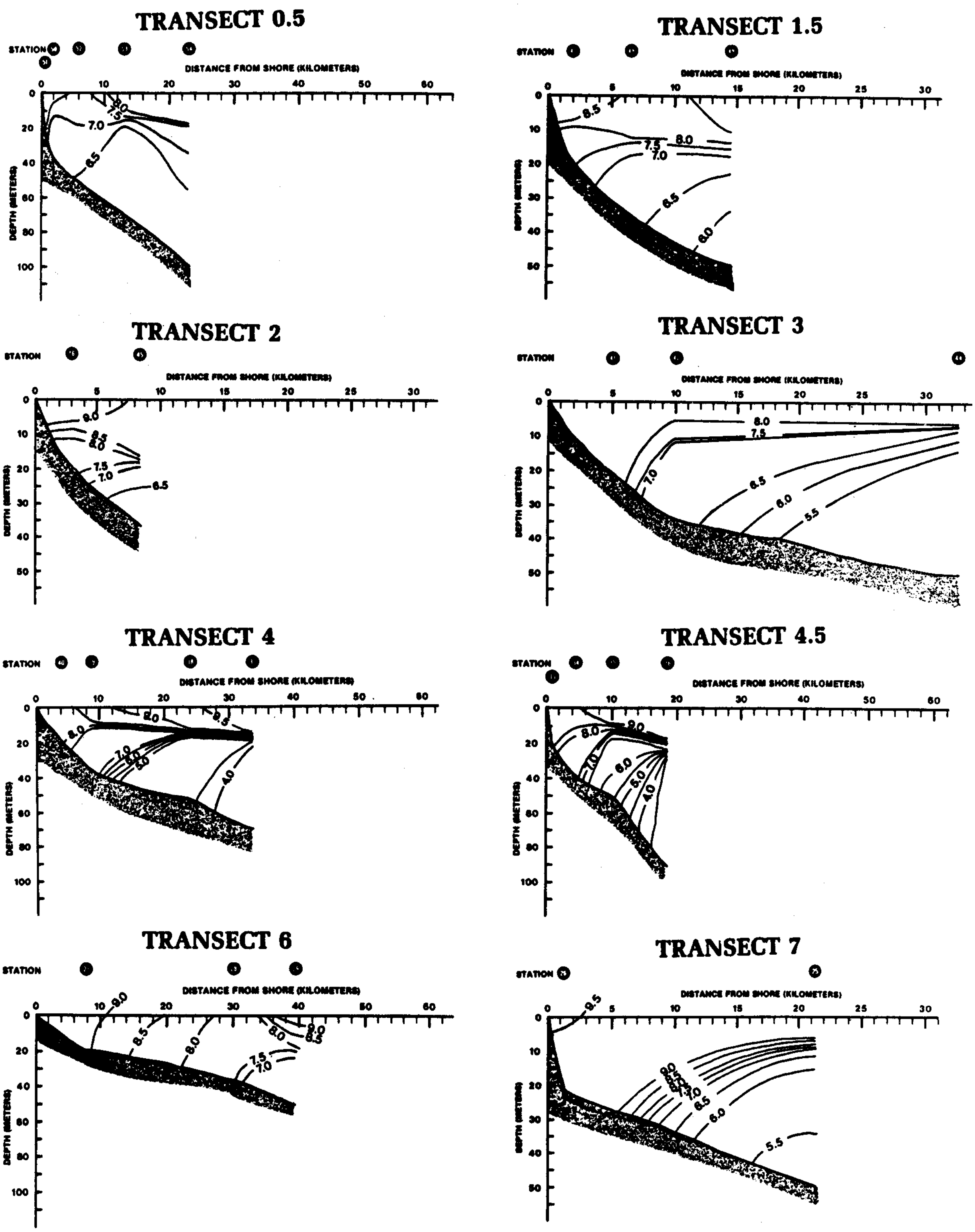
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Figure 2.16. Vertical temperature contours for July 1985.

ranged from 30.4 $^{o}/_{oo}$ in the northeast to 33.3 $^{o}/_{oo}$ off of Unimak Island. The higher salinity values observed near-surface and bottom in the vicinity of Unimak Island suggest that there may have been some oceanic influence in July.

2.6.4.7 Discussion

The horizontal and vertical distribution of salinity and temperature generally agree with previous investigators (Coachman 1986, Schumacher and Moen 1983, Kinder and Schumacher 1981a, Ingraham 1981). The coastal domain, characterized by vertically well-mixed water, usually extended out to the 50-m isobath. Nevertheless, there were exceptions to this general characterization. Stratification was observed during May 1984 and 1985 and July 1985. Usually, the nearshore stratification resulted from runoff from the land. The offshore, and most extreme, stratification resulted from intrusion of central domain water into the NAS nearshore zone. During July 1985 this intrusion (and stratification) extended inshore as far as the 20-m isobath along most of the NAS. There were isolated instances of intrusion during other cruises as well, although generally beyond the 40-m isobath.

Within the coastal domain the near-surface and near-bottom salinity increased with distance offshore, usually ranging from approximately 31 $^{o}/_{oo}$ nearshore to 32 $^{o}/_{oo}$ offshore. The difference between surface and bottom salinities was usually less than 0.5 $^{o}/_{oo}$. Occasionally, salinity values greater than 33 $^{o}/_{oo}$ were observed in the vicinity of Unimak Pass and values less than 31 $^{o}/_{oo}$ were observed in the vicinity of Cape Seniavin. During any given cruise the salinity rarely varied more than 2 $^{o}/_{oo}$. The general trend was toward higher salinities in the southwestern periphery of the NAS study area. The lower salinity values in the northeastern periphery of the study area resulted from the higher runoff in that area of the Alaska Peninsula.

Both surface and bottom temperatures decreased with distance offshore except during January and April 1985 when temperatures increased offshore. The near-surface temperature also increased with distance offshore during July 1985. During the six cruises surface and bottom temperatures ranged from -0.1^{o}C (April 1985) to 10.5^{o}C (September-October 1984). Temperature, more than salinity, determined the degree of stratification observed within the NAS nearshore zone. Because the water was usually well mixed, the difference between surface and bottom temperature at any given station was less than 1°C. Only during July 1985, during a period of relatively intense stratification, did the temperature difference approach 5°C. Presumably if the water in July had become rapidly mixed (e.g., as a result of a storm), the bottom temperature could have been warmed by 1° to 2°C.

2.6.5 Lagoonal Influence

2.6.5.1 Bathymetry

Water depths were measured across the three entrances to Izembek Lagoon to determine the cross-sectional area and configuration of each entrance and determine the relative importance of each entrance for transmitting water in and out of the lagoon. The configuration of each entrance is presented in Figure 2.17.

The south entrance, estimated to be 900 m wide, has a relatively simple configuration with a single main channel with a maximum depth of approximately 13 m below MLLW. Of the three, this entrance appears to have changed the least (based on previous charts). The middle entrance is interspersed with many small channels and shoal areas, and over 50% of the entrance would be exposed at MLLW. The width was estimated to be 1600 m, and the deepest channel was located approximately midway with a maximum depth of 9 m below MLLW. The north entrance is the largest and most complex with many channels. The section profiled was estimated to be 2320 m wide, with a maximum depth measured approximately 13 m below MLLW.

The cross-sectional areas were calculated for a tide range of -0.5 m below MLLW to +1.7 m above MLLW. Within the tide range specified, cross-sectional areas ranged from 4000 to 5940 m^2 for the south entrance, 850 to 3560 m^2 for the middle entrance, and 8400 to 13,330 m^2 for the north entrance. The total inlet cross-sectional area available to water transport ranges from approximately 14,860 m^2 (at a tide stage of 0.0 m) to 20,440 m^2 (tidal stage of 1.2 m). Assuming the fraction of Izembek Lagoon effectively communicating with each tidal entrance is a function of

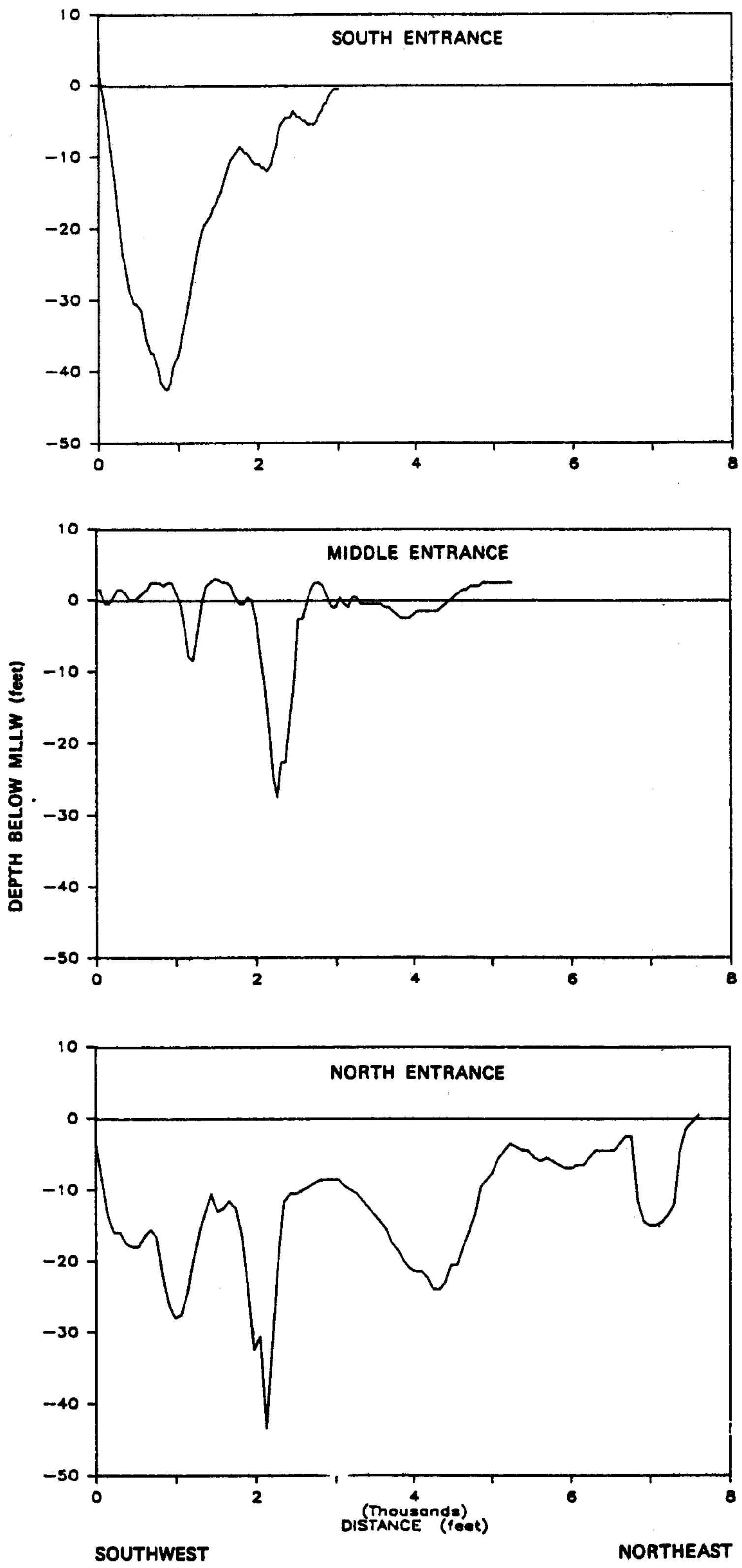


Figure 2.17. Izembek Lagoon entrance cross sections (adjusted to MLLW).

the entrance cross-sectional area in relation to the total available cross-sectional area, then the area of the north, middle, and south entrances, relative to the total area at a tidal elevation of 0.0 m would effectively communicate 62.5%, 7.5%, and 30% of the total volumetric flow, respectively.

Izembek Lagoon, with a surface area of 218 km^2, is comprised largely of tidal flats (78%) and, to a lesser extent (22%), tidal channels (Barsdate et al. 1974). During a typical semidiurnal tidal cycle the mean tidal excursion is 1.6 m with a second average tidal excursion equal to 23% of the principal tidal range. These values result in a tidal prism of approximately 4.29 x 10^8 m^3.

2.6.5.2 Drogue Studies

Plots of drogue motion for the south entrance revealed that flood and ebb flow is concentrated along the west bank of the inlet. Drogues released from the south entrance remained within 5.5 km of shore (i.e., out to the 20- to 25-m isobath) during the four days of tracking. The net direction of travel was upcoast to the northeast, although drogues traveled as far as 9.5 km southwest of Cape Glazenap in the first one or two days following release. The northeasterly maximum range was 25 km from Cape Glazenap. Two of the drogues reentered Izembek Lagoon through the south entrance and one drogue entered the middle entrance.

Much of the offshore movement of the drogues occurred within the immediate area of the south entrance. For example, one of the drogues traveled 5 km directly offshore within six hours after release. The maximum average speed during ebb tides observed (excluding speeds within the entrance) was 38 cm/s. The maximum average speed observed for the south entrance drogues during flood tide was 65 cm/s. The overall net flow upcoast after 75 to 80 hours of tracking ranged from 3 to 8 cm/s.

The drogue release location at the north entrance was approximately 2.5 km from shore north of the actual entrance. This was necessary because of foggy conditions at the time of release. These drogues exhibited a stronger offshore movement than those released at the south entrance. Whereas the drogues released at the south entrance tended to remain a relatively constant distance from shore, most of those at the north entrance continued to move offshore. During the first two days following release, all the drogues except one remained downcoast of the north entrance.

The maximum current speed measured by drogues released from the north entrance was 35 cm/s during flood tide. During ebb tide the maximum current speed was 30 cm/s.

The results suggest that water is being pushed offshore of the north entrance in a type of tidal pumping effect. This effect apparently does not extend offshore beyond the 25-m isobath. This transport may be an important mechanism for mixing organic matter discharged from Izembek Lagoon with adjacent waters which are subsequently transported northeast. During periods of cross-shelf transport this material could migrate into the central domain.

The trajectories of drogues in the nearshore zone reflect a complex interaction of regional currents, tidal currents, winds, and water exchange from Izembek Lagoon. Trajectories confirm upcoast flow (to the northeast) during flood, and downcoast flow (to the southwest) during ebb. Nevertheless, distinct differences existed in the trajectories between the south and the north entrance releases (Fig. 2.18). Additional plots of drogue trajectories and wind and tide data are presented in an appendix (see Section 2.11).

2.6.5.3 Twenty-four Hour Inlet Survey

The results of the single 24-hour inlet survey, conducted at the south entrance of Izembek Lagoon are presented in Figure 2.19. The semidiurnal tidal influence was very evident during the survey period. Current speeds ranged from 0 to 216 cm/s (one-minute-averaged) with the highest speeds observed during the flood tide. The currents set 240°T on the ebb tide and 080°T on the flood tide. Some vertical shear was evident as the tides began to change as shown in Figure 2.19 (0300 19 May 84). The temperature fluctuations observed were probably the result of lagoonal heating due to insolation during this late spring observation period.

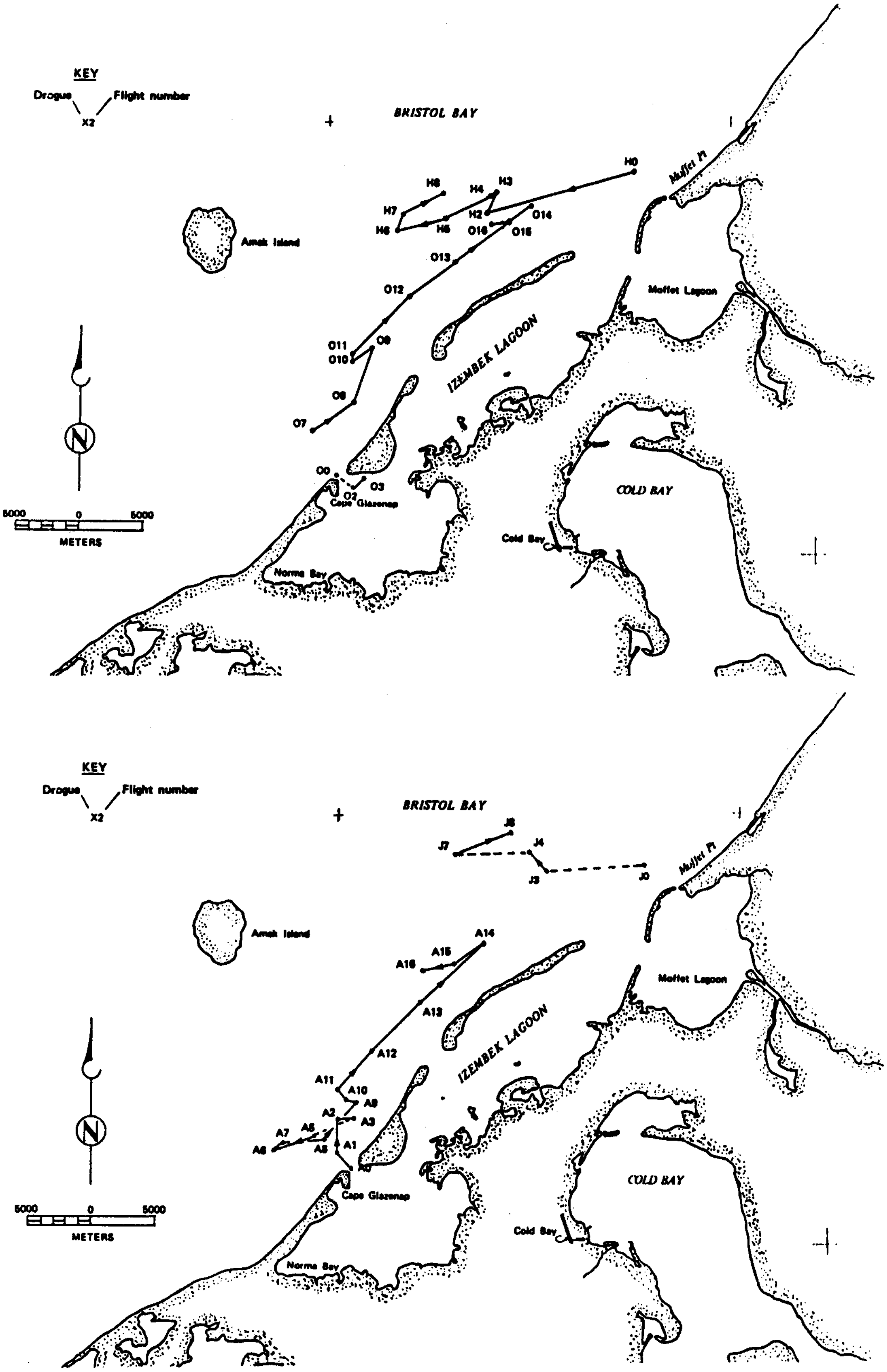


Figure 2.18. Trajectories for the first (A) and second (B) drogue releases.

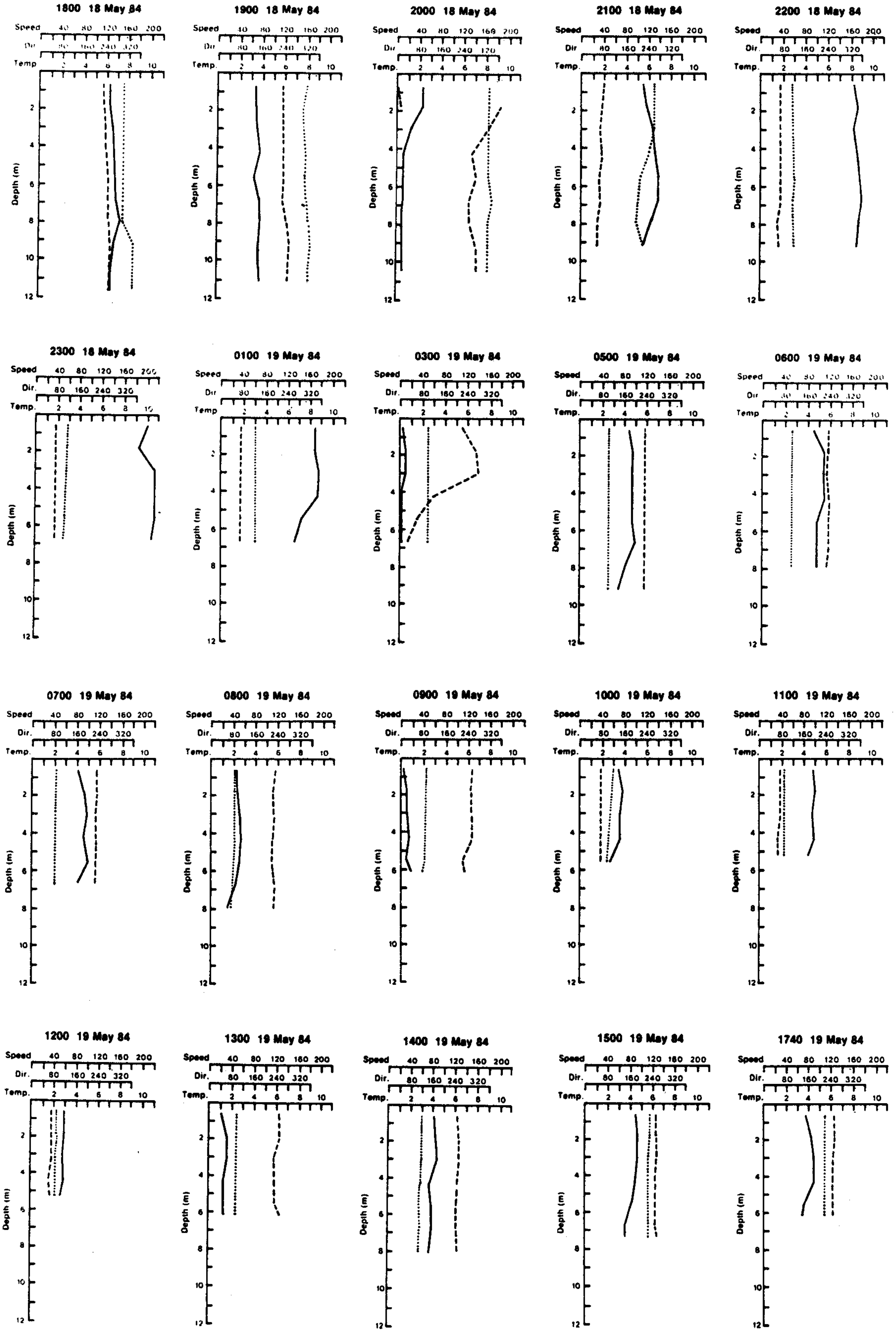


Figure 2.19. Vertical profiles of current speed (——), direction (- - -), and temperature (······) during the diurnal survey at the south inlet of Izembek Lagoon.

2.6.5.4 Discussion

Based on historical data as well as the data presented above, Izembek Lagoon may be characterized as a shallow lagoon with an area of 218 km^2. At low tide much of the surface area (approximately 78%) of the lagoon is a mudflat. Izembek Lagoon has three entrances or inlets--a southern, middle, and northern inlet with cross-sectional areas that ranged from 850 to 8400 m^2 at -0.5 m (referenced to MLLW) and from 3560 to 13,300 m^2 at 1.7 m above MLLW.

The northern or Moffet Point inlet could communicate as much as 62.5% of the total tidal volumetric flow. Therefore, the water adjacent to the northern inlet would most likely be influenced by the lagoon. This was evident in the vertical stratification of water adjacent to the northern inlet as delineated by temperature and/or salinity, particularly during the months of January 1985 (appendix), May 1984 (Fig. 2.10 - Transect 4) and 1985 (Fig. 2.15 - Transect 4), and October 1984 (appendix). Nevertheless, this same degree of stratification was seen at transects located off of Unimak Island and Cape Seniavin suggesting that the influence of the numerous unnamed streams discharging to the NAS is equally important in affecting the distribution of nearshore salinity and temperature. The influence of the lagoons and the streams of the Alaska Peninsula within the study area, however, is limited only to those areas directly adjacent to the lagoon or stream, and probably extend offshore no further than the 20-m isobath.

2.7 CONCEPTUAL PHYSICAL MODEL AND CONCLUSIONS

A conceptual model of the hydrographic characteristics of the NAS coastal zone has been developed to support interpretation of the data collected in this and numerous previous studies, and to provide a hydrographic basis to support interpretation of ecosystem dynamics. The conceptual model is highly simplified, but illustrates some important factors controlling materials transport and temperature distribution along the NAS. The conceptual model has been based primarily on previous investigations and publications, and is consistent with the findings of this study.

The model considers water, salt, and thermal fluxes through the NAS coastal zone. It could be used to support estimates of nutrient and carbon fluxes as well, if integrated with appropriate databases. The modeled domain (illustrated in Fig. 2.20) is the coastal zone, shoreward of the 50-m isobath and extending from Urilia Bay (Unimak Island) to Cape Seniavin. The alongshore length is approximately 280 km. Looking alongshore, the average cross-sectional area of the domain is 440,000 m^2 (0.44 km^2), so the total volume of seawater is 123 km^3 (1.23×10^{11} m^3).

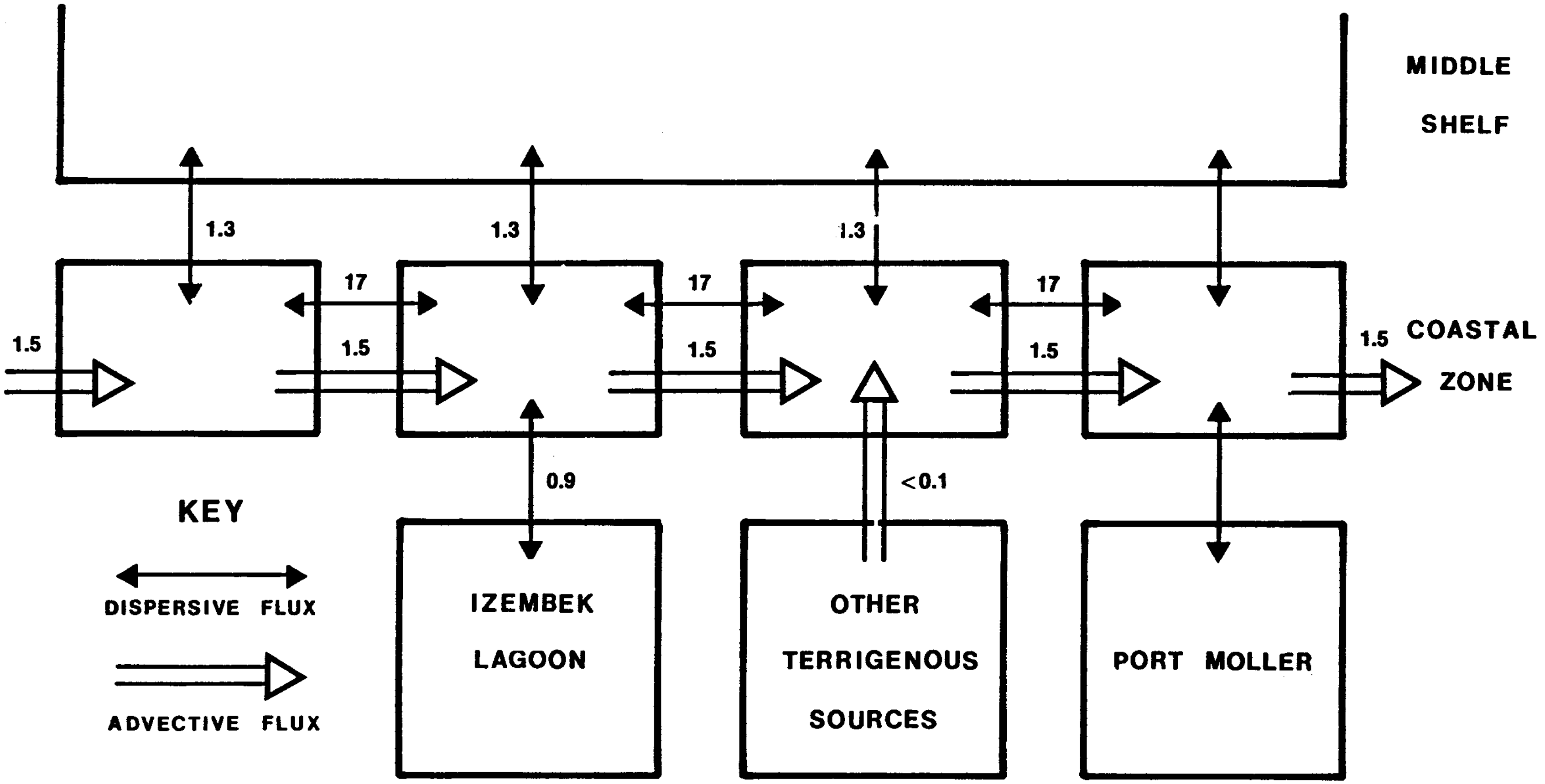
Within the modeled domain the net drift is alongshore toward the northeast. Coachman (1986) presents estimates of mean circulation (adapted from Kinder and Schumacher 1981b) in the model domain at 2 to 5 cm/s. Schumacher and Moen (1983) present mean circulation estimates based on dynamic topography of 2 to 7 cm/s, and a similar range in moored current meter observations (Mooring TP8) from January to May 1981.

Our investigation deployed both shallow and deep moored current meters for approximately two weeks in the spring and three weeks in the autumn of 1984 at the 20- and 50-m isobaths off the north inlet of Izembek Lagoon. The net drift observed during these relatively brief deployments generally deviated from the long-term mean circulation reported by the previously referenced investigators. These results do not contradict the earlier findings. The time series current data collected by Schumacher and Moen (1983) include frequent 2- to 3-week periods of cross-shelf and southwest currents. The data sets collected in our investigation were simply too limited in duration to reveal the long-term mean circulation.

Drogues were also released from Izembek Lagoon inlets on ebb tide during May 1984. Net drifts observed were alongshore to the northeast for 7 of the 11 drogues released and net drift ranged from 2 to 10 cm/s over 2 to 3.5-day tracking times.

Thus, it is assumed that net circulation within the NAS coastal zone is alongshore to the northeast at 2 to 7 cm/s (2 to 6 km/day). Since the alongshore length of the modeled domain is approximately 280 km, the length of time required for a parcel of water to travel through the domain is 50 to 140 days.

It is useful to compare different mechanisms resulting in mass transport in terms of characteristic time scales. A simple and readily applicable basis for development of such time scales is the half-life



NOTE: Volumes of water exchanged in km^3/day

Figure 2.20. Approximate quantification of conceptual model of NAS coastal zone.

related to the pseudo-first-order rate constant. A first order process is one in which the loss rate of a constituent is proportional to the concentration of the constituent. In a well-mixed reactor the concentration of a constituent is the amount or mass of the constituent divided by the volume of the reactor. Thus the rate of loss is also proportional to the amount or mass in the reactor. In a first order, or linear, reactor, the mass of constituent is reduced over time as $M = M_o e^{-kt}$. If several first order processes affect the constituent, then $M = M_o e^{-(k1 + k2 + ...)t}$. In systems that are not truly linear, it is always possible to define a pseudo-first-order rate constant which approximates the first order behavior by defining as the rate of loss of the constituent divided by the total amount remaining. Then a characteristic time scale for the process is estimated by the "half-life" $t_{1/2} = \ln 2/k$. In this simple conceptual model, the NAS coastal zone is treated conceptually as a well mixed linear reactor. Individual processes resulting in losses from the system can readily be compared by comparing their pseudo-first-order rate constants or their characteristic time scales. For loss of water by the advective mean circulation, the pseudo-first-order rate constant is given by:

$$k_{advection} = \frac{\text{flow past Cape Seniavin/day}}{\text{total volume of water in domain}}$$

$$= \frac{0.8 \text{ to } 2.7 \text{ km}^3\text{/day}}{123 \text{ km}^3}$$

$$= 6.5 \times 10^{-3} \text{ to } 2.2 \times 10^{-2} \text{ (day)}$$

where the flow is calculated as the cross-sectional area times the current speed, and the indicated range is based on the probable range of 2 to 7 cm/s.

A half-life can be calculated as:

$$t_{1/2} = \frac{\ln 2}{k}$$

$$t_{1/2}\ (\text{advection}) = \frac{0.693}{6.5 \times 10^{-3} \text{ to } 20 \times 10^{-2}/\text{day}}$$
$$= 30 \text{ to } 110 \text{ day}$$

It is seen that these half-lives, or characteristic time scales for advection are similar in magnitude to the transit time across the domain.

For water parcels entering the model domain at Unimak Island the only other significant process that could result in loss from the coastal zone is dispersive exchange across the 50-m isobath and onto the central shelf. In our investigation, significant cross-shelf transport was observed at the 50-m isobath over periods of two to three weeks duration. In May, mean surface net drift at the 50-m isobath was due north at 11 cm/s, indicating a cross-shelf component of 8 cm/s. Bottom currents at the 50-m isobath did not exhibit a significant cross-shelf component during this period. During September the near-surface current meter measured a net onshore drift of 3 cm/s over 19 days while bottom currents continued to indicate no significant cross-shelf transport.

As illustrated by the time series data of Schumacher and Moen (1983), such bursts of cross-shelf transport are not uncommon in longer duration current records (Schumacher, pers. comm.). In the context of longer time scales, for example the approximately 100 days required for transit through the study area, it is appropriate to conceptualize these bursts of cross-shelf transport as turbulence contributing to a dispersive cross-shelf material flux. Clearly net transport across the shelf is minimal on the basis of both hydrodynamic and water balance considerations.

A characteristic time scale, i.e., dispersive half-life, for this process may be defined as:

$$t_{1/2}\text{ (cross-shelf dispersion)} = \frac{\ln 2}{k\text{ (cross-shelf dispersion)}}$$

$$\text{where } k = \frac{\text{dispersive flux X 280 km X 50 m}}{\text{volume of water in coastal zone}}$$

$$\text{and the dispersive flux} = \frac{K_y}{W}$$

K_y is the cross-shelf dispersivity [5.6 km^2/day (Coachman 1986)] and W is the width of the inner front [20 km (Coachman 1986)]. Applying these values for K_y and W:

$$\text{dispersive flux} = 0.28\text{ km/day}$$

$$k = \frac{0.28\text{ km/day X 280 km X 0.05 km}}{123\text{ km}^3}$$
$$= 3.2 \text{ X } 10^{-2}\text{ day}^{-1}$$

$$t_{1/2} = \frac{0.693}{3.2 \text{ X } 10^{-2}\text{ day}^{-1}} = 22\text{ days}$$

Comparison of the half-lives for dispersive flux (approximately 20 days) with the half-life for the alongshore advection process (30 to 110 days) reveals that a water parcel in the coastal zone is more likely to be dispersively exchanged with central shelf water than to pass to Cape Seniavin. The pseudo-first-order rate constants can be linearly combined to indicate that the typical half-life or residence time of a water parcel in the coastal domain is 10 to 20 days.

The water balance for the coastal domain is completed by considering direct precipitation (P), evaporation (E), and runoff (R). Net precipitation (P-E) in the region is approximately 20 cm/year (Neumann and Pierson 1966), the surface of the study area is 5800 km^2, therefore, net precipitation contributes an estimated 0.003 km^3/day or less than 0.49% of the advective transport, and less than 0.1% of the dispersive exchange. In other words, the contribution of net precipitation is negligible.

Freshwater input to the NAS by runoff from the Alaska Peninsula and Unimak Island has been estimated. The estimate is based on the assumption that the streams of the peninsula yield the same amount of runoff per unit area as nearby gaged basins. For example, the Kvichak River at Igiugig yields 96 cm/year (511 m^3/s from a drainage area of 16,800 km^2), while Eskimo Creek at King Salmon yields 27 cm/year (0.4 m^3/s from a drainage area of 41.7 km^2). These observed yields are widely disparate and do not provide the basis for a reliable estimate of the yield of the Alaska Peninsula. Nonetheless the yield is probably between these two extreme values, and less than or approximately equal to 96 cm/year.

The portion of the Alaska Peninsula draining to the NAS coastal zone is approximately 8200 km^2. Therefore, the freshwater runoff from the area is less than, or approximately equal to, 0.02 km^3/year, it is apparent that runoff is an insignificant source of water to the coastal zone. This finding is intuitively reasonable in consideration of the fact that salinity is not markedly lower in the coastal zone than in the offshore regions of the shelf, nor is there a large reduction in salinity toward the northeast. This calculation should not be construed to imply that freshwater inputs are unimportant in the dynamics of the coastal zone, which may be influenced more by the buoyancy of the freshwater input than by the volumetric flow of the water.

To summarize this discussion, then, two major processes affect the residence time of water in the NAS coastal zone; cross-shelf exchange with central domain water and alongshore transport toward the northeast. Simple calculations suggest that water transported alongshore past Unimak Island is slightly more likely to cross the inner front into the central domain than to be transported in the coastal domain to Cape Seniavin. The necessary corollary to this conclusion is that most (60 to 80%) of the water moving alongshore at Cape Seniavin entered the coastal domain by dispersive exchange across the inner front between Unimak Island and Cape Seniavin. A secondary contributor to water passing Cape Seniavin in the coastal domain is water that came into the model domain by transport in the coastal zone past Unimak Island. Freshwater input by rain and runoff are minor contributors to this water mass.

The temperature of water in the coastal zone is thus determined by the temperature of these water masses, modified by thermal exchange with the atmosphere. Significant warming in summer and cooling in winter as one proceeds up the coast from the southwest has been observed in this, as well as earlier, studies. Schumacher and Moen (1983) present contour maps indicating that both the coastal zone waters off Unimak Island and the central domain water adjacent to the coastal zone had similar summer temperatures of about 8°C in 1980. In 1984, a slightly higher temperature of 8.5°C was observed in the coastal zone off Unimak Island, while the vertically averaged temperature at the 50-m isobath was somewhat lower than observed by Schumacher and Moen in 1980, at about 7.5°C. In either case, however, the average temperatures for the water masses contributing to flow at Cape Seniavin was approximately 8°C. The coastal zone waters at Cape Seniavin are significantly warmer in summer, between 9° and 10°C, implying a 1° to 2°C warming in summer during flow through the domain. Considering the flow and surface area of the domain, net surface heat flux of 30 to 60 calories per square centimeter per day (cal/cm^2/day) is inferred from observed warming, and the value is consistent with the regional climatology of Budyko (1956).

The temperature of coastal zone water entering the study area was approximately 3.2°C in February, 1981 (Schumacher and Moen 1983) and 4.0°C in January of 1985. Adjacent central shelf water appeared to be about 2°C in February of 1981, while 4.0°C was observed at the 50-m isobath in January, 1984. Water exiting the domain at Cape Seniavin in January of 1985 averaged about 3°C implying a cooling of about 1°C during transit for a loss to the atmosphere of about 30 cal/cm^2/day, which is somewhat less than would be expected. This result, in 1985 when offshore water was relatively warm, may be explained by the cross-shelf exchange process highlighted in the water mass balance discussion earlier in this section. The temperature of the central domain waters is less sensitive to surface cooling in winter since this heat loss is distributed through greater depths.

Observations from the Izembek Lagoon inlet and hydrographic transects in the coastal zone indicate that solar heating in the shallow water of the lagoon may be a significant process affecting the coastal zone, at least out to about the 20-m isobath. During the inlet survey the inlet temperature on the flood tide was about 3°C, while on the ebb the temperature rose to about 8°C. Air temperature averaged about 5°C at this time, so insolation was the predominant cause for this warming as the water resided in Izembek Lagoon. Considering the volume of the tidal prism, this net thermal input to the coastal zone could nearly account for the total warming observed at Cape Seniavin. Of course, a significant fraction of this heat is undoubtedly dissipated to the atmosphere rapidly since the tidal discharge from Izembek Lagoon during spring is stratified and stays near the surface, and the warmer-than-air temperatures promote heat losses to the atmosphere.

An important seasonal factor affecting temperature and salinity of the coastal zone, and the Bering Sea as a whole, is the winter ice sheet. These effects have been studied by several investigators. The extent and duration of ice cover is especially important in its effect on springtime temperatures, a critical period for the ecosystem of the coastal zone. Temperature variability and the effects of ice cover on that variability have been investigated for May and June. From 1953 to 1982, the temperature in the study area during May averaged 4.3°C and in June, 6.3°C (Ingraham 1981). The standard deviation in May was 1.8°C and in June 1.1°C. In other words, in one year out of ten one would expect the May temperature to exceed 6.6°C and the June temperature to exceed 7.7°C.

A significant factor affecting the variability in temperature is the extent and duration of ice cover. Ice extent statistics for the period 1973-74 to 1978-79 were reported by Niebauer (1983). During these six ice seasons, the observed May and June temperatures (Ingraham 1981) were inversely correlated with maximum extent of the ice sheet ($r = -0.54$ and -0.59, respectively). Regression equations were derived as follows:

$$T\ (\text{May}) = 7.3^{\circ}\text{C} - 0.053\ (\%\ \text{cover})$$

$$T\ (\text{June}) = 9.3^{\circ}\text{C} - 0.055\ (\%\ \text{cover})$$

where % cover is the percentage of the eastern Bering Sea (as defined by Niebauer) covered by ice at the maximum seasonal extent.

The percentage cover ranged from 42 to 76% during the 1973 to 1979 period. The regression equations reproduced observed May and June temperatures to within 1.3°C (standard error of prediction = 0.8°C). This represents a slight improvement over predicting that the observed temperature will be the long term average temperature. Such a prediction would have been accurate to within 1.6°C during 1974-79 (standard error of prediction = 1.3°C).

Although it has been demonstrated that runoff is insignificant to the overall water and salt balances of the NAS coastal zone, there are localized and seasonal effects of this runoff. The May 1984 hydrographic data clearly show a warm, low salinity water mass directly offshore of Izembek Lagoon out to the 20-m isobath. The average salinity in the study area at the 20-m isobath was approximately 31.2 $^{o}/_{oo}$ compared with 31.7 $^{o}/_{oo}$ at the 50-m isobath. Drogues released from Izembek Lagoon inlets rather consistently moved approximately 3 km offshore (near the 20-m isobath) soon after deployment. The effect of the lagoon, however, is not noticeable at the 50-m isobath and apparently does not result in transport across the inner front. The significance of runoff from the Alaska Peninsula suggests that the severity of the previous winter may affect nearshore temperature and salinity not only through the effect of the sea ice cover, but also through the amount of snowfall and timing of snowmelt in the mountains of the peninsula. This is illustrated by the more obvious effect of freshwater nearshore in 1984 (this study) than in 1981 (Schumacher and Moen 1983). Snowfall at Cold Bay in 1983-84 was nearly double the amount recorded in 1980-81.

The coastal domain has generally been characterized as homogeneous. The preceding discussion of the localized effects of runoff, however, suggests that there are some deviations to this, as well as other, characterizations. Schumacher and Moen (1983) clearly demonstrated the influence of the Kvichak River on inner Bristol Bay and suggested the numerous rivers along the Alaska Peninsula may contribute freshwater in quantities equal to those of the Kvichak River. Our 1984 findings, in particular, support this suggestion. This "line source" (so called by Schumacher and Moen 1983) of freshwater definitely influenced the hydrographic structure of nearshore water off Unimak Island, Moffet Point, and Cape Seniavin.

In addition to localized stratification resulting from runoff, large scale (i.e., covering the entire NAS study area as far landward as the 20-m isobath) vertical stratification was observed during July 1985. This non-local phenomenon could have resulted from an intrusion of the central domain into the NAS nearshore zone. This stratification was atypical for the summer season in the eastern Bering Sea when the coastal domain, with its well-mixed water, should extend to the 50-m isobath.

2.8 RECOMMENDED FURTHER RESEARCH

The first recommendation is to modify and expand the CTD hydrographic sampling grid and sample on at least a seasonal basis. Ideally the transects should extend from Unimak Pass up into Bristol Bay. One of the endpoints of these transects should be as close to shore as practical; the other endpoint should extend out beyond the 50-m isobath. This modification to the sampling grid would increase sensitivity to detecting the effects of the passage of water through Unimak Pass and confirm the limit of influence of the Kvichak River. Information on the effects of nearshore stratification and the location of the inner front will be enhanced by extending the transects shoreward and seaward. The location of this front and the processes occurring in and about the front are important not only to physical and chemical oceanographers, but to biologists as well. As an example, Hunt et al. (1981) discusses the importance of fronts on the pelagic distribution of marine birds, which in turn suggests the importance of these fronts to productivity.

The second recommendation is to establish year-round gaging and water quality stations at selected representative rivers along the Alaska Peninsula. Ideally, precipitation should also be measured at some point within each river's drainage basin. A minimum of four stations would be required to begin quantifying the effects of runoff on the NAS nearshore environment. Additional streams that remain ungaged should still be monitored sporadically for water quality. Total discharge for these streams may be estimated using drainage basin areas and precipitation data from nearby rain gages. The minimum water quality parameters to be measured should include: conductivity, temperature, pH, color turbidity, nitrates, nitrites, phosphates (total and dissolved), silicates, and total organic carbon.

Because meteorological length scales are short, the third recommendation would be the installation of several remote meteorological stations along the Alaska Peninsula and, if none exists, one on Amak Island. These stations as a minimum should record wind speed and direction, air temperature, and precipitation. Barometric pressure, although not as variable over tens of kilometers, should be measured at selected stations. These meteorological stations would be augmented by the rain gages discussed previously.

Finally, the fourth recommendation would be to conduct additional current studies using multi-depth current meter arrays and, given the poor visibility in the Bering Sea, telemetering drogues. These studies, concentrating on either side of and in the inner front zone, would contribute significantly to our understanding of cross-front transport of water, nutrients, and plankton. Armstrong (1986) in a personal communication indicated that the fate of king crab larvae (and, hence, the fishery) may hinge on the movement of larvae into or out of the NAS nearshore zone. More detailed current studies would also provide valuable information for numerical modeling should it be required.

2.9 ACKNOWLEDGEMENTS

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2.11 APPENDIX

The appendix material for this section was too extensive for publication as part of this volume. It is retained as unpublished information by NOS/OMA/OAD, Alaska Office. It is filed under the authorship, title, and date for this report. It contains the following sections:

Meteorology - 27 pages
Tides - 2 pages
Currents - 26 pages
Lagoonal Influence - 9 pages
Hydrography - 367 pages

Section 3

PRIMARY PRODUCTION, CARBON ENERGETICS, AND NUTRIENT CYCLING

by

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Section 3

PRIMARY PRODUCTION, CARBON ENERGETICS, AND NUTRIENT CYCLING

3.1 SUMMARY

This project seeks to describe the nutrient dynamics, primary productivity and trophic energetics of the nearshore waters of the NAS. Through consideration of the availability of nutrients and the consequent primary productivity, the carbon derived from in situ primary producers has been quantified and compared with that derived from allochthonous sources, in this case, the extensive eelgrass (Zostera marina) beds in Izembek Lagoon. We used natural abundances of radiocarbon isotopes as indicators of primary production by phytoplankton in upwelled waters and abundances of stable carbon isotopes as tracers of eelgrass carbon in the coastal food webs.

Our results confirm that the deep-mixing and advection of nutrient-rich waters onto the shelf in the vicinity of Unimak Pass subsequently produces very high rates of primary productivity over much of the study area during the spring and summer seasons. Vertical mixing in the region of the inner frontal system separating the coastal and middle shelf domains produces water columns rich in nutrients. Nitrate-N concentrations were often in excess of 5 mg-atoms/m^3 in the euphotic zone with the exception of apparent nutrient depleted water sampled throughout the study area in July. Integrated water column productivities were high, with the fastest rate being 6.7 gC/m^2-day. The annual productivity in the study area is about 220-240 gC/m^2-yr although our temporal coverage is not sufficient for confident estimates.

In spite of the extensive Zostera beds in Izembek Lagoon, the role of eelgrass in the food web energetics of the nearshore zone appears to be minimal. The stable isotope data indicate that in situ phytoplankton production supplies nearly all carbon in the nearshore food web. Our estimates of primary productivity by phytoplankton also indicate that the in situ inputs of carbon to the inner shelf waters exceed that derived from eelgrass by about three-fold inside the 50-m contour near Izembek Lagoon. Although eelgrass has the potential to contribute a substantial amount of energy to the food web, the conversion of detrital eelgrass to animal biomass may proceed through a microbial-meiofaunal pathway, and the conversion efficiency losses in the trophic steps alone might account for the lack of eelgrass carbon in higher levels.

3.2 INTRODUCTION AND CURRENT STATE OF KNOWLEDGE

The southeastern Bering Sea is one of the most biologically productive regions of the world oceans and has been the focus of several studies concerned with its abundant marine resources. These studies have been updated in Hood and Calder (1981) and the physical and biological processes have been most recently studied in the NSF-sponsored PROBES (1982) (Processes and Resources of the Bering Sea Shelf) and the current ISHTAR (Inner Shelf Transfer and Recycling) programs. This study seeks to build upon the database accumulated for the more offshore region and extend the information to include the waters inside of the 50-m contour to the beach. In some aspects, the nearshore zone is easier to describe: the stratified water types and structures described by Dodimead et al. (1963) and Kinder and Schumacher (1981) for the middle and outer shelf "domains" usually lie outside of the 50-m contour and the tidal and wind-mixing of the water nearshore leads to uniform vertical structure. Exceptions to this occur during early spring when runoff and/or coastal current inputs, such as the Kenai Current, can result in transitory stratification (Schumacher and Moen 1983). Phytoplankton respond to water column nutrient supply on a short time scale and depletion of nutrients can occur within a few days. Replenishment of nutrients recurs through periodic mixing in the frontal systems and active phytoplankton growth at rates typical of bloom conditions can be seen at any time during the summer months (Sambrotto 1983). Tidally driven mixing is the mechanism responsible for the vertical movement in the coastal domain in the Bering and the overall hydrographic environment is similar to situations found in the northeastern Atlantic (Pingree et al. 1978).

The plant biomass resulting from uptake of nutrients in the southeastern Bering Sea water column is transferred to higher trophic levels via two distinct pathways (Walsh and McRoy 1985). The efficiently grazed outer domain is closely coupled, supporting a large pelagic community. The middle and coastal domains are much less efficiently grazed and much of the early spring bloom sinks to the seafloor. This contributes to the high secondary productivity of the benthos and demersal fishes in the middle and coastal domains.

On the NAS, especially in the vicinity of Izembek Lagoon and Port Moller, the extensive beds of eelgrass contribute large quantities of detrital carbon to the ecosystem. Barsdate et al. (1974) estimated that 1.66×10^8 kg/yr of eelgrass carbon was exported from Izembek Lagoon in the fall and the ubiquitous patches of eelgrass on the sea surface near Izembek Lagoon show that the process is active throughout the year. McConnaughey (1978) sought to determine the importance of eelgrass to benthic detrital consumers within the lagoon through the use of stable carbon isotope abundances in eelgrass, consumers, and phytoplankton. Although the presence of eelgrass carbon was evident in the composition of some lagoon fauna, no information was obtained on its importance to organisms outside of the lagoon.

The overall goal of this project was to describe the processes supplying nutrients to nearshore NAS waters, estimate the resulting phytoplankton production, and contrast this in situ carbon source to the importance of the allochthonous carbon inputs from eelgrass as energy sources to the nearshore food web.

Our specific objectives were to:

1. Measure ambient nutrient concentrations in the nearshore water column both temporally and spatially throughout the study area.
2. Conduct primary productivity measurements in the euphotic zone and obtain seasonal estimates of in situ carbon fixation in the nearshore waters.
3. Compare in situ primary productivity with estimates of eelgrass carbon fluxes from Izembek Lagoon to nearshore waters.
4. Collect specimens of nearshore water column and benthic fauna for isotopic analysis of radiocarbon content and $^{13}C/^{12}C$ ratios. This information was used to determine if phytoplankton production is the major source of energy and if eelgrass transport from the lagoon is also important as a carbon source. This information also offers insight into

the importance of deep mixing and upwelling to the nutrient supply of the coastal zone.

3.3 METHODS

3.3.1 Chlorophyll Concentrations

Water samples obtained from Niskin bottles were filtered on Gelman Type A/E 47 mm glass fiber filters with a few drops of $MgCO_3$ suspension added as a preservative. The filters were folded in half and placed in glassine envelopes. The filters were then frozen until pigment extraction was done in Fairbanks. The extraction and chlorophyll-a calculation procedures were from Strickland and Parsons (1972), and the phaeopigment calculations were from Lorenzen (1966). Chlorophyll-a and phaeopigments were measured on a Turner Designs Fluorometer (Model 10-005). For chlorophyll-a determinations, the fluorometer was periodically calibrated against a Bausch and Lomb Spectronic 2000 spectrophotometer.

Primary Production

Carbon fixation was measured at each station on the primary transects along the coast (Fig. 3.0). Light intensity profiles were obtained with a Li-cor photometer to obtain photic depths to the 1.0% light level. Water samples were then obtained from the CTD rosette at depths corresponding to the 100, 50, 25, 10, and 1% light levels. Two clear 250-ml glass bottles and one dark bottle (for non-photosynthetic uptake corrections) were filled from each sample. Each bottle was injected with 2 microcuries of ^{14}C-labelled sodium bicarbonate. All transfers and inoculations were carried out in subdued light. The bottles were then placed in an on-deck incubator cooled with flowing seawater and fitted with neutral density screens to approximate 50, 25, 10 and 1% of incident solar radiation. Incubations were 4-6 hours long and were started in early morning to minimize diurnal variations in carbon fixation rates. After incubation, samples were filtered (in subdued light) onto 25-mm Millipore filters, dessicated, and stored in airtight containers. When ready to be counted, samples were treated according to the standard procedure described in

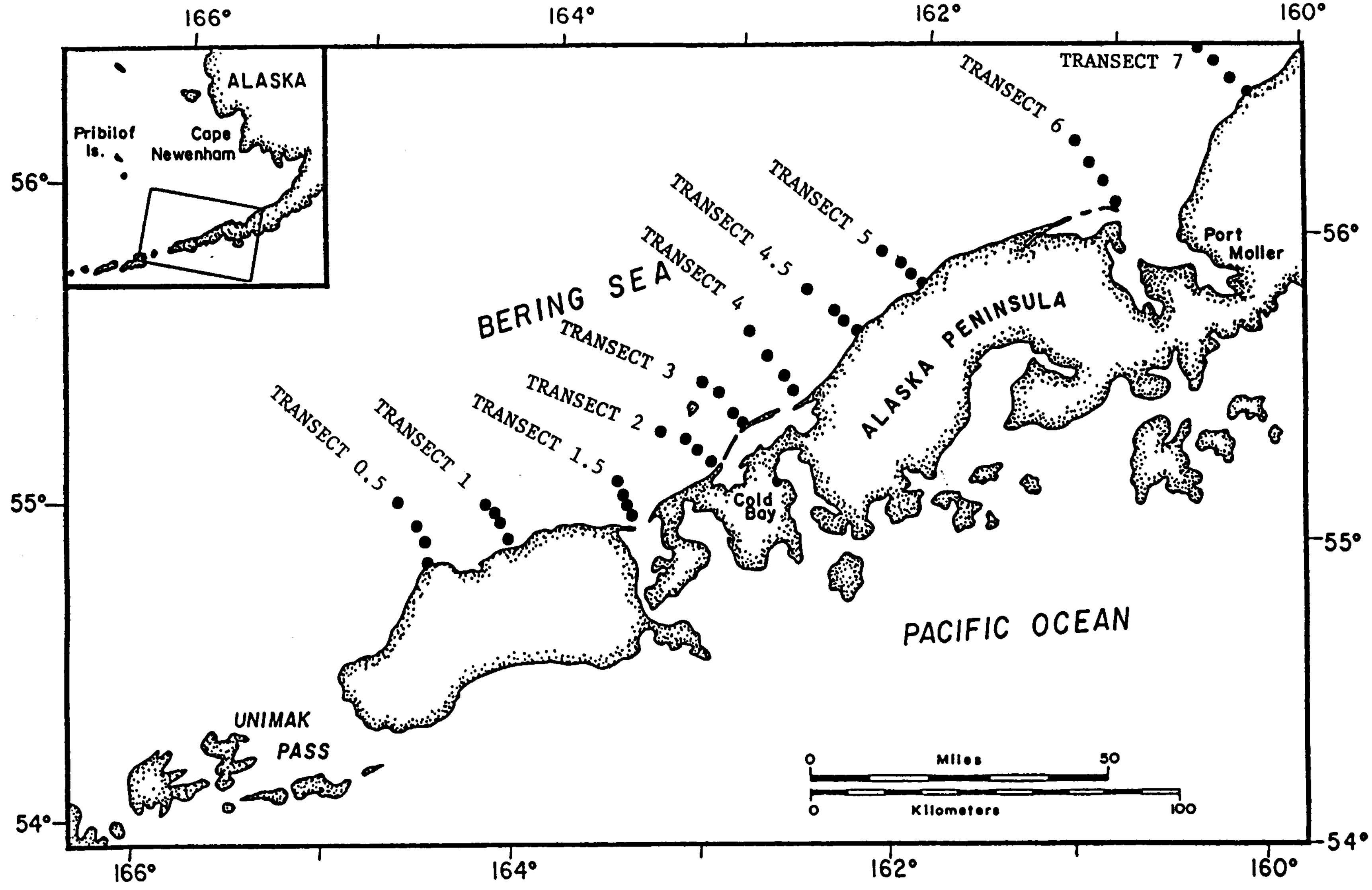


Fig. 3.0. Location of transects and stations on the NAS, Alaska, where data on nutrients and primary productivity were collected.

Strickland and Parsons (1972). Incorporated radiocarbon was determined with either a Beckman 7400 or Beckman 5801 Liquid Scintillation Counter.

Instantaneous primary productivity rates were extrapolated to daily fixation rates by multiplying by the integrated light intensities and average monthly day lengths. The seasonal estimates were obtained from extrapolations made with our data when available and the data obtained by PROBES (1982) when we had no comparable temporal equivalents.

3.3.2 Nutrient Concentrations

Water samples were obtained from the water column, filtered through Gelman A/E filters to remove particulates, transferred to 250-ml bottles, and immediately frozen. After returning to Fairbanks, these samples were analyzed for nitrate, phosphate, silicate, and ammonia concentrations using standard methods (Strickland and Parsons 1972) adapted to a Technicon Autoanalyzer. Quality assurance was maintained through the collection of random replicate samples while on station, the use of internal standards on composite samples in the laboratory and the analysis of replicates from each bottle.

3.3.3 Carbon Isotope Analyses

Samples of fishes and benthic invertebrates for isotopic analysis were collected directly from try-net or Marinovich trawls. Some benthic samples were collected using a rock dredge. A shotgun was used to obtain birds to collect breast muscle tissue. Plankton samples were collected with 333-micron bongo nets and sorted to obtain the animals of interest. Phytoplankton samples were also collected with a 333-micron bongo net and were cleaned of animals. All specimens for isotope analysis were frozen until ready to be processed.

Samples were prepared for combustion by soaking in 10% HCl solution to remove carbonates, rinsed with distilled water, dried at 50°C, and then ground to a fine powder with a mortar and pestle. In cases where organisms were very small, several animals were combined and ground together. Subsamples of the ground organisms (10-15 mg) were mixed intimately with powdered CuO and sealed into a glass tube while under high vacuum. The tubes were combusted for 2 hours at 570°C to convert the organic carbon to carbon dioxide. The gas was then cryogenically purified to remove water, sulfur dioxide and nitrogen and resealed into a glass tube. The purified carbon dioxide was then analyzed on a VG Isotopes SIRA-9 mass spectrometer. These ratios are reported as del ^{13}C relative to the PDB standard where:

$$\text{del } ^{13}C = \{[(^{13}C/^{12}C_{sample})/(^{13}C/^{12}C_{stand})] - 1\} \times 10^3.$$

Radiocarbon analyses were performed on selected samples where five grams of carbon were available for precision counting. Samples were collected and bagged immediately after bringing the trawls on board since the presence of artificial ^{14}C in the primary productivity studies presented a contamination hazard. Samples were processed in Fairbanks in a radiocarbon free lab where muscle tissue was excised from larger fish and whole specimens were used in the case of smaller animals. When necessary, samples were soaked in 10% HCl to remove carbonates. Samples were then dried under vacuum at 80°C. Dissolved inorganic carbon was obtained from the water column by stripping acidified seawater in 100 liter barrels onboard the ship and collecting the liberated carbon dioxide in 4N sodium hydroxide in a set-up similar to that used by Nydal et al. (1980). All radiocarbon analyses were performed by Beta Analytic Inc., a commercial laboratory specializing in radiocarbon determinations.

3.4 RESULTS AND DISCUSSION

3.4.1 Primary Productivity and Nutrient Dynamics

Nutrient supply processes and consequent primary production on the NAS are complex and subject to wide variations in magnitude. The advection of nutrient-rich Pacific Ocean/Bering Sea deep water onto the shelf in the vicinity of Unimak Pass is followed by intense primary production as the water moves northeastward. Since nitrate supply to the euphotic zone represents the basis for the "new" productivity of each summer season (Dugdale and Goering 1967), we have focused on its supply and consumption in the analysis of our data. In addition, the much more detailed work of Sambrotto (1983) on the uptake of inorganic nitrogen at the PROBES station line near our study area presents a good basis for comparative interpretation. Many of the same phenomena observed by the PROBES investigators are evident in our work and allow extrapolation of productivity estimates for periods in which we have no data.

Nitrate concentrations are often as high as 10 mmoles/m^3 in surface water near Unimak Island but biological consumption reduces the concentrations to levels limiting to phyplankton growth by midsummer. Figures 3.1 to 3.12 illustrate the variations in nitrate concentrations and the increases in chlorophyll that become evident with the progression of the spring bloom. Northeast toward Bristol Bay the water column is much more depleted in nutrients during the spring and fall. Apparently the replenishment of the nitrate may not be as effective toward the northeast over the winter due to the greater cross-shelf distances. Concentrations at Transect 6 were lower than at Transects 1 and 4 in January and April. By early April the maximum amount of deep mixing has occurred and the concentrations of nitrate present in the surface waters are the highest in the annual cycle. The onset of the spring bloom was evident in the chlorophyll concentrations found at Transect 6 in April and assimilation reduces the surface nitrate available to less than 1.0 micromolar by midsummer over the study area. In contrast, a July station in Unimak Pass had surface nitrate concentrations greater than 8 micromolar, indicating effective mixing by through-pass turbulence. Also evident for much of the summer season was a zone of low salinity in the nearshore waters along the beach (see ESE, this report). This zone persists throughout much of the year and appears to establish a variable frontal system shoreward of the "inner" front, which is typically further seaward than our study area.

Although the nutrients are depleted to near zero in the euphotic zone during midsummer, the primary productivity rates remain high, with individual values as high as 2.6 gC/m^2-day during July. The summer rates are sustained by periodic inputs of deeper water nutrients, and contribute significantly to the high annual primary production. Our estimates of annual production are based on our seasonal determinations of primary productivity (Fig. 3.13) and extrapolation from PROBES data (1982) during periods when we had no comparable temporal equivalents. We conclude that

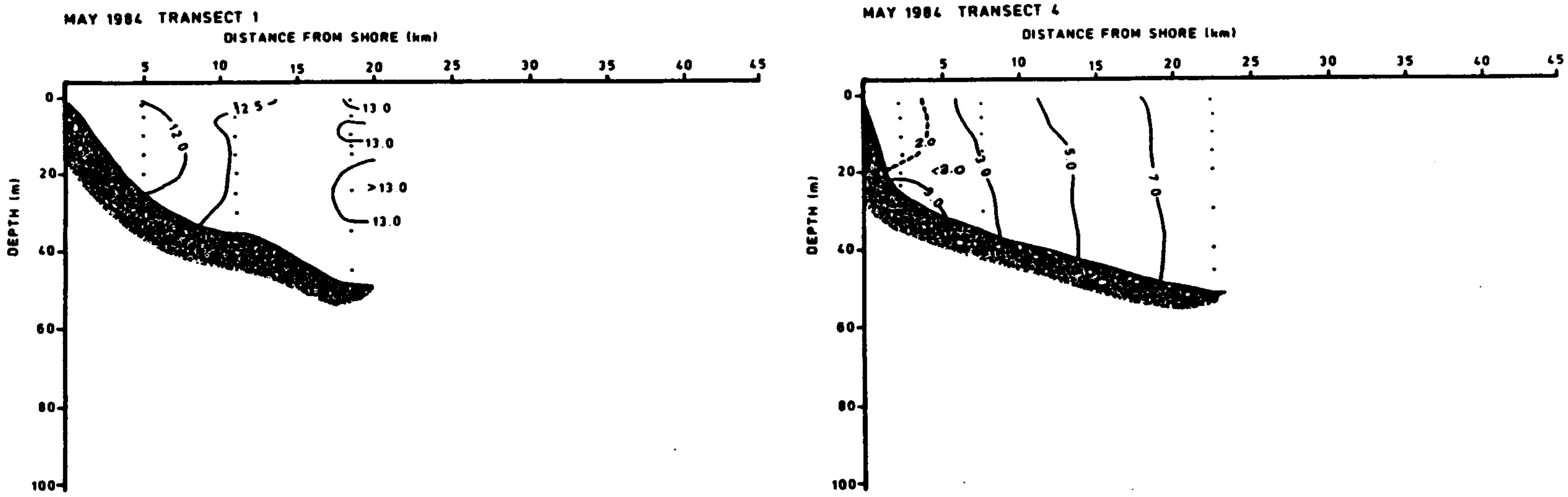


Fig. 3.1. May 1984 nitrate concentrations (uM). Stations are indicated with letters above the x-axis. Data from transects in the NE end of the study area are not contoured as not enough stations were sampled. At both Transects 6 and 7, nitrate concentrations were less than 1.0 uM at all depths.

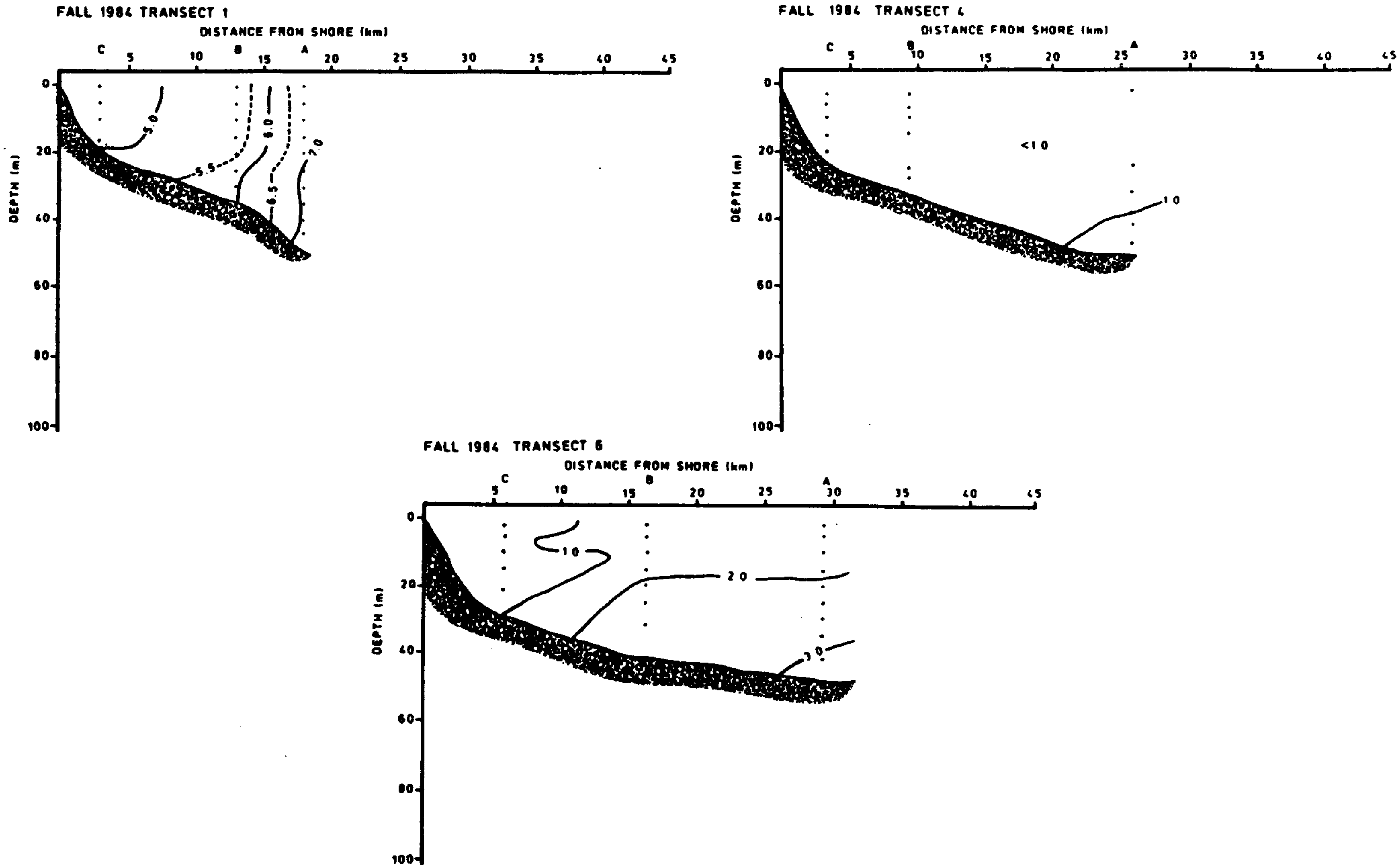


Fig. 3.2. Fall 1984 nitrate concentrations (uM). Stations are indicated with letters above the x-axis.

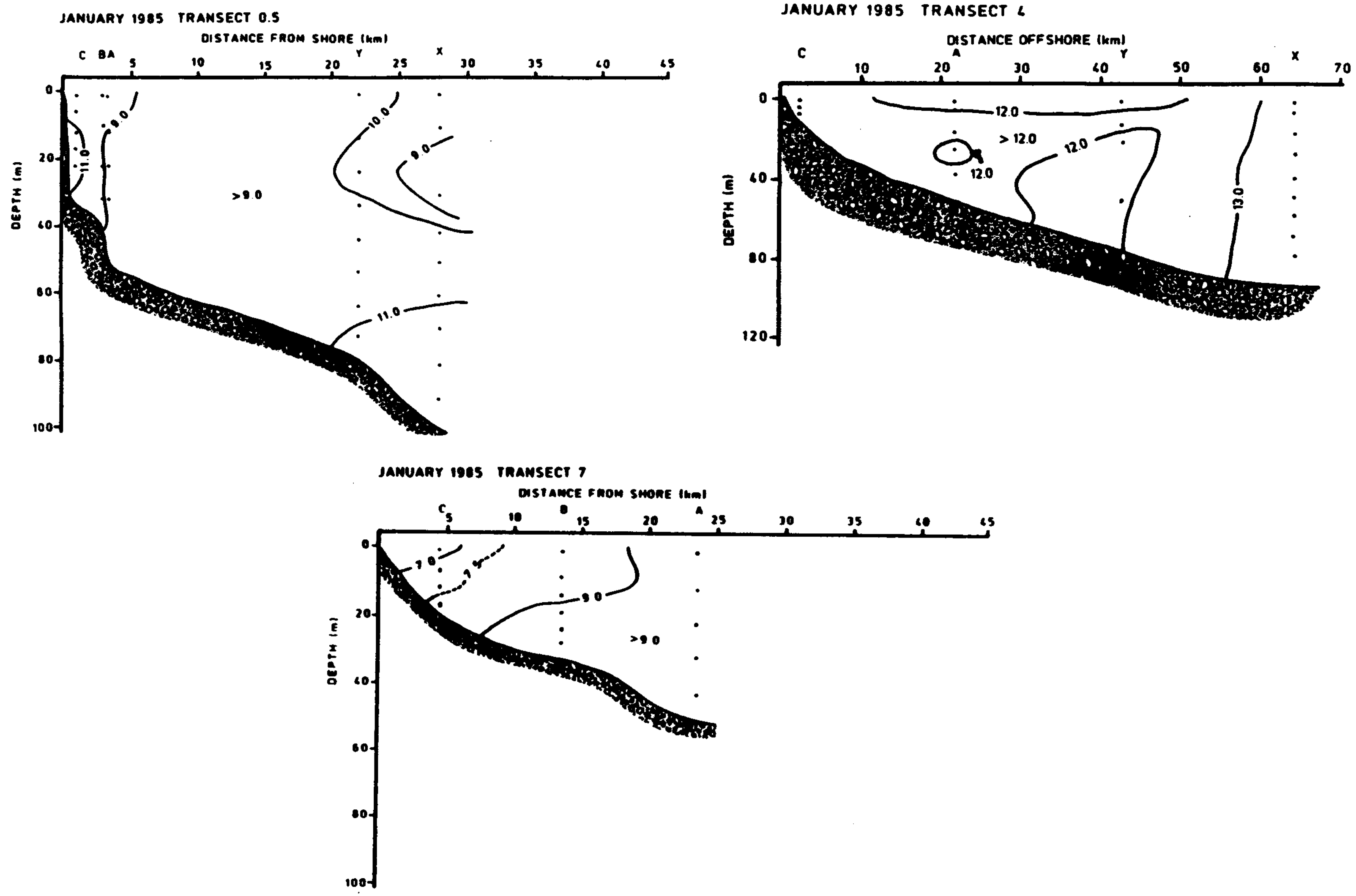


Fig. 3.3. January 1985 nitrate concentrations (uM). Stations are indicated with letters above the x-axis.

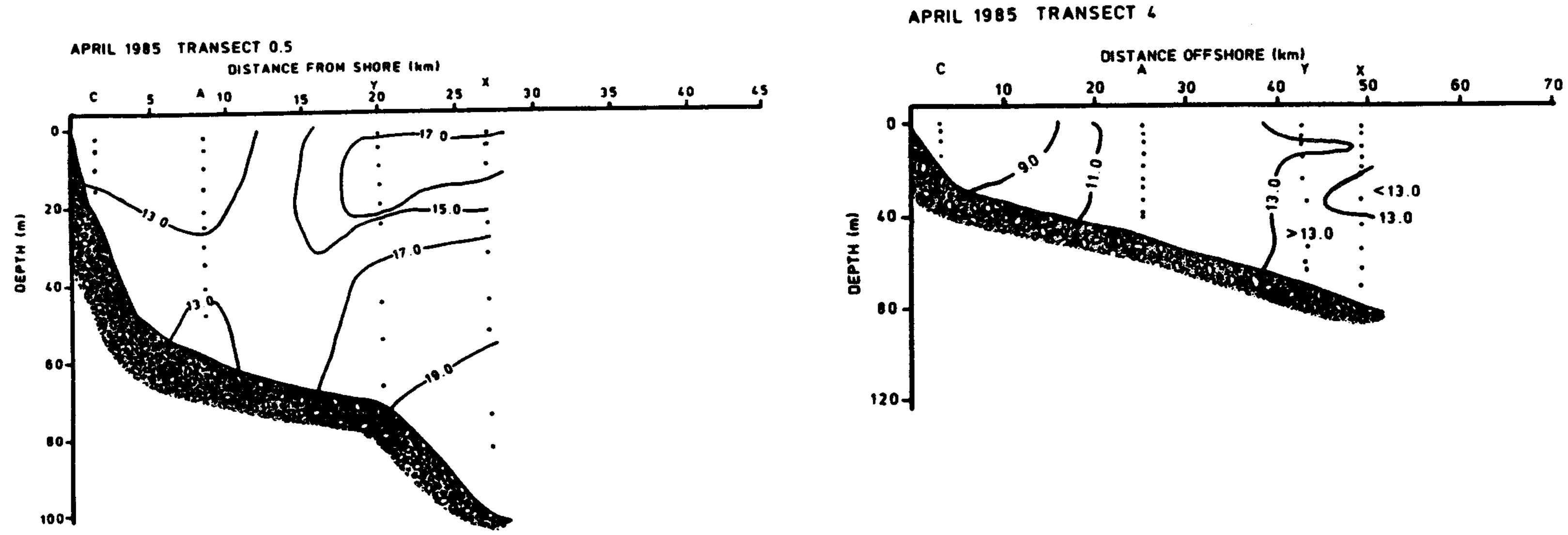
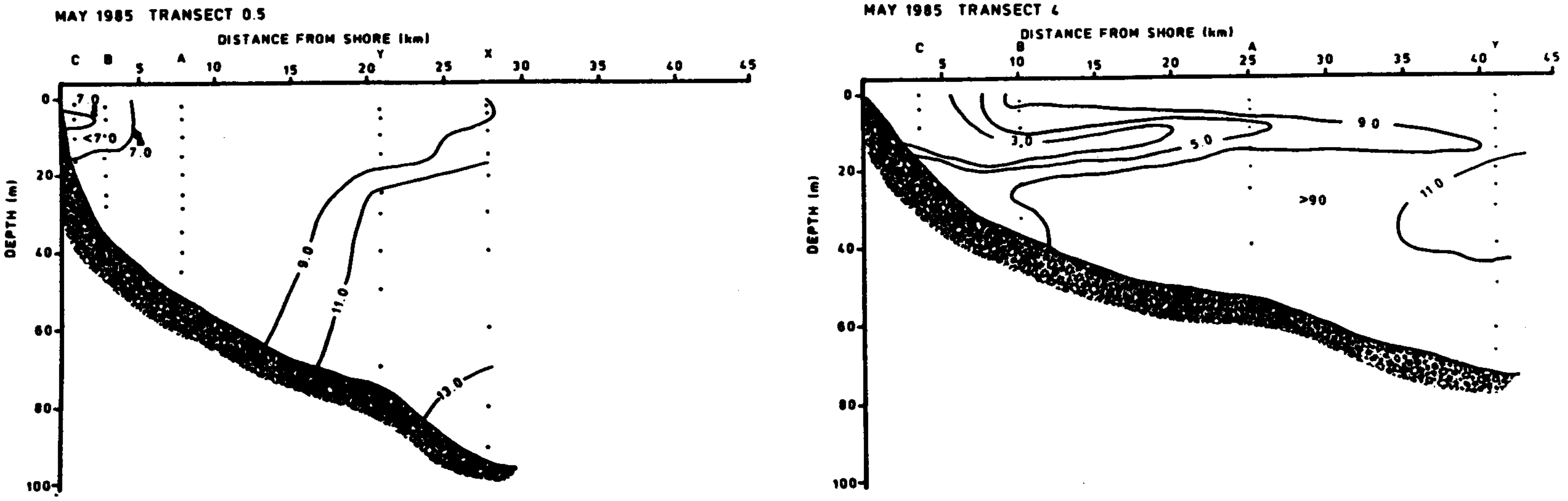


Fig. 3.4. April 1985 nitrate concentrations (uM). Stations are indicated with letters above the x-axis. Transects from the NE end of the study area are not included as not enough stations were sampled. At Transect 6, Station A, all nitrate concentrations were greater than 5 uM while at Station C all concentrations were less than 1 uM.



MAY 1985 TRANSECT 0.5

MAY 1985 TRANSECT 4

Fig. 3.5. May 1985 nitrate concentrations (uM). Stations are indicated with letters above the x-axis. Transects from the NE end of the study area are not contoured as not enough stations were sampled. At Transect 6, Station C, the concentrations were reduced to zero at all depths. At Station A the concentrations were greater than 3.7 uM at all depths.

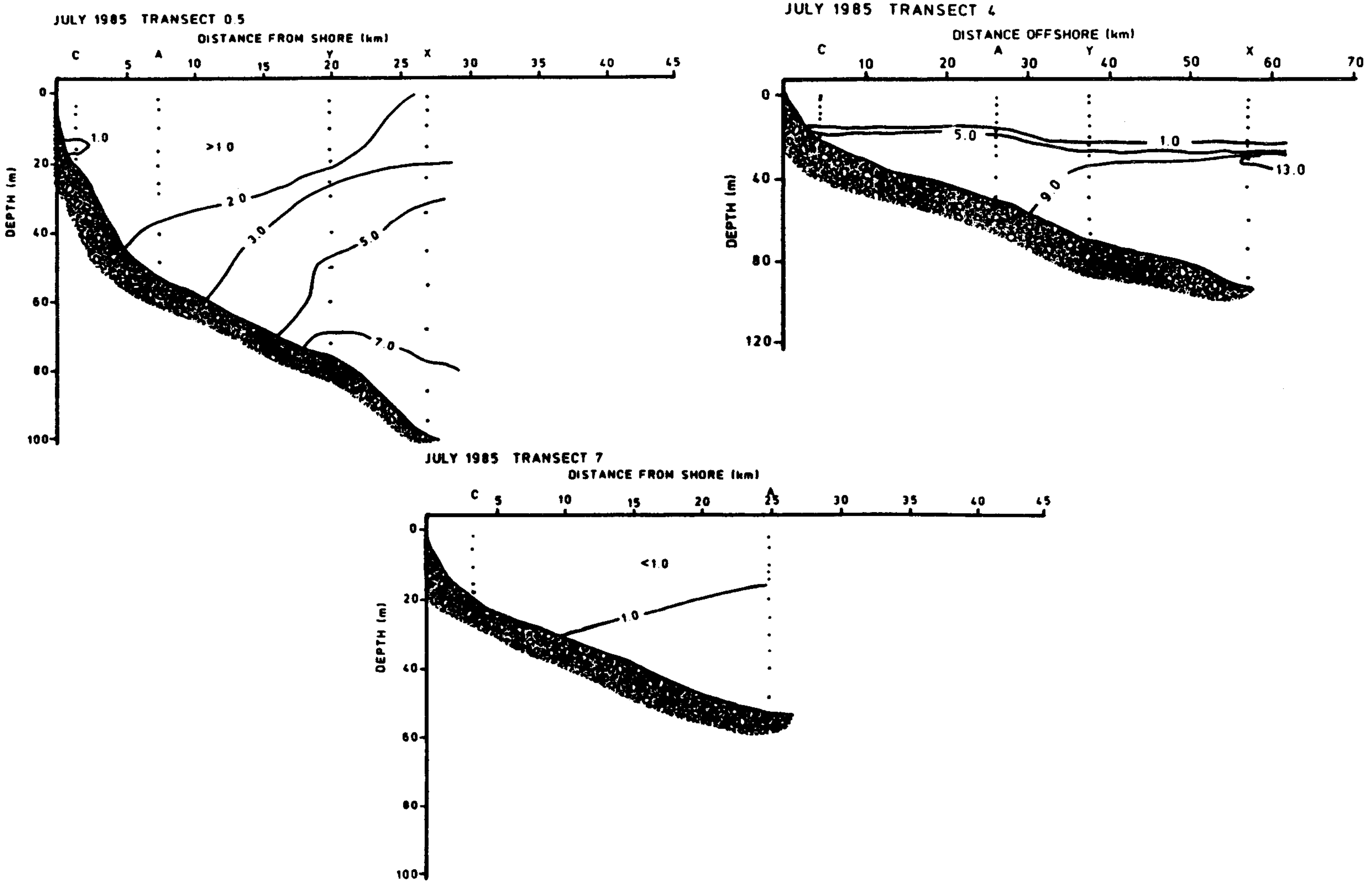


Fig. 3.6. July 1985 nitrate concentrations (uM). Stations are indicated with letters above the x-axis.

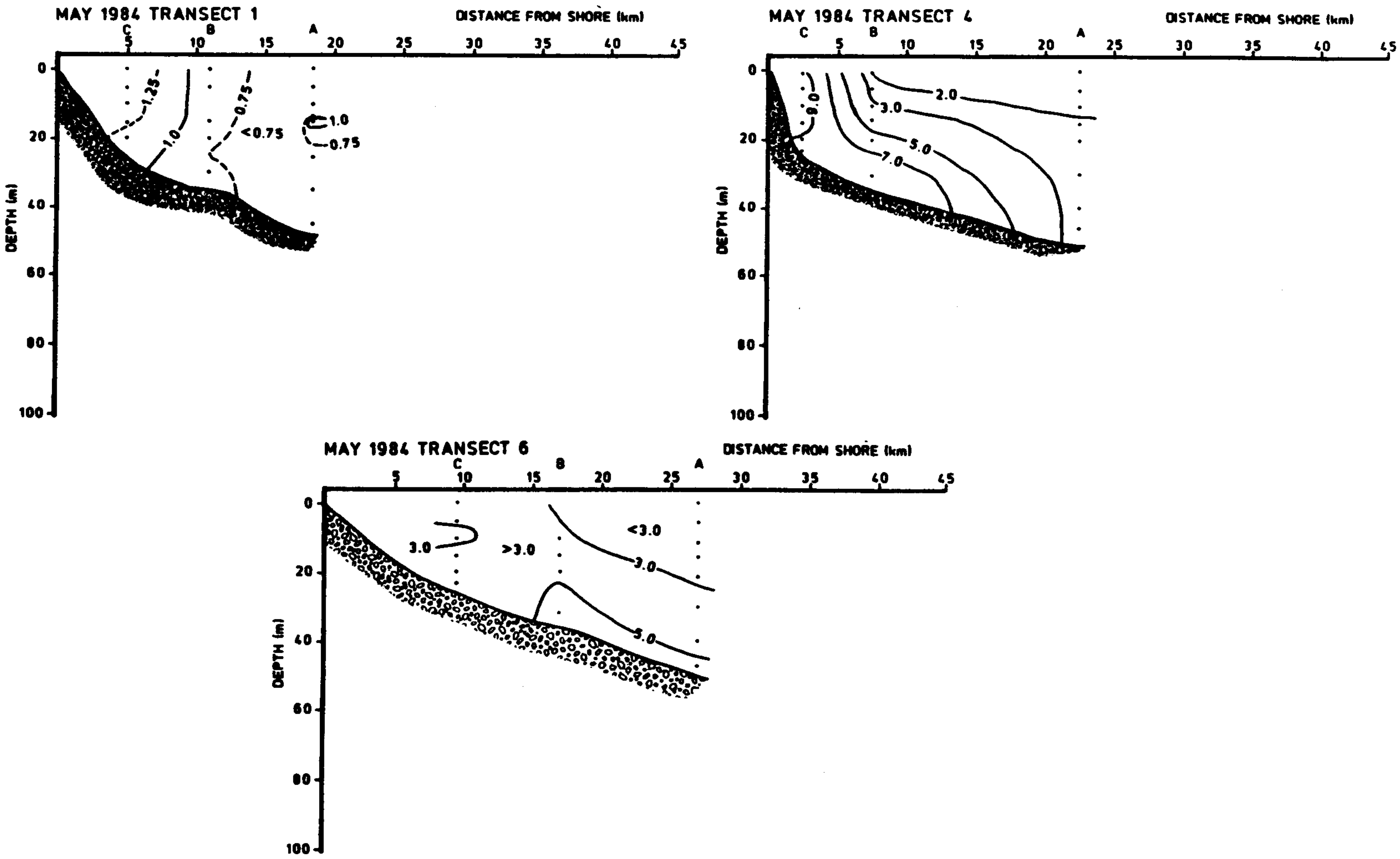


Fig. 3.7. May 1984 chlorophyll-a concentrations (mg/m^3). Stations are indicated with letters above the x-axis.

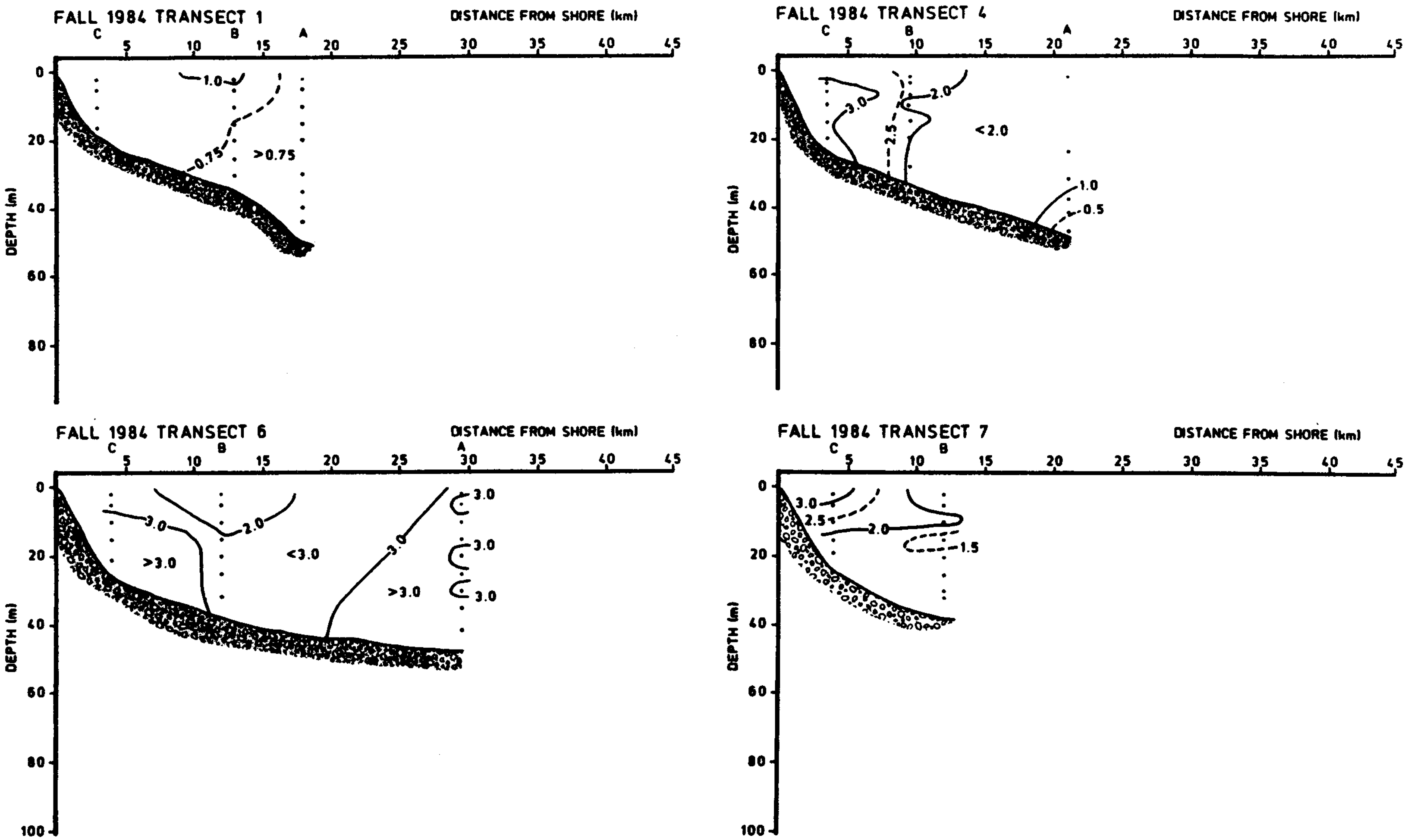


Fig. 3.8. Fall 1984 chlorophyll-a concentrations (mg/m^3). Stations are indicated with letters above the x-axis.

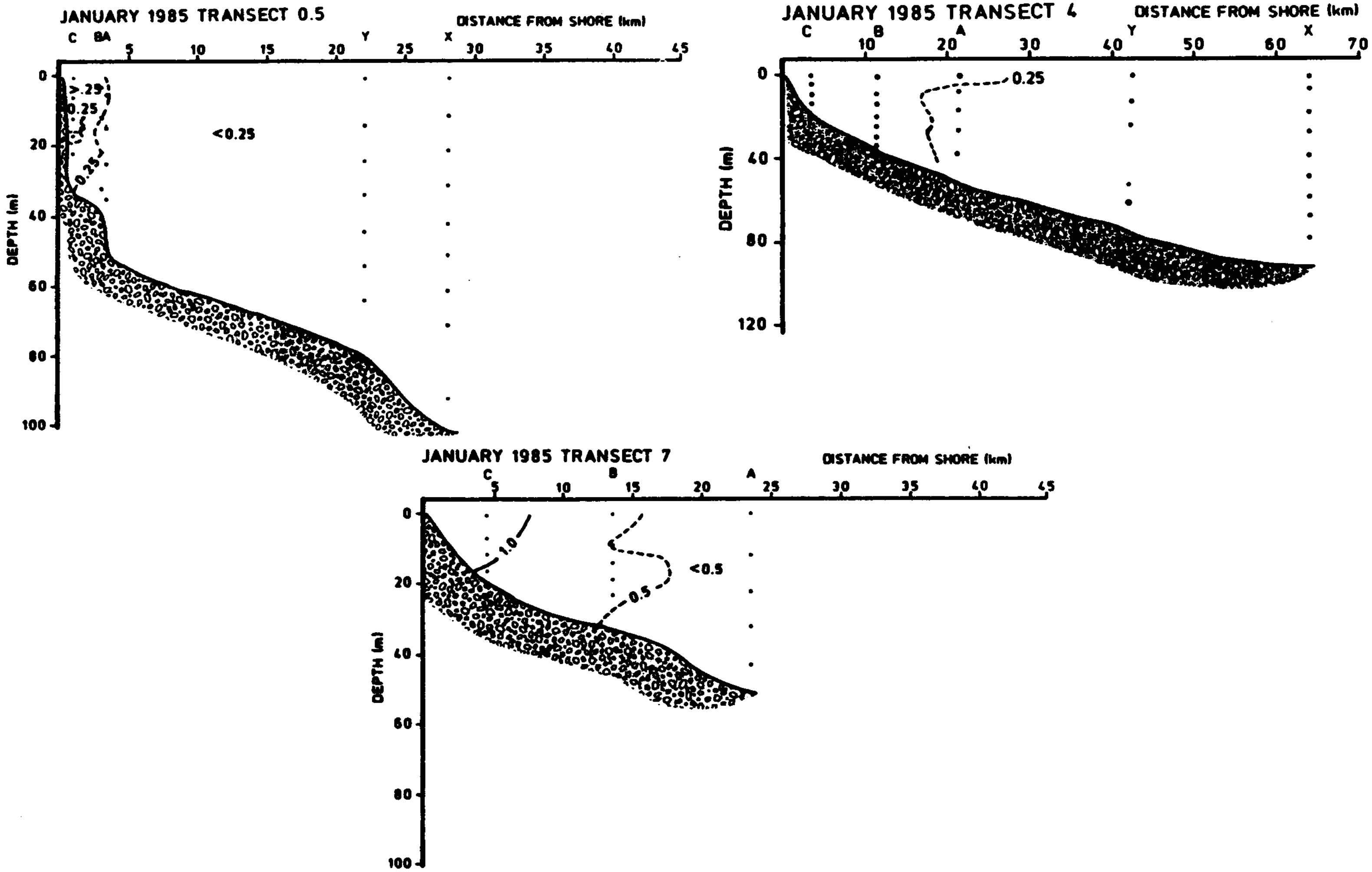


Fig. 3.9. January 1985 chlorophyll-a concentrations (mg/m^3). Stations are indicated with letters above the x-axis.

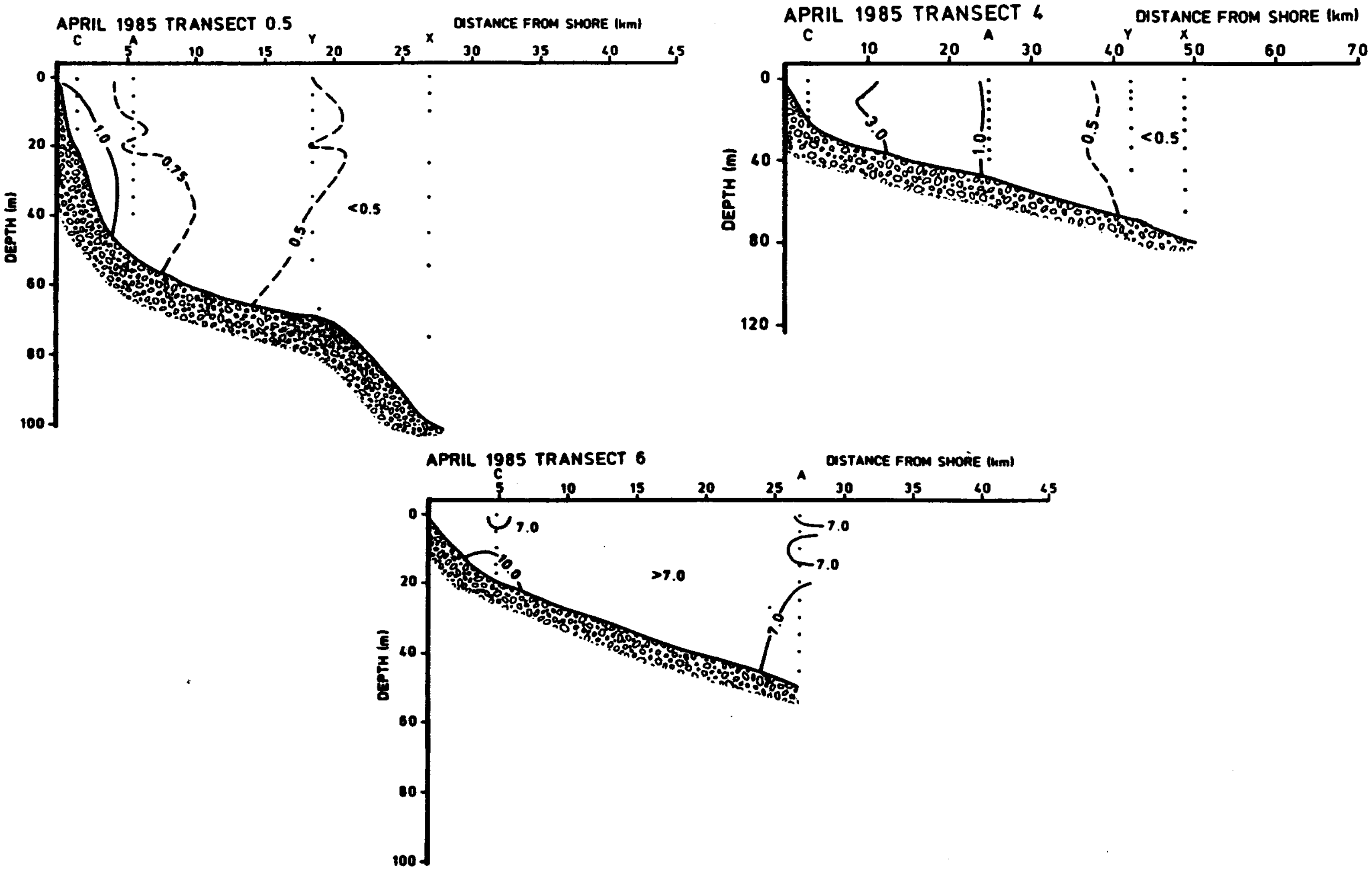


Fig. 3.10. April 1985 chlorophyll-a concentrations (mg/m^3). Stations are indicated with letters above the x-axis.

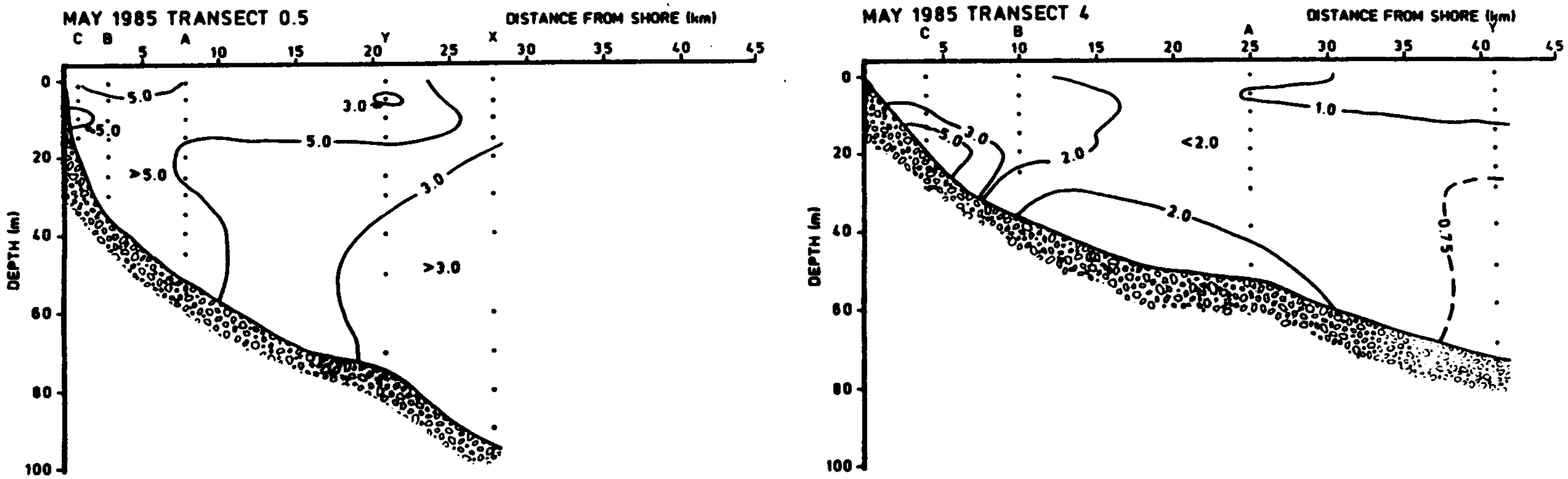


Fig. 3.11. May 1985 chlorophyll-a concentrations (mg/m^3). Stations are indicated with letters above the x-axis. Data from transects in the NE end of the study area were not contoured as not enough stations were sampled. At Transects 5 and 6 the chlorophyll-a concentrations were all higher than 4 mg/m^3 in the photic zone, and were as high as 12.7 mg/m^3.

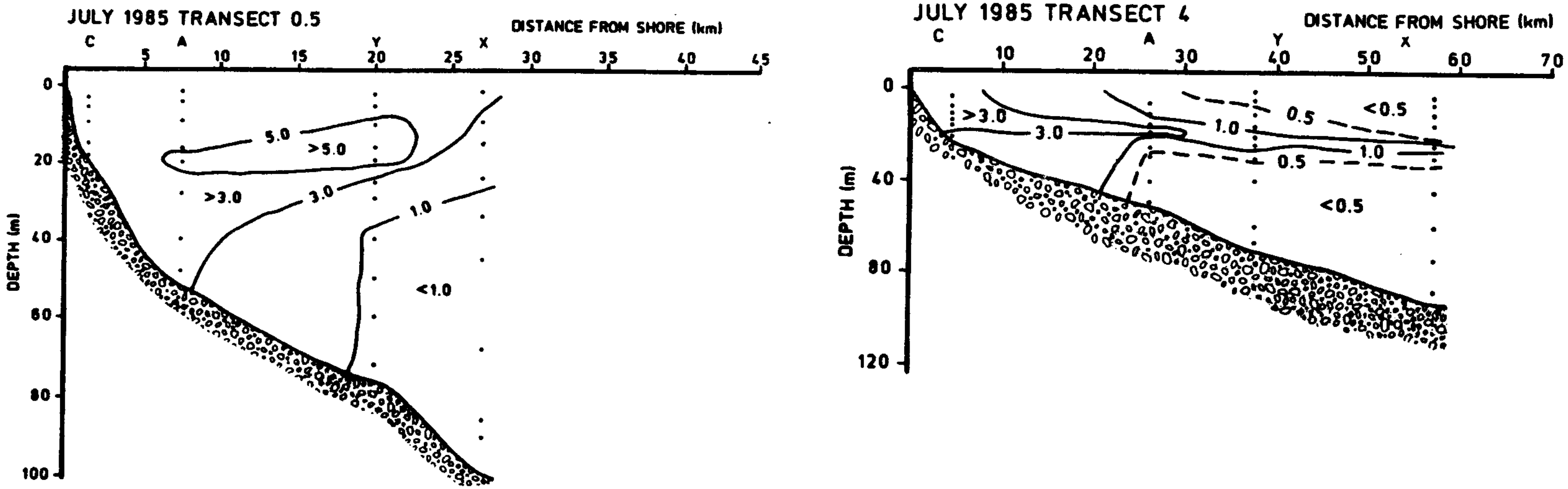


Fig. 3.12. July 1985 chlorophyll-*a* concentrations (mg/m^3). Stations are indicated with letters above the x-axis. Transects in the NE end of the study area are not contoured as not enough stations were sampled. At both Transects 6 and 7 the chlorophyll-*a* concentrations were less than 1 mg/m^3 Station A and greater than 1 mg/m^3 at Station C.

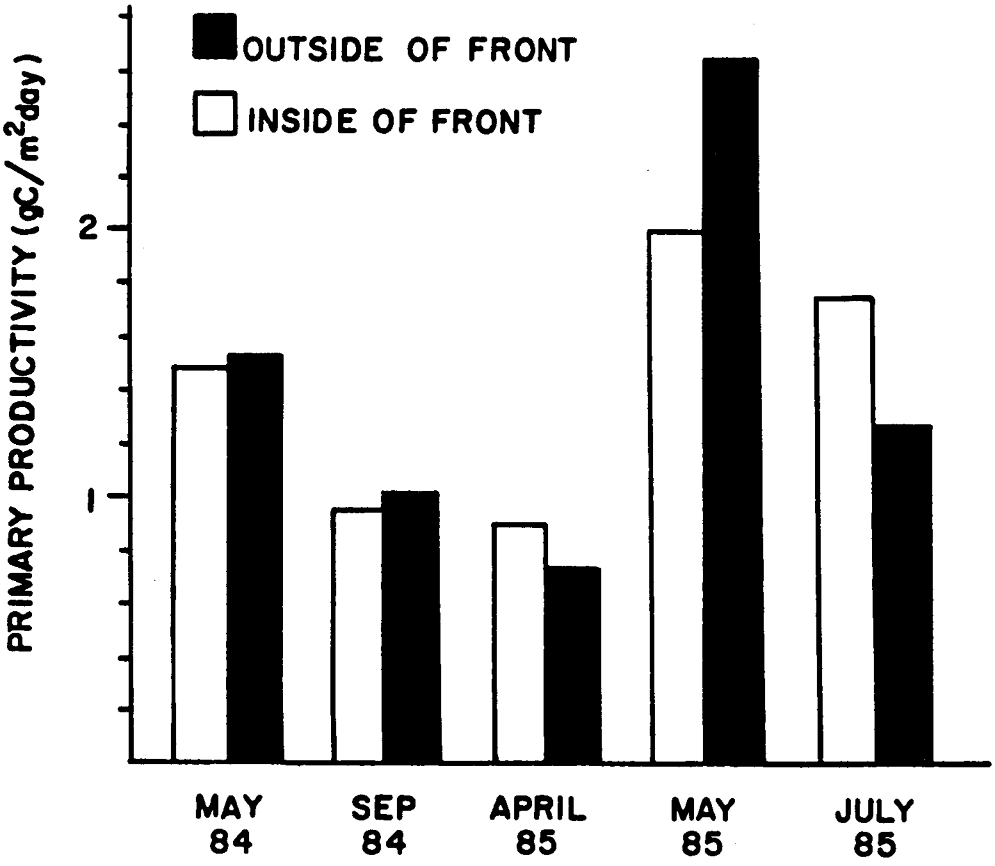


Figure 3.13. Primary productivity over the seasonal cycle during an ice-free year. Productivities are integrated for the water columns shoreward and seaward of the nearshore low salinity boundary.

carbon fixation amounts to 220-240 gC/m^2-yr in the study area. This is higher than the estimate by Sambrotto (1983) of 188 gC/m^2-yr based on nitrogen uptake for the PROBES area further offshore, but similar to the estimate communicated to him by Iverson based on the ^{14}C method. Also similar to the PROBES data are our findings that the seasonal maximum productivity occurs in late spring. One measurement of over 6.7 gC/m^2-day at Transect 4, Station C on 14 May 1984 is among the maximum rates observed anywhere in the world oceans and approaches the high fixation rates of the dense *Zostera* beds of Izembek Lagoon. Although the chlorophyll data and the nutrient concentrations often show marked changes and pronounced structure in moving offshore, these differences are not reflected in our measurements of primary productivity. When we compared productivity rates of waters shoreward of the lowered salinity boundaries with rates offshore we found no significant difference. Indeed, given the variability and uncertainties in the techniques for measuring primary production, no significant difference (see Fig. 3.13) is noted in moving either up the coast or perpendicular to it within the study area. The differences undoubtedly do exist but the temporal and spatial coverage does not allow a quantitative statement on the possible magnitude of the variation.

The water column productivity within the lagoon is sometimes a significant fraction of the eelgrass productivity, but only during high tides. During the remaining time eelgrass production greatly exceeds that by phytoplankton. But the inefficiencies in the trophic transfer of eelgrass carbon to higher levels result in generally lower secondary and tertiary productivities in the lagoon than in waters outside (excluding some birds and crabs which feed directly on eelgrass). This premise is substantiated by the stable carbon isotope data on the fauna collected from both within the lagoon and immediately outside.

The eelgrass constitutes a large fraction of the total inputs of carbon to the biota immediately outside of the lagoon, assuming that it is consumed within the area. This probably is quite unlikely, for eelgrass is observed floating several tens of miles from the nearest sources (Fig. 3.14) and anecdotal evidence indicates it may float for over a hundred miles. Nevertheless, we can use a scenario of near maximum consumption near the lagoon to illustrate the potential for eelgrass support of the

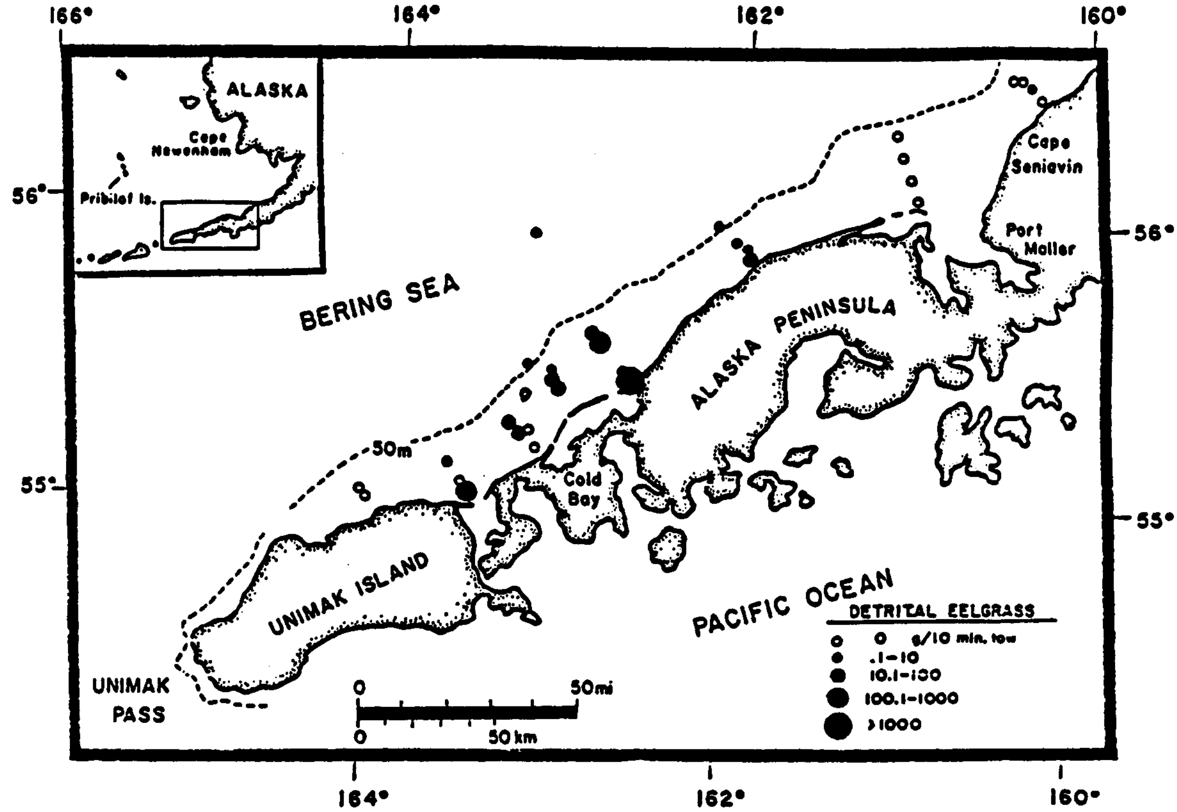


Fig. 3.14. Distribution of detrital eelgrass, 1-3 October 1984. Samples were collected by a neuston net which was towed for 10 min. and filtered approximately 770 m^2.

nearshore ecosystem. Using our primary productivity estimates and the estimates of Barsdate et al. (1974) on eelgrass transport, the following approximation can be made:

Eelgrass transport from lagoon	161 x 10^6kg/yr
Phytoplankton production	0.25 kg/m^2-yr
Assumed area of consumption - shoreward of 50-m contour, between Bechevin Bay and 50 km NE of Moffet Lagoon entrance	26 x 10^8m^2

Calculation of the relative inputs reveals that the eelgrass would contribute about 62 gC/m^2-yr or an amount equivalent to 28% of the annual phytoplankton crop. Thus the possibility exists that eelgrass is a significant energy source either if concentrations accumulate in seafloor depressions or if a grazer is well adapted to use this resource.

3.4.2 Carbon Isotope Studies

3.4.2.1 Stable Carbon Isotope Results

Table 3.1 lists the del ^{13}C values of the organisms analyzed from the study area. It is important to note that the variation in the del ^{13}C values of these animals is not due solely to the presence or absence of eelgrass carbon, but also reflects biochemical fractionation resulting from the position of carbon in the trophic levels. Offshore studies have shown that a trend toward less negative del ^{13}C values occurs from primary producers to benthic consumers (Eadie 1972, Mills et al. 1983, McConnaughey and McRoy 1979a, Fry et al. 1983, Fry 1977, Fry and Parker 1979, Gearing et al. 1984, Thayer et al. 1983). From laboratory experiments, DeNiro and Epstein (1978) estimated that each trophic step enriches an organism 0.8 ± 1.1 del units and field studies have estimated trophic step enrichments ranging from 0.4 (Gearing et al. 1984) to 1.5 (McConnaughey and McRoy 1979a). Although trophic enrichments are not always consistent with increasing trophic levels, they offer insight into the trophic transfers of carbon necessary to support the organism. The $^{13}C/^{12}C$ ratio of eelgrass collected in the study area and in Izembek

Table 3.1. Del ^{13}C values for plants and animals collected in lagoon and nearshore waters of the NAS. Sample numbers differing only by a number in parentheses at the end represent separate organisms collected from the same trawl. Sample numbers differing by a letter at the end represent replicates of the same organism. Middle digits represent the month and year of cruise.

Sample Number	Sample Identification	Transect/Station	del ^{13}C (ppt)
PLANKTON			
AS–585–1A	Phytoplankton	0.5C	– 25.0
AS–785–9	Phytoplankton	0.5C	– 22.9
AS–785–13	Phytoplankton		– 22.6
AS–785–27	Phytoplankton	6A	– 23.8
AS–785–26	Zooplankton	B85–2725	– 22.5
AS–785–24	Zooplankton	7A	– 23.7
AS–785–7	Zooplankton	0.5A?	– 21.8
AS–785–25	Zooplankton	0.5 (70 m)	– 23.7
AS–785–40(1)	Jellyfish (*Chrysaora* (?) sp.)	B85–728	– 21.1
AS–785–40(2)	Jellyfish (*Chrysaora* (?) sp.)	B85–728	– 20.3
AS–785–41	Jellyfish (J-1)	B85–785, 4X	– 21.6
AS–584–15	*Thysanoessa raschii*	4B–6	– 19.5
EELGRASS			
AS–185–16	*Zostera marina*	4C	– 10.6
AS–1084–1	*Zostera marina*	4.5C	– 10.0
AS–1084–2	*Zostera marina*	1.5C	– 9.9
AS–1084–3	*Zostera marina*	3C	– 11.5
AS–1084–4	*Zostera marina*	7B	– 11.5
AS–1084–5	*Zostera marina*	4.5A	– 9.4
AS–286–1(2)	*Zostera marina*	Grant Pt.	– 13.0
BENTHIC CRUSTACEANS			
AS–584–1	*Crangon dalli*	1D	– 18.2
AS–584–8	*Crangon dalli*	4D	– 18.8
AS–1084–10	*Crangon dalli*	2D	– 16.4
AS–185–18	*Crangon dalli*	6C	– 16.8
AS–185–17	*Crangon dalli*	4X	– 19.8
AS–185–22	*Crangon dalli*	6A	– 16.9
AS–185–20	*Crangon dalli*	0.5C	– 17.3
AS–185–21	*Crangon dalli*	4C	– 16.5
AS–785–10	*Crangon dalli*	0.5C	– 17.5
AS–785–14	*Crangon dalli*	043 (50 m)	– 17.7
AS–785–16	*Crangon dalli*	6A	– 17.2

Table 3.1 (Continued)

Sample Number	Sample Identification	Transect/Station	del ^{13}C (ppt)
BENTHIC CRUSTACEANS (Continued)			
AS–785–19	*Crangon dalli*	093 (30 m)	- 17.7
AS–785–18	*Crangon dalli*	7D (10 m)	- 17.5
AS–785–12	*Crangon dalli*	0.5 (70 m)	- 19.0
AS–785–17	*Crangon dalli*	086	- 17.9
POLYCHAETES			
AS–585–7a	*Ophelia limacina*	4Y	- 19.0
AS–585–5b	*Ophelia limacina*	0.5Y	- 17.4
AS–585–6	*Ophelia limacina*	2A	- 17.1
AS–585–7(2)	*Ophelia limacina*	4Y	- 19.1
AS–585–8	*Ophelia limacina*	4A	- 16.3
AS–585–2	*Nephthys caeca*	4C	- 16.0
AS–585–10	*Nephthys caeca*	2A	- 16.0
AS–585–3	*Nephthys caeca*	2C	- 15.8
AS–585–4	*Nephthys caeca*	5A	- 16.8
AS–585–1	*Nephthys caeca*	0.5A	- 17.0
BIVALVES			
AS–585–14	*Astarte borealis*	0.5A	- 18.9
AS–585–15	*Astarte borealis*	4Y	- 20.4
AS–585–17	*Astarte borealis*	2C	- 19.3
AS–585–18	*Cyclocardia crebricostata*	2A	- 19.8
AS–585–19	*Cyclocardia crebricostata*	6A	- 17.9
AS–585–20	*Cyclocardia crebricostata*	4A	- 18.2
AS–585–26	*Cyclocardia crebricostata*	0.5C	- 18.3
FISH			
AS–984–1	White-spotted Greenling	4E	- 17.3
AS–984–1(2)	White-spotted Greenling	4E	- 16.5
AS–785–37	White-spotted Greenling	4F	- 15.9
AS–584–21	White-spotted Greenling	7C	- 16.2
AS–784–7	Masked Greenling	—	- 15.6
AS–984–10	Masked Greenling	5D	- 16.4
AS–185–1	Staghorn Sculpin	1C	- 14.5
AS–785–5	Staghorn Sculpin	0.5 Nearshore	- 15.9
AS–785–5b	Staghorn Sculpin	0.5 Nearshore	- 15.8
AS–785–33	Staghorn Sculpin	4F	- 14.6

Table 3.1 (Continued)

Sample Number	Sample Identification	Transect/Station	del ^{13}C (ppt)
FISH (Continued)			
AS–984–12	Sculpin	4E	- 14.6
AS–584–3	Rainbow Smelt	6E	- 17.1
AS–584–3(2)	Rainbow Smelt	6E	- 17.2
AS–784–12	Rainbow Smelt	—	- 16.6
AS–984–3	Rainbow Smelt	4E	- 17.6
AS–984–8	Pacific Cod	4B	- 18.3
AS–984–6	Pacific Cod	4C	- 18.1
AS–984–7	Pacific Cod	5C	- 17.4
AS–185–26	Pacific Cod	4D	- 16.0
AS–185–4	Pacific Cod	4D	- 16.7
AS–785–8	Pacific Herring	0.5C	- 21.2
AS–785–8(2)	Pacific Herring	0.5C	- 20.6
AS–985–3	Pacific Sand Lance	5C	- 20.0
AS–584–2	Pacific Sand Lance	1D (3 m)	- 17.5
AS–984–1	Pacific Sand Lance	4C	- 20.5
AS–984–3	Pacific Sand Lance	5D	- 19.2
AS–984–7	Pacific Sand Lance	1C	- 19.7
AS–984–7(2)	Pacific Sand Lance	1C	- 18.6
AS–785–44	Pacific Sand Lance	4C	- 19.7
AS–584–14	Pacific Sandfish	—	- 17.2
AS–185–14	Pacific Sandfish	4D (10 m)	- 17.7
AS–785–2	Pacific Sandfish	0.5E	- 17.7
AS–785–2(2)	Pacific Sandfish	0.5E	- 17.7
AS–984–5	Prickly Snailfish	5B	- 17.9
AS–784–4	Chum Salmon		- 21.5
AS–784–8	Chum Salmon (juv.)		- 18.2
AS–785–46	Chum Salmon (juv.)*		- 17.2
AS–785–43	Chum Salmon (juv.)*		- 20.9
AS–784–6	Sockeye		- 21.6
AS–785–21	Sockeye	4E	- 21.9
AS–785–22	Sockeye	2E	- 21.1
AS–785–23	Sockeye	5E	- 21.2
AS–785–42	Coho (juv.)	3.5 mi. off Port Moller*	- 19.1
AS–785–42b	Coho (juv.)	3.5 mi. off Port Moller*	- 19.3
AS–784–5	Dolly Varden		- 19.5
AS–784–9	Walleye Pollock (juv.)		- 16.9
AS–984–4	Walleye Pollock (juv.)	2A	- 18.4
AS–984–5	Walleye Pollock (juv.)	5B	- 17.3
AS–185–2	Walleye Pollock (juv.)	2C	- 18.3
AS–185–2(2)	Walleye Pollock (juv.)	2C	- 18.4

Table 3.1 (Continued)

Sample Number	Sample Identification	Transect/Station	del ^{13}C (ppt)
FISH (Continued)			
AS–185–6	Walleye Pollock (juv.)	5A	-18.5
AS–185–6(2)	Walleye Pollock (juv.)	5A	-18.0
AS–185–9	Walleye Pollock (juv.)	4B	-18.5
AS–185–9(2)	Walleye Pollock (juv.)	4B	-19.0
AS–785–35(1)	Walleye Pollock (juv.)	4A	-19.9
AS–785–31	Walleye Pollock (juv.)	0.5C	-18.4
AS–785–35(2)	Walleye Pollock (juv.)	4A	-20.0
AS–785–11	Halibut	0.5D	-16.9
AS–185–3b	Rock Sole	4Y	-18.1
AS–185–3	Rock Sole	4Y	-17.8
AS–185–15	Rock Sole	4Y	-16.7
AS–185–7	Rock Sole	4A	-17.5
AS–185–10	Rock Sole	6A	-15.6
AS–185–19	Rock Sole	4C	-15.4
AS–584–4	Yellowfin Sole	6E	-15.6
AS–185–13(2)	Yellowfin Sole	2C	-16.4
AS–185–5	Yellowfin Sole	0.5C	-17.4
AS–185–8	Yellowfin Sole	6C	-15.6
AS–185–12	Yellowfin Sole	4C	-15.8
AS–785–45	Yellowfin Sole	2E	-18.0
AS–785–20	Yellowfin Sole	6D	-15.9
AS–785–46	Yellowfin Sole	6A	-15.5
AS–185–13	Yellowfin Sole	2C	-16.8
AS–785–38	Yellowfin Sole	4D (10 m)	-17.1
AS–784–2	Starry Flounder		-14.4
AS–785–3	Starry Flounder	0.5E	-16.5
AS–785–3(2)	Starry Flounder	0.5E	-16.2
AS–785–3(3)	Starry Flounder	0.5E	-16.0
AS–785–34	Starry Flounder	0.5E	-17.9
AS–785–36	Starry Flounder	4F	-14.3
AS–785–1	Alaska Plaice	0.5 (10 m)	-15.7
BIRDS AND MAMMALS			
AS–984–11	Steller's Eider	Port Moller Area	-17.9
AS–785–44	Steller's Eider	5 Nearshore	-17.0
AS–785–45	Steller's Eider	Nelson Lagoon	-18.1
AS–685–1	Harbor Seal†	Port Heiden	-17.0
AS–685–2	Harbor Seal†	Port Heiden	-16.8
AS–685–3	Harbor Seal†	Port Heiden	-16.9

* Samples collected by Dames and Moore.

† Samples provided by Alaska Department of Fish and Game.

Lagoon ranged from -9.4 to -13.0. The phytoplankton in the Bering Sea water column had a del value of -23.6 ± 1.1. This is similar to the value reported by McConnaughey and McRoy (1979a) of -24.4 ± 0.3 ppt for Bering Sea phytoplankton. With few exceptions, all other organisms have values ranging between phytoplankton and eelgrass and are less than 9 ppt enriched with ^{13}C compared with phytoplankton. Integrating our data into the compilation of Gearing et al. (1984) of average del ^{13}C values for organisms in phytoplankton-based ecosystems worldwide (Table 3.2), our ^{13}C enrichments match closely those of the other authors.

A food web based heavily on eelgrass, however, would be much more enriched in ^{13}C. McConnaughey (1978) found that the Izembek Lagoon benthic community depended on eelgrass detritus for some of its carbon. A value of -22.3 ppt was used for lagoon phytoplankton. His isotopically lightest lagoon copepod had a del value of -18.8, enriched by 3 del units relative to our most enriched zooplankton sample. His detritus feeders in the lagoon were also enriched relative to detritus feeders analyzed in our study. The bivalve Macoma inconspicua had a del value of -14.4 in Izembek Lagoon. We found an average value for filter feeding bivalves in the Bering Sea of -19.0, considerably more depleted in ^{13}C. Eelgrass is contributing a substantial amount of carbon to these organisms in the lagoon, but not in the nearshore Bering Sea, since the Bering Sea samples compare closely with values for phytoplankton-based food webs.

To quantify the amount of eelgrass carbon in even the lagoon bivalves is difficult although an approximation can be made. If the food ingested by bivalves in the lagoon undergoes the same metabolic fractionation as that in pelagic food webs, (a major assumption) then a pure eelgrass diet should yield a clam with a del ^{13}C of about -7 ppt (a 3 ppt enrichment). If the -19 ppt value represents no eelgrass, then the -14.4 bivalve contains 40% eelgrass carbon. McConnaughey (1978) performed similar calculations on several resident fauna in the lagoon and found eelgrass carbon fractions ranging from undetectable to over 50% in the crab Telmesus, but our data indicate that the eelgrass contribution to faunal nutrition is quickly diluted to insignificant amounts outside of the lagoon.

DeNiro and Epstein (1978) reported that in the laboratory different species of animals fed the same diet had similar del ^{13}C values. In field

Table 3.2. Average del ^{13}C values for organisms in plankton-based ecosystems worldwide (Ph = phytoplankton, Z = zooplankton, S = shrimp, B = bivalve, NP = non-carnivorous polychaete, CP = carnivorous polychaete, CG = carnivorous gastropod). From Gearing et al. (1984).

Location	Ph	Z	S	B	NP	CP	CG
Bering Sea[a]	-24.4	-22.1	-17.8	-18.6	—	-17.8	-16.4
Off Maine[b]	—	—	—	-17.7	—	—	—
Narragansett Bay[c]	-21.3	-20.8	-17.9	-18.5	-18.7	-16.5	-16.7
Off California[d]	—	—	—	-16.2	-17.2	-16.1	—
Gulf of Mexico[e]	-20.0[g]	—	-16.0	-18.4	—	-17.7	—
Off Malaysia[f]	-21.0	—	-16.5	-18.1	—	-17.3	-15.3
AVERAGE	-21.7	-20.9	-17.1	-17.9	-18.3	-17.1	-16.1
This Study	-23.6	-23.0	-17.7	-19.0	-17.8	-16.4	—

[a] McConnaughey and McRoy (1979)
[b] Incze et al. (1982)
[c] Gearing et al. (1984)
[d] Spies and Desmarais (1983)
[e] Fry and Parker (1979)
[f] Rodelli et al. (1984)
[g] Fry (1977)

studies, organisms with similar feeding behaviors are often treated as a group when estimating isotopic enrichments with trophic level (Gearing et al. 1984, Fry et al. 1984). Figure 3.15 shows histograms and average values of del ^{13}C for organisms with similar feeding patterns. The shifts toward higher ^{13}C concentrations with increasing trophic level are apparent and follow the trend expected for a phytoplankton-based food web. Walleye pollock were separated into two groups for plotting in Figure 3.15, those less than 50 mm and those 50 mm or larger. This separation reflects the shift from pelagic feeding to demersal feeding when the juveniles reach 35-50 mm (see Section 5 on Fishes). The two pollock less than 50 mm in length had del values of -19.9 and -20.01 ppt while those larger had an average of -18.2 ± 0.6 ppt (n=10). The change from pelagic feeding on isotopically lighter zooplankton to more enriched benthic invertebrates in their demersal existence is indicated in these del values.

Detritus-feeders are probably the major link between eelgrass and large demersal and benthic organisms (McConnaughey and McRoy 1979b). Eelgrass should be evident in organisms such as crangonid shrimp and deposit feeding polychaetes such as Ophelia limacina if it was a major energy source to the food web. The average for these two detritivores is -17.7 ± 1.0 ppt, close to the value given by McConnaughey (1978) for Bering Sea Crangon dalli of -16.9 ppt. The lagoon samples of Crangon which he collected had an average del value of -14.1 ppt, and he estimated that eelgrass contributed 17% of the carbon to the shrimp. Therefore, even for crangonid shrimp in the lagoon, eelgrass is not contributing a large fraction of carbon to the organisms. From our isotopic evidence, we cannot detect eelgrass in crangonid shrimp outside of the lagoon.

3.4.2.2 Radiocarbon Studies

The ^{14}C contents of the organisms sampled provide indirect evidence that the nutrients needed for primary production are being supplied by upwelling of deep Pacific Ocean water. After a deep mixing event occurs, phytoplankton growth fixes the marine carbon dioxide before complete equilibration can occur with the radiocarbon background in the atmosphere. The ^{14}C activity of the atmospheric pool is currently about 122% of the

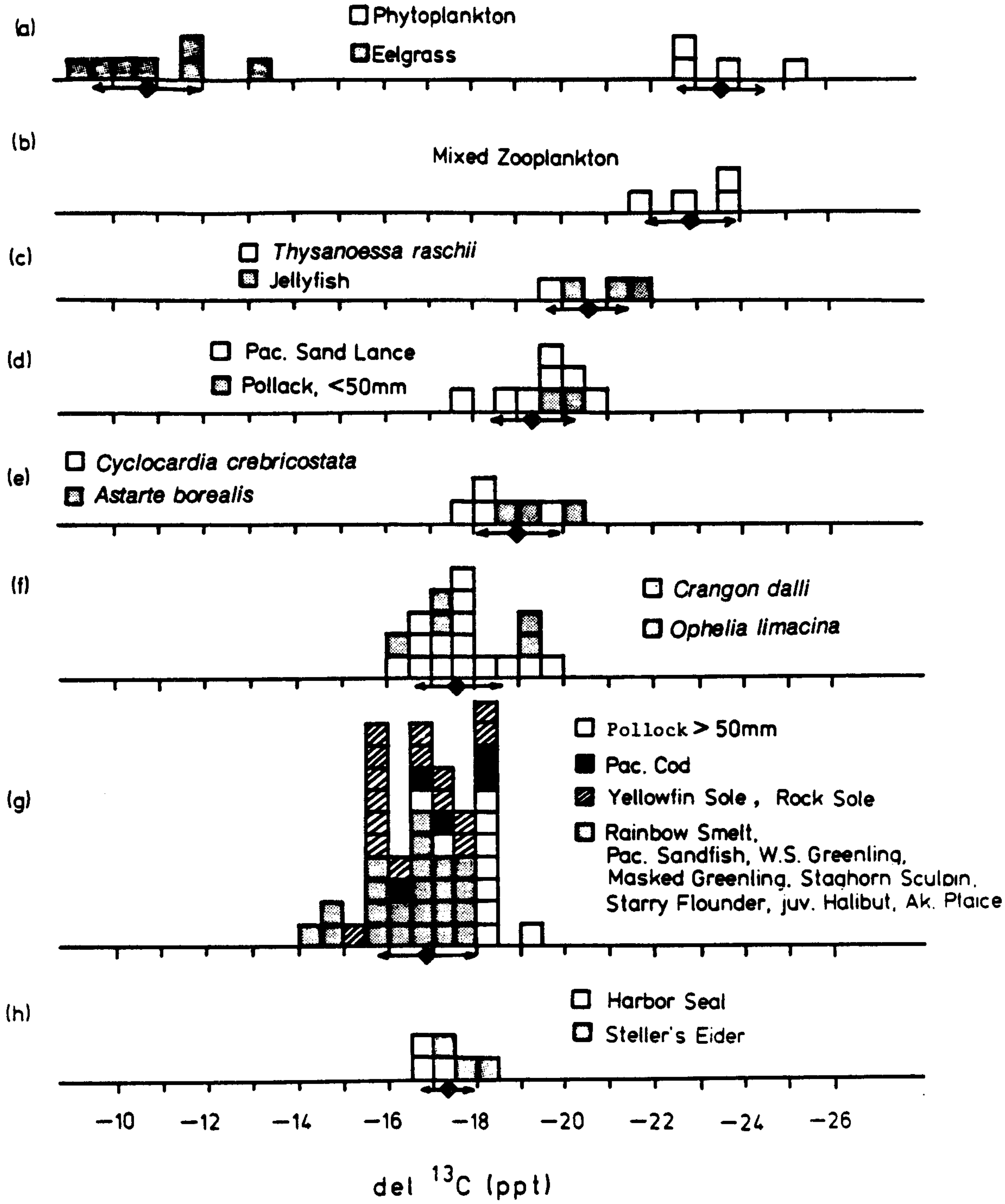


Figure 3.15. Histogram showing del ^{13}C values of the plants and animals listed in Table 1. Organisms collected within the lagoon are not included except for the Steller's Eiders. Organisms with similar feeding habits were grouped together: primary producers (a), zooplankton, mostly copepods (b), omnivorous zooplankton (c), pelagic forage fish (d), filter feeding bivalves (e), detritivores (f), demersal/benthic fishes (g), and marine mammals and birds (h). The black diamonds and bars show the average and standard deviation of each group.

1950 standard activity (100%). If the organisms were feeding on phytoplankton growing in a stable or well ventilated water column, the expected radiocarbon content would yield activities of about 112-118% modern, values typical of surface water bicarbonate in more temperate latitudes (Ostlund and Stuiver 1980). The ^{14}C activities of the animals listed in Table 3.3 are all depressed by at least 2% from the lower limit of this range showing that the nearshore waters of the NAS are not as equilibrated with atmospheric carbon dioxide and must have been recently upwelled from the deep Pacific. Even within Izembek Lagoon eelgrass radioactivities are indicative of plants growing in water not fully equilibrated with atmosphere. The chronologically old Pacific deep water is influencing the lagoon before complete equilibration with atmosphere can occur. The radioactive content of the dissolved inorganic carbon (DIC) in surface waters agree well with radiocarbon activities from the GEOSECS Stations 218 and 219 (Ostlund and Stuiver 1980) which show the shallowing of the radiocarbon gradients in the North Pacific (Fig. 3.16). This shallowing of the gradient is caused by the surfacing of older, deep Pacific water in areas of upwelling and deep winter mixing in high latitudes. There is insufficient difference in radiocarbon activity between Izembek eelgrass and nearshore fauna to use radiocarbon to quantify the eelgrass contribution to nearshore food webs.

3.5 CONCLUSIONS

With the determination of temporal and spatial nutrient concentrations and primary productivity rates in NAS waters, we have acquired insight into the principal environmental and biological processes controlling the productivity of this region. Specifically, we note:

Primary productivity along the NAS coastal zone is higher than the values reported by PROBES investigators for areas further northeast and offshore. This may be due to the advection of nitrate-N rich deep-mixed water into the study area. Productivities are very high and by July the nutrient supply has been depleted to limiting concentrations in the euphotic zone. Our annual production estimate is 220-240 gC/m^2-yr for the study area.

Table 3.3. Radiocarbon activities of fishes, eelgrass, and dissolved inorganic carbon collected from NAS waters. Activities are normalized and reported to 1950 atmospheric ^{14}C 100%.

Sample Identification	^{14}C Activity (percent modern)
BIOCARBONATE	
Surface Water, 4A, 19 Sep 84	99.0 ± 0.9
Surface Water, 4Y, 23 May 85	107.3 ± 0.9
Surface Water, 4E, 21 May 85	109.8 ± 0.9
Surface Water, Unimak Pass, 1 Aug 85	104.1 ± 0.9
EELGRASS	
Glazenap Pass, 29 Sep 84	111.0 ± 0.9
Grant Point, Feb 86	107.9 ± 0.9
FAUNA	
Rainbow Smelt, 399–6C1, 29 Sep 84	107.7 ± 1.1
Pacific Sandfish, 340–1C, 24 Sep 84	105.4 ± 1.2
Pacific Cod, 399–6C1, 29 Sep 84	104.0 ± 0.7
Pacific Sand Lance, 350–5C, 25 Sep 84	108.5 ± 0.9
Pacific Sand Lance, B85–340, 1C, 24 Sep 84	105.7 ± 0.8
Pacific Sand Lance, 4C, Jul 85	109.1 ± 0.6
Walleye Pollock, 399–6C1, 29 Sep 84	109.6 ± 0.8
Yellowfin Sole, 317–2A, 21 Sep 84	104.6 ± 0.7
Yellowfin Sole, 2C, 1 Feb 85	108.0 ± 0.7
Yellowfin Sole, B85–742, 2E, 22 Jul 85	108.4 ± 0.7
Yellowfin Sole, 6A, 27 Jul 85	106.4 ± 0.8
Flathead Sole, 317–2A, 29 Sep 84	109.5 ± 0.8
Rock Sole, 0.5A, 21 Jul 85	106.3 ± 0.8
Rock Sole, B85–522, 4Y, 26 Jan 85	103.4 ± 0.7

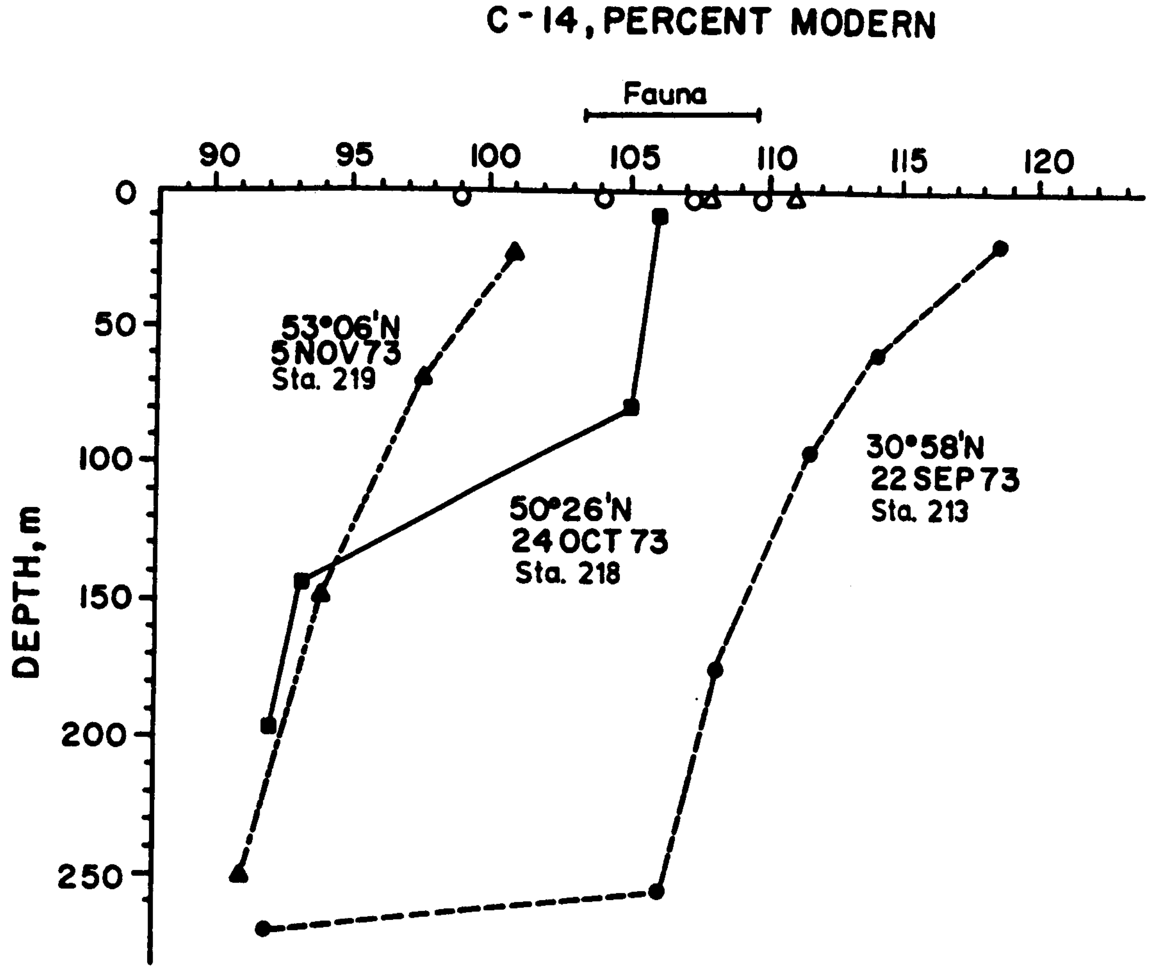


Fig. 3.16. Radiocarbon activities from the GEOSECS stations 213, 218, and 219 (Ostlund and Stuiver 1980). Fauna (shown on x-axis), DIC (o), and eelgrass (Δ) activities are also included from Table 3.

Nutrient supply to the coastal waters occurs in the vicinity of Unimak Island and represents deep Pacific Ocean/Bering Sea water advected onto the shelf. Nitrate concentrations in the southwestern portion of the study area reach 20 micromolar in surface waters and account for the high primary production. Replenishment of the nitrate in the euphotic zone is accomplished by storm and tidal mixing during the summer months and high rates of primary productivity are possible at any time in the summer depending upon the recent history of mixing events and water column stability.

In spite of the large inputs of eelgrass carbon to the coastal zone, equivalent to about one-quarter to one-third of the local in situ production, the isotopic compositions of the sessile benthos and the forage fishes resident in the area show that very little of the eelgrass carbon enters the food web. This is attributed to losses of carbon in inefficient transfers to higher trophic levels and, perhaps, dispersal of the eelgrass over a much larger region than the study area.

Radiocarbon abundances in the animals of the coastal zone are markedly depressed from the concentrations expected for a food web in a water column equilibrated with atmospheric carbon dioxide. North Pacific/Bering Sea deep water is known to be the chronologically oldest water in the world oceans (Ostlund and Stuiver 1980). The radiocarbon depression in the animals indicates that the upake of inorganic carbon by phytoplankton occurs before water-column carbon dioxide can equilibrate with the atmosphere. This presents prima faci evidence that deep mixing of Bering Sea water supplies nutrients to the nearshore community.

3.6 RECOMMENDED FURTHER RESEARCH

There are many questions left unanswered as to the interactions between the environmental variables and the organisms in the nearshore zone. We have identified the following tasks as useful toward clearing up the roles of the terrestrial and lagoonal inputs versus oceanic inputs to the nearshore zone:

1. Samples of forage fishes and commercially-important fishes are needed from the lagoon environment for both radiocarbon

and stable carbon isotope analyses. Trawls for benthic species would be very desirable from inside the lagoon. Neither the literature data nor the sampling efforts so far have provided information on many of these species.

2. Early stabilization of the water column associated with sea ice melt may extend phytoplankton production to include the early spring. Data collected during the spring of a heavy ice year would give information on the effects of ice on primary productivity.
3. More information is needed on the composition of the phytoplankton community--diatom versus blue-green algae versus dinoflagellate production. Phytoplankton floristics may regulate the carbon available to primary consumers and control the species succession and recruitment.
4. Synoptic collection of nutrient and chlorophyll samples would help to determine whether the large concentration gradients we see during much of the year between the SW and NE boundaries of the study area are due to temporal effects or to physical factors such as the advection of nutrient rich water from the vicinity of Unimak Pass.

3.7 ACKNOWLEDGEMENTS

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Section 4

INVERTEBRATES

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Section 4

INVERTEBRATES

4.1 SUMMARY

1. Zooplankton biomass on the NAS during 1984 and 1985 was extremely low compared with that of offshore Bering Sea shelf waters, other arctic waters and other marine waters in general. Other Bristol Bay nearshore waters are, like the NAS, typically low in biomass.
2. Sample results show that biomass and composition of zooplankton varied among seasons; important points are as follows:
   (a) Total biomass was highest in July samples, but may have actually been highest in June (when no samples were taken). The biomass peak on the NAS (June?/July) and other inshore areas (July/August) was later than that on the outer shelf (May) or middle shelf (early June). Biomass on the NAS was lowest in September, probably as a result of jellyfish predation.
   (b) Chaetognaths were the dominant taxon in winter, but decreased in abundance through spring and summer. Copepods generally increased in abundance from a January low to a late spring (May) high, sometimes remaining abundant into late summer. Abundance of euphausiids showed no clear seasonal trend. Decapod larvae and fish larvae both increased in absolute biomass from a January low to a July high.
   (c) Carnivorous zooplankton were dominant in winter; the abundance of herbivores began increasing in April with onset of the spring bloom, and generally increased through July.
   (d) Timing of life cycles of *Calanus marshallae* (a middle shelf copepod) and of *Neocalanus plumchrus* (an outer shelf copepod) on the NAS

was similar to timing of their life cycles elsewhere.

3. The spatial distribution and composition of the plankton was strongly influenced by the distribution of water masses. Distributions of copepod and euphausiid species, and in some cases their biomasses, were strongly affected by intrusions of middle shelf water into the NAS study area. Intrusions of mid-shelf water were marked by the presence of middle shelf copepods, high biomasses of euphausiids, and, in some cases, high total biomasses.
4. Large schyphozoan jellyfish were the most conspicuous zooplankters present in the study area. Their biomass was higher than that of the rest of the plankton combined. Biomass of jellyfish was highest in September; predation by jellyfish may have been one factor responsible for the generally low biomass of other zooplankton in late summer and early fall.
5. Benthic infaunal biomass was very low at depths of less than 10 m. This is typical of northern shorelines exposed to ice scour and heavy wave action. Biomasses of infauna at depths of 20-50 m were typical of those found in deeper parts of the Bering Sea shelf. Beyond 20 m, bivalves and echinoderms were found in approximately equal proportions and together accounted for 88% of the total biomass. Polychaetes were the dominant group in terms of numbers.
6. Total infaunal biomass was highest in the western portion of the study area. Biomass was relatively high between Cape Mordvinof and Moffet Lagoon, low between Moffet Lagoon and Nelson Lagoon, and high off Port Moller. Biomass distributions of bivalves and echinoderms followed the same pattern; polychaetes were more uniformly distributed.
7. Surface deposit-feeding was the dominant mode of feeding of infaunal animals. This is typical of other northern areas.
8. Starfish, mysids, crangonid shrimp, and amphipods were the dominant epibenthic animals; shrimp and mysids were the dominant epibenthic animals inside the 10-m depth contour.

This and other studies show that crab populations have declined drastically in the past several years. Distributional patterns of various epifaunal groups were as follows:

(a) Starfish were most abundant beyond the 20-m depth contour.

(b) Crangonids were most abundant at depths of 3-10 m and off Port Moller and Cape Seniavin.

(c) Mysids were most abundant at depths of 3-10 m and 50 m. At 3-10 m, they were abundant off Port Moller and Cape Seniavin and on Transect 5.

(d) More amphipods were taken by the grab than by any other method, indicating that they were in or on the sediment rather than above it. They were most abundant at water depths of 10-50 m.

4.2 INTRODUCTION

Invertebrates on which this study focused are those that are important because (1) they are of commercial or subsistence value to man, and/or (2) they are major food web components of vertebrates or invertebrates important to man. Those commercially important species for which the NAS study area provides important habitat have been identified mainly from existing literature. Those that are important food web components have been identified from the literature and from current findings of this study.

4.3 CURRENT STATE OF KNOWLEDGE

4.3.1 Substrates

Substrate (sediment) characteristics are important measures of invertebrate habitat quality. Cimberg et al. (1984), on the basis of 38 substrate samples at depths of 10 to 60 m within the NAS study area, characterized the sediments in most localities as being composed of well-sorted sands (Fig. 4.1). Gravel comprised a significant fraction of the

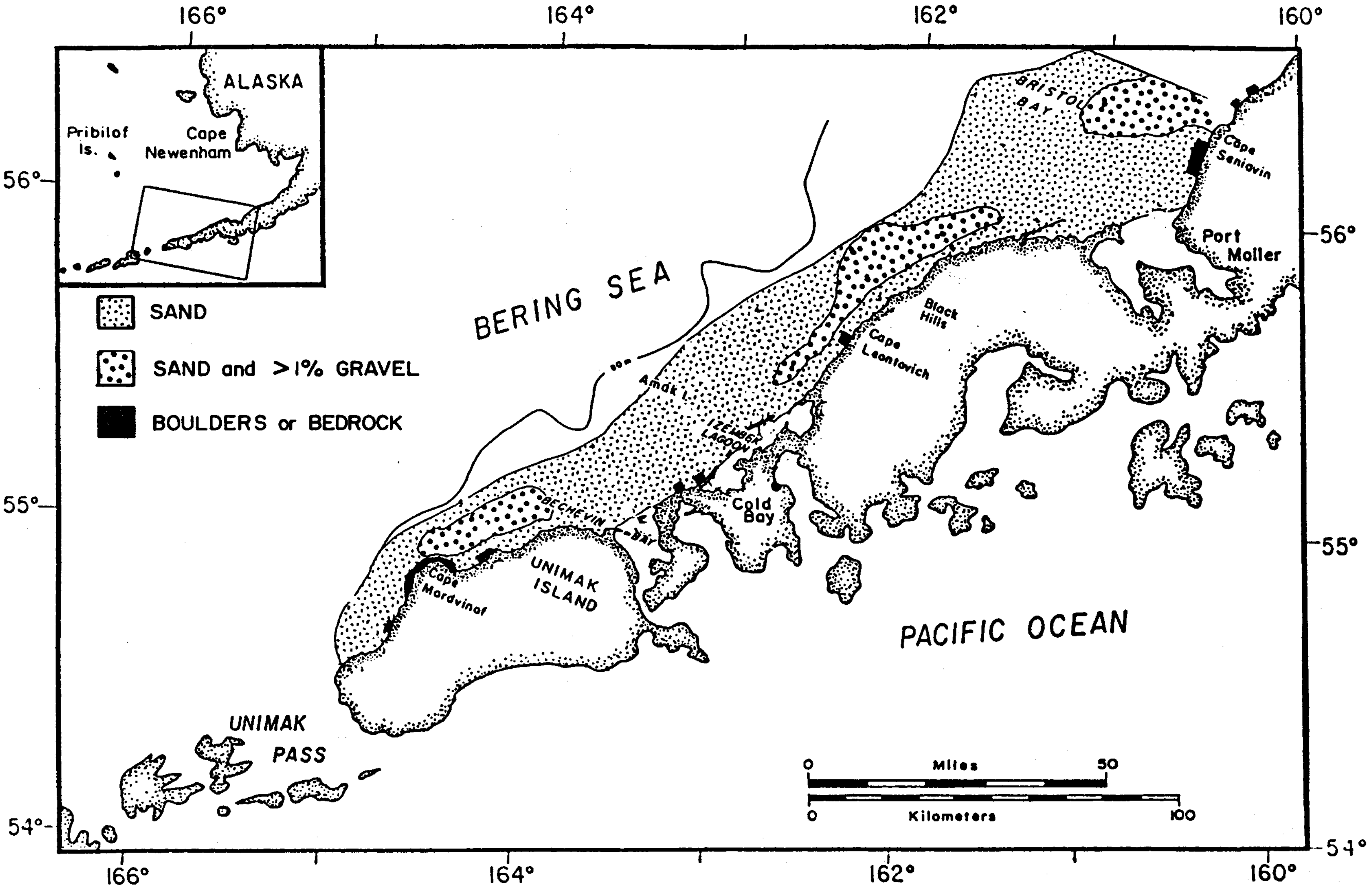


Fig. 4.1 General distribution of benthic substrate types on the North Aleutian Shelf (After Cimberg et al. 1984, Sears and Zimmerman 1977)

substrate at depths of 21 to 40 m off Unimak Island (19.2%), Black Hills (64.8%), and Cape Seniavin (11.1%). Silt comprised 7% or less of the sediments in 95% of the samples.

Shorelines are mainly sand. Boulders and bedrock are found in the vicinity of Cape Mordvinof and Cape Seniavin but in few other locations (Sears and Zimmerman 1977) (Fig. 4.1).

4.3.2 Species Important to Man

Three species have been identified that are important to man and that make significant use of the NAS study area. The red king crab (*Paralithodes camtschatica*) is undoubtedly the most important of these; it has great commercial value and its Bering Sea population is highly dependent on the shallow nearshore zone (Armstrong et al. 1983). The Tanner crab (*Chionoecetes bairdi*) is also commercially significant to the Bering Sea fishery, but its populations are less dependent on nearshore habitats (Otto 1981). Extensive concentrations of the Alaska surf clam (*Spisula polynyma*) have recently been found near the north coast of the Alaska Peninsula; these seem to have potential as a harvestable resource (Hughes and Bourne 1981). Few other invertebrate species that are currently useful to humans make appreciable use of the nearshore zone.

4.3.2.1 Red King Crab

The red king crab is widely distributed in the North Pacific Ocean and the Bering Sea (Armstrong et al. 1983). A major fishery is centered in the southeastern Bering Sea; over 10% of the world's red king crab catch in 1976 and 1977 came from this area (Otto 1981). The vast majority of red king crabs in the Bering Sea are found in outer Bristol Bay and the area immediately north of the Alaska Peninsula (Fig. 4.2).

Red king crabs in the Bering Sea are distributed somewhat in accord with sex and life-history stage. In summer, female and small male crabs are generally found closer to shore than are the large males (Fig. 4.3). During late winter and early spring, adult males apparently migrate closer to shore to join females for breeding (McMurray et al. 1984).

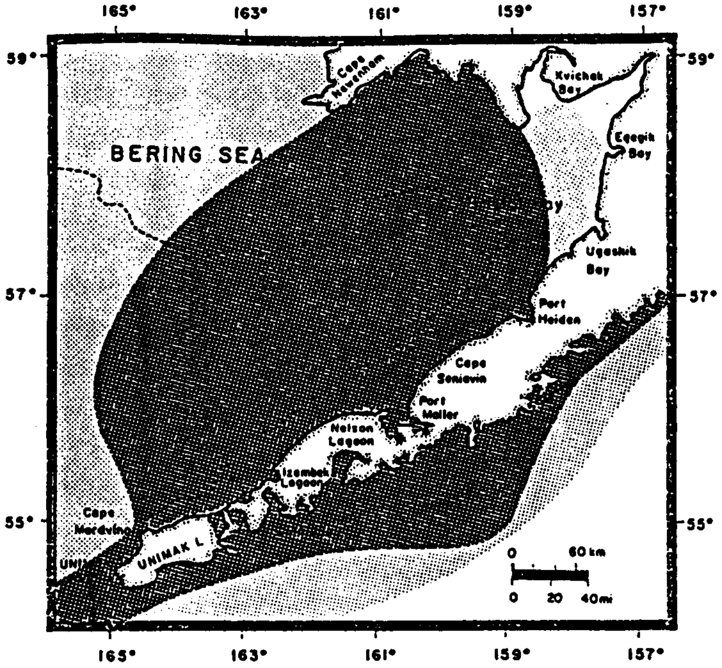


Figure 4.2. Distribution of red king crab in the southeastern Bering Sea. Darkly shaded portions indicate areas of consistent abundance (from Otto 1981).

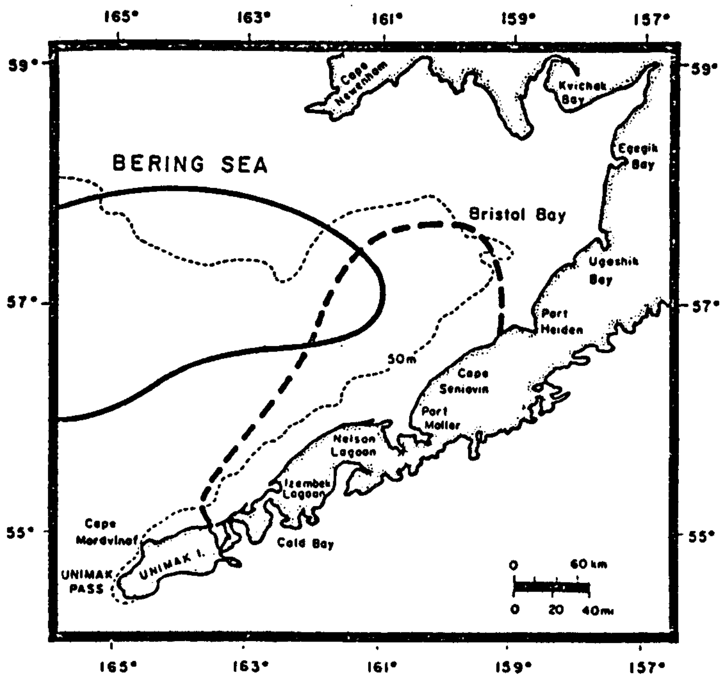


Figure 4.3. Centers of abundance of large (>134 mm carapace length) male red king crabs (solid line) and of female red king crabs (dotted line) in the southeastern Bering Sea, May-July 1980 (after Otto 1980).

Eggs carried from the previous year hatch about 1-20 April in this nearshore region, and the larvae drift with currents until July or August before settling to assume a benthic life mode (Armstrong et al. 1983, McMurray et al. 1984). Thus, although the majority of mating (and presumably the hatch as well) normally occurs between Unimak Island and Port Heiden (Fig. 4.3), the greatest abundance of juveniles is normally from Port Heiden to Kvichak Bay in eastern Bristol Bay, northeastward from the point of hatch, in the direction of the prevailing transport (Fig. 4.4). Very few juvenile crabs are found southwest of Port Moller.

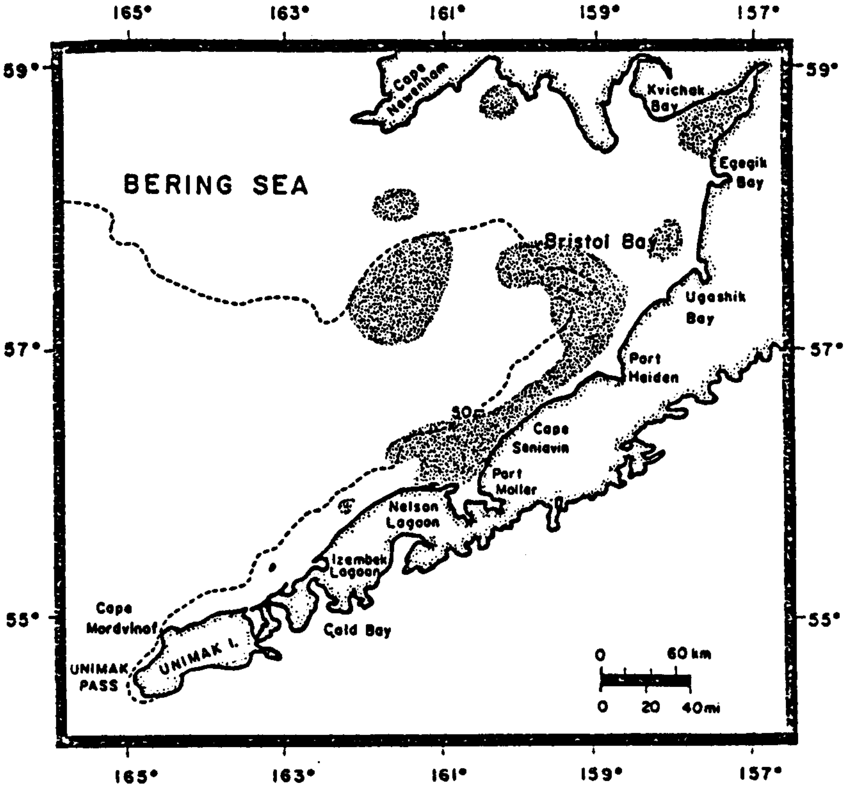


Figure 4.4. General distribution of juvenile red king crabs (age 3 and younger) in the southeastern Bering Sea as determined by sampling in April-May, June, and September, 1983 (adapted from McMurray et al. 1984).

Adult king crabs in the southeastern Bering Sea consume polychaete worms, sand dollars, gastropods, bivalves, echinoderms and other benthic invertebrates. Early post-larval crabs have been observed to feed on hydroids, copepods, ostracods, diatoms, and detritus (Feder and Jewett 1981). Crab larvae presumably feed on zooplankton.

Predators on adult king crabs include halibut, sea otters, and man. Sculpins (and presumably other benthic fishes) eat juvenile crabs (Feder and Jewett 1981), and larval crabs are probably consumed by pelagic fishes and invertebrates.

Physical habitat factors appear to strongly influence the distribution and abundance of populations of the various life stages of crabs. Water temperature in spring and summer may affect the distributional patterns of adults (Armstrong et al. 1983); females are generally found in warmer waters than are males. It has been postulated that the growth rates and survival of larval crabs are temperature-dependent (Armstrong et al. 1983, McMurray et al. 1984). Juvenile crab distribution on the NAS is strongly associated with substrate type--juveniles are usually found where the bottom is composed of gravel or coarser materials (McMurray et al. 1984).

Armstrong et al. (1983) and McMurray et al. (1984) have speculated that the sizes of red king crab populations are determined largely by the production of eggs and the subsequent survival of the crabs during their larval and early post-larval stages. The number of eggs produced may be relatively unimportant, but the survival of larvae and young may be more critical. Larval survival probably is strongly temperature-dependent: the higher the water temperature, the greater the rate of survival. Juvenile survival rates seem strongly related also to the availability of protective "refuge" substrates (shell, cobble, invertebrate aggregates) (McMurray et al. 1984). This suggests that the precipitous decline in catches by the fishery from 1966 to 1970 (Otto 1981) was probably not caused by fishing pressure.

4.3.2.2 Other Species

Other NAS species of actual or potential direct interest to man include Tanner crab (*Chionoecetes bairdi*) and the Alaska surf clam (*Spisula polynyma*). The other species of Tanner crab abundant in the Bering Sea (*C. opilio*) occurs in relatively low numbers in the NAS study area, and will not be addressed here.

Chionoecetes bairdi is widely distributed in the southern Bering Sea and the northern Gulf of Alaska; its juvenile and adult stages are most abundant along the outer shelf from west of the Pribilof Islands to Unimak Island, and along the NAS between Unimak Island and Cape Seniavin (Otto 1981) (Fig. 4.5). Tanner crab larvae hatch about mid-April and disperse throughout the southeastern Bering Sea (Armstrong et al. 1984). High larval abundances occur over the outer and middle shelf areas in depths less than 150 m; larvae are also abundant near the Alaska Peninsula (Armstrong et al. 1983). Unlike red king crabs, neither larval abundance nor crab age-class strengths of Tanner crabs vary dramatically from year to year.

Adult Tanner crabs in the southeastern Bering Sea feed mainly on polychaetes, and young crabs feed on crustaceans, polychaetes, and molluscs, in decreasing order of importance (Feder and Jewett 1981, quoting Tarverdieva 1976). Tanner crabs are, in turn, fed upon by king crabs, several species of benthic and demersal fishes, and walrus; in the NAS they are also the target of a commercial fishery (Feder and Jewett 1981). Chionoecetes bairdi appear to distribute themselves in areas that are relatively warm in summer--the outer shelf (100-200 m depths) and the North Aleutian Shelf--and to avoid cold areas (e.g., the northern Bering Sea and most of the middle shelf environment) (Armstrong et al. 1983). In addition to cold water temperatures limiting crab distribution, fishing efforts by domestic and foreign fleets since 1975 may have caused a drastic decline in Tanner crab abundance in the eastern Bering Sea (Otto 1981).

In 1977, an exploratory survey in the southeastern Bering Sea revealed extensive concentrations of Alaska surf clams along the north coast of the Alaska Peninsula (Hughes and Bourne 1981). Preliminary investigations (Fig. 4.6) suggest that these clam populations have the potential to support a viable fishery. The greatest concentrations are apparently located between Port Moller and Ugashik Bay, and at depths of 30-32 m (Hughes and Bourne 1981). Surf clams are primarily suspension feeders, consuming a variety of small plankton and detritus from the water column; in turn, they are probably eaten by crabs, sea stars, fishes and walruses (Feder and Jewett 1981). It has been speculated that unfavorably low salinities and excessive depths may limit surf clam abundance in other areas of the southeastern Bering Sea (Hughes and Bourne 1981), and that the population is currently at environmental equilibrium. It is likely,

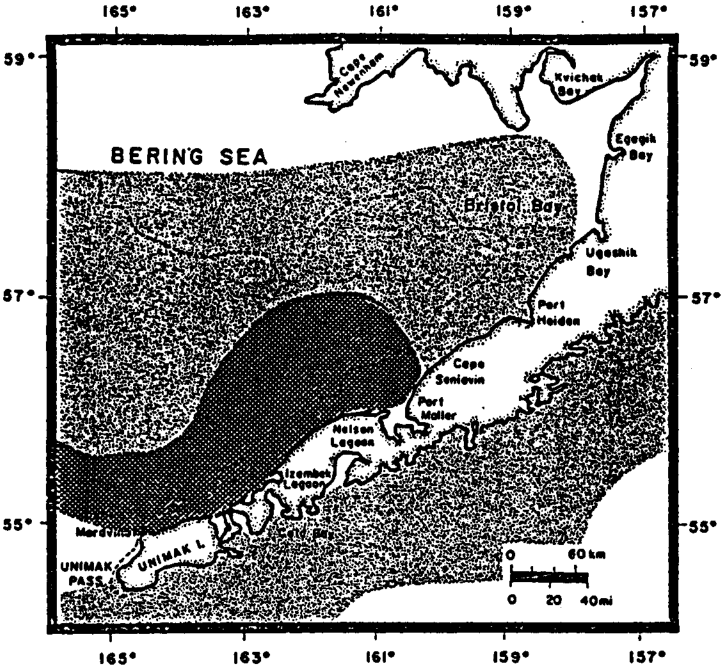


Figure 4.5. Distribution of the Tanner crab in the southeastern Bering Sea. Darkly shaded portions indicate areas of consistently high abundance (from Otto 1981).

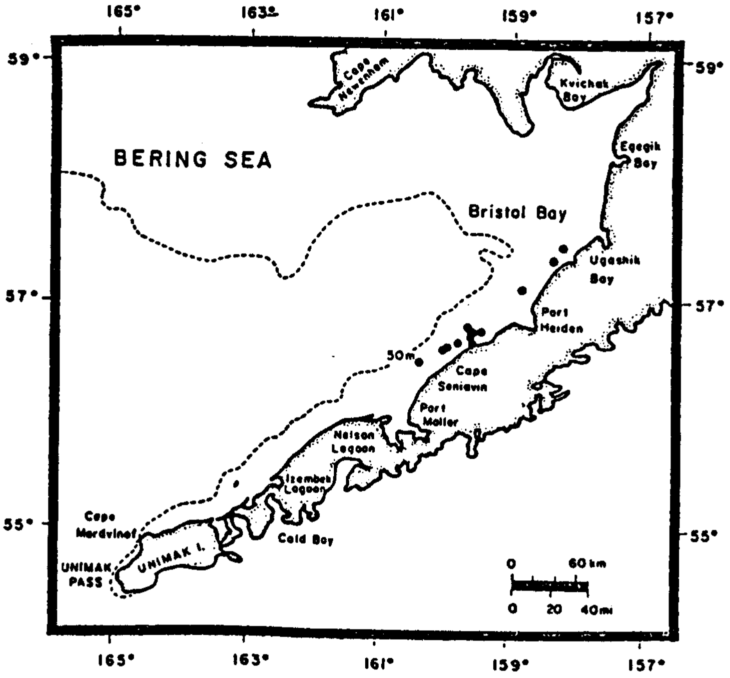


Figure 4.6. Locations where production fishing studies for the Alaska surf clam were conducted on the NAS in 1978 (from Hughes and Bourne 1981).

however, that appreciable fishing pressures could quickly reduce its abundance because of the slow growth (about 10 years) of individuals to harvestable size (Hughes and Bourne 1981).

4.3.3 Invertebrates Important in Food Webs

Based on existing information and the findings of this study, invertebrate groups important in food webs of animals directly important to humans include copepods, euphausiids, amphipods, mysids, polychaetes, shrimps, bivalves, and echinoderms (sand dollars). The most important of these are probably copepods, euphausiids, amphipods, and bivalves. Other groups generally are less important in these food chains, even though some are extremely abundant on the NAS (e.g., starfish, jellyfish, and chaetognaths).

4.3.3.1 Copepods

Copepods are extremely important in the diets of fishes in the southeastern Bering Sea. Seasonally, they constitute major proportions of the diets of adult sand lance, capelin, and herring; and young of salmon and pollock. Furthermore, they are consumed by other invertebrates--euphausiids, for example--that are important in vertebrate food webs. Copepods are the main constituent of zooplankton biomass in the Bering Sea (and elsewhere); as such, they are the principal water-column consumers of phytoplankton (Heinrich 1962).

A considerable amount is known about the copepod communities on the outer and middle portions of the shelf of the southeastern Bering Sea. In the outer portions of the shelf (> 100 m deep), large copepods (e.g., *Neocalanus cristatus*, *N. plumchrus*, and *Eucalanus bungii*) dominate (Fig. 4.7) and are efficient at grazing phytoplankton because they are present in large numbers at the beginning of the spring phytoplankton bloom, having overwintered in deep waters. The middle shelf (50-100 m deep) is hydrographically isolated from the deep waters beyond the shelf break; the copepods in the middle shelf are mainly the smaller *Pseudocalanus* spp., *Calanus marshallae*, *Oithona similis*, and *Acartia longiremis* that enter the spring phytoplankton bloom in small numbers, having overwintered on the

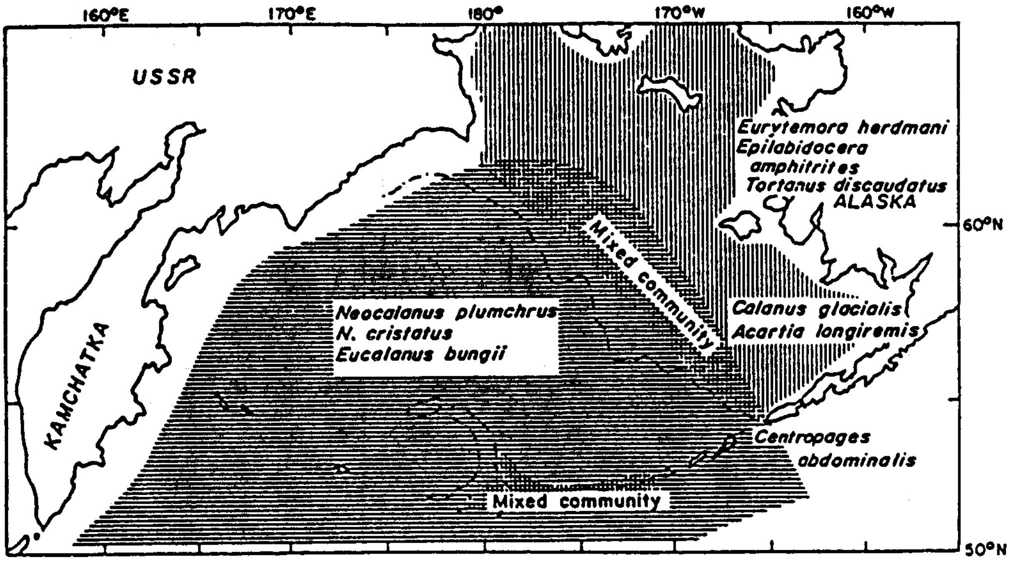


Figure 4.7. Dominant copepod species in various parts of the Bering Sea in early to mid-summer (adapted from Motoda and Minoda 1974).

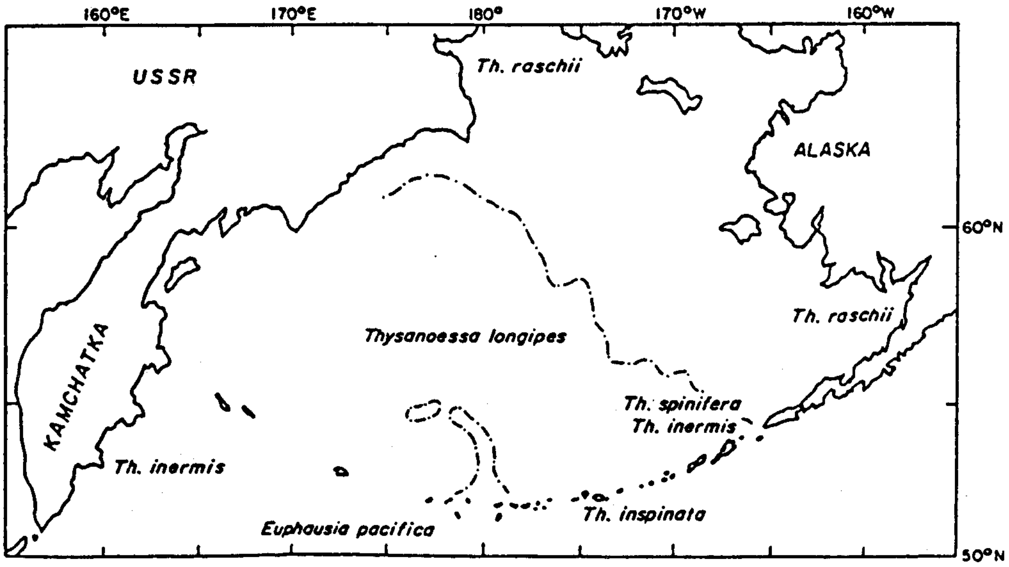


Figure 4.8. Dominant species of euphausiid in various parts of the Bering Sea (from Motoda and Minoda 1974).

shelf. Their populations are not able to grow quickly enough to graze the phytoplankton efficiently (Motoda and Minoda 1974, Dagg 1982, Cooney and Coyle 1982). As a consequence of these differences between outer shelf and middle shelf copepod communities, the outer shelf supports a mainly pelagic food web but the middle shelf supports a relatively large benthic food web fueled by the large amount of sinking phytoplankton.

Little is known about the species composition or grazing efficiency of the copepod community inside the 50-m isobath. The species composition is, at times, similar to that of the middle shelf. Further, because the waters here probably are not strongly isolated from those of the deep parts of the North Pacific and/or the Bering Sea (see Schumacher and Moen 1983), large, deep-water species that are efficient grazers also spill into the area from the middle and outer shelf.

Given the early spring population levels of copepods in various places, low temperatures, rather than food scarcity, are suspected to limit their annual productivity. Dagg (1982) found that, after the water warms in the spring and the phytoplankton bloom begins, many copepods are saturated with food until late fall. This is particularly true of the smaller copepods such as those found in the middle shelf domain; they require a lower food concentration to obtain a maximum daily ration than do the larger, outer-shelf copepods.

4.3.3.2 Euphausiids

Euphausiids on the NAS are major components of the diets of mammals (minke whale), birds (shearwaters, black-legged kittiwakes), and fishes (salmon, herring, capelin, sand lance, pollock, yellowfin sole). The principal euphausiid in diets of nearshore consumers is probably Thysanoessa raschii, which tends to be dominant in the less saline coastal waters (Fig. 4.8) (Ponomareva 1966). Thysanoessa inermis is also sometimes important on the NAS.

Most of the abundant, high-latitude euphausiids are omnivorous to varying degrees (Mauchline and Fisher 1969). Dagg (1982) showed that, in the southeastern Bering Sea, Thysanoessa individuals eat phytoplankton at most times and places, but can derive most of their ration from phytoplankton only if phytoplankton standing crops reach bloom levels. At sub-bloom levels, they consume relatively more copepods, crustaceans, and eggs of other organisms. Because they can switch food sources, they can persist through much of the summer despite declines in phytoplankton production (Dagg 1982).

Euphausiids in general, and Thysanoessa in the Bering Sea (Dagg 1982), tend to aggregate in large swarms, to become stratified in the water column, and to migrate vertically on a diurnal time scale. Typically, T. raschii and T. inermis migrate toward the surface at night and to the bottom during daylight hours (Dagg 1982), except during the breeding season in late spring and early summer, when they may swarm at the surface both day and night (Ponomareva 1966).

Dagg (1982) suggests that Thysanoessa populations need relatively high densities of food (phytoplankton, copepods, etc.) to maintain themselves. Under other than bloom conditions, they may be able to find high densities only where natural phenomena (ocean currents, etc.) concentrate the food.

Euphausiids probably figure prominently in Bering Sea carbon budgets, and may form a significant portion of total zooplankton biomass, especially on the middle shelf and perhaps in coastal waters (Vidal and Smith 1986).

4.3.3.3 Amphipods

Amphipods important in the diets of vertebrates on the shelf of the southeastern Bering Sea include pelagic hyperiid species (Parathemisto libellula, P. pacifica) and benthic species (corophiids, gammarids and Anonyx spp.) (Feder and Jewett 1981). Parathemisto spp. are common pelagic species of the nearshore zone (Armstrong et al. 1984, Modota and Minoda 1974) (Fig. 4.9); P. libellula appears to be the most common (Lewbel 1983, Motoda and Minoda 1974). Parathemisto libellula is important in vertebrate diets; Hunt et al. (1981) reported that over 60% of the fall diet of short-tailed shearwaters in the Bering Sea was P. libellula, and that murres and black-legged kittiwakes frequently consumed large amounts of this species. Benthic amphipods are common in the diets of some fishes, especially benthic fishes such as yellowfin and rock sole.

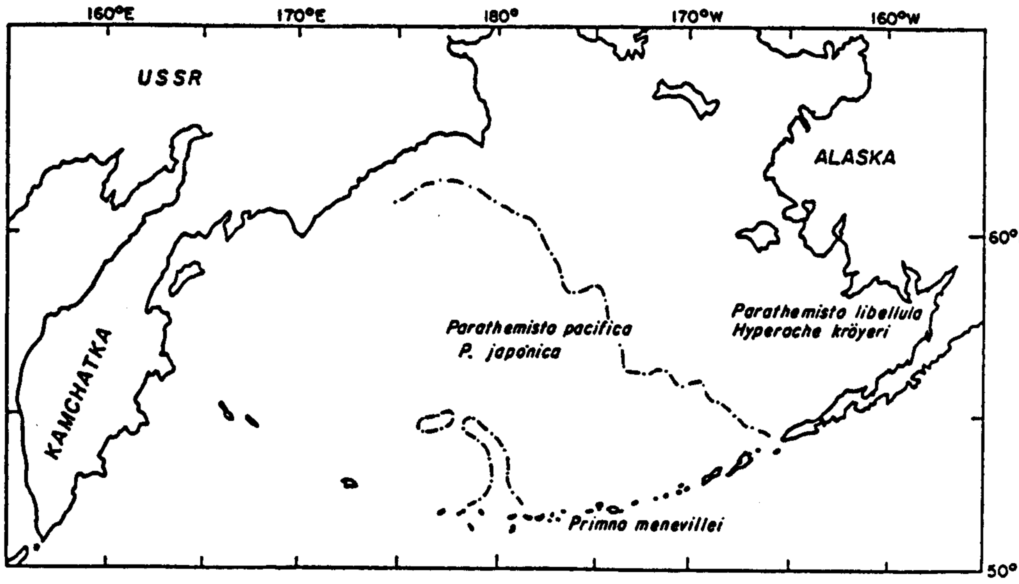


Figure 49. Regional differences in dominant species of amphipods in the Bering Sea in early to mid-summer (from Motoda and Minoda 1974).

4.3.3.4 Bivalves

Bivalves are important in the diets of yellowfin sole, sea ducks, walruses, and sea otters; they also dominate nearshore infauna biomass (Armstrong et al. 1984). Abundant bivalve species on the NAS include Tellina lutea, Macoma calcarea, Cyclocardia crebicostata, Spisula polynyma, and Siliqua patula (Armstrong et al. 1984, Cimberg et al. 1984, McDonald et al. 1981). Bivalves are, in general, patchily distributed on the NAS. A few species (e.g., Spisula polynyma, Tellina lutea) are so highly clumped in local situations that commercially viable quantities can be harvested by clam dredge (McDonald et al. 1981). Each species tends to be distributed according to specific sediment types (McDonald et al. 1981). Sediments in the NAS nearshore zone are relatively coarse (sand size and larger) (see previous Section 4.3.1), and thus sustain bivalve populations adapted to coarse-grained substrates.

Bivalves identified as important prey for otters, yellowfin sole, and walruses on the NAS include Macoma, Cyclocardia, and Siliqua, Spisula, and Tellina, respectively (Cimberg et al. 1984, Lowry et al. 1982). Most of these bivalves are suspension feeders, though Macoma and Tellina are able to function as deposit feeders as well (Feder and Jewett 1981, McDonald et al. 1981, Stoker 1981).

4.3.3.5 Intertidal Animals

Exposed sand beaches, the predominant shoreline type in the NAS, appear to harbor very sparse populations of infaunal animals. O'Clair et al. (1981) found no infauna on a sand beach on Operl Island, and only a few polychaetes on Cape Glazenap. Very low densities of infaunal animals are a feature of shorelines that are exposed to ice and heavy wave action (Thomson et al. 1986).

Intertidal soft (mud) substrates within the protected confines of Port Moller, Moffet Lagoon and Izembek Lagoon support an abundance of infaunal animals, especially bivalves and polychaetes (O'Clair et al. 1981). Infaunal biomass within lagoons may reach 1000 g/m^2.

Exposed bedrock and boulder substrates in the NAS support substantial biomasses of seaweed and animals as documented by O'Clair et al. (1981) from samples collected at Cape Mordvinof and Cape Lapin on Unimak Island, and on Amak Island. _Fucus_, _Alaria_ and other seaweeds, and mussels, barnacles, and limpets are common on these rocky substrates. Mean density of mussels was 229 individuals/m^2 at the two lowest strata sampled at Cape Sapin by O'Clair et al. (1981). Distribution of these rocky shoreline substrates and their associated biota is limited to the Cape Mordvinof, Cape Seniavin, and Amak Island areas, and a few other isolated spots in the study area (Fig. 4.1).

4.3.3.6 Other Groups

Although copepods, euphausiids, amphipods, and bivalves appear to be the most important invertebrates in food webs of the species of immediate interest to people, other groups are sometimes important. Polychaetes, mysids, shrimps, red king crab, and sand dollars are frequently reported as important foods for species such as rock sole (polychaetes), pollock (mysids), Pacific cod and gray whale (shrimps), and sea otters (king crab, sand dollar).

4.4 METHODS

Zooplankton samples were collected at the 20-, 35- and 50-m stations on each transect (Fig. 1.2). Additional samples were collected at 75- and

100- m depths on Transects 4 and 5. At each station, oblique and horizontal tows (10 min duration) were made with paired bongo nets (0.6 m diameter with 333-and 505-micron meshes) equipped with General Oceanics 2030 flowmeters. Samples were preserved in 10% formalin on board ship.

In the laboratory, zooplankton samples were sorted to major taxonomic category and weighed on a Mettler PT 200 electronic balance (± 1 mg). When subsampling was necessary, large animals were picked out of the entire sample and the remaining portion of the sample was mixed and subsampled by weight. In some samples, copepods were identified to species.

Infaunal animals were collected with a 0.1-m^2 Van Veen grab operated from the ship in water depths >30 m. Animals collected in the grab were rinsed through nested 5.6-mm and 1-mm screens and preserved in 10% formalin on board ship. Epifaunal animals were collected in the trynet bottom trawl (see Section 5.0, this report), an epibenthic sled, and a drop net. The epibenthic sled consisted of a rectangular (76 x 35.5 cm) box with a 2-mm-mesh net, mounted on steel runners such that the bottom of the box was 11.5 cm off the bottom. It was towed from the Monark launch for 10 min at depths of 3, 5, 10, 20 and 50 m. A modified Clutter (1965) drop net was used to sample epibenthic invertebrates from the Zodiac launch at depths of 3, 5, and 10 m. The net was 0.5 m in diameter and 0.75 m high, with a 1.0-mm-mesh net that pursed at both ends. In most cases, starfish and crangonids were counted and weighed on board ship and then discarded. Other invertebrates were preserved in 10% formalin.

In the laboratory, benthic invertebrates were identified and weighed on a Mettler PT 200 electronic balance (± 1 mg).

Jellyfish were collected in a Marinovich midwater trawl (see Section 5.0, this report). The catch was dumped into a 800-L square container, and the volume was estimated by measuring the depth of the catch in the container.

Microprocessor-controlled LORAN C receivers on the ship and the launch were used to determine position and distance towed for the sled and trawls.

Data analysis was performed on an IBM PC-AT microcomputer equipped with a 20-MB hard disk, using programs developed by LGL, Lotus 123, and the BMDP statistical software package (IBM PC version). Zooplankton species assemblages were identified with the BMDP4M factor analysis program (Dixon 1981). Before factoring, a logarithmic transformation was applied to density data (log [no./m^3 + 1]) in order to reduce the skewness inherent in such data. The correlation matrix of transformed species abundances was calculated, principal components were extracted from this matrix, and factors were generated by Varimax rotation. Four factors were considered (nine principal components had eigenvalues >1); these four factors accounted for 79% of the variance among the 12 species variables. Each factor represents a group of species that tended to occur together. A measure of the abundance of each species assemblage in a particular sample was obtained by calculating the corresponding factor score. A factor score is a linear additive function of the original variables, with each variable weighted in proportion to its correlation with the factor. A high factor score indicates that the group of species represented by the factor is common in the sample in question, and a low or negative factor score indicates that those species are rare or absent.

Cimberg et al. (1984) collected 103 grab samples on the NAS at depths of 10 m to 60 m and presented density data for each sample. A rough estimate of the biomass contained in each of their samples was made by multiplying the mean density of each taxon in each sample by an estimate of the mean weight of an individual of that taxon. Mean weight was determined using the 29 grab samples analyzed during the present study.

A Ross Fineline 100 kHz and a Simrad EQ 39 kHz echosounder were run during plankton tows, trawls and continuous bird and marine mammal surveys. The echosounder tapes were marked at the beginning and end of trawls and plankton tows, as well as every 10 min during continuous surveys. At these times, the ship's course, speed and position, and the water depth were noted.

Forbes and Nakken (1972) noted that zooplankton abundance is proportional to the squared value of the intensity of registration on the echogram. We established a system of visually grading the echograms against 'standards' that reflected increasing densities of echo. With care, this method can provide reasonably unbiased estimates of echo abundance (Forbes and Nakken 1972).

The standard against which echograms were compared consisted of a 10-level (0-9) ordinal scale graduated by echo density. For each of the 10 levels, three examples were selected from locations where echo (zooplankton) density appeared similar (Fig. 4.9). Each segment corresponded to a 10-min time interval.

A jig was designed to restrict visual reference to one rectangle of sounder tape. This jig covered an area of approximately 1-2 m by 100 m during tows and trawls and 1-2 m by 600 m during continuous surveys. For continuous surveys, an estimate of hydroacoustic echo density was made in each 10-m depth stratum at the beginning, middle, and end of each 10-min segment. Depending on water depth, between 9 and 30 rectangles were coded for each segment. For tows, measurements were made at the depth of tow at the beginning, middle, and end of the tow.

Echosounder tapes recorded during plankton tows (100 kHz) and trawls (38 kHz) were coded by two independent observers as a check on reproductivity of coding procedures. There was close correspondence between readings made by the two observers, as shown below.

	Frequency	Mean Reading + SD		Correlation	Sample
Sample Type	(kHz)	Reader 1	Reader 2	Coefficient	Size
Trynet tows	38	1.93±1.45	1.82±1.50	0.97	33
Marinovich tows	38	2.08±1.72	2.05±1.74	0.97	61
Plankton tows	100	1.99±1.38	2.08±1.46	0.96	57

4.5 RESULTS AND DISCUSSION

4.5.1 Zooplankton (Other Than Jellyfish)

In the following sections, zooplankton communities are characterized in terms of biomass (wet weight) distributions, taxonomic composition, and relationships to various water masses. Comparisons are made between NAS communities and those of adjacent areas. Trophic relationships of the zooplankton are discussed. Gelatinous zooplankton (jellyfish) are not included in this section, but are discussed separately in the following Section 4.5.2.

4.5.1.1 Distribution of Biomass

Total zooplankton biomass was low and relatively constant from January to May 1985, and was similar in May 1984 and 1985 (Table 4.1).

Biomass was highest in July (Table 4.1), presumably representing a delayed response to the spring phytoplankton bloom which began in April (see Section 3.0, this report). The lowest zooplankton biomass was found in September. Primary production was still high in September (see Section 3.0, this report), so it seems likely that predation on zooplankton caused the low standing crop in September (see Section 8.0, this report).

Although zooplankton biomass in samples was greatest in July, the peak in biomass could have occurred in June. (Sampling was not conducted in June.) On the outer Bering Sea shelf, zooplankton biomass is typically highest in May and declines in early June; on the middle shelf biomass is low in May but increases in late May and early June (Vidal and Smith 1986).

There was no apparent annual trend in the spatial distribution of total zooplankton biomass, but some patterns were evident within seasons (Fig. 4.10). In May 1984, biomass declined from west to east; this same trend was evident also in May 1985 (except for an anomalously high biomass on Transect 6 near the east end of the study area). In May, July, and September, total zooplankton biomass was higher at the deeper stations than at the shallow stations (Table 4.2), but in winter (January), biomass was highest in shallow water. These patterns may be a consequence of infusions of shelf-break and middle-domain zooplankton communities into the study area at western and deeper parts, respectively. This is discussed further in Section 4.5.1.3.

The total biomass of zooplankton on the NAS was low in all seasons when compared with that occurring in offshore waters of the Bering Sea and other marine areas (Table 4.3). Even areas at appreciably higher latitudes in North America (Beaufort Sea, Lancaster Sound) have larger standing stocks of zooplankton.

4.5.1.2 Taxonomic Composition

For all 6 cruises combined, copepods accounted for 33% of the mean biomass in all oblique bongo tow samples. Euphausiids were the next most abundant group (25% of total biomass), followed by chaetognaths (22%), decapod larvae (6%), eggs (5%), fish larvae (3%), and larvaceans (3%).

There was considerable seasonal variation in both relative and absolute biomass of the various zooplankton taxa (Figs. 4.11 and 4.12).

Table 4.1. Mean biomass (mg/m^3 wet weight ± SD) of all zooplankton except jellyfish in oblique bongo net tows on six cruises on the NAS.

	Cruise					
	1984		1985			
	May	Sep	Jan	Apr	May	Jul
Total biomass	39 ± 44	15 ± 12	51 ± 71	32 ± 26	36 ± 35	143 ± 121
Sample size	19	19	9	10	9	13

Table 4.2. Mean biomass (mg/m^3 wet weight ± SD) of all zooplankton except jellyfish in oblique bongo net tows over two depth ranges on the NAS.

	Cruise					
	1984		1985			
Depth Range (m)	May	Sep	Jan	Apr	May	Jul
Biomass						
20	24 ± 27	10 ± 9	68 ± 90	30 ± 35	16 ± 22	75 ± 93
35-50	49 ± 51	18 ± 14	30 ± 37	35 ± 17	61 ± 32	221 ± 106
Sample size						
20	8	7	5	5	5	7
35-50	11	12	4	5	4	6

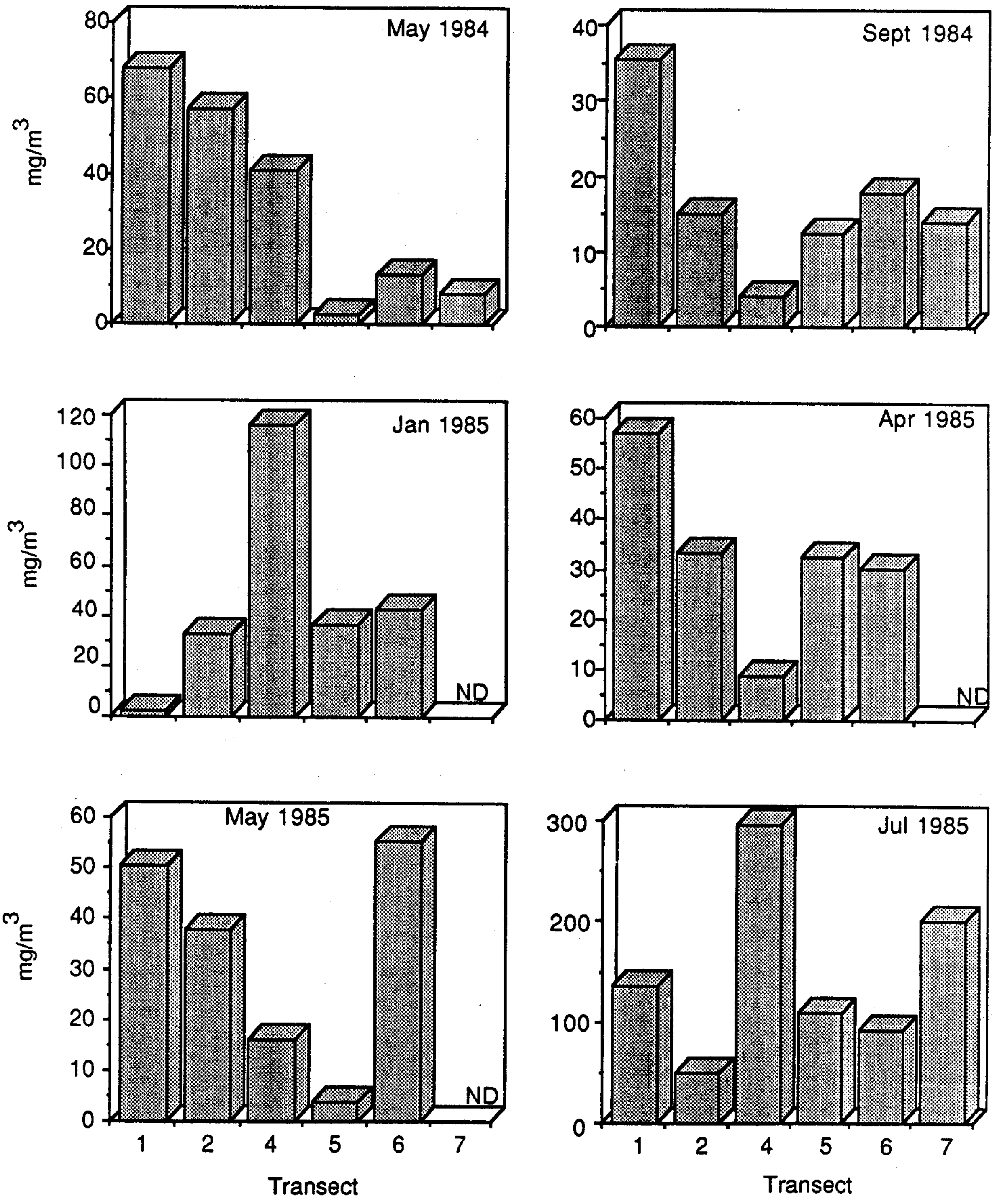


Fig. 4.10. Total biomass of zooplankton in oblique bongo net tows at water depths of 20 to 50 m at six sampling times on seven transects on the North Aleutian Shelf, Alaska. (Jellyfish and ctenophores are not included in the total. See Fig. 1.2 for transect locations.). ND means no data.

Table 4.3. Biomass of zooplankton on the NAS and in other marine areas. Based on oblique or vertical tows in the upper 50 to 150 m of the water column.

Location	Time of Year	Biomass (mg/m^3 wet weight)	Reference
Bering Sea			
North Aleutian Shelf	Sep-May	15-51 (40-166)[a]	This study
	July	143 (238)[a]	This study
Bristol Bay	Summer	849	Ikeda and Motoda (1978)
Central Water	Summer	529	Ikeda and Motoda (1978)
Northern	Summer	1117	Ikeda and Motoda (1978)
Beaufort Sea			
Alaskan	Sep	244	Griffiths et al. (1986)
Canadian	August	150-476	Griffiths and Buchanan (1982)
Canadian	August	210	Bradstreet and Fissel (1986)
Lancaster Sound	August	400	Sekerak et al. (1979)
North Atlantic			
Slope	Summer	430-1600	Riley and Gorgy (1948)[b]
Subarctic	Spring	300-700	Be' et al. (1971)
Sargasso Sea		<25	Be' et al. (1971)
North Pacific			
Northern	Summer	244	Ikeda and Motoda (1978)

[a] Numbers in parentheses include jellyfish.
[b] In Be' et al. (1971).

For example, in May 1984, euphausiids were the dominant group, with a biomass of over 26 mg/m^3. They were very rare in the plankton in September, when copepods were dominant. Chaetognaths were the dominant group in both January and April 1985, but accounted for only 11% of total biomass in July. Both copepod and euphausiid biomass (absolute and relative) fluctuated more than an order of magnitude between highs and lows.

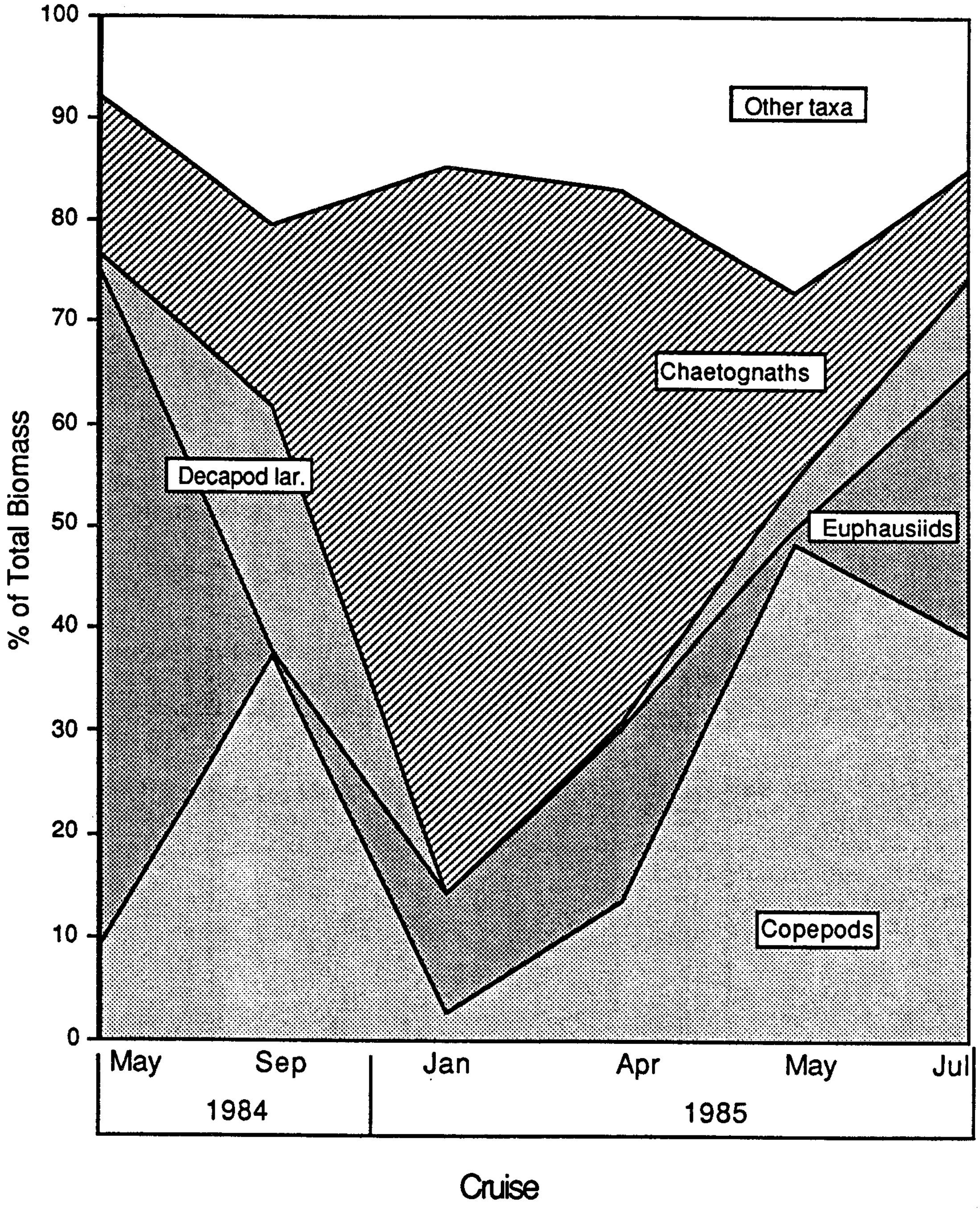


Fig. 4.11. Percent contribution of various zooplankton taxa to total biomass taken in bongo tows at water depths of 20 to 50 m during six cruises on the North Aleutian Shelf, Alaska. (Jellyfish and ctenophores are not included.)

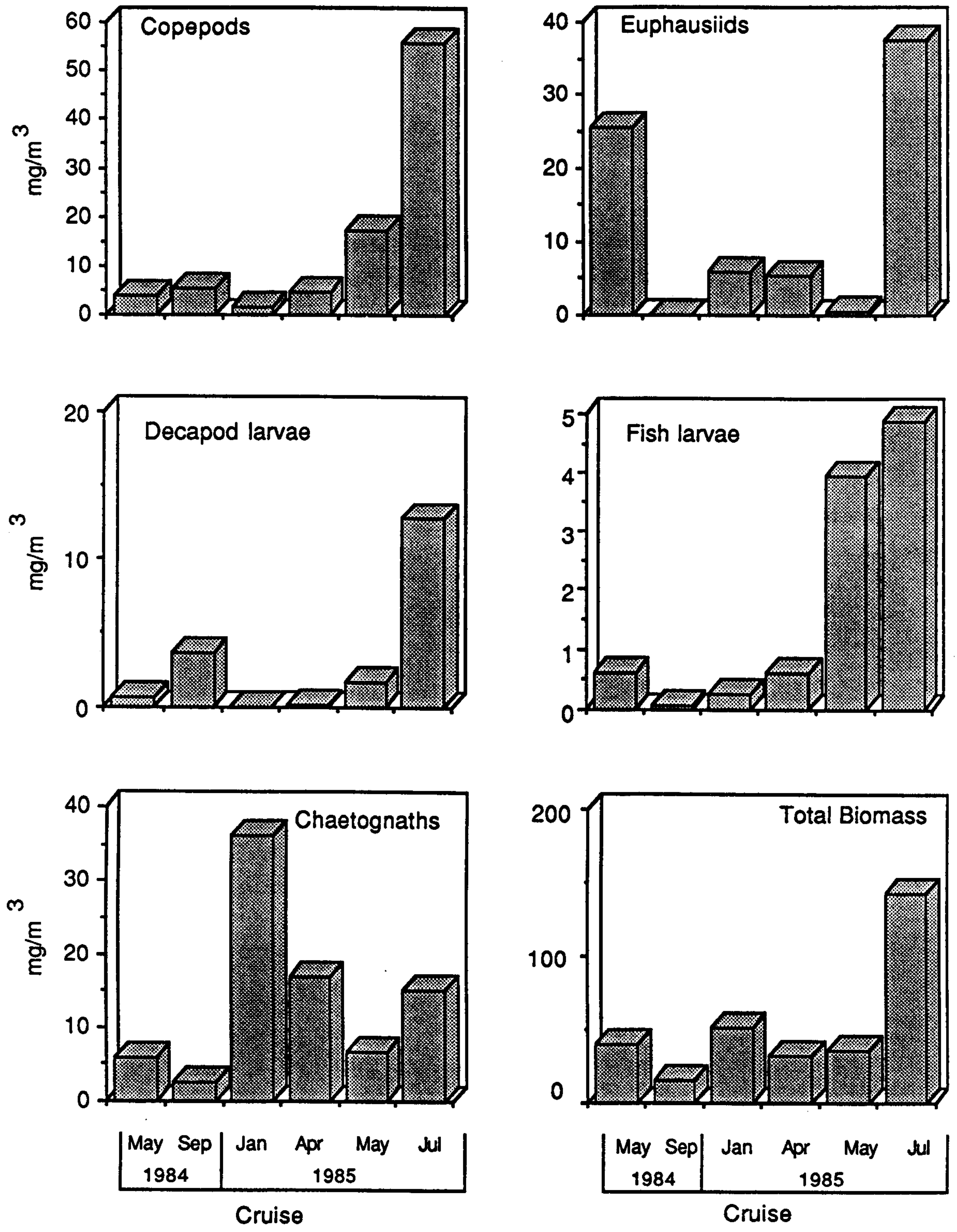


Fig. 4.12. Biomass of dominant zooplankton taxa taken in oblique bongo net tows at water depths of 20 to 50 m during six cruises on the North Aleutian Shelf, Alaska. (Jellyfish and ctenophores are not included in total biomass.)

Annual variability in biomass was likewise large. Euphausiids were scarce in May 1985 in comparison with their relative and absolute abundance in May 1984; copepods, on the other hand, were more abundant in May 1985 (Figs. 4.11 and 4.12). Biomass of fish larvae increased continuously from September 1984 through July 1985; it was several times higher in May 1985 than in May 1984.

Seasonal changes in relative and absolute biomasses of taxa are readily explainable in some cases. The dietary dependencies and life cycles of copepods suggest that they would increase from a winter-spring low to a midsummer high. Seasonal changes in behavior of euphausiids (breeding at the surface in late spring/early summer; descending to deep water at most other times) suggest that they would be more readily caught in the shallow waters of the NAS in late spring and early summer. Increased abundances of zooplankton predators (e.g., chaetognaths, fishes, birds) in summer would suggest a potential decline in zooplankton prey (copepods, euphausiids) by fall. The copepod-eating chaetognaths, not common as prey for other organisms, would be expected to reach highest biomasses in fall and winter.

Reasons for the observed annual changes in biomass of some taxa (see above) are less obvious. However, annual changes in total zooplankton biomass were very small; total biomass of spring 1984 (May) was about equal to that of spring (April, May) 1985. Some possible causes of variability in taxonomic composition of the zooplankton of the NAS are discussed in Section 4.5.1.3 below.

4.5.1.3 Copepods and Water Masses

There is a juxtaposition of four water masses in the vicinity of the NAS--the coastal, middle shelf, outer shelf, and oceanic domains. The study area itself has been presumed to be almost wholly within the coastal domain (Fig. 4.13). Evidence from physical oceanography (Section 2.0, this report) and primary productivity (Section 3.0, this report) suggest that intrusions of one or more of the other water masses into the study area are common. Because zooplankton are more or less passively transported, frequent occurrences in the study area of zooplankton assemblages not characteristic of the coastal domain support the idea that

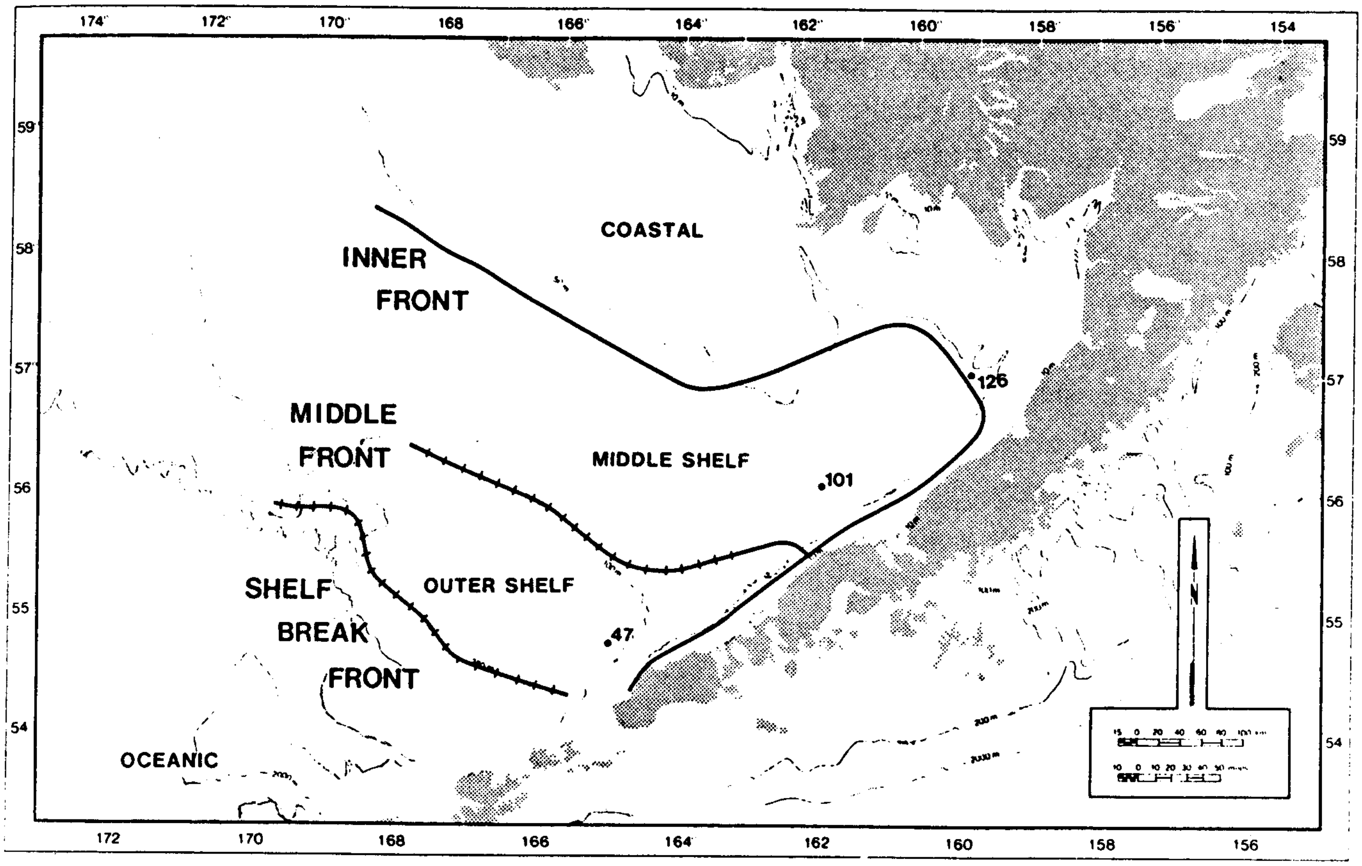


Fig. 4.13. Hydrographic domains and fronts in the southeastern Bering Sea. (From Kinder and Schumacher 1981)

other water masses are intruding. In the following paragraphs, we evaluate the use of zooplankton as tracers of water masses and discuss zooplankton distribution as evidence for intrusions of water from the middle shelf, outer shelf, and oceanic domains into the study area.

Copepods in particular, but also euphausiids, are useful as tracers of water masses. Different domains have different dominant species groups, frequently with different life history patterns (see Mitoda and Minoda 1974, Cooney 1981). A brief analysis of copepod species assemblages and life cycles on the NAS and their associated habitat requirements in offshore waters will illustrate this point. This has already been addressed briefly in Section 4.3.3.1.

The oceanic community is dominated by the large copepods *Neocalanus cristatus*, *N. plumchrus*, *Eucalanus bungii*, and *Metridea pacifica*. These large copepods must overwinter at ocean depths beyond the shelf edge; they migrate upward in large numbers in spring to take advantage of phytoplankton blooms at the surface. The shelf community (including middle and, to some extent, inner shelf domains) is dominated by the small copepods *Acartia longiremis*, *Pseudocalanus* spp., and *Oithonia similis* that overwinter on the shelf, surviving in low numbers until spring. Outer shelf waters adjacent to ocean depths contain a mixture of these dominants in summer. Very near the coast, another copepod community typically occurs; the composition of this community on the NAS is strongly influenced by the transport of Alaska Coastal Current water through Unimak Pass and into the study area (see Cooney 1981).

Calanus marshallae is the only large-sized copepod that reproduces in the middle shelf domain (Vidal and Smith 1986). It also appears to reproduce on the NAS, where it overwinters as adults and Stage V copepodites. *Calanus marshallae* may produce two cohorts per year (Smith and Vidal 1986). We found copepodites II and III on the NAS in April and May 1985. By July 1985, stage II was absent and a large proportion of stage IV were present. In September 1984 only stage IV and V were present (Fig. 4.14). The life cycle of this species on the NAS during 1984 and 1985 was similar to its life cycle on the middle shelf (see Smith and Vidal 1986, Vidal and Smith 1986).

Neocalanus plumchrus is a dominant copepod of the outer shelf domain; it penetrates the middle shelf only in small numbers. On the outer shelf

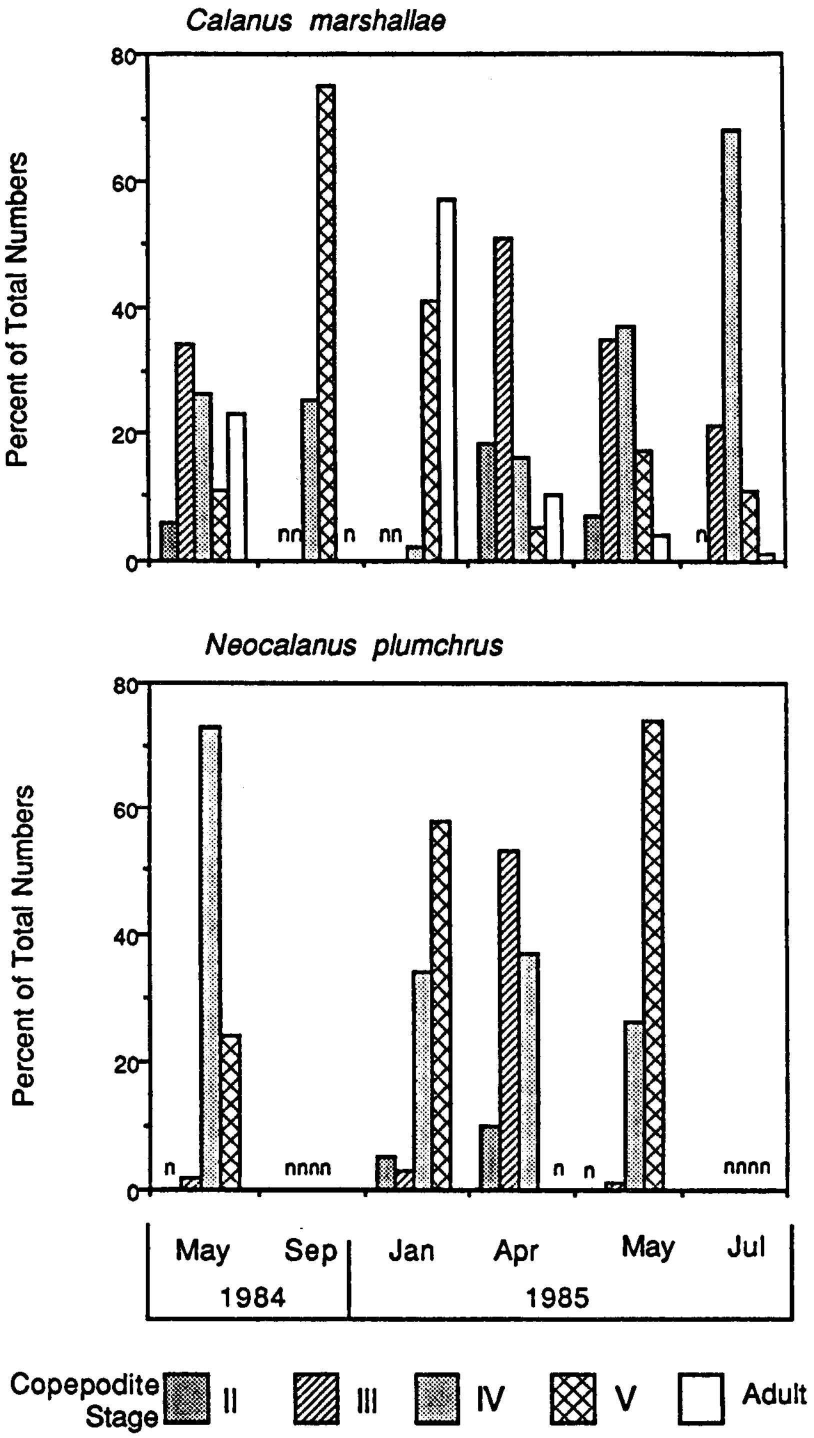


Fig. 4.14. Relative abundance of life stages of two copepod species during six cruises on the North Aleutian Shelf, Alaska, expressed as a percent of the total number of each species collected. N means none collected.

and slope, it appears to complete its life cycle by the end of May, at which time the population descends to deep (>300 m) water (Smith and Vidal 1986). On the NAS, stages II and III were common in January and April and rare in May (Fig. 4.14). By May, most individuals had matured to stages IV and V, and by July, C. plumchrus was absent from the NAS.

We analyzed zooplankton samples from the NAS in an attempt to determine their water mass affiliations. Species identifications were carried out for copepods in oblique bongo net samples taken at 20 and 50 m on Transects 2 and 6 and at one offshore (depth >50 m) station. Calanus marshallae was the most common copepod in the samples, followed by Acartia longiremis and Pseudocalanus minutus (Table 4.4).

Factor analysis was used to identify recurrent copepod assemblages (see Appendix 4A for details). Each factor shown on Table 4.5 represents an assemblage of copepod species that occur together. The community affinities (oceanic, middle shelf, etc.) for each of these species are also shown.

Factor one, representing Pseudocalanus spp., Acartia longiremis, Calanus marshallae, and two other species, is characteristic of water masses that contain a mixture of oceanic, middle shelf and coastal water. The second factor represents an assemblage of species that are characteristic of the nearshore domain. The third factor, representing Neocalanus cristatus, N. plumchrus, and one other species, is characteristic of oceanic offshore waters. The fourth factor, representing Eucalanus bungii and Calanus marshallae, is also characteristic of oceanic offshore water.

The dominant assemblage for each transect/depth/cruise combination was determined through an analysis of the factor scores (see Section 4.4, this report). The results (Table 4.6) show that different zooplankton assemblages were predominant during various time periods, and that during some time periods, the distribution of assemblages in the study area was quite heterogeneous.

Zooplankton distributions indicate that intrusion of middle shelf water onto the NAS study area occurred during most of the cruises, but was generally confined to the portion seaward of the 40-m contour. The evidence indicates that this intrusion was most pronounced in May 1984 and July 1985. In May 1984, there was oceanographic evidence that intrusion

Table 4.4. Mean density (no./100 m^3) of copepod species in oblique bongo tows during six cruises on the NAS.

	Cruise							
Species	May 84	Sep 84	Jan 85	Apr 85	May 85	Jul 85	Mean	% of Total
Calanus marshallae	120	2	96	284	1604	7436	1590	38.3
Calanus sp. (small)	66	0	43	63	0	0	29	0.7
Neocalanus cristatus	4	0	0	3	18	0	4	0.1
Neocalanus plumchrus	259	1	19	174	478	0	155	3.7
Mesocalanus tenuicornis	1	0	6	0	2	0	1	0.0
Eucalanus bungii	0	1	7	0	7	362	63	1.5
Pseudocalanus spp.	117	3	0	647	2255	961	664	16.0
Metridia pacifica	4	2	3	69	77	891	174	4.2
Scolecithricella minor	0	0	0	0	0	2	0	0.0
Eurytemora herdmani	0	5	0	31	2	36	12	0.3
Centropages abdominalis	0	753	0	4	10	923	282	6.8
Epilabidocera longipedata	0	60	9	0	0	2	12	0.3
Acartia longiremis	19	41	5	740	1164	3281	875	21.1
Acartia tumida	17	0	0	1	179	828	171	4.1
Tortanus discaudatus	0	481	1	3	2	185	112	2.7
Unidentified Calanoid	3	16	0	1	0	18	6	0.2
Calanidae	0	0	0	0	0	0	0	0.0
Lubbockia sp.	0	1	0	0	0	0	0	0.0
Oithona spinirostris	0	0	0	1	3	0	1	0.0
Oithona sp.	0	1	0	0	10	0	2	0.0
Total	609	1367	188	2020	5809	14925	4153	100
Sample size	4	4	5	5	5	5	28	

Table 4.5. Results of a factor analysis of the 12 most common zooplankton species in 28 oblique bongo net samples from the NAS, Alaska during six cruises in 1984 and 1985. The values shown are the correlations between the log transformed densities of various species (the original variables) and each of the four factors determined in the analysis. Species whose densities were weakly correlated with a factor ($r < 0.4$) are not shown. Also shown are the community affinities of each species according to Cooney (1981).

Factor 1. Mixed (oceanic/shelf/coastal)		Community affinities *
Pseudocalanus spp.	0.924	O/M
Acartia longiremis	0.842	M
Calanus marshallae	0.733	M
Metridia pacifica	0.659	O
Acartia tumida	0.551	
Factor 2. Nearshore		
Centropages abdominalis	0.937	N
Totanus discaudatus	0.824	N
Epilabdocera longipedata	0.571	Coastal in N. Pacific
Eurytemora herdmani	0.424	N
Factor 3. Oceanic 1 (oceanic/outer shelf)		
Neocalanus cristatus	0.902	O
Neocalanus plumchrus	0.879	O
Acartia tumida	0.415	
Factor 4. Oceanic 2 (oceanic/outer shelf)		
Eucalanus bungii	0.723	O
Calanus marshallae	0.482	M

* O = Oceanic, outer shelf. M = Middle shelf, coastal. N = Nearshore.

Table 4.6. Dominant copepod assemblages at selected stations on the NAS. Assemblages were determined through a factor analysis of the density of the most common copepod species. The dominant assemblage(s) were determined through consideration of the factor scores for each sample. N = 1 for each cruise, transect depth combination.

		Cruise					
Transect	Depth	May 1984	Sep 1984	Jan 1985	Apr 1985	May 1985	Jul 1985
2	20	Oceanic1	Nearshore	Oceanic2	Mixed	Mixed	Nearshore/Oceanic2
	50	Oceanic1	Nearshore	Oceanic2	Oceanic2	Oceanic1	Oceanic2
6	20	*	Nearshore	*	Mixed	Mixed	Nearshore
	50	Mixed	*	Oceanic2	Mixed	Mixed	Mixed/Nearshore
1 and 4	>50	ND	ND	Oceanic2	Oceanic1	Oceanic1	Oceanic2

ND means no data.
* No score >0.

Table 4.7. Number of 10 minute segments of 38 kHz and 100 kHz echosounder tapes that were coded, total distance represented by the coded data and mean coded value for five cruises on the NAS.

	38 kHz			100 kHz		
Date	Distance (km)	No. of Segments	Mean Value ± SD	Distance Covered (km)	No. of Segments	Mean Value ± SD
May 1984	239	82	0.4 ± 0.6	160	57	3.6 ± 1.1
Sep 1984	559	172	2.1 ± 1.0	594	183	1.8 ± 0.8
Jun 1985	259	70	1.2 ± 0.9	252	66	1.1 ± 0.7
May 1985	805	217	1.5 ± 0.8	351	95	2.2 ± 0.7
July 1985	464	114	2.4 ± 0.9	464	114	3.5 ± 0.9

of offshore water occurred in the western portion of the study area to the 20-m contour (see Section 2.0, this report). At the same time, copepods associated with oceanic waters were found at 20- and 50-m depths on Transect 2 (west) but not on Transect 6 (east), and high biomasses of euphausiids were found in the western portion of the study area, but not in the east (Fig. 4.15). (Sampling evidence suggests that euphausiids are much more abundant in the deeper shelf waters than in NAS waters.) Total zooplankton biomass was also highest in the western part of the study area at this time.

The pronounced intrusion of offshore water into the study area in July was also associated with the presence of oceanic copepod assemblages and high biomasses of euphausiids and of zooplankton in general. This intrusion was very strong at the 50-m contour and weak at 20 m (see Section 2.0, this report). The highest biomass of euphausiids was found at 50 m (Fig. 4.15) and total zooplankton biomass at 35-50 m was three times as high as that at 20 m (see Table 4.2).

Water masses present on the NAS in September were typically coastal in nature. Nearshore copepod assemblages predominated at three of four stations sampled on Transects 2 and 6 (Table 4.6). Euphausiids were not found at any of the stations, either because intrusion of water from beyond the 50 m contour was weak or because the euphausiids had migrated to offshore waters (or to benthic habitats when samples were being taken).

In April 1985, the coastal domain extended to the 50-m isobath. Euphausiids were scarce and copepod assemblages representative of a mixed regime were present (Fig. 4.15; Table 4.6) (see Section 2.0, this report). In May 1985, there appears to have been an intrusion of offshore water that was similar in magnitude to that observed in May 1984. In May of both years, this intrusion extended to the 20-m isobath. Despite this similarity, there were substantial differences in the composition of the plankton (Fig. 4.11) and in the species composition of the copepods. In May 1985, *Calanus marshallae*, *Pseudocalanus* sp., and *Acartia longiremis* were the dominant copepods (Table 4.4). In May 1984, *Neocalanus plumchrus* was the dominant copepod and the abundances of *C. marshallae*, *Pseudocalanus* sp., and *A. longiremis* were much lower than in May 1984 (Table 4.4). As shown below, *N. plumchrus* was equally abundant in May of

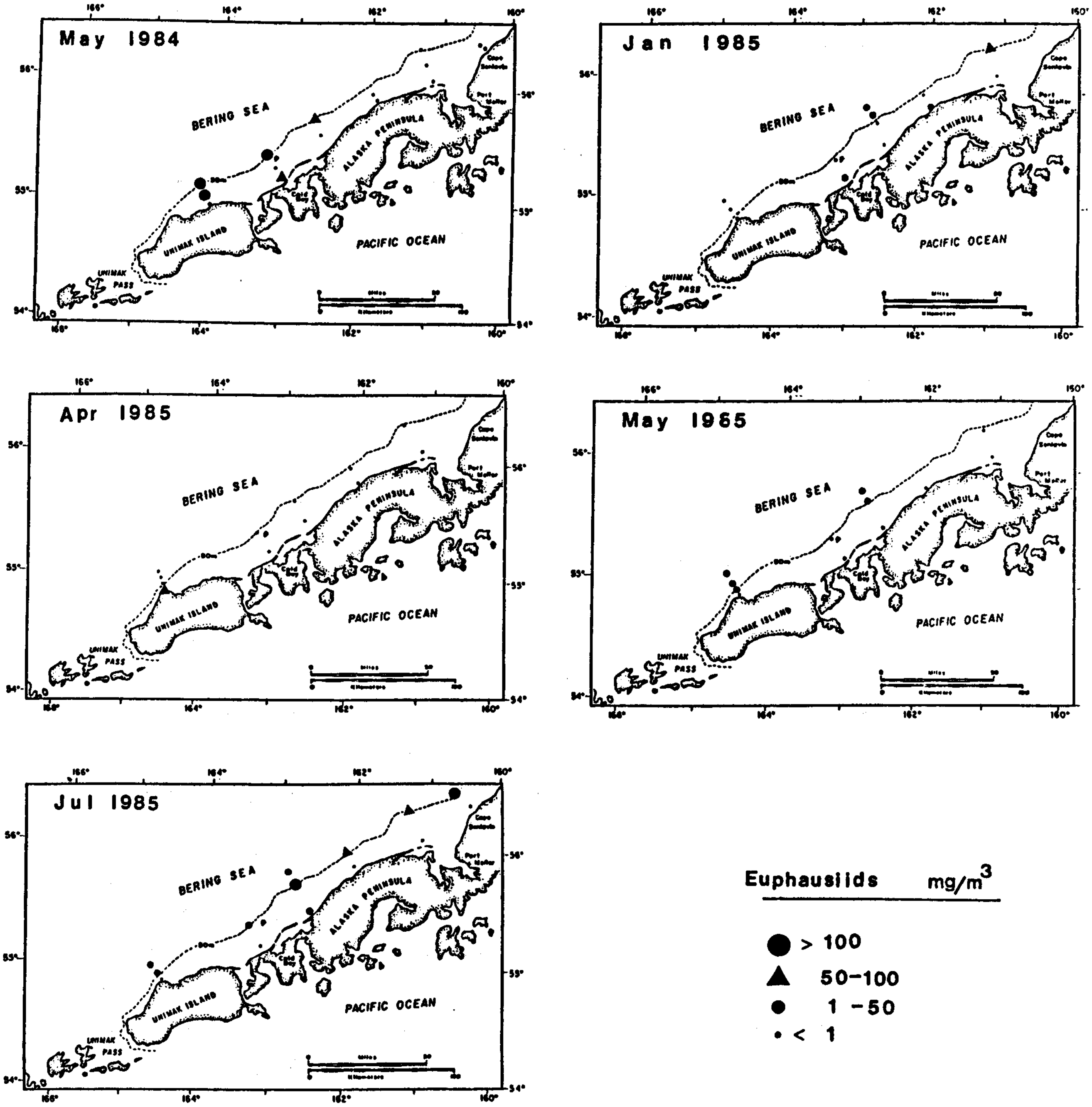


Fig. 4.15. Distribution of euphausiid biomass in oblique bongo net tows during five cruises on the North Aleutian Shelf, Alaska. (Euphausiids were absent in September 1984.)

both years on Transect 2, but the other three species were far more abundant in 1985, especially on Transect 6.

TRANSECT:	2 (West)		6 (East)	
YEAR:	May 1984	May 1985	May 1984	May 1985
Density (no./1000 m^3)				
Neocalanus plumchrus	517	550	1	19
Calanus marshallae	122	265	117	1886
Pseudocalanus sp.	83	309	152	3946
Acartia longiremis	10	1237	27	1071

Neocalanus plumchrus is found on the outer shelf and slope (Smith and Vidal 1986), and is thus indicative of oceanic water intrusion. The other three species are characteristic of the middle shelf, and show the influence of that water mass, especially on Transect 6. On the middle shelf, the abundance of these three species may vary from year to year, depending on thermal conditions in spring (Smith and Vidal 1986). Physically, the intrusion of offshore water appears to have been the same in both years; however, differing conditions on the middle shelf during the two years may have affected the quantities of zooplankton that were advected onto the shelf.

The species composition and abundance of zooplankton on the NAS appear to be determined by (1) the seasonal cycle, (2) the degree of advection of offshore waters, (3) the source of the offshore waters, and (4) conditions in offshore waters. As shown below, predation may also be an important factor structuring nearshore zooplankton communities.

4.5.1.4 Hydroacoustic Sampling of Zooplankton

Hydroacoustic sampling was conducted during most zooplankton tows and during transects conducted for shipboard censusing of seabirds and marine mammals. Hydroacoustic surveys provided information on zooplankton at far more locations than could be sampled during net sampling. However, before the hydroacoustic data can be interpreted, it is necessary to understand the relationships between the hydroacoustic data and amounts of zooplankton estimated during net sampling.

There was a significant positive correlation between the ordinal estimates of echo-intensity and the biomass of zooplankton (not including jellyfish) in horizontal tows ($r = 0.40$, $p<0.01$, df = 62). However, correlations between ordinal estimates of echo-intensity were better for biomass of large zooplankters than for biomass of copepods or gelatinous zooplankton as shown below:

	Correlation Coefficient	P	df
Total	0.40	<0.01	62
Euphausiids, mysids, fish larvae (grouped)	0.45	<0.01	62
Copepods	0.17	NS	62
Chaetognaths	0.08	NS	62
Jellyfish	0.19	NS	62

NS means not significant, P>0.05.

Thus, the coded hydroacoustic data appears to represent mainly the biomass of large non-gelatinous zooplankters.

Using similar methods, Bradstreet and Fissel (1986) obtained a correlation coefficient of 0.77 between coded echo-intensity and total zooplankton biomass. However, they deleted samples taken close to the thermocline. (No samples were deleted in this study.) In addition, they used 200 kHz echosounder. The higher frequency gives a better return from small zooplankters such as copepods.

A total of 515 10-min segments of 100-kHz echosounder data representing 1821 km of ship's track recorded during continuous surveys were coded in the present study (Table 4.7). Mean values of hydroacoustic echo-density were highest in May of 1984 and July 1985 (Table 4.7), months with the highest biomass of euphausiids (Fig. 4.12). Echosounder transects were not run on the three eastern transects in May of 1985 and, thus, mean values for that month are not directly comparable with those recorded for other cruises.

Figure 4.16 shows the distribution of mean values of echo-intensity for each 10-min transect segment (about 3.5 km). Depending on depth, between 9 and 30 values were coded for each segment. Similar mean intensity values have been enclosed by contours. This figure represents the broad-scale distribution of large zooplankters. During most cruises these large zooplankters appear to have been homogeneously distributed throughout the study area.

Figure 4.17 shows the distribution of the maximum of the 9 to 30 values of echo-intensity recorded for each 10-min transect segment. Similar maximum intensity values are enclosed by contours. This figure represents the distribution of patches of large zooplankters. It is evident from this figure that many adjoining transect segments had at least one patch of zooplankton that was similar in intensity. The presence of patches over large areas would indicate that those large areas would be good foraging areas for fish and birds. Extensive areas with patches of the highest intensity category were found in May 1984 and July 1985. These types of areas were of limited extent in September 1984 and non-existent in January 1985.

4.5.1.5 Trophic Relationships

In evaluating trophic relationships, we first categorized the zooplankton taken in the oblique bongo tows as herbivores or carnivores. The herbivores included copepods, larvaceans, mysids and euphausiids. Euphausiids apparently feed on phytoplankton when it is abundant, and become predatory when it is not (Dagg 1982). Because the availability of phytoplankton on the NAS is far in excess of its consumption by zooplankton for the period April to October (see Section 8.4, this report), we assumed euphausiids to be herbivorous. Carnivores included hyperiid amphipods and chaetognaths.

The relative abundances of herbivores and carnivores changed with the seasons. In winter, the zooplankton was dominated by carnivores (see Fig. 4.18). With the onset of the spring phytoplankton bloom, herbivores increased in abundance, and by midsummer the relative abundance of herbivores was far greater than that of the carnivores. Predation by jellyfish in late summer (see next section) may reduce the standing crop of zooplankton in early fall to its lowest observed level of the year.

4.5.2 Gelatinous Zooplankton

Large scyphozoans (jellyfish) were the most conspicuous zooplankters present during most cruises, but they were not sampled effectively by plankton nets because of their relative scarcity as individuals. Using 500 g as the biomass of an average jellyfish and a mean biomass of 1.5 g/m^3 in September (as determined in Marinovich tows), jellyfish density was estimated to be 1 individual/333 m^3. The mean volume sampled in oblique bongo net tows was only 110 m^3, an insufficient volume to effectively sample these organisms. The Marinovich midwater trawl, on the other hand, sampled from 1000 to 250,000 m^3, and thus yielded a more reliable estimate of biomass of these large jellyfish than did the bongo nets. Even the Marinovich trawl, however, underestimated actual biomass, because some individuals or fragments likely passed through the large diameter mesh of the net.

Biomass estimates of large gelatinous zooplankton taken in Marinovich tows (mainly scyphozoans) were very high relative to those of other zooplankters and of jellyfish taken in plankton nets (Table 4.8). The biomass of gelatinous zooplankton in Marinovich tows was highest in September 1984 and lowest in May 1985 (Table 4.8, Fig. 4.19). Gelatinous zooplankton can be voracious predators on zooplankton and fish larvae (Arai and Hay 1982, Moller 1984, Van der Veer 1985). The high biomass of gelatinous zooplankton in September 1984 could, through predation, have been one of the causes of the concomitant low biomass of other zooplankters (Table 4.8).

In contrast to conditions on the NAS, predation on copepods of the middle shelf appears to be slight, and a high biomass is maintained into October (Smith and Vidal 1986). In other areas, and apparently in the southeastern Bering Sea as well, gelatinous zooplankters are generally more abundant in nearshore than in offshore waters (Alldredge 1984). Thus, on the NAS, predation pressure by gelatinous zooplankton could be an important factor in shaping seasonal zooplankton dynamics, and could be

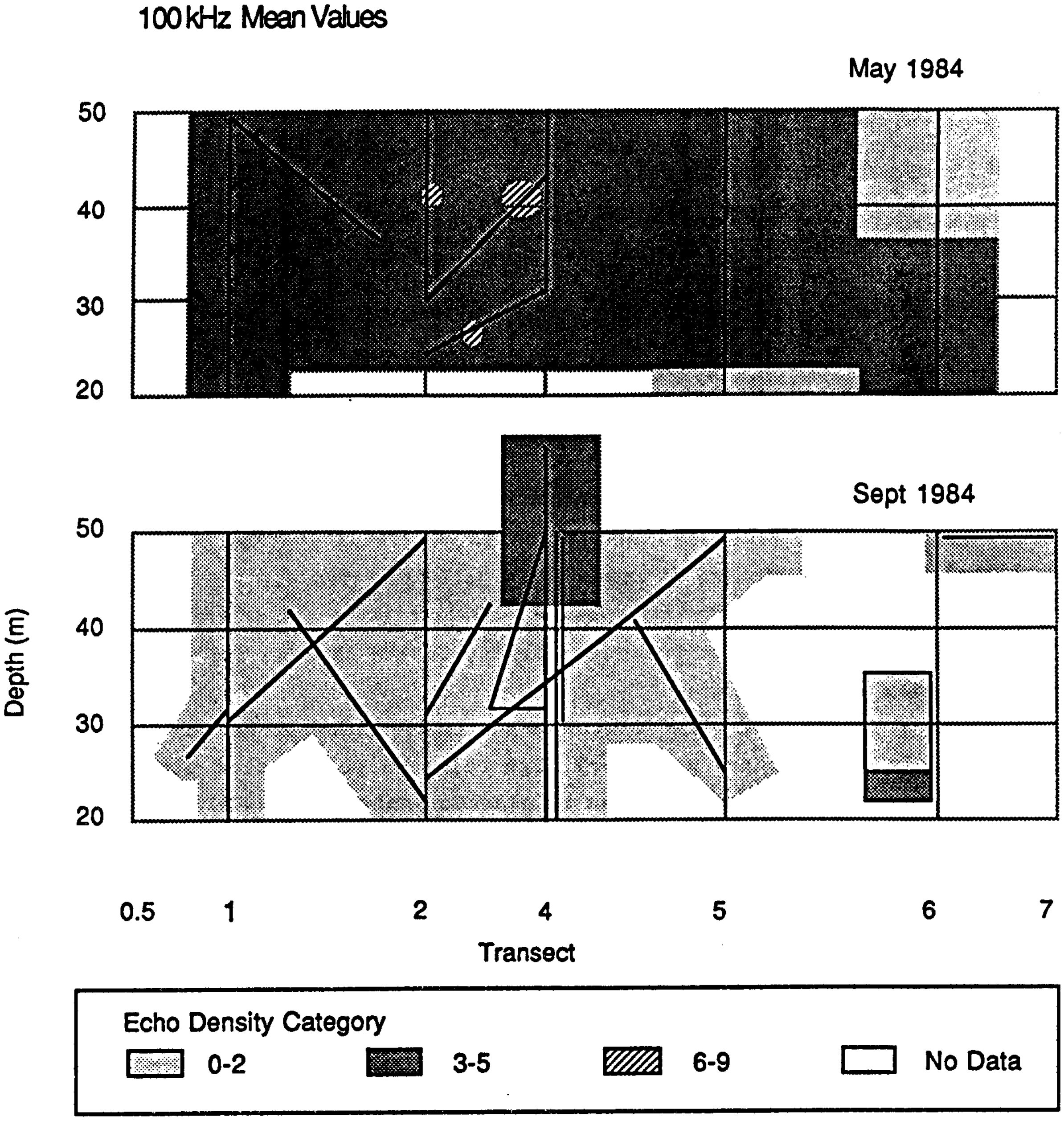
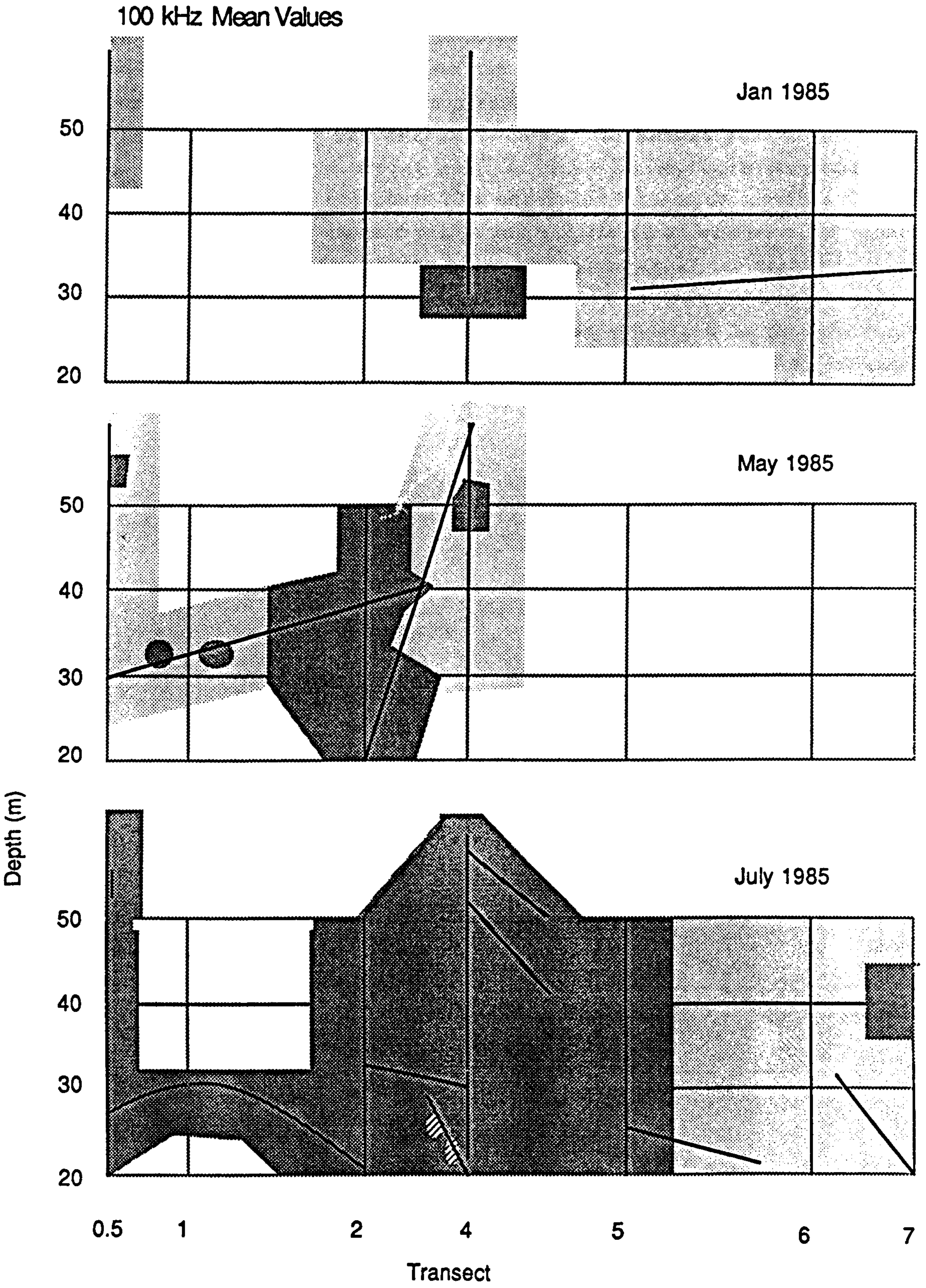


Fig. 4.16. Stylized map of the NAS, Alaska, showing the distribution of mean hydroacoustic echo-density recorded on a 100 kHz echosounder during five cruises. For each 10-min transect segment, the mean of the 9 to 30 coded values of echo-density recorded for that segment are shown. Similar mean values are enclosed by contours. Solid lines show transect locations. Echo-densities recorded during offshore sampling between 50 and 100 m water depths are also shown.


100 kHz Mean Values
Jan 1985
May 1985
July 1985
Depth (m)
50
40
30
20
Transect
0.5
1
2
4
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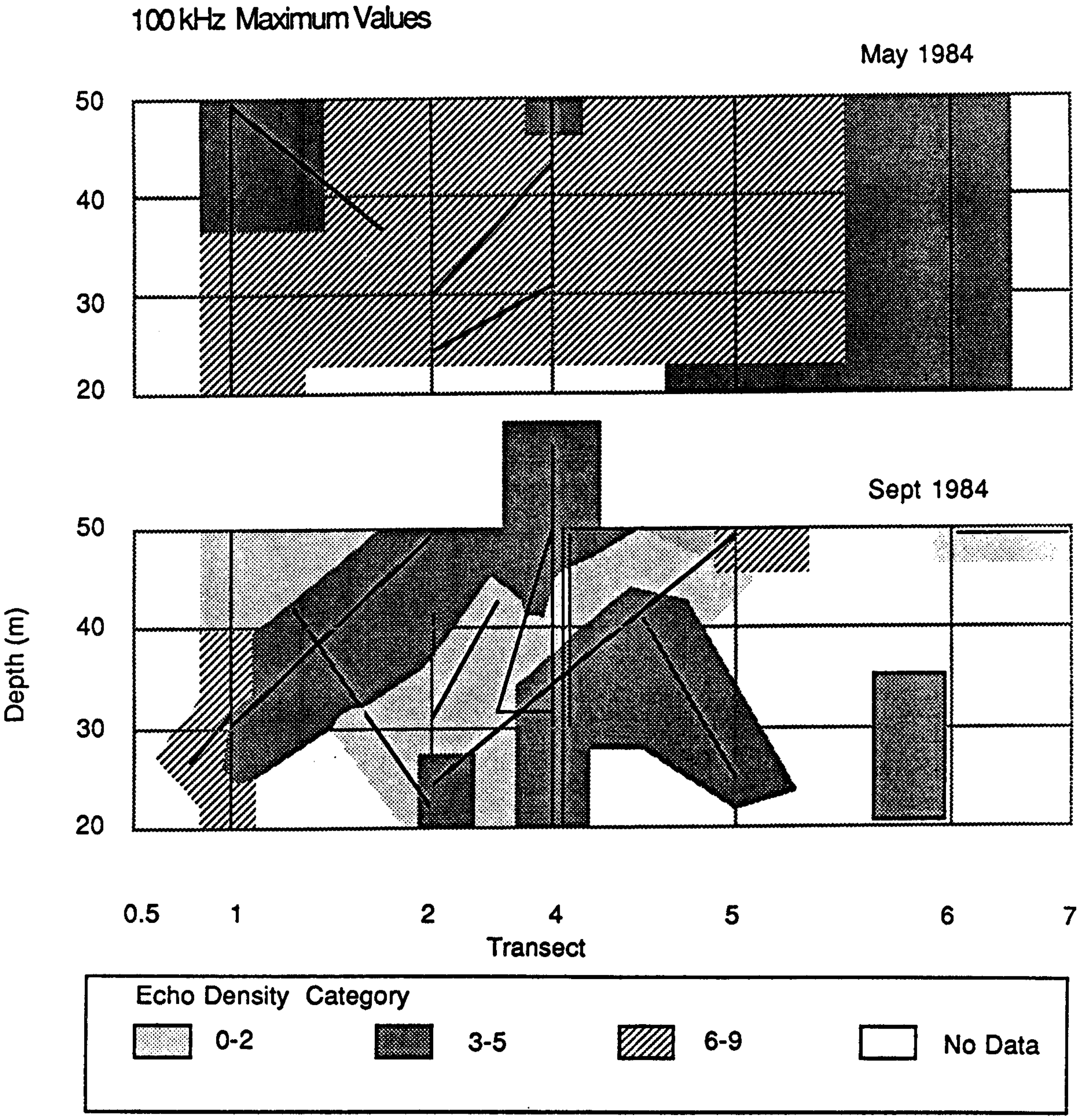
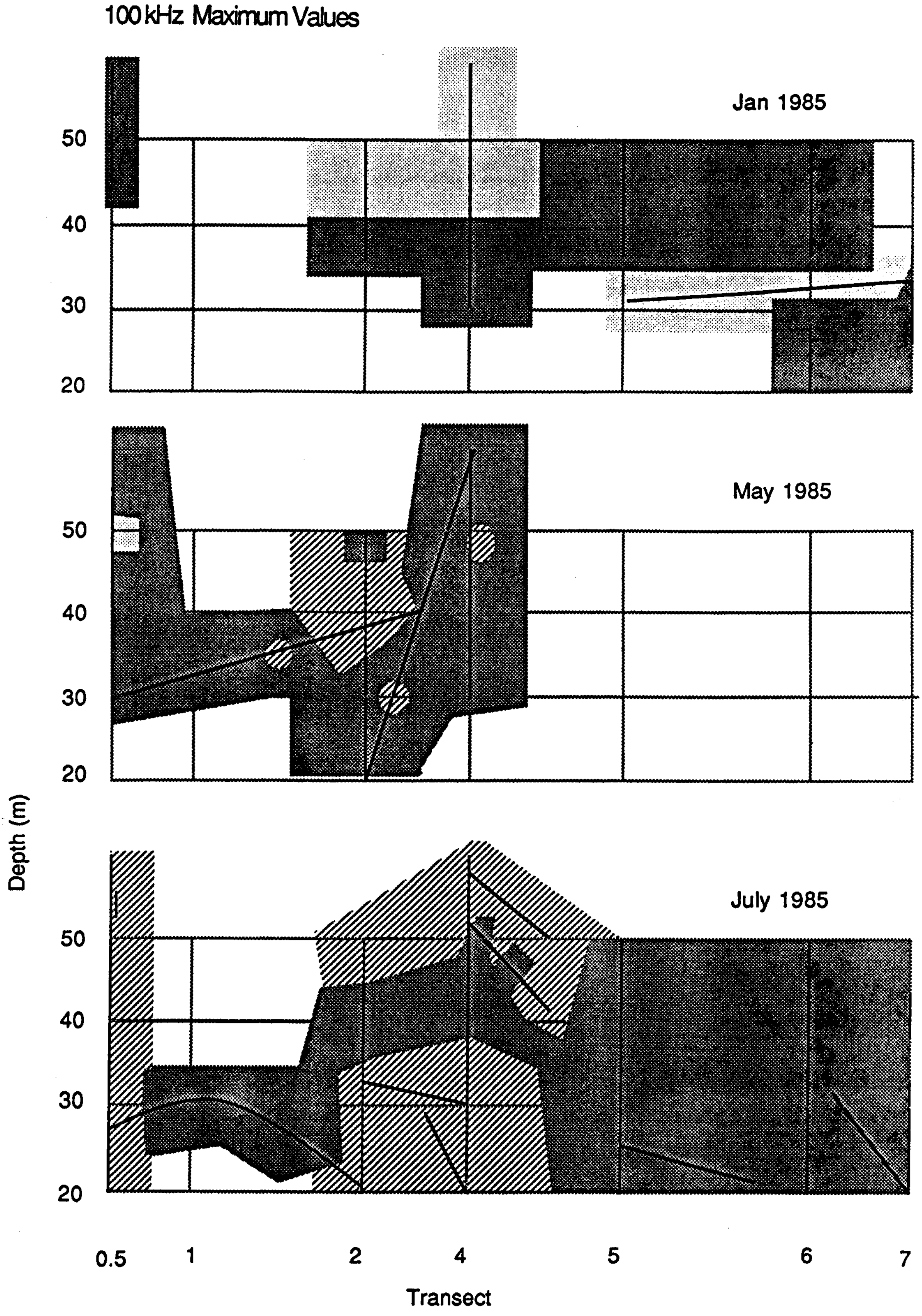


Fig. 4.17. Stylized map of the NAS, Alaska, showing the distribution of maximum hydroacoustic echo-density recorded on a 100 kHz echosounder during five cruises. For each 10-min transect segment, the maximum of the 9 to 30 coded values of echo-density recorded for that segment are shown. Similar maximum values are enclosed by contours. Solid lines show transect locations. Echo-densities recorded during offshore sampling between 50 and 100 m water depths are also shown.


100 kHz Maximum Values
Jan 1985
May 1985
July 1985
50
40
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20
Depth (m)
0.5
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Transect

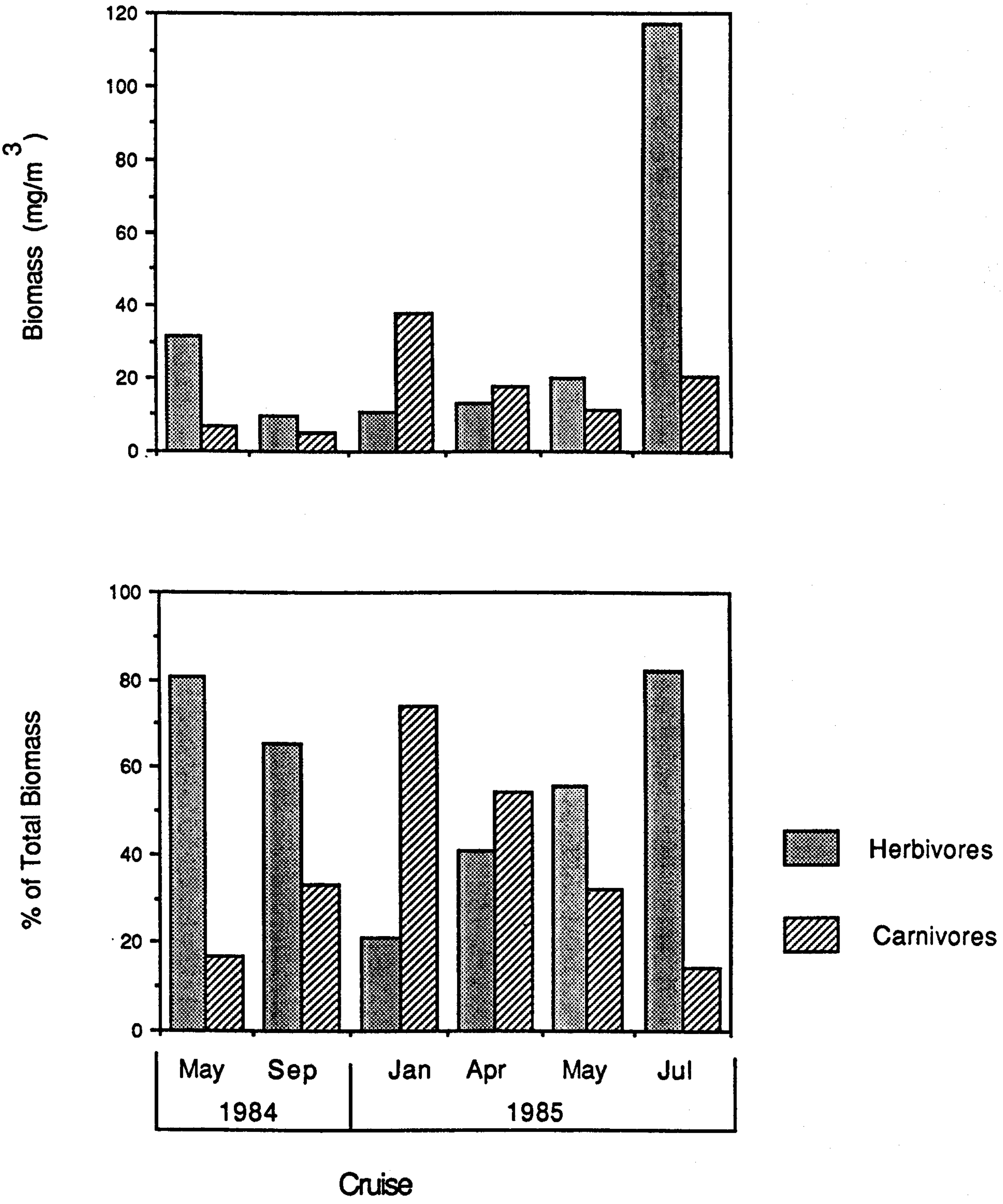

Fig. 4.18. Estimated biomasses of planktonic herbivores and carnivores (excluding jellyfish and ctenophores) in the water column at depths of 20 to 50 m during six cruises on the North Aleutian Shelf, Alaska.

Table 4.8. Mean biomass (mg/m^3 ± SD wet weight) of herbivores, carnivores and gelatinous zooplankton (jellyfish) taken in oblique bongo tows, and of gelatinous zooplankton taken in Marinovich mid-water tows on the NAS.

	Cruise					
	May 1984	Sep 1984	Jan 1985	Apr 1985	May 1985	Jul 1985
Oblique bongo tows						
Herbivores	31	10	11	13	20	117
Carnivores	7	5	38	18	12	21
Total biomass*	39	15	51	32	36	143
All jellyfish	1	74	115	ND	17	89
Marinovich trawls						
All jellyfish	ND	1522	195	ND	111	210
Sample size						
Bongo tows	19	19	9	10	9	13
Marinovich tows	0	27	8	0	7	11

* not including gelatinous zooplankton.

ND means no data.

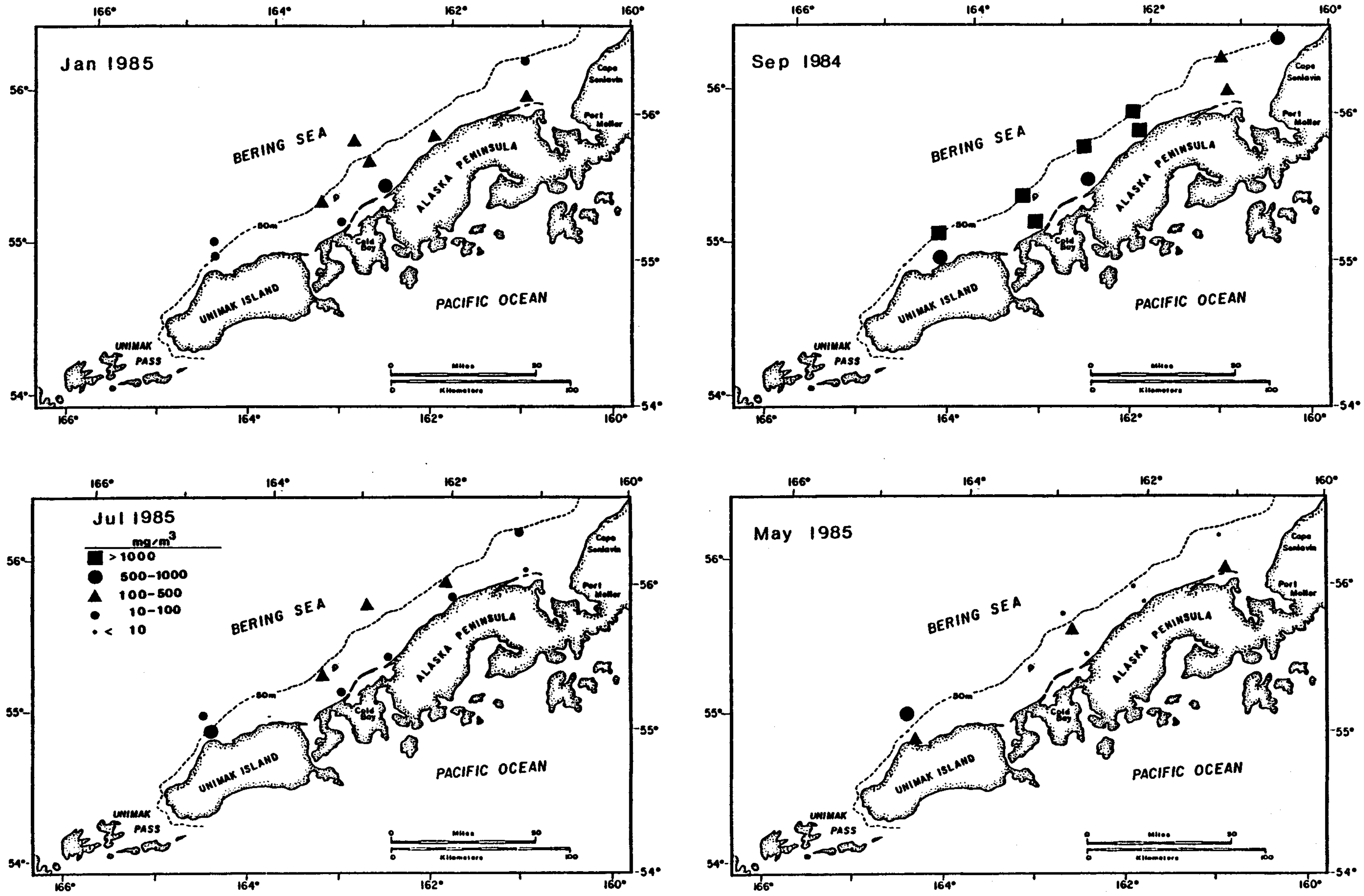

Fig. 4.19. Distribution of biomass of gelatinous zooplankton taken in Marinovich mid-water tows during four cruises on the North Aleutian Shelf, Alaska.

one cause of major differences in seasonal cycles between nearshore and offshore waters.

4.5.3 Benthic Invertebrates

4.5.3.1 Infaunal Benthos

General results of benthic grab samples taken during this study (Table 4.9) compare well with benthic grabs taken in the same area by Cimberg et al. (1984). Cimberg et al. (1984) took 63 samples with a grab similar to that used in the present study at depths of 30 to 60 m. Shown below is a comparison of their results with those of the present study; data for each taxon, as determined in this study, were applied to Cimberg et al.'s density data to estimate biomass.

	Mean Density ± SD (no./m^2)		Mean Biomass ± SD)g/m^2)	
	This Study (20-50 m)	Cimberg et al. (1984) (30-50 m)	This Study (20-50 m)	Cimberg et al. (1984) (30-50 m)
Polychaetes	606± 542	761±816	16± 13	13± 10
Bivalves	515± 921	68± 85	85±119	31± 53
Echinoderms	73± 67	58± 67	101±227	101±116
Total	1290±1379	1028±942	208±229	152±160

With the exception of bivalve density and biomass, there was close correspondence between the results of the two studies. Biomass and density of bivalves were about 50 g/m^2 and 450 individuals/m^2 higher, respectively, in samples collected during this study than in samples collected by Cimberg et al. (1984). The spatial distribution of sampling effort was different between the two studies and could account for these differences.

Table 4.9. Taxonomic composition of the infauna collected over two depth ranges during six cruises on the NAS, expressed as a percentage of mean total infaunal biomass or density.

	% of Total Biomass			% of total Density	
	3-10 m	20-50 m		3-10 m	20-50 m
Bivalves	0	41		0	40
Echinoderms	8	48		<1	6
Polychaetes	92	8		99	47
Gastropods	0	2		0	2
Other taxa	<1	1		<1	6
Total (g/m^2)[a]	3	208	Total (indiv./m^2)	1029	1290
Sample size	9	20	Sample size	9	20

[a] Not including crustaceans.

Biomass. Total infaunal biomass was very low at depths less than 10 m (Table 4.10). A subtidal barren zone is a common feature of northern shorelines that are affected by ice (Thomson 1982, Thomson et al. 1986). The NAS coast is heavily invaded by ice only during some years, but infauna typically recolonize slowly, and even infrequent ice scour might explain the observed scarcity of infauna. Wave action in shallow water may also be responsible for the faunal break at 10 m depth (Cimberg et al. 1984).

Biomass was quite high at depths of 20 to 60 m (mean of 166 g/m^2), but appeared to decrease with increasing depth beyond 60 m (Table 4.10). The relatively low biomass at 30-m depths may be related to the relatively high percentage of gravel at this depth (Fig. 4.1).

At depths of 20 to 50 m, biomass was marginally higher in the western portion of the study area than in the eastern portion (mean of 188 g/m^2 in the west, 134 g/m^2 in the east). However, 9 of 22 stations (41%) in the eastern portion of the study area contained a biomass >200 g/m^2, and only 3 of 23 stations (13%) in the west contained a biomass >200 g/m^2. Biomass was high off Cape Mordvinof and Isembek Lagoon, uniformly low between Izembek Lagoon and Port Moller and high at three stations off Port Moller, (Fig. 4.20). Mean biomass of infauna on the NAS was comparable to that recorded in other parts of the Bering Sea shelf, much higher than that in the Beaufort Sea, and lower than that found in the Canadian High Arctic (Table 4.11).

Bivalves accounted for 20 to 40% of total infaunal biomass at depths of 20 to 50 m (Tables 4.9 and 4.12). The density of bivalves was highest at stations off Bechevin Bay, Izembek Lagoon, and Port Moller (Fig. 4.21). Biomass of bivalves was especially high at depths of 40-50 m (Table 4.12). Bivalves of the genera Tellina, Yoldia, Macoma, and Siliqua were important biomass contributors.

Echinoderms were a co-dominant taxon (with bivalves) in terms of wet weight biomass (Tables 4.9 and 4.12) and were most common in the region west of Izembek Lagoon and off Port Moller (Fig. 4.22). Of these, sand dollars were the most important biomass contributors.

Polychaetes dominated in terms of infaunal numbers (Tables 4.9 and 4.12). They were relatively abundant in the western and eastern portions of the study area (most stations) and at the 60-m depth contour in the

Table 4.10. Mean biomass (wet weight) of infaunal benthos in relation to depth on the NAS and offshore waters. Data are from this study and Cimberg et al. (1984) for depths 3 to 60 m and from Haflinger 1981 for depths 65 to 121 m.

Depth (m)	Biomass (g/m^2)	Sample Size
3	<1	3
5	1	3
10	43	24
20	340	6
30	107	42
50	207	35
60	181	19
65-121	92	7[a]

[a] From Haflinger (1981): five grabs at each of seven stations off the NAS to a distance of 150 km offshore.

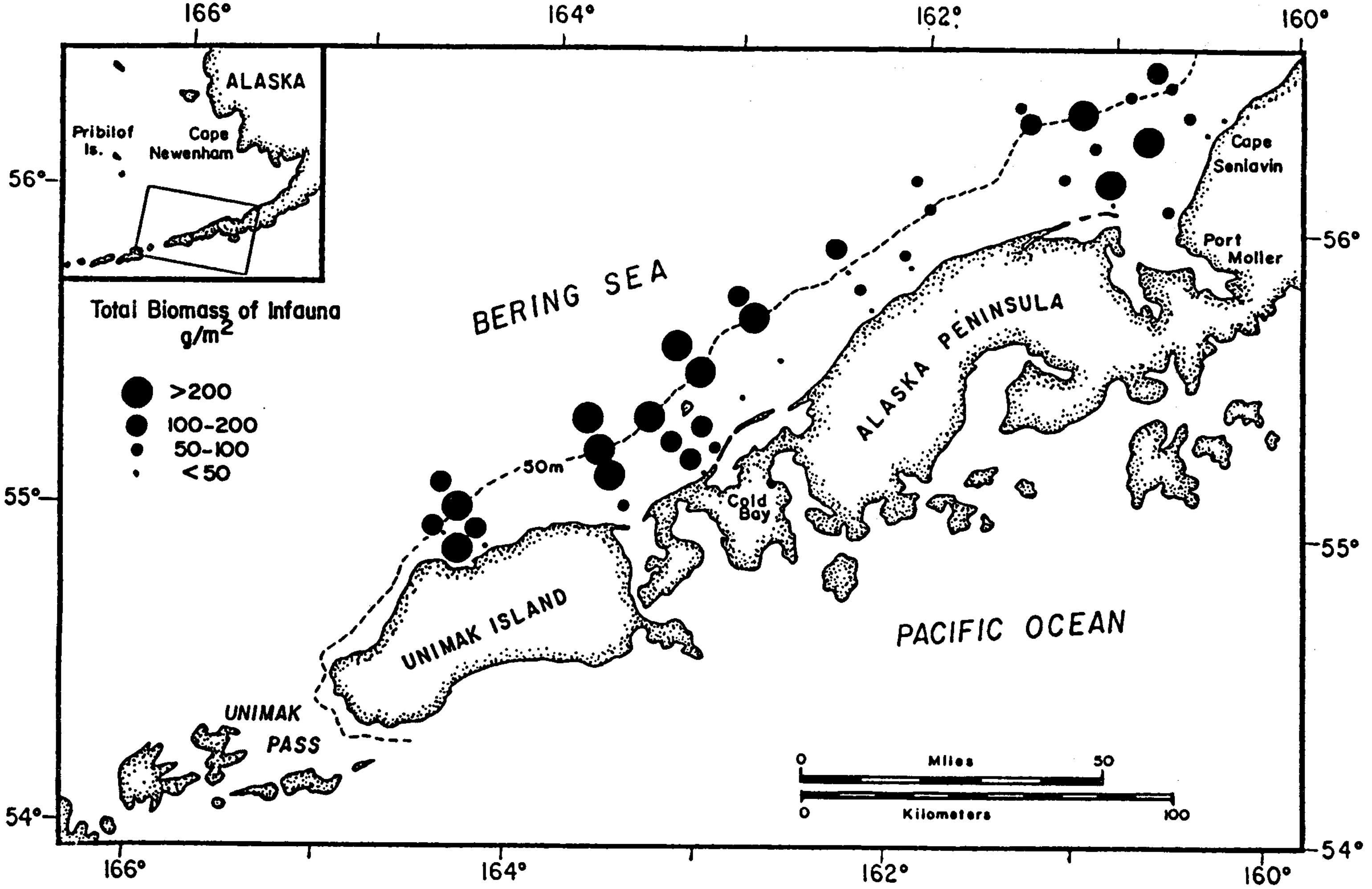

Fig. 4.20. Total infaunal biomass (wet weight) estimated from benthic grab samples taken at stations on the North Aleutian Shelf, Alaska.

Table 4.11. Biomass of infaunal benthos on the NAS, Alaska, and in other marine areas.

Location	Depth Range (m)	Biomass (mg/m^3 wet weight)	Reference
Bering Sea			
North Aleutian Shelf	20-50	208	This study
Offshore of N. Aleutian Shelf	54-121	95	Haflinger (1981)
Chirikof Basin	20-50	210	Thomson (1984)
St. Lawrence Island	11-23	284-353	Thomson (1984)
Bering Chukchi Shelf		301	Stoker (1981)
Canadian Arctic			
Lancaster Sound	5-50	520	Thomson (1981)
NW Baffin Bay	5-50	297	Thomson (1981)
N Baffin Island	6-20	933-2267	Thomson et al. (1986)
NW Passage	6-20	13-689	Thomson et al. (1986)
Alaska Beaufort Sea	5-50	41	Carey (1977)

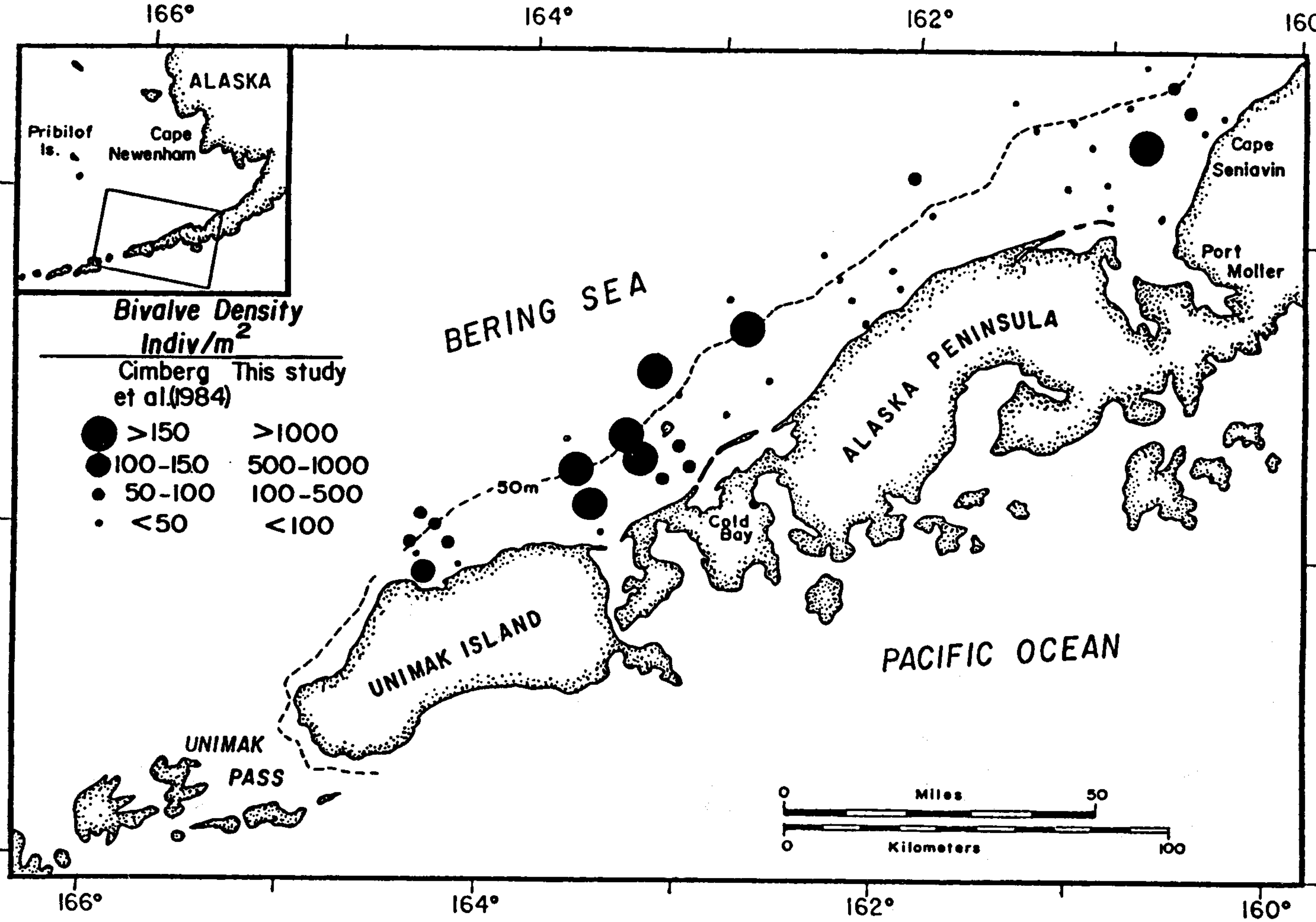

Fig. 4.21. Bivalve densities estimated from benthic grab samples taken at stations on the North Aleutian Shelf, Alaska. Data are from Cimberg et al. (1984) and from this study. Two different scales were used because of differences in density recorded during the two studies.

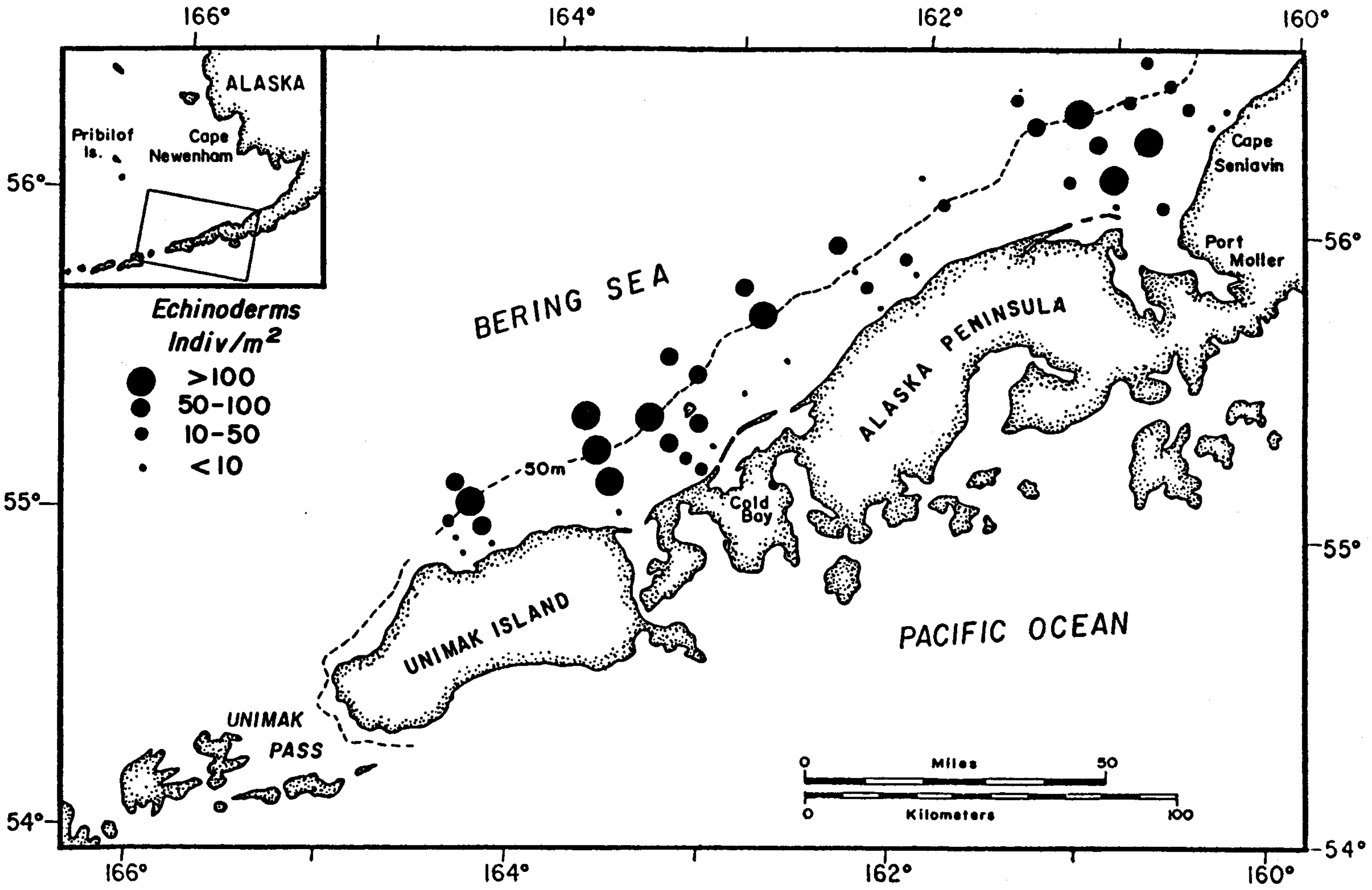

Fig. 4.22. Echinoderm densities estimated from benthic grab samples taken at stations on the North Aleutian Shelf, Alaska. Data are from Cimberg et al. (1984) and this study.

Table 4.12. Depth distribution of total infaunal biomass and biomass of dominant infaunal taxa (g/m^2 ± SD wet weight) collected during this study on the NAS, and by Haflinger (1981) in adjacent offshore waters.

	Depth (m)					
	3	5	10	20-35	43-52	54-121[a]
Total Biomass	<1	1 ± 1	8 ± 5	179 ± 263	278 ± 104	95 ± 86
Bivalves	0	0	0	45 ± 87	178 ± 139	26 ± 35
Echinoderms	0	0	1 ± 1	112 ± 270	74 ± 72	ND
Polychaetes	0	1 ± 1	7 ± 5	13 ± 10	24 ± 16	ND
Sample Size	3	3	3	14	6	41

[a] From Haflinger (1981): 11 stations sampled off the NAS to a distance of 150 km offshore.

ND means no data.

central portion (Fig. 4.23). At depths of 10 to 50 m they were least abundant between Port Moller and Izembek Lagoon.

Trophic Relationships. Animals collected in grabs were assigned to one of four feeding guilds (surface deposit feeder, deposit feeder, filter feeder, carnivore), using published information. Surface deposit feeders glean food from sediment surfaces by means of tentacles or palps; included are spionid and cirratulid polychaetes; bivalves of the genera *Macoma*, *Nucula*, and *Yoldia*; ophiuroids; and sand dollars. Deposit feeders burrow through the substrate and extract whatever nutritive value they can from it, usually in the form of bacteria. These include opheliid, maldanid, and capitellid polychaetes and sipunculids. Filter feeders extend tentacles or siphons above the sediment surface and filter the water. Filter feeders include sabellid polychaetes, mussels, bivalves of the genera *Mya* and *Astarte*, and tunicates. Carnivores consume living organisms, typically invertebrates in the benthic community.

At depths of 20 to 60 m, surface deposit feeding was the dominant mode of feeding on the NAS (Table 4.13). Filter feeders were dominant at the 10 m depth, but their biomass was not higher than it was in deeper water. Carnivores and deposit feeders showed no obvious depth preferences. Biomass of surface deposit feeders was highest in the western portion of the study area and off Port Moller (Fig. 4.24).

The prevalence of surface deposit feeding at depths of 20 to 50 m has been noted in the northern Bering Sea and throughout the Canadian Arctic. This mode of feeding appears to be an adaptation to a pulsed primary production that is underutilized by zooplankton (Thomson 1984, Thomson and Martin 1984).

4.5.3.2 Epibenthic Animals

Biomass. Biomass dominants among the epibenthos of the NAS included starfish, crangonid shrimp, mysids, and amphipods. Biomass estimates for the epibenthos were based on several sampling methods, and estimates frequently varied widely among methods. Results from all appropriate methods are presented in the following discussions.

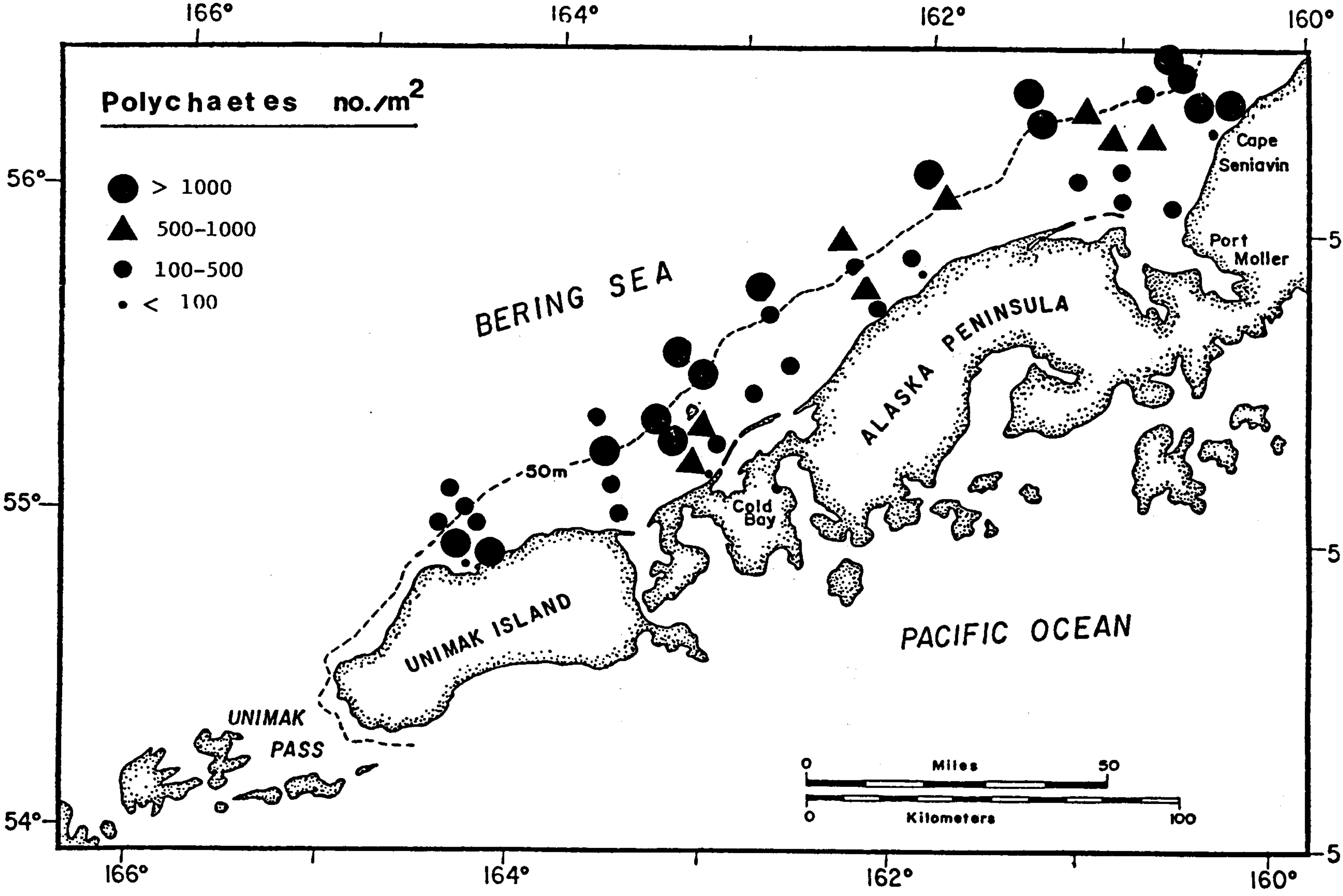

Fig. 4.23. Polychaete densities estimated from benthic grab samples taken at stations on the North Aleutian Shelf, Alaska. Data are from Cimberg et al. (1984) and this study.

Table 4.13. Distribution of infaunal benthic feeding guilds over six depth ranges on the NAS. Biomass was measured in samples taken during this study, and was estimated from density data presented by Cimberg et al. (1984).

	Depth (m)					
	3-5	10	20	30	50	60
Biomass (g/m^2)						
Surface deposit feeders	0.0	10.3	313.8	73.8	164.9	148.5
Deposit feeders	0.4	2.1	3.8	4.2	5.8	7.1
Filter feeders	0.0	20.4	4.2	18.6	22.9	9.8
Carnivores	0.0	9.0	4.9	7.2	7.7	10.5
Not classified	0.0	1.4	12.8	3.0	5.2	4.8
As % of total biomass						
Surface deposit feeders	0.0	23.8	92.4	69.1	79.8	82.2
Deposit feeders	97.6	4.9	1.1	4.0	2.8	3.9
Filter feeders	0.0	47.3	1.2	17.4	11.1	5.4
Carnivores	2.4	20.8	1.4	6.7	3.7	5.8
Not classified	0.0	3.2	3.8	2.8	2.5	2.6
Total biomass (g/m^2)	0.4	43.1	339.5	106.7	206.5	180.7
Sample size	6	24	6	42	35	19

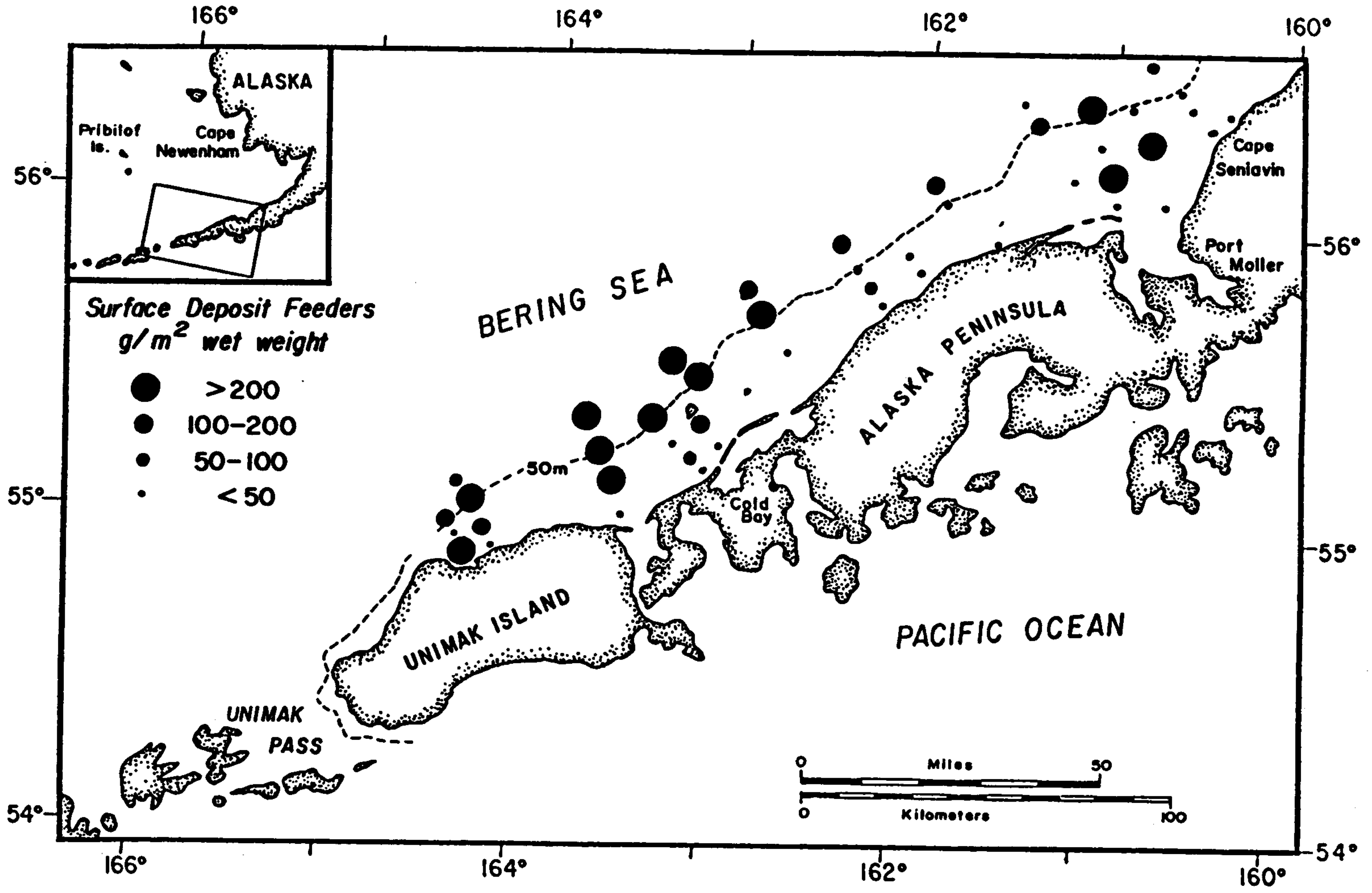

Fig. 4.24. Biomass of surface-deposit feeding invertebrates, estimated from benthic grab samples taken at stations on the NAS, Alaska.

Starfish, top-level predators on the NAS, were collected by trynet bottom trawl. Starfish biomass was highest at depths of 30 to 50 m; no starfish were collected in the 73 trawls taken at depths of 3 to 10 m, as shown below.

	Depth (m)			
	3-10	20	30-53	67-100
Starfish g/m^2	0	0.6±0.9	1.2±1.4	0.7±1.2
Sample size	73	11	16	11

Crangonid shrimp were the most conspicuous epibenthic animal collected in shallow water, and were the most common decapod collected. They were collected in the trynet bottom trawl, epibenthic sled, and drop net. In most cases, the drop net and trynet yielded higher estimates than did the sled (Tables 4.14 and 4.15), this indicates that the crangonids were not above the sediment surface, because the drop net and trynet sampled on the sediment surface, whereas the sled sampled 11.5 cm off the bottom. All three methods show that biomass of crangonids were highest in shallow water and lowest in deep water, and that in shallow water biomass was highest off Cape Seniavin (Transect 7) and Port Moller (Transect 6) at the eastern end of the study area (Tables 4.14 and 4.15).

Shrimp other than crangonids accounted for only 4% of the total biomass of shrimp collected in sled tows at depths of 3 to 50 m, and were rare in trynet tows (only 2 of 261 shrimp collected at seven tows in July 1985 were not crangonids). In shallow (3-10 m) drop net samples, however, shrimp other than crangonids accounted for 42% of shrimp biomass.

Feder and Jewett (1980) did not mention crangonids as being one of the common species collected in a trawl survey of Bristol Bay. Cimberg et al. (1984) found that hippolytid shrimp were the most common decapod shrimp collected in trynet tows, and did not find crangonids in any tows on the NAS in 1982. Hippolytid shrimp were relatively rare in the trynet tows and sled tows carried out during the present study.

Table 4.14. Mean biomass of crangonid shrimp (mg/m^2 ± SD wet weight) over six depth ranges sampled by three methods on the NAS. Sample sizes are shown in parentheses. ND means no data.

Method	Depth (m)					
	3	5	10	20	30-50	54-100
Trinet tow	307 ± 511 (22)	286 ± 623 (26)	183 ± 302 (25)	154 ± 263 (11)	10 ± 14 (16)	11 ± 13 (11)
Epibentic sled	101 ± 279 (12)	47 ± 103 (30)	39 ± 103 (35)	36 ± 104 (54)	13 ± 24 (12)	ND
Drop net	364 ± 1038 (29)	1341 ± 3259 (27)	0 (3)	ND	ND	ND

Table 4.15. Mean biomass of crangonid shrimp (mg/m^2 ± SD wet weight) sampled by three methods at depths of 3 to 10 m on six transects on the NAS. Sample sizes are shown in parentheses.

Method	Transect					
	0.5 or 1	2	4	5	6	7
Trinet tow	82 ± 198 (14)	55 ± 98 (16)	122 ± 256 (15)	15 ± 10 (5)	758 ± 844 (15)	423 ± 225 (9)
Epibentic sled	24 ± 53 (13)	10 ± 22 (13)	38 ± 111 (20)	23 ± 48 (9)	88 ± 154 (14)	48 ± 76 (7)
Drop net	48 ± 158 (15)	0 ± 0 (5)	121 ± 364 (9)	286 ± 494 (12)	1672 ± 4142 (11)	3018 ± 3783 (6)

Mysids were sampled by drop net, epibenthic sled, and plankton net tows. The first two methods yielded biomass estimates by unit area; the latter provided a mean biomass estimate for the water column. Only the latter method was used consistently among sampling periods, so seasonal comparisons of abundance rely mainly on the plankton net results. Tables 4.16 and 4.17 show that biomass estimates based on drop net and sled samples varied widely among water depths and transects. The extreme variability obscured any strong patterns, although there was a tendency for the highest biomass to be found in the shallows and at the easternmost stations, as was observed for crangonid shrimp. Table 4.18 indicates that the water-column biomass of mysids also varied widely among sampling times; no clear seasonal patterns are evident.

Amphipod biomass estimates are based on results of three different sampling techniques--benthic grab, epibenthic sled, and drop net. Benthic grab results provided the highest estimates (Tables 4.19 and 4.20). Infaunal amphipods (the families Haustoriidae, Corophiidae, and Oedicerotidae) accounted for over 90% of the biomass of amphipods collected in the grab. Most of these amphipods would have been within the substrate, and not effectively sampled by the drop net or the epibenthic sled. As with mysids, estimates were highly variable among depths and transects. The highest biomasses occurred at the deeper (10-50 m) stations. No among-transect (alongshore) pattern was evident.

King crabs (Paralithodes sp.) and Tanner crabs (Chionoecetes sp.) were rare in the study area. Only 29 specimens were collected in 111 bottom trawls taken at depths of 3 to 105 m during six cruises (Table 4.21). During the July 1985 cruise, virtually no red king crabs were caught within the study area even though a specific effort to survey newly settled larvae was conducted by the University of Washington (P. Denhall, pers. comm.). The University of Washington effort did collect some juvenile Tanner crabs.

In 1975 and 1976, Feder and Jewett (1980) collected king and/or Tanner crabs at all seven of their stations that were within our study area. They collected up to 867 individuals at one station. In 1982, Cimberg et al. (1984) collected insignificant quantities of crabs (0.4% of total epifaunal biomass) within our study area. The general decline in crab populations of the entire Bering Sea is reflected in the low

Table 4.16. Mean biomass of mysids (mg/m^2 ± SD wet weight) sampled by two methods over five depth ranges on the NAS. Sample sizes are shown in parentheses. ND means no data.

Method	Depth (m)				
	3	5	10	20	50
Epibenthic sled	101 ± 25 (8)	109 ± 193 (24)	22 ± 60 (28)	6 ± 24 (46)	95 ± 166 (12)
Drop net	23 ± 69 (29)	687 ± 1166 (27)	79 ± 98 (3)	ND	ND

Table 4.17. Mean biomass of mysids (mg/m^2 ± SD wet weight) sampled by two methods at depths of 3 to 10 m on six transects on the NAS. Sample sizes are shown in parentheses.

Method	Transect					
	0.5 or 1	2	4	5	6	7
Epibenthic sled	9 ± 24 (8)	32 ± 64 (9)	1 ± 5 (15)	33 ± 54 (9)	91 ± 125 (11)	238 ± 298 (7)
Drop net	39 ± 55 (15)	4 ± 9 (5)	0 (9)	206 ± 316 (12)	14 ± 20 (11)	2702 ± 742 (6)

Table 4.18. Mean biomass (mg/m^3 ± SD for bongo nets; mg/m^2 ± SD for sled tows) of mysids collected in oblique bongo net tows and epibenthic sled tows during six cruises on the NAS. Sample sizes are shown in parentheses.

	Cruise					
	May 1984	Sept 1984	Jan 1985	April 1985	May 1985	July 1985
Depth 30-50 m						
Oblique tows	0.2 ± 0.5 (11)	0 ± 0 (11)	0.1 ± 2 (4)	0.9 ± 1.2 (5)	0 ± 0 (4)	0 ± 0 (6)
Sled tows	95.1 ± 165.8 (12)	ND	ND	ND	ND	
Depth 20 m						
Oblique tows	0 ± 0 (8)	0.2 ± 0.3 (7)	5.8 ± 7 (5)	4.7 ± 10.6 (5)	0 ± 0 (5)	0.4 ± 1.1 (7)
Sled tows	1.4 ± 3.2 (18)	13.9 ± 37.2 (18)	ND	ND	ND	0.3 ± 0.6 (10)
Depth 3-10 m						
Sled tows	32.7 ± 71.7 (19)	104 ± 195 (23)	ND	ND	ND	19.2 ± 55.7 (17)

ND means no data.

Table 4.19. Mean biomass of amphipods (mg/m^2 ± SD wet weight) sampled by three methods over five depth ranges on the NAS. Sample sizes are shown in parentheses.

Method	Depth (m)				
	3	5	10	20	50
Grab	500 ± 870 (3)	40 ± 70 (3)	1040 ± 660 (3)	3830 ± 3600 (14)	1190 ± 1370 (6)
Epibenthic sled	6 ± 14 (8)	<1 (24)	<1 (28)	<1 (46)	4 ± 10 (12)
Drop net	72 ± 223 (29)	7 ± 17 (27)	1 ± 2 (3)	ND	ND

ND means no data.

Table 4.20. Mean biomass of amphipods (mg/m^2 ± SD wet weight) collected by three methods on six transects and two depth ranges on the NAS. Sample sizes are shown in parentheses.

Method	Transect					
	1	2	4	5	6	7
<u>Depth 3-10 m</u>						
Grab	ND	380 ± 660 (3)	ND	ND	1090 ± 840 (3)	110 ± 200 (3)
Epibenthic sled	1 ± 1 (8)	<1 (9)	3 ± 10 (15)	<1 (9)	<1 (11)	1 ± 1 (7)
Drop net	34 ± 109 (15)	239 ± 507 (5)	39 ± 61 (9)	6 ± 8 (12)	10 ± 25 (11)	5 ± 4 (6)
<u>Depth 20-50 m</u>						
Grab	1400 ± 1440 (5)	3560 ± 2980 (6)	ND	6090 ± 5540 (3)	3350 ± 3150 (6)	ND
Epibenthic sled	7 ± 14 (6)	<1 (8)	<1 (11)	1 ± 1 (11)	<1 (14)	<1 (8)

ND means no data.

Table 4.21. Total number of red king and Tanner crabs collected in bottom trawls on all NAS cruises, 1984 and 1985.

Transect	Depth (m)	Date	No. Caught Red King	No. Caught Tanner
4	72-74	Jan/Feb 1985	2	2
4	50	Jan/Feb 1985	1	2
6	22	Jan/Feb 1985	1	0
5	50	Jan/Feb 1985	4	0
5	105	Jan/Feb 1985	0	9
4	75	May 1985	3	0
6	50	May 1984	2	0

abundance of crabs on the NAS during 1982, 1984, and 1985. In samples collected in 1975 and 1976 by Feder and Jewett (1980), crabs were the dominant epifaunal animals at depths of less than 80 m in Bristol Bay (1.8 g/m^2; 54% of total biomass), and asteroids were second ranked (0.6 g/m^2; 19% of total biomass). Mean biomass of asteroids in 1982 on the NAS at depths of 15 to 60 m (1.2 g/m^2; Cimberg et al. 1984) and in 1984-85 at depths of 20 to 105 m (0.9 g/m^2; this study) was higher than that found in 1975-76. It could be argued that the modest increase in starfish biomass resulted from the decline in crab populations. However, Feder and Jewett (1980) showed that there appears to be little overlap between the diets of these crabs (bivalves and polychaetes) and that of the asteroids (a wide variety of other invertebrates; see below). The flatfish, primarily yellowfin and rock sole, do feed extensively on bivalves and polychaetes (see 5.0, this report) and could possibly have benefited from declines in crab populations.

Trophic Relationships. With the exception of starfish, which are predatory, the benthic epifauna is supported by a detrital food chain. Starfish consume a wide variety of benthic animals. *Asterias amurensis*, the dominant starfish on the NAS (Cimberg et al. 1984), is classified as a feeding generalist by Feder and Jewett (1980); dominant food items in Bristol Bay included shrimp, hydrozoans and sand dollars, sponges, barnacles, and fish. Crangonids in Cook Inlet fed on small crustaceans, polychaetes, diatoms and sediment (Feder et al. 1980); they were opportunistic generalist feeders that relied heavily on the sediment detrital food chain. Crangonids are also active predators, but their prey are most often detritivores themselves. Infaunal amphipods in the northern Bering Sea are also mainly detritivores, feeding on sediment and diatoms (Thomson 1984). Mysids may be raptorial predators or filter-feeding herbivores, or they may feed on organic detritus, diatoms and meiofauna at or near the sediment surface; the same species can exhibit different feeding modes (Johnston and Lasenby 1982).

Summary. In summary, epibenthic biomass on the NAS was dominated by starfish, crangonid shrimp, mysids, and amphipods. Starfish, which are top-level predators, were most abundant in waters deeper than 20 m. Shrimp and mysids, which probably feed on phytoplankton and detritus, tended to be most abundant in waters less than 20 m deep and in the eastern parts of the study area. Amphipods, like starfish, were more abundant in deeper areas. It is perhaps noteworthy that the groups preferring shallow water (shrimp, mysids) are probably more mobile as individuals than the starfish and amphipods that are more abundant in deeper water; thus, they could rapidly recolonize shallow areas that are periodically disturbed by ice and wave action.

4.5.3.3 Comparison with Previous Studies

There appear to be two differences between the benthic community sampled in this study and that of previous (1982) studies on the NAS. First, populations of bivalves seem to have been substantially higher in this study than in 1982. Second, there may have been an increase in populations of crangonid shrimp. These changes could be related to observed declines in crab populations over the last several years. King and Tanner crabs feed extensively on bivalves (Feder et al. 1980, Feder and Jewett 1980), and the decline in crab populations could have reduced predation pressure on the bivalves. (Rock sole and yellowfin sole also feed on bivalves; however, commercial fishing could have kept flatfish populations from increasing in response to this increased food supply.) Snow crabs (Chionoecetes bairdi) feed on crangonids in Cook Inlet, and apparently take prey in proportion to abundance (Feder et al. 1980); thus declines in crab populations on the NAS could also have allowed the crangonid populations to increase.

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Section 5

FISH RESOURCES

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Section 5

FISH RESOURCES

5.1 SUMMARY

The North Aleutian Shelf nearshore zone (0-50 m) is a gradually sloping shoreward extension of the relatively shallow Bering Sea middle shelf. The fish community of the nearshore zone is likewise an extension of that occurring on the middle shelf, consisting largely of similar pelagic species (salmon, sand lance, young-of-year cod) and demersal species (yellowfin and rock sole, pollock, Pacific cod), except in nearshore habitats such as lagoons and embayments where the fauna is more diverse (sand lance, herring, capelin, salmon, yellowfin sole, smelt, sculpin, greenling, and other species). Some fish inhabit the nearshore zone year-round while others are present seasonally; highest usage occurs during spring and summer months (Fig. 5.1). The fish fauna can be separated into three ecologically distinct groups--forage fishes, salmon, and demersal fishes.

Forage fishes migrated into shallow areas in large schools in spring to spawn (herring, capelin) and/or to feed (sand lance). This seasonal occurrence of these highly mobile species resulted in an abundant supply of forage fishes (peaking at over 10 g/m^2 of sea surface area) available for seabirds, marine mammals and other fishes from spring through mid-summer. Fluctuations in abundance from year to year are probably high; for example, capelin are reported to be abundant in some years but few were caught in 1984 or 1985. The main foods eaten by forage species were zooplankton (euphausiids, copepods, and crustacean larvae).

Salmon are a significant component of the nearshore environment in spring and early summer. Though salmon adults and juveniles are most abundant farther offshore, several million adult salmon, mostly sockeye and chum, migrate through nearshore waters on their way into Bristol Bay. During this time, many continue to feed (mainly on euphausiids), accumulating final food reserves for migration and spawning requirements. Juvenile salmon also feed in and pass through the study area on their migration out of Bristol Bay. Juvenile salmon ate zooplankton (euphausiids, copepods, and decapod larvae), epibenthos (mysids and amphipods), fish (primarily sand lance), and insects.

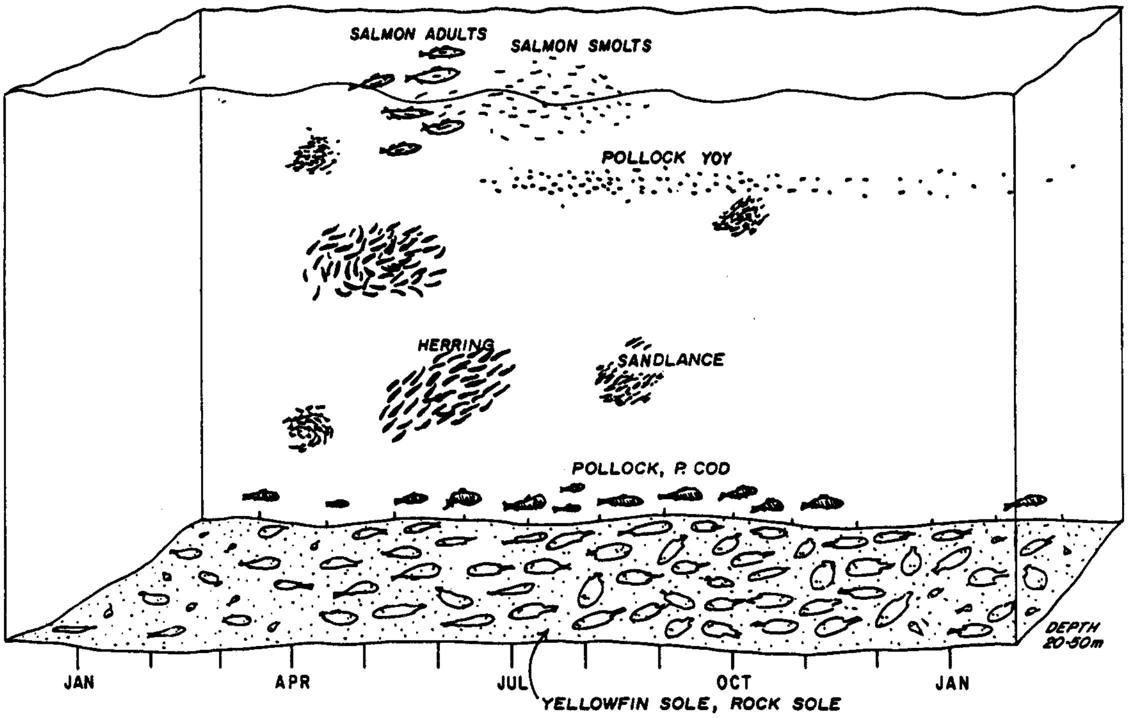


Figure 5.1. Schematic diagram showing seasonal patterns of fish use in the North Aleutian Nearshore Zone.

Demersal fishes in the nearshore zone were dominated by yellowfin and rock sole, which together comprised about 80% of the total biomass caught by bottom trawls in this study. Pollock and Pacific cod were also common, but all of these species are reported to be equally or more abundant elsewhere in the eastern Bering Sea. Use of the nearshore waters by demersal species was greatest in summer when a peak abundance of $4.5\ g/m^2$ was recorded, but this biomass is thought to be a gear-biased underestimate. Although many demersal fishes vacated shallow waters in winter, juvenile yellowfin and rock sole wintered there. Demersal fish abundance was annually variable as well.

Foods of the demersal fishes varied among fish species and ages. Yellowfin and rock sole consumed epibenthic and infaunal invertebrates. Small soles ate copepods, amphipods, polychaetes, and fish; large ones ate polychaetes, crangonid shrimp, bivalves, fish, and a variety of other benthic invertebrates. Young-of-year pollock and Pacific cod ate mainly zooplankton (copepods, crustacean larvae, and amphipods). Older juveniles of these species ate primarily epibenthic invertebrates and some fish. Adults ate fish, euphausiids, and various crabs.

5.2 INTRODUCTION

The productive waters of the southeastern Bering Sea are among the world's richest fishing grounds. Over 300 fish species, about 20 of which are of major commercial importance, inhabit the area. Large quantities of salmon, cod, pollock, flatfish and other species are harvested annually. Though most of the commercial fisheries operate outside the North Aleutian Shelf nearshore zone (0-50 m water depth) addressed in this study, many of the species involved migrate through or disperse into shallow waters during particular phases of their life cycles. Other species, not of commercial value, occur in the study area in vast numbers and are a vital component in the diets of other fishes, seabirds, and marine mammals.

The importance of these resources in the eastern Bering Sea has been well-documented (e.g., Hood and Calder 1981, Lewbel 1983, Pace 1986), but little is known about fish use of shallow-water habitats adjacent to the North Aleutian Shelf lease area. Specific objectives of the present study were to describe the nearshore fish community and to obtain estimates of fish abundances, seasonal and spatial distributions, and dietary requirements. The approach followed in this section will be to use new data and available literature to examine how fish use shallow coastal waters and, for perspective, to determine whether these uses are specific to, or dependent on, shallow water habitats.

5.3 SOURCES OF INFORMATION

The eastern Bering Sea has long been the focus of fisheries studies, and a vast body of information has accumulated (e.g., Thorsteinson and Thorsteinson 1982 and 1984). Detailed reviews of the commercial species are available for salmon (e.g., Straty 1974, Neave et al. 1976, French et al. 1976, Hartt 1980, Straty and Jaenicke 1980, Straty 1981, Bax 1985, Isakson et al. 1986), groundfish (e.g., Pereyra et al. 1976, Hood and Calder 1981, Smith and Bakkala 1982, Forester et al. 1983, June 1984, Bakkala et al. 1985), and herring (e.g., Warner and Shafford 1981, Wespestad and Barton 1981, Wespestad and Fried 1983, Fried and Wespestad 1985). The fishery resources are monitored annually by the Alaska Department of Fish and Game (ADFG) and the National Marine Fisheries Service (NMFS). ADFG (1985) has distilled much of this information in their statewide series of Habitat Management Guides. Other general sources of information include a review of fishes in the Unimak Pass area (Craig 1986), an extensive compilation of information about forage fishes and other non-salmonids in the eastern Bering Sea (Macy et al. 1978), and the distribution of ichthyoplankton (Waldron 1981).

The shallow waters of the study area have historically received much less research attention than have waters deeper than 50 m, but some data are available. Recent OCSEAP studies have examined bottomfish, juvenile salmon, and forage fishes in shallow waters along the northern coastline of the Alaska Peninsula (Barton et al. 1977, Warner and Shafford 1981, Cimberg et al. 1986, Isakson et al. 1986). Other sources of information include descriptions of fishes in Izembek Lagoon (Tack 1970, Smith and Paulson 1977, McConnaughey 1978), ADFG catch statistics for small commercial fisheries for salmon (Urilia Bay, Izembek Lagoon area, Port Moller area) and herring (Port Moller), catches of adult salmon in a test fishery off Port Moller (Eggers and Fried 1984), and salmon escapement counts for some streams on the Alaska Peninsula which flow into the study area (ADFG 1985).

5.4 STUDY AREA

This study focused mainly on the nearshore zone from 0-50 m deep (herein called the North Aleutian Nearshore Zone, NANZ) along the northern coastline of the Alaska Peninsula between capes Mordvinof and Seniavin (Fig. 5.2). Aquatic habitats in the NANZ fall into two natural groupings: (1) the coastal zone extending from shore out to the 50-m isobath, and (2) varied nearshore habitats such as lagoons and embayments. Brief descriptions follow. (For more details, see Section 2.0, this report).

5.4.1 Coastal Zone

The eastern Bering Sea is characterized by three hydrographic domains: coastal (0-50 m), middle (50-100 m), and outer domain (100-150 m). NANZ is usually contained within the well-mixed coastal domain, although some vertical stratification of the water may occur when this zone is affected locally by freshwater runoff or when there is a shoreward intrusion of the middle domain. Freshwater inputs by rain and runoff are

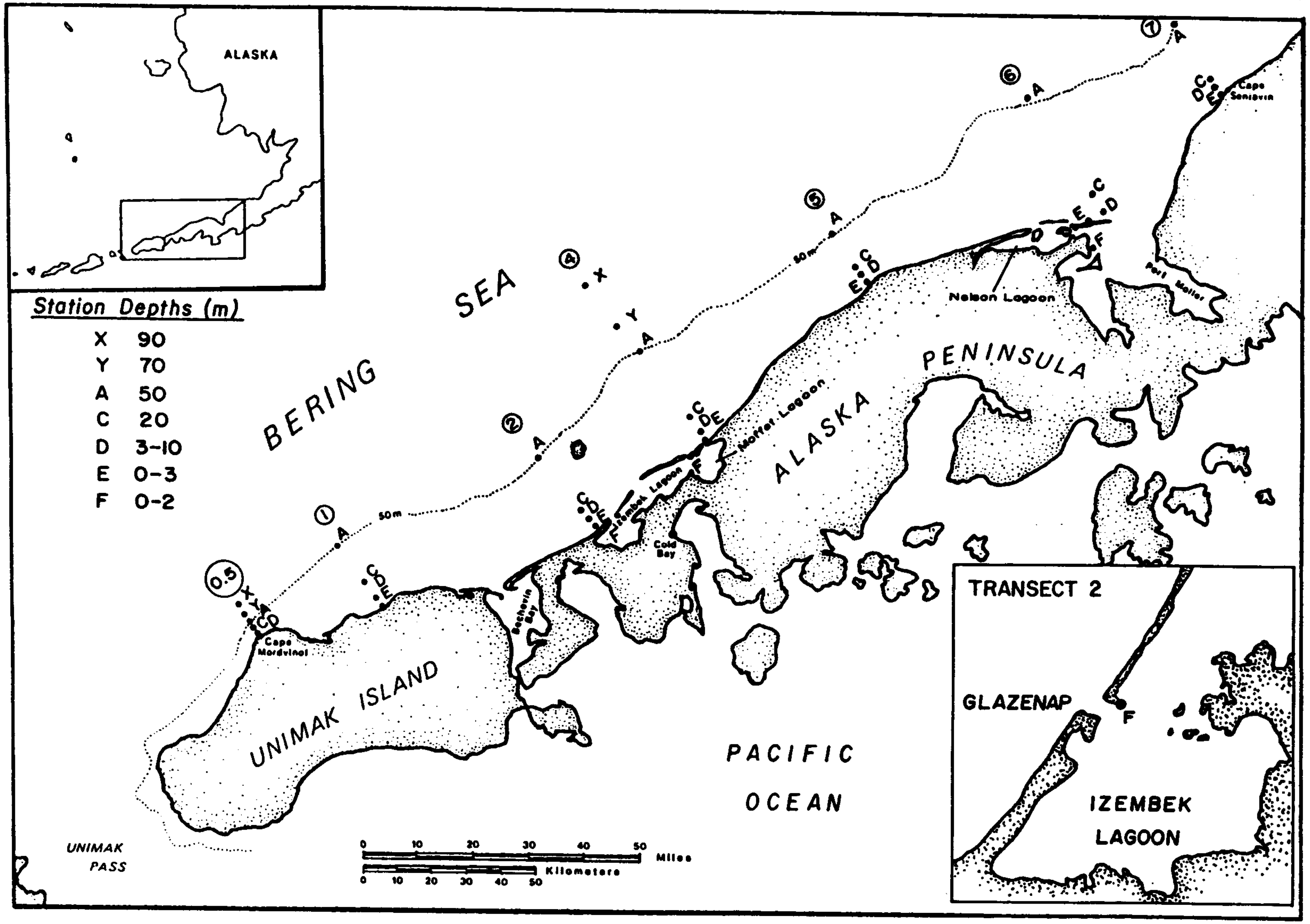


Figure 5.2. Fish sampling sites in the North Aleutian Nearshore Zone (NANZ) study area, Alaska, showing locations of Transects 0.5-7 and sampling station depths. The lower inset shows the primary sampling site (2F) in Izembek Lagoon.

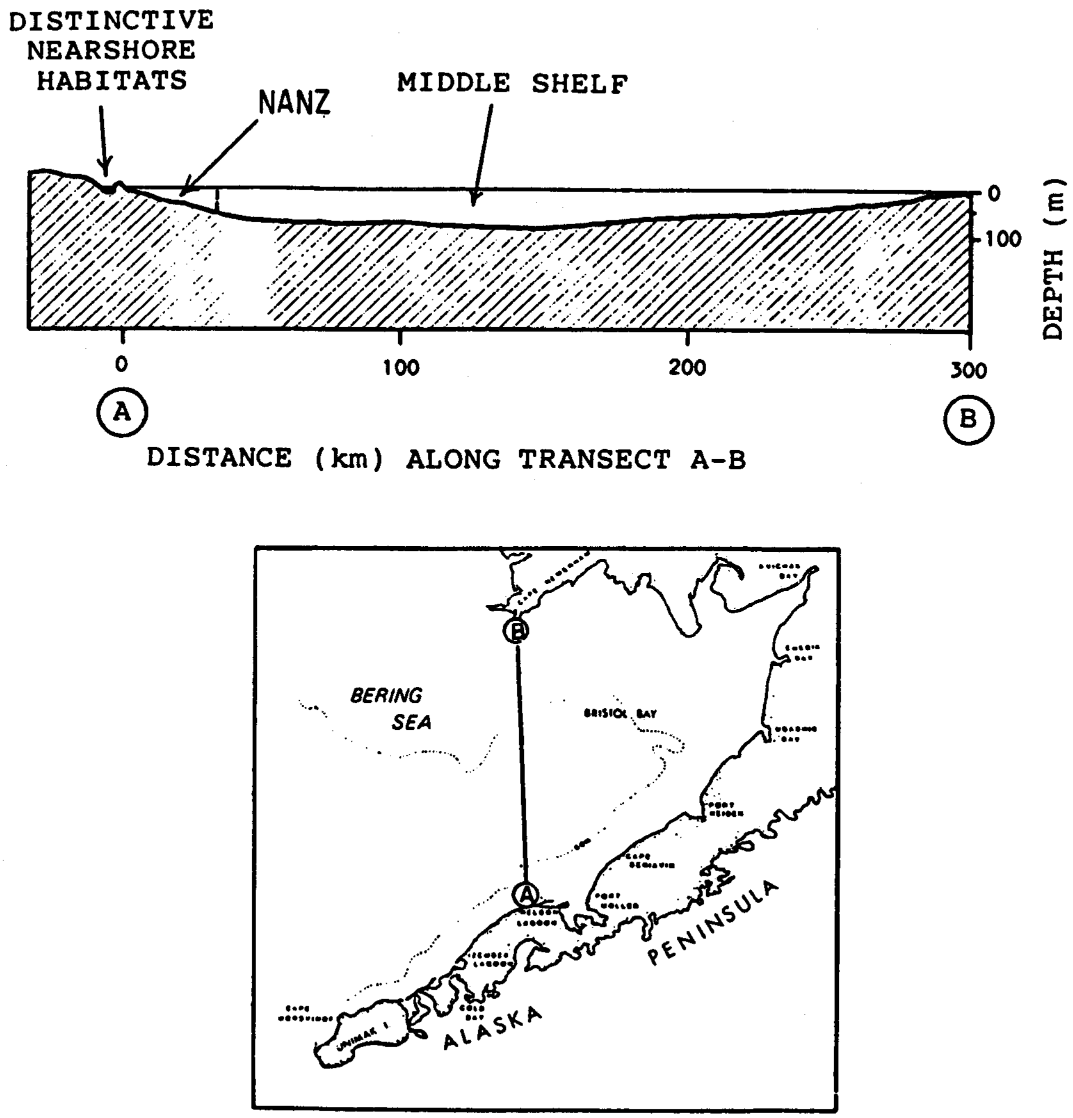


Figure 5.3. Schematic cross-section of the eastern Bering Sea showing habitats along a transect extending from the Port Moller area (A) to Cape Newenham (B). (NANZ = North Aleutian Shelf Nearshore Zone.)

minor contributors to the coastal water mass in this area.

The coastal zone is a relatively homogeneous habitat, consisting of a gentle slope of sand, gravel and shell hash substrates, interrupted by a single island, Amak Island (Fig. 5.2). The continental shelf in this area continues to slope gently beyond the 50-m isobath, leveling off at about 80-100 m (Fig. 5.3).

During the course of this study, the salinity of the NANZ remained nearly constant at about 31.5 ppt (Fig. 5.4). Shoreline waters (at the 1-

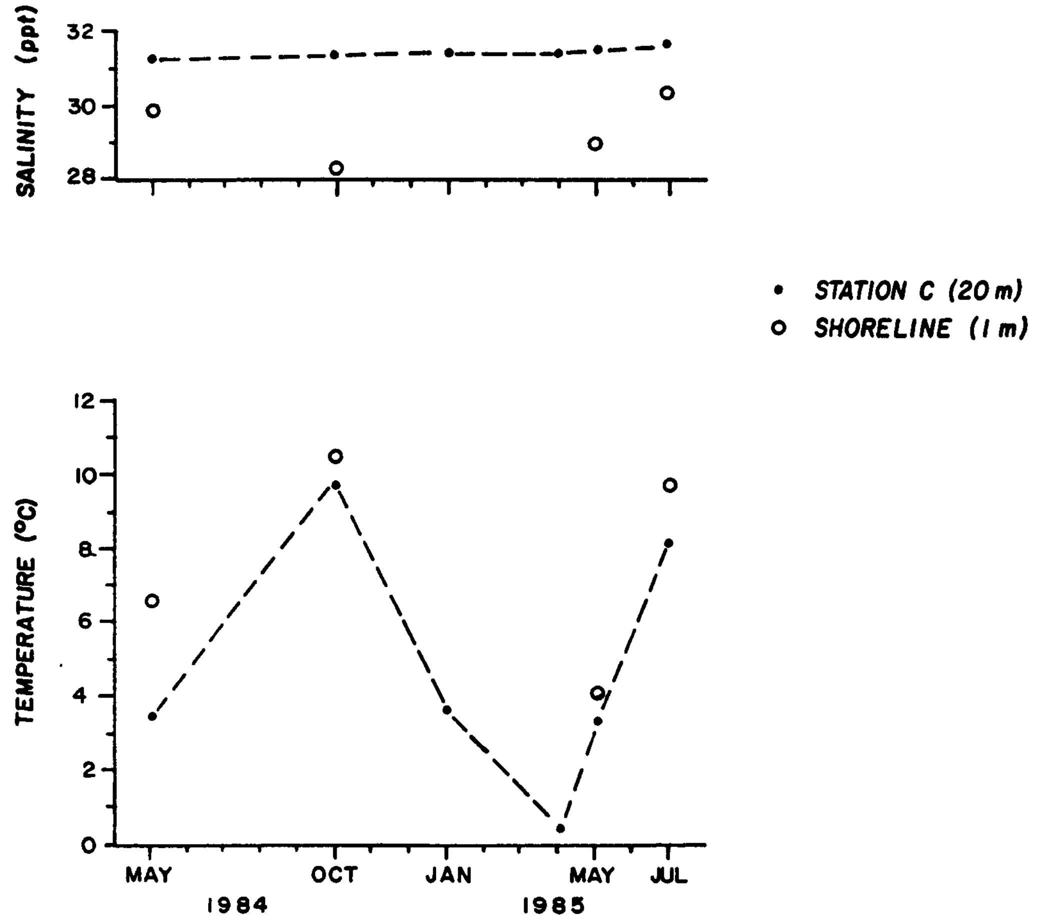


Figure 5.4. Seasonal water temperature and salinity trends at Stations C (20 m) and E (1 m) in the NANZ study area, Alaska. Shoreline values are means of measurements taken in 1 m of water (n = 3-8 transects). For Station C (20 m), temperatures and salinities are average values at mid-depth (10 m).

m isobath) tended to be about 2-3 ppt less saline than offshore waters (at the 20-m isobath) due to freshwater runoff from the Alaska Peninsula.

Water temperatures in the NANZ varied from summer highs of about 9-10 C to winter/spring lows of 0.5-3.5 C (Fig. 5.4). Shoreline waters tended to be 1-3 C warmer than offshore waters.

In extremely cold winters, the Bering Sea icepack may extend as far south as the study area, but this did not occur during 1984 or 1985.

5.4.2 Nearshore Habitats

Nearshore habitats are defined as those waters that are very shallow, immediately adjacent to the coast, and inshore from the coastal zone. Exposed shorelines and embayments are included in this category.

5.4.2.1 Exposed Shorelines

The north side of the Alaska Peninsula presents a relatively straight coastline with direct exposure to the Bering Sea. There are some rocky headlands, but most of the exposed shoreline consists of black sand and gravel beaches, pounded by a rough surf. Beaches are littered at the high tide mark by fisherman's lines, buoys and other debris cast up by frequent and forceful storms in the Bering Sea. Kelp beds are generally absent except at Amak Island and a few other scattered areas. About 98 streams, most very small (2-5 km long) but still supporting salmon populations, flow into the study area between Capes Mordvinof and Seniavin.

5.4.2.2 Protected Embayments

Three major embayments are located along the NANZ coast: Izembek Lagoon/Moffet Lagoon, Port Moller/Nelson Lagoon, and Bechevin Bay. Izembek Lagoon is large (218 km^2) and shallow, consisting primarily of tidal mud flats (78% of surface area) which support extensive eelgrass beds. Several small salmon streams flow into the lagoon, and a small amount of commercial fishing for adult salmon occurs in the deeper portions of the lagoon in summer. Port Moller is a very large and complex water body containing a diverse array of aquatic habitats, from expansive tidal mudflats in Nelson Lagoon to inner embayments up to 40 m deep. Small fisheries for both salmon and herring occur in the Port Moller area. Bechevin Bay was not examined.

5.5 METHODS

5.5.1 Collection Activities

The fish community of the NANZ between capes Mordvinof and Seniavin was sampled at seasonal intervals in 1984 and 1985. Five cruises aboard the RV Miller Freeman and an additional shore-based sampling effort in Izembek Lagoon were made, as follows:

PERIOD	AREA SAMPLED
1. 10-25 May 1985	(NANZ)
2. 7-13 July 1985	(Izembek Lagoon)
3. 18 Sept.-4 Oct. 1985	(NANZ)
4. 23 Jan.-2 Feb. 1986	(NANZ)
5. 17-25 May 1986	(NANZ)
6. 19 July-1 Aug. 1986	(NANZ)

The primary sampling design for the NANZ cruises consisted of seven transects extending from the shoreline out to the 50-m depth contour (Fig. 5.2). Two modifications to this design were that Transects 2, 4 and 6 extended landward into Izembek Lagoon and Port Moller, and in 1985 Transects 0.5 and 4 extended seaward to about the 90-m depth contour.

Fish sampling stations on each transect were located at the shoreline and the 3-10, 20, 35, and 50 m depth contours, together with additional sampling stations inside lagoons (Transects 2, 4, 6) and at the 70 and 90 m contours (Transects 0.5, 4). For the purposes of this report, Transects 0.5 and 1 have been combined and labeled Transect 1.

A variety of methods was used to sample different components of the fish community (Table 5.1). Total sampling efforts during Periods 1-6 are listed in Table 5.2. Additional details about gear dimensions and methods of collection are presented in Table 5.3 and below:

Gill Nets. Two sizes of gill nets were used, a large net (200'x20') for sampling offshore sites (20-50 m water depths) and a smaller net (100'x6') for sampling nearshore sites (0-10 m depths). Both surface and bottom nets were used at most

Table 5.1. Sampling gear used at various water depths along a shore-to-sea transect.

Water Depth (m)	Station	Gear*	Sampling Platform
Shoreline	E	gn,bs	Zodiac inflatable
3-10	D	gn,bt	Monark Launch
20	C	gn,bt,mt	RV *Miller Freeman*
50	A	gn,bt,mt	RV *Miller Freeman*
70	Y	bt,mt	RV *Miller Freeman*
90	X	bt,mt	RV *Miller Freeman*

*gn (gill net), bs (beach seine), bt (bottom trawl), mt (midwater trawl).

Table 5.2. Sampling effort per sampling period.

		Sampling Period						
Gear	Gear Code	1	2	3	4	5	6	Total
Gill net (offshore)	GN-S,GN-B	14						14
Gill net (nearshore)	GNXS,GNXB	6	5	12		8	16	47
Beach seine	BS-1,BS-3	9	6	19		5	23	62
Trynet bottom trawl	TRY1	36		38	26	15	28	143
Misc. bottom trawl	-	17		1				18
83/112 bottom trawl	BT-1			3			1	4
Marinovitch midwater trawl	M-4			22	16	13	22	73
Misc. midwater trawl	-	14		17				31
Misc. gear	-	3	8	4	9		10	34

[1] Period 1 (10-25 May 1984, 2 (7-13 July 1984), 3 (18 September-4 October 1984), 4 (23 January-2 February 1985), 5 (17-25 May 1985), 6 (19 July-1 August 1985).

Table 5.3. Description of sampling gear and gear codes.

Code Net Type	Dimensions	Mesh (Stretched)	Comments and CPUE Units
Gill Nets			
GN-S GN-B Offshore nets	200x20'	1.5,2.5,3.5,4.5"	Monofilament, both floating (GN-S) and bottom (GN-B) nets. No./h
GNXS GNXB Nearshore nets	100x6'	1,2,3,4"	Monofilament, both floating (GNXS) and bottom (GNXB) nets. No./h
Bottom Trawls			
TRY1 Trynet (otter) trawl	12' opening, 16' long	1.5" with 0.75" codend liner	No./m^2
BT-1 83/112 trawl	83' headrope, 112' footrope, 53' horizontal and 7' verticle opening when trawling	4" with 3.5" codend and 1.25" liner	No./m^2
Midwater Trawls			
M-3 trynet	16' opening, 24' long with attached depth sounder	1.5" with 0.75" codend liner	Used May 1985 cruise only. No./m^3
M-4 Marinovitch	50' long, 33' diameter	graduated (3,2.5,2,1.25") with 0.5" liner	80 m^3 mouth area. No./m^3
M-6 Diamond	12x12 fm mouth	graduated (4-36")	No./m^3
Zooplankton Trawl			
Bongo nets	60 cm diameter	505 micron	No./m^3
Seines			
BS-1 Beach seine	200x6'	0.75"	Nylon marquisette. No./haul
BS-3 Beach seine	100x6'	1"	Nylon marquisette. No./haul
Sonar Transects	38 khz		Simrad
Misc. Miscellaneous			
Rock dredge	1.5x4' mouth	1 mm	
Drift net	1x2' mouth		
Fyke net	4x4' mouth		Izembek Lagoon only
Hook & line			Creel census
Epibenthic sled	1x3' mouth		

stations. The small gill net was set along shorelines in protected waters (lagoons), or seaward of the surf zone along exposed coastlines (about 100 m offshore). Use of the large nets was discontinued after Period 1 due to difficulties in retrieving the nets with available small boats.

Gill net sets averaged 9 hr (range 2-23 hr). Total sampling efforts with the various types of gill nets (see Table 5.3 for gear codes) were: GN-S (7 sets, 48 h), GN-B (7 sets, 45 h), GNXS (31 sets, 306 h), GNXB (16 sets, 151 h).

Bottom Trawls. Demersal fishes were sampled using a Trynet (otter) trawl which was towed by the *Miller Freeman* at deep stations (20-50 m) and by the ship's launch at shallow stations (3-10 m). Trawls were towed for approximately 10 min at 2.5 kt. The distance towed was determined by Loran coordinates except during Period 1 when the distance trawled at shallow sites was estimated based on an average boat speed of 2.3 kt for 10 min. Catch per unit effort (CPUE) and biomass per unit effort (BPUE) were calculated according to the area (m^2) sampled which was typically 1500-3500 m^2 per trawl.

On four occasions, a larger trawl (the 83/112 trawl = BT-1) was used to evaluate whether large demersal fishes were avoiding the smaller Trynet trawl.

Midwater Trawls. Midwater samples were taken by Trynet (Period 1) and Marinovitch (Periods 3-6) trawls. Tows were 10 min at 2.5 kt and the distance trawled was determined by Loran coordinates. Horizontal tows were made at depths where the shipboard echosounder (38 khz) showed the highest apparent density of fish, thus catch values were assumed to be maximal. At the same time, however, some of the smallest fish caught (sand lance, young-of-year pollock) were observed falling through the trawl mesh as the nets were hauled aboard ship. The magnitude of such losses is not known.

Midwater catches in the Marinovitch trawl (M-4) were generally low, so a larger midwater trawl (M-6) was used on three occasions in September 1984 for comparative purposes to see if the smaller trawl might be missing large mobile fish. The results suggest that this was not the case because the larger trawl caught fewer fish. The CPUE and BPUE of the M-6 (0.0003 fish/m^3, 4 mg/m^3) were much lower than those obtained by the M-4 during the same period (0.017 fish/m^3, 49 mg/m^3), presumably because the larger mesh of the M-6 did not retain the smaller fish which were often the only fish present.

Zooplankton Trawls. Larval fish were sampled by bongo net (505 micron mesh) towed obliquely for 5-10 min from water surface to about 5 m above the seabottom and back to the surface. An Oceanics flow meter attached to the mouth of the bongo net was used to calculate the volume of water filtered.

Beach Seine. The beach seining effort consisted of 1-3 hauls at shoreline stations except where wave action prohibited sampling.

Creel Census. Fish caught by hook and line provided a few samples of large halibut which were not caught by other means.

Other Methods. Additional stomach samples of fishes from the study area were provided to us by Steve Fried, ADFG (adult chum and sockeye salmon) and John Isakson, Dames and Moore (juvenile salmon).

Captured fish were identified, measured (to the nearest mm), and weighed (to the nearest g for fish over 10 g, and to the nearest 0.1 g for fish less than 10 g). Stomach contents of fish were preserved and later examined in the laboratory where contents were identified and weighed (damp weight) to the nearest 0.001 g. These weights were summed for the fish group being examined, and the composition (%) of food items in the diet of this group was calculated as the proportion of each food category in the total weight of identifiable foods in the collective stomachs. The weight of the unidentifiable portion of contents was excluded from the above calculations but included in the total weight of contents in the stomachs. One exception to these procedures occurred with adult chum salmon--in this case, virtually all of the stomach contents were unidentifiable (99.8%) and so the remaining 0.2% was not expanded in the above manner.

5.5.2 Echosounder Analyses

A Simrad EQ 38 kHz echosounder was used on all *Miller Freeman* cruises to help evaluate patterns of fish abundance in the study area. During trawls and continuous seabird/marine mammal surveys, the echosounder tapes were marked at 10-min intervals. At these times, the ship's course, speed and position, and the water depth were recorded.

For each 10-min segment of recording, the echograms were compared visually against standards consisting of 10 levels (0-9) graduated by echo density. A standard of 0 represented the faintest density of tracings on the echogram and a standard of 9 represented the densest concentration of tracings. For analysis, an overlay was used to cover the echogram and restrict visual reference to a single depth stratum of 1-2 m. The area of the stratum examined was approximately 1-2 m x 100 m for trawls and 1-2 m x 600 m for continuous surveys. Echosounder tapes were coded independently by two technicians whose readings were very similar (correlation coefficient = 0.97).

Two kinds of analyses were conducted. First, estimates of fish abundance in 61 midwater and 33 bottom trawls (i.e., CPUE, BPUE, mean weight of fish) were compared by correlation coefficient to the density value on the echogram at the depth where the trawl was towed. For these trawls, an average echogram density was obtained from the values at the beginning, middle, and end of the tow. Second, an overview of the study area was obtained from the echograms during the sets of continuous surveys. For these surveys, an estimate of hydroacoustic echo density was made within each 10-m depth stratum of the watercolumn at the beginning, middle, and end of each 10-min segment. Depending on water depth, between 9 and 30 depth strata rectangles were coded for each 10-min segment. These data were examined as both the average and maximum echo-intensity within the watercolumn per 10-min segment.

5.6 RESULTS AND DISCUSSION

5.6.1 Regional Perspective

The NANZ study area is, in large part, a gradually sloping shoreward extension of the relatively shallow, featureless basin of the Bering Sea middle shelf (Fig. 5.3). The primary differences between the NANZ and middle shelf waters are depth (0-50 m vs. 50-100 m) and watercolumn structure (mixed vs. layered--see Section 2.0, this report), differences that could, in theory, affect fish populations. A major hypothesis investigated was that the abundance and species composition of the important fishes are different in the NANZ than they are in deeper, farther offshore waters. As described below, this hypothesis could not be validated--the dominant fish species in the NANZ (excluding those species found only in very shallow shoreline habitats such as lagoons) were the same as those occurring across the vast middle shelf. Thus, one might view the NANZ as the periphery of an expansive continental shelf rather than as a unique habitat for fish.

5.6.1.1 Demersal Fishes

The annual trawl surveys conducted by NMFS provide a good overview of the demersal fish community in the eastern Bering Sea, including areas adjacent to the NANZ. It is clear from these surveys that the spatial distribution patterns of demersal fishes vary from year to year; areas of highest abundance occur adjacent to the NANZ in some years (Fig. 5.5).

Walters and McPhail (1982) applied numerical classification techniques to the NMFS trawl data to examine large-scale patterns in the community structure of demersal fishes in the eastern Bering Sea. Two major groups of organisms (species assemblages) repeatedly emerged in their analyses--a middle shelf group and an outer shelf group (Group 2 and Group 3, respectively, in Fig. 5.6a). The outer shelf group, found between about the 70-and 260-m isobaths, was dominated primarily by pollock. The middle shelf group, located between the 25-and 100-m isobaths, was dominated by yellowfin sole and pollock.

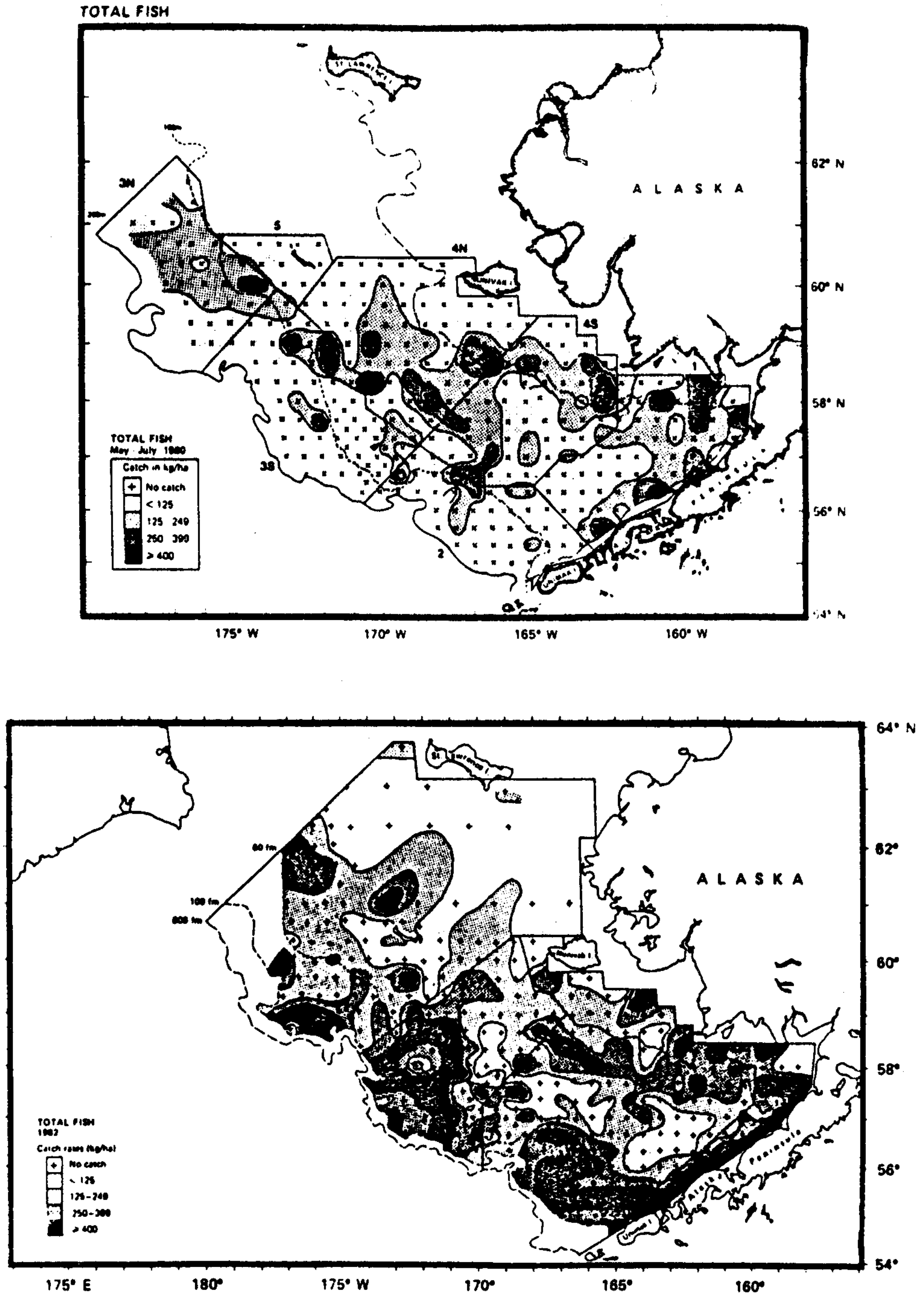


Figure 5.5 Biomass distributions of total fish catches by NMFS trawl surveys in 1980 (top) and 1982 (bottom) in the southeastern Bering Sea. From Umeda and Bakkala (1983) and Bakkala et al. (1985).

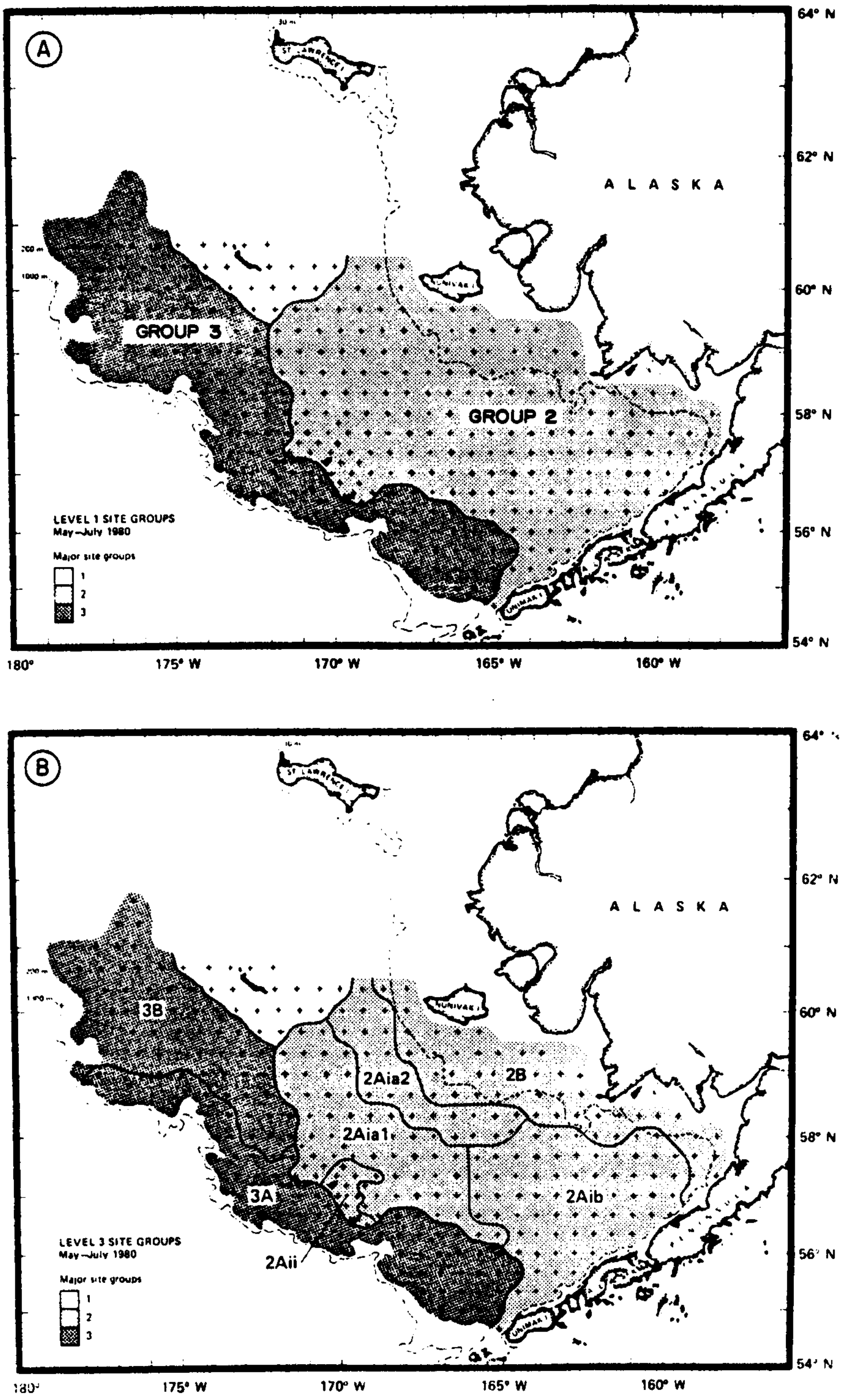


Figure 5.6. Species assemblages of fish and invertebrates in the eastern Bering Sea (1980), illustrating major groupings (top) and subgroupings (bottom). From Walters and McPhail (1982).

The middle shelf group is of particular interest because it shows that the NANZ lies adjacent to, or is part of, a fairly homogeneous and widespread community of demersal fishes. Yellowfin sole and pollock account for an average of 65% of the total fish biomass in the middle shelf region, followed by Pacific cod, Alaska plaice and rock sole (22%), and miscellaneous other fishes (Table 5.4). The community structure in the middle shelf subarea immediately adjacent to the NANZ (Subarea 2Aib in Fig. 5.6b) is similar; the dominant species in the two areas are the same but the fish tend to be more abundant in the subarea. These same species are also abundant in the NANZ, as will be described shortly.

5.6.1.2 Pelagic Fishes

Biological associations of pelagic fishes over the Bering Shelf are less well known than are those for the demersal species. Smith et al. (1984) note that the pollock is probably one of the dominant members of the midwater zone; it is widespread and abundant over the outer and middle shelf areas. About 10 other pelagic species are also important as resident or migratory members of the middle shelf community: salmon (5 species), herring, capelin, rainbow smelt, eulachon, and sand lance (Macy et al. 1978). With the exception of eulachon, these pelagic species are also abundant in the NANZ.

5.6.2 Species Composition and Relative Abundance

The shallow coastal waters of the eastern Bering Sea support a diverse fish fauna--nearly 100 species have been collected there (summarized by Isakson et al. 1986). Fifty-eight of these species were caught in the NANZ during this study (Table 5.5) though only ten species contributed 10% or more of the total numbers or biomass of catches by any one gear type (Table 5.6). The composition of the catch varied according to the sampling gear used and the habitat sampled. (Sampling gear and habitat are related, in that different gear types generally are used to sample different habitats.) Detailed results about catches by gear type are listed in Appendix 5.1.

Table 5.4. Species composition and abundance of demersal fishes which characterize (a) the middle Bering Shelf, and (b) the middle shelf subarea adjacent to the NANZ (see Fig. 5.6), based on NMFS trawl data. Source: Walters and McPhail 1982.

Fish	Species	BPUE[1]			
		Middle[2] Bering Shelf		Subarea[3] Nearest NANZ	
		kg/ha	%	kg/ha	%
Yellowfin sole	*Limanda aspera*	67	38	103	43
Walleye pollock	*Theragra chalcogramma*	47	27	62	26
Pacific cod	*Gadus macrocephalus*	19	11	26	11
Alaska plaice	*Pleuronectes quadrituberculatus*	10	6	13	5
Rock sole	*Lepidopsetta bilineata*	9	5	18	8
Sculpin	*Myoxocephalus* spp.	5	3	4	2
Greenland turbot	*Reinhardtius hippoglossoides*	2	1	*	*
Yellow Irish Lord	*Hemilepidotus jordani*	2	1	*	*
Flathead sole	*Hippoglossoides elassodon*	2	1	3	1
Wattled eelpout	*Lycodes palearis*	2	1	1	*
Longhead dab	*Limanda proboscidea*	1	1	3	1
Sculpin	*Gymnocanthus* spp.	1	1	*	*
Pacific halibut	*Hippoglossus stenolepis*	1	1	2	1
Skates	*Raja* spp.	1	1	1	*
Eelpouts	*Lycodes* spp.	1	1	*	*
Butterfly sculpin	*Hemilepidotus papilio*	1	1	*	*
Sturgeon poacher	*Agonus acipenserinus*	*	*	1	*
Other		4	2	3	1
Total Fish		175		240	
Water Depth (m)					
Mean		69		58	
Range		11-274		11-102	
No. Trawls		944		319	

*<0.5.

[1] Biomass per unit effort, four-year average (1978-1981).

[2] Region 2 in Walters and McPhail 1982 (see Fig. 5.6a).

[3] Areas 2A (1978), 2Aib (1979,1980), and 2B (1981) in Walters and McPhail 1982. This area is roughly similar to NMFS Subarea 1.

Table 5.5. Fish species, codes and total catches in the NANZ, 1984-85.

Species	Code	Total Catch
Alaska plaice	AKPL	269
Aleutian alligatorfish	ALAL	17
Arrowhead sculpin	AHSC	1
Arrowtooth flounder	ARRO	51
Bering flounder	BERF	4
Bering (warty) poacher	BPOA	189
Butter sole	BUTS	34
Capelin	CAPE	5
Chum salmon	CHUM	255
Crested sculpin	CRES	3
Crescent gunnel	CRGU	11
Crescent prickleback	P-2	4
Dolly Varden	DOLL	16
Eulachon	EULA	1
Flatfish (unident.)	F-1	8
Flathead sole	FLAT	152
?Flathead sole (larvae)	L-2	10
Great sculpin	GRSC	22
Greenland turbot	GRTU	1
Greenling (unident.)	GREE	79
Kamchatka flounder	KAMC	1
Kelp greenling	KGRE	8
Longhead dab	LDAB	4
Longsnout prickleback	LSPB	4
Masked greenling	MASK	45
Pacific cod	PCOD	2,119
Pacific halibut	HALI	102
Pacific herring	HERR	708
Pacific sandfish	TRIC	1,610
Pacific sand lance	SANL	62,211
Pacific staghorn sculpin	STAG	227
Pacific tomcod	TOMC	1
Padded sculpin	PADS	1
Pink salmon	PINK	10
Plain sculpin	JOAK	8
Prickleback (unident.)	PRIC	4
Rainbow smelt	RBSM	1,848
Red Irish Lord	REDL	6
Ribbed sculpin	RIBS	8
Rock greenling	RGRE	7
Rock sole	ROKS	3,729
Sablefish	SABL	6
Salmon (unident.)	SALM	13
Sand sole	SSOL	1
Sculpin (unident.)	SCUL	12
Silverspotted sculpin	SILV	20
Slim sculpin	SLIM	1
Smooth lumpsucker	SMLP	1
Snailfish (unident.)	SNAL	128
Snake prickleback	SNAK	26
Sockeye salmon	SOCK	12
Spiny lumpsucker	SLUM	1
Spiny cheeked starsnout poacher	SSPO	1
Starry flounder	STAR	112
Sturgeon poacher	STUR	35
Surf smelt	SURF	14
Threaded sculpin	S-2	30
Threespine stickleback	3ST	3
Tubenose poacher	TUBE	354
Walleye pollock	POLK	13,377
Warthead (Greenland) sculpin	WASC	3
Whitespotted greenling	WGRE	101
Yellow Irish Lord	YEIL	52
Yellowfin sole	YELS	4,706
Unidentified		39
Total		92,841

Table 5.6. Abundant fish species (> 10% of catch) in the NANZ.

	Catch Composition (%)							
	Bottom Trawls[1]		Midwater Trawls[2]		Gill Nets[3]		Beach Seines[4]	
Fish	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
Yellowfin sole	32	46						
Rock sole	23	36						
Sand lance	10		80	46				
Pollock			16	21	16	32		
Herring				26				
Pacific cod					15	21		
Rainbow smelt					14		20	
Pac. staghorn sculpin							13	37
Chum salmon							27	10
Starry flounder								31
Totals: No.	14,413		76,131		544		920	
kg.		1,412		595		201		45
Effort (sets)	166		107		62		63	

[1] Combined gears: TRY1, BT-1, Misc. (see Table 5.3 for gear codes).

[2] Combined gears: M-3, M-4, Misc.

[3] Combined gears: GN-S, GN-B, GNXS, GNXB, Misc.

[4] Combined gears: BS-1, BS-3.

Additional information about the composition of species collected by different gear types (and in different years) is provided by several other studies conducted in the NANZ (Tack 1970, Cimberg et al. 1984, Isakson et al. 1986). These and the present study show that the abundant species (those comprising 10% or more of biomass or numbers of catches) are as follows:

Commercial Species	Forage Fishes	Miscellaneous Residents
Pacific cod	Sand lance	Pacific sandfish
Pollock	Rainbow smelt	Whitespotted greenling
Herring	Herring	Masked greenling
Sockeye salmon	Capelin	Starry flounder
Chum salmon		Staghorn sculpin
Pink salmon		Dolly Varden
Coho salmon		Surf smelt
Yellowfin sole		Tubenose poacher
Rock sole		

It is apparent that commercial species are well represented in the NANZ.

The distributions of these species were examined in four habitat categories in the NANZ: (1) Pelagic zone, (2) Demersal zone, (3) Exposed nearshore coastlines, and (4) Protected nearshore coastlines such as lagoons:

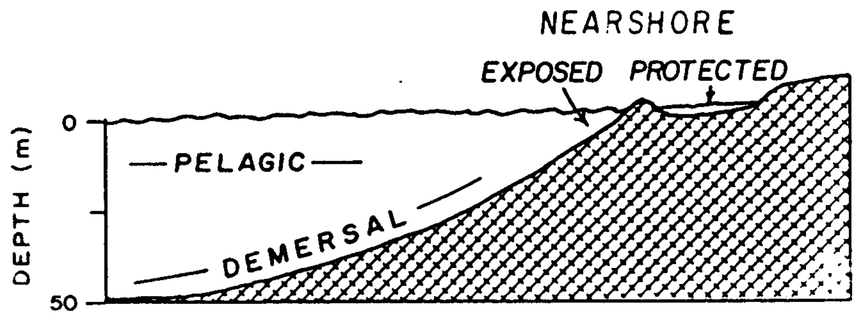


Table 5.7 lists the abundant species in each habitat; Table 5.8 provides the data upon which Table 5.7 is based. The information in

Table 5.7. Abundant fish species (>10% of catch numbers or biomass) in four coastal habitats. See text for explanation of asterisks. Sources: the present study, Tack 1970, Cimberg et al. 1984, Eggers and Fried 1984, Isakson et al. 1986.

	Dominant Fishes In Coastal Habitats			
Fish	Demersal (10-50 m)	Pelagic (20-50 m)	Nearshore (Exposed) (0-10 m)	Nearshore (Protected) (0-5 m)
Sand lance	x	x	x	x
Pacific cod	x	x	x	x
Pollock	x	x		x
Yellowfin sole	x		x	x
Rock sole	x			
Herring		x	*	*
Sockeye salmon		x	x	x
Chum salmon		x	x	x
Pink salmon		x		x
Pacific sandfish		x	x	
Whitespotted greenling		x		x
Rainbow smelt			x	x
Dolly Varden			x	x
Starry flounder			x	x
Staghorn sculpin			x	x
Capelin			*	
Masked greenling				x
Coho salmon				x
Surf smelt				x
Tubenose poacher				x

Table 5.8. Abundant fishes (>10% of catch) in various habitats in the NANZ. Abbreviations: N (number caught), W (weight).

A. PELAGIC HABITATS (20-50 m)

Fish	1984-85[1] Midwater Trawls		Purse Seine[2] 1984		Purse Seine[2] 1985		Gill[3] Net
	% N	% W	% N	% W	% N	% W	
Sand lance	80	46			28		
Pollock	16	21					
Herring		26					
Pacific cod			78	30			
Chum salmon				10			*
Pink salmon				26			
Sockeye salmon					56	95	*
Whitespotted greenling			12				
Pacific sandfish				18			
Total Catch (n)	76,131		1,853		2,223		
(kg)		595		15.5		598	
Effort (sets)	107		21		29		-

[1] Gear: M-3, M-4, misc.

[2] Isakson et al. (1986): Transects 4-6, offshore Stations 0-2 (20-50 m).

[3] Eggers and Fried (1984): ADFG test fishery off Port Moller.

*See text.

Table 5.8 (cont'd)

B. DEMERSAL HABITATS (10-50 m)

	1984		1984-85		1982[3]	1984[4]	
	Gill Net[1]		Bottom Trawls[2]		Trynet Trawl	Otter Trawl	
Fish	% N	% W	% N	% W	% W	% N	% W
Yellowfin sole	22		32	46	55	44	64
Rock sole	15		23	36	29	29	14
Pollock	47	54					
Pacific cod	13	32				21	
Sand lance			10				
Total catch (n)	179		14,413			1,420	
(kg)		119		1,412	1,422		54
Effort (sets)	7		166		79	30	

[1] Gear: GN-B.

[2] Gear: TRY1, BT-1, Misc.

[3] Cimberg et al. (1984).

[4] Isakson et al. (1986): Transects 4-6, Stations 2 and 3.

Table 5.8 (cont'd)

C. NEARSHORE HABITATS - EXPOSED COASTLINE (0-10 m)

Fish	1984-85[1] Gill Nets		1984-85[2] Beach Seine		1984-85[3] Trawl		Beach Seine[4]		Tow Net[4]	Purse Seine[4]
							1984	1985	1984	1985
	% N	% W	% N	% W	% N	% W	% N	% N	% N	% N
Chum salmon		15	27	10				24		28
Rainbow smelt	21		20					12	25	26
Staghorn sculpin	19	18	13	17						
Sand lance					11		94	51	72	12
Dolly Varden		14								
Pacific cod	16									
Starry flounder		18		13						
Pacific sandfish	12									
Yellowfin sole					33	69				
Sockeye salmon										27
Herring*										
Capelin*										
Total catch (n)	357		920		6,629		35,122	16,266	27,979	2,732
(kg)		81		45		388				
Effort (sets)	47		63		94		47	41	40	34

---

[1] Gear: GNXS, GNXB.

[2] Gear: BS-1, BS-3.

[3] Gear: TRY1.

[4] Isakson et al. (1986).

*See text.

Table 5.8 (cont'd)

D. IZEMBEK LAGOON

Fish	Gill Net[1]		Fyke Net		Beach Seine[2]		1984 Beach Seine[3]		1985 Beach Seine[3]		Otter Trawl[3]		Purse Seine[3]		Pushnet[4]	Seine	Gill Net
	% N	% W	% N	% W	% N	% W	% N	% W	% N	% W	% N	% W	% N	% W	% N	% N	% N
Chum salmon	10	62			85	26				11			30	12			
Staghorn sculpin	62	16		25		68	14	35								61	43
Sand lance							46		95	60	49						
Dolly Varden		13								10							
Masked greenling				18											19		
Whitespot greenling				19													22
Greenling unident.			17														
Pollock			32														
Tubenose poacher			28												56	12	
Starry flounder												60					
Coho salmon													16	48			
Sockeye salmon													49	37			
Pacific cod											25						
Rainbow smelt								13									
Surf smelt							21	41									
Total catch (n)	39		466		171		844		4,443		1,840		62		4,169	466	403
(kg)		19		9		3		20		9		26		1			
Effort (sets)	5		6		6		13		4		12		3		193	29	

[1] Gear: GNXS.

[2] Gear: BS-3.

[3] Isakson et al. (1986): Transect 6; Stations 5÷11.

[4] Tack (1970).

Table 5.8 (cont'd)

E. PORT MOLLER

Fish	Tow Net[1]		Otter Trawl[1]		Purse Seine[1]		1984 Beach Seine[1]		1985 Beach Seine[1]	
	% N	% W	% N	% W	% N	% W	% N	% W	% N	% W
Sand lance	94	94			35	33	99	52	30	46
Yellowfin sole			79	80						
Chum salmon					12			37	58	29
Sockeye salmon					43	34				
Rainbow smelt						14				
Pink salmon									12	
Herring*										
Total catch (n)	9,848		3,818		1,643		30,856		15,940	
(kg)		18		147		20		178		59
Effort (sets)	14		16		14		15		24	

[1] Isakson et al. (1986).

*See text.

Tables 5.7 and 5.8 is thought to provide a reasonable overview of fish distribution trends in the NANZ because it is a composite of a large sampling effort in time and space, and the data were obtained using a variety of gear, each one of which is typically selective for certain species or size classes of fish.

The most prominent features of Table 5.7 are that many of the abundant species are distributed throughout the NANZ, and that the diversity of fishes increases in nearshore habitats. Six species were both abundant and widely distributed, being ranked as abundant species in at least three of the four habitats: sand lance, Pacific cod, pollock, yellowfin sole, sockeye salmon and chum salmon. A brief description of the fishes in each habitat follows.

5.6.2.1 Pelagic Zone (20-50 m depth range)

The pelagic fish community generally refers to species in the watercolumn that are not closely associated with either the seafloor or the very shallow waters adjacent to the shoreline. In the NANZ, pelagic fishes were caught by midwater trawl, purse seine, and surface gill net in waters 20-50 m deep. Abundant species in this zone were salmon, sand lance, young-of-year cod (pollock and Pacific cod), herring, and two other species not normally thought of as being pelagic--whitespotted greenling and Pacific sandfish (Table 5.8).

Salmon are abundant in the NANZ during two phases of their life cycle--smolts migrate through the study area as they leave Bristol Bay, and adult salmon migrate back through the area as they return to spawn in Bristol Bay streams. Cod young-of-year, particularly pollock, were abundant in the offshore portions of the study area and, together with jellyfish, were often the only organisms caught in midwater trawls in the NANZ. Sand lance were also present, but their overwhelming contribution to pelagic fish catches was due to a few samples from dense schools of fish. (Two midwater trawls caught a total of 47,000 sand lance, equaling 50% of all fish caught during this study.)

5.6.2.2 Demersal Zone (10-50 m depth range)

Two flatfishes (yellowfin sole, rock sole) and two semi-demersal species (pollock, Pacific cod) dominated the demersal fishes in the NANZ (Tables 5.7 and 5.8). These same species also characterize the demersal fish community throughout most of the southeastern Bering Sea shelf (Table 5.4).

Sand lance are also members of this community, though large numbers were not caught in bottom trawls. This species, which was abundant in the pelagic zone (see above), burrows into bottom sediments at night and thus would be equally abundant in the demersal zone. Our low catches could have been caused by one or more of several factors: (1) sand lance distribution is very patchy and schools could have been missed by the bottom trawls, (2) bottom trawls may not catch them efficiently, and (3) trawling was not conducted at night, and sand lance are near the seafloor only at night.

5.6.2.3 Nearshore Zone - Exposed Coast (0-10 m)

The nearshore zone has been sampled by a variety of gear (gill net, tow net, purse seine, bottom trawl, beach seine). Abundant species here generally include those occurring in the nearby pelagic zone (sand lance, salmon, Pacific sandfish) and demersal zone (yellowfin sole, Pacific cod). Additional species that are abundant at various times of the year include rainbow smelt, Dolly Varden, starry flounder, and staghorn sculpin (Table 5.8). Two other species, herring and capelin, were not abundant in collections in this study but are known to spawn in the study area and migrate through in large schools (Barton 1979).

5.6.2.4 Nearshore Zone - Protected Coasts

Two semi-enclosed bodies of water, Izembek Lagoon and Port Moller, have been studied sufficiently that their fish fauna can be characterized. Results from these studies may suggest which species use other lagoons and bays in the NANZ.

Izembek Lagoon (0-5) m). This lagoon supports a diverse assemblage of year-round residents and summer transients (Tack 1970, Smith and Paulson 1977, Isakson et al. 1986, the present study). Over 30 species have been collected in the lagoon; 14 of these comprised 10% or more of the total catch in the above studies (Table 5.8). The principal residents were the staghorn sculpin, tubenose poacher, whitespotted and masked greenlings, and starry flounder. The most abundant summer transients were salmon juveniles and adults, sand lance, Dolly Varden, pollock juveniles, Pacific cod, rainbow and surf smelts (Tables 5.7 and 5.8). Herring and capelin may pass through the lagoon as well. Of all these species, only four (masked greenling, coho salmon, surf smelt, tubenose poacher) were not abundant in samples from pelagic, demersal or exposed nearshore zones.

Port Moller (0-40 m). This very large waterbody contains a diverse array of aquatic habitats, from expansive tidal mudflats in Nelson Lagoon to embayments 40 m deep. Isakson et al. (1986) sampled Port Moller with a variety of gear and caught primarily sand lance, salmon, yellowfin sole, and rainbow smelt, all of which are common in other areas of the NANZ (Tables 5.7 and 5.8).

5.6.3 Seasonal Abundance

Fish abundance in the NANZ can be characterized as (1) dominated by demersal fishes, which are probably present in similar concentrations farther offshore, and (2) subject to large, but sporadic, pulses of forage fishes in spring and summer. Fish CPUE (catch per unit effort) and BPUE (biomass per unit effort) are summarized in Table 5.9 and examined below by season and habitat. More detailed CPUE and BPUE estimates are listed by species and gear type in Appendix 5.1 and by season in Appendix 5.2. Sample sizes are also listed in these appendices.

5.6.3.1 Demersal Zone

In the eastern Bering Sea, many demersal fishes are reported to undergo a seasonal migration from deep overwintering areas on the outer shelf or slope to shallower waters of the shelf during summer (e.g., Hood

Table 5.9. Fish catch per unit effort (CPUE) and biomass per unit effort (BPUE), all sites and dates combined.

Habitat	Gear	CPUE	BPUE
Pelagic			
- larval fish	Bongo	-	1.0 mg/m^3
- non-larvae	M-4	0.01 $fish/m^3$	0.07 g/m^3
Benthic			
- small trawl	TRY1	0.04 $fish/m^2$	2.0 g/m^2
- large trawl	BT-1	0.04 $fish/m^2$	10.6 g/m^2
Nearshore			
- gill net	GNXS,GNXB	0.8 fish/h*	180.0 g/h*
- beach seine	BS-1,3	15.0 fish/haul*	461.0 g/haul*

*Weighted averages.

[1] See gear codes in Table 5.3.

and Calder 1981). Some supportive evidence for this general pattern was observed in this study--fish biomass in 1985 in the NANZ was high in summer and low in winter, although there was little such difference the previous year (Fig. 5.7a).

The winter data suggest that migration patterns may be different among different age groups. Fish numbers in winter remained at about summer levels even though biomass decreased. This was apparently caused by the winter exodus of many (but not all) large fish and the movement of smaller individuals into the shallows to overwinter (discussed further in Section 5.6.5, this report).

Estimates of biomass of demersal fishes in this study were similar to those reported in previous studies in the NANZ, ranging from about 2-4 g/m^2 when small bottom trawls were used to sample fish (Table 5.10). For comparative purposes, we used a larger bottom trawl (gear code BT-1) on four occasions to determine if some fish were able to avoid being captured by the smaller gear. The larger trawl caught about five times more fish biomass than the small trawl (Table 5.10), but the numbers of fish caught by the two trawl sizes were generally similar (Fig. 5.7a), thus indicating that small trawls missed some of the larger fish in the population. The biomass of demersal fishes thus appears to be under-represented by the small-trawl data. It is not known if this bias applies equally throughout the NANZ, because the large trawl was not used in water less than 50 m deep.

In the deeper waters of the eastern Bering Sea, the estimated biomass of demersal fishes (based on catches by large trawls) is usually about 20-40 g/m^2 (Table 5.10). Although this indicates that the biomass of demersal fish in the NANZ is relatively low, there are two reasons why this conclusion may be premature. First, the NMFS trawl surveys in shallow waters (20-50 m deep) around Bristol Bay (of which our study area is a part) caught a biomass of demersal fish (29.3 g/m^2) which is similar to that in deeper waters, thus suggesting that our estimates, even with the large trawl, are too low (Table 5.10). Second, the NMFS surveys also found that the biomass of demersal fish in and adjacent to the NANZ is locally variable (12.5-40 g/m^2 = 125-400 kg/ha, see Fig. 5.4), thus our results with the large trawl may simply reflect the small sample size with this gear (n=4).

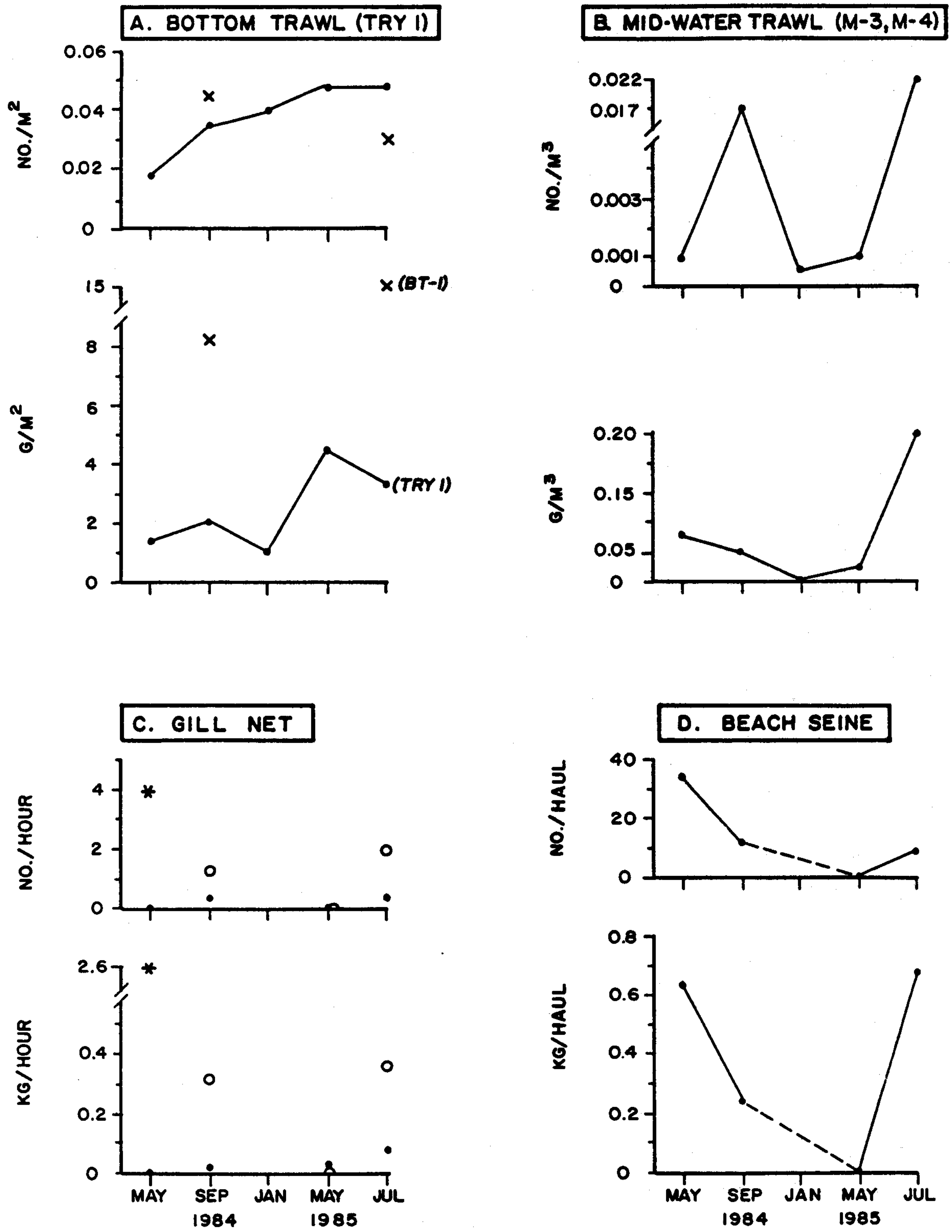


Figure 5.7. Seasonal CPUE and BPUE by four gear types in the NANZ study area, Alaska, species combined. Symbols: x (large bottom trawl BT-1), * (offshore gill net, bottom set), • (nearshore gill net, surface set), o (nearshore gill net, bottom set).

Table 5.10. Biomass of demersal fishes (species combined) caught by large and small bottom trawls in the NANZ and NMFS Subarea 1 in the eastern Bering Sea.

			NMFS Subarea 1	
	NANZ		Old[e]	New[f]
Year	Small Trawl	Large Trawl	Large Trawl	Large Trawl
1978			28.7	
1979			29.1	14.5
1980			24.1	20.8
1981			24.7	26.5
1982	4.3[a]		50.0	38.6
1983				44.1
1984	1.5[b]		39.4	36.7
1984-85	2.0[c]	10.6[d]		
1985				23.7
Means	2.6	10.6	32.7	29.3

[a] Cimberg et al. 1984, Trynet trawl (18' mouth, L. Thorsteinson, pers. comm.).

[b] Isakson et al. 1986, Trynet trawl (24' mouth), Transects 1-6.

[c] This study, Trynet trawl (16' mouth) (TRY1).

[d] This study, 83/112 trawl (BT-1).

[e] Bakkala et al. 1982, 1985; Umeda and Bakkala 1983; Bohle and Bakkala 1984; Sample et al. 1985. Miscellaneous large trawls were used, including the 83/112.

[f] Bakkala, pers. comm. New Subarea 1 = shallow waters (20-50 m) around Bristol Bay from Unimak Island to Nunivak Island.

5.6.3.2 Pelagic Zone

Fish caught in the pelagic zone of the NANZ consist of two gear-related size components--larval fish (caught by zooplankton net) and small to large fish (caught by midwater trawl and surface gill net).

Densities of larval fishes in the NANZ were low, averaging only 1 mg/m^3 (in 91 oblique bongo net tows) which is equivalent to about 1-2 larvae/m^3. Highest densities were recorded in May 1985 (4 mg/m^3) and July 1985 (5 mg/m^3).

The abundance of larger pelagic fishes was also low, due in part to gear limitations and to the low intensity of sampling. Juvenile and adult salmon, for example, are not particularly vulnerable to the gear used in this study (juvenile salmon were specifically targeted in the companion OCSEAP study by Isakson et al. 1986). Other schooling species such as herring and sand lance are highly clumped in time and space, and precise estimates of their abundance requires a much more intensive sampling effort than was possible in this study. Despite these considerations, the ship's 38 kHz was monitored during all mid-water trawls, and it only occasionally identified fish schools that the trawls missed. Further, even if the mid-water trawls had accurately sampled pelagic fishes during the sampling periods, large pulses of fish activity could have occurred between sampling cruises (e.g., one such probable pulse was the spawning migration of herring through the NANZ in June, a time not sampled during this study).

CPUE and BPUE of trawl-caught fish were generally only about 0.001 fish/m^3 and 0.05 g/m^3, respectively, except during summer periods when high but sporadic catches of sand lance were made (Fig. 5.7b). These estimates are probably biased by two opposing methodological problems: (1) the estimates are biased upward because mid-water tows were generally made at depths where sonar indicated the highest concentrations of fish to be, but (2) the values are also biased downward because small individuals of the principal species caught (sand lance and pollock young-of-year) were not effectively retained by the mesh of the trawl used. The magnitudes of these biases are not known.

Isakson et al. (1986) used a small-mesh purse seine to sample fishes in the watercolumn in the study area and obtained an average biomass estimate of 0.02 g/m3. Although this value is similar to our estimate (excluding our large catches of sand lance), the similarity is coincidental because the two gear types sampled different parts of the fish community. Our mid-water trawl generally caught sand lance and small pollock at offshore stations (20-90 m depths), usually at tow depths 10 m or more below the water surface. In contrast, their purse seine sampled surface waters (0-11 m) closer to shore (10-30 m depths) and caught a variety of fishes, including some adult salmon.

In May 1984, large gill nets (gear code GN-S) were used to sample pelagic fishes in offshore waters of the NANZ (at the 20- and 50-m stations). Catches of fish in surface waters were almost nil--only a single fish was caught in 7 gill net sets (= 48 h fishing time). The timing of this sampling effort contributed to its low catches because it was conducted too early in the season to catch adult salmon returning to Bristol Bay. Herring, however, migrate into the NANZ about this time to spawn, but their pre-spawning aggregations were highly localized and not in the few areas sampled.

5.6.3.3 Nearshore Zone

Fish catches along the NANZ shoreline were surprisingly low. Average gill net and beach seine catches consisted of only 1 fish/h and 15 fish/haul, respectively (Fig. 5.7c,d). Isakson et al. (1986) report a considerably higher beach seine CPUE in the NANZ (mean = 815 fish/haul in their Transects 4 and 6), largely due to sporadically high catches of sand lance and juvenile chum salmon.

Gill nets were also used in May 1984 in nearshore and offshore areas. Catches indicated a low abundance of fish in both areas. Nearshore catches were zero (n=6 sets), offshore surface catches were 0.02 fish/h (n=7 sets), and offshore bottom catches were 4 fish/h (n=7 sets). Even the latter rate must take into account that the offshore nets were 6 times larger than the nearshore nets, so it is to be expected that the offshore nets would catch more fish.

5.6.4 Echosounder Analyses

Hydroacoustic sampling was conducted during most fish trawling efforts and also during continuous transects conducted for shipboard censusing of seabirds and marine mammals. These hydroacoustic surveys provide information about general patterns of fish distribution at far more locations that could be sampled by nets. Further, they showed that conventional sampling gear was not missing large concentrations of pelagic or semi-demersal fishes (such as the dense concentrations of pollock which occur in deeper waters beyond the study area).

5.6.4.1 Comparison of Echosounder and Trawl Data

Before the hydroacoustic data can be interpreted, it is necessary to examine the relationships between the hydroacoustic data and fish catches by net. For the 61 midwater trawls (M-4) examined, there were significant positive correlations between estimates of echo-intensity and the abundance of fish caught (Table 5.11). But the biomass of fish in midwater trawls was also positively correlated with the biomass of jellyfish. Thus, it is likely that the higher codes of echo-intensity represent increases in both fish and jellyfish abundance in the mid-water zone. For the 33 bottom trawls (TRY1) examined, there was no significant positive correlation between echo-intensity and numbers or biomass of bottomfish (Table 5.11). This probably reflects the fact that most demersal species in the study area were flatfishes which usually lie directly on the seafloor and thus are not highlighted by echo-intensity.

5.6.4.2 Regional Patterns

A total of 655 10-min segments of 38-kHz echosounder tapes, representing 2326 km of the ship's track was examined to provide an overview of fish distributions in the study area. Mean values of echo-intensity were highest during summer periods and low in winter and spring (Table 5.12), which is in agreement with data obtained by other gear used in this study.

Table 5.11. Relationships between fish catches in midwater and bottom trawls and echosounder intensity (38 kHz) at the trawl depth in the NANZ study area.

	Correlation Coefficient	P
MIDWATER TRAWLS		
CPUE	0.28	0.05
BPUE	0.31	0.05
Mean wt. of fish	0.38	0.01
BOTTOM TRAWLS		
CPUE total fish	-0.09	NS
CPUE pelagic fish	-0.01	NS
CPUE flatfish	-0.11	NS
BPUE total fish	-0.18	NS
BPUE pelagic fish	0.02	NS
BPUE flatfish	-0.03	NS

Table 5.12. Echosounder records (38 kHz) from the NANZ study area coded for echo-intensity. Grand mean refers to the echo-intensity standards which ranged from 0 to 9.

Cruise	No. 10-min Segments	Total Distance Covered (km)	Grand Mean	SD
May 1984	82	239	0.4	0.6
September 1984	172	559	2.1	1.0
January 1985	70	259	1.2	0.9
May 1985	217	805	1.5	0.8
July 1985	114	464		
	655	2326		

For each of the five sampling periods the mean and maximum values of the hydroacoustic data are stylistically illustrated in Figures 5.8 and 5.9, where data obtained along transect lines have been expanded to cover both sides of the transect. As previously described, the mean value is the average of values obtained in the watercolumn during each 10-min segment of echosounder recording. The maximum value is the largest value obtained anywhere within the watercolumn.

The mean echo-intensities (Fig. 5.8) show the broad-scale distribution of fishes (and probably jellyfish). During most cruises, they tended to be homogeneously distributed throughout the shallow waters of the study area.

The maximum echo-intensities (Fig. 5.9) indicate a more patchy distribution of fishes, which is somewhat similar to the distribution of zooplankton during the same periods (see Section 4.0, this report). Locations of maximum fish abundance were seasonally variable and without consistent spatial trends within the limits of the study area.

5.6.5 Species Accounts

The temporal and spatial distributions and food habits of the abundant species are described in the following sections. Emphasis is placed on the most abundant species in the NANZ (sand lance, yellowfin sole). Life history highlights of other common species (pollock, rock sole, salmon, herring), and only a few details are presented for the less abundant species (rainbow smelt, capelin, Pacific cod, halibut, and others). Because of the large number of species involved, the fishes have been divided into four functional groupings: forage fish, salmon, demersal fishes, and nearshore residents.

An overview of the uses of the study area by the various species is summarized in Table 5.13. Major uses for all groups involve feeding and migration. A relatively small degree of spawning occurs in the NANZ by herring, capelin, and nearshore residents. In winter when many species have departed, the NANZ is inhabited by several demersal fishes as well as the resident species that remain year-round.

Table 5. 13. General patterns of fish use of nearshore waters along the northern Alaska Peninsula.

Species	Use of Study Area			
	Spawn	Feed	Migrate	Overwinter
Forage Fishes				
Sand lance	?	X	X	
Herring	X	X	X	
Capelin	X	X	X	
Rainbow smelt	?	X	X	
Pollock young-of-year		X		
Salmon				
Adults		X	X	
Juveniles		X	X	
Bottomfish				
Yellowfin sole	?	X	X	X
Rock sole	?	X	X	X
Pollock		X	X	
Pacific cod		X	X	
Lagoon and Nearshore Residents				
Greenling	X	X	X	X
Poachers	X	X	X	X
Sculpins	X	X	X	X

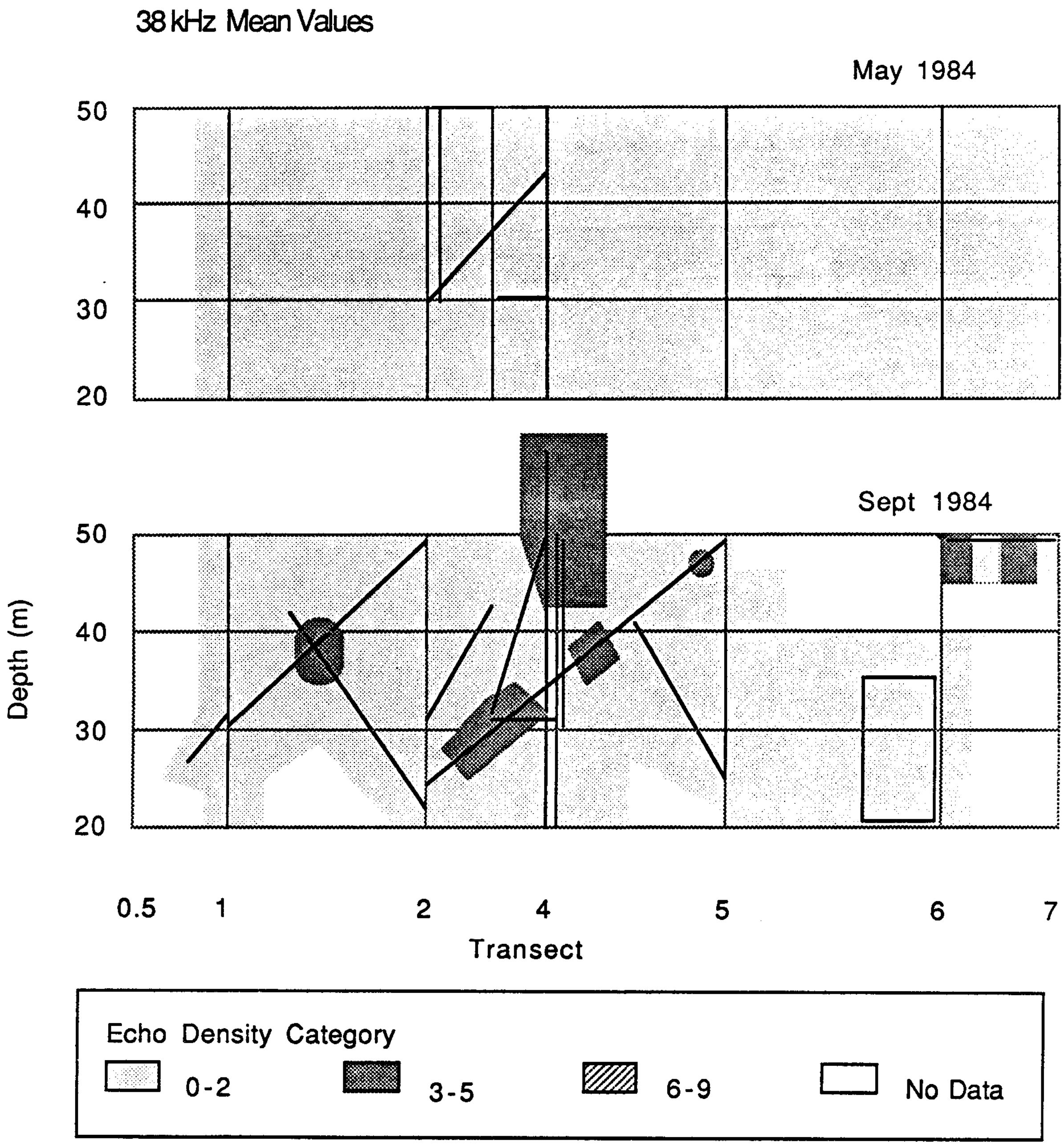
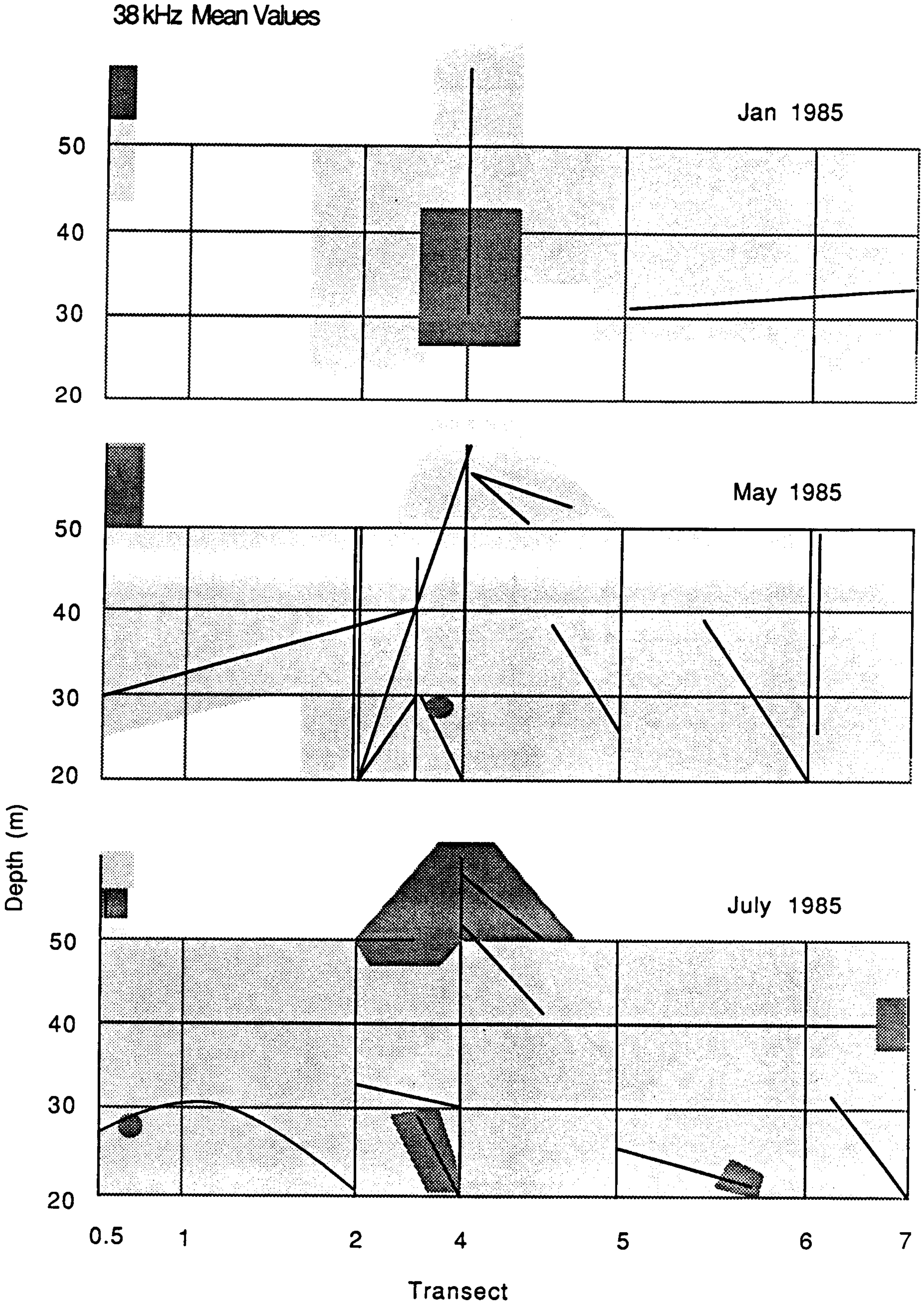


Figure 5.8. Stylized map of the NANZ study area, Alaska, showing the mean hydroacoustic echo-intensity (38 kHz) in the watercolumn during five cruises. Echosounder transects (dark solid lines) have been expanded to both sides of the transect line.


38kHz Mean Values
Jan 1985
May 1985
July 1985
Depth (m)
50
40
30
20
50
40
30
20
50
40
30
20
0.5
1
2
4
5
6
7
Transect

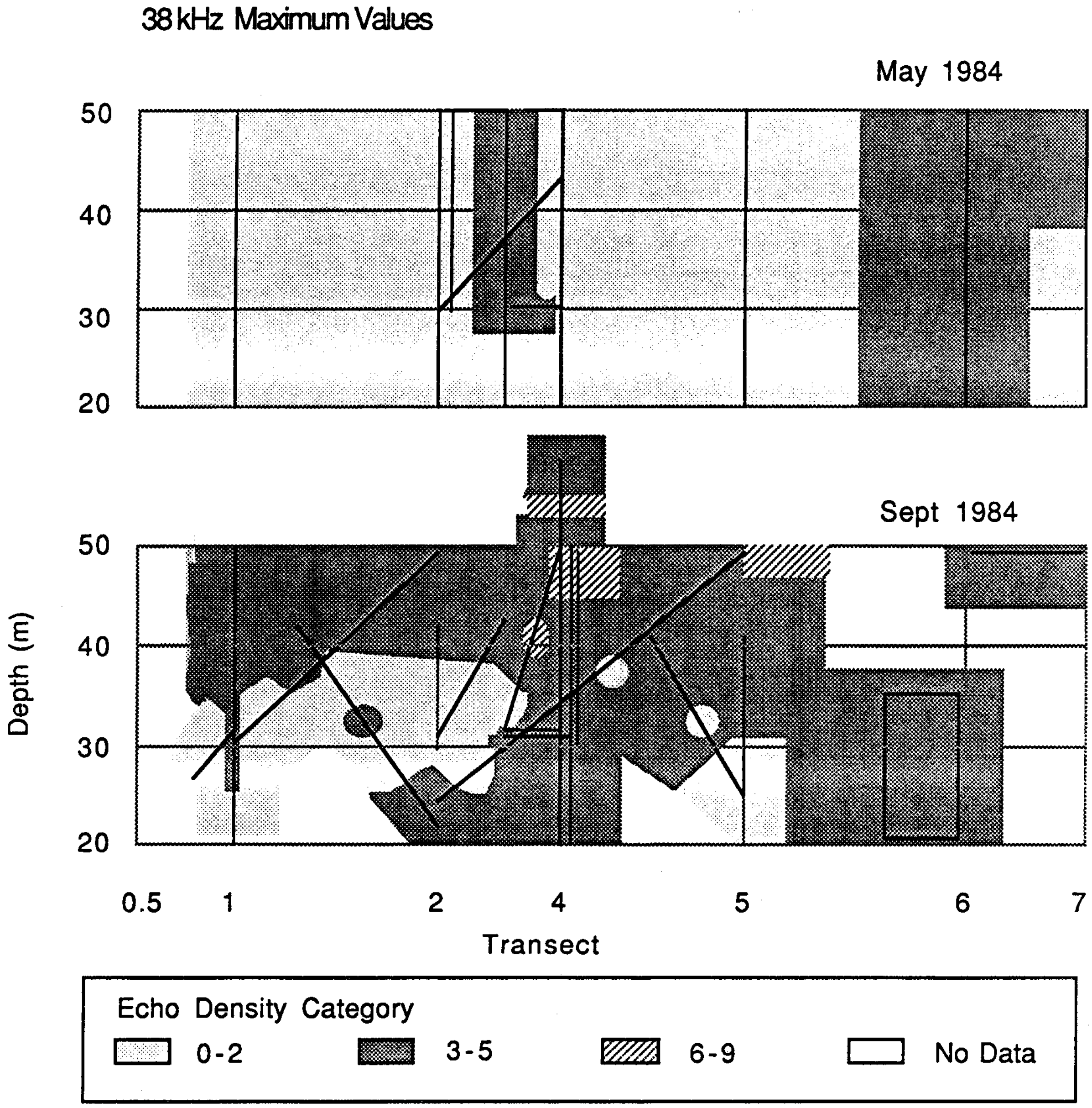
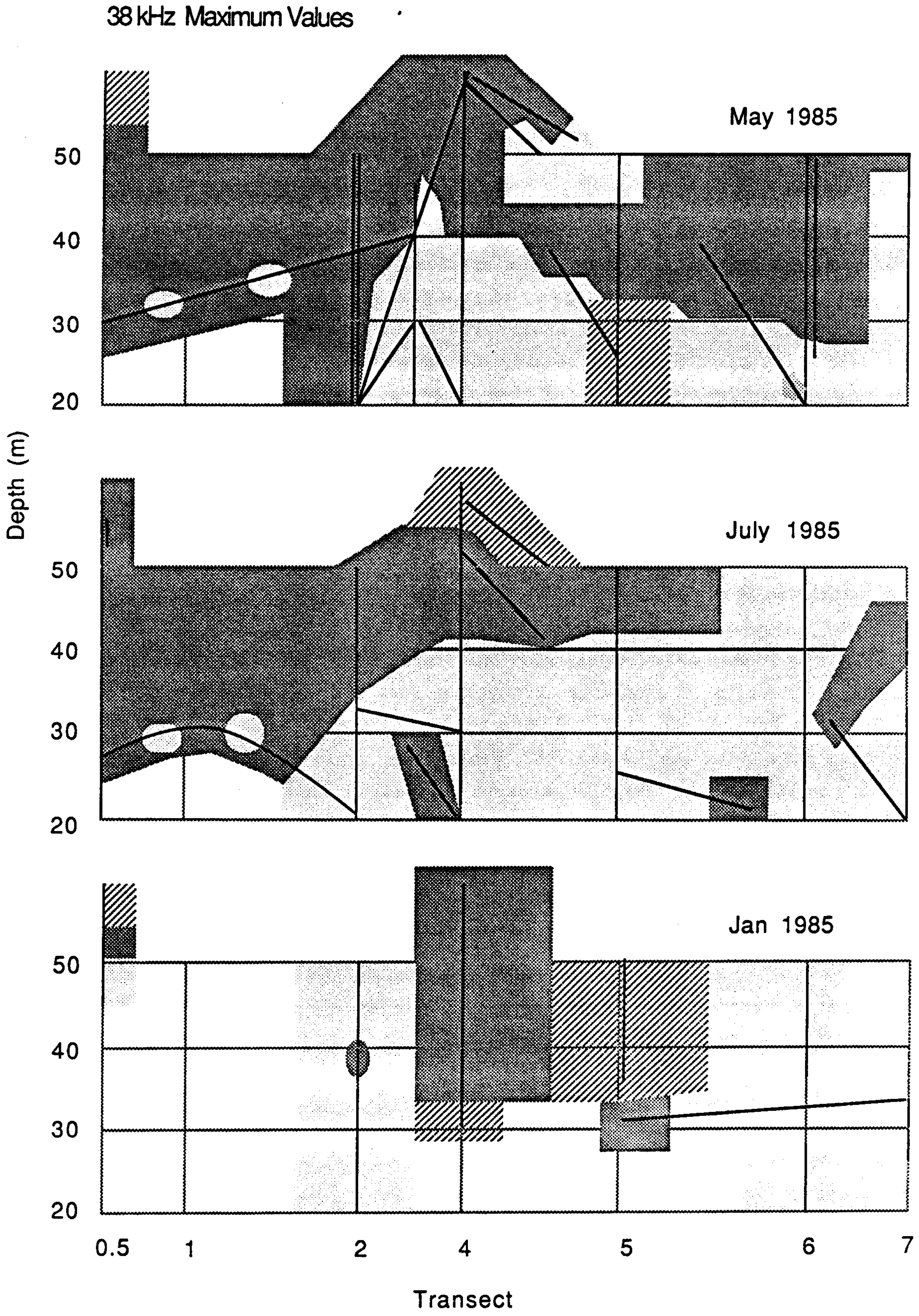


Figure 5.9. Maximum hydroacoustic value (38 kHz) in the watercolumn during five cruises in the NANZ study area, Alaska. Echosounder transects (dark solid lines) have been expanded to both sides of the transect lines.


38 kHz Maximum Values
May 1985
July 1985
Jan 1985
Depth (m)
50
40
30
20
0.5
1
2
4
5
6
7
Transect

5.6.5.1 Forage Fishes

The term 'forage fish' refers to species that are abundant, small, and significant in the diets of other consumers. Important forage species in the NANZ include sand lance, herring, capelin, rainbow smelt, and young-of-year pollock.

From early spring to late summer, there is a series of activity pulses as each forage fish species enters the area for various life history functions (Fig. 5.10a). Some species spawn in nearshore habitats, producing large numbers of eggs and young which later enter the study area. Other species feed in nearshore waters and may occur in dense schools. All species may be locally abundant at different times through the summer as they migrate to and from spawning, feeding, and overwintering areas. The net result is an abundant and presumably dependable supply of food for seabirds, marine mammals, and other fishes (Fig. 5.10b).

Pacific Sand Lance. The sand lance is a seasonally abundant fish which plays an important role in the Bering Sea food web. This small fish is a key food item for many species of seabirds, marine mammals, and other fishes. Although sand lance species are harvested commercially elsewhere in the world, they have largely gone unnoticed in the northeastern Pacific Ocean. Summaries of available information have been compiled by Trumble (1973) and Macy et al. (1978). More recent information is limited but growing (e.g., Dick and Warner 1982, Pinto 1984, Pinto et al. 1984, Hobson 1986, Isakson et al. 1986). Because knowledge about sand lance is limited, this species has been examined in more detail than other species in this report.

Sand lance in our area probably spawn in late fall or winter (Macy et al. 1978, Dick and Warner 1982). They may spawn intertidally (Dick and Warner 1982) or at depths of 25-100 m in areas having strong currents (Trumble 1973). These fish require particular substrate compositions for burrowing and presumably for spawning. Their adhesive eggs probably hatch in about 30 days, the exact time depending on water temperature. After the yolk sac is absorbed, the larvae become pelagic and widely distributed in the eastern Bering Sea (Fig. 5.11). Thereafter, the fish apparently

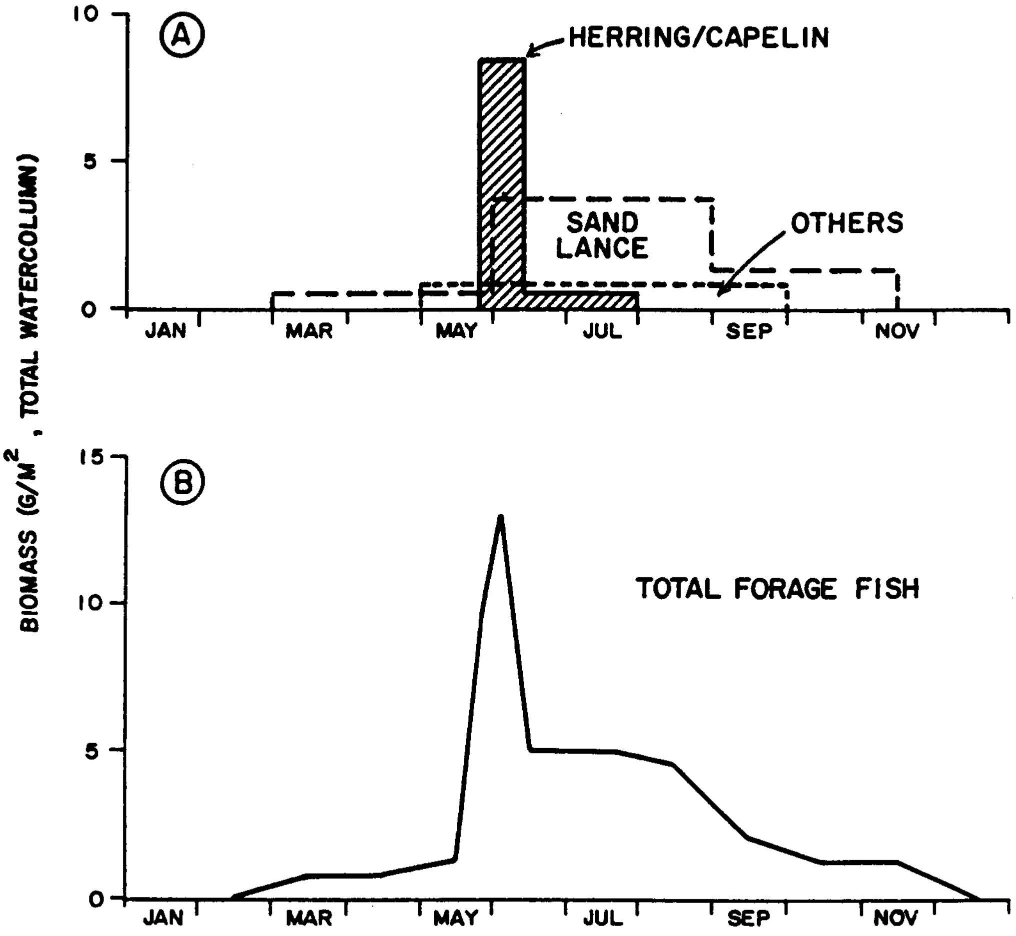


Figure 5.10. Estimated seasonal biomass of forage fishes in the NANZ study area, Alaska, 1984 and 1985 combined. Estimates are based on trawl data and assumptions outlined in Section 8.0.

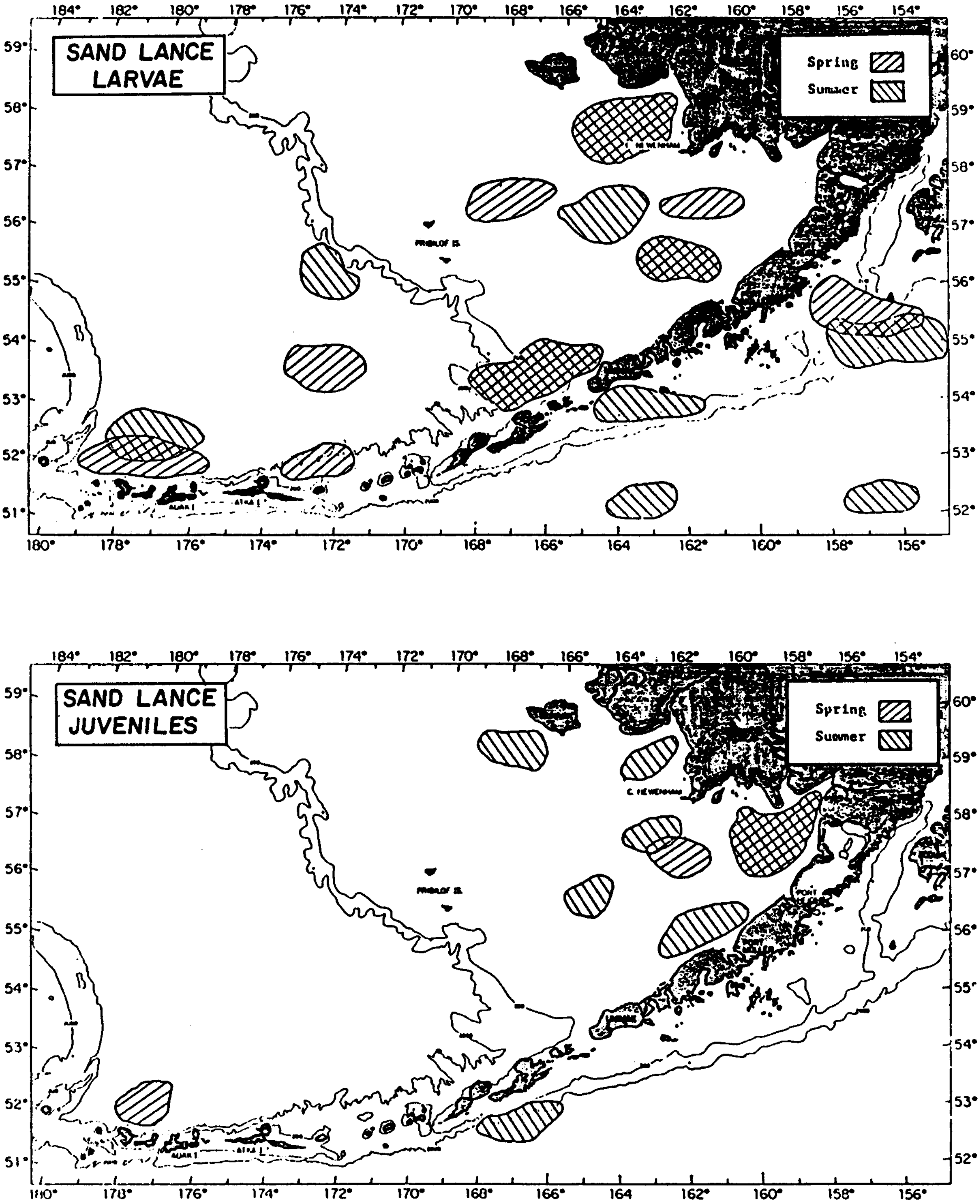


Figure 5.11. Generalized areas in which Pacific sand lance larvae (top) and juveniles (bottom) were caught by plankton nets, seine nets, and bongo nets in spring and summer, eastern Bering Sea and western Gulf of Alaska, by the NMFS. From Macy et al. (1978).

move into coastal waters where they are thought to be most abundant in water less than 50 m deep, at least in summer.

Sand lance have a wide range of tolerance to many physical factors. They have been collected in nearshore waters at temperatures ranging 0-20°C and over wide salinity and depth ranges. The most important physical factor in regard to their distribution may be the availability of suitable substrates for spawning and burrowing.

Most sand lance caught in the NANZ ranged in size from 70-160 mm (Fig. 5.12). Their sizes varied inconsistently between sampling periods, suggesting that we sampled different groups of fish passing through the region rather than following one population through time. Isakson et al. (1986) caught generally smaller sand lance (40-100 mm) in their beach seine hauls along the north side of the Alaska Peninsula.

The abundance of sand lance in the NANZ was highly variable in time and space. They were abundant in all four coastal habitats sampled (Table 5.7) but were most frequently encountered in shallower waters (Fig. 5.13). Highest BPUE values were usually in waters 20 m or less in both midwater and bottom trawls (Fig. 5.14). Isakson et al. (1986) report that, as summer progressed, sand lance moved away from the beaches and farther offshore--the CPUE in their beach seines dropped steadily from 5107 sand lance in late June to 4 in late August.

Sand lance were most abundant in the study area from spring to late summer (Fig. 5.15). Their distribution at this time was very patchy as illustrated by highly variable catches. An example of sand lance schools is shown on an echo-sounder recording made offshore of Izembek Lagoon (Fig. 5.16)--over 30,000 sand lance were caught at this site during a single 10-min midwater trawl (equaling about 50% of all sand lance caught during this study). On a local scale, annual variablilty of sand lance is large, depending on the size and number of schools moving through a given area and their presumably erratic residency time at any one site.

There is little background information about the food habits of sand lance in the northeast Pacific Ocean. Harris and Hartt (1977) and Rogers et al. (1979) examined sand lance from Kodiak Island and Smith and Paulson (n.d.) recorded the stomach contents of 5 sand lance from Izembek Lagoon.

During the present study, the food habits of 288 sand lance were examined. They had consumed a variety of zooplankton, but euphausiids

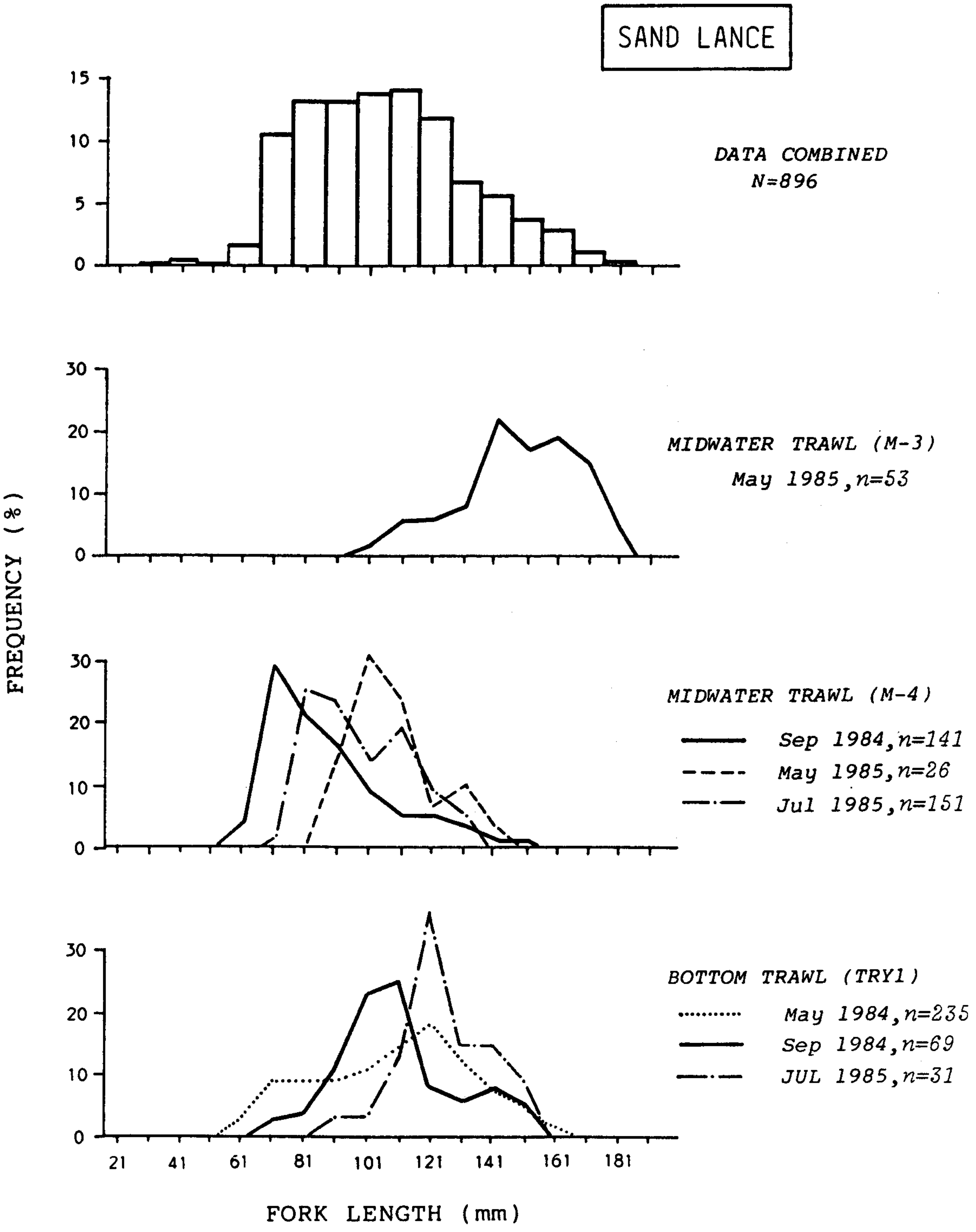


Figure 5.12. Length frequencies of sand lance in all catches and in catches separated by gear and date, NANZ study area, Alaska.

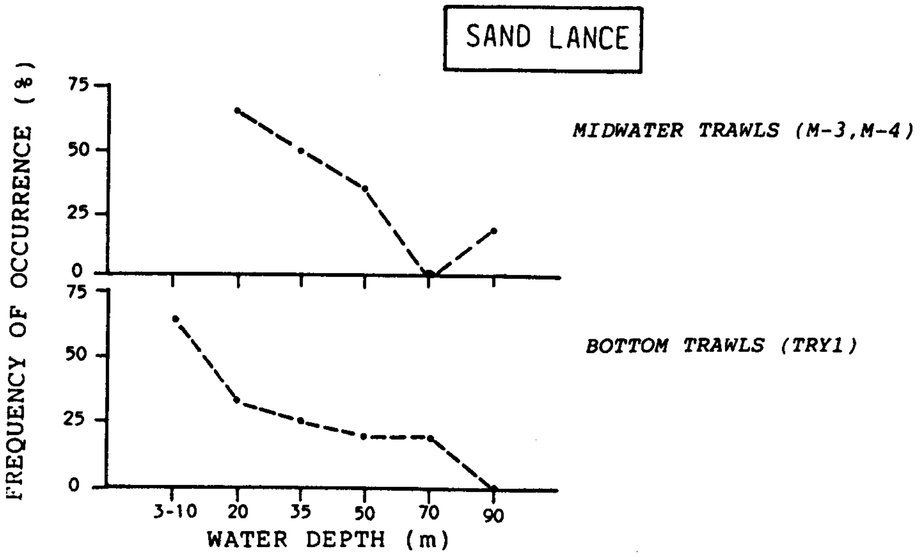


Figure 5.13. Frequency of occurrence of sand lance caught in trawls at various water depths, dates combined (January-September), in the NANZ study area, Alaska.

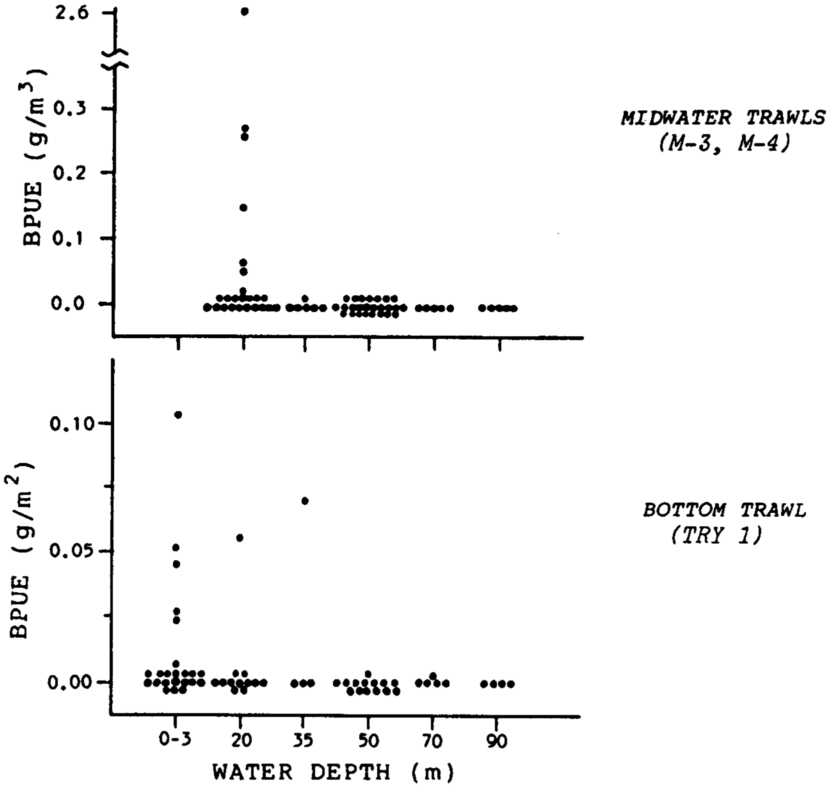


Figure 5.14. BPUE of sand lance caught in trawls at various water depths, dates combined (January-September), in the NANZ study area, Alaska. Data points represent station averages.

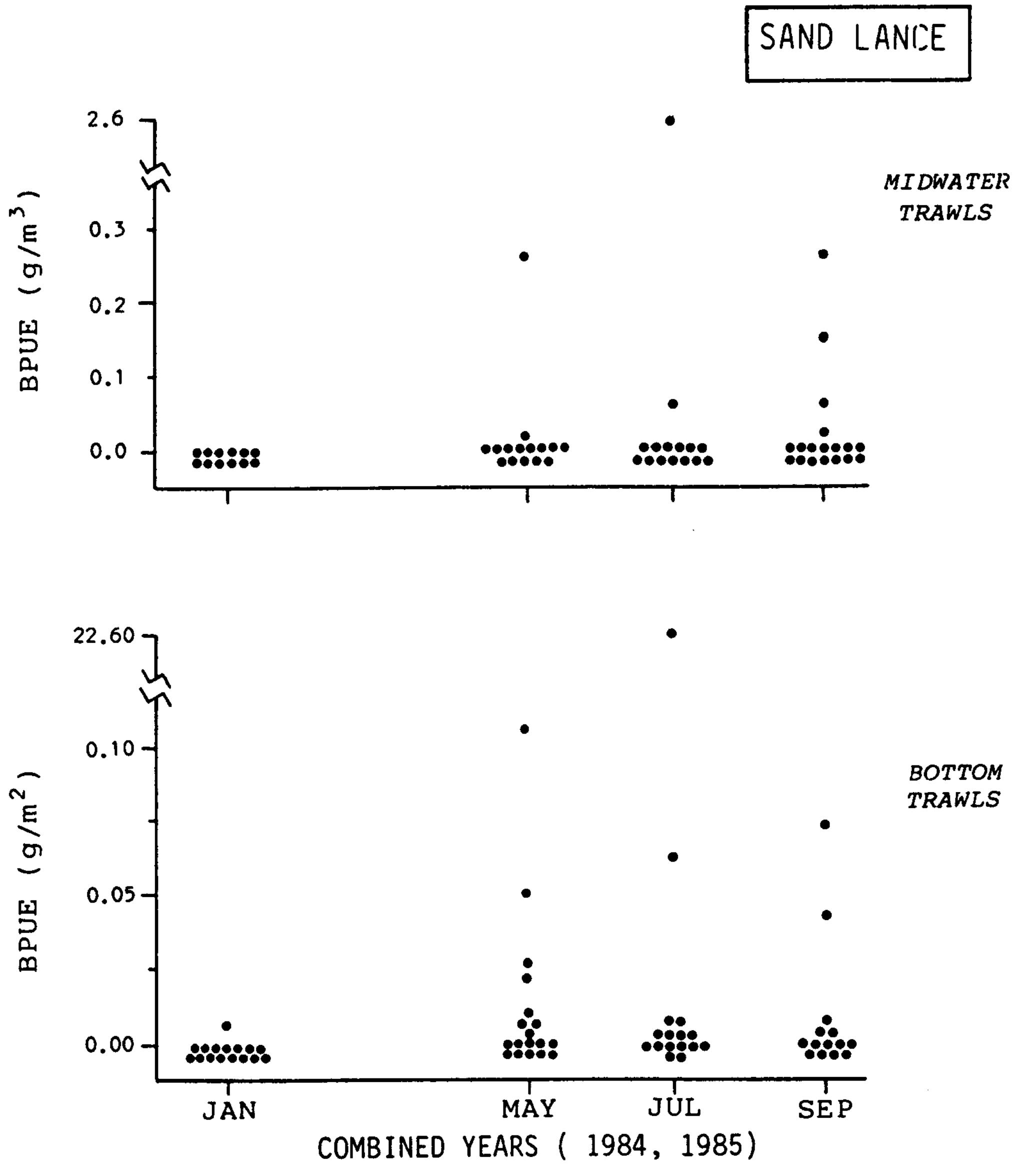


Figure 5.15. Seasonal BPUE of sand lance caught in midwater trawls (top) and bottom trawls (bottom), in the NANZ study area, Alaska. Data points represent station averages.

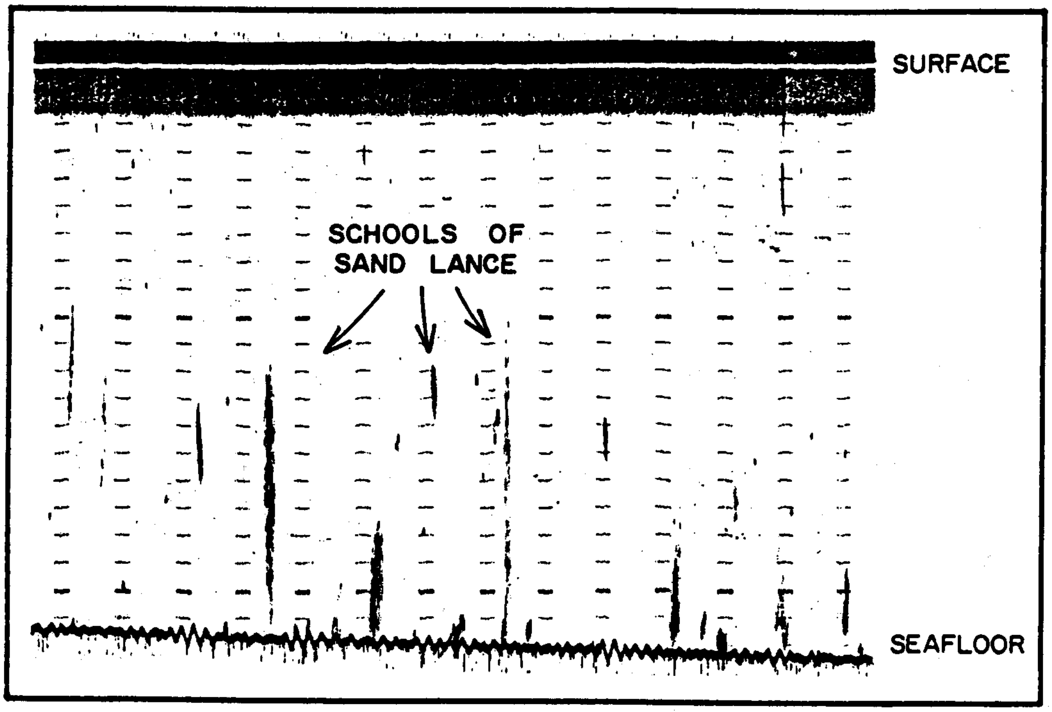


Figure 5.16. Echo-sounder record of fish schools in 26 m of water on Transect 4, July 1985, in the NANZ study area, Alaska. A 10-min trawl through this area caught over 30,000 sand lance.

accounted for most of their winter diet and copepods were eaten in summer (Table 5.14, Fig. 5.17). While feeding occurs year round, most consumption apparently occurs in winter and early spring as indicated by the degree of stomach fullness at these times, which was about four times greater than occurred in summer (Table 5.14, Fig. 5.17). This finding is in agreement with the observation by others that the main growth period for sand lance occurs in the first part of the year, February to June (Oshima 1950) or January to August (Macer 1966).

Sand lance diets were compared with the available food supply (as measured by invertebrate sampling methods described in Section 4.0, this report) to determine if the fish selected particular prey groups. Using Ivlev's (1961) electivity index (EI), proportions of prey groups in sand lance stomachs (% weight) were compared to proportions of the same prey groups in the watercolumn (% weight). The index has a possible range of -1 to +1, with negative values indicating avoidance or inaccessiblity of the prey item, zero indicating random selection from what is available in the environment, and positive values indicating active selection. In these calculations, jellyfish and ctenophores were excluded because they dominate the biomass of zooplankton but are not eaten by sand lance.

The results indicate that a sharp change in preferred prey occurred from winter to summer (Table 5.15). In January, sand lance consumed euphausiids in much greater proportion than their measured abundance in the watercolumn (EI= +0.8) and avoided, or could not catch, copepods (EI= -0.9). There was a transition period in May when euphausiids and copepods were eaten in proportion to their apparent availability (EI= 0) or copepods were preferred (EI= +0.4 in 1984) over euphausiids (EI= -1.0 in 1985). By July and September, sand lance consistently preferred copepods (EI= +0.3 to +0.5) over euphausiids (EI= -0.9 to -1.0). Reasons for the apparent avoidance of copepods in winter and euphausiids in summer are not known. Some possibilities include changes in prey size or species composition, or prey avoidance.

During all sampling periods, sand lance ate few chaetognaths and fish larvae compared with the apparent abundance of these prey groups. Electivity results for the remaining groups were mixed.

Several additional types of dietary comparisons were possible with the sand lance data, as follows:

Table 5.14. Seasonal diets of sand lance (see Appendix 5.3A for more details).

Food Item	Diet Composition (% Weight)		
	Winter[a]	Spring[b]	Summer[c]
Copepod		26	90
Euphausiid (total)	(100)	(40)	
Thysanoessa inermis	30	18	
T. raschii	19		
misc. & unident.	51	20	
Amphipod		7	
Mysid		7	
Crustacea (unident.)		11	
Other		11	10
Ave. contents (mg)	12	12	3
Mean fish size	101	128	104
No. fish examined	9	110	169

[a] Winter (January 1985).
[b] Spring (May 1984 and 1985).
[c] Summer (July 1985, September 1984).

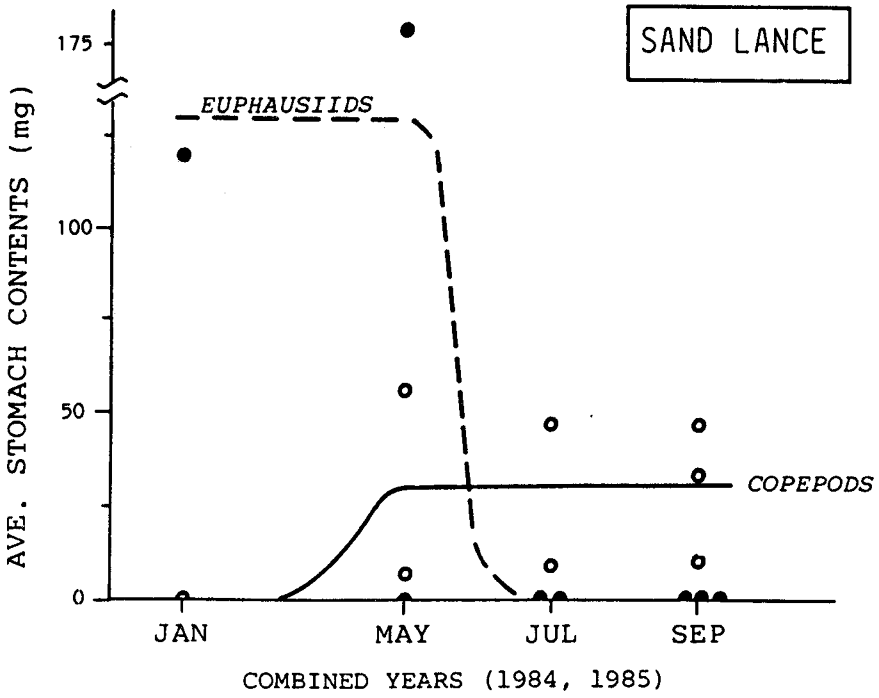


Figure 5.17. Seasonal importance of euphausiids and copepods in the diets of sand lance in the NANZ study area, Alaska. Each data point represents one size or site-specific group of fish listed in Appendix 5.3A.

Table 5.15. Comparisons of proportions of zooplankton in the diets of sand lance and in the water column. Gelatinous zooplankton (jellyfish, ctenophores) are not eaten by sand lance and have therefore been excluded from these comparisons.

	Electivity Index (EI)[a]				
	Jan. 1985	May 1984	May 1985	July 1985	Sep. 1984
Euphausiids	0.8	0.0	-1.0	-0.9	-1.0
Copepods	-0.9	0.4	0.0	0.3	0.5
Chaetognaths	-1.0	-0.8	-1.0	-0.9	-0.7
Fish larvae	-0.7	-0.7	-1.0	-0.5	-1.0
Decapod larvae	-1.0	-1.0	0.5	-0.2	-1.0
Hyperiid amphipods	-1.0	0.3	-1.0	0.0	-0.2
Mysids	-0.9	0.8	0.0	-1.0	-1.0

[a] Ivlev 1961.

1. Annual Differences. Sand lance diets differed greatly between the May 1984 and May 1985 samples (Table 5.16). Euphausiids were the primary food in the former period, and copepods in the latter period. This disparity is, in large part, a reflection of the very different abundances of these prey groups in the watercolumn during the two years:

	Euphausiids (%)		Copepods (%)	
	Available	Eaten	Available	Eaten
May 1984	65	66	9	21
May 1985	2	0	48	58

Availability data were derived from oblique bongo net tows (see Section 4.0, this report).

2. Nearshore vs. Offshore. Sand lance were collected from two depth zones during the May and September 1984 cruises (Table 5.16). Some dietary differences were noted in the May 1984 collections--sand lance from Izembek Lagoon ate fewer copepods but more amphipods and polychaetes than did fish collected farther offshore at Station C (20 m), but the offshore fish had three times more food in their stomachs. The September samples also show slight differences in diet. In both cases, these differences are likely due to differences in prey distributions.

3. Fish Size. Diets of medium-sized sand lance (70-100 mm) were compared with those of large sand lance (101-159 mm) on two occasions (Table 5.16). The principal difference was that the smaller fish ate more copepods and had perhaps a less varied diet than the larger fish. The larger fish also had more food in their stomachs, as might be expected due to fish size alone.

Table 5.16. Sand lance diets: comparisons between years, water depths, and fish sizes.

			Diet Composition (% weight) Comparisons							
	Years		Locations				Fish Sizes			
	May 1984	May 1985	May 1984		September 1984		July 1985		September 1984	
			Lagoon	20 m	20 m	30-50 m	93 mm	126 mm	83 mm	114 mm
Copepod	21	58	*	21	88	96	93	79	96	88
Euphausiid	66		55	66				1		
Amphipod	2		20	2	8	1		1		8
Mysid	9		13	9						
Polychaete	*		6	*				1	1	
Chaetognath	2			2	3			1		3
Crustacean larvae	*	30	2	*	*	1		5	1	*
Decapod larvae		12	*		*		1	6		*
Other	*	0	4	*	1	2	6	6	2	1
Ave. contents (mg)	270	10	80	270	40	50	10	60	10	40
No. stomachs	40	24	46	40	29	32	33	30	45	29

*<0.5%.

4. Prey Species. The species composition of euphausiids and copepods consumed by sand lance was examined in a subsample of fish stomachs (Table 5.17). In May 1984, the species eaten were those which characterized the zooplankton of the outer shelf of the Bering Sea (Cooney 1981). In September 1984, the dominant species eaten were those of the nearshore zooplankton community. These results reflect the changes in water masses (and their zooplankton communities) that occurred in the NANZ (see Sections 2.0 and 4.0, this report).

Pacific Herring (Clupea harengus). Herring are very abundant in the eastern Bering Sea, with major spawning concentrations occurring in the Togiak area of northern Bristol Bay. Spawning populations in the NANZ at Port Moller (Fig. 5.18) are a relatively small part of the overall herring biomass in the eastern Bering Sea, but the study area is thought to be part of a migration corridor for herring stocks spawned elsewhere in Bristol Bay (Fig. 5.19). Scale-pattern analyses indicate that about 80% of the herring harvested at nearby Unalaska Island are from Bristol Bay (Togiak stock) with 10% from farther north (Nelson Island) and 10% from Port Moller (Walker and Schnepf 1982, Lebida et al. 1984, Rogers and Schnepf 1985).

Schools of herring (some mixed with capelin) are most abundant from late May to mid June along the northern shoreline of the Alaska Peninsula (Fig. 5.20). They are even more abundant, however, outside our study area. Proceeding eastward along the Alaska Peninsula, springtime schools of herring and capelin increase from maximum densities of only 0.02 schools/km of coastline near Bechevin Bay to 1.7 schools/km near Port Heiden (Fig. 5.20). Furthermore, the average density of such schools along the Alaska Peninsula is overshadowed by much larger densities occurring in the Togiak area (Fig. 5.21).

Despite the use of Port Moller/Herendeen Bay by herring for spawning (average commercial harvest = 570 tons -- Schwartz 1985), few herring were caught in the NANZ by us or Isakson et al. (1986) in 1984 or 1985. Only 708 herring in total were caught in the present study, 87% of which were taken in a single midwater trawl. These fish were caught at the western

Table 5.17. Sand lance diets: species composition of copepods and euphausiids.

	Species Composition (% wt.)			
	May 1984		September 1984	
Prey	Sta. C	CA[1]	Sta. C	CA[1]
COPEPODS				
Neocalanus plumchrus	57	outer shelf		
Calanus marshallae	22	mid shelf		
Neocalanus cristatus	13	outer shelf		
Calanoid	8		15	
Centrophages abdominalis	*		47	nearshore
Pseudocalanus minutus	*		15	
Eurytemora herdmani	*		15	nearshore
Epilabidocera longipedata			9	nearshore
Metridia pacifica	*			
Acartia longiremis	*		*	
Oithona similis	*			
Tortanus discaudatus			*	
EUPHAUSIIDS				
Thysanoessa inermis	90	outer shelf		
T. raschii	4			
T. spinifera	6			
No. stomachs examined	5		2	

*<0.5%.

[1] Community Affinity (Cooney 1981).

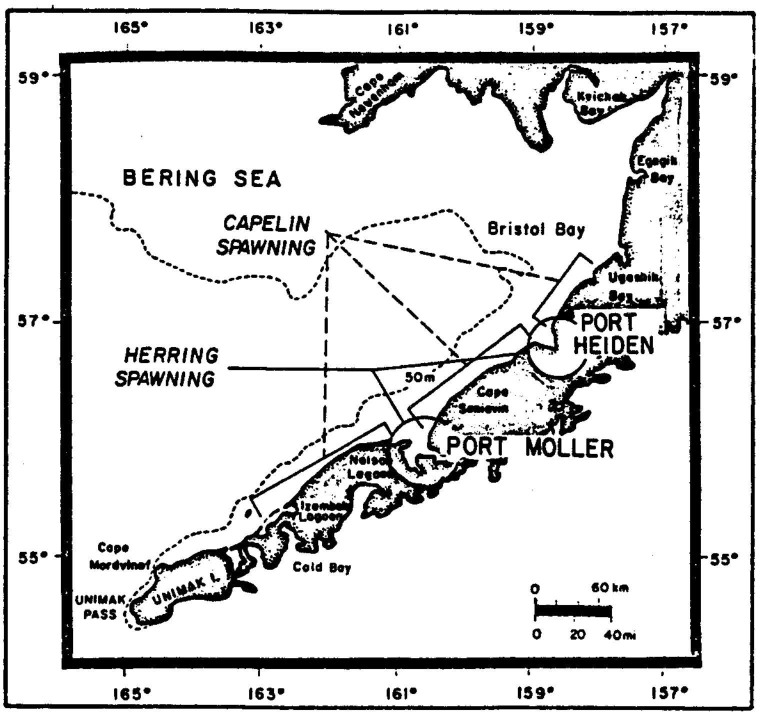


Figure 5.18. Primary spawning areas for forage fishes (Barton et al. 1977).

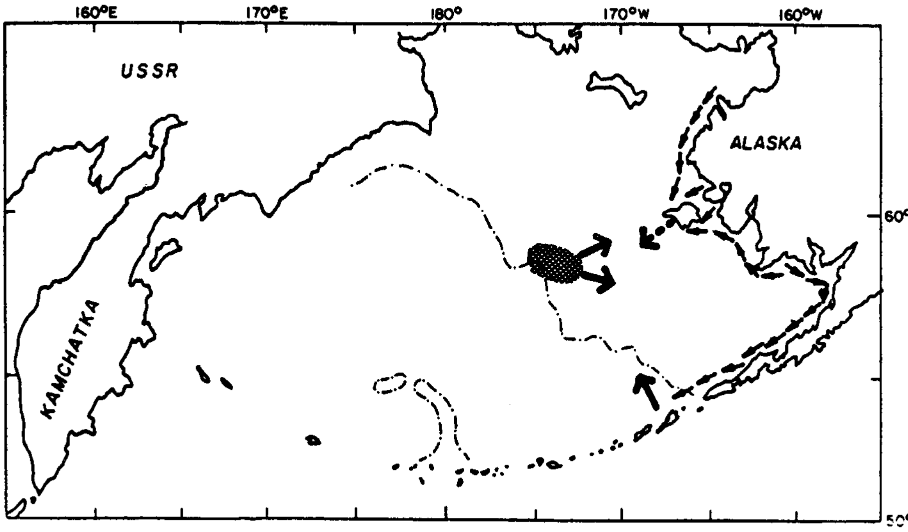


Figure 5.19. Conceptualized migration routes of herring from offshore wintering grounds (stippled area) to coastal areas in spring, and return routes in summer and fall, in the southeastern Bering Sea, Alaska. Redrawn from Wespestad and Barton (1981) and Wespestad and Fried (1983), as modified by ADFG (1985b) to include Unalaska data.

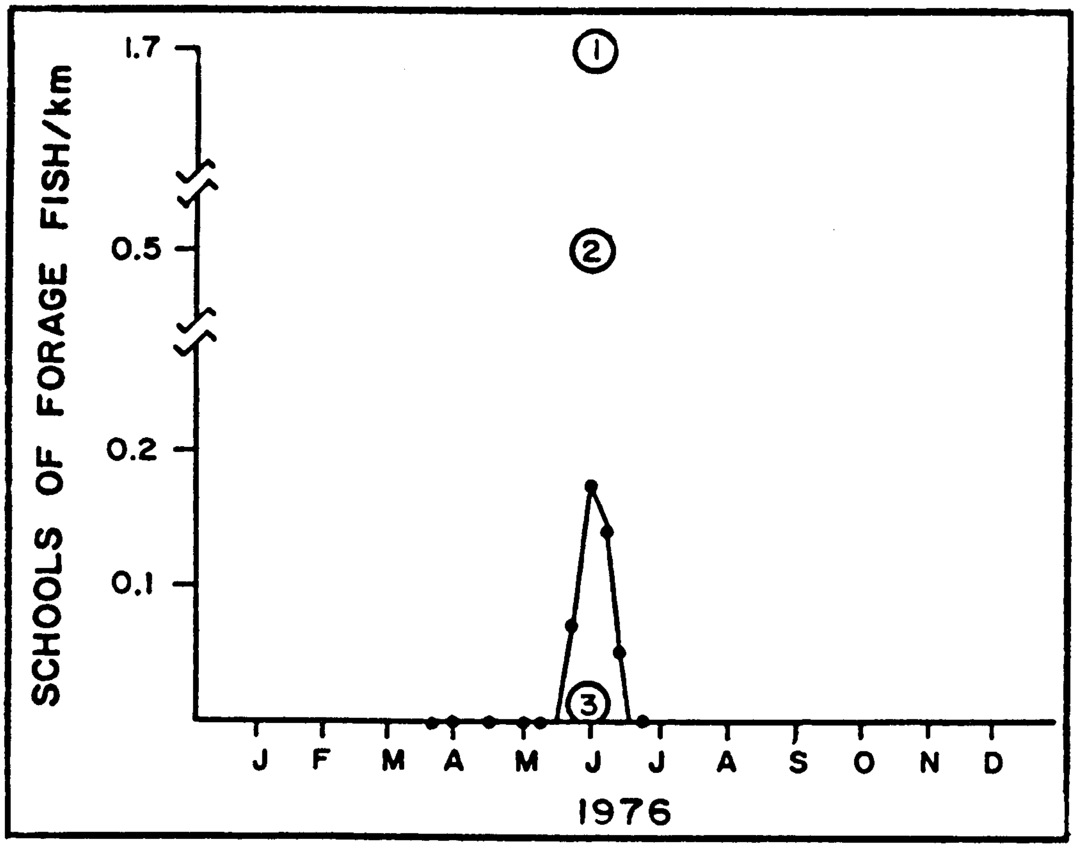


Figure 5.20. Average number of forage fish schools (herring, capelin) observed along the northern shore of the Alaska Peninsula from Unimak Island to Port Heiden (ADFG census areas 1-5) (from Barton et al. 1977). Also shown are maximum numbers at (1) Point Heiden, (2) Izembek area, and (3) Bechevin Bay area.

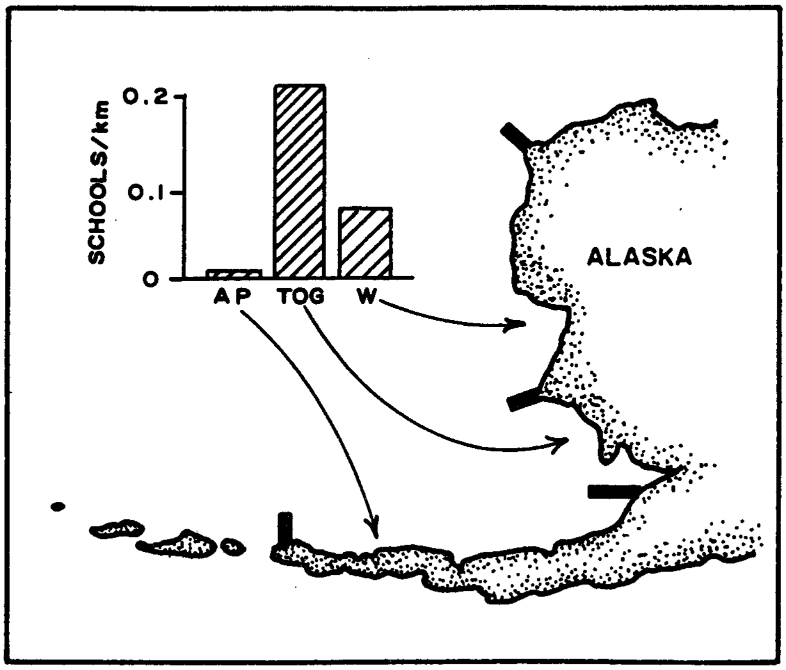


Figure 5.21. Average density of forage fish schools (mostly herring and capelin) observed along the Bering Sea shoreline in spring. Abbreviations: AP (Alaska Peninsula), TOG (Togiak), W (Western Alaska). From Warner and Shafford (1981).

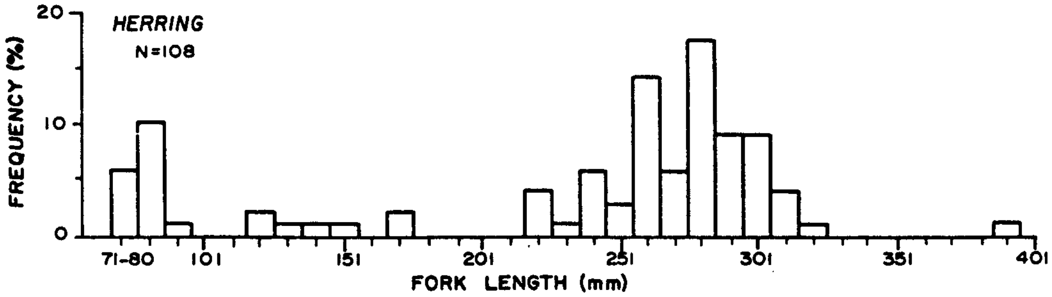


Figure 5.22. Length frequencies of herring collected during this study in the NANZ study area, Alaska.

end of the study area (Transect 1, 20 m) on 20 July 1985, which seems reasonable since herring are known to gather and feed near Unimak Pass and Unalaska Island in summer (summarized by Craig 1986).

The main reason for these low catches was probably that our sampling efforts did not coincide with the June spawning period when herring would be most abundant in nearshore waters. However, the low catches made immediately before this period (May, this study) and afterward (late June, Isakson et al., and July, this study) indicate that the herring did not remain long in the NANZ, and that the migration pattern shown in Figure 5.19 probably occurs, for the most part, farther offshore than our study area extended.

Most of the herring collected by Isakson et al. (1986) were young-of-year (37-55 mm) from the Port Moller area. Our samples consisted of older juveniles and adults, ranging in size from 71-400 mm (Fig. 5.22).

Early Soviet studies documented a seasonal pattern of feeding for herring in the eastern Bering Sea. Feeding is greatest after the herring spawn, declines later in summer, and may cease in winter (Svetovidov 1952, Dudnik and Usoltsev 1964, Rumyantsev and Darda 1970). Rumyantsev and Darda (1970) felt that feeding intensity declined in summer because the open waters of the eastern Bering Shelf provided poor summer feeding conditions for herring at this time (Fig. 5.23). Perhaps this is the reason why herring leave the NANZ soon after spawning.

Herring feed on a variety of zooplankton. In the eastern Bering Sea, Rumyantsev and Darda (1970) found that herring consumed mostly euphausiids, fish fry, and copepods. The fish fry eaten were, in order of importance, pollock, sand lance, capelin and smelt. Chaetognaths were also consumed (Dudnik and Usoltsev 1964). In the NANZ, the diets of both large herring (mean size 282 mm) and small herring (mean size 91 mm) were generally similar (Table 5.18). Copepods, crustacean larvae, decapod larvae, and chaetognaths were the main food items.

Capelin (Mallotus villosus). Capelin range throughout the Bering Sea and are extremely abundant in some years (Warner and Shafford 1979). They are generally found offshore in large schools, except during spring when they migrate shoreward to spawn (Macy et al. 1978, Paulke 1985). Schools of spawners are most abundant along the northern shoreline of the Alaska

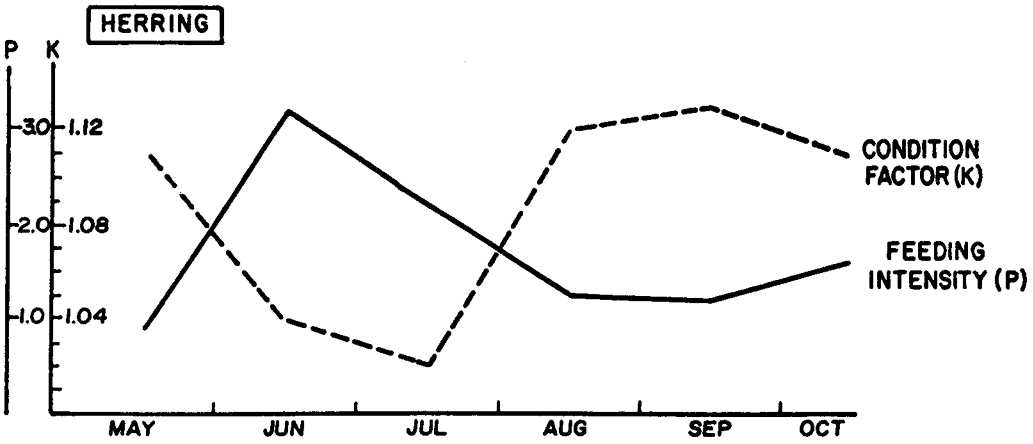


Figure 5.23. Feeding intensity and condition factors of herring caught in the eastern Bering Sea. From Rumyantsev and Darda (1970).

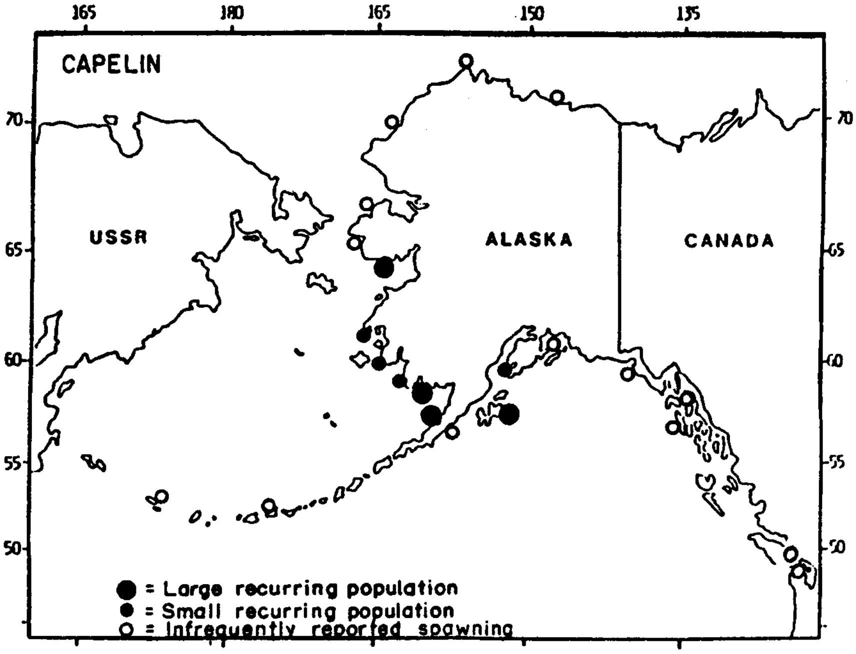


Figure 5.24. Locations of capelin spawning in the Northeast Pacific Ocean. From Paulke (1985).

Table 5.18. Herring diets. Note differences in fish sizes.

Food Item	Diet Composition (%.wt.) July 1985	Diet Composition (%.wt.) September 1985
Copepod	26	32
Crustacea larvae	52	1
Decapod larvae	6	36
Amphipod (Total)	(1)	(*)
Hyperiid	1	*
Corophiid	*	
Euphausiid (Total)	(13)	(3)
T. spinifera	2	
T. raschii	1	1
Unidentified	10	2
Chaetognath	*	21
Cypris larvae	1	
Crangonid larvae		5
Mysid (*Acanthomysis*)		1
Jellyfish	1	
Miscellaneous	*	*
Mean contents (mg)	600	45
Fish size (mm) - mean	282	91
- range	240-393	76-172
Sample location	1C	6C
No. fish examined	30	19

*<0.5%.

Table 5.19. Rainbow smelt diets (see Appendix 5.3B for more details).

	Diet Composition (% wt.) by Fish Size, Date and Location		
	Medium Fish		Large Fish
	May 1984	September 1984	September 1984
Barnacle larvae	13		
Amphipod	41	24	
Mysid	39	68	29
Crangonid shrimp			35
Caridean shrimp			11
Fish		6	24
Other	7	2	1
Ave. contents (mg)	107	48	215
Ave. fish size (mm)	114	111	184
Sample location	6E	6C, 7D	D
No. fish examined	33	36	47

Peninsula from late May to mid-June (Fig. 5.20). Some spawning may occur in the NANZ (Fig. 5.18), but the major spawning areas are located farther east in Bristol Bay (Fig. 5.24).

Although large schools of capelin (and/or herring) have been sighted in the Port Moller region by ADFG (McCullough 1984, Schwartz 1985), few were caught by us or Isakson et al. (1986) in 1984 and 1985. In the two studies combined, less than 10 capelin were caught in 1984 and about 110 in 1985, virtually all of which were taken in the Port Heiden area. Reasons for the discrepancy between our low catches and ADFG estimates of capelin abundance are probably due to the timing of our surveys, which did not coincide with the early June spawning period when these fish would be most abundant nearshore. The absence of capelin in our surveys before this period (May) and afterward (late June for Isakson et al., and July for us) suggests that capelin were present in the NANZ for only a few weeks.

Rainbow Smelt (Osmerus mordax). Rainbow smelt are anadromous fish that spend most of their lives in coastal waters but enter rivers to spawn. Though present in the NANZ, they are more abundant in inner Bristol Bay (Isakson et al. 1986) and have good runs in Nushagak and Togiak rivers (Baxter 1976). It is not known if rainbow smelt spawn in any streams in the study area.

Rainbow smelt were present in the NANZ during all sampling periods, but catches were highest in September in waters less than 20 m deep (Fig. 5.25). They were also caught directly against the shoreline by beach seines and shoreline gill net sets. Virtually all rainbow smelt (99%) were caught in the eastern portion of the study area (Transects 4-7). They varied in size from 61 to 260 mm (Fig. 5.26).

The feeding habits of rainbow smelt in western Alaska are not well known, but available data indicate that three prey groups--amphipods, mysids and fish--commonly comprise their diets (Warner and Shafford 1981, Haldorson and Craig 1984, this study). In the NANZ, medium-sized smelt (91-138 mm) consumed mostly amphipods and mysids (Table 5.19). About twice as much feeding occurred in May as in September, as indicated by average weights of stomach contents (Table 5.19). Larger rainbow smelt ate more fish and shrimp and fewer amphipods than did the smaller fish.

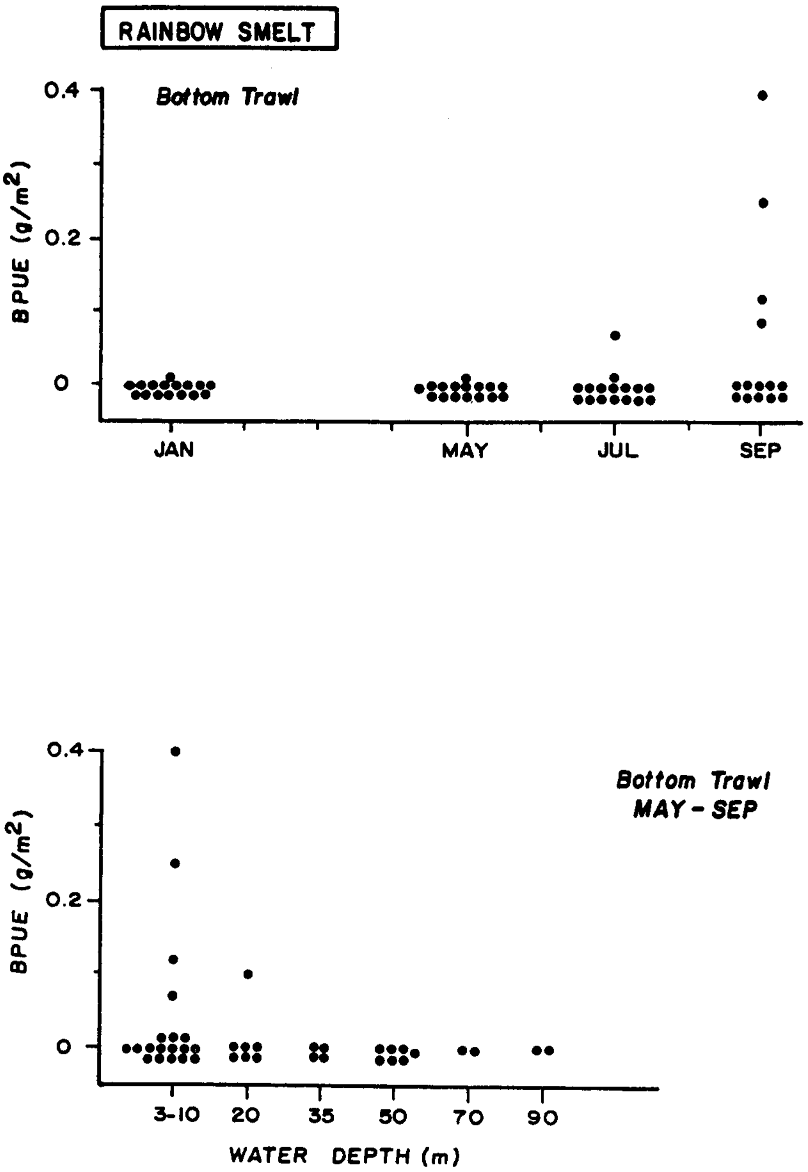


Figure 5.25. Seasonal abundance (top) and abundance at various water depths (bottom) of ranbow smelt caught in the NANZ study area, Alaska. Fish were caught in May and September 1984, and July 1985. Data presented are station averages during various sampling periods (N = 143 bottom trawls TRY1).

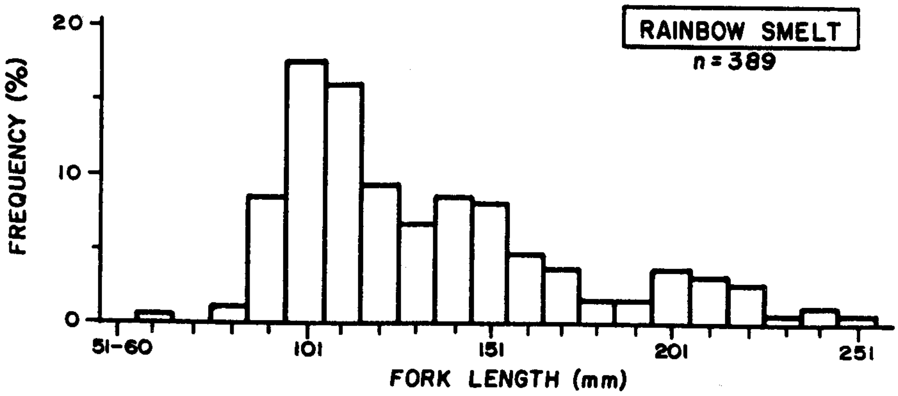


Figure 5.26. Length frequencies of rainbow smelt caught in this study in the NANZ study area, Alaska.

Smith and Paulson (n.d.) note that rainbow smelt in Izembek Lagoon ate amphipods and copepods.

Pollock Young-of-year. These fish are described together with older pollock in Section 5.6.5.3, this report.

5.6.5.2 Salmon

Salmon are the most important anadromous fish in the study area. All five salmon species occur there, but sockeye salmon (*Oncorhynchus nerka*) are by far the most abundant. The annual commercial harvest of salmon in the Bristol Bay region averages about 12 million salmon of which 10 million are sockeye. Approximately 90% of the total salmon run is associated with five river systems (Nushagak, Kvichak-Naknek, Egegik, Ugashik, Togiak) which flow into inner Bristol Bay (Stern et al. 1976).

The total number of adults returning to Bristol Bay streams is impressive--over 25 million fish in recent years (commercial catch plus escapement) (Eggers and Fried 1984). The peak period for these fish passing by the NANZ is from mid June to early July (Fig. 5.27).

Most of these fish migrate in offshore waters beyond the NANZ (Fig. 5.28), but both local and non-local stocks occur in the NANZ. Each year some 1.5 million adult salmon (5-year average) enter streams in the study area to spawn or are caught in nearshore waters by commercial fishermen (Shaul et al. 1983). Many non-local salmon pass through the nearshore zone as well. Data obtained at the ADFG test fishery off Port Moller in 1982 indicate that, while most adult salmon migrate more than 90 km offshore, up to 19% of the sockeye and 13% of the chum salmon migrate closer to shore and within the 50-m depth contour (Fig. 2.29). Using these proportions and an estimated run of 22,000,000 sockeye and 2,600,000 chum in 1982, we calculate that about 4,500,000 non-local adult salmon migrated through the NANZ in that year.

Although adult salmon cease feeding as they near their natal rivers, many are still feeding when they pass through the NANZ. Samples collected from the ADFG test fishery off Port Moller showed that only 5% of the sockeye adults had essentially ceased feeding, i.e., had less that 1 g of food in their stomachs (Fig. 5.30). Sockeye stomachs contained an average

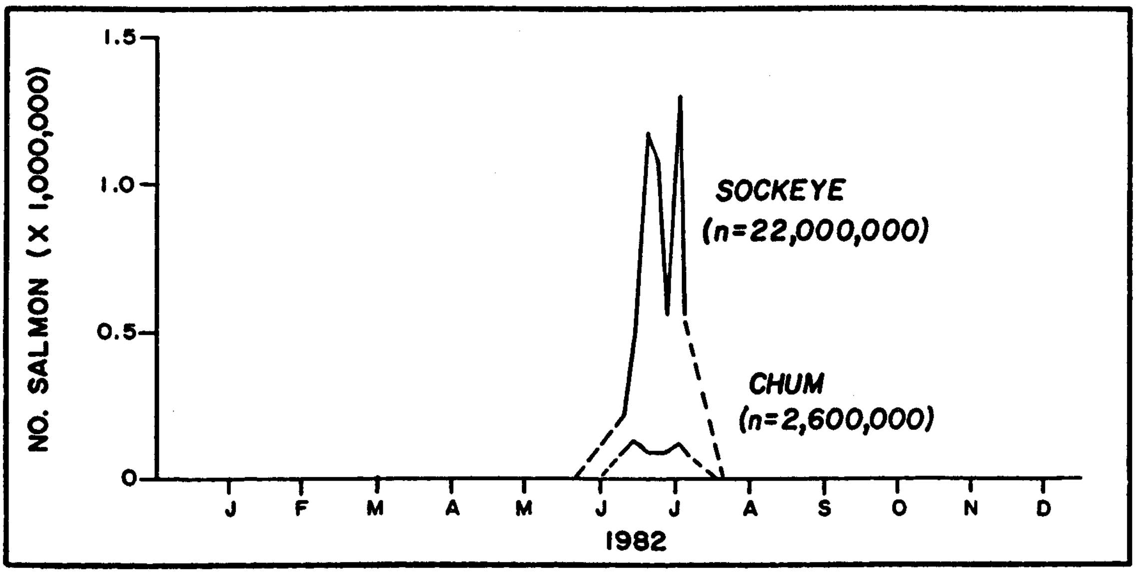


Figure 5.27. Estimated number of adult salmon migrating eastward by Port Moller, derived from catch data from the ADFG test fishery located 45-130 km offshore from Port Moller, 1982. Calculations from Eggers and Fried (1984). Dashed lines indicate possible tail ends for the available data.

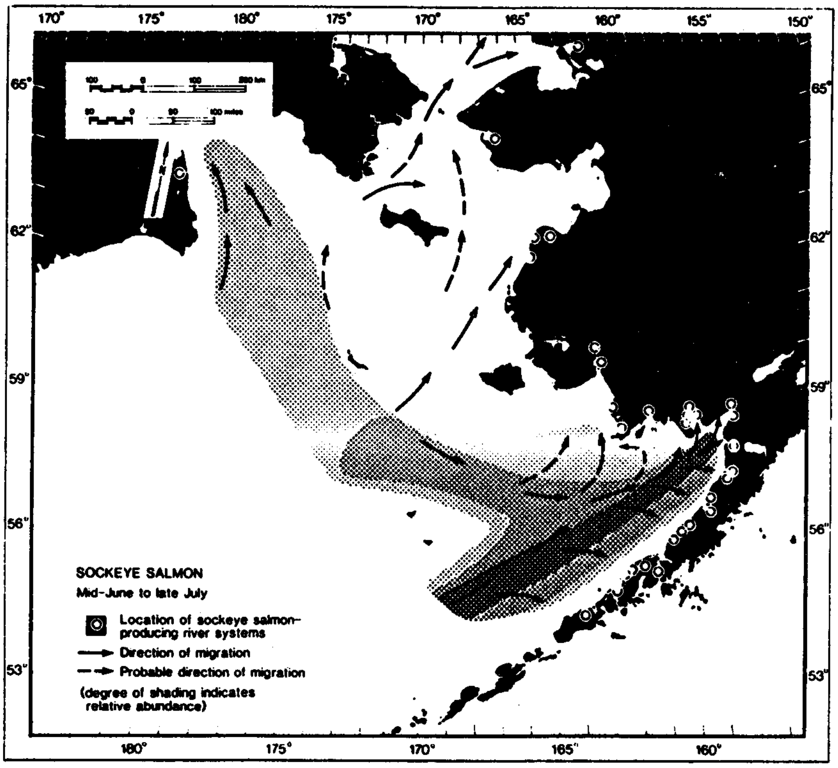


Figure 5.28. Distribution of sockeye salmon during spawning migration. From Straty (1981).

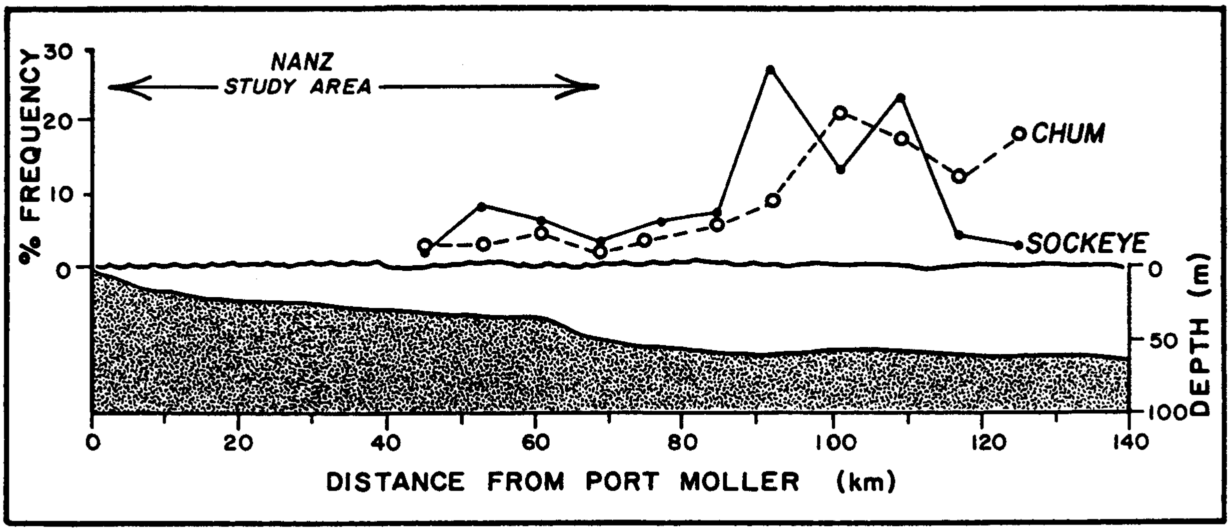


Figure 5.29. Pathway (distance offshore) for some adult salmon migrating eastward past Port Moller, 1982. Calculated from Eggers and Fried (1984).

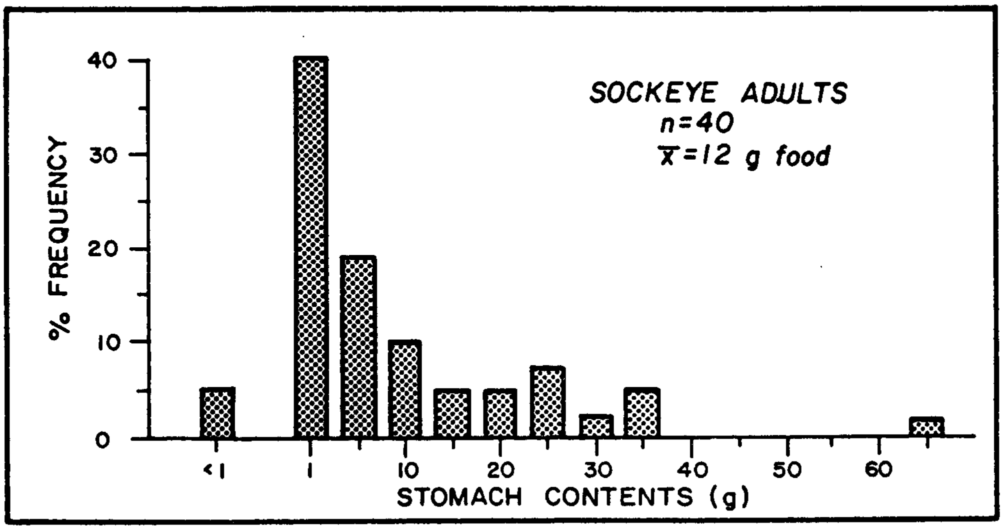


Figure 5.30. Stomach fullness of adult sockeye caught in the ADFG test fishery off Port Moller, June 1985.

of 11.9 g of food and chum stomachs 6.5 g (Table 5.20). Euphausiids (Thysanoessa) comprised virtually all of the sockeye's diet; this agrees with Nishiyama's (1974) finding that sockeye caught in the central basin region of the Bering Sea consumed a variety of pelagic species (squid, fish larvae, amphipods, euphausiids), but that those on the continental shelf ate euphausiids almost exclusively.

Using these figures, and assuming that the average amount of food found in their stomachs is the amount consumed daily, we estimate that adult sockeye and chum together consume about 280,000 kg of euphausiids daily as they migrate through the NANZ. The average migration speed of sockeye during this time is 60 cm/s or 30 nautical miles/day (Hartt 1966). At this rate, it would take about seven days for a salmon to traverse the NANZ. Thus, the total consumption of euphausiids by adult salmon would be about 2 million kg, extended over the one-month period of their run through this area.

The escapement of juvenile salmon into Bristol Bay averages about 580 million, all species combined. These smolts migrate westward across southern Bristol Bay in a band about 50 km wide, after which they apparently move seaward in the vicinity of Port Moller and thus are generally dispersed seaward of our study area (Straty 1981). They are most abundant from late May through September (Straty and Jaenicke 1980, Isakson et al. 1986). Juveniles generally take six months or longer to reach the north Pacific where they remain for 1-4 years before returning to spawn.

Juvenile salmon in Bristol Bay and the eastern Bering Sea feed on zooplankton, epibenthic crustaceans, and small fish during their initial months at sea. Depending on season and location, the most important foods of juvenile sockeye are copepods (Carlson 1963), sand lance (Straty 1974), or larval fish and euphausiids (Dell 1963). Most feeding (and initial growth at sea) occurs only after the newly smolted sockeye migrate out of inner Bristol Bay to the Port Moller area and beyond (outer Bristol Bay), where densities of prey are higher and sockeye stomachs are fuller (Fig. 2.31). Food type, size, and abundance probably determine how long juvenile salmon reside in a given geographical region during their seaward migration (Straty and Jaenicke 1980).

Table 5.20. Adult sockeye and chum salmon diets. Samples were provided by the Alaska Department of Fish and Game from their test fishery off Port Moller.

Food Item	Diet Composition (% wt.) by Species Adult Salmon (June 1985)	
	Sockeye	Chum
Euphausiid (total)	(98)	
Thysanoessa	49	
Miscellaneous	49	
Fish	1	*
Crustacea	*	
Cypris larvae	*	
Decapod larvae	*	*
Amphipod		*
Copepod		*
Ave. contents (g)	11.9	6.5
Fish size (mm) - mean	580[1]	582[1]
- range	527-621[1]	560-601[1]
Sample site	6Y	6Y
No. stomachs examined	40	7

*<0.5%.

[1] Mid-eye to tail fork.

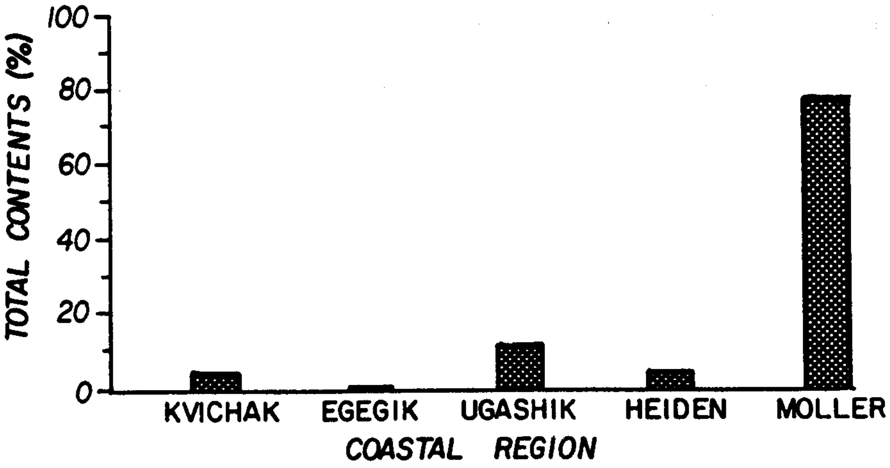


Figure 5.31. Proportions of foods eaten by sockeye salmon smolts at five Bristol Bay regions, proceeding from the inner bay (Kvichak) to outer bay (Moller). From Carlson (1963).

In the NANZ, samples of juvenile salmon were collected in Izembek Lagoon, and over a wider coastal area (Izembek Lagoon to Port Heiden). The main foods eaten were as follows (Table 5.21):

sockeye juveniles	- euphausiids, sand lance
chum juveniles	- decapod larvae, amphipods, sand lance, insects, mysids, and plant material
coho juveniles	- sand lance
pink juveniles	- amphipods, copepods, decapod larvae

5.6.5.3 Demersal Fishes

As previously described (Section 5.6.1, this report), the community of demersal fishes of the NANZ is similar to that which characterizes the Bering Sea middle shelf. Yellowfin and rock sole together accounted for most of the catch, followed by pollock and Pacific cod:

TOTAL BOTTOM TRAWL CATCH

Fishes	Number (%)	Biomass (%)
Yellowfin and rock sole	56	79
Pollock and Pacific cod	18	4
Other	26	17

Gear: TRY1

Seasonal trends in the total biomass of demersal fish catches reflected the biomass fluctuations of yellowfin sole (Fig. 5.32). Total numbers of fish, however, were more evenly divided among the abundant species. Summary tables of all species caught in bottom trawls are presented in Appendix 5.1.

Note that CPUE and BPUE data presented herein for the Marinovitch bottom trawl (=TRY1) probably underestimate actual fish numbers and biomasses, as discussed in Section 5.6.3.1.

Table 5.21. Juvenile salmon diets (see Appendix 5.3 C for more details).

	Diet Composition (% wet.) by Species, Date and Location					
	Sockeye	Chum			Coho[1]	Pink
	1984	7/84	7/85	9/84[1]	1984	7/84
Euphausiid	42				1	
Fish	36		13	95	93	
Mysid	7	18		3		
Barnacle larvae	6					1
Insects	5		31	1	1	
Amphipod		27	20		5	39
Copepod		3	2			28
Decapod larvae		45	4			24
Cumacea		6	4			4
Polychaete						4
Plant material			25			
Other	4	1	1	1		
Ave. contents (mg)	429	116	29	864	1410	38
Ave. fish size (mm)	107	82	75	134	129	75
Sample site	misc.[1]	2F	2F	PH	misc.[1]	2F
No. stomachs	30	30	30	20	26	7

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[1] Samples from combined locations and dates (Izembek Lagoon to Port Heiden, June-September 1984) provided by J. Isakson (Dames and Moore).

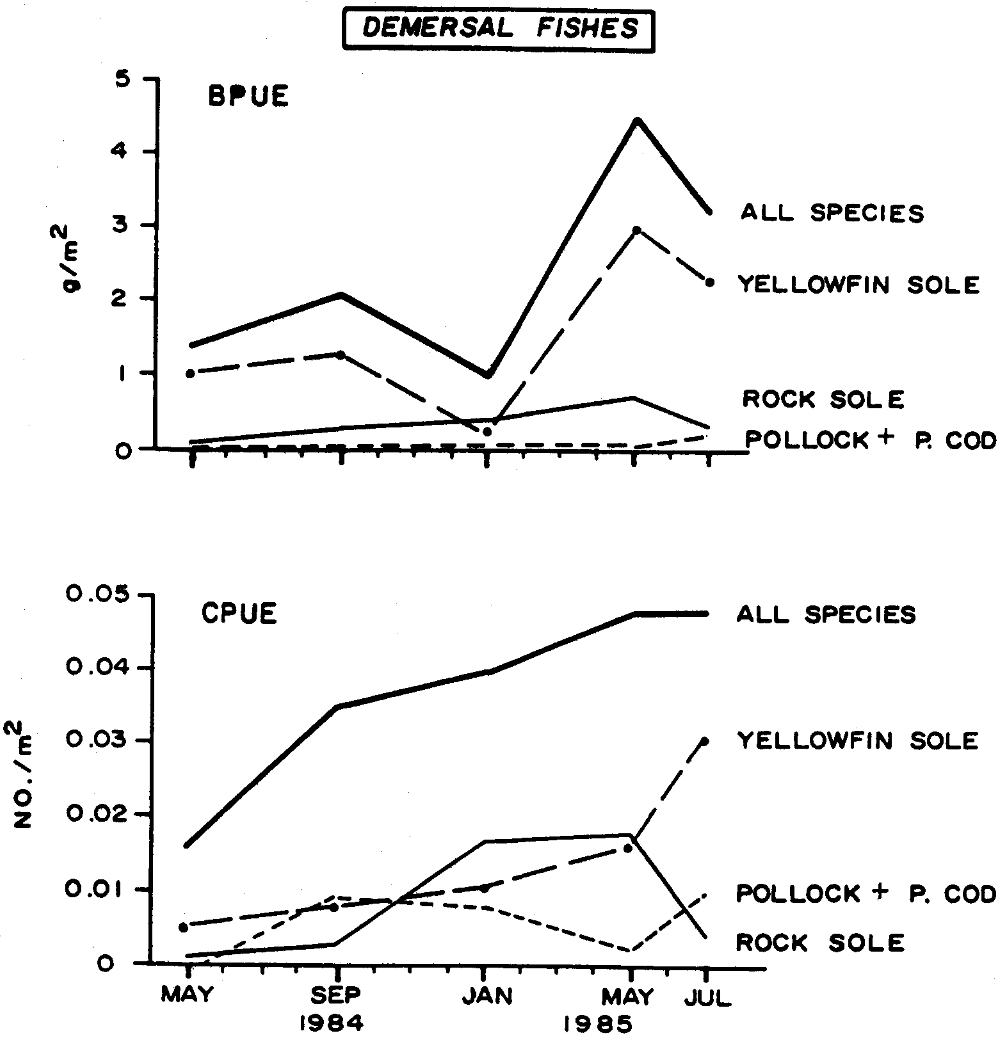

Figure 5.32. Seasonal BPUE and CPUE for demersal fishes caught by bottom trawl (TRY1) during this study in the NANZ study area, Alaska. Note that BPUE and CPUE are probably underestimated due to gear-related bias (see Section 5.6.3.1).

Yellowfin Sole (Limanda aspera). This species is by far the dominant flatfish in the Bering middle shelf (Table 5.4) and in the shallow waters of the NANZ as well (Table 5.6). Yellowfin sole were abundant in demersal habitats throughout the study area (Table 5.7) and accounted for 36% of the catch and 66% of the biomass of all fish caught by small bottom trawl.

The seasonal distribution and abundance of yellowfin sole in the study area need to be viewed in the context of their overall movement patterns in the eastern Bering Sea (summarized by Bakkala 1981 and ADFG 1985a). Adult yellowfin overwinter in large schools along the outer shelf, with largest concentrations at depths of 100 to 200 m. One major overwintering area is located north of Unimak Island. In spring (May), these fish migrate into shallower water on the middle and inner shelves to feed and spawn (Fig. 5.33). By summer, the Unimak winter group is found in the Bristol Bay area between the 40-to 100-m depth contours (Fig. 5.34). As winter approaches, the fish move back into deeper water, although in warm years some may remain on the middle shelf throughout the winter. Young yellowfin remain in relatively shallow nearshore waters throughout their first few years of life.

Data obtained in the NANZ support the above patterns of movement. Although yellowfin catches were highly variable, ranging from 0-20 g/m2 in individual trawls, BPUE estimates were low in winter and high in summer (Fig. 5.35). In contrast, CPUE results showed a steady increase throughout the study. An interpretation of these results is aided by viewing the length frequencies of the fish present during each sampling period (Fig. 5.36). Beginning in May 1984, both large and small yellowfin were present in the NANZ. More small fish entered the area by September (Fig. 5.36), ultimately accounting for the CPUE increase and BPUE decrease in January. The following spring (May 1985), many large yellowfin moved into the study area as shown by their length frequencies and by increases in both CPUE and BPUE. These fish were presumably on their way from the Unimak wintering area to Bristol Bay to spawn. By midsummer (July), many of the larger fish had left the area and were replaced by smaller fish as occurred the previous year.

The winter (January) data indicate two important points: (1) some yellowfin inhabit the shallow waters of the study area year-round, and (2)

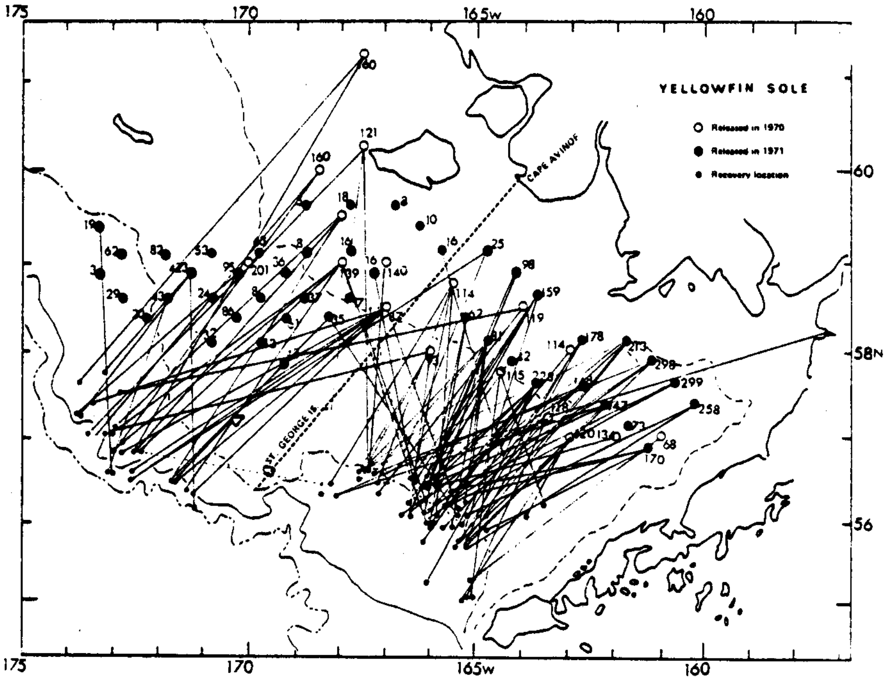

Figure 5.33. Tag and recovery sites for yellowfin sole in the southeastern Bering Sea, Alaska. From Wakabayashi et al. (1977).

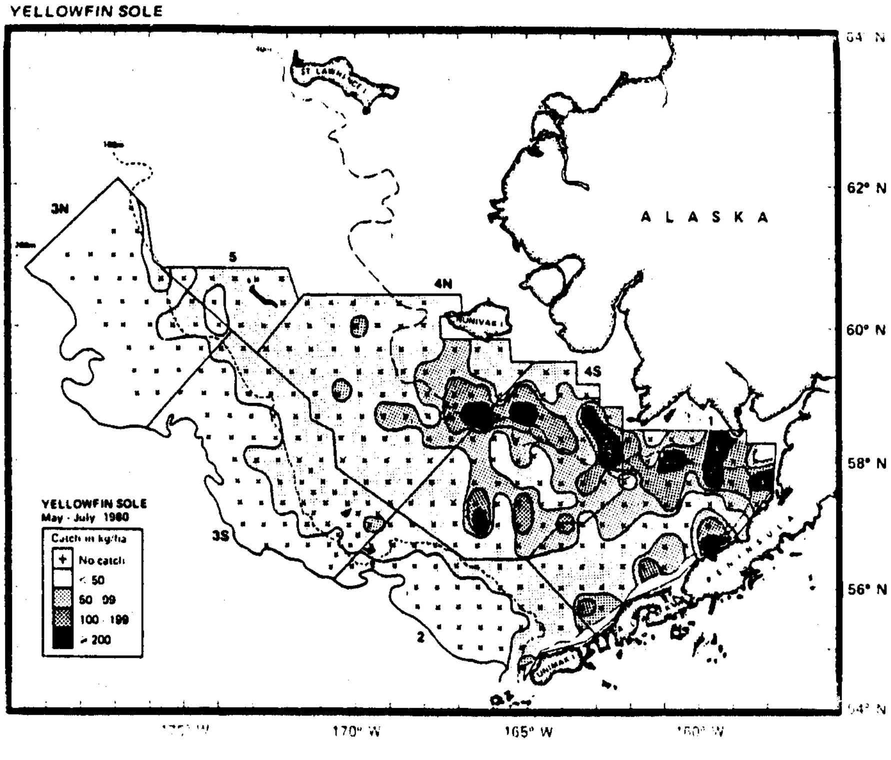

Figure 5.34. Catch distribution of yellowfin sole in the southeastern Bering Sea, Alaska, during the 1980 NMFS trawl survey. From Umeda and Bakkala (1983).

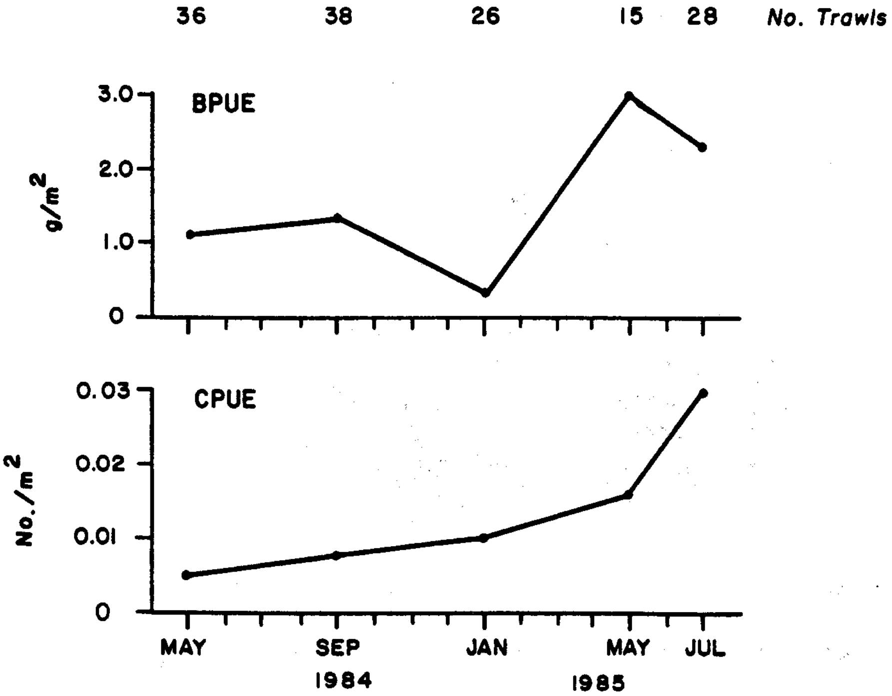

Figure 5.35. Seasonal BPUE and CPUE of yellowfin sole caught in bottom trawls (TRY1) during this study in the NANZ study area, Alaska. Note gear-related bias in Section 5.6.3.1.

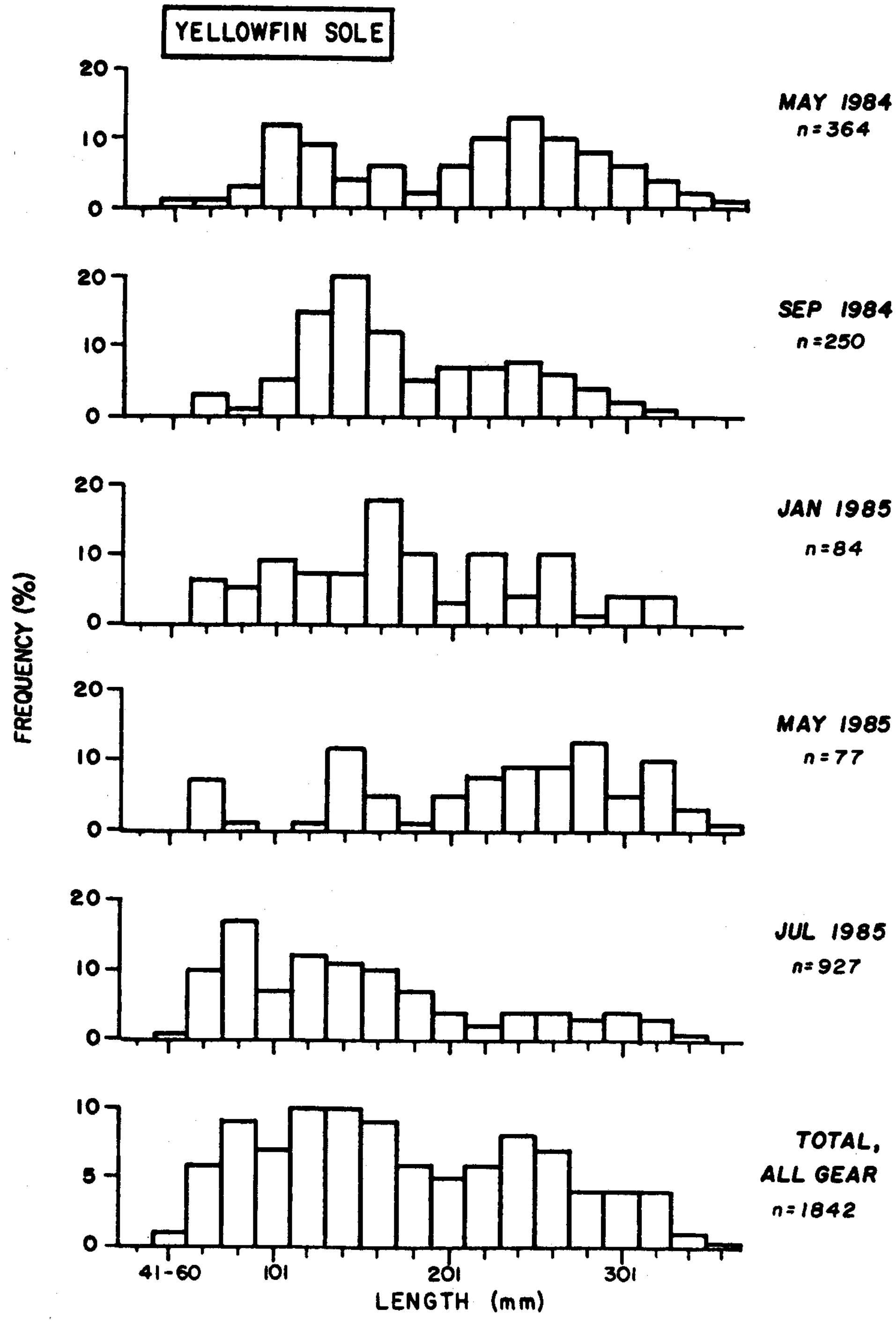

Figure 5.36. Length frequencies of yellowfin sole caught in bottom trawls (TRY1) in the NANZ study area, Alaska. The bottom graph shows all gear and dates combined.

the relatively high CPUE but low BPUE in January indicate that many juvenile yellowfin sole used the NANZ to overwinter.

The total sample of yellowfin ranged from 35-373 mm in length (Fig. 5.36). Isakson et al. (1986) caught proportionally more small yellowfin along the north side of the Alaska Peninsula, perhaps because they did not sample in May when many large yellowfin moved through the nearshore zone.

Although small yellowfin (less than 200 mm) were abundant in nearshore waters, it is not known if they are also abundant farther offshore, because most trawl surveys in offshore waters (e.g., the annual NMFS surveys) use large trawls with mesh sizes that may be too large to retain the smaller fish.

Within the NANZ, yellowfin were most abundant in water less than 50 m deep, with highest catches in 20 m or less (Fig. 5.37). A few yellowfin were also caught in even shallower water by beach seine and gill nets set adjacent to the shoreline. By comparison, rock sole were more abundant in slightly deeper water (Fig. 5.38).

Yellowfin tended to be most abundant in the Port Moller area (Fig. 5.39, Transects 6 and 7), although high catches were occasionally made throughout the study area during the various sampling periods. NMFS trawl data also show a local abundance near Port Moller (Fig. 5.34), but this concentration was not present in all years that their surveys have been conducted.

The food habits of yellowfin sole in the eastern Bering Sea have been summarized by several authors (e.g., Pereyra et al. 1976, Bakkala 1981), based in large part on earlier studies by Skalkin (1964). Yellowfin sole are benthic feeders, consuming a variety of infauna and epibenthos. The kinds and amounts of prey consumed vary with season, area and size of fish. They feed relatively little in winter; in summer their diets include polychaetes, amphipods, bivalves, euphausiids, echiuroid worms, and echinoderms. Near Port Moller, Haflinger and McRoy (1983) found that yellowfin sole consumed small surf clams, polychaetes, amphipods, and sand dollars.

Diets of yellowfin sole in the NANZ were similar to the above (Table 5.22). The amount consumed was greatest in spring, intermediate in summer, and least in winter (Fig. 5.40). Small yellowfin sole ate copepods, amphipods, polychaetes, and fish; large yellowfin ate a varied

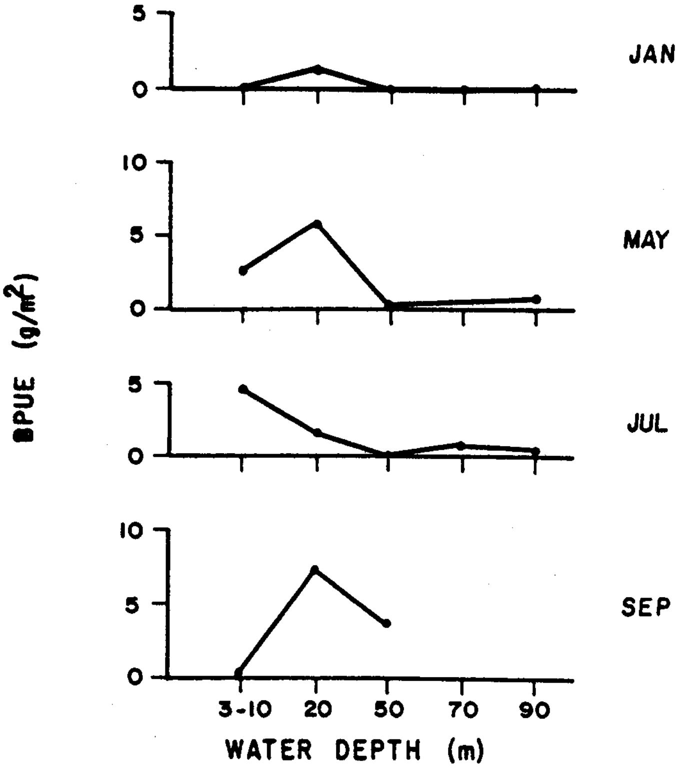

Figure 5.37. Depth distribution of yellowfin sole caught by month in the NANZ study area, Alaska. Data presented are station averages for catches in TRY1.

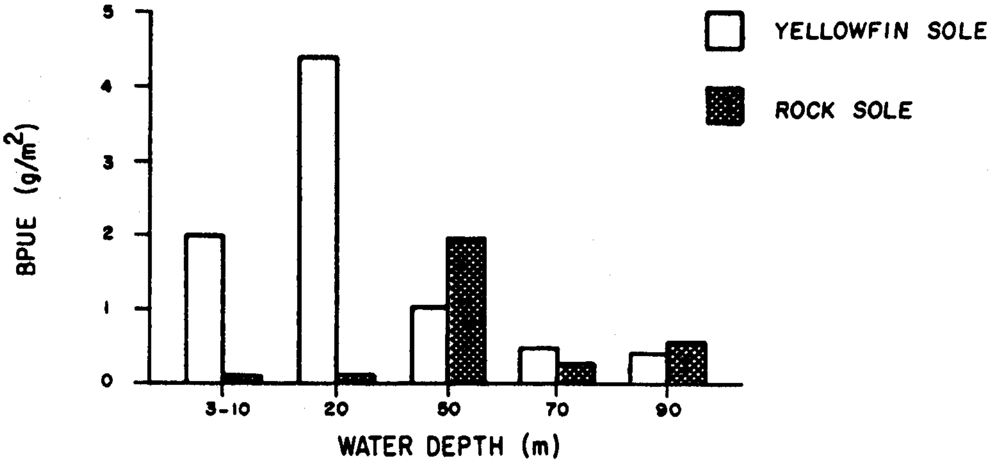

Figure 5.38. Depth distribution of yellowfin and rock sole caught by TRY1 in the NANZ study area, Alaska, all sampling dates combined.

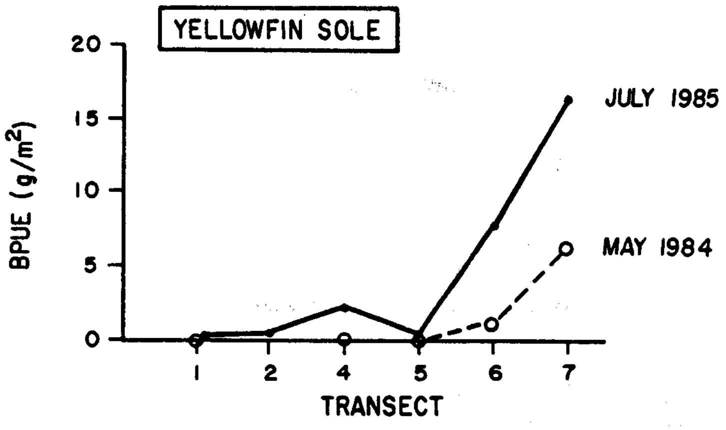

Figure 5.39. Relative abundance of yellowfin sole from east to west along the 3-10 m depth zone in the NANZ study area. Gear: TRY1; note gear-related bias in Section 5.6.3.1.

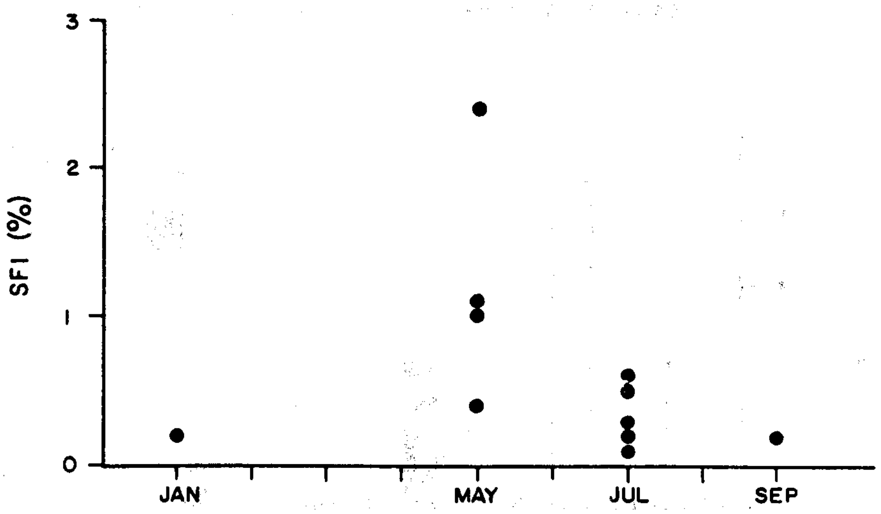

Figure 5.40. Stomach fullness index (SFI) for yellowfin sole by month in the NANZ study area. For each group of fish listed in Table 5.22, SFI = 100 x average weight of stomach contents divided by the average weight of fish in the group.

Table 5.22. Yellowfin sole diets (see Appendix 5.3 D for more details).

	Diet Composition (% wt.) by Fish Size, Date and Location										
	Small Fish			Large Fish							
Food Item	May 1984	July 1985a	July 1985b	Jan 1985	May 1984a	May 1984b	May 1985	July 1985a	July 1985b	July 1985c	Sept 1984
Copepod		60	2								
Amphipod	81	10	17	4	5	8	1	2	2	1	11
Polychaete	3	17	5	35		46	41	47	7	35	
Crangonid			1	27	4	1	13	8	33	1	19
Bivalve	8			6	76	1	18	15	17	22	26
Echinoderm	5			1	4	13	11			10	
Pagurid		6				17				5	
Echiuroid worm				15							
Decapod misc.	1	2			2			1		2	32
Fish			73	3		7	2	28			3
Euphausiid				2	9					4	
Plant							2		39		5
Isopod							8				
Gastropod										11	
Jellyfish										9	
Other	1	5	2	7		7	4		2		4
Ave. contents (mg)	224	11	67	209	2939	1795	695	413	312	576	260
Ave. fish size (mm)	115	76	104	212	222	243	251	183	280	290	216
Sample sites	2B,C	D,E	D	A,C	2B,C	6A,C	misc.	1D,E	6D	X,Y	6D
No. stomachs	18	32	30	25	17	46	33	24	38	28	23

diet of polychaetes, crangonid shrimp, and bivalves, with lesser amounts of amphipods, sand dollars, fish (sand lance), and, unexpectedly, plant material.

The available data provide some dietary comparisons between years and locations (Table 5.23). Yellowfin sole diets were generally similar in May of both 1984 and 1985, but location-specific differences were noted. The foods eaten in the eastern and western portions of the study area (Transect 6 versus Transects 1 and 2) differed in May 1984 and July 1985, but no consistent pattern was apparent. Similarly, yellowfin diets in nearshore sites (water depths 3-10 m) differed from those in offshore sites (50-70 m), but the only "new" foods encountered offshore were gastropods (11% of diet) and jellyfish (9%). The remaining 80% of their offshore diet consisted of food groups eaten in nearshore waters at different locations or seasons. The diet of yellowfin sole thus appears to be flexible.

Rock Sole (Lepidopsetta bilineata). Though much less numerous than yellowfin sole, the rock sole is a common and widely distributed species in the eastern Bering Sea (Table 5.4, Fig. 5.41). Seasonal movements are not well known but are thought to be similar to those of other flatfish such as yellowfin sole.

Rock sole were moderately abundant in the NANZ, accounting for 13% of the biomass and 20% of the total catch in TRY1 bottom trawls. The average catch was 0.3 g/m^2 and 0.007 $fish/m^2$. The seasonal abundance was highly variable, with minimum and maximum catches occurring in the spring of the two years of study (Fig. 5.42).

The CPUE, BPUE, and length frequencies of rock sole (Figs. 5.42 and 5.43) suggest the following movements of fish in the study area. The low catches of rock sole in May 1984 consisted primarily of small fish less than 80 mm. By late summer (September), large rock sole had moved into the area and the small fish had departed, perhaps moving into shallower water as suggested by the catches of small rock sole (91-160 mm) in nearby embayments by Isakson et al. (1986). In winter (January), the high CPUE but unchanged BPUE indicates that many small rock sole wintered in the NANZ, especially juveniles 41-60 mm in length but including larger fish as well. High catches in May 1985 consisted primarily of small fish (as

Table 5.23. Yellowfin sole diets: comparisons between years and locations.

	Diet Composition (% wt.) by Year and Location							
			Locations					
			May 1984		July 1985		July 1985	
	Years							
	1984	1985	East	West	East	West	Near-shore	Off-shore
Polychaete	23	41		46	47	7	27	35
Crangonid	3	13	4	1	8	33	20	1
Bivalve	38	18	76	1	15	17	16	22
Amphipod	6	1	5	8	2	2	2	1
Echinoderm	9	11	4	13				10
Pagurid	8			17				5
Decapod misc.	1		2		1			2
Fish	4	2		7	28		14	
Euphausiid	4		9					4
Plant		2				39	20	
Isopod		8						
Gastropod								11
Jellyfish								9
Other	4	4		7		2	1	
Ave. contents (mg)	2367	695	2939	1795	413	312	363	576
Ave. fish size (mm)	233	251	222	243	183	280	232	290
Sample sites	misc.	misc.	2B,C	6A,C	1D,E	6D	D,E	X,Y
No. stomachs	63	33	17	46	24	38	62	28

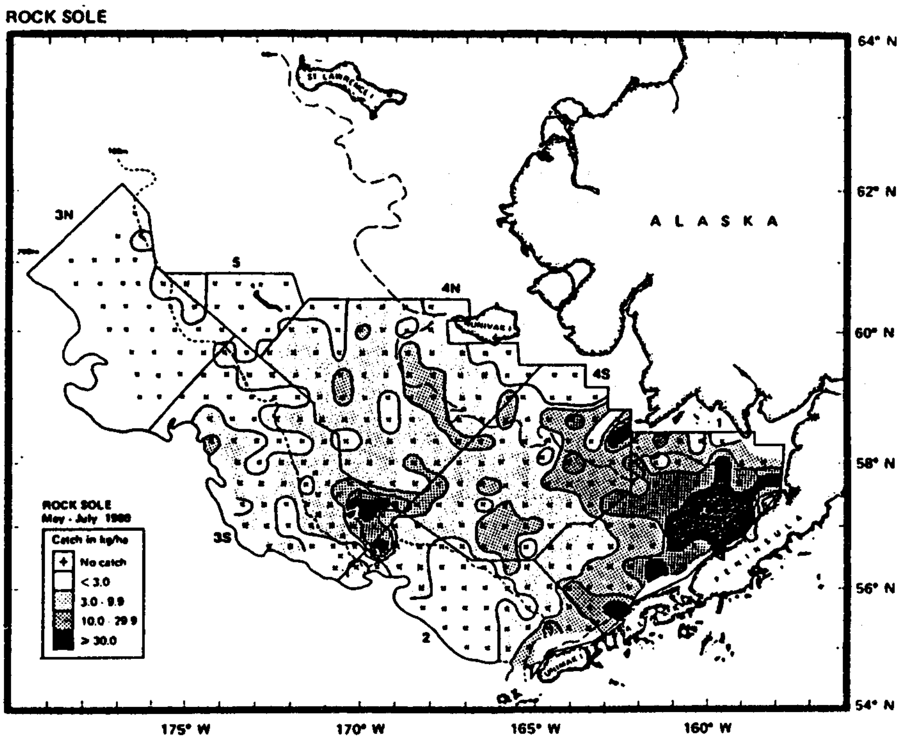

Figure 5.41. Catch distribution of rock sole during the 1980 NMFS survey, Bering Sea, Alaska. From Umeda and Bakkala (1983).

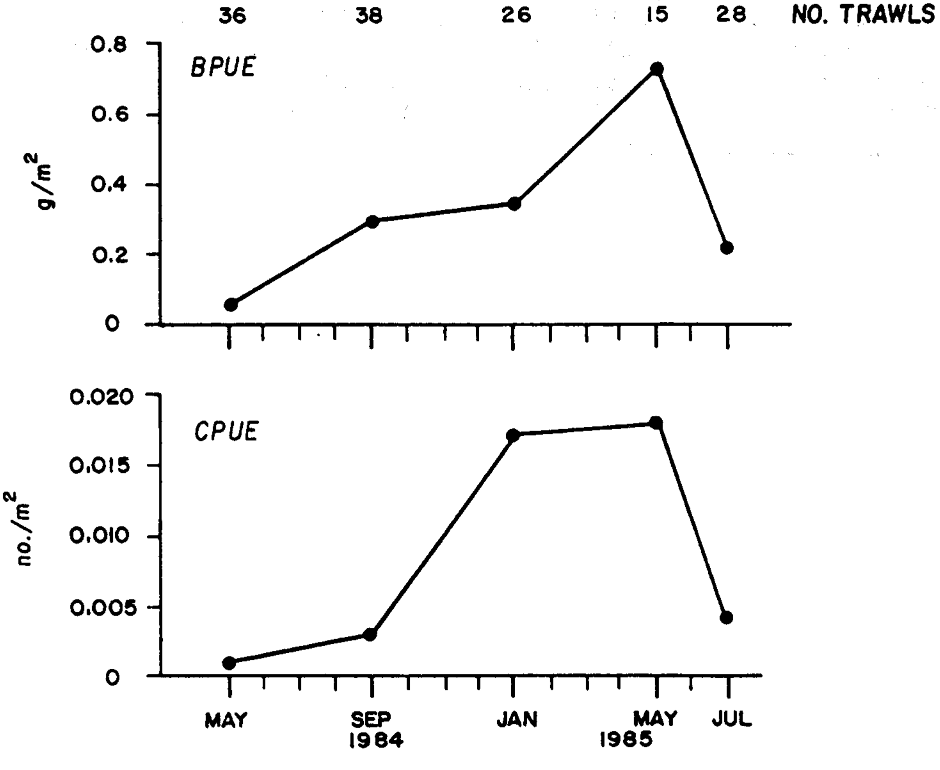

Figure 5.42. Seasonal BPUE and CPUE of rock sole caught in bottom trawls in the NANZ study area, Alaska. (Gear: TRY1). Note gear-related bias in Section 5.6.3.1.

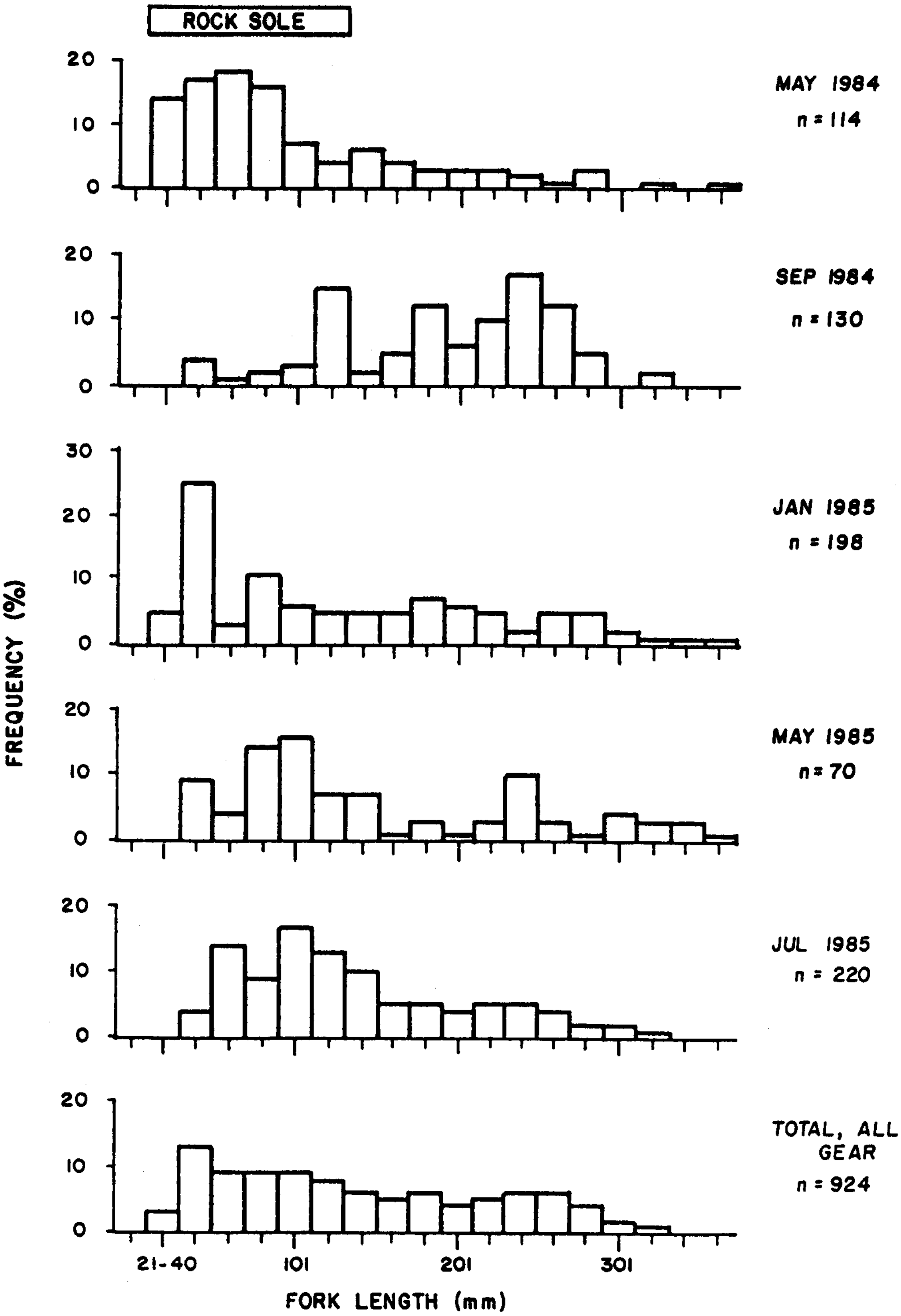

Figure 5.43. Length frequencies of rock sole caught by TRY1 bottom trawl on various dates in the NANZ study area, Alaska. Bottom graph shows all gear and dates combined.

occurred the previous spring), although the high BPUE indicates many large fish as well. A precipitous exodus of rock sole from the area occurred prior to mid-summer.

While the above information is sketchy, the scenario indicates the same two points previously noted for yellowfin sole: (1) rock sole inhabit the shallow waters of the NANZ year-round, and (2) the area is particularly important to juveniles.

Rock sole were distributed throughout the NANZ but were most abundant in the deeper portions of the study area. Highest BPUE estimates occurred at the 50-m Station in contrast to yellowfin sole which were more abundant in shallower water (Fig. 5.38).

The benthic food habits of rock sole in the NANZ are generally similar to diets reported for this species in the offshore waters of the Bering Sea shelf. There, large rock sole eat polychaetes, fish, amphipods, mollusks, and echinoderms (Skalkin 1964, Shubnikov and Lisovenko 1964, Mito 1974). In the NANZ, polychaetes and amphipods were important food items for all size classes of rock sole in this study (Table 5.24). Some size-related shifts in diet were apparent; small rock sole ate copepods, medium-sized sole ate mysids and euphausiids, and large sole ate fish (often sand lance), benthic worms, and echinoderms (sea urchins, sand dollars, brittle stars). Cimberg et al. (1984) reported generally similar diets for rock sole in the NANZ as well. Stomach fullness data indicate that rock sole fed more in spring and summer than in winter (Fig. 5.44), as has been reported in earlier studies (Shubnikov and Lisovenko 1964).

Our data show considerable variability among rock sole diets at different locations in the NANZ. In shallow habitats (about 10 m deep), rock sole ate proportionally more fish, amphipods, and bivalves and fewer polychaetes than in deeper water (Table 5.25). Diets in eastern and western portions of the study area (Transects 6 and 7 versus Transect 2) also differed in the proportions and amounts of foods eaten.

Walleye Pollock (Theragra chalcogramma). The walleye pollock is a major species in the eastern Bering Sea, accounting for 27% of catches in NMFS trawl surveys on the middle shelf and 26% of catches adjacent to the NANZ (Table 5.4). Within the NANZ, however, pollock were only moderately abundant in our samples (Table 5.6) and those of Isakson et al. (1986).

Table 5.24. Rock sole diets (see Appendix 5.3E for more details).

	Diet Composition (% wt.) by Fish Size, Date and Location										
	Small Fish	Medium Fish			Large Fish						
	May 1984	Jan 1985	May 1984	July 1985	Jan 1985	May 1984a	May 1984b	July 1985a	July 1985b	Sept 1984a	Sept 1984b
Copepod	48	3		2							
Amphipod	26	37	52	4	13	3	4	8	2	8	31
Polychaete	22	31	39	71	46	87	44	70	2	79	10
Mysid		6	2	5							
Euphausiid		8	2					10			
Echinoderm*		8			14	1	12	6		3	5
Crangonid				1	7	3					
Bivalve				15		1	4	3	10	3	16
Echiuroid worm					12						
Sipunculid worm					7	3					
Flatworm							29				
Fish									84	1	29
Crab										2	7
Other	4	7	5	2	1	2	7	3		4	2
Ave. contents (mg)	5	8	44	27	130	700	2048	650	857	446	447
Ave. fish size (mm)	29	75	88	74	187	209	253	236	177	246	221
Sample site	2B	A,C	2C	D	A,C	2C	6A,7C	A-Y	D,E	A	1C
No. stomachs	15	36	28	31	31	10	31	39	13	38	15

*Urchins, sand dollars, brittle stars.

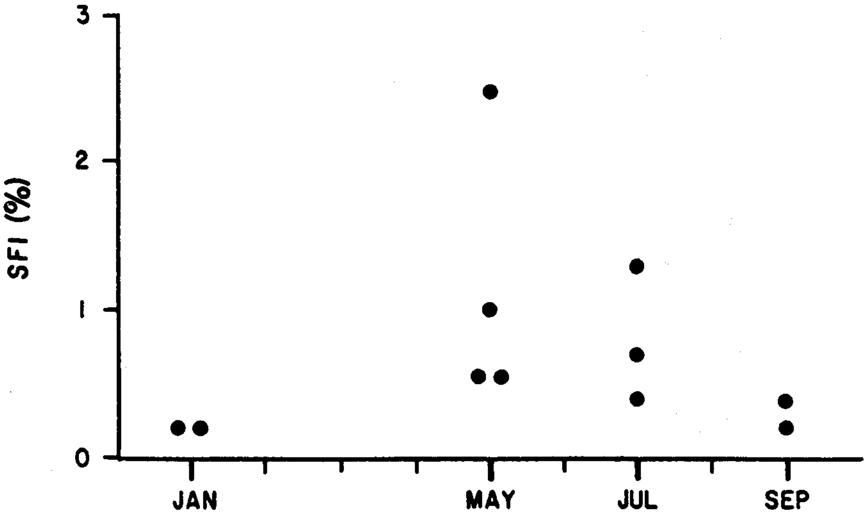

Figure 5.44. Seasonal stomach fullness index (SFI) of rock sole caught in the NANZ study area, Alaska. For each group of fish in Table 5.24, SFI = 100 x average weight of stomach contents divided by the average weight of fish in the group.

Table 5.25. Rock sole diets: comparisons between locations in the NANZ.

	Diet Composition (% wt.)			
	Dates Combined*		May 1984	
	Nearshore	Offshore	East	West
Polychaete	75	6	44	87
Fish	1	57		
Amphipod	8	17		3
Bivalve	3	13	4	1
Euphausiid	5			
Echinoderm	5	3	12	1
Crab	1	4		
Crangonid				3
Sipunculid worm				3
Flatworm			29	
Other	4	1	7	2
Ave. contents (mg)	652	548	2048	700
Ave. Fish size (mm)	199	241	253	209
Sample site	C-E	A-Y	6,7	2
No. stomachs	28	77	31	10

*September 1984, July 1985.

Pollock catches consisted primarily of young-of-year (25-100 mm) in the watercolumn, juveniles (81-180 mm) on the seabottom, and occasional adults (Fig. 5.45). Young-of-year or small juveniles were also caught by fyke net in Izembek Lagoon in July 1984 (Fig. 5.45).

The average catch of young-of-year in midwater trawls was only 1 mg/m^3 or 0.001 $fish/m^3$. Catches were highest in pollock biomass during summer months (Fig. 5.46) in offshore waters, as follows:

Transect Stations	Water Depth (m)	No. Stations Sampled	Young-of-Year Annual Mean (mg/m^3)
C	20	24	1
A	50	25	5
X,Y	70-90	10	17

Gear: M-4

Juvenile abundance was low during most sampling periods (Fig. 5.46), averaging 42 mg/m^2 or 0.003 $fish/m^2$.

This limited information agrees with Lynde's (1984) conceptual model of pollock distribution in the eastern Bering Sea (Fig. 5.47). Although some pollock of all sizes are present in the NANZ, we would expect to find primarily age 0 fish, especially when middle shelf waters intrude into the shallows of the study area.

The small pollock in the watercolumn were assumed to be age 0 fish. Their fork lengths (mm) were:

Month	Mean	Range	N
July 1985	46	25-80	248
September 1984	87	46-130	247
January 1985	103	77-130	25

Periods of high abundance of young-of-year pollock coincided with those of jellyfish in the NANZ (see Section 4.0, this report). While these

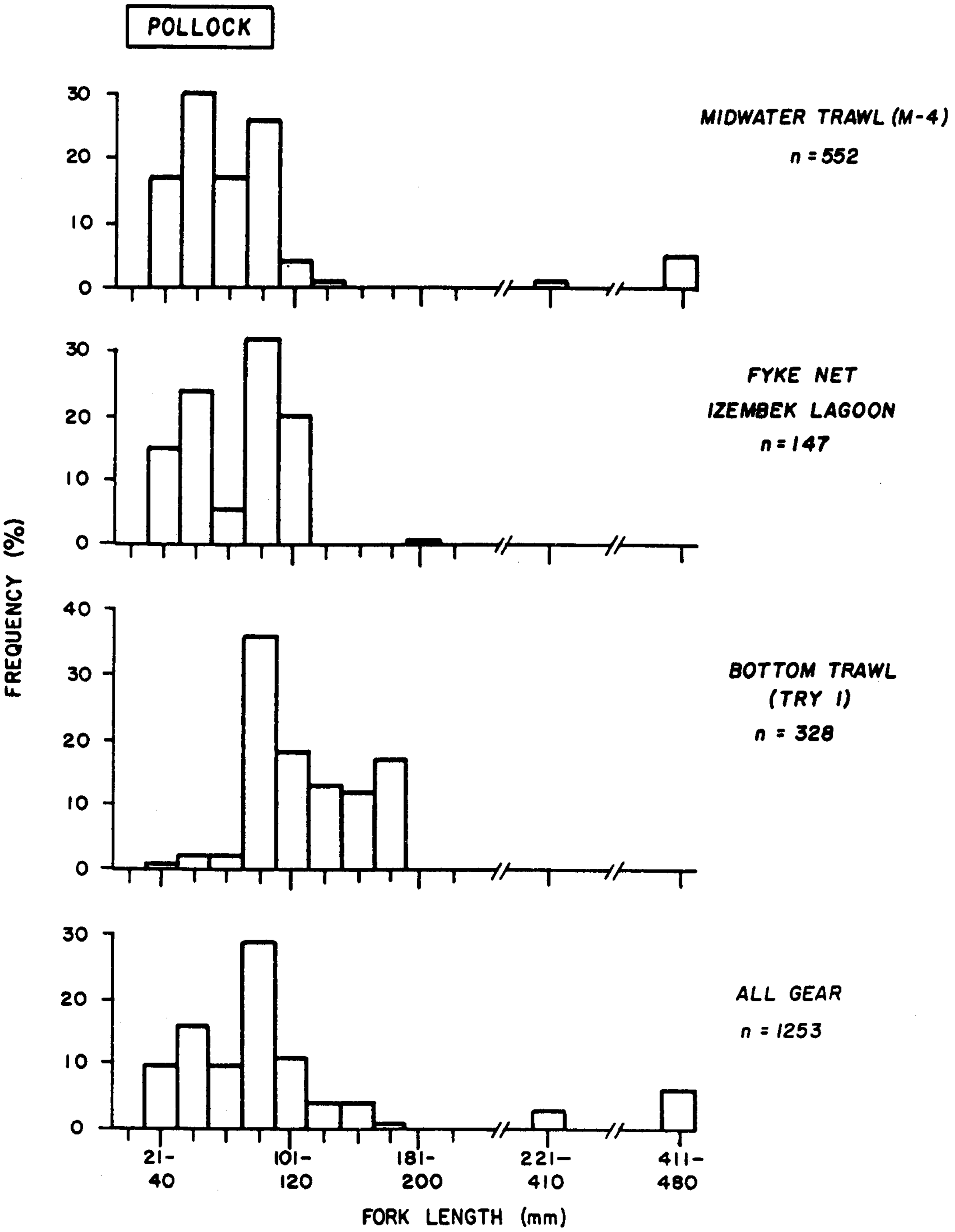

Figure 5.45. Length frequencies of pollock caught in the NANZ study area, Alaska. All dates and locations are combined. (Izembek Lagoon samples taken in July 1984 are excluded.)

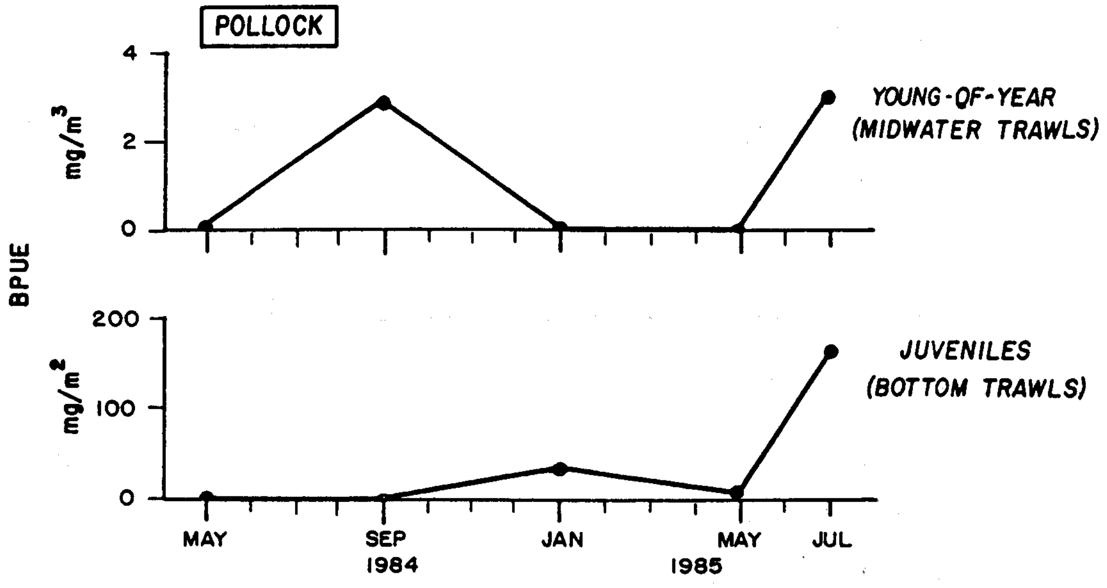

Figure 5.46. Seasonal abundance of young-of-year pollock (25-100 mm) in the water column and juveniles (81-180 mm) in bottom trawls in the NANZ study area, Alaska.

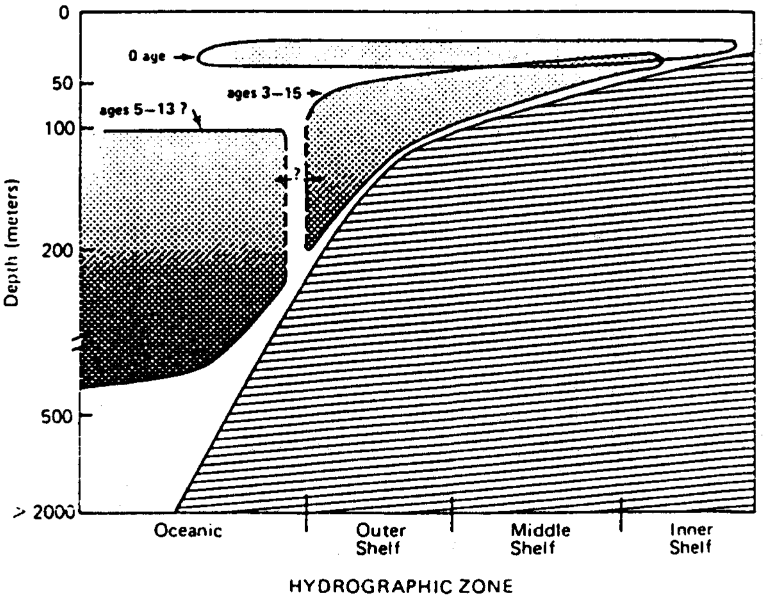

Figure 5.47. Conceptual model of the vertical distribution of juvenile and adult walleye pollock across the eastern Bering Sea shelf and slope, and Aleutian Basin areas. Age 1 and Age 2 pollock range throughout the water column over the outer, middle, and inner shelf domains. From Lynde (1984).

events may be unrelated, the juveniles of several cod species (including pollock and Pacific cod) are known to associate symbiotically with jellyfish medusae (Mansueti 1963, Van Hyning and Cooney 1974). By remaining near medusae, these juvenile fish presumably derive protection from other predators. A comparison was therefore made between catches of young-of-year pollock and medusae in midwater trawls, but no trend was detected; however, as previously noted, this negative result was not entirely unexpected because the midwater trawl used has a mesh size that is not 100% efficient at retaining very small fish.

Because of the economic and trophic importance of pollock in the Bering Sea, previous studies have closely examined the diets of larval fish (PROBES studies) and commercial-sized fish (NMFS surveys). Both size- and season-related trends in pollock food habits have been documented. Larval and young juveniles feed almost exclusively on copepods (Cooney et al. 1980); larger pollock eat copepods, euphausiids and fish in proportions that vary with the size of the pollock (Fig. 5.48). Dwyer (1984) notes that pollock feed primarily during the summer months.

Diets of pollock in very shallow water habitats and for the intermediate-size ranges of fish are not often reported in the literature. The NANZ data indicate that important foods of intermediate-sized pollock (40-150 mm) consist of amphipods, mysids and crustacean larvae, copepods, and euphausiids (Table 5.26). The diets of larger pollock were primarily euphausiids and fish, which is generally similar to that reported in the literature. And, as elsewhere, the amount of food in pollock stomachs tended to be greater in summer than winter (Fig. 5.49).

<u>Pacific Cod (Gadus macrocephalus)</u>. Use of the study area by Pacific cod is similar to that described for pollock. Catches were moderately low, consisting primarily of young-of-year in the watercolumn, juveniles on the seabottom, and occasional adults (Fig. 5.50).

The average abundance of young-of-year caught in midwater trawls was only 0.2 mg/m^3 and 0.0001 fish/m^3; juveniles in bottom trawls averaged 28 mg/m^2 and 0.003 fish/m^2. Highest catches of biomass were in summer (July and September samples), averaging 0.1-0.8 mg/m^3 in midwater trawls and 62-73 mg/m^2 in bottom trawls.

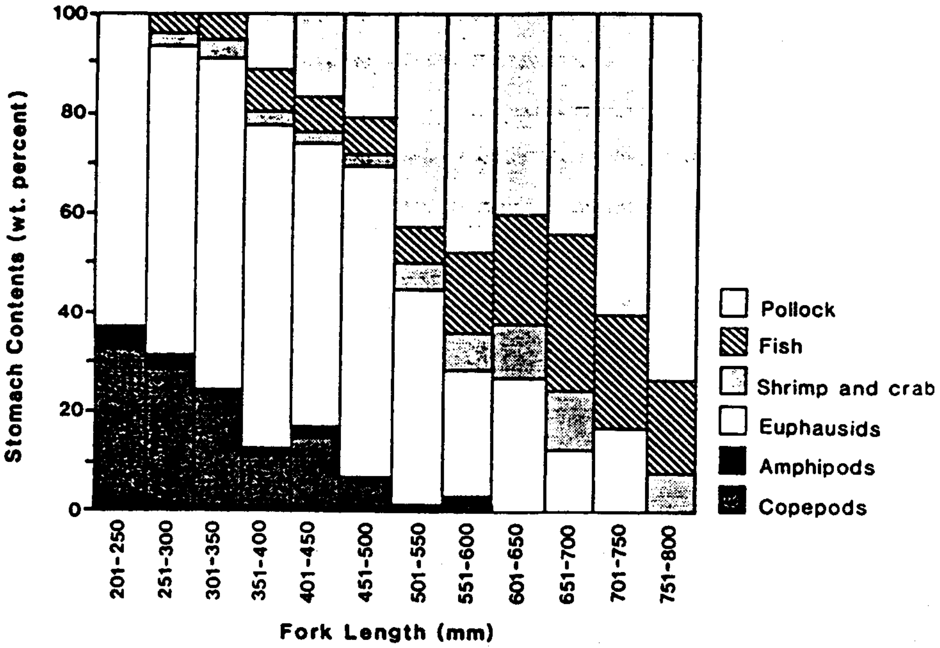

Figure 5.48. Changes in composition of pollock prey with size. From Takahashi and Yamaguchi (1972).

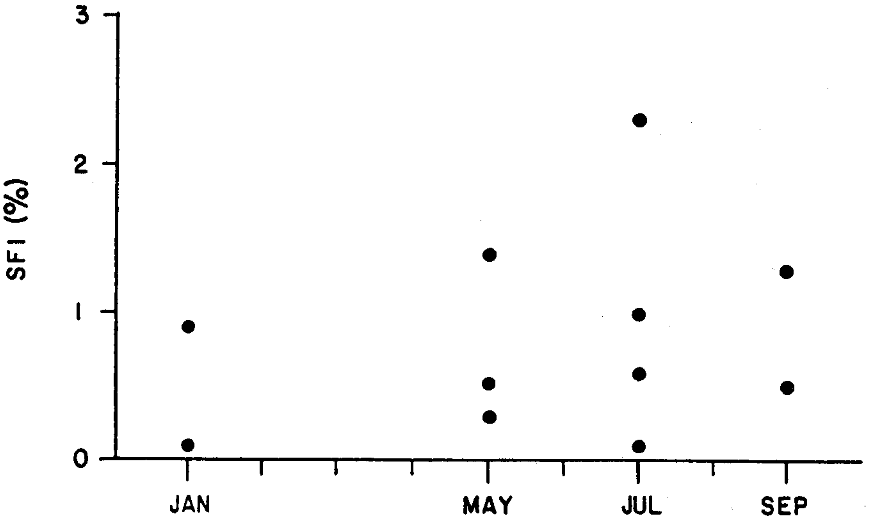

Figure 5.49. Seasonal stomach fullness index (SFI) of pollock caught in the NANZ study area, Alaska. For each group of fish listed in Table 5.26, SFI = 100 x average weight of stomach contents divided by average weight of fish in the group.

Table 5.26. Walleye pollock diets (see Appendix 5.3F for more details).

	Diet Composition (% wt.) by Fish Size, Date and Location										
	Small Fish		Medium Fish					Large Fish			
Food	July 1984	July 1985	Jan 1985	May 1984	July 1984	July 1985	Sept 1984	Jan 1985	May 1984	May 1985	Sept 1984
Decapod larvae	1	15			7						
Crustacean larvae		75					3				1
Amphipod	59		16	2	28	5	18				
Copepod	22		1			2	56			4	
Mysid	6		5	70	15	69	2				
Crustacea misc.	9						11				4
Euphausiid			76	28				100	95	96	
Crangonid shrimp					4	14					14
Crab							3				
Fish					45	10			5		77
Other	3	10	2		1		7				4
Ave. contents (mg)	4	6	66	120	160	14	21	603	5100	1940	1383
Ave. fish size (mm)	45	43	101	106	99	148	86	479	515	457	246
Sample site	2F	A	A,C	misc	2F	D,E	A	X,Y	A	A	2A
No. fish examined	32	40	32	15	30	30	33	8	30	21	16

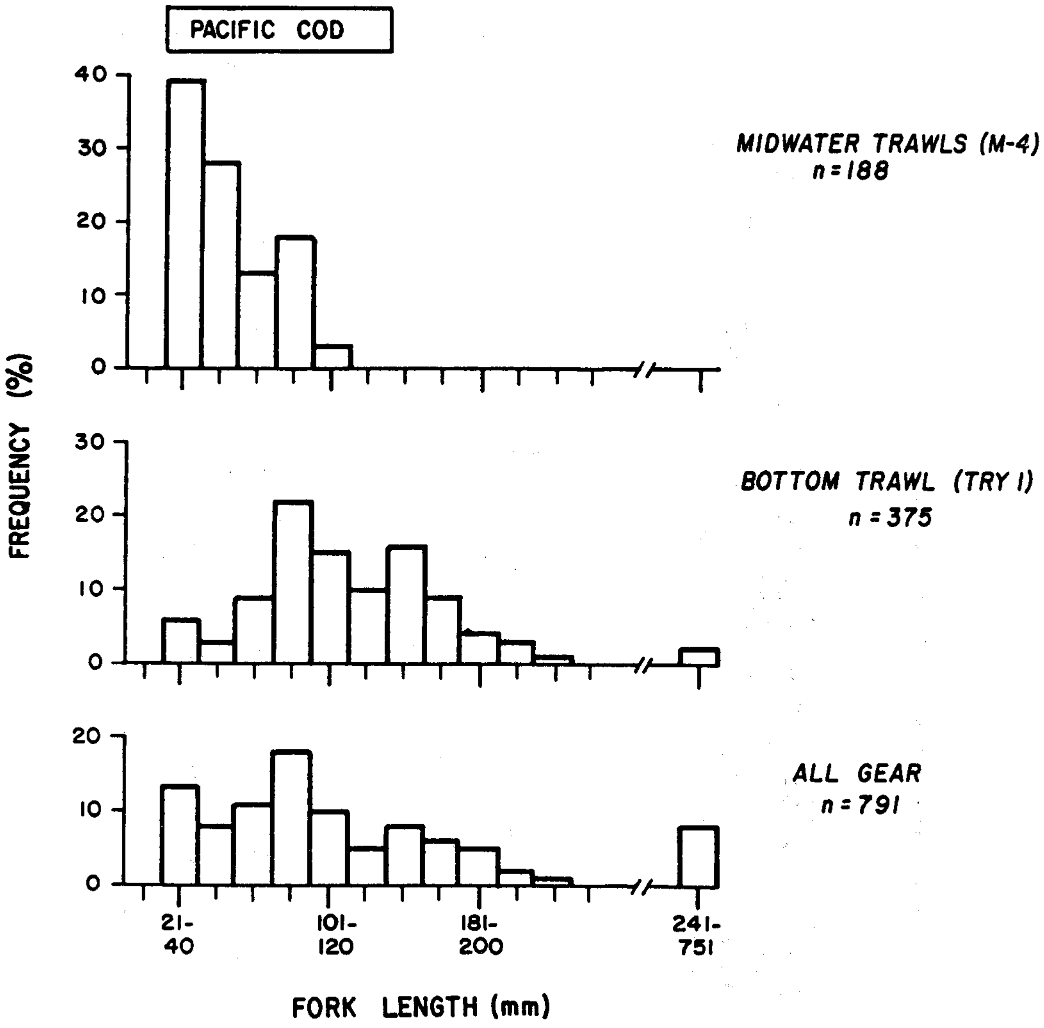

Figure 5.50. Length frequencies of Pacific cod caught in the NANZ study area, Alaska. Catches from all dates and locations are combined.

Information about the food habits of Pacific cod in the eastern Bering Sea is limited. Bakkala (1984) reports that their diets were geographically variable across the Bering Sea shelf and that the primary foods consumed were snow crab, euphausiids, fish, and other miscellaneous invertebrates.

In the NANZ, the foods eaten by Pacific cod were diverse (Table 5.27), but there was a definite change in prey types with change in fish size. Small Pacific cod (mean size 41 mm) ate copepods; medium-sized cod (mean sizes 88 and 191 mm) ate mostly small epibenthic invertebrates such as mysids, amphipods, and crangonid shrimps; large cod ate primarily fish and crabs.

Pacific Halibut (Hippoglossus stenolepis). Catches of halibut in small bottom trawls (TRY1) were low, averaging 4 mg/m^2 and 0.0001 $fish/m^2$ in 143 trawls. Highest catches were made in summer: 158 mg/m^2 (July) and 41 mg/m^2 (September).

Higher catches were made when a larger bottom trawl was used in deeper waters (maximum catch 897 mg/m^2, average catch 231 mg/m^2; gear = BT-1), but the sampling effort with this gear was low (n=4 trawls). A comparison of catches in large and small trawls at the same depth and time period (50 m, September 1984), though based on only three samples for each gear type, showed that the large trawl caught more halibut (TRY1: 0 halibut; BT-1: 0.001 $halibut/m^2$, 486 mg/m^2). The average size of these fish was 305 mm (range 184-527 mm, n=21).

Although most halibut caught by trawl (particularly the small trawl) measured less than 300 mm in length, larger fish were also present in the NANZ as indicated by samples collected by hook and line (Fig. 5.51).

The foods eaten by these fish demonstrate size-related changes in diet. Small halibut (mean size 66 mm) ate mysids, shrimp, and amphipods; medium-sized halibut (mean sizes 138 and 366 mm) ate fish, crabs, and crangonid shrimps; and large halibut (788 mm) ate fish, cephalopods, and crabs (Table 5.28).

Table 5.27. Pacific cod diets (see Appendix 5.3G for more details.)

	Diet Composition (% wt.) by Fish Size, Date and Location					
	Small Fish	Medium Fish			Large Fish	
Food Item	July 1985	May 1984	July 1985	Sept 1984	May 1984	Sept 1984
Copepod	72			11		
Crustacea	11			19		8
larvae	13					
Amphipod		32	16	8		
Mysid		62	4	4		
Decapod						
Crangonid			60	26	1	8
Crab					28	13
Pagurid						23
Larvae, eggs	3			32		
Misc.			7			7
Fish			8		54	36
Other	1	6	5		17	6
Ave. contents (g)	0.02	0.16	1.01	0.06	20.9	4.1
Ave. fish size (mm)	41	99	191	88	526	394
Sample site	A,C	E,C	D,E	misc	A,C	B,C
No. fish examined	30	5	31	30	13	24

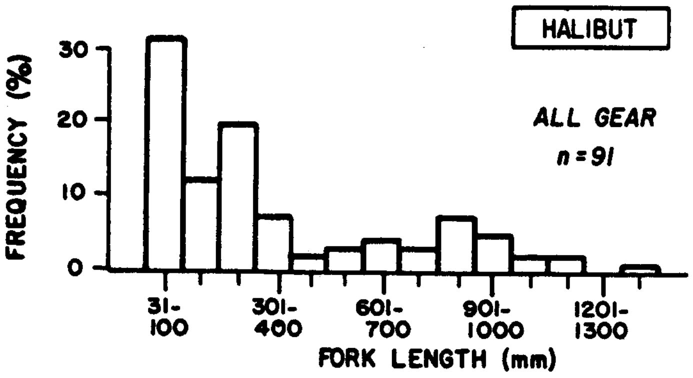

Figure 5.51. Length frequencies of halibut caught in the NANZ study area, Alaska. Catches from all gears, dates and sites are combined.

Table 5.28. Halibut diets (see Appendix 5.3H for more details).

	Diet Composition (% wt.) by Fish Size and Location			
	Small Fish	Medium Fish		Large Fish
	Jan. 1985	July 1985	Sept 1984	July 1985
Mysid	51	6		
Amphipod	11			
Crustacea	9			
Shrimp (misc.)	28			
Crangonid shrimp		12	17	
Crabs		16	44	7
Fish		60	32	71
Cephalopods				19
Other	1	6	7	3
Ave. wt. contents (g)	0.15	0.64	5.3	28.4
Ave. fish size (mm)	66	138	366	788
Sample site	2C,4C	D	3,4	misc
No. fish	17	17	21	11

5.6.5.4 Nearshore and Other Fishes

Figure 5.52 presents length frequencies for Pacific sandfish, Pacific staghorn sculpin, Alaska plaice, flathead sole, and starry flounder. Of these, only the sandfish were moderately abundant in catches.

The 1610 sandfish caught in the NANZ measured 68-264 mm in length. They were occasionally caught in both midwater and bottom trawls, averaging 3 mg/m^3 and 16 mg/m^2, respectively. More were caught in winter and spring (21-40 mg/m^2) than in summer or fall (3 mg/m^2). Most were taken in shallow water, ranging about 3-25 m deep (i.e., Station C for midwater trawls and Station D for bottom trawls).

The 227 staghorn sculpin caught measured 42-375 mm (Fig. 5.52). This shallow-water species was taken in waters 20 m or less by bottom trawl, gill net, and beach seine.

Alaska plaice were caught in small numbers (n=269) throughout the study area, primarily by bottom trawl but also by beach seine and nearshore gill nets.

Flathead sole (n=151) were caught in bottom trawls in the western portion of the study area (Transects 1-4) in waters ranging from 10-90 m deep. These fish measured 48-341 mm.

Starry flounder (n=112) were usually caught by bottom trawl in waters 20 m or less, but occasionally out to 50 m. They were also taken by beach seine and nearshore gill net. These fish measured 48-550 mm.

5.7 RECOMMENDED FURTHER RESEARCH

1. <u>Forage fishes</u> such as sand lance, herring, and capelin are the most likely fishes to be impacted by an oilspill because they use intertidal or shallow coastal waters for spawning, feeding and migrating, and as a nursery area for their young. Sand lance also will avoid burrowing into oil-contaminated substrates (Pearson et al. 1984). Therefore, it would be useful to gain a better understanding of their seasonal abundance, spawning areas, the distribution of their juveniles, and their pre- and post-spawning migrations in the NANZ. For example, we do

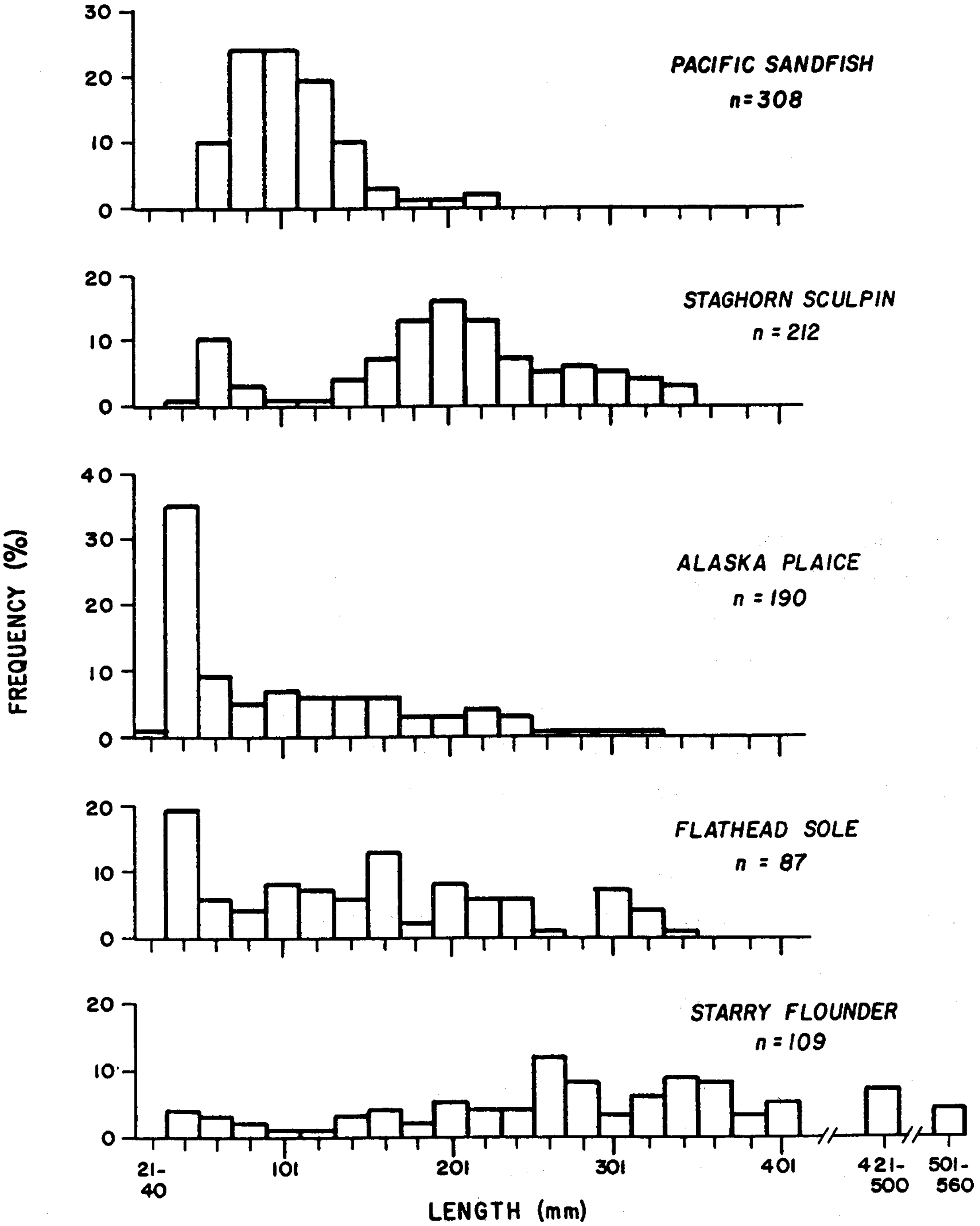

Figure 5.52. Length frequencies of five species caught in the NANZ study area, Alaska. Catches by all gear types and dates are combined.

not know where or when sand lance spawn in the eastern Bering Sea, or where they go in winter, which is the period when most of their feeding occurs. For herring and capelin, we know little about the distribution of larvae and juveniles, or the migration pathways of either the Port Moller spawners or the Togiak spawners, which migrate to the Unimak area to feed in summer.

2. Special habitats. Selected nearshore habitats such as Port Moller and Herendeen bays and Izembek Lagoon support both resident fish populations and important seasonal migrants such as juvenile salmon, herring, young-of-year pollock, sand lance and smelt. Fish use these areas for feeding and, at least for herring in Port Moller, as spawning and nursery areas as well. A better understanding of the role of these nearshore habitats to important fish species is needed.

3. Winter conditions. Most data describing NANZ fishes have been gathered during the 6-month summer period from April to September. Our January (1985) cruise in the study area represents one of the few attempts to address the need for an assessment of winter conditions. The data gathered indicate that there is an abundance of fish (particularly juvenile yellowfin and rock sole) that winter in the NANZ. The fisheries significance of nearshore habitats in winter needs further examination.

4. Fish-jellyfish relationships. In summer, two of the most abundant pelagic organisms in the NANZ (and eastern Bering Sea) are young-of-year pollock and jellyfish. The relationship between these two may be much more than an academic curiosity -- the ecological significance of jellyfish (and other gelatinous zooplankton) is receiving growing attention in the scientific literature. Due to

their often overwhelming abundance, jellyfish may affect fishes negatively or positively in several ways:

A. Predation. Jellyfish may seriously reduce numbers of larval fish. For example, Moller (1984) found that a larval herring population was less affected by the number of herring spawners than it was by the abundance of jellyfish.

B. Competition. As shown in the present study, jellyfish consumed about 50% of all available zooplankton in the water, thereby significantly reducing the amount of food available to fish (and seabirds).

C. Symbiosis. The juveniles of several cod species, including pollock and Pacific cod, are known to associate symbiotically with jellyfish (Mansueti 1963, Hyning and Cooney 1974). By remaining near medusae, the cod juveniles are presumably protected from other predators.

In all three of the above relationships, young-of-year pollock may be significantly influenced by jellyfish. This interaction merits investigation. Is it a mere coincidence that a major pollock spawning area lies adjacent to a site officially designated on maps as "Slime Bank" due to its well-known abundance of jellyfish?

5.8 ACKNOWLEDGEMENTS

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5.10 APPENDIXES

Appendix 5.1. Total fish catches, CPUE AND BPUE for individual gear types (all dates and sampling efforts combined).

Key to Tables

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1. Gear Codes (see text Table 5.3).
2. Fish Species Codes (see text Table 5.5).
3. Total Biomass = grams.
4. Units:

Gear	CPUE	BPUE
Bottom trawls (TRY1=small, BT-1=large)	no. fish/m^2	mg/m^2
Mid-water trawls (M-3=period 1, M-4= periods 3-6)	no. fish/m^3	mg/m^3
Gill nets (GN-S, GN-B, GNXS, GNXB)	no. fish/hour	mg/hour
Beach series (BS-1 and BS-3, combined)	no. fish/haul	mg/haul
Fyke net (FYKE)	--experimental--	

Appendix 5.1 (cont'd)

Gear == TRY1

Location	Species	Total # Samples	Total Number	CPUE	Total Biomass	BPUE
ALL		143	0			
ALL	AHSC	143	1	.0000029	2.20	.0064
ALL	AKPL	143	255	.0007369	9927.30	28.6897
ALL	ALAL	143	17	.0000491	162.70	.4702
ALL	ARRO	143	6	.0000173	889.10	2.5695
ALL	BERF	143	4	.0000116	184.00	.5318
ALL	BPOA	143	151	.0004364	1136.60	3.2848
ALL	BUTS	143	6	.0000173	382.20	1.1045
ALL	CAPE	143	5	.0000144	55.20	.1595
ALL	CRES	143	1	.0000029	79.00	.2283
ALL	CRGU	143	11	.0000318	73.70	.2130
ALL	EULA	143	1	.0000029	97.00	.2803
ALL	F-1	143	2	.0000058	.20	.0006
ALL	FLAT	143	128	.0003699	7430.10	21.4728
ALL	GRSC	143	6	.0000173	3639.20	10.5172
ALL	GRTU	143	1	.0000029	82.30	.2378
ALL	HALI	143	47	.0001358	1312.80	3.7940
ALL	JADK	143	7	.0000202	7076.00	20.4495
ALL	KGRE	143	7	.0000202	72.50	.2095
ALL	L-1	143	2	.0000058	1.10	.0032
ALL	LDAB	143	4	.0000116	178.80	.5167
ALL	LSPB	143	3	.0000087	131.10	.3789
ALL	MASK	143	3	.0000087	46.40	.1341
ALL	P-1	143	5	.0000144	56.10	.1621
ALL	PCOD	143	941	.0027195	15390.90	44.4794
ALL	POLK	143	1175	.0033957	14524.80	41.9764
ALL	PRIC	143	5	.0000144	194.70	.5627
ALL	RBSM	143	854	.0024680	11169.60	32.2799
ALL	REDL	143	1	.0000029	585.50	1.6921
ALL	RIBS	143	2	.0000058	6.70	.0194
ALL	ROKS	143	2377	.0068695	87457.10	252.7491
ALL	SSOL	143	1	.0000029	434.00	1.2543
ALL	SANL	143	976	.0028206	3871.50	11.1886
ALL	SCUL	143	9	.0000260	6.80	.0197
ALL	SILV	143	1	.0000029	8.90	.0257
ALL	SLIM	143	1	.0000029	4.60	.0133
ALL	SNAK	143	26	.0000751	488.80	1.4126
ALL	SNAL	143	53	.0001532	1167.60	3.3743
ALL	SSPO	143	1	.0000029	1.20	.0035
ALL	STAG	143	25	.0000722	6653.80	19.2293
ALL	STAR	143	49	.0001416	27625.20	79.8362
ALL	STUR	143	23	.0000665	323.30	.9343
ALL	TRIC	143	276	.0007976	5569.90	16.0969
ALL	TUBE	143	194	.0005607	310.70	.8979
ALL	WASC	143	3	.0000087	3588.30	10.3701
ALL	WGRE	143	16	.0000462	345.40	.9982
ALL	YEIL	143	31	.0000896	17645.30	50.9945
ALL	YELS	143	4342	.0125483	445230.00	1286.7050
ALL	?PB	143	1	.0000029	42.10	.1217
			12056	.0348416	675662.30	1952.6500

Appendix 5.1 (cont'd)

```
------------
Gear == BT-1
------------

                   Total #  Total                        Total
Location  Species  Samples  Number       CPUE           Biomass          BPUE
-----------------------------------------------------------------------------
  ALL      AKPL       4          1     .0000303         1208.00        36.5850
  ALL      ARRO       4         45     .0013629         8624.20       261.1890
  ALL      BUTS       4         28     .0008480         6672.90       202.0927
  ALL      FLAT       4         21     .0006360         9441.20       285.9323
  ALL      GRSC       4          6     .0001817         5701.20       172.6642
  ALL      HALI       4         21     .0006360         7643.30       231.4819
  ALL      HERR       4          8     .0002423         2251.90        68.2001
  ALL      PCOD       4        142     .0043006        56781.80      1719.6700
  ALL      POLK       4          6     .0001817         3320.90       100.5754
  ALL      RBSM       4          1     .0000303           98.90         2.9952
  ALL      ROKS       4        874     .0264696       165539.20      5013.4530
  ALL      SABL       4          6     .0001817         2636.10        79.8359
  ALL      STAR       4          2     .0000606         1331.70        40.3313
  ALL      YEIL       4         21     .0006360         8172.00       247.4938
  ALL      YELS       4        174     .0052697        70715.60      2141.6640
                            -------------------------------------------------
                              1356     .0410673       350138.90     10604.1600
```

Appendix 5.1 (cont'd)

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------------
Gear == M-3
------------

                       Total #  Total                          Total
 Location   Species   Samples   Number        CPUE             Biomass          BPUE
------------------------------------------------------------------------------------
   ALL                   12        0
   ALL       POLK        12        7        .0000710          791.90          8.0310
   ALL       ROKS        12       33        .0003347         1016.00         10.3036
   ALL       SANL        12       53        .0005375         3808.90         38.6275
   ALL       YELS        12       16        .0001623         1959.00         19.8669
                                 ---------------------------------------------------
                                 109        .0011054         7575.80         76.8290


------------
Gear == M-4
------------

                       Total #  Total                          Total
 Location   Species   Samples   Number        CPUE             Biomass          BPUE
------------------------------------------------------------------------------------
   ALL                   73        0
   ALL       CRES        73        1        .0000001          407.00           .0537
   ALL       F-1         73        1        .0000001            1.20           .0002
   ALL       FLAT        73        1        .0000001            6.70           .0009
   ALL       HERR        73      678        .0000895       152464.60         20.1233
   ALL       KAMC        73        1        .0000001           24.70           .0033
   ALL       L-1         73       19        .0000025            3.10           .0004
   ALL       L-2         73       10        .0000013            4.50           .0006
   ALL       PCOD        73      744        .0000982         1610.40           .2126
   ALL       POLK        73    11023        .0014549        39415.60          5.2023
   ALL       PRIC        73        2        .0000003           32.20           .0042
   ALL       RBSM        73      476        .0000628         7632.80          1.0074
   ALL       ROKS        73        4        .0000005          680.60           .0898
   ALL       SANL        73    60436        .0079767       272190.70         35.9255
   ALL       SLUM        73        1        .0000001            0.00          0.0000
   ALL       SMLP        73        1        .0000001          717.60           .0947
   ALL       SNAL        73       64        .0000084         1346.00           .1777
   ALL       STAG        73        1        .0000001          509.00           .0672
   ALL       STAR        73        1        .0000001          480.50           .0634
   ALL       TRIC        73      983        .0001297        19161.30          2.5290
   ALL       U-1         73        2        .0000003          102.80           .0136
   ALL       YELS        73       12        .0000016         2102.00           .2774
                                 ---------------------------------------------------
                               74461        .0098279       498893.40         65.8473
```

Appendix 5.1 (cont'd)

Gear == GNXS

Location	Species	Total # Samples	Total Number	CPUE	Total Biomass	BPUE
ALL		31	0			
ALL	AKPL	31	2	.0065270	101.00	329.6129
ALL	BPOA	31	1	.0032635	9.50	31.0032
ALL	CHUM	31	4	.0130540	12039.60	39291.1600
ALL	DOLL	31	3	.0097905	3663.00	11954.1800
ALL	GRSC	31	2	.0065270	745.50	2432.9340
ALL	MASK	31	3	.0097905	397.00	1295.6070
ALL	RBSM	31	22	.0717969	622.00	2029.8940
ALL	RGRE	31	2	.0065270	796.70	2600.0260
ALL	ROKS	31	4	.0130540	185.20	604.3991
ALL	SALM	31	1	.0032635	12.20	39.8146
ALL	SOCK	31	3	.0097905	3595.80	11734.8700
ALL	STAG	31	39	.1272763	8600.20	28066.7000
ALL	STAR	31	4	.0130540	622.00	2029.8939
ALL	STUR	31	1	.0032635	52.40	171.0071
ALL	TRIC	31	2	.0065270	247.40	807.3884
ALL	YELS	31	3	.0097905	279.10	910.8413
			96	.3132954	31968.60	104329.3000

Gear == GNXB

Location	Species	Total # Samples	Total Number	CPUE	Total Biomass	BPUE
ALL		16	0			
ALL	BPOA	16	11	.0727754	198.50	1313.2650
ALL	DOLL	16	8	.0529276	7410.00	49024.1500
ALL	GRSC	16	1	.0066159	786.10	5200.7940
ALL	HALI	16	1	.0066159	3750.00	24809.7900
ALL	HERR	16	3	.0198478	572.20	3785.6430
ALL	LSPB	16	1	.0066159	30.30	200.4631
ALL	MASK	16	15	.0992392	1137.40	7524.9760
ALL	PADS	16	1	.0066159	30.40	201.1247
ALL	PCOD	16	57	.3771088	3682.50	24363.2200
ALL	POLK	16	3	.0198478	27.10	179.2921
ALL	PRIC	16	1	.0066159	31.70	209.7254
ALL	RBSM	16	53	.3506451	2985.80	19753.8900
ALL	RGRE	16	2	.0132319	1137.30	7524.3140
ALL	SOCK	16	2	.0132319	3775.50	24978.5000
ALL	STAG	16	28	.1852465	6364.80	42109.1600
ALL	STAR	16	11	.0727754	14078.60	93143.2400
ALL	STUR	16	2	.0132319	119.30	789.2822
ALL	TOMC	16	1	.0066159	55.60	367.8465
ALL	TRIC	16	40	.2646378	1491.80	9869.6670
ALL	WGRE	16	14	.0926232	1016.90	6727.7540
ALL	YELS	16	6	.0396957	796.20	5267.6150
			261	1.7267620	49478.00	327343.7000

Appendix 5.1 (cont'd)

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------------
Gear == GN-S
------------

                   Total #  Total                         Total
Location  Species  Samples  Number       CPUE            Biomass          BPUE
--------------------------------------------------------------------------------
  ALL                 7        0
  ALL      TRIC       7        1       .0208333           27.00         562.5000
                          ----------------------------------------------------
                                   1       .0208333           27.00         562.5000


------------
Gear == GN-B
------------

                   Total #  Total                         Total
Location  Species  Samples  Number       CPUE            Biomass          BPUE
--------------------------------------------------------------------------------
  ALL                 7        0
  ALL      FLAT       7        1       .0223464          363.00        8111.7310
  ALL      HERR       7        2       .0446927          630.00       14078.2100
  ALL      JAOK       7        1       .0223464          852.00       19039.1100
  ALL      PCOD       7       23       .5139665        37748.00      843530.7000
  ALL      POLK       7       84      1.8770950        64459.00     1440424.0000
  ALL      ROKS       7       26       .5810056         6867.00      153452.5000
  ALL      SNAL       7        1       .0223464            0.00           0.0000
  ALL      STUR       7        1       .0223464          118.00        2636.8710
  ALL      YELS       7       40       .8938548         8019.00      179195.5000
                          ----------------------------------------------------
                             179      4.0000000       119056.00     2660469.0000
```

Appendix 5.1 (cont'd)

Gear == BS

Location	Species	Total # Samples	Total Number	CPUE	Total Biomass	BPUE
ALL		63	0			
ALL	AKPL	63	8	.1269841	226.80	3600.0000
ALL	BPOA	63	14	.2222222	216.30	3433.3330
ALL	CHUM	63	247	3.9206350	2730.10	43334.9200
ALL	DOLL	63	5	.0793651	1899.10	30144.4400
ALL	F-1	63	5	.0793651	0.00	0.0000
ALL	GRSC	63	1	.0158730	3.10	49.2063
ALL	MASK	63	6	.0952381	83.30	1322.2220
ALL	PCOD	63	98	1.5555560	422.40	6704.7620
ALL	PINK	63	9	.1428571	25.10	398.4127
ALL	RBSM	63	183	2.9047620	1505.50	23896.8200
ALL	ROKS	63	9	.1428571	139.70	2217.4600
ALL	SALM	63	10	.1587302	49.70	788.8890
ALL	SANL	63	82	1.3015870	637.10	10112.7000
ALL	SCUL	63	1	.0158730	15.20	241.2698
ALL	SOCK	63	1	.0158730	14.20	225.3968
ALL	STAG	63	119	1.8888890	10547.80	167425.4000
ALL	STAR	63	41	.6507937	8861.90	140665.1000
ALL	STUR	63	4	.0634921	266.20	4225.3970
ALL	SURF	63	11	.1746032	477.10	7573.0160
ALL	TUBE	63	25	.3968254	33.60	533.3333
ALL	WGRE	63	3	.0476190	32.20	511.1111
ALL	YELS	63	7	.1111111	271.20	4304.7620
ALL	3ST	63	31	.4920635	125.70	1995.2380
			920	14.6031700	28583.30	453703.1000

Appendix 5.1 (cont'd)

Izembek Lagoon:

Gear == FYKE

Location	Species	Total # Samples	Total Number	CPUE	Total Biomass	BFUE
ALL	AKPL	7	3		87.50	
ALL	BPOA	7	9		169.60	
ALL	CHUM	7	4		17.20	
ALL	GREE	7	79		101.90	
ALL	GRSC	7	6		645.20	
ALL	L-1	7	2		0.00	
ALL	MASK	7	18		1576.40	
ALL	P-2	7	2		7.60	
ALL	PCOD	7	9		101.00	
ALL	PINK	7	1		4.10	
ALL	POLK	7	147		669.00	
ALL	RBSM	7	3		181.90	
ALL	SANL	7	3		21.00	
ALL	SILV	7	19		53.50	
ALL	SNAL	7	1		8.00	
ALL	SOCK	7	6		0.00	
ALL	STAG	7	12		2186.30	
ALL	STAR	7	1		727.00	
ALL	SURF	7	3		18.90	
ALL	TRIC	7	2		12.00	
ALL	TUBE	7	131		444.90	
ALL	WGRE	7	15		1662.20	
			476		8695.20	

Appendix 5.2. Seasonal CPUE and BPUE, fish species combined; gear codes are listed in Table 5.3.

A. Fish CPUE (sampling effort in parentheses)

Gear Codes	May 1984	July 1984	Sept. 1984	Jan. 1985	May 1985	July 1985	Mean
Gill Nets (no./h)							
GN-S	0.20(7)						
GN-B	4.00(7)						
GNXS	0.00(6)	0.53(5)	0.34(6)		0.05(5)	0.30(9)	0.31(31)
GNXB			1.29(6)		0.00(3)	1.97(7)	1.73(16)
Beach Seine (no./haul)							
BS-1	34.00(9)					9.5(23)	16.40(32)
BS-3		28.5(6)	11.7(19)		0.00(5)		13.10(30)
Bottom Trawl (no./m^2)							
TRY1	0.02(36)		0.04(38)	0.04(26)	0.05(15)	0.05(28)	0.04(143)
BT-1			0.05(3)			0.03(1)	0.04(4)
Mid-Water Tr. (no./m^3)							
M-3	0.001(12)						
M-4			0.02(22)	0.001(16)	0.001(13)	0.02(22)	0.01(73)

B. Fish BPUE (sampling efforts as above)

Gear Codes	May 1984	July 1984	Sept. 1985	Jan. 1985	May 1985	July 1985	Mean
Gill Nets (g/h)							
GN-S	0.60						
GN-B	2660.00						
GNXS	0.00	262.00	11.00		31.00	74.00	104.00
GNXB			323.00		0.00	361.00	327.00
Beach Seine (g/haul)							
BS-1	643.00					673.00	664.00
BS-3		462.00	239.00		0.00		244.00
Bottom Trawl (g/m^2)							
TRY1	1.30		2.00	1.00	4.50	3.20	2.00
BT-1			8.50			15.00	10.60
Mid-Water Tr. (g/m^3)							
M-3	0.77						
M-4			0.05	0.004	0.02	0.20	0.07

Appendix 5.3. Detailed listings of fish diets.

A. Sand Lance Diets

	Diet Composition (%.wt.) by Date, Station and Fish Size								
Food Item	Jan 1985	May 1984		May 1985	July 1985[1]		Sept 1984[1]		
Copepod	*	*	21	58	93	79	96	88	96
Euphausiid (Total)	(100)	(55)	(66)			(1)	(*)		
Thysanoessa inermis	30	16	38						
T. raschii	19		6						
Misc. and unident.	51	39	22						
Amphipod (Total)		(20)	(20)			(1)		(8)	(1)
Gammarid		5							
Corophiid		5				*			*
Hyperiid		*	2			1		8	1
Other		10	*						
Mysid (Total)	*	(13)	(9)						*
Ancanthomysis			9						
Neomysis		6							
Misc. and unident.		7							
Misc. Crustacea (Total)		(2)	*	(30)		(5)	(1)	*	(1)
Larvae, nauplii						5	1		1
Decapod larvae, zoea		*		12	1	6			
Polychaete		6	*			1	1		
Chaetognath			2			1		3	
Fish eggs, larvae	*	1	1			1			
Bivalvia					5		1		*
Barnacle larvae					1	2		*	1
Plant		1					1		
Misc.			*			*		*	*
Average contents (mg)	120	80	270	10	10	60	10	40	50
Fish size (mm)									
mean	101	146	129	109	93	126	83	114	105
range	65-185	113-169	82-191	78-128	85-100	101-159	70-99	100-135	73-157
Sample location[2]	misc.	E	C	misc.	C	C	C	C	A,B
No. fish examined	9	46	40	24	33	30	45	29	32

* < 0.5%.

[1] Note differences in fish size at bottom of table.

[2] Station codes: E (lagoon), C (20m), AB (30-50m), x (combined).

Appendix 5.3 (cont'd).

B. Rainbow Smelt Diets

	Diet Composition (% wt) by Fish Size, Date and Location		
	Medium Fish		Large Fish
Food Item	May 1984	Sept 1984	Sept 1984
Amphipod (Total)	(41)	(24)	(*)
Lysianassid	6	*	
Corophiid	2	*	
Gammarid	19	23	
Mysid (Total)	(39)	(68)	(29)
Neomysis zerniawski	38	1	
N. rayii		37	7
N. mirabilis		21	12
Anthomysis pseudomacropsis		6	*
Caridean Shrimp			11
Crangonid Shrimp (Total)			(35)
Crangon septemspirosa			17
Fish		6	24
Cyprid (barnacle) larvae	13		
Copepoda	1	1	*
Crustacean larvae	1		1
Cumacea	4	*	*
Polychaete	1	1	*
Misc.	1	*	
Average Contents (mg)	107	48	215
Fish Size (mm)			
mean	114	111	184
range	104-138	91-135	140-258
Sample Location	6E	6C,7D	D
No. Fish Examined	33	36	47

* < 0.5%

Appendix 5.3 (cont'd).

C. Juvenile Salmon Diets

	Diet Composition (% wt) by Species, Date and Location					
	Sockeye	Chum			Coho	Pink
Food Item	1984	July 1984	July 1984	Sept. 1984	1984	July 1984
Euphausiid (Total)	(42)				(1)	
Thysanoessa	19				*	
Misc.	23				*	
Fish (Total)	(36)		(13)	(95)	(93)	
Sand lance	24			67	88	
Misc.	12		13	28	5	
Mysid (Total)	(7)	(18)		(3)	(*)	
Acanthomysis	3					
Neomysis		13				
Misc.	4	5		3	*	
Barnacle Larvae	6				*	1
Insects (Total)	(5)		(31)	(1)	(1)	
Diptera	5		2	*	1	
Coleoptera			18			
Hymenoptera			9			
Misc.			2	*		
Amphipod (Total)		(27)	(20)	(*)	(5)	(39)
Gammarid		10	1		1	8
Corophiid		4	7		1	18
Caprellid		5	1			4
Calliopiid		8	11	*		2
Misc.					3	7
Copepod	*	3	2	*	*	28
Decapod Larvae	1	45	4		1	24
Cumacea	*	6	4		*	4
Crustacea	2					
Polychaete		1	1	*	*	4
Chaetognath	2					
Plant			25			
Average contents (mg)	429	116	29	864	1410	38
Fish size (mm)						
mean	107	82	75	134	129	75
range	90-132	64-108	70-80	114-152	90-111	63-86
Sample sites	misc.[1]	2F	2F	PH[1]	misc.[1]	2F
No. fish examined	30	30	30	20	26	7

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* < .05%

[1] Samples from combined locations and dates (Izemgek Lagoon to Port Heiden, June-Sept, 1984) provided by J. Isakson (Dames and Moore).

Appendix 5.3 (cont'd).

D. Yellowfin Sole Diets

	Diet Composition (% wt.) by Fish Size, Date and Location										
	Small Fish			Large Fish							
Food Item	May 1984	July 1985a	July 1985b	Jan. 1985	May 1984a	May 1984b	May 1985	July 1985a	July 1985b	July 1985c	Sept. 1984
Amphipod (Total)	(81)	(10)	(17)	(4)	(5)	(8)	(1)	(2)	(2)	(1)	(11)
Corophiid	66	3		*	2	6	*		*	*	4
Haustoriid			5				*		*		
Atylid		3	4		*		*	*	*		
Oedicerotid	*		5	3	*	*	*				*
Misc.	15	4	3	*	3	2		2	1	1	7
Polychaete (Total)	(3)	(17)	(5)	(35)	(*)	(46)	(41)	(47)	(7)	(35)	(*)
Errant	*		2	25		34	4	47		1	*
Sedentary			2	9		5	21	*	3	31	*
Misc.	3	17	1	1	*	7	16		4	3	
Decapod (Total)	(1)	(8)	(1)	(27)	(6)	(18)	(13)	(9)	(33)	(8)	(51)
Crangonid			1	27	4	1	7	2	1		
Crangonus dalli							6	6	26		
C. septemspinosa									6	1	19
Pagurid		6				17		*		5	
Misc.	1	2			2	*		1		2	32
Fish (Total)			(73)	(3)		(7)	(2)	(28)			(3)
Sand lance						7					
Larvae			27								
Misc.			46	3			2	28			3
Euphausiid	*			2	9	*	*			4	
Mysid		1		*		1		*	*	*	*
Gastropod	*				*	*				11	
Bivalve (Total)	(8)			(6)	(76)	(1)	(18)	(15)	(17)	(22)	(26)
Macoma				6				2	16	1	
Mussel							8				
Misc	8				76	1	10	13	1	21	26
Echinoderm (Total)	(5)			(1)	(4)	(13)	(11)			(10)	
Echinoid	*				2		6			1	
Sand dollar	5				2	13	5				
Brittle star	*				*					9	
Misc.				1							
Copepod		60	2	*			*				
Cumacea	*		1	*	*	2	1		*	*	
Barnacle larvae		4	*								
Crustacea misc.	1			7	*		*				
Jellyfish								*		9	
Euchurian worm				15							
Isopod		*					8				*
Plant			*				2		39		5
Other	1				2	4	3		2		4
Av. contents (mg)	224	11	67	209	2939	1795	695	413	312	576	260
Fish size (mm)											
mean	115	76	104	212	222	243	251	183	280	290	216
range	101-128	61-90	82-119	144-330	162-287	154-319	152-368	151-245	153-356	207-363	134-330
Sample location	2B,C	D,E	D	A,C	2B,C	6A,C	Misc.	1D,E	6D	X,Y	6D
No. fish examined	18	32	30	25	17	46	33	24	38	28	23

* < .05%.

Appendix 5.3 (cont'd).

E. Rock Sole Diets

Diet Composition (% wt) by Fish Size, Date, and Location

	Small Fish	Medium Fish			Large Fish						
Food Item	May 1984	Jan. 1985	May 1984	July 1985	Jan. 1985	May 1984a	May 1984b	July 1985a	July 1985b	Sept. 1984a	Sept. 1984b
Polychaete (Total)	(22)	(31)	(39)	(71)	(46)	(87)	(44)	(70)	(2)	(79)	(10)
Errant	11	6	4		20	9	31	20		51	4
Sedentary		8		71	24		5	17		20	6
Misc.	11	17	35		2	78	8	33	2	8	*
Amphipod (Total)	(26)	(37)	(52)	(4)	(13)	(3)	(4)	(8)	(2)	(8)	(31)
Corophiid		7	36	3	5	2	2	1		2	30
Oedicerotid		15		*	6			*		*	
Misc.		15	16	1	2	1	2	7	2	6	1
Mysid		6	2	5		*		*		*	
Euphausiid		8	2			*	*	10			
Decapod (Total)			(3)	(1)	(8)	(3)		(*)	(*)	(2)	(8)
<u>Crangon</u> <u>dalli</u>				1	7	3					
Crab								*	*	2	7
Misc.			3		1						1
Echinoderm (Total)		(8)	(*)		(14)	(1)	(12)	(6)		(3)	(5)
Sand dollar					6	1	8				
Urchin		8			8						
Echinoid unident.								5		3	
Ophiuroid							3	1			
Holothuroid							1				2
Copepod	48	3		2	*						
Cumacea		7	1	1		*	*	1		2	*
Fish (Total)									(84)	(1)	(29)
Sand lance									71		
Misc.									13	1	29
Crustacea		*	1		1	1	1	1		*	
Nemertean							8				
Bivalve				15		1	4	3	10	3	16
Flatworm							29				
Sipunculid					7	3					
Echuria					12						
Other	4			1		1		1	2	2	1
Average contents (mg)	5	8	44	27	130	700	2048	650	857	446	447
Fish Size (mm)											
mean	29	75	88	74	187	209	253	236	177	246	221
range	21-41	48-123	53-106	50-100	123-308	140-273	145-326	128-379	132-323	149-340	118-277
Sample location	2B	A,C	2C	D	A,C	2C	6A,7C	A,X,Y	D,E	A	1C
No. fish examined	15	36	28	31	31	10	31	39	13	38	15

* < .05%

Appendix 5.3 (cont'd).

F. Walleye Pollock Diets

Diet Composition (% wt) by Fish Size, Date and Location

Food Item	Small Fish July 1984	Small Fish July 1985	Medium Fish May 1984	Medium Fish July 1984	Medium Fish Sept. 1984	Medium Fish Jan. 1985	Medium Fish July 1985	Large Fish May 1984	Large Fish Sept. 1984	Large Fish Jan. 1985	Large Fish May 1985
Amphipod (Total)	(59)		(2)	(28)	(18)	(16)	(5)	*	*	*	*
Hyperiid					6	4					
Gammarid	11			8	6	*	1				
Caprellid	7			1	*						
Atylid				1		1	3				
Pontogeneia				3							
Corophid	15		1	3	4	*					
Oedicerotid				*		3					
Misc.	26		1	12	2	8	1				
Decapod (Total)	(1)	(15)		(11)	(3)		(14)		(16)		(*)
Larvae	1	15		7			*				*
Crab				*	3						
Crangonid				4			14		14		
Misc.									2		
Mysid (Total)	(6)		(70)	(15)	(2)	(5)	(69)	*			*
Archeomysis grebnitzhii	3		2	2	2						
Acanthomysis psuedomacropsis			11				1	*			
Neomysis czenniawski			13								
N. rayii			11				24				
N. mirabilis				5			10				
Misc.	2		33	8			34				
Euphansiid (Total)			(28)	(*)		(76)		(95)		(100)	(96)
Thysanoessa inermis						16				9	26
T. raschii										7	1
Thysanoessa spp.								95		67	
Misc.						60				16	69
Crustacea	9				11	*			4		*
Larvae		75		*	3		*		1		
Fish (Total)				(45)			(10)	(5)	(77)	(*)	(*)
Larvae				13							
Misc.				32				5			
Cypsia Larvae	1			*	2				*		
Copepod	22			*	56	1	2			*	4
Polychaete				1			*		2		*
Pteropod					1						
Chaetognath					2	1					
Eggs		10									
Misc.	1				1		1				
Average Contents (mg)	4	6	120	160	21	66	14	5100	1383	603	1940
Fish Size (mm)											
mean	45	43	106	99	86	101	148	515	246	479	457
range	37-50	35-48	69-119	82-114	55-120	89-120	133-156	457-682	228-364	455-509	354-579
Sample location	2F	A	misc.	2F	A	A,C	D,E	A	2A	X,Y	A
No. Fish examined	32	40	15	30	33	32	30	30	16	8	21

* < 0.5%

Appendix 5.3. (cont'd).

G. Pacific Cod Diets

Food Item	Diet Composition (% wt) by Fish Size, Date and Location					
	Small Fish	Medium Fish			Large Fish	
	July 1985	May 1984	July 1985	Sept 1984	May 1984	Sept 1984
Fish (Total)			(8)		(54)	(36)
Sand Lance					12	
Sole					12	
Misc.			8		30	36
Decapod (Total)	(3)		(67)	(58)	(25)	(52)
Crangonid			60	26	1	8
Crab					28	13
Pagurid						23
Larvae, eggs	3			32		
Misc.			7	*		7
Amphipod (Total)		(32)	(16)	(8)	(*)	(*)
Lysianissid			5	1		
Atylid			7	2		
Gammarid			2	1		
Misc.		32	2	4		
Mysid (Total)		(62)	(4)	(4)	(*)	(*)
Acanthomysis		30		3		
Misc.		32	4	1		
Euphausiid		2			1	
Crustacea	11			19		7
Larvae	13					
Copepod	72	2		11		
Ostracod		1				
Anemone					7	
Polychaete			1		1	2
Gastropod eggs					7	
Isopod			3	*		*
Plant			1			1
Misc.		1			1	2
Average Contents (g)	0.02	0.16	1.01	0.06	20.9	4.1
Fish Size (mm)						
mean	41	99	191	88	526	394
range	32-54	89-109	143-236	70-115	330-683	324-336
Sample location	A,C	E,C	D,E	misc.	A,C	B,C
No. fish examined	30	5	31	30	13	24

* < .05%

Appendix 5.3 (cont'd).

H. Halibut Diets

Food Item	Diet Composition (% wt) by Fish Size, Date and Location			
	June 1985	July 1985		Sept. 1985
		Small	Large	
Decapod (Total)	(28)	(31)	(7)	(69)
Crab		16		
Cancer			2	40
Telmessus			4	
Oregonia	?		*	1
Hyas	?		1	
Crangonid		7		3
Crangon dalli				14
C. stylirostris		5		
Shrimp (misc.)	28			
Pagurid			*	3
Misc.		3	*	8
Crustacea	9			*
Amphipoda (Total)	(11)	(*)		(*)
Corophiid	1	*		
Calliopiid	1			
Oedicerotid	9			*
Misc.		*		*
Mysid (Total)	(57)	(6)		
Acanthocephala	30	6		
Misc.	21	*		
Fish (Total)		(60)	(71)	(32)
Sand lance			12	
Agonid			4	
Pholis laeta			3	
Halibut		4		
Flatfish			13	
Misc.		56	39	32
Copepod	1			
Cephalopod			19	
Isopod			1	*
Plant		2	*	1
Average Contents (mg)	147	640	28390	5310
Fish Size				
mean	66	138	788	366
range	50- 83	86- 262	610- 1100	210- 900
Sample location	2C,4C	D	misc.	3,4
No. fish examined	17	17	11	21

* < .05%

Section 6

MARINE BIRDS

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Section 6

MARINE BIRDS

6.1 SUMMARY

6.1.1 Distribution and Abundance

Marine birds common in the North Aleutian Shelf (NAS) nearshore zone include shearwaters, gulls, kittiwakes, murres, auklets, sea ducks, and cormorants. Abundance of the various species groups varies seasonally, with shearwaters and kittiwakes most abundant in summer and sea ducks and auklets often more abundant in winter.

Shipboard surveys conducted seaward of about the 20-m depth contour show that some birds were unevenly distributed by water depth. In spring, shearwaters appeared to concentrate between 30- and 60-m depths; murres were most abundant in 30- to 40-m depths. Cormorants, gulls, and ducks were most abundant in shallow waters <30 m deep. In September, the two most common species groups, Short-tailed Shearwater and phalaropes, appeared clumped in the 40- to 50-m zone; murres peaked beyond 60-m depths. In January, the two most common species groups, Crested Auklet and murres, were highly concentrated in the 50- to 60-m zone; sea ducks and cormorants were largely restricted to waters <40 m deep.

6.1.2 Feeding Studies

In shallow (< 50 m deep) nearshore waters of the NAS, diets of the four dominant species of surface-feeding birds (Black-legged Kittiwake, Short-tailed Shearwater, Aleutian Tern, Glaucous-winged Gull) changed radically between spring (May) and summer-fall (July-September) sampling periods. During May, diets were composed largely of euphausiid crustaceans and secondarily of fish (mainly sand lance in 1985). By July, and continuing into September, all surface-feeding birds that we collected had switched to fish, primarily sand lance.

These results are surprising for two reasons. First, they contrast in some ways with the results of others studying seabirds, many of the same species, at other southeastern Bering Sea locations that were primarily deeper and farther offshore; in these studies walleye pollock was the dominant fish prey. Second, we found virtually no salmonid prey in the diets of surface-feeding birds, even though very large numbers of the smolts of salmonids are reported to pulse through our study area annually.

Diets of the three dominant species of water-column-feeding birds (Thick-billed Murre, Common Murre, and Red-faced Cormorant) were composed almost entirely of fish, with sand lance comprising well over 95% of the identifiable prey from samples collected in waters shallower than 50 m. Similarly to diets of surface-feeding birds, these results contrast with those of others studying seabird food habits in deeper waters of the southeastern Bering Sea (in the middle domain near St. George Island and close to the shelf break community), where walleye pollock was the dominant fish prey. Walleye pollock otoliths were abundant (over 2000) only in stomachs of birds (8 murres) taken at a relatively deep station (70 m).

Diets of the six species of sea ducks (Steller's and King eiders, White-winged and Black scoters, Oldsquaw, Harlequin Duck) that feed on benthos were largely bivalve molluscs, but amphipod crustaceans and echinoderms also were strongly represented during some periods. Several species appeared to specialize in preying on specific taxa (e.g., Harlequin Duck on gastropod molluscs and scoters on bivalve molluscs). Other species appeared to feed on several different taxa (e.g., Oldsquaw on crustaceans, fish, and molluscs; King and Steller's eiders on bivalve molluscs during the molt period in September and on molluscs and crustaceans during May and July).

6.2 INTRODUCTION

The Bering Sea supports a bird community of immense proportions that includes large numbers of pelagic birds (an estimated 40 million; Hunt et al. 1981b), major seabird breeding colonies (see Fig. 6.1), and concentrations of migrant, staging, and molting waterfowl (King and Dau 1981) and shorebirds (Gill et al. 1981). The region is of ornithological importance not only because of the large numbers of individual birds involved, but because these concentrations represent at times the entire Alaskan or even world populations of several taxa (e.g., Short-tailed

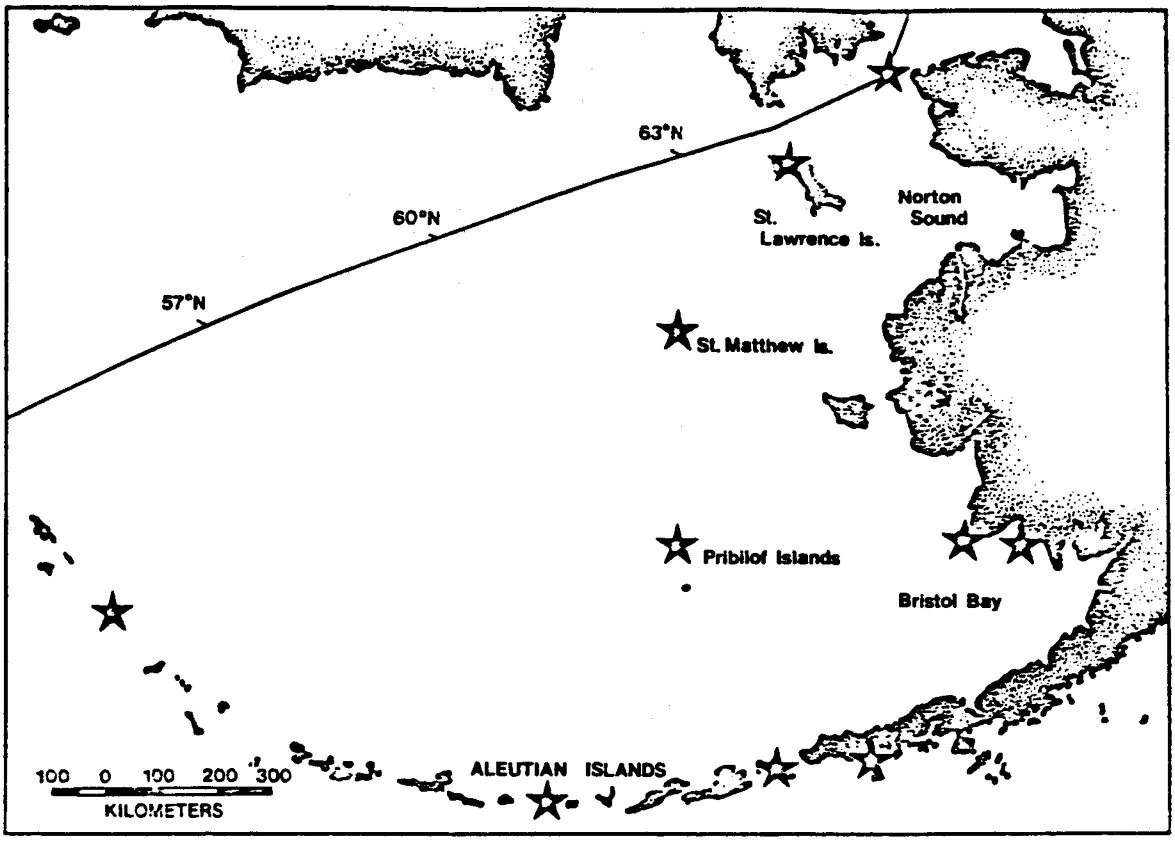


Figure 6.1. Major breeding concentrations (more than 500,000) of seabirds in the Bering Sea. From Lewbel (1983).

Shearwater, Western Sandpiper, pacifica Dunlin, nigricans Brant, Emperor Goose, and Bar-tailed Godwit). Gill and Handel (1981) considered the northern coast of the Alaska Peninsula to be the most extensive and diverse expanse of intertidal shorebird habitat along the Pacific coast of the Americas. Feeding seabirds (especially shearwaters, kittiwakes, and murres) rely on the nearshore zone (<50 m) of Bristol Bay and the Alaska Peninsula, and on the oceanic front associated with the shelf break (Pace 1984).

A considerable volume of research, much of it sponsored through the OCSEAP program, has described the distribution and abundance of birds in the southwestern Bering Sea as a whole. Locally detailed study has been made of the lagoon systems along the north side of the Alaska Peninsula, most notably Izembek and Nelson lagoons. These lagoons are both known to be quite important to birds, especially Brant, Steller's Eider, scoters, and shorebirds, though the specific use of the two lagoons differs. The

Table 6.1. Seabird colonies of the North Aleutian Shelf study area. Values listed are the most representative estimates as listed in the FWS seabird colony data base (USFWS 1986). Asterisks denote possible nesting species or unknown population size.

Colony Number Colony Location	29-001 N. Isanotski Island	29-002 Amak Island	29-003 Sealion Rock	29-005 Birdsall Island	28-041 Dowitcher Island	28-042 Lagoon Point	28-043 Unnamed Is. e. of Lagoon Pt.	28-044 Walrus Island	28-045 Gull Island
Fork-tailed Storm Petrel		*							
Cormorant									
Double-crested Cormorant							20		
Pelagic Cormorant		2							
Red-faced Cormorant		2952							
Common Eider							400		
Glaucous-winged Gull	191	150					12600		100
Mew Gull					300				
Black-legged Kittiwake		3570	74						50
Arctic Tern				*		1000		80	
Aleutian Tern				*					
unidentified murre		6536	2300						
Common Murre		*	*						
Thick-billed Murre		*	*						
Pigeon Guillemot		10							50
Horned Puffin		150							50
Tufted Puffin	1600	3	50				30		
TOTAL	1791	13373	2424	0	300	1000	13050	80	250

offshore waters of the Bering Sea have been the focus of considerable research, both through OCSEAP-sponsored reconnaissance programs and integrated multidisciplinary studies such as PROBES.

The following discussions focus on the abundances, distributions, trophic interactions, and population limiting factors of common species in marine habitats within the 50-m isobath. In keeping with the objectives of this project, birds largely restricted to bays and lagoons, or to waters beyond the 50-m isobath, will not be addressed.

Abundances of seabirds at colonies within the study area are summarized in Table 6.1. Although major colonies exist in coastal areas

Table 6.1. (Continued)

SPECIES/LOCATION	28-046 Entrance Point	28-047 Left Triangle	28-049 Unnamed Island	28-051 Cannery Islands	28-052 Kudobin Islands	30-002 Cape Seniavin	30-003 Unnamed Cape	TOTAL
Fork-tailed Storm Petrel								0
Cormorant						1700	100	1800
Double-crested Cormorant			60					80
Pelagic Cormorant						*		2
Red-faced Cormorant						*		2952
Common Eider					*			400
Glaucous-winged Gull		50	200	400	*			13691
Mew Gull								300
Black-legged Kittiwake			*			3500	100	7294
Arctic Tern	400			0-1000	*			1480
Aleutian Tern	600							600
unidentified murre								8836
Common Murre						500	100	600
Thick-billed Murre								0
Pigeon Guillemot								60
Horned Puffin								200
Tufted Puffin		100						1783
								0
TOTAL	1000	150	260	400	0	5700	300	40078

of the southern Bering Sea (e.g., Cape Newenham), few colonies of appreciable size are found within the area in which sampling was conducted for this study. The major breeding seabirds in the area are Glaucous-winged Gull, murres (both species but presumably Common Murres predominate), Black-legged Kittiwake, Red-faced Cormorant, and Tufted Puffin. The most numerous breeding species in the study area, with approximately 14,000 nesting birds, is Glaucous-winged Gull. Cliff-nesting species such as murres and Black-legged Kittiwakes are relatively uncommon, with total breeding populations on the order of 7,000-9,000 birds. The major cliff colonies are at Amak Island and Cape Seniavin.

Marine birds common in the NAS study area include representatives of five major taxonomic groups: (1) shearwaters and fulmars (family Procellariidae), (2) cormorants (family Phalacrocoracidae), (3) seaducks (family Anatidae), (4) gulls and terns (family Laridae), and (5) murres, murrelets, auklets, and puffins (family Alcidae).

Very little work on seabird feeding ecology has been done in the waters offshore from the bays and lagoons of the Alaska Peninsula but nearshore from the 50-m depth contour. Most of the published information on marine bird feeding in the southeastern Bering sea is based on OCSEAP and PROBES studies conducted near the Pribilof Islands and along transects well north of our NAS study area (see references in Hunt et al. 1981a,d and Schneider et al. 1986). Much of the seabird sampling conducted during those investigations was directed towards pelagic species; nevertheless, systematic sampling was also conducted in the inner domain waters south of Cape Newenham. Other work (see references in King and Dau 1981, Gill and Handel 1981, and Petersen 1981) was focused on the bays and lagoons along the north side of the Alaska Peninsula. Arneson (1980) flew several surveys the length of the Alaska Peninsula. He found large concentrations of birds (mostly geese and ducks) in the estuaries during spring and fall, and seaducks in protected areas (estuaries and lagoons ?) during winter. His only mention of bird concentrations in our area of interest were of shearwaters during summer off the southern end of the peninsula and gulls along exposed beaches during winter.

6.3 CURRENT STATE OF KNOWLEDGE

6.3.1 Northern Fulmar (Fulmarus glacialis)

The Northern Fulmar occurs year-round in the study area. The eastern Bering Sea population is estimated to be near one million and is highly concentrated at a few breeding locations (Sowls et al. 1978). All but a few thousand breed in three areas: Chagulak Island in the Aleutians, the Pribilof Islands, and St. Matthew/Hall islands. No Northern Fulmars nest in the North Aleutian Shelf study area. Northern Fulmars at sea during the summer are concentrated along the shelfbreak and outer shelf near the Pribilof Islands and south to Unimak Pass (Fig. 6.2), often in close

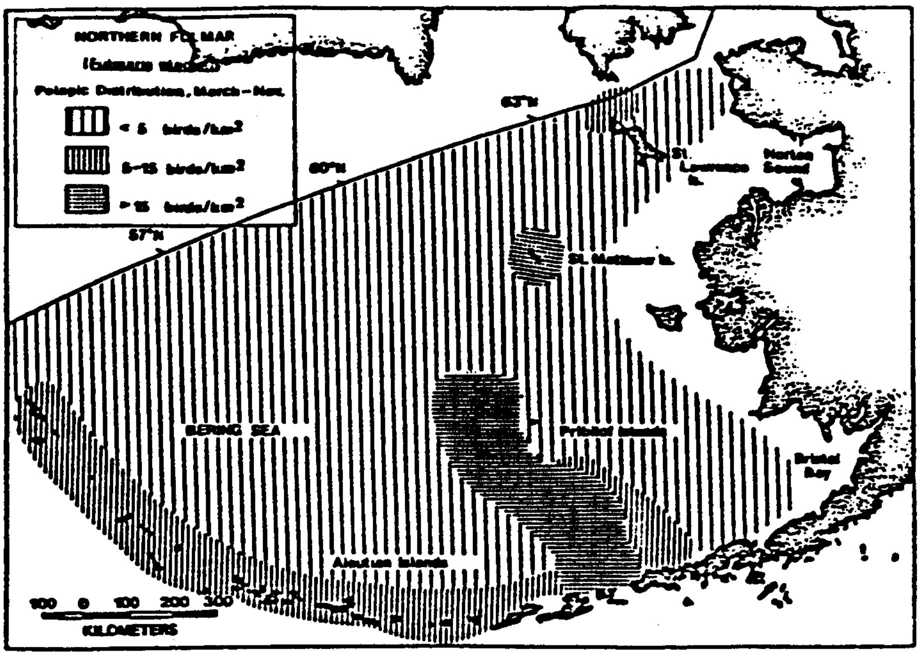


Figure 6.2. Pelagic distribution of Northern Fulmars in the Bering Sea, March-November. From Lewbel (1983).

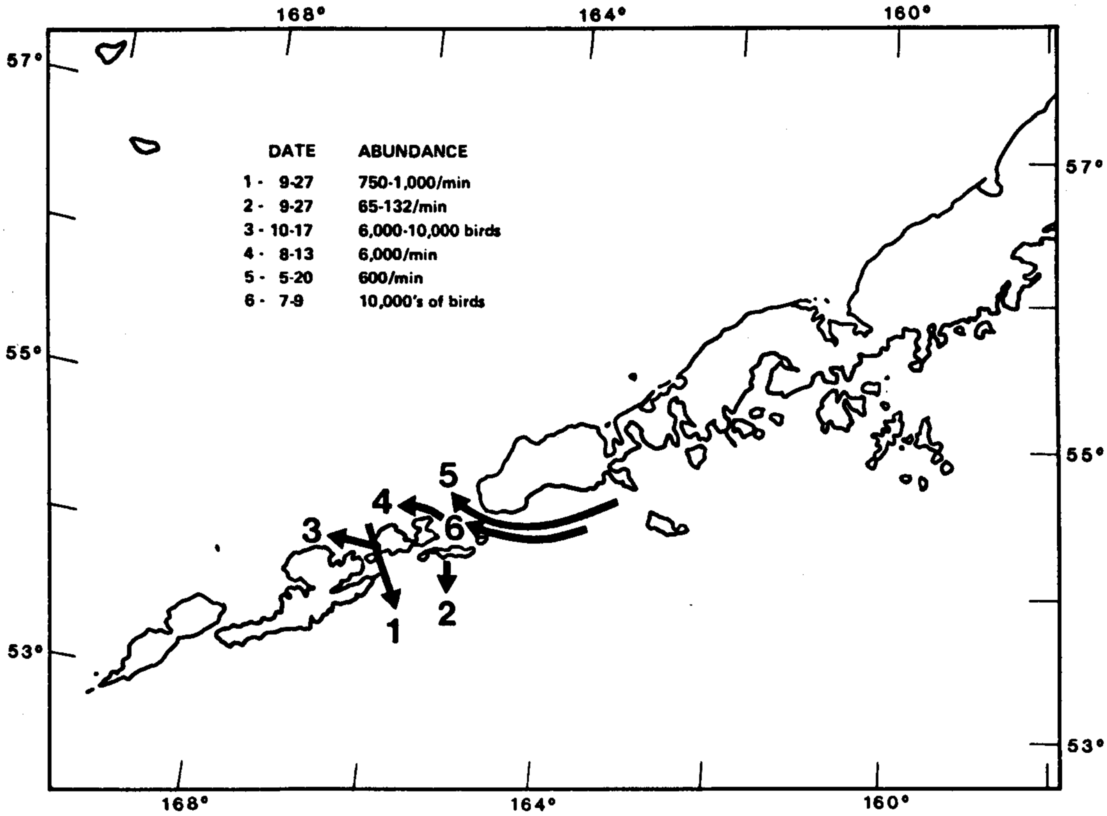


Figure 6.3. Distribution of flying flocks of 10,000 or more shearwaters observed in the eastern Aleutian Islands. From Strauch and Hunt (1982).

association with fishing fleets. They are markedly less common in the shallow waters of Bristol Bay and the inner shelf (Hunt et al. 1981d). In winter, most Northern Fulmars leave the Bering Sea for the North Pacific; however, some are still present in ice-free waters north and west of the Pribilof Islands and towards Unimak Pass.

Northern Fulmars feed by surface-seizing (Ashmole 1971). They prey on cephalopods, crustaceans, and fish. Northern Fulmars have become habituated to scavenging fish offal from fishing vessels as a major food source (Hunt et al.1981d).

6.3.2 Short-tailed Shearwater (Puffinus tenuirostris)

Both the Short-tailed and Sooty shearwaters (P. griseus) occur in the study area but the former is much more numerous (perhaps 90% of the total in the Bering Sea as a whole). The two species are not always differentiated during pelagic surveys and thus specific areas of abundance of each species are difficult to delineate. In general it appears that Sooty Shearwaters are most abundant in the Gulf of Alaska whereas Short-tailed Shearwaters predominate within the Bering Sea. There is a zone of overlap in the southern Bering Sea and both species are known to occur in our area of interest. Reported densities and distributions of "pelagic shearwaters" in the Bering Sea, in which species are not named, are assumed to refer mostly to the Short-tailed Shearwater.

From June through September the Short-tailed Shearwater is the most abundant species in the Bering Sea; at this time approximately 8-10 million are thought to occur in the area (Hunt et al. 1981a). Large aggregations of this species (over 10,000) have been found in Unimak Pass from mid-May through late October (Jaques 1930, Gould 1982). They are typically found over the continental shelf, with only moderate numbers occurring over the shelf break. They are concentrated in the coastal domain, near and within the 50-m isobath. Concentrations of over 1,000,000 shearwaters have been recorded feeding in Unimak Pass in July. Large movements have been recorded through Unimak Pass, Baby Pass and Derbin Strait (Trapp 1975) (Fig. 6.3). Passage of Short-tailed Shearwaters between the Pacific Ocean and Bering Sea is widespread; however, the area between Akutan Pass and Amak Island appears to be the most heavily visited region in Alaskan waters (Guzman 1981, Guzman and Myres 1982). Really high numbers of Short-tailed Shearwaters (up to 1,000,000) have been reported only from the Unimak Pass area and the waters northeast of Unimak Island (Byrd 1973, Guzman and Myres 1982). Late summer concentrations occur in northeastern Unimak Pass/Akun Bay. The Akun Bay area was also found to harbor large numbers of shearwaters on 20 October 1981, with estimates ranging from 8-84 million (USFWS memorandum, 12 January 1982).

Shearwaters feed mainly by pursuit diving but also by surface seizing (Hunt et al. 1981a). They probably feed entirely within the upper 5 m of the water column (Sanger 1972). In the Kodiak Island area, Short-tailed Shearwaters feed mostly on euphausiids, fish (capelin and osmerids), and squid (Sanger et al. 1978). In the Bering Sea euphausiids are important prey in summer (70%), while in fall the hyperiid amphipod <u>Parathemisto libellula</u> is taken extensively (60%), with cephalopods and fish used both seasons (Hunt et al. 1981a). Sooty Shearwaters appear to depend more heavily on fish and squid at all times during their stay in Alaska (Sanger et al. 1978). As is probably the case with many seabirds, shearwaters can be opportunistic. In the Kodiak area in spring and summer 1977, Sanger et al. (1978) found both species eating capelin, which were apparently extremely abundant in the area.

A striking feature of shearwater distribution in the Bering Sea is its patchiness; flocks of over 100,000 birds are often reported (Hunt et al. 1981a). Schneider (1982) and Hunt et al. (1982) found shearwaters to concentrate along the inner front of the southeastern Bering Sea, presumably in response to prey concentrations. Brown (1980) points out that it is characteristic of many seabirds elsewhere to congregate on shoals to feed on euphausiids. The implications of this are that places where prey (euphausiids and perhaps fish or squid) concentrate are also apt to be areas of concentration for shearwaters on the NAS. Little investigation of this phenomenon has taken place.

It is not known what regulates populations of shearwaters. Straty and Haight (1979) note that people harvest shearwaters in the southern hemisphere. Large-scale mortalities (of uncertain magnitude) of shearwaters in the Bering Sea have recently been reported. Major die-offs of first-year shearwaters have occurred as they pass Japan on their first northbound migration. Another source of mortality has been entanglement in nets of North Pacific fisheries. This latter source may take hundreds of thousands of birds annually.

6.3.3 Red-faced Cormorant (Phalacrocorax urile)

Red-faced Cormorant, Pelagic Cormorant (P. pelagicus), and Double-crested Cormorant (P. auritus) all occur in the area of interest, but Red-faced Cormorant predominates. Nelson (1976) estimated that the three species occurred in a 6:2:1 ratio at Unimak Island during the fall. The seabird colony catalogue (Table 6.1) shows the ratio in the NAS to be 1476:1:40; however, many nesting cormorants are unidentified to species. Red-faced Cormorants nest on cliffs; in the Pribilofs they are restricted to portions of cliffs less than 200' (Hickey 1976, Troy and Baker 1985). Virtually all cliffs in the NAS fall within this range.

Red-faced Cormorants are probably year-round residents through most of their range. Cormorants are generally found within a few kilometers of their colonies, especially in summer but also in winter if open water remains available (Hunt et al. 1981a), as it usually does in the NAS study area. Two main nesting concentrations of cormorants exist in the study area--one near Cape Seniavin and the largest on Amak Island (Table 6.1)--and it is near these locations that the birds are likely to forage in nearshore marine waters. A southward movement of cormorants, predominantly Red-faced, was recorded through Unimak Pass from 7 April to 26 May 1976 (Nelson and Taber, FWS, unpubl. data). Gill et al. (1979) thought it unlikely that this was the result of cormorants wintering in the Bering Sea, but our surveys (this report) suggest that cormorant densities in northern Unimak Pass may peak during mid-winter.

Cormorants feed near shore and are most numerous within a few km of their breeding colonies during the nesting season. A few are seen in small numbers in the open ocean during spring and fall (Hunt et al. 1981d). Their feeding method is pursuit-diving (Ashmole 1971). Fish are the primary prey, but decapods (shrimp and crab) and amphipods are also eaten. Sculpins appear to be the most frequently taken fish. The cormorants appear to be restricted to foraging near the bottom (Hunt et al. 1981a) and consequently are generally close to land.

The numerous incidental observations of cormorants have not been pieced together to form a reasonable overview as to what controls their populations. It is known that the Red-faced Cormorant invaded Prince William Sound in the Gulf of Alaska and became the dominant breeding cormorant between 1959 and 1976, indicating that some controlling factor was altered.

6.3.4 King Eider (Somateria spectabilis)

At least 90% of the estimated two million King Eiders in North America utilize habitats within the Bering Sea at some time of the year (King and Dau 1981). The greatest numbers of King Eiders occur in the Bering Sea during spring and fall migrations, when they migrate through the area. The primary nesting areas are located along the arctic slopes of North America, Europe, and Asia. None nest near the study area (Bellrose 1976) (Fig. 6.4).

Adult males move to salt water molting areas soon after egg-laying, as do the subadults. Molting congregations for many North American and Siberian birds probably occur in the Chukchi Sea in late summer. In fall and winter there are gradual movements of the birds south into the Bering Sea in association with the movements of pack ice (Palmer 1976).

In spring, large rafts of King Eiders congregate in bays and lagoons along the western end of the Alaska Peninsula. For example, between late March and May 1964, the refuge manager from Izembek NWR counted 50,000 King Eiders at Ugashik Bay, large rafts from Moffett Lagoon to Nelson Lagoon, 20,000 in Kululak Bay, 22,000 in Port Moller, 10,000 at Cinder River Lagoon, and 10,000 in Port Heiden (Palmer 1976). From here they pass northward, following leads in the ice pack and the coastline of western Alaska.

Except during the nesting season, King Eiders are found in marine habitats. They occur in shallow coastal waters wherever their main food item, mollusks, occur. Bivalve mollusks, along with crustaceans and echinoderms, provide the bulk of the diet in marine waters (Cottam 1939).

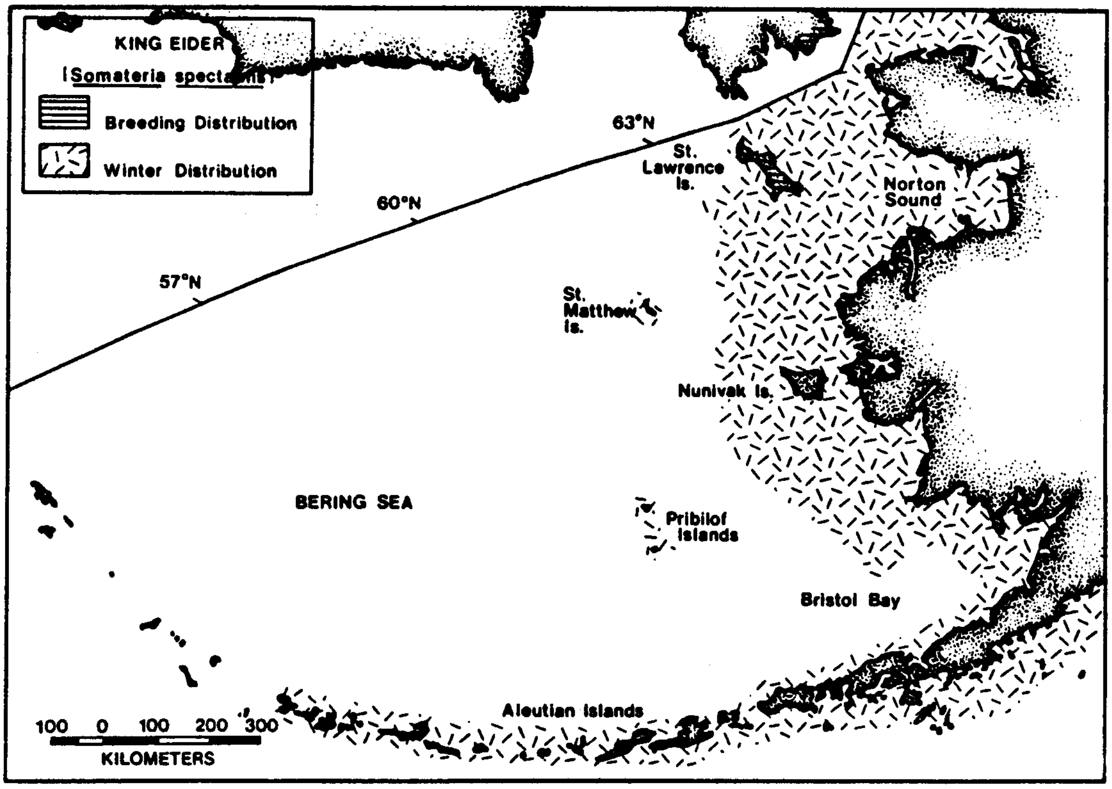


Figure 6.4. Breeding areas and winter distribution of King Eiders in the Bering Sea region. From Lewbel (1983).

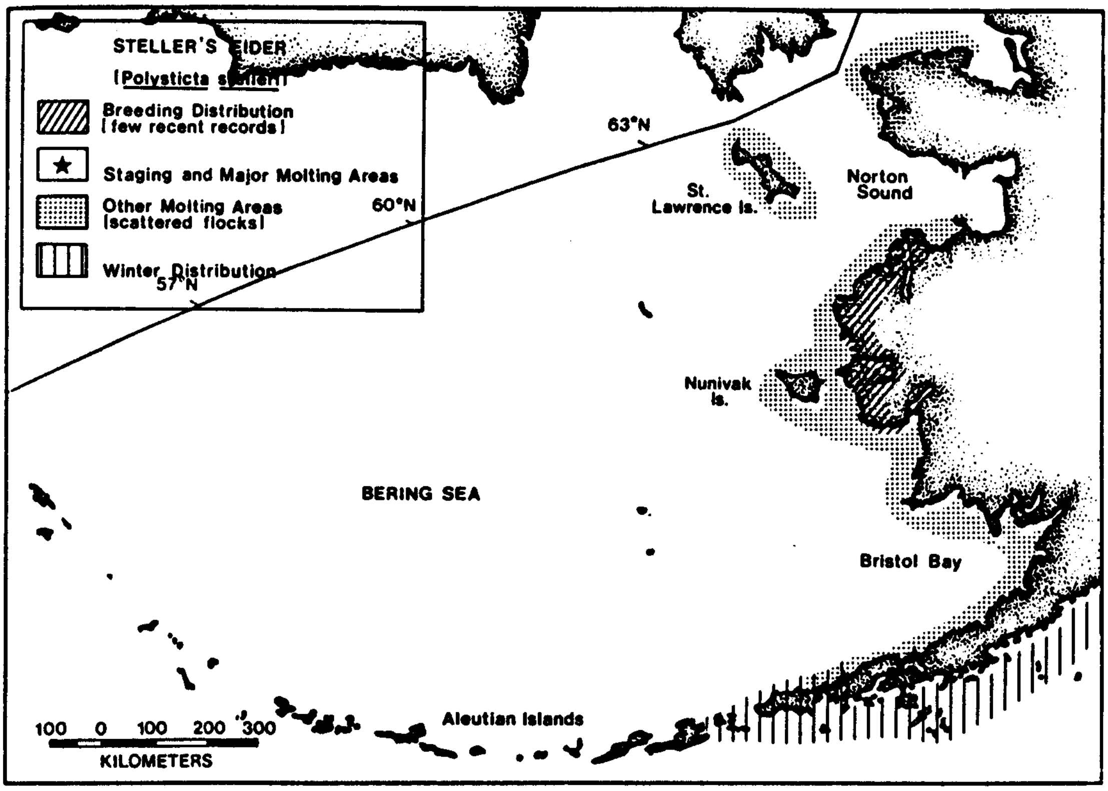


Figure 6.5. Former breeding area, molting areas, and winter distribution of Steller's Eiders in the eastern Bering Sea region. From Lewbel (1983).

6.3.5 Steller's Eider (*Polysticta stelleri*)

Steller's Eiders are most commonly sighted in the Bering Sea during the fall and winter months. The historical breeding range included the Yukon-Kuskokwim Delta and St. Lawrence Island (Fay and Cade 1959, Gabrielson and Lincoln 1959), but the primary nesting areas are now restricted to northern Siberia (Kistchinski 1973). Some Steller's Eiders still nest in widely scattered locations along the coast of northern Alaska.

Steller's Eiders occur in huge flocks during the spring and fall in the lagoons of Bristol Bay and the Alaska Peninsula (Fig. 6.5) (King and Dau 1981). The greatest concentrations occur at Izembek and Nelson lagoons (Petersen 1980). Up to 100,000 Steller's Eiders, mainly subadult and adult males, occur in Nelson Lagoon between early August and late September. Adult females molt primarily in Izembek Lagoon, but in lesser numbers than the males and subadults molting elsewhere (Petersen 1981). Following the molt, Steller's Eiders move to wintering areas along the Alaska Peninsula (to Kodiak Island), in the eastern Aleutian Islands, and in lower Cook Inlet (Jones 1965, King and Dau 1981). In the spring, concentrations again occur in bays and lagoons along the north side of the Alaska Peninsula and along coasts of Bristol Bay, before the major movements to northern nesting areas occur.

Off the breeding grounds, Steller's Eiders are found in marine areas, inhabiting shallow water areas along coasts. They feed primarily on bivalves (especially the blue mussel *Mytilus edulis*) and other invertebrates; including amphipods, polychaete worms, pycnogonids, and nudibranchs (Peterson 1980).

6.3.6 Scoters

All three species of scoters are common seaducks in the Bering Sea. Black Scoters (*Melanitta nigra*) nest on tundra ponds and lakes, primarily in coastal areas from Unimak Island to the Bering Strait region. Surf (*M. perspicillata*) and White-winged (*M. fusca*) scoters breed on boreal lakes and ponds in the interior of Alaska (Fig. 6.6). All three species migrate through, and molt in, coastal areas in the Bering Sea. In the winter,

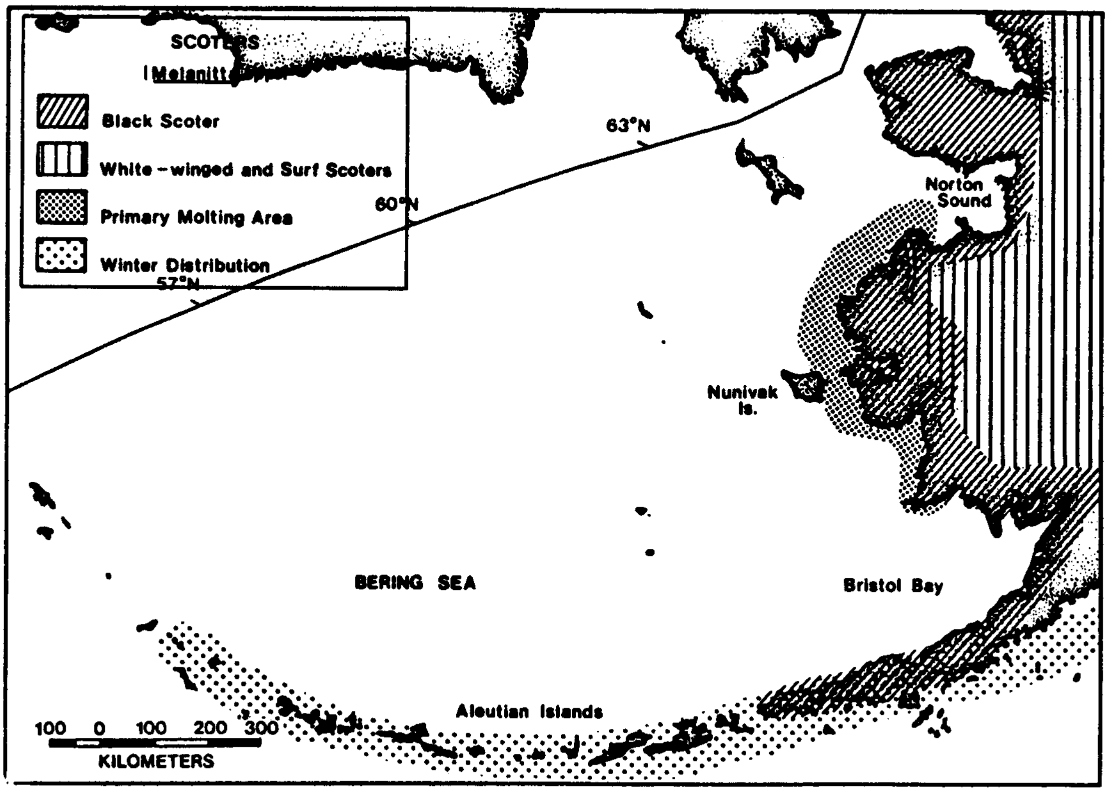


Figure 6.6. Distribution of scoters in the eastern Bering Sea region. From Lewbel (1983).

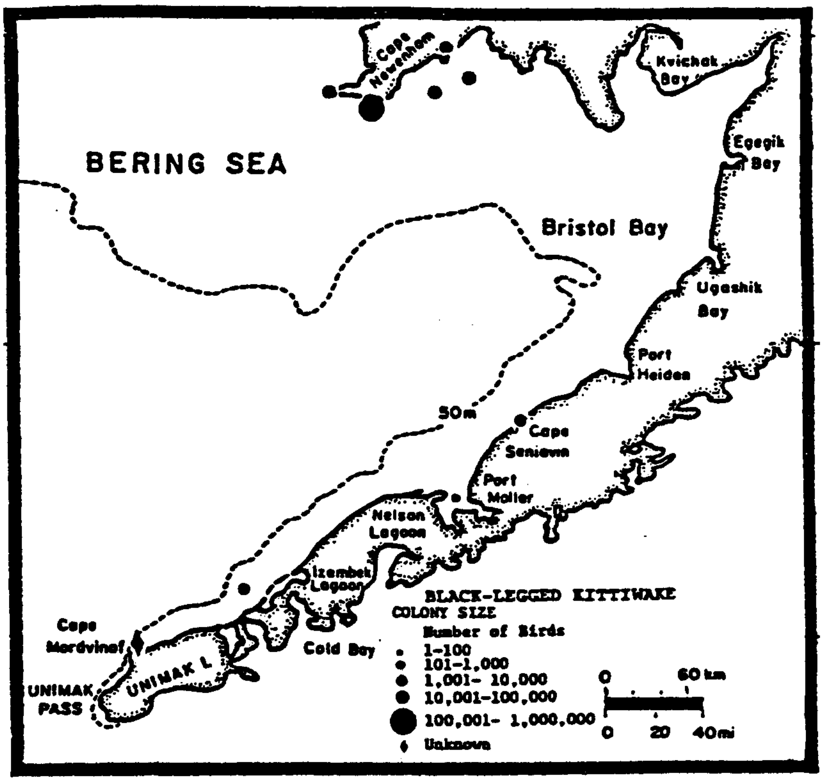


Figure 6.7. Black-legged Kittiwake colonies in the southeastern Bering Sea. From Hunt et al. (1981c).

most scoters retreat to more southern areas along the Pacific coast, but several hundred thousand winter in the eastern Aleutian Islands and along the southern Alaska Peninsula (Murie 1959).

Scoter numbers are inprecisely known due to their dispersed and/or remote breeding and wintering areas. Numbers in the Bering Sea, and the percent that represents of the total North American populations, are estimated at 489,000 (50%) for Black Scoters, 116,000 (25%) for Surf Scoters, and 401,000 (33%) for White-winged Scoters (King and Dau 1981).

Little is known about the nesting biology of Black Scoters because nests are very difficult to locate and are often not initiated until late June or July, when other waterfowl young are hatching. As a result, few field biologists searching for waterfowl nests encounter those of this species. Black Scoters usually lay 5-8 eggs which hatch in late July or early August (Shepherd 1955, Dick and Dick 1971, Gill et al. 1981). Little information exists on brood dispersal, but ducklings are likely raised on lakes, rivers, and estuaries near their natal ponds. Molting areas of scoters in the Bering Sea have only recently been identified (though incompletely) by C.P. Dau (presentation to Alaska Migratory Bird Conference, Anchorage, 15-18 March 1982). Surveys in nearshore waters off the Yukon-Kuskokwim Delta indicated tens of thousands of molting scoters, primarily Surf Scoters from mid-July to mid-August, and Black Scoters from mid-August to mid-September. White-winged Scoters were found in consistently lower numbers throughout the molting period. Waters off the Yukon-Kuskokwim Delta thus appear to be a major molting area of scoters. Molt migration of scoters westward past Cape Peirce in July and August indicate that birds breeding in areas other than the Yukon-Kuskokwim Delta also move there to undergo molt (Dick and Dick 1971). Migration routes are little known; however, birds molting in the Bering Sea probably make the relatively short flight to and from wintering areas in the Aleutians and adjacent Pacific coast on a gradual basis.

Scoters, like most seaducks, are bottom feeders, and although they have phenomenal diving abilities, most birds feed in shallow waters (<25 m) (Palmer 1976). Foods of scoters at sea consist mainly of mollusks (clams and mussels), crustaceans, echinoderms, other marine invertebrates, some marine algae, and other plants (Cottam 1939, Palmer 1976).

6.3.7 Glaucous-winged Gull (Larus glaucescens)

The summary in Table 6.1 shows Glaucous-winged Gull to be one of the most numerous seabirds encountered in the study area. Their abundance varies seasonally; peak densities occur in summer and fall, at least in coastal areas. About 13% of the Alaska population of nesting Glaucous-winged Gulls occurs between Cape Newenham and Unimak Pass. Glaucous-winged Gulls are important in the NAS study area because the largest colony in Alaska is located at Nelson Lagoon, where 13,000 gulls nest. This and several smaller colonies make Glaucous-winged Gull the most numerous breeding colonial bird in the study area.

Glaucous-winged Gulls are omnivorous and are opportunistic foragers. Their diet includes a variety of intertidal organisms, fish, garbage, offal, and other prey. Most foraging occurs in nearshore habitats, especially during the breeding season, but this species is often encountered quite far offshore, well beyond the limits of our study area. Because of its opportunistic foraging behavior, the Glaucous-winged Gull is prone to great geographic variability in its diet. In the western Aleutians, Glaucous-winged Gulls specialized on whatever species was abundant and vulnerable; prey selection varied among invertebrates (sea urchins), fish, and seabirds, depending on the location, tide state, and (presumably in the case of seabirds) the season (Trapp 1979, Irons et al. 1986). The relative use between fish and invertebrates was partially dependent on whether sea otter populations were sufficiently large that they reduced macroinvertebrate numbers and made them less available to the gulls.

Gulls tend to be quite adaptable to variations in their environment but this does not imply that extrinsic factors do not regulate their populations. Gull colonies vary markedly in their productivity and a large colony such as exists in Nelson Lagoon would need a close, abundant source of food to fledge very many chicks. Further, Hatch et al. (1978) found egging activity by humans to reduce hatching success at the Nelson Lagoon colony to 3.9%. Many gull populations have increased markedly in size in recent decades, indicating that some previously limiting factor has been relaxed. [Gull populations have not been monitored in Alaska or on the NAS to document such a population growth, but expanding populations have been noted in many other areas of North America]. Presumably the greater availability of food associated with municipal dumps, canneries, and fishing fleets have aided gulls but how this affects their populations--e.g., enhanced winter survivorship or greater reproductive output--is unknown. Part of the initial increase in gull populations this century was probably due to reduced mortality of adults caused by the termination of gull harvests that were conducted to provide feathers for the millinery trade.

6.3.8 Black-legged Kittiwake (*Rissa tridactyla*)

Black-legged Kittiwakes are circumpolar in distribution and are numerous in the eastern Bering Sea, with a minimum breeding population estimated at 750,000 (Sowls et al. 1978). From Unimak Pass to Cape Newenham, the breeding population is estimated to be in excess of 490,000 birds. Most of these cluster near Cape Newenham (Hunt et al. 1981c). In the NAS study area, the Black-legged Kittiwake has a population estimated to be in excess of 7100 birds; it is the third most numerous breeding marine bird in the area.

The breeding distribution of Black-legged Kittiwakes in the Bering Sea is depicted in Fig. 6.7, The pelagic distribution during all seasons may be characterized as low-density and dispersed. In the southern sector of the Bering Sea, Hunt et al. (1982) described a tendency for higher densities between the 100-m isobath and deeper waters of the shelfbreak, and for lower densities between the 50- and 100- m isobaths. Despite the low densities, the vast area occupied by kittiwakes translates into large numbers of birds. Population indices derived from aerial and shipboard censuses indicate the presence of 1-3 million kittiwakes in summer and 3-4.5 million in fall over the eastern Bering Sea (Gould et al. 1982). In summer, kittiwakes seem no more abundant nearshore than offshore, despite the coastal locations of their nesting colonies (Bartonek and Gibson 1972); in fall they are apparently more abundant in the middle and outer domains of the Bering Sea (Hunt et al. 1981d).

In winter, most Black-legged Kittiwakes leave the Bering Sea (Armstrong et al. 1984), although they still occur in low densities north of the Aleutians, on the shelfbreak, and in oceanic waters north of the

Pribilofs. Kenyon (1949) reported few in the Gulf of Alaska and northeastern Pacific in winter, but they become more common in winter along the California coast and over a broad zone of deep oceanic water south of the Aleutians. Gould et al. (1982) described kittiwakes as virtually absent from shallow waters of Bristol Bay in winter, but present in "fair numbers" over shelfbreak and oceanic waters. Probably most of the kittiwakes breeding in colonies in the Bering Sea concentrate in the western portion of their major wintering area south of the Aleutians.

Northward displacement of kittiwakes begins in mid-March, with intensive movements occurring through straits of the eastern Aleutian ridge in April. Fall migration through Unimak Pass occurs from the middle of September and into late October (Nelson 1976), at which time there is a broad and gradual movement of the eastern Bering Sea population from breeding colonies to wintering areas south of the Aleutians.

Kittiwakes feed on or near the water surface (Hunt et al. 1981b), primarily by dipping; however, surface-seizing and occasionally shallow pursuit-diving are also employed (Hunt et al. 1981a). Fish are the primary prey, but crustaceans (euphausiids, amphipods) and cephalopods are also consumed. Off the Pribilof Islands, the most important prey species is apparently walleye pollock, but capelin, sand lance, and myctophids are also preyed upon. In other regions sand lance and capelin predominate over pollock as principal prey items (Hunt et al. 1981a).

The breeding distribution of kittiwakes is restricted by the availability of suitable nesting cliffs. Productivity and the capacity of populations to expand is apparently influenced by short- and long-term changes in weather and oceanographic conditions that in turn regulate the availability of food to the kittiwakes. Unusually cold waters in foraging areas seem to depress reproduction (Springer et al. 1982). During years when prey availability is poor, productivity at the nesting cliffs may be very low, because of fewer nests, smaller clutch sizes, and greater egg mortality (Hunt et al. 1981c). Even though adults are long-lived, several successive years of poor food supply and reproductive failure may cause significant population reductions.

6.3.9 Murres

Both species of murre, Common (Uria aalge) and Thick-billed (U. lomvia), are abundant and widespread in the southeastern Bering Sea. Both occur in the study area throughout the year, and both nest there in summer. Common Murres appear to predominate in the NAS. The two species differ in many aspects of their biology and distribution; it is unfortunate that a great many studies could not, or did not, use methods that would distinguish between them. In this discussion we have to treat them as a group.

The eastern Bering Sea supports a minimum of 5.3 million breeding murres (Sowls et al. 1978). In general, Common Murres predominate at the mainland colonies of the Bering Sea, and Thick-billed Murres predominate in the Aleutian, Pribilof, and other offshore Islands (Fig. 6.8). Between Cape Newenham and Unimak Pass, the breeding population of murres exceeds 1,300,000 birds, of which more than 1,000,000 are Common Murres; most are clustered at Cape Newenham colonies and are thus outside the NAS study area. Within the NAS study area the known breeding population is approximately 9300 birds. Most of these birds occupy the colonies at Amak Island and Sea Lion Rock (over 8800 birds). Although both species are known to be present, estimates of their relative abundance have not been made.

Murres are most common over the continental shelf. In the spring they occur in areas of open water, but begin to aggregate on waters near the colonies in late March and April (Hunt et al. 1981b). In the summer they are concentrated around the major breeding colonies. In the fall they again disperse over the continental shelf from the Gulf of Anadyr to Bristol Bay. Their numbers appear to increase in the eastern Aleutians and Unimak Pass during the fall. They may remain in northerly areas of the Bering Sea until forced south by advancing ice. They are the most abundant seabirds wintering in the Bering Sea. The pelagic distribution of murres in winter is shown in Fig. 6.9.

A substantial number of the Bering Sea breeders migrates through Unimak Pass in spring and fall between the Bering Sea and the Gulf of Alaska (Nelson 1976). The spring migration through Unimak Pass into the Bering Sea commences in late March, peaks in late April, and continues

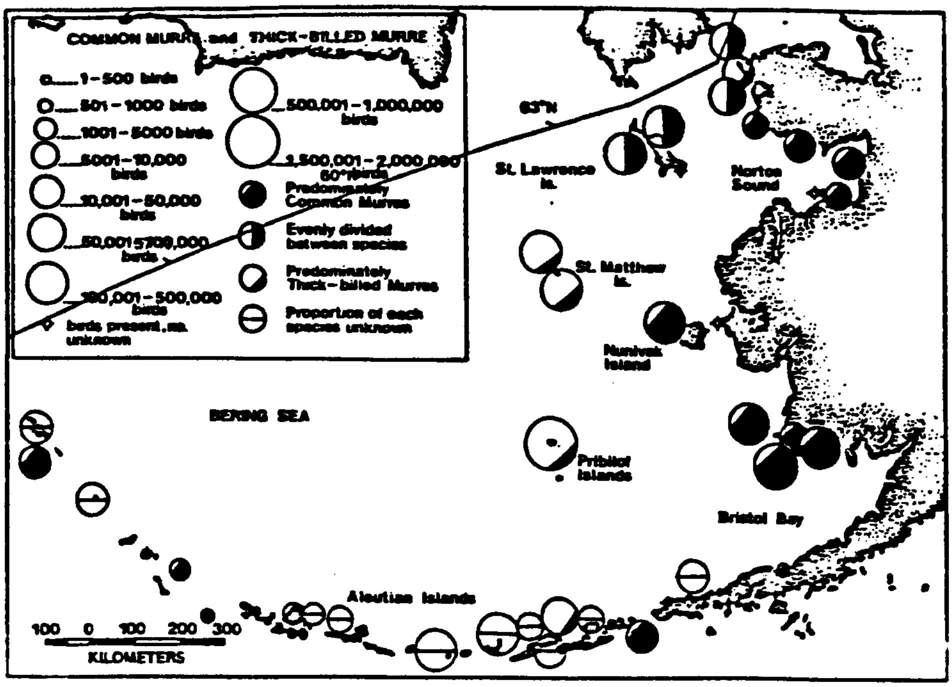


Figure 6.8. Breeding distribution of Common and Thick-billed murres in the Bering Sea. From Lewbel (1983).

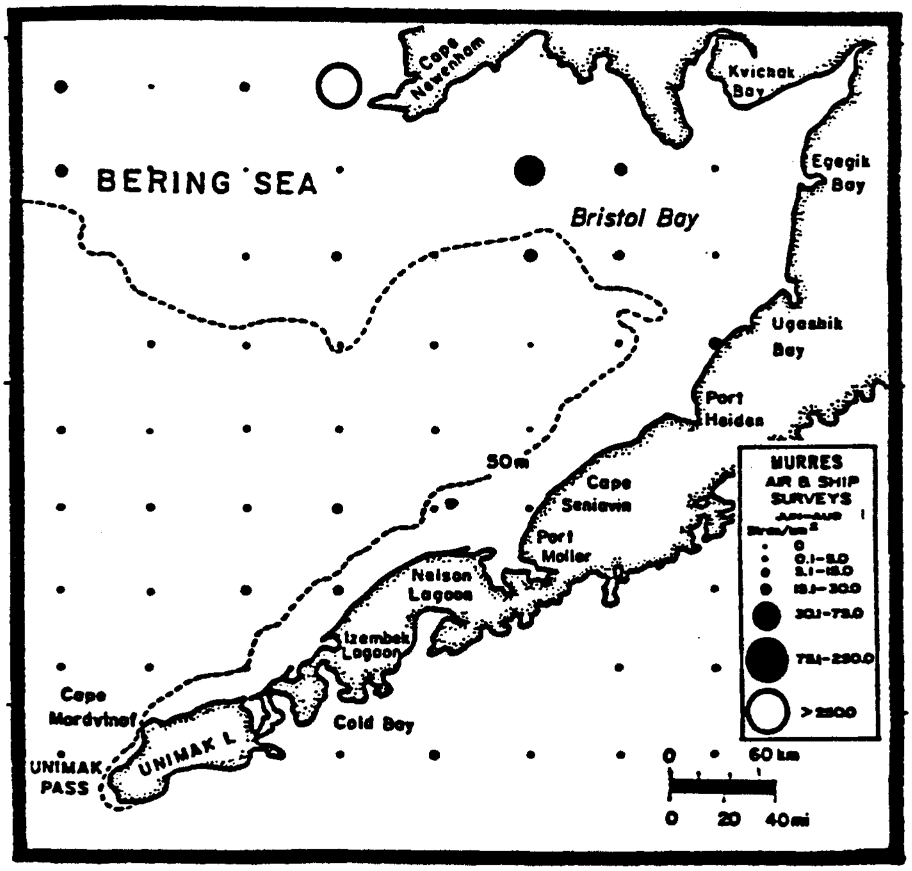


Figure 6.9. Pelagic distribution of murres determined by air and ship surveys in July and August, southeastern Bering Sea. From Hunt et al. (1981a).

into May. Phillips (1976) estimated 20,000 murres swimming in Unimak Pass off Cape Sarichef on 14 May. Gould (1982) reported mean at-sea densities of 10-28 murres/km^2 in Unimak Pass during spring. Autumn migration through Unimak Pass is also quite protracted, extending from late July through October. Peak movements have been recorded during the last week of August and again during October (Nelson 1976).

Aerial and shipboard survey data (Bartonek and Gibson 1972, Hunt et al. 1981a) show murres to be moderately common in late spring and summer in the vicinity of the NAS study area even though the NAS breeding population is not large. This could indicate that many subadult murres summer here. Murres remain common in the study area during winter when birds breeding to the north are forced south by sea ice.

Both species of murres feed by diving, often attaining depths of 110-130 m (Forsell and Gould 1980). Fish are the principal prey, but invertebrates are often an important constituent of the diet. Common Murres tend to feed within a few km of shore in water 50 m or less in depth; Thick-billed Murres may feed tens of kilometers to sea in deep water (Roseneau and Springer 1982). Correspondingly, Common Murres are dependent on nearshore mid-water fishes, whereas Thick-billed Murres use demersal fishes. Thick-billed Murres also take a greater variety of prey (with a greater proportion of invertebrates in the diet) than Common Murres.

Common Murres in the Bering Sea feed on a variety of fish including cod, sand lance, capelin and pricklebacks (Stichaeidae); the latter is used principally as food for the chicks. Thick-billed Murres frequently prey on all the above fish (except pricklebacks) and also take sculpins, which occur near the seabottom (Roseneau and Springer 1982). Invertebrates consumed by both species (but mostly by Thick-billed Murre) include, in approximate order of importance, shrimps, amphipods, euphausiids, cephalopods, and polychaetes (Roseneau and Springer 1982). There is considerable regional variability in diet; murres on the Pribilof Islands take walleye pollock extensively (Bradstreet 1985), whereas murres in Norton Sound are dependent on sand lance and arctic cod (Hunt et al. 1981a).

Habitat factors to which murres respond include availability of suitable nesting cliffs and perhaps concentrations of food. Pelagic distributions of murres in summer reflect distributions of nesting colonies. Schneider (1982) found feeding aggregations of murres (Common and Thick-billed together) associated with the inner front (about the 50-m isobath) southwest of Cape Newenham in late spring, 1981, presumably in response to prey concentrations. Factors important in limiting murre populations are not known for sure, though food availability appears to play a significant role. Bourne (1976) suspected that food shortages caused an observed instance of mass mortality of Common Murres in the Irish Sea. Bailey and Davenport (1972) thought that a massive die-off of Common Murres they observed in April 1970 on the north side of Unimak Island and the Alaska Peninsula resulted from starvation. The starvation was apparently precipitated by severe weather that prevented normal access to food.

6.3.10 Crested Auklet (*Aethia cristatella*)

Four species of auklet--Parakeet (*Cyclorrhynchus psittacula*), Least (*Aethia pusilla*), Whiskered (*A. pygmaea*), and Crested--occur in the study area, but the Crested Auklet is more numerous than all the others combined. The Crested Auklet has its population center in the Bering Sea, where an estimated two million nest in Alaskan waters. This species is not known to nest in our area of interest although large colonies are found to the west in the Aleutian chain. Insufficient data are available to accurately describe the wintering distribution of this species. Most small auklets may leave the Bering Sea in fall, wintering along the Aleutian chain and in the North Pacific. Kodiak Island is a known wintering area for Crested Auklets (Gould et al. 1982). Arneson (1977) reports rafts of this species during winter in both Unimak and Akutan passes. A minimum of 150,000 Crested Auklets in several large rafts was observed 2-5 mi off Swanson Lagoon, Unimak Island, Feb. 23,1984 by C. Dau (Gibson 1984).

Crested Auklets feed by pursuit diving (Ashmole 1971) and specialize in preying on zooplankton at moderate depths (Hunt et al. 1981d). At the Pribilof Islands Crested Auklets take mostly euphausiids, with secondary reliance on copepods and amphipods (Hunt et al. 1981d). Searing (1977) indicated that Crested Auklets at St. Lawrence Island were foraging almost completely on calanoids, at least as food for their young.

6.4 METHODS

Distribution and abundance of marine birds was assessed using two types of platforms: 1) fixed-wing aircraft surveys, and 2) shipboard surveys. The methods employed and purpose of each type of survey are described below.

The two survey methods used complement each other and in concert permit a better evaluation of bird (and marine mammal) distribution and abundance than would either alone. Each has advantages and disadvantages. The aerial surveys are a much more efficient and reliable means of enumerating the study organisms, because these surveys rapidly cover very large areas, providing almost synoptic documentation of the distribution of animals in the study area. Shipboard counts suffer from the problem that the organisms being censused can move much more rapidly than the counter; this fact alone makes reliable density estimation impossible (Burnham et al. 1980). Many ad hoc methods of minimizing this inherent bias have been employed but the accuracy of them all is unverifiable. Surveys near shore are impossible using ship board surveys alone since the minimum sampling depth from the ship is approximately 20 m. On the other hand, the ship permits more detailed study of the smaller organisms that are missed or cannot be identified from the air. The ship allows more precise documentation of certain important behaviors that cannot be ascertained from the air. For example,the use of the area by molting murres and loons was determined during the cruises, but molting individuals could never be verified from aircraft. Most importantly, the ship permits concurrent measurements of prey availability and oceanographic conditions, information that is critical to trying to determine correlative and/or probable causative factors for bird and marine mammal distributions.

6.4.1 Aerial Surveys

Aerial surveys were conducted from a Dehaviland Twin Otter. During most surveys the aircraft was equipped with bubble windows to provide maximum visibility for the observers. Two biologists surveyed, one on each side of the aircraft. Fixed transects were censused during each sample session.

The initial survey design consisted of four survey lines, each approximately 200 miles long and parallel to the coast (Fig. 6.10, Table 6.2). Each line was divided into eight transects. The rationale of this design was to provide samples (transects) at a variety of water depths and along a gradient of distances away from the lagoon entrances.

In November 1984 our survey lines were extended to the west approximately 50 miles (two transects) to provide coverage to the west side of Unimak Pass. This decision was made in response to the observation that densities of several species of birds appeared to increase dramatically at the western extreme of the study area. Results of the other disciplines appeared to corroborate our suspicion of higher productivity/richness in this area, and consequently other research efforts (ship-based) shifted westward beginning in January 1985. Thus, the final study design consisted of four parallel lines with a total of 40 transects, resulting in the surveying of approximately 1000 miles per survey period.

Surveys were flown at 150 m above sea level. This height was a compromise between heights that were optimal for observing birds and those best for observing marine mammals. A greater height would be more efficient for whales, a lower height would permit more accurate detection of the smaller birds. However, for the most numerous species in the study area; i.e., large birds (gulls, waterfowl) and small marine mammals (sea otters), the survey height has proved satisfactory.

Surveys were flown at a ground speed of 100 knots. Transect endpoints were identified by means of LORAN. The effective survey strip was set at 200 m on either side of the aircraft and each observer used an inclinometer to ensure that a constant transect boundary was maintained. Observations, pertinent environmental and weather information, as well as the behavior of the animals sighted were recorded using tape recorders.

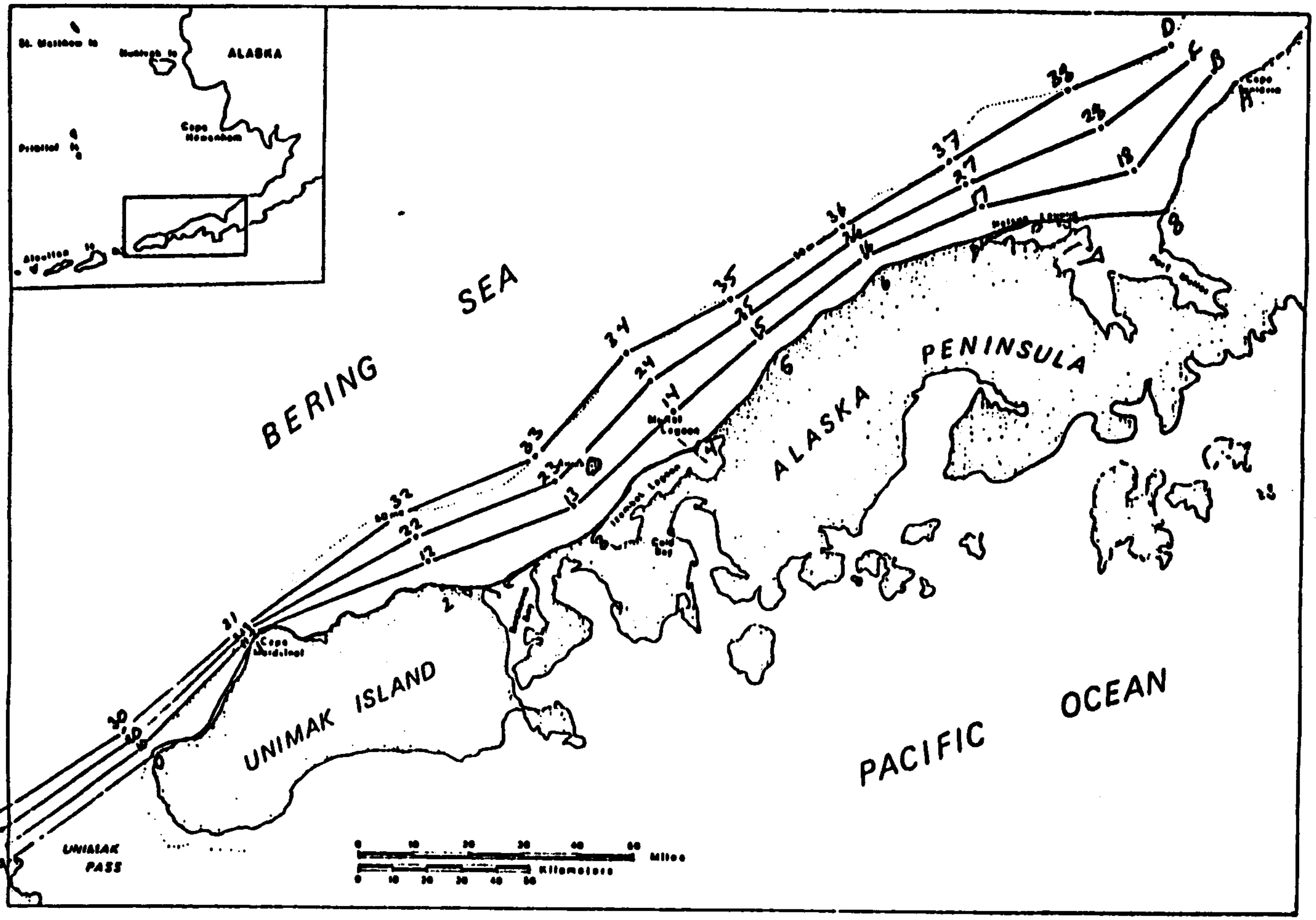


Figure 6.10. Aerial survey transects for bird and marine mammal distribution and abundance, North Aleutian Shelf, Alaska.

Table 6.2. Coordinates for ends of aerial survey transects.

TRANSECT	LAT	LONG	TRANSECT	LAT	LONG
9	54°17'.8	165°30'.0	29	54°24'.4	165°37'.0
0	54°35'.4	164°55'.2	20	54°45'.1	165°07'.1
1	54°55'.3	164°28'.4	21	54°59'.6	164°32'.0
2	55°02'.2	163°53'.6	22	55°11'.9	164°03'.2
3	55°08'.4	163°17'.0	23	55°24'.1	163°32'.1
4	55°23'.6	162°46'.3	24	55°39'.8	163°03'.9
5	55°39'.1	162°16'.7	25	55°53'.6	162°33'.4
6	55°54'.4	161°43'.3	26	56°06'.8	161°56'.8
7	56°01'.2	161°03'.4	27	56°15'.3	161°18'.6
8	56°05'.9	160°27'.0	28	56°20'.8	160°42'.1
A	56°23'.8	160°08'.2	C	56°31'.6	160°16'.7
19	54°21'.1	165°33'.7	39	54°27'.0	165°39'.9
10	54°39'.3	165°00'.2	30	54°50'.0	165°15'.0
11	54°57'.2	164°31'.2	31	55°02'.7	164°37'.8
12	55°07'.2	163°58'.4	32	55°15'.3	164°06'.6
13	55°16'.1	163°24'.0	33	55°31'.7	163°39'.4
14	55°28'.0	162°51'.1	34	55°48'.0	163°12'.8
15	55°45'.5	162°24'.0	35	56°01'.5	162°41'.4
16	56°00'.5	161°49'.9	36	56°13'.0	162°05'.5
17	56°08'.2	161°11'.2	37	56°22'.2	161°26'.6
18	56°13'.4	160°35'.7	38	56°28'.5	160°49'.2
B	56°27'.6	160°12'.4	D	56°35'.5	160°21'.3

Systematic records of 2-minute time increments are identified along each line. These time markers permitted a fine-scale means of mapping bird and marine mammal location within each transect and aided in making inferences about the importance of lagoons and seabird colonies in determining distribution trends.

The survey schedule is summarized below.

	YEAR		
MONTH	1984	1985	1986
January			X
February			X
March		X	
April		X	
May	X		
June		X	
July	X		
August		X	
September	X		
October		X	
November	X		
December		X	

All of the original 32 transects were successfully censused during all surveys. The Unimak Pass lines were not surveyed during the first three flights and some of these lines were missed due to fog problems since they were first included in the study in November 1984.

6.4.2 Shipboard Transects

Counts of marine birds and mammals were made also during the multidisciplinary cruises of the Miller Freeman. Surveys were made when the ship was at or near full steam. Some surveys were made on predetermined lines where samples for other disciplines were collected (Fig. 1.2), but the majority were made while the ship was ferrying between sample locations. Transects were defined as 10-minute intervals, as is the customary protocol for marine bird surveys in Alaska. The biologist censused from the flying bridge, using either a 90° or 180° arc depending on the viewing conditions and on the occurrence of small birds in the area. For example, if the observer thought using a 180° arc would result in birds being missed, a 90° arc was used, and this was usually the case.

Birds were recorded as being in one of four distance increments parallel to the course of the boat: 0-100 m, 100-200 m, 200-300 m, and >300 m. Calculations of densities are based on the first three bands only; the fourth zone was used to record off-transect sightings of major seabird concentrations and/or whales. Although not practiced in the analyses used in this study, if less biased density estimates are required, the effective zone used for the calculation of densities can be varied depending on the species. For example the sightability of storm-petrels may be too low for reliable censusing beyond 100 m, whereas Northern Fulmars can easily be censused to 300 m.

At the time of each transect, location and environmental conditions were recorded. The most important characteristics were time, coordinates of starting and endpoints, observer speed, and water depth. Weather information including temperature, cloud cover, sea state, precipitation, wind speed, and temperature (air and sea surface), were obtained hourly from the ship's log. During most survey periods the ship echosounders were run to provide a qualitative record of prey availability. Both 100 kHz (invertebrate) and 38 kHz (fish) recorders were used.

6.4.3 Sampling for Prey Analysis

The primary purpose of the bird feeding study was to determine which organisms comprised the important proportions of the diets of species of birds most widely distributed and most abundant in the study area. Samples of birds were collected on an opportunistic basis, e.g., at times and locations when and where other sampling activities were least compromised. Thus, samples were not collected systematically along predefined transects or at predefined stations, but at locations (usually nearshore) where other disciplinary tasks and sea surface conditions allowed the use of small boats. As a consequence, few birds were collected at offshore locations where some species (e.g., shearwaters, murres, puffins, and auklets) were typically most abundant. In this report, we base most of our discussion of seabird food habits on the samples we collected on an opportunistic basis in waters less than 50 m deep.

6.4.3.1 Bird Collection Methods

Collections were made from one of two pneumatic boats (Avon or Zodiac) carried aboard the R/V Miller Freeman. The small boats were equipped with high-powered outboard motors that could propel them over relatively calm water at speeds up to about 35 kts. Once birds were located, and in most instances observed to be feeding, they were approached at high speed from the boat and a sample was collected using a 12 ga. shotgun. Birds were retrieved rapidly and their guts (proventriculus and ventriculus) were injected with absolute isopropyl alcohol to preserve food items; the esophagus was plugged with a paper wad to prevent food from spilling out. Each bird was labeled and packed in a bag with all other birds collected at that location. The location and number of the collection was marked on a hydrographic chart of the area so the approximate depth category of the collection location could be estimated.

Food availability was estimated from results of the invertebrate sampling program (see Section 4.0 INVERTEBRATES, this report). Systematic samples of invertebrates (zooplankton, epibenthos, infauna) were taken in nearshore waters similar to those where birds were collected; this allowed some cursory comparisons to be made between food availability and food eaten by the birds (see Section 8.0 Patterns of Energy Flow, this report).

6.4.3.2 Laboratory Analysis of Bird Specimens and Stomach Contents

Within 24 hours of collection, all birds were dissected and food items found in the esophagi and guts were preserved. The esophagus and gut were removed as a single unit from each bird. These organs were slit lengthwise, and an arbitrary measure of fullness (Hynes 1950, see Johnson and Richardson 1981) was assigned to the total unit in the field laboratory (aboard the Miller Freeman), and a cursory and tentative description of the contents was recorded. The intact esophagus and gut of each specimen were washed, stored in absolute isopropanol, and labelled for future analyses.

More detailed laboratory analyses of the stomach contents of each bird were conducted at LGL's laboratory. The preserved stomach contents were sorted into major taxa (most often taxonomic class, but sometimes family or species), counted and weighed (g wet weight). Fish otoliths found in bird stomachs were identified to major taxa (family or species), counted, weighed, and sorted into separate vials. A separate analysis of the number of otoliths found in the stomach of each bird helped in the identification of well-digested fish eaten by those birds.

In order to determine the origin of carbon consumed by birds in the NAS study area, samples of breast muscle tissue were extracted from several individuals of each important bird species for carbon analysis (see Section 3.0 this report). These results give insights into the importance of nearby lagoons as sources of carbon for nearshore primary and secondary consumers.

6.5 RESULTS AND DISCUSSION

6.5.1 Distribution and Abundance

6.5.1.1 Species Composition by Season

Aerial Surveys. A summary of relative densities of marine birds observed during aerial surveys is provided for each month in Table 6.3. Overall bird use of the survey area was highest during summer when shearwaters were abundant and during late winter/early spring (February-April) when Crested Auklets occurred in large aggregations north of Unimak Island. The lowest counts of birds also occurred during early spring (March). Arenson (1981) also found bird use of the area to peak during summer, but in his study the other seasons ranked, in order of importance, fall, spring, and winter. The difference in importance of the seasons in our study compared with Arneson's is likely due to his surveys being more restricted to the coast (except during summer). This also results in his

Table 6.3. Average densities of marine birds (birds/km^2) on aerial survey transects between Cape Mordvinof and Cape Seniavin, North Aleutian Shelf, Alaska. All species listed occurred during the surveys but some were so infrequent that their density appears as 0.0 d-ring all months. Highest densities are shown in boldface, lowest in italics.

SPECIES	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov
Red-throated Loon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.1**	0.0	0.0
Pacific Loon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Common Loon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Loon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grebe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Northern Fulmar	0.1	0.1	0.1	*0.0*	0.1	0.1	1.0	0.2	0.2	**0.5**	*0.0*
Shearwater-dark	*0.0*	*0.0*	*0.0*	*0.0*	**50.3**	48.4	30.7	3.3	0.2	0.2	*0.0*
Fork-tailed Storm-Petrel	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	**0.2**	*0.0*	*0.0*	*0.0*	0.1	*0.0*
Cormorant	1.3	*0.2*	1.6	0.4	0.9	0.8	0.7	0.9	0.4	**1.4**	0.4
Emperor Goose	*0.0*	*0.0*	*0.0*	0.1	*0.0*	*0.0*	*0.0*	*0.0*	**1.1**	0.5	*0.0*
Brant	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	**0.3**	0.1	0.1	*0.0*
Mallard	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Common Eider	0.1	0.2	*0.0*	*0.0*	**0.9**	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
King Eider	4.1	**5.4**	2.3	4.1	0.1	0.5	0.1	0.9	0.9	0.3	0.1
Steller's Eider	1.4	4.6	0.2	1.9	0.1	*0.0*	*0.0*	0.3	0.1	0.7	**5.4**
Harlequin Duck	*0.0*	*0.0*	*0.0*	**0.1**	**0.1**	*0.0*	**0.1**	*0.0*	*0.0*	*0.0*	*0.0*
Oldsquaw	0.5	**1.3**	0.2	1.1	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	0.1	0.3
Scoter	4.1	2.3	5.4	**13.6**	2.6	5.0	*0.0*	1.4	5.0	3.4	9.5
Red-breasted Merganser	0.0	0.1	*0.0*	0.1	0.1	**0.3**	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
duck	0.1	*0.0*	*0.0*	0.1	**1.4**	0.5	0.2	0.6	1.1	0.0	1.1
Bald Eagle	**0.1**	**0.1**	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Rock Sandpiper	0.0	0.1	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	**4.2**	1.2
small Sandpiper	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	**0.1**	*0.0*	*0.0*	*0.0*	*0.0*
Phalarope	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	**1.2**	0.3	*0.0*	*0.0*
shorebird	*0.0*	*0.0*	*0.0*	*0.0*	0.1	**0.8**	0.1	*0.0*	0.2	*0.0*	*0.0*
Jaeger	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	**0.3**	0.1	*0.0*	*0.0*	*0.0*
Bonaparte's Gull	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mew Gull	0.2	0.1	*0.0*	*0.0*	*0.0*	0.1	*0.0*	*0.0*	*0.0*	**0.5**	*0.0*
Herring Gull	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Glaucous-winged Gull	3.6	3.8	4.1	14.6	21.3	**50.0**	23.5	15.7	20.3	12.0	4.4
Glaucous Gull	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Black-legged Kittiwake	*0.0*	*0.0*	0.1	2.4	3.4	14.4	**32.8**	30.5	9.5	1.1	0.1
Sabine's Gull	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tern	*0.0*	*0.0*	*0.0*	*0.0*	**0.3**	**0.3**	0.1	**0.3**	*0.0*	*0.0*	*0.0*
Murre	0.3	**8.4**	1.5	3.5	0.3	0.2	0.5	0.2	0.9	*0.1*	0.2
Pigeon Guillemot	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Murrelet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Auklet	32.0	91.5	1.4	**91.8**	1.6	*0.0*	0.1	0.1	0.3	0.1	0.3
Tufted Puffin	*0.0*	*0.0*	*0.0*	*0.0*	0.1	0.1	0.2	**0.4**	0.1	0.2	0.1
Horned Puffin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
alcid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Common Raven	**0.1**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Snow Bunting	**0.2**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
passerine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.2**	0.0	0.0
TOTAL	48.0	118.2	17.1	133.8	83.8	121.7	90.6	56.5	40.9	25.6	23.1

recording relatively fewer seabirds but more waterfowl than we recorded. Based on earlier work (Guzman 1981, Arneson 1981), high densities of shearwaters were expected to occur during the summer. Arneson recorded no tubenoses (the group including shearwaters) during his May surveys but his July density of tubenoses (~330 birds/km2) was higher than densities he recorded for any other species group during any season.

In our study, Crested Auklets were by far the most numerous bird in the area during the late-winter period, and the wide fluctuations in bird abundance were caused mainly by fluctuations in the number of auklets we encountered. The auklets were recorded in a rather small portion of the study area north of Unimak Island. Their absence during the March survey may indicate either a minor movement to deeper waters to the west, or their departure from the area, perhaps into or through Unimak Pass.

In addition to the shearwaters and auklets, common species in the area included seaducks, especially scoters and eiders. Among the scoters, White-winged was the most numerous, Black Scoters were locally common, and Surf Scoters were relatively infrequent. Both King and Steller's eiders were numerous but Common Eiders were never more than a small proportion of the ducks (although they are probably the most numerous breeding seaduck in the area). Seaducks were largely restricted to the coastal transects, being quite scarce on the other lines. Their abundance peaked during the winter months, generally November through April. But there were seaducks present year-round, and they were quite numerous within the lagoons adjacent to our study area during late summer and early fall.

Glaucous-winged Gull was the most consistently common species. We counted peak numbers during the summer, perhaps reflecting their littoral distribution during the nesting season. (Recall the major colony near Nelson Lagoon.) Abundance reached a minimum during winter (December) but even then this species was the fifth most numerous bird counted. Another larid, the Black-legged Kittiwake, was also an abundant bird in the area. Its seasonal trend in abundance was more pronounced than that of Glaucous-winged Gull; it was essentially absent for virtually half the year.

Murres were present year-round in the study area but their seasonal abundance varied markedly. Numbers peaked during late winter, probably when murres from northern breeding areas reached the NAS. Lowest counts were recorded in fall when local breeding birds had left the colonies.

Incidental observations suggested that the successful breeding birds swam offshore with their chicks after "fledging."

Cormorants, predominantly Red-faced, were present year-round. Highest counts were in fall and winter, indicating an influx of birds from other breeding areas. There are no major breeding areas to the north or northeast (small numbers nest in Bristol Bay outside the NAS), so the wintering birds may have been from the Pribilofs or Aleutians.

During fall migration two shorebirds, phalaropes and Rock Sandpipers, were among the most numerous birds. The Rock Sandpipers were restricted to shorelines along the Alaska Peninsula and thus made use of the nearshore zone only at the water's edge. Their occurrence on our surveys is a reminder of the importance of littoral areas and lagoons of this area to migrating shorebirds. In contrast, phalaropes are pelagic; during the August survey this species group was one of the most common encountered seaward from the coastal transects.

Shipboard Surveys. The results of the five cruises are shown in Table 6.4; densities of the more common species are summarized in Fig. 6.11. The species composition differs in many respects from that described for the aerial surveys. This reflects sampling coverage. One-quarter of the aerial survey lines were along the shoreline of the Alaska Peninsula, but it was rare for the ship to enter waters less than 20 m deep. Thus coastal species such as seaducks, cormorants, and many marine mammals (see Section 7.0, this report) are poorly represented in the shipboard survey summaries.

May--During the May 1984 cruise, overall densities were high but the vast majority of sightings were of Short-tailed Shearwaters (almost 200/km^2). (Sooty Shearwaters were also encountered during some of our cruises; however our observations and specimen collections both indicate that this species makes up a very small proportion of the dark shearwaters in the study area. For tabulation purposes all have been pooled as Short-tailed Shearwaters.) The next most common species group was murres with approximately 15/km^2. Although all murres are pooled in the summary tables, the vast majority of murres identified during the surveys were Common Murres. Thick-billed Murres also occur, especially in the deeper

Table 6.4. Densities of marine birds ($\#/km^2$) by cruise, North Aleutian Shelf, Alaska. Highest densities are shown in boldface, lowest in italics.

SPECIES	MAY 84	SEPT 84	JAN 85	MAY 85	JULY 85
Loon	*0.0*	**0.2**	*0.0*	*0.0*	*0.0*
Red-necked Grebe	0.0	0.0	0.0	0.0	0.0
Northern Fulmar	1.5	0.2	*0.0*	**10.8**	0.8
Sooty Shearwater	0.0	0.0	0.0	0.0	0.0
Short-tailed Shearwater	193.7	2.4	*0.0*	**418.9**	21.4
Fork-tailed Storm-Petrel	*0.0*	*0.0*	*0.0*	**0.4**	*0.0*
Leach's Storm-Petrel	0.0	0.0	0.0	0.0	0.0
Red-faced Cormorant	*0.0*	*0.0*	**2.0**	*0.0*	0.1
Cormorant	**0.3**	0.1	**0.3**	0.1	*0.0*
Brant	*0.0*	*0.0*	*0.0*	**0.3**	*0.0*
dark goose	0.0	0.0	0.0	0.0	0.0
King Eider	0.2	*0.0*	**2.4**	*0.0*	*0.0*
Eider	**1.2**	*0.0*	0.1	*0.0*	*0.0*
Harlequin Duck	0.0	0.0	0.0	0.0	0.0
Oldsquaw	*0.0*	*0.0*	**0.1**	*0.0*	*0.0*
Black Scoter	0.0	0.0	0.0	0.0	0.0
White-winged Scoter	*0.0*	*0.0*	**0.1**	*0.0*	*0.0*
Merganser	0.0	0.0	0.0	0.0	0.0
duck	0.1	*0.0*	**0.4**	*0.0*	*0.0*
Lesser Golden-Plover	0.0	0.0	0.0	0.0	0.0
Least Sandpiper	0.0	0.0	0.0	0.0	0.0
Phalarope	*0.0*	**1.8**	*0.0*	*0.0*	*0.0*
Jaeger	0.1	*0.0*	*0.0*	0.1	**0.5**
Bonaparte's Gull	0.0	0.0	0.0	0.0	0.0
Mew Gull	*0.0*	*0.0*	**0.1**	*0.0*	*0.0*
Herring Gull	0.0	0.0	0.0	0.0	0.0
Glaucous-winged Gull	**9.8**	*1.0*	5.5	4.2	2.0
Glaucous Gull	0.0	0.0	0.0	0.0	0.0
Black-legged Kittiwake	2.1	0.9	*0.4*	**10.0**	5.2
Sabine's Gull	0.0	0.0	0.0	0.0	0.0
Gull	0.0	0.0	0.0	0.0	0.0
Arctic Tern	0.0	0.0	0.0	0.0	0.0
Aleutian Tern	*0.0*	*0.0*	*0.0*	*0.0*	**0.2**
Murre	14.7	*0.1*	**16.5**	3.0	9.5
Pigeon Guillemot	*0.0*	*0.0*	**0.4**	*0.0*	*0.0*
Murrelet	*0.0*	*0.0*	0.1	0.1	**0.7**
Crested Auklet	0.2	0.0	**30.0**	1.9	0.0
Auklet	0.1	*0.0*	*0.0*	**1.1**	*0.0*
Tufted Puffin	0.7	0.1	*0.0*	0.8	**1.3**
Horned Puffin	0.0	0.1	*0.0*	0.1	**0.3**
alcid	**0.1**	**0.1**	*0.0*	*0.0*	*0.0*
Lapland Longspur	0.0	0.0	0.0	0.0	0.0
TOTAL	224.9	*7.3*	58.6	**451.9**	42.1

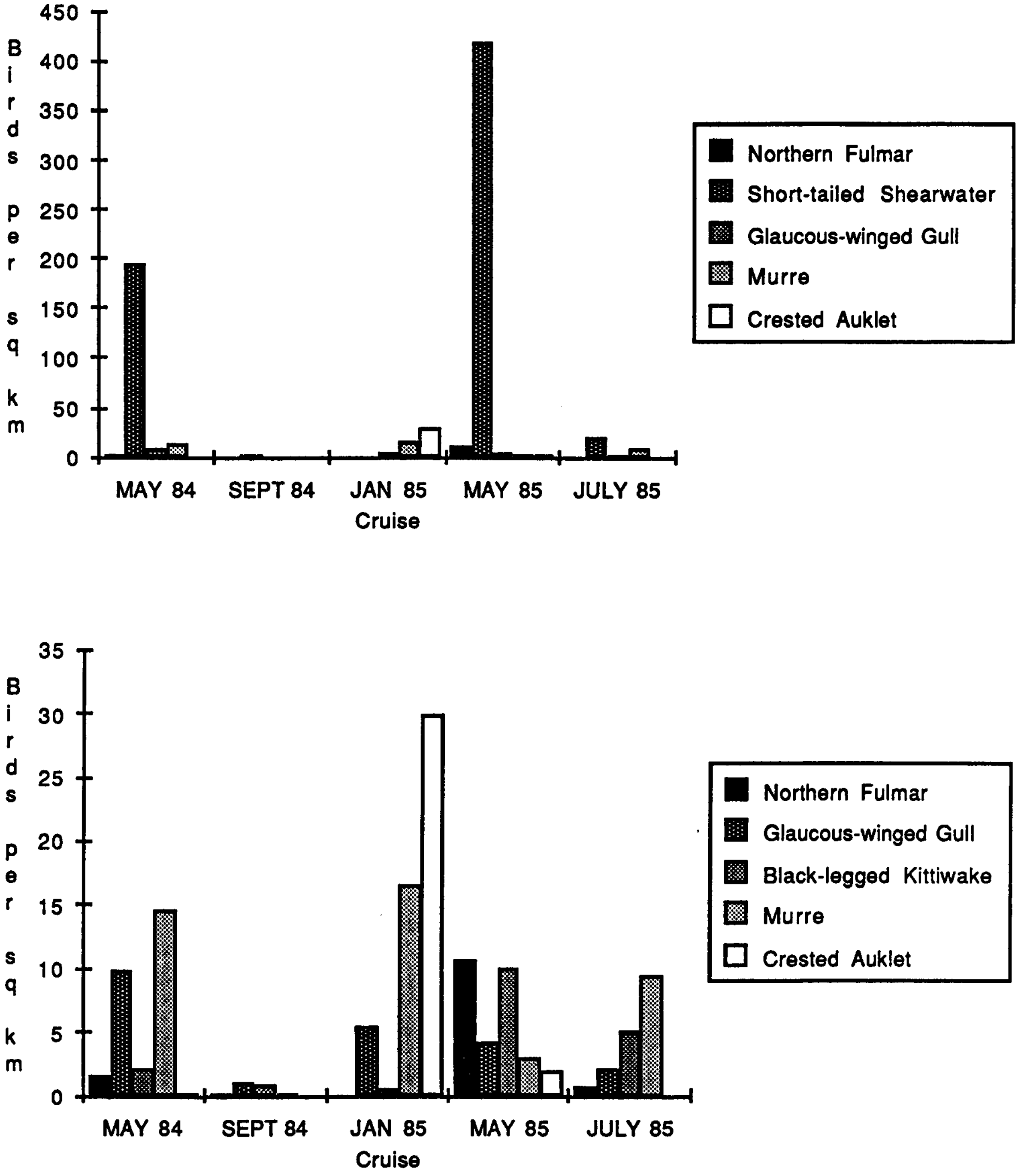


Figure 6.11. Densities of the most common birds recorded during North Aleutian Shelf, Alaska cruises on the Miller Freeman. Short-tailed Shearwaters, shown to reach very high densities in the top graph, are omitted from the lower figure to show trends in the other species.

areas, and both species nest at Amak Island. Glaucous-winged Gull was the only other bird species occurring in appreciable numbers (approaching 10 birds/km^2).

During May 1985 another cruise was made that provided the opportunity to collect additional information during this dynamic portion of the year. Again the area was found to have exceptionally high densities of marine birds. Overall densities in 1985 were substantially higher than in 1984, but the abundance of birds in general and the overwhelming number of shearwaters was similar.

Care must be taken in estimating the number of shearwaters because, as mentioned earlier, it is not possible to accurately census objects that move fast relative to the observer. Streams of migrating shearwaters are an extreme case. The numbers for this species are difficult to interpret beyond indicating that there were a lot of shearwaters. The aerial survey results give a more useful index of shearwater abundance.

Some other important contrasts between the two May surveys include differences in the abundances of Northern Fulmars, Glaucous-winged Gulls, Black-legged Kittiwakes, and murres. The increased abundance of Northern Fulmars in 1985 was likely merely a function of more sampling in deep water relative to 1984; this species favors deep areas. A valid interpretation of the other differences is not possible without further examination of the sampling distribution and intensity. Despite the between-year differences, if the densities of these species are ranked by cruise, the two May samples always group together relative to the other samples.

September--In contrast with May surveys, September counts on the NAS showed the area to be virtually devoid of birds. The most numerous species was still Short-tailed Shearwater; however, its density had decreased by two orders of magnitude. Even gulls were virtually absent. One "positive" change in September was that the greatest species richness occurred at this time (i.e., there were more species, but all were rare). Also, phalaropes reached their peak abundance in September; both Red and Red-necked phalaropes were recorded using the study area.

January--Birds were again numerous in January; however, the species composition differed considerably from that of May. The most numerous bird in January was Crested Auklet at approximately 30/km^2. The only other widely-encountered species group was murres, which were found at densities very similar to those recorded in May 1984. Species that peaked in abundance during this cruise were Red-faced Cormorant and King Eider, but neither could be considered very common on the transects.

July--In many respects counts of marine birds during July 1985 were intermediate between counts made in May and those made in September. The surface-feeding species, birds that typically reach the highest abundances in the Bering Sea during the summer months, all had intermediate densities between counts in May and counts in September. Alcids, especially murres, Tufted Puffins, and murrelets, peaked in July. This contrast is not as apparent in the aerial survey data; indeed, only the July peak of Tufted Puffins and the intermediate abundance of Short-tailed Shearwaters was common to the two sets of summaries. As will be noted later when bird use of depth zones is discussed, the July cruise occurred during a period when the inner front was located unusually close to shore and this may have greatly affected bird use of the area. The aerial survey data for July were collected during 1984 (as opposed to in 1985 when the cruise took place) and, although no oceanographic measurements are available to ascertain the location of the front in 1984, it is possible that it was closer to the 50-m isobath with which it is customarily associated.

Species reaching their peak abundance during the July cruise were jaegers, Aleutian Terns, murrelets, and Horned and Tufted puffins. Among the jaegers, Pomarine Jaeger was the most numerous; it appeared to be migrating "south" at this time. Aleutian Terns nest along the Alaska Peninsula and are resident in the area only during the nesting season. The abundance of murrelets and puffins is more difficult to explain. None is a particularly common breeding species in the area. As mentioned above, part of the cause for their abundance may be oceanographic events (i.e, intrusion of the middle domain into the study area) that caused middle-domain seabirds to move nearer to shore. In the case of murrelets and Horned Puffins the numbers recorded using the area was relatively small and it may be premature to attach much significance to their presence.

Summary. Comparison of the cruise results shows that the study area supports seasonally high densities of marine birds. Species that reach peak densities do so only for portions of the year. Species that exhibited highest peaks in abundance are Short-tailed Shearwater and Crested Auklet. Both of these species use the NAS during their "wintering" seasons (the shearwaters nest in the southern hemisphere and "winter" in the north Pacific during May-August). The cruise summary is misleading in that some important attributes of bird use of the area are poorly represented by the data. Most importantly, seaduck use was greatly underestimated in cruise censuses because these groups are probably most widespread in areas shallower than those surveyed from the ship. The use of the extreme nearshore areas by several species of ducks and gulls is more apparent when the aerial survey results are considered.

In summary the nearshore zone (at least the portions > 20m deep) receives widespread use by birds in spring and winter. Early fall finds the area relatively devoid of these organisms.

6.5.1.2 Segregation By Depth

The transect data were compiled by water depth to see if bird abundance was influenced by this variable. Selection of depth as a criterion was inspired by its use as the delimiting character of the nearshore zone for this study, and because PROBES researchers found that a regularly occurring front that influenced bird distribution was found near the 50-m isobath in the southern Bering Sea.

Aerial Surveys. The data are summarized by the four major tracks along which the transects were aligned (the westernmost lines added midway through the program are compiled separately). The transect groups are thus named and characterized as follows:

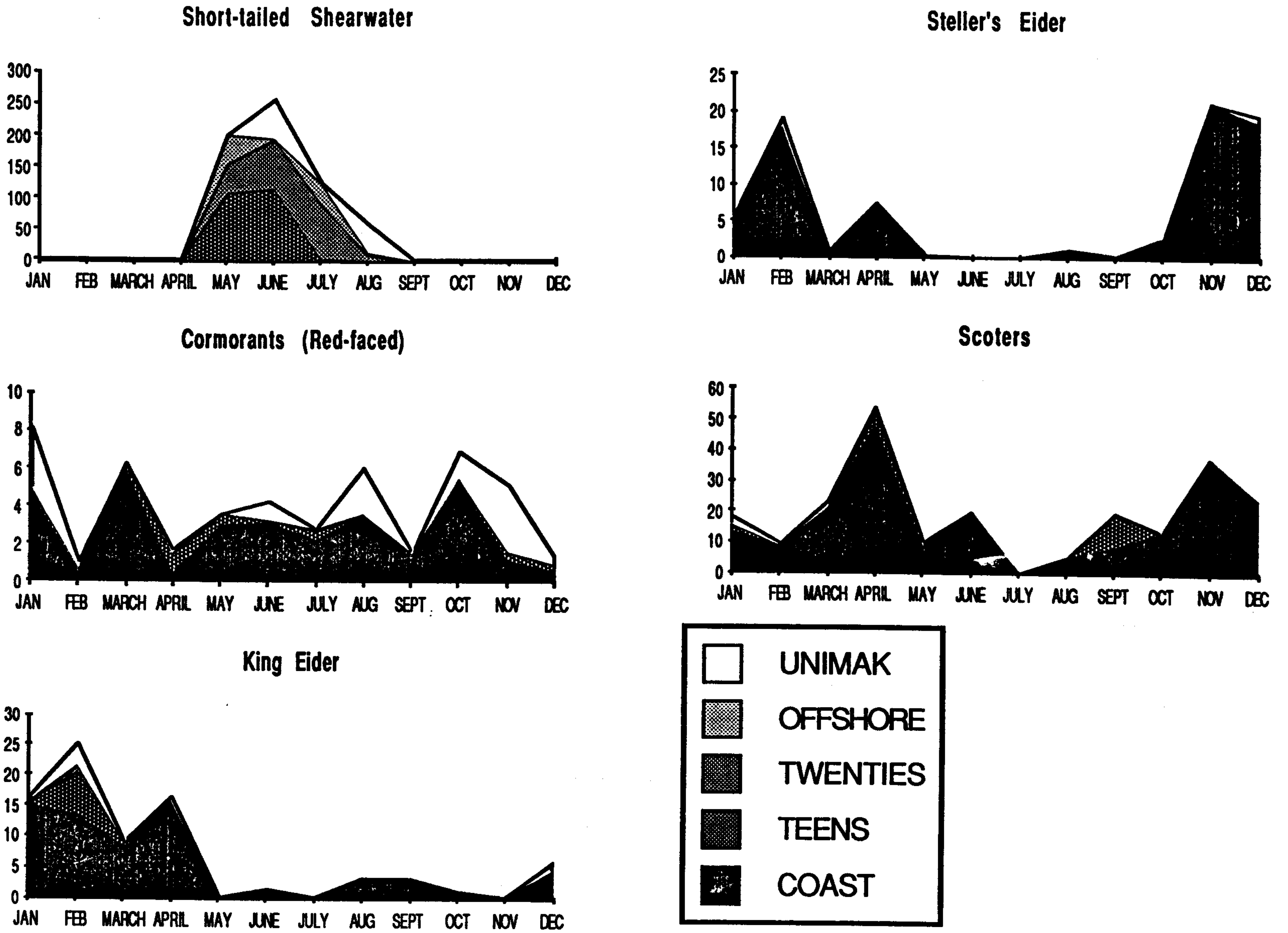
- Unimak--The eight transects added midway through the project, all located to the west of Cape Mordvinof. All four of the major lines were extended by two transect lengths to achieve this coverage. This group is quite heterogenous in terms of water depths and oceanographic regions it covers. Habitats sampled extended from shoreline (Unimak Island) to almost 200-m depths.

- Coast--The shoreline transects from Cape Mordvinof to Cape Seniavin. The exact depths sampled are hard to ascertain due to different depth profiles adjacent to the coast and the poor bathymetry information on nautical charts for this part of the coast. Near Cape Mordvinof some areas surveyed may have been in the vicinity of 30 m but on average the coastal transects probably sampled to water depths of about 13 m. Along most portions of the coast the transect width included the beach, but off Port Moller the transect included some deeper waters. This line includes the portions of the study area not surveyed from the Miller Freeman.

- Teens--The first track line off the coast. The "teens" includes transect numbers 11 though 18. The average depth sampled by these transects was estimated to be 35 m. These transects characterize use of the coastal domain beyond the shoreline areas.

- Twenties--The second track line off the coast. The "twenties" includes transect numbers 21 through 28. The average depth sampled by these transects was estimated to be 53 m. This set of transects thus sampled the area where the "inner front" was usually expected to be, although the percent of the time that the inner front was within the area sampled is not known.

- Offshore--The outermost line of transects. The offshore group comprised transect numbers 31 though 38. The average depth sampled by these transects was thought to be 70 m. These transects should characterize bird use of the middle domain.


Short-tailed Shearwater

Steller's Eider

Cormorants (Red-faced)

Scoters

King Eider

Figure 6.12. Monthly trends in abundance (#/km^2) of marine birds by transect group (depth class) in the North Aleutian Shelf. "Unimak" was not sampled during the May, July, and September surveys.

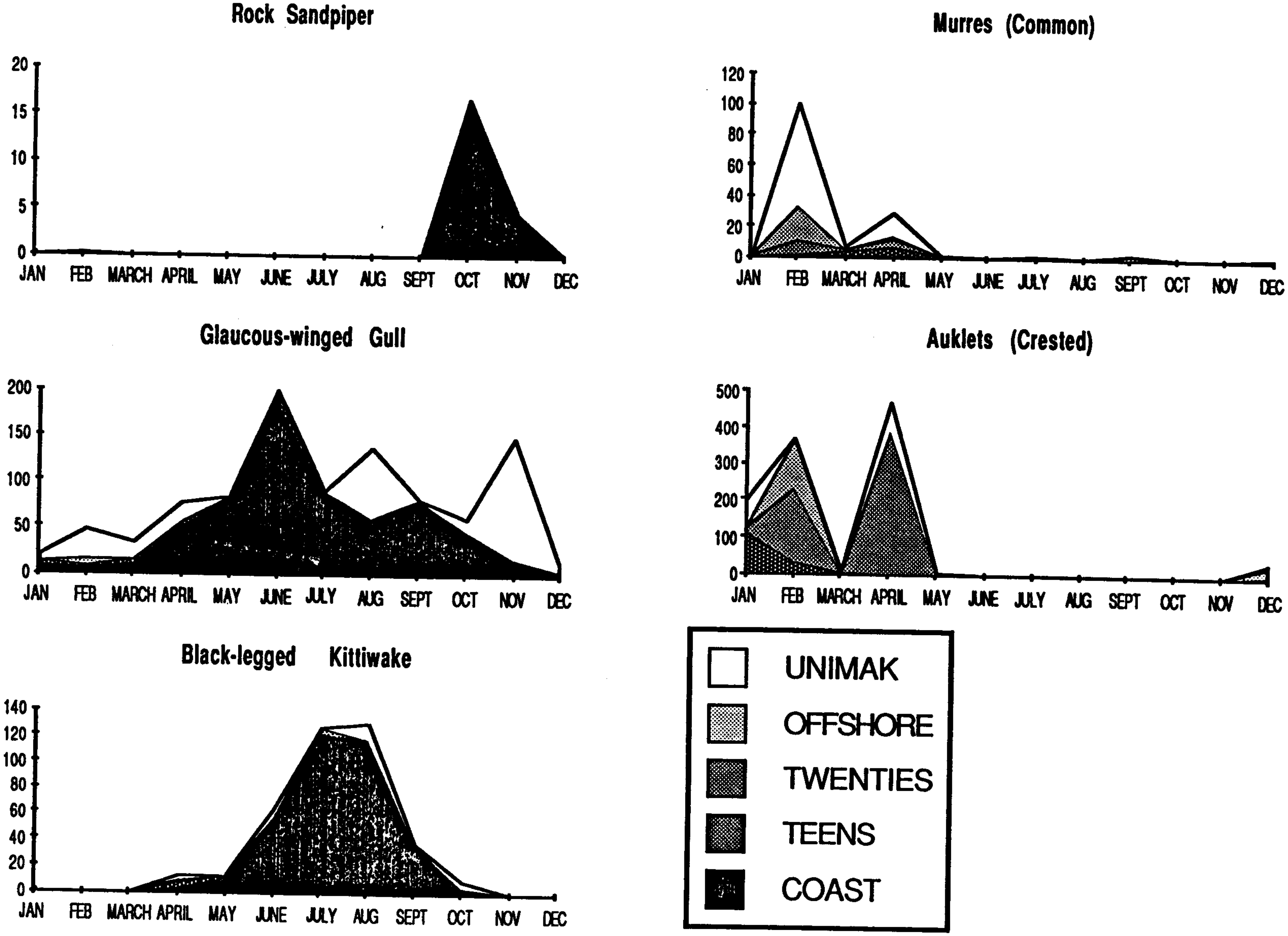


Figure 6.12 (cont'd)

Use of the above zones by marine birds is summarized in Figure 6.12. Both seasonal (monthly) and spatial (depth) information is included in these charts. Short-tailed Shearwaters are shown to occur only during the summer months and to shift their areas of use from the coastal domain (teens) to farther offshore areas as the summer progressed. By the end of the summer shearwaters were found only in Unimak Pass. Although Figure 6.12 shows shearwater use ending by September, it should be noted that our September aerial survey was done prior to the extension of the study area to include northern Unimak Pass. Studies of Unimak Pass in progress (LGL for NOAA) show this species to be numerous in that area through at least early October. Most of the remaining species (all the ducks, gulls, cormorants, and Rock Sandpiper) are shown to have predominately strictly coastal peaks in abundance within the NAS. The absolute numbers of some, especially Glaucous-winged Gull and Black-legged Kittiwake, are higher in the coastal domain waters (teens and twenties) than in the littoral band (coast) by virtue of the former's much greater areal extent (portions of the study area < 10 m ~557 km^2, 10-50 m ~7740 km^2); however, the seaducks were observed to be quite infrequent seaward of 10-m depths. Two remaining groups--murres and Crested Auklets--were characteristic of the nearshore waters (< 50 m but not along the shoreline), not being encountered along the strictly coastal transects. The murres were found in the coastal domain during the breeding season but tended to be in deeper waters, at or beyond the inner front, during the winter months when they were most numerous in the NAS area. Crested Auklets were generally most numerous along the "twenties" transects, generally close to the inner front.

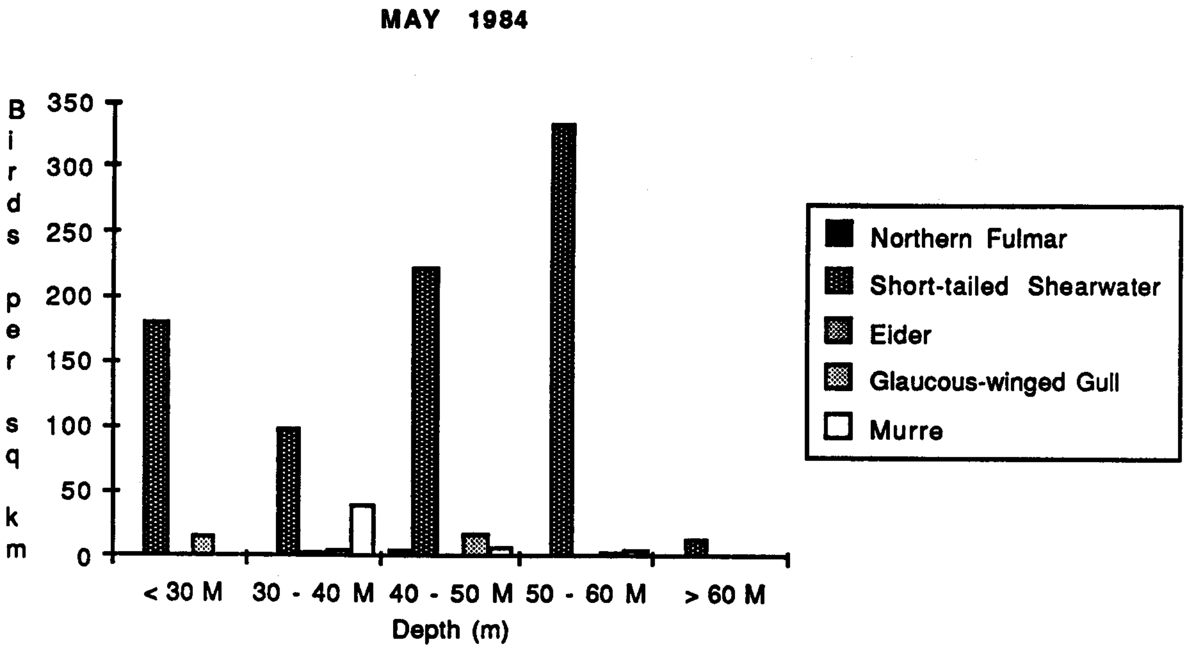
Shipboard Surveys. Densities of marine birds were determined for five depth classes: < 30 m, 30-40 m, 40-50 m, 50-60 m, and >60 m. The analyses were repeated for each cruise.

May--Densities by depth class for the May 1984 cruise are summarized in Table 6.5 and Figure 6.13; results for May 1985 are in Table 6.6 and Figure 6.14.

In May 1984 the predominant species were Short-tailed Shearwater and murres. The shearwaters were the most common species at all depths but

Table 6.5. Densities of marine birds (#/km^2) by water depth classes on the North Aleutian Shelf, Alaska during May 1984. Highest densities are shown in boldface, lowest in italics.

SPECIES	≤30 M	30 - 40 M	40 - 50 M	50 - 60 M	≥60 M
Loon	0.05	0.02	**0.06**	*0.00*	*0.00*
Northern Fulmar	*0.00*	*0.00*	**5.37**	0.59	0.75
Short-tailed Shearwater	170.88	96.71	243.56	**329.21**	*14.38*
Red-faced Cormorant	**0.02**	*0.00*	*0.00*	*0.00*	*0.00*
Cormorant	**0.70**	0.54	0.06	*0.02*	0.11
dark goose	*0.00*	**0.10**	*0.00*	*0.00*	*0.00*
King Eider	*0.00*	**0.58**	*0.00*	*0.00*	*0.00*
Eider	0.09	**4.02**	0.06	*0.00*	*0.00*
Harlequin Duck	*0.00*	*0.00*	*0.00*	**0.02**	*0.00*
duck	**0.37**	*0.00*	*0.00*	*0.00*	*0.00*
Jaeger	*0.02*	0.03	0.09	0.07	**0.11**
Glaucous-winged Gull	15.33	4.40	**19.08**	2.62	*1.93*
Black-legged Kittiwake	2.46	1.52	1.41	**3.92**	*0.54*
Aleutian Tern	0.02	**0.03**	*0.00*	*0.00*	*0.00*
Murre	1.33	**38.28**	8.64	4.56	*0.32*
Pigeon Guillemot	0.02	*0.00*	**0.02**	*0.00*	*0.00*
Murrelet	*0.00*	**0.05**	*0.00*	*0.00*	*0.00*
Crested Auklet	0.05	0.02	**0.85**	*0.00*	0.11
Auklet	*0.00*	**0.11**	**0.11**	*0.00*	*0.00*
small alcid	**0.30**	0.11	0.04	*0.00*	0.21
Tufted Puffin	*0.00*	0.05	1.59	0.88	**2.25**
Horned Puffin	*0.00*	*0.00*	*0.00*	**0.02**	*0.00*
Phalarope	*0.00*	*0.00*	*0.00*	*0.00*	**0.11**
TOTAL	191.66	146.56	280.94	**341.91**	*20.83*



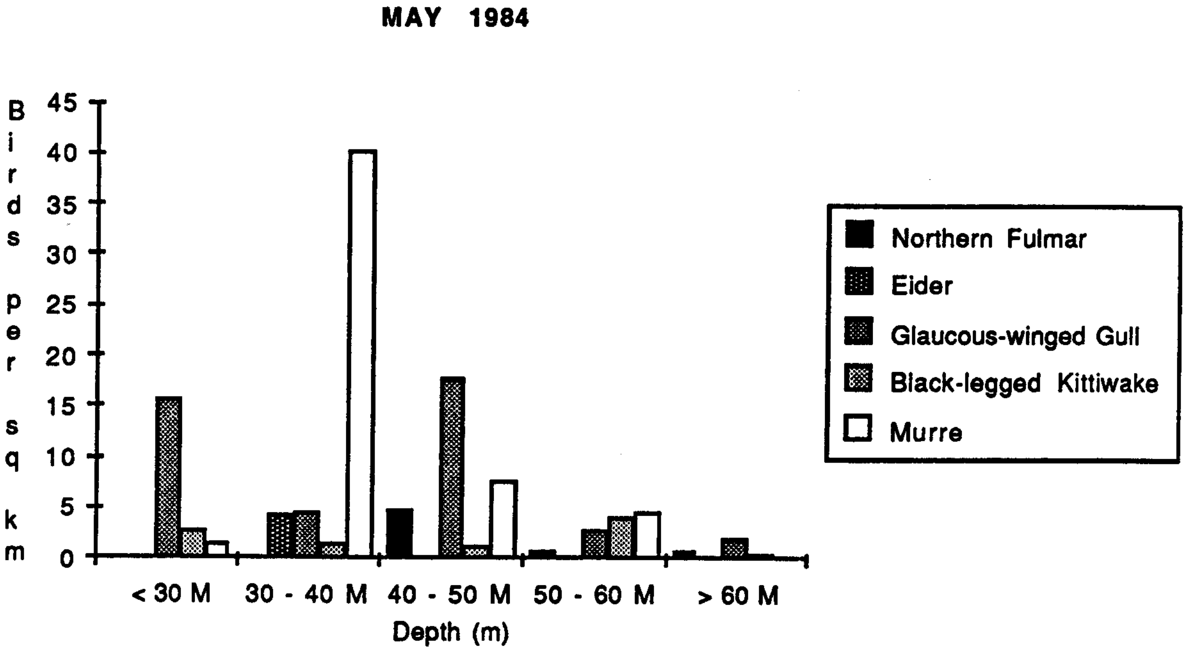
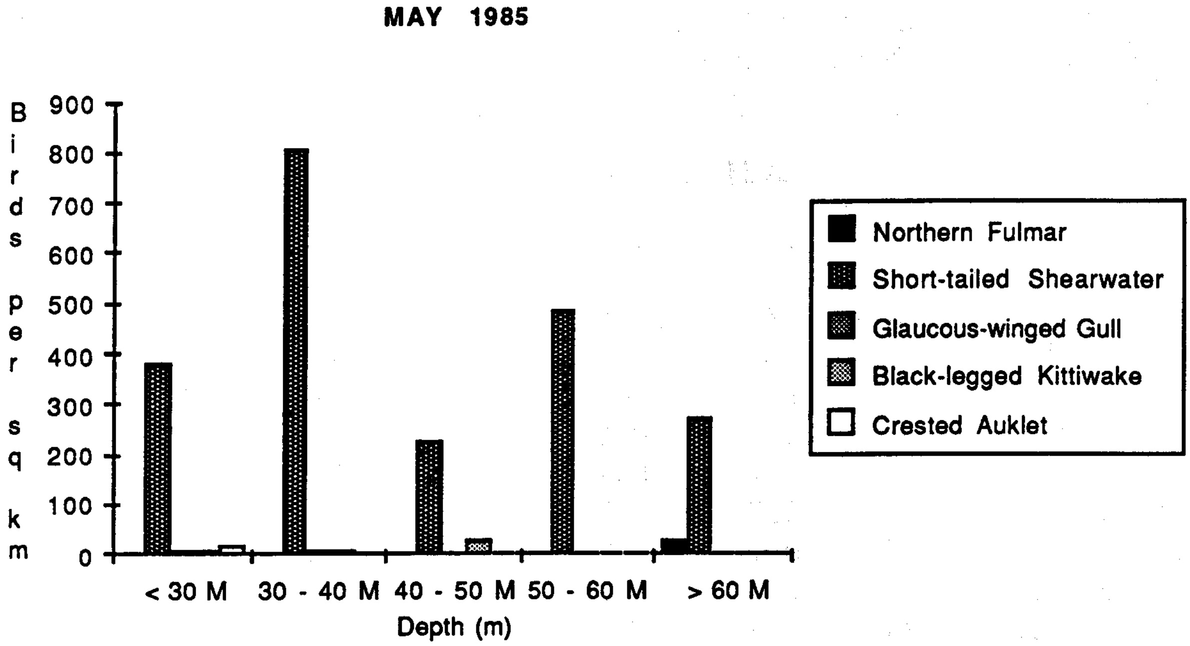


Figure 6.13. Densities of marine birds by depth as recorded during the May 1984 cruise, North Aleutian Shelf, Alaska. Short-tailed Shearwaters, shown in the top graph to reach very high densities, are omitted from the lower graph to show trends in the other species.

Table 6.6. Densities of marine birds (#/km^2) by water depth classes on the North Aleutian Shelf, Alaska during May 1985. Highest densities are shown in boldface, lowest in italics.

SPECIES	≤ 30 M	30 - 40 M	40 - 50 M	50 - 60 M	≥ 60 M
Loon	0.1	**0.2**	*0.0*	*0.0*	*0.0*
Northern Fulmar	*0.2*	2.1	2.0	6.3	**27.9**
Short-tailed Shearwater	384.2	**807.6**	*224.0*	483.7	271.0
Fork-tailed Storm-Petrel	*0.0*	*0.0*	*0.0*	0.6	**0.9**
Red-faced Cormorant	*0.0*	*0.0*	**0.1**	*0.0*	**0.1**
Cormorant	0.1	**0.3**	*0.0*	*0.0*	*0.0*
Brant	*0.0*	**0.7**	*0.0*	*0.0*	0.5
King Eider	**0.2**	*0.0*	*0.0*	*0.0*	0.1
Oldsquaw	**0.1**	*0.0*	*0.0*	*0.0*	*0.0*
Black Scoter	0.0	0.0	0.0	0.0	0.0
White-winged Scoter	0.0	0.0	0.0	0.0	0.0
Least Sandpiper	0.0	0.0	0.0	0.0	0.0
Parasitic Jaeger-light ph	0.0	0.0	0.0	0.0	0.0
Jaeger	**0.1**	**0.1**	**0.1**	**0.1**	*0.0*
Herring Gull	0.0	0.0	0.0	0.0	0.0
Glaucous-winged Gull	7.5	**8.9**	3.7	2.8	*2.1*
Glaucous Gull	0.0	0.0	0.0	0.0	0.0
Black-legged Kittiwake	10.8	8.4	**28.8**	4.0	*1.5*
Sabine's Gull	0.0	0.0	0.0	0.0	0.0
Aleutian Tern	**0.1**	**0.1**	**0.1**	*0.0*	*0.0*
Murre	3.6	4.0	**4.2**	2.6	*1.7*
Pigeon Guillemot	**0.5**	*0.0*	*0.0*	*0.0*	*0.0*
Murrelet	**0.5**	0.2	0.1	0.1	*0.0*
Crested Auklet	**17.1**	0.3	1.7	1.7	*0.1*
Auklet	0.2	*0.1*	*0.1*	**0.3**	3.0
Tufted Puffin	*0.4*	*0.4*	0.9	**1.3**	0.7
Horned Puffin	*0.0*	**0.1**	*0.0*	**0.1**	*0.0*
Lapland Longspur	0.0	0.0	0.0	0.0	0.0
Gull	0.0	0.0	0.0	0.0	0.0
alcid	**0.2**	*0.0*	*0.0*	*0.0*	*0.0*
TOTAL	426.0	833.4	*265.9*	503.6	309.6



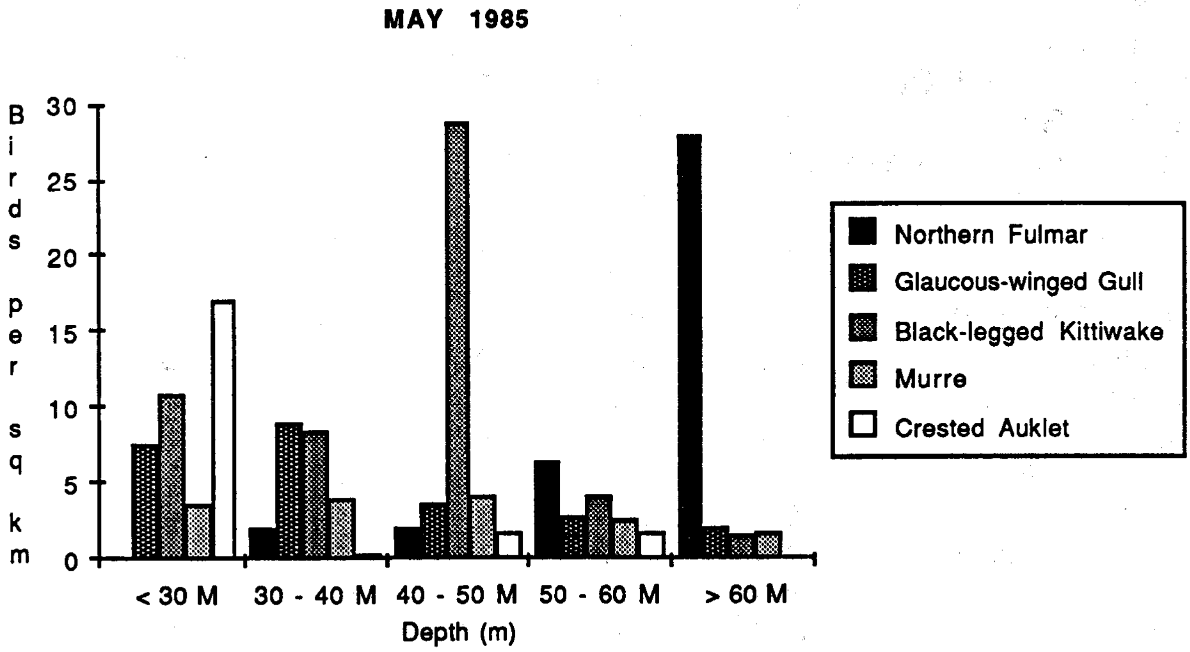


Figure 6.14. Densities of marine birds encountered by depth zone on the North Aleutian Shelf, Alaska, May 1985. Short-tailed Shearwaters, shown in the top graph to reach very high densities, are omitted from the lower graph to show trends in the other species.

they were not evenly distributed. The highest densities occurred at 50-60 m; high densities were found in the 40-50 m zone as well. The lowest densities of shearwaters were found in waters deeper than 60 m. Murres in contrast appeared to exhibit a marked affinity to the 30-40 m zone. Among the less common species, cormorants and seaducks were largely restricted to the shallow zones; i.e., < 30 m and 30-40 m. Northern Fulmars peaked quite markedly in the 40-50 m zone. Puffins were most numerous (but still very uncommon) in the deeper waters.

Oceanographic measurements in May 1984 indicated that the inner front was probably seaward of, and at least in a few cases, very near the 50-m isobath. The distribution of Short-tailed Shearwaters is consistent with the idea that greater bird densities occur near this front, but no marked concentrating effect was evident.

The results of the May 1985 cruise are not entirely congruent with those of the preceding year. Short-tailed Shearwaters continued to be the most abundant bird in every depth class; however, they peaked in abundance in shallower water (30-40 m) and were markedly more abundant in the > 60 m class than during the preceding year. Murres were not as abundant in May 1985 as they were during the preceding May and were more evenly distributed across all depths. Northern Fulmars were more numerous in 1985 and appeared to exhibit a pronounced tendency to occur in deeper waters, especially > 60 m. Other species that were common in May 1985 were Glaucous-winged Gull, Black-legged Kittiwake and Crested Auklet. These species were all predominant in shallow waters although the actual peak in abundance of kittiwakes was in the 40-50 m zone. The location of the inner front appeared to be similar to the situation in 1984, i.e, generally seaward of 50 m. The bird distribution did not reveal any concentrating or boundary effects of this front. Surprising was the occurrence of Short-tailed Shearwaters in deeper waters than in 1984, concurrent with the presence of Northern Fulmar (a typically offshore species) in shallower waters than in 1984.

<u>September</u>--So few birds were present in September that the occurrence of distinct trends is difficult to detect (Table 6.7, Fig. 6.15). However, the limited data suggest that the two most common species, Short-tailed Shearwater and phalaropes, were decidedly clumped within the 40-50

Table 6.7. Densities of marine birds (#/km^2) by water depth classes during September 1984. Highest densities are shown in boldface, lowest in italics.

SPECIES	< 30 M	30 - 40 M	40 - 50 M	50 - 60 M	> 60 M
Loon	**0.3**	**0.3**	0.2	0.2	*0.0*
Northern Fulmar	*0.0*	0.2	**0.4**	0.2	0.3
Short-tailed Shearwater	1.2	1.4	**6.6**	*0.3*	*0.3*
Fork-tailed Storm-Petrel	*0.0*	*0.0*	*0.0*	**0.1**	*0.0*
Leach's Storm-Petrel	0.0	0.0	0.0	0.0	0.0
Red-faced Cormorant	*0.0*	**0.1**	*0.0*	*0.0*	*0.0*
Cormorant	**0.1**	**0.1**	*0.0*	*0.0*	*0.0*
King Eider	**0.1**	*0.0*	*0.0*	*0.0*	*0.0*
Harlequin Duck	0.0	0.0	0.0	0.0	0.0
Oldsquaw	*0.0*	*0.0*	*0.0*	**0.1**	*0.0*
White-winged Scoter	**0.2**	*0.0*	*0.0*	*0.0*	*0.0*
Merganser	0.0	0.0	0.0	0.0	0.0
duck	0.0	0.0	0.0	0.0	0.0
Lesser Golden-Plover	**0.1**	*0.0*	*0.0*	*0.0*	*0.0*
Jaeger	0.0	0.0	0.0	0.0	0.0
Bonaparte's Gull	**0.2**	*0.0*	*0.0*	*0.0*	*0.0*
Mew Gull	0.0	0.0	0.0	0.0	0.0
Glaucous-winged Gull	**1.7**	1.1	0.7	*0.5*	0.8
Glaucous Gull	0.0	0.0	0.0	0.0	0.0
Black-legged Kittiwake	**1.9**	0.8	*0.4*	0.8	1.3
Murre	*0.0*	*0.0*	0.2	*0.0*	**0.3**
Pigeon Guillemot	**0.2**	*0.0*	*0.0*	*0.0*	*0.0*
Murrelet	0.0	0.0	0.0	0.0	0.0
Auklet	0.0	0.0	0.0	0.0	0.0
small alcid	0.0	0.0	0.0	0.0	0.0
Tufted Puffin	**0.1**	**0.1**	*0.0*	*0.0*	*0.0*
Horned Puffin	*0.0*	**0.2**	0.1	*0.0*	0.1
large alcid	*0.0*	*0.0*	**0.1**	**0.1**	*0.0*
Phalarope	*0.0*	1.1	**5.6**	0.1	*0.0*
TOTAL	6.2	5.6	**14.5**	*2.3*	3.2

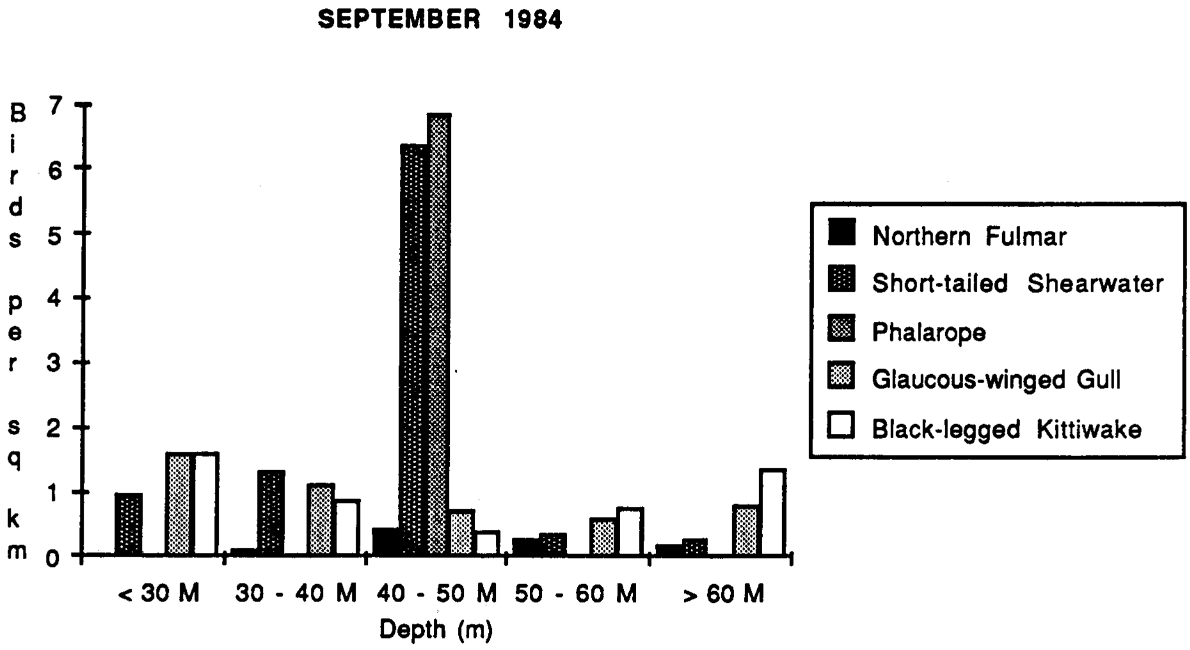


Figure 6.15. Densities of marine birds encountered by the depth zone durin the September 1984 cruise on the North Aleutian Shelf, Alaska.

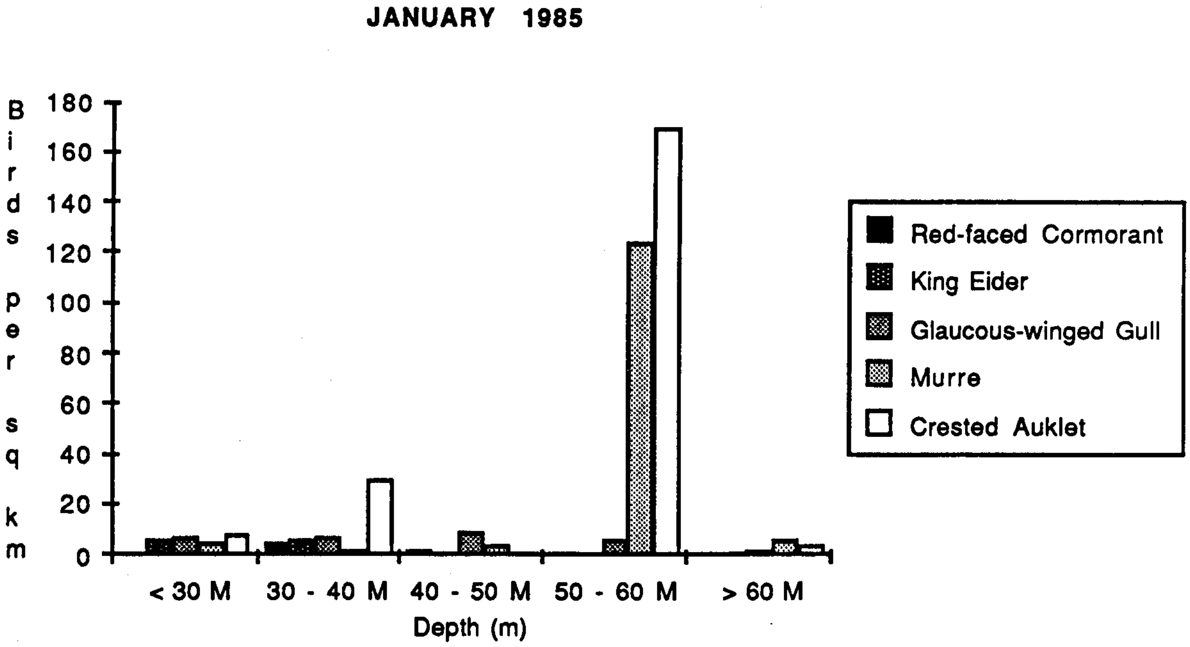


Figure 6.16. Densities of marine birds encountered by depth zone during January, 1985 on the North Aleutian Shelf, Alaska.

m zone. Murres, which were quite rare, peaked in the > 60 m zone, suggesting that post-breeding murres (which nest in summer within the study area) disperse offshore. Although the oceanographic measurements did not provide strong indication of the presence of the inner front within the study area, the birds, at least phalaropes and Short-tailed Shearwaters, were decidedly aggregated in the 40-50 m depth classes, suggesting that some important attractant was present in the area. Phalaropes in particular are well known for their affinity for convergences where the small zooplankters they prey upon are concentrated.

January--Several interesting patterns in bird abundance by depth are evident in the January results (Table 6.8, Fig. 6.16). The two most common species, Crested Auklet and murres, were very concentrated in the 50-60 m zone where they occurred in densities exceeding 100 /km^2. The auklet was also relatively common in shallower areas, especially in the 30-40 m zone, but was conspicuously absent from 40-50 m. Murres were the most abundant group in water >60 m. Glaucous-winged Gulls were moderately common in all zones except the deepest waters, and peaked from 40-50 m. Ducks (eiders and Oldsquaws) and cormorants (especially Red-faced Cormorant) were at their greatest abundance of any cruise and were largely restricted to waters <40m.

Oceanographic measurements showed no evidence of inner front or middle domain conditions within the study area. But evidence that a distinct front should exist at all in winter is ambiguous (see Section 2.0, this report). The marked concentration of birds in the 50-60 m depth class may indicate that the front existed just outside our main sampling area. Or conversely, Unimak Pass or the shelf break, rather than the inner front, might have been responsible for the observed concentrations, because concentrations of Crested Auklets, whose numbers were a large proportion of the total bird numbers, were limited to the Umimak Pass-shelf break vicinity.

The January results are intriguing in the apparent zonation of several species and the extremely high densities that occurred in some depth classes. Unfortunately this is also the cruise for which we have the least data (short cruise and limitations on daylight). The sampling intensity is very low for some of these depth classes, (i.e, one transect

Table 6.8. Densities of marine birds (#/km^2) by water depth classes during January 1985, on the North Aleutian Shelf, Alaska. Highest densities are shown in boldface, lowest in italics.

SPECIES	< 30 M	30 - 40 M	40 - 50 M	50 - 60 M	> 60 M
Loon	*0.0*	*0.0*	**0.1**	*0.0*	*0.0*
Red-necked Grebe	*0.0*	*0.0*	**0.1**	*0.0*	*0.0*
Northern Fulmar	0.0	0.0	0.0	0.0	0.0
Red-faced Cormorant	*0.0*	**4.2**	2.1	0.4	*0.0*
Cormorant	*0.0*	**0.4**	0.1	0.1	0.3
King Eider	2.8	**6.1**	0.4	*0.0*	*0.0*
Eider	**2.8**	0.3	*0.0*	*0.0*	*0.0*
Oldsquaw	**5.7**	*0.0*	*0.0*	*0.0*	*0.0*
White-winged Scoter	*0.0*	**0.2**	*0.0*	*0.0*	*0.0*
duck	*0.0*	*0.0*	*0.0*	*0.0*	**1.1**
Mew Gull	*0.0*	**0.3**	*0.0*	*0.0*	*0.0*
Herring Gull	*0.0*	*0.0*	*0.0*	**0.1**	*0.0*
Glaucous-winged Gull	6.6	6.6	**9.5**	5.6	*2.0*
Black-legged Kittiwake	*0.0*	0.2	**0.7**	0.6	0.6
Murre	4.7	*2.3*	3.5	**123.9**	6.2
Pigeon Guillemot	*0.0*	**0.8**	0.3	*0.0*	0.2
Murrelet	*0.0*	0.2	*0.0*	0.3	*0.0*
Crested Auklet	8.5	29.3	*0.0*	**169.5**	3.7
Tufted Puffin	*0.0*	*0.0*	**0.1**	*0.0*	*0.0*
TOTAL	31.3	50.8	16.8	**300.5**	*14.4*

in the < 30 m zone, and very little in the apparently important 50-60 m zone).

July--During the July cruise all common species peaked in abundance in waters less than 40m deep; many peaked in waters less than 30m (Table 6.9, Fig. 6.17). Tufted Puffins were unusually numerous during this cruise. This compression of seabirds shoreward of their depth distributions on other cruises was coincident with a tendency of the inner front to be well shoreward of the 50-m isobath. Oceanographic data revealed that many of the stations, including some of the shallower stations, were apparently located in the middle domain (see Section 2.0 PHYSICAL OCEANOGRAPHY, this volume).

6.5.1.3 Population Estimates

Estimates of the number of marine birds using the study area are presented in Table 6.10. These estimates, determined for use in the energy flow model (Section 8.0, this report), were calculated using the following formula:

$$N_i = \Sigma a_j t_{ij}$$

where

N_i = estimated population of species "i" in the NAS study area

a_j = the total area (km^2) in depth class "j" in the study area

and

t_{ij} = the average density of species "i" on all transects in depth class "j"

Six depth classes were used: (1) the 100-m band directly along the shoreline; i.e., the area censused from the nearshore side of the plane on the coastal transects. (This area, ~66 km^2, was sampled in its entirety.) (2) coastal waters seaward of zone 1 but less than 10 m deep, total area ~557 km^2; (3) waters 10 -20 m deep, total area ~1133 km^2; (4) waters 20-30 m deep, total area ~1543 km^2; (5) 30-40 m deep, total area ~2471 km^2; and (6) waters 40-50 m deep, total area ~2593 km^2.

Table 6.9. Densities of marine birds (#/km^2) by water depth classes during July 1985 on the North Aleutian Shelf, Alaska. Highest densities are shown in boldface, lowest in italics.

SPECIES	< 30 M	30 - 40 M	40 - 50 M	50 - 60 M	> 60 M
Loon	0.0	0.0	0.0	0.0	0.0
Northern Fulmar	0.4	*0.0*	0.1	0.8	**2.6**
Sooty Shearwater	0.0	0.0	0.0	0.0	0.0
Short-tailed Shearwater	32.0	**42.8**	7.0	7.3	*4.1*
Fork-tailed Storm-Petrel	*0.0*	*0.0*	**0.1**	*0.0*	*0.0*
Red-faced Cormorant	*0.0*	*0.0*	*0.0*	**0.3**	*0.0*
Cormorant	0.0	0.0	0.0	0.0	0.0
Phalarope	0.0	0.0	0.0	0.0	0.0
Parasitic Jaeger-light ph	**0.1**	**0.1**	*0.0*	*0.0*	*0.0*
Long-tailed Jaeger	*0.0*	*0.0*	**0.1**	*0.0*	*0.0*
Jaeger	**0.8**	0.7	0.3	0.2	*0.1*
Glaucous-winged Gull	**4.1**	2.3	1.1	0.5	*0.4*
Black-legged Kittiwake	**12.9**	2.7	0.9	1.7	*0.6*
Sabine's Gull	*0.0*	*0.0*	**0.1**	*0.0*	*0.0*
Arctic Tern	0.0	0.0	0.0	0.0	0.0
Aleutian Tern	**0.6**	*0.0*	0.1	*0.0*	*0.0*
Murre	**23.7**	5.0	1.7	4.2	*0.3*
Murrelet	**1.7**	0.2	0.4	0.2	*0.0*
Auklet	0.0	0.0	0.0	0.0	0.0
small alcid	**0.1**	*0.0*	*0.0*	*0.0*	*0.0*
Tufted Puffin	0.7	**4.5**	0.8	0.5	*0.4*
Horned Puffin	**0.6**	0.5	*0.0*	*0.0*	*0.0*
alcid	0.0	0.0	0.0	0.0	0.0
TOTAL	**77.7**	58.8	12.7	15.8	*8.6*

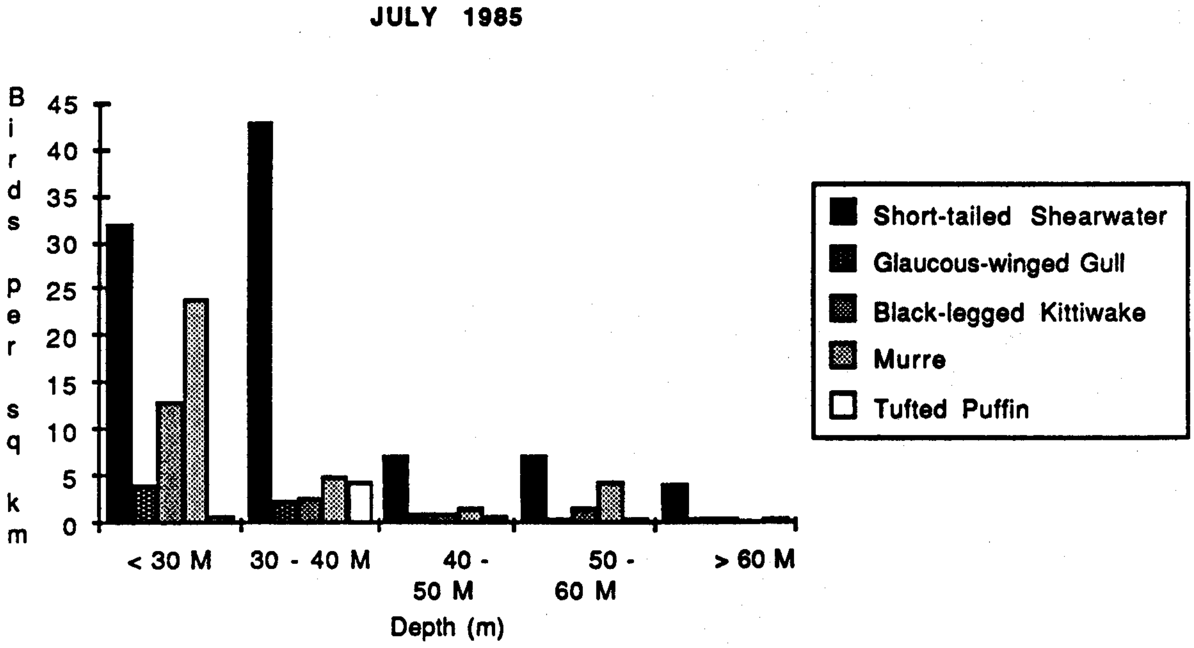


Figure 6.17. Densities of marine birds encountered by depth zone in July, 1985 on the North Aleutian Shelf, Alaska.

Table 6.10. Rough estimates of total bird populations within the North Aleutian Shelf, Alaska study area at the time of each aerial survey. Estimates were derived by extrapolating average density on transects within each 10-m depth class to the total area of each depth class in the study area.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Red-throated Loon	0	0	0	0	20	37	0	0	807	0	0	54
Pacific Loon	0	8	0	0	40	0	0	0	107	41	20	0
Common Loon	0	0	0	21	0	2	0	0	0	0	0	0
Loon	0	435	101	124	56	0	0	64	299	74	0	0
Grebe	0	95	1	0	0	0	0	0	0	156	0	115
Northern Fulmar	383	159	685	20	354	1,513	1,492	1,156	1,100	1,447	20	733
Shearwater-dark	0	0	0	0	318,896	1,278,410	10,773	2,646	1,524	1,404	60	20
Fork-tailed Storm-Petrel	0	0	0	0	0	20	101	121	20	216	0	0
Cormorant	7,633	1,709	6,834	3,378	10,786	4,601	2,037	2,929	2,648	3,327	2,571	1,697
Emperor Goose	0	262	0	49	16	0	0	244	14,014	868	189	0
Brant	0	0	0	0	20	2	0	1,606	30	185	0	0
Mallard	0	0	0	3	0	1	0	0	0	0	0	0
Common Eider	842	2,403	353	96	5,480	2	186	0	447	5	27	1,230
King Eider	32,514	70,508	18,761	26,058	112	350	811	4,966	9,073	2,863	51	12,126
Steller's Eider	15,130	40,261	1,602	24,751	229	1	0	4,520	1,015	10,196	74,308	54,429
Harlequin Duck	56	117	0	26	520	182	1,143	9	7	90	61	36
Oldsquaw	5,521	12,838	2,264	12,380	58	81	0	0	0	1,369	4,236	3,236
Scoter	41,864	16,888	18,215	161,346	25,594	14,077	461	16,614	95,118	36,371	121,518	31,337
Red-breasted Merganser	2	693	0	426	1,015	348	0	0	0	0	0	170
duck	40	9	92	431	28,459	269	2,377	381	561	171	19,930	234
Bald Eagle	69	102	1	0	28	36	1	0	1	2	0	11
Rock Sandpiper	0	40	0	0	0	0	0	0	0	2,200	600	0
small Sandpiper	0	0	0	0	0	0	50	0	0	0	0	0
Phalarope	0	0	0	0	37	0	0	11,519	1,895	105	0	0
shorebird	3	0	0	0	45	468	61	129	86	77	0	0

Table 6.10 (cont'd)

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Jaeger	0	0	0	0	27	422	3,272	971	60	37	0	0
Bonaparte's Gull	0	0	0	0	0	0	0	0	0	229	80	0
Mew Gull	2,546	676	23	0	30	312	40	0	0	7,617	1	265
Herring Gull	0	0	0	37	1	2	0	0	54	64	0	27
Glaucous-winged Gull	18,258	14,859	17,953	55,065	52,839	110,732	37,386	14,898	62,270	22,032	11,094	6,811
Glaucous Gull	20	27	219	211	0	57	0	0	0	40	0	40
Black-legged Kittiwake	40	179	1,591	28,750	25,379	38,878	45,548	51,287	125,788	13,897	1,480	27
Sabine's Gull	0	0	0	0	27	0	40	0	0	0	0	0
Tern	0	0	0	0	2,920	2,541	559	2,901	0	0	0	0
Murre	2,809	7,632	21,385	46,572	3,372	2,768	7,238	1,127	684	725	844	2,937
Pigeon Guillemot	20	21	27	0	0	1	0	0	20	0	0	0
Murrelet	156	895	0	20	0	0	0	0	0	0	227	53
Auklet	304,822	100,475	17,587	643	5,287	114	527	524	141	221	261	11,886
Tufted Puffin	0	0	94	0	955	168	1,197	1,844	302	0	101	121
Horned Puffin	0	0	20	159	0	89	101	155	181	0	0	222
alcid	0	0	181	134	343	0	222	20	0	80	0	0
Common Raven	45	0	0	0	1	0	2	0	0	0	0	12
Snow Bunting	134	0	0	0	0	0	0	0	0	0	40	15
passerine	0	0	0	0	0	0	0	0	2,619	0	0	0
TOTAL	432,909	271,292	107,991	360,699	482,945	1,456,484	115,626	120,631	320,871	106,109	237,721	127,844

These calculations indicate that bird use of the NAS peaked during June with almost 1.5 million birds present. Most of these birds were shearwaters. Spring migration (April and May) and mid-winter (January) were the other major periods of bird use. During spring shearwaters were always the predominant species whereas during the winter Crested Auklets were most numerous.

6.5.2 Trophic Relationships

Studies of the trophics of marine birds and mammals provide a link in the interpretation of relationships among physical parameters, biological productivity, and distributions and abundances of key species of marine birds and mammals. In this study, one of the major objectives was to test the hypothesis that the organic materials transported from the lagoons along the Alaska Peninsula to the adjacent NAS nearshore zone contribute significantly to the food webs in that zone and cause heightened utilization of the zone by higher trophic level organisms (marine birds, mammals, and fish). Another important objective was to determine the manner in which the dominant birds, mammals, and fish contribute to or utilize the nearshore zone and its organic resources. In terms of birds, these objectives were addressed primarily through sampling programs conducted during five cruises in nearshore waters of the NAS (May and September 1984, and January, May, and July 1985). The sampling programs during each cruise involved collections of key species at different levels in the food chain.

We collected representatives of 18 species of birds in three foraging guilds (Table 6.11): (1) surface feeders (Glaucous-winged Gull, Black-legged Kittiwake, Aleutian and Arctic terns, Short-tailed Shearwater), whose prey is obtained primarily in the top 3 m of water, (2) water column feeders (Common and Thick-billed Murres, Red-faced Cormorant), whose prey is obtained generally in waters deeper than 3 m, and (3) bottom (benthic, epibenthic) feeders (scoters, eiders, Oldsquaw, Harlequin Duck), whose prey is obtained from or slightly above the bottom substrate. In total, 365 individuals were collected at over 30 different locations (Fig. 6.18). Except for 8 birds collected at a 70-m sampling station during the July 1985 cruise, all birds were collected in waters shallower than 50 m

Table 6.11. Summary of bird collections, North Aleutian Shelf, Bering Sea, Alaska, 1984 and 1985.

	Collection Dates											
	1984						1985				ALL DATES	
Feeding Habitat/	16-18 May		26 Sept. -4 October		30 Jan.		19-24 May		20-29 July			
Species	S	D	S	D	S	D	S	D	S	D	S	D
Surface												
BLKI	1	0	19	0			50	0	15	0	85	0
STSH	12	0	4	0			9	0	9	3	34	3
GWGU			12	0	4	0	25	0	3	0	44	0
ALTE							6	0	11	0	17	0
ARTE									1	0	1	0
MEGU					1	0					1	0
Mid-Water												
RFCO			17	0			9	0	7	0	33	0
PECO					3	0	1	0			4	0
TBMU							8	0	3	1	11	1
COMU	1	0					6	0	8	4	15	4
Bottom												
STEI			17	0			5	0			22	0
KIEI			14	0			12	0	5	0	31	0
OLDS					5	0	7	0			12	0
WWSC			20	0			1	0	2	0	23	0
BLSC			7	0	2	0	4	0			13	0
HADU			4	0			5	0			9	0
Subtotals	14	0	115	0	15	0	149	0	64	8	357	8
TOTAL	14		115		15		149		72		365	

*S=Shallow collection location (<50m).
D=Deep collection location (>50m).

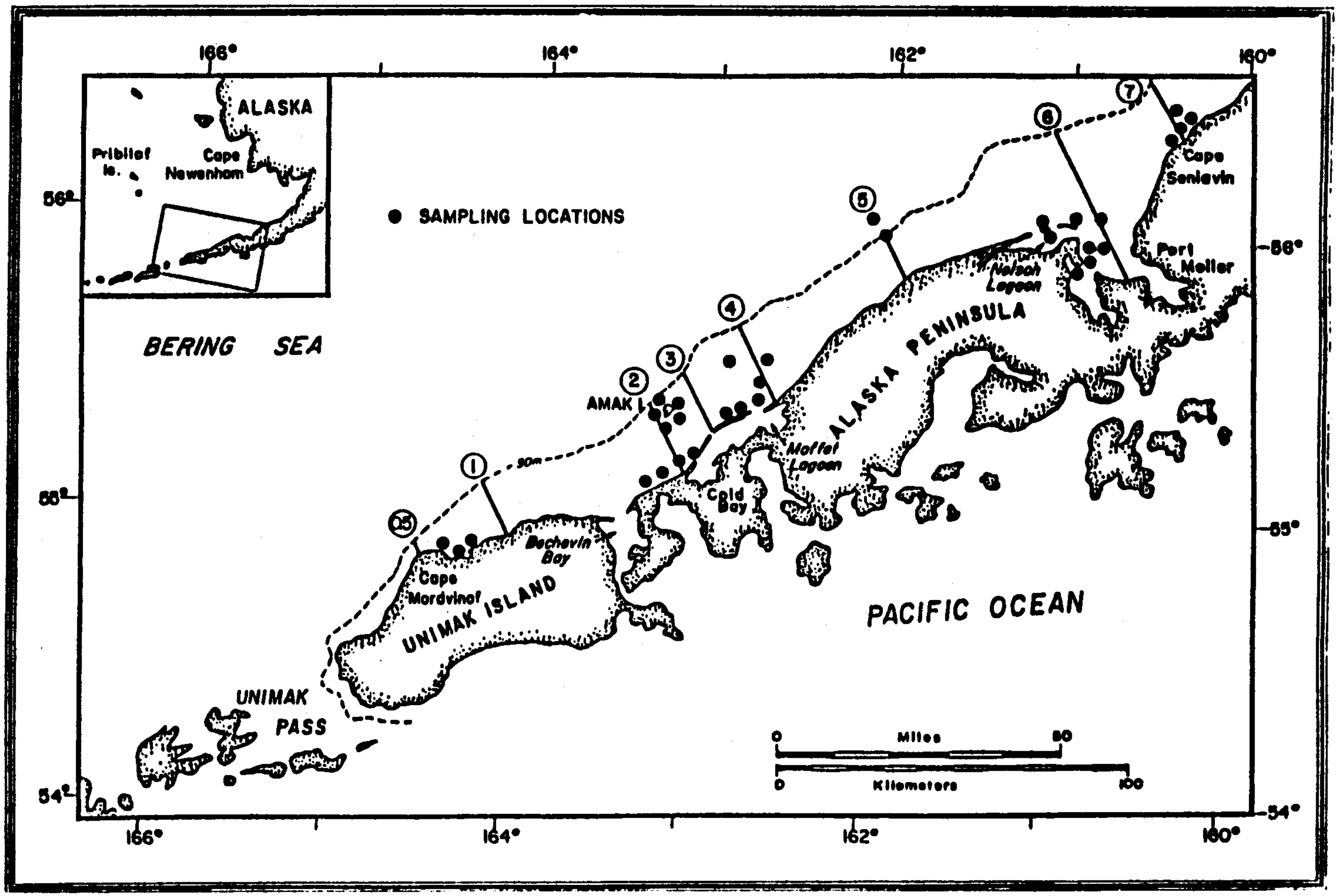


Figure 6. 18. Map of the North Aleutian Shelf study area, showing bird collection locations.

(the primary area of interest in this study). Very small samples of four species (1-4 birds totaling 8 individuals) have not been included in the analyses of food habits because these samples were thought to be too small to be representative.

6.5.2.1 Surface-Feeding Birds

Diets of surface-feeding birds collected in May were mainly euphausiids. Euphausiid crustaceans comprised approximately 66% of the wet weight diets of Black-legged Kittiwakes collected during cruises in May 1984 and 1985. Fish (principally sand lance, Ammodytes hexapterus, but also several unidentified species) comprised most of the remainder of the spring diet (see Table 6.12, Fig. 6.19). Figure 6.20 shows the very high proportion of sand lance otoliths taken from the stomachs of kittiwakes during May. Shearwaters, showing an even greater preference for invertebrates, ate exclusively euphausiids in May 1984 (96.7%) and primarily euphausiids and some fish in May 1985 (about 80% and 16%, respectively; see Table 6.13, Fig. 6.19). Although only one shearwater stomach from a spring sample (May 1985) contained otoliths, all otoliths were identified to be from sand lance (Fig. 6.20).

No birds were collected during summer 1984, but those collected in summer 1985 indicated that the diets of Black-legged Kittiwakes and Short-tailed Shearwaters had switched almost entirely to fish by July (Tables 6.12 and 6.13, Fig. 6.19). Although most of the fish were digested and unidentifiable, virtually all otoliths taken from bird stomachs were identified to be from sand lance (see Fig. 6.20). Based on samples collected in 1984, sand lance remained the dominant item in kittiwake and shearwater diets through at least September (Tables 6.12 and 6.13; Fig. 6.20). No winter samples of either kittiwakes or shearwaters were collected during this study (both species are largely absent from the study area). However, Glaucous-winged Gulls, whose spring, summer, and fall diets (see Table 6.14 and Figs. 6.21 and 6.22) were similar to those of kittiwakes and shearwaters (euphausiids in spring with a switch to fish, primarily sand lance, during summer and fall), apparently ate no fish during January.

Table 6.12. Organisms consumed by Black-legged Kittiwakes (*Rissa tridactyla*) in nearshore waters of the North Aleutian Shelf, Bering Sea, Alaska.

	1984				1985			
	May (n=1)		Sept. (n=19)		May (n=50)		July (n=15)	
	Wet wt.		Wet wt.		Wet wt.		Wet wt.	
Major Taxa	(g)	(%)	(g)	(%)	(g)	(%)	(g)	(%)
Euphausiids	1.2	66.5	0.0	0.0	307.0	66.7	0.0	0.0
Mysids	0.0	0.0	tr	tr	1.5	0.3	0.0	0.0
Crustaceans	1.2	66.5	tr	tr	308.5	66.7	0.0	0.0
Sand lance	0.0	0.0	28.1	25.2	67.4	14.6	43.7	45.1
Other fish	0.0	0.0	1.5	1.3	0.0	0.0	1.3	1.3
Unid. fish	0.6	29.7	81.1	72.8	79.1	17.2	49.5	51.0
All fish	0.6	29.7	110.7	99.3	146.5	31.8	94.5	97.4
Other/Unknown	0.1	3.8	0.8	0.7	5.3	1.2	2.5	2.6
Total	1.9	100.0	111.5	100.0	460.3	100.0	97.0	100.0

*tr = trace amounts (<0.1%) organisms.

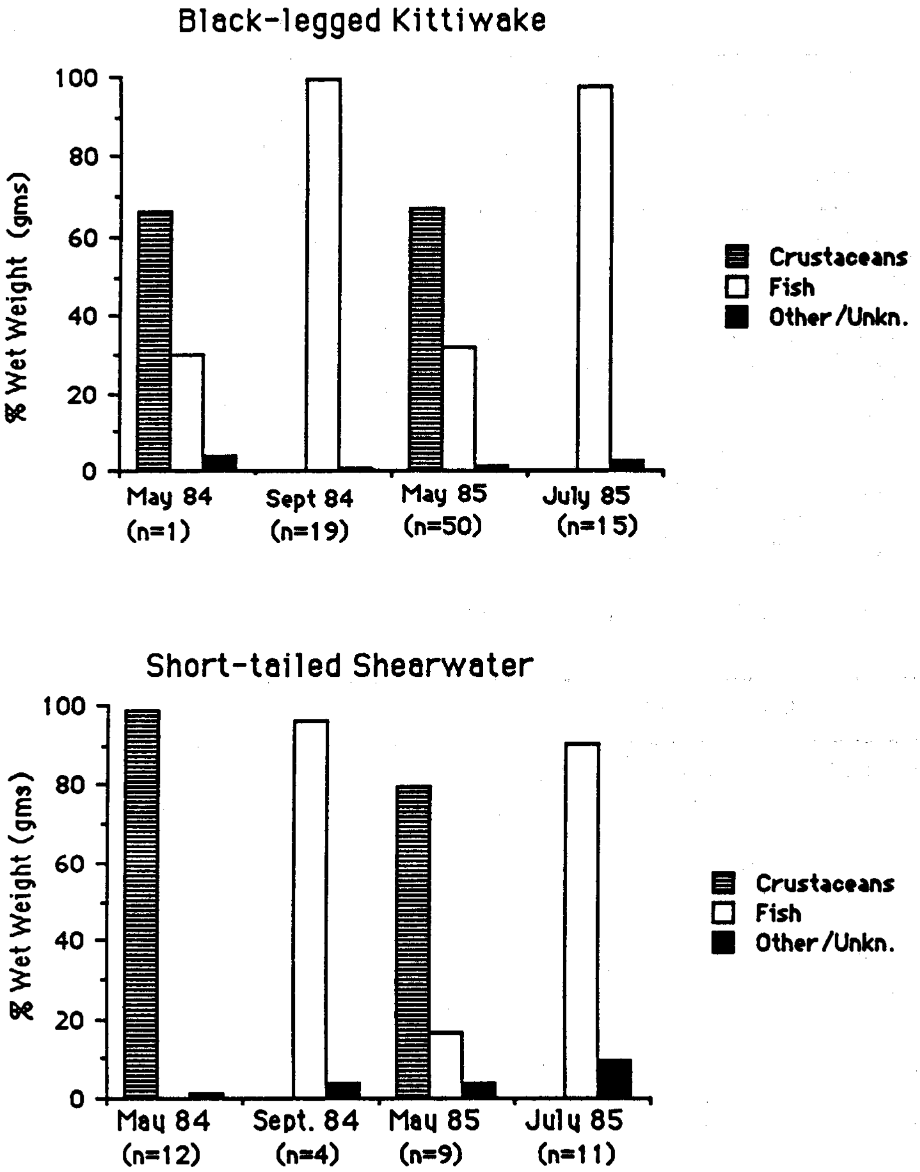
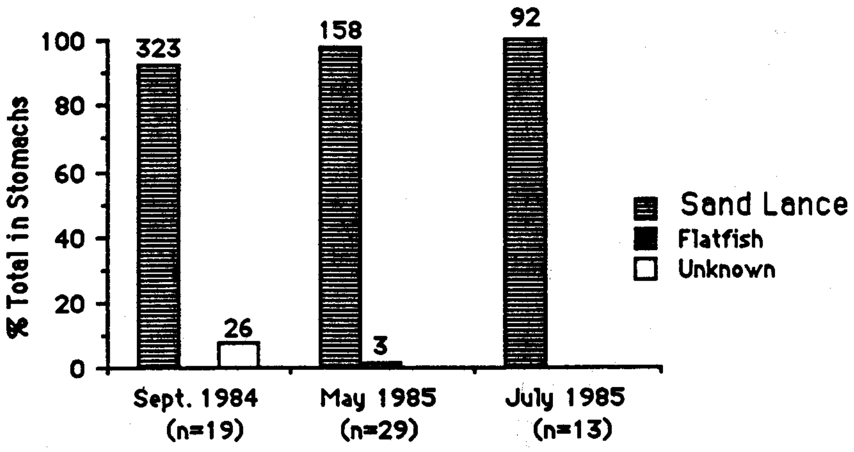


Figure 6.19. Diet Composition of Stomach Contents of Black-legged Kittiwakes and Short-tailed Shearwaters collected in the North Aleutian Shelf area, Bering Sea, Alaska, May 1984 to July 1985.

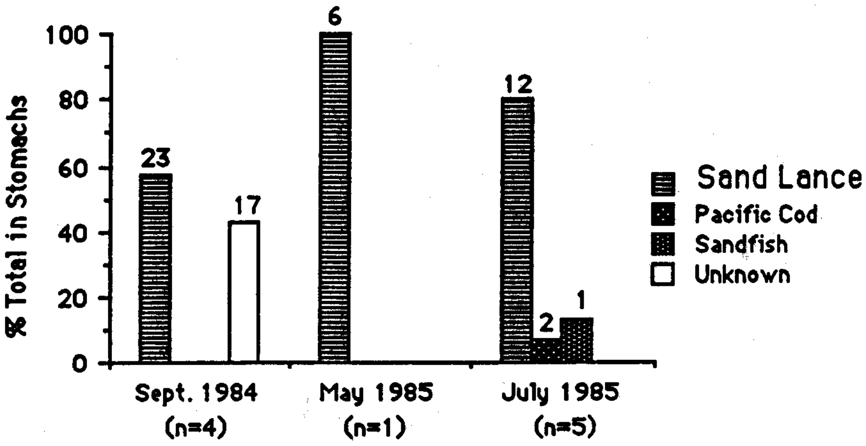
Table 6.13. Organisms consumed by Short-tailed Shearwaters (<u>Puffinus tenuirostris</u>) in nearshore waters of the North Aleutian Shelf, Bering Sea, Alaska.

	1984				1985			
	May (n=12)		Sept. (n=4)		May (n=9)		July (n=11)	
	wet wt.		wet wt.		wet wt.		wet wt.	
Major Taxa	(g)	(%)	(g)	(%)	(g)	(%)	(g)	(%)
Decapods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Euphausiids	379.0	96.7	0.0	0.0	77.0	79.5	tr	tr
Amphipods	0.0	0.0	tr *	tr	0.0	0.0	0.0	0.0
Mysids	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Crustaceans	379.0	96.7	tr	tr	77.0	79.5	tr	tr
Squid	7.5	1.9	tr	tr	0.1	0.1	tr	tr
Jellyfish	tr	tr	0.0	0.0	0.0	0.0	0.0	0.0
Sand lance	0.0	0.0	11.6	23.3	0.0	0.0	0.0	0.0
Other fish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unid. fish	tr	tr	36.1	72.6	16.1	16.6	49.8	90.5
All fish	tr	tr	47.7	95.9	16.1	16.6	49.8	90.5
Other/Unknown**	5.5	1.4	2.0	4.1	3.7	3.8	5.2	9.5
Total	392.0	100.0	49.7	100.0	96.9	100.0	55.0	100.0

* tr = trace amounts (<0.1%) of organisms.
** Sludge, blood clots, otoliths, etc.



Otoliths in Black-legged Kittiwake Stomachs



Otoliths in Short-tailed Shearwater Stomachs

Figure 6.20. Identity of fish otoliths from stomachs of Black-legged Kittiwakes and Short-tailed Shearwaters collected in the North Aleutian Shelf area, Bering Sea, Alaska, September 1984 to July 1985.

Table 6.14. Organisms eaten by Glaucous-winged Gulls (*Larus glaucescens*) in nearshore waters of the North Aleutian Shelf, Bering Sea, Alaska, 1985 .

Major Taxa	September 1984 (n=12) wet weight		January 1985 (n=4) wet weight		May 1985 (n=25) wet weight		July 1985 (n=3) wet weight	
	g	%	g	%	g	%	g	%
All Fish	7.6	53.3	0.0	0.0	96.0	39.0	4.4	61.1
Decapod	0.0	0.0	0.7	2.1	tr	tr	0.0	0.0
Euphausiid	0.0	0.0	0.0	0.0	132.1	53.7	0.0	0.0
Mysid	0.0	0.0	0.0	0.0	0.2	tr	0.0	0.0
Crustaceans	3.6	25.0	2.0	6.0	132.3	53.7	0.0	0.0
Bivalves	0.0	0.0	0.0	0.0	tr	tr	0.0	0.0
Gastropods	0.0	0.0	0.0	0.0	1.1	0.5	0.0	0.0
Molluscs	0.3	1.8	0.0	0.0	1.1	0.5	0.0	0.0
Echinoderms	0.0	0.0	29.5	88.6	tr	tr	0.0	0.0
Unknown/Other	2.8	19.9	1.8	5.4	16.7	6.8	2.8	38.9
TOTAL	14.19	100.0	33.3	100.0	246.1	100.0	7.2	100.0

*tr = trace amounts (<0.1%) organisms.

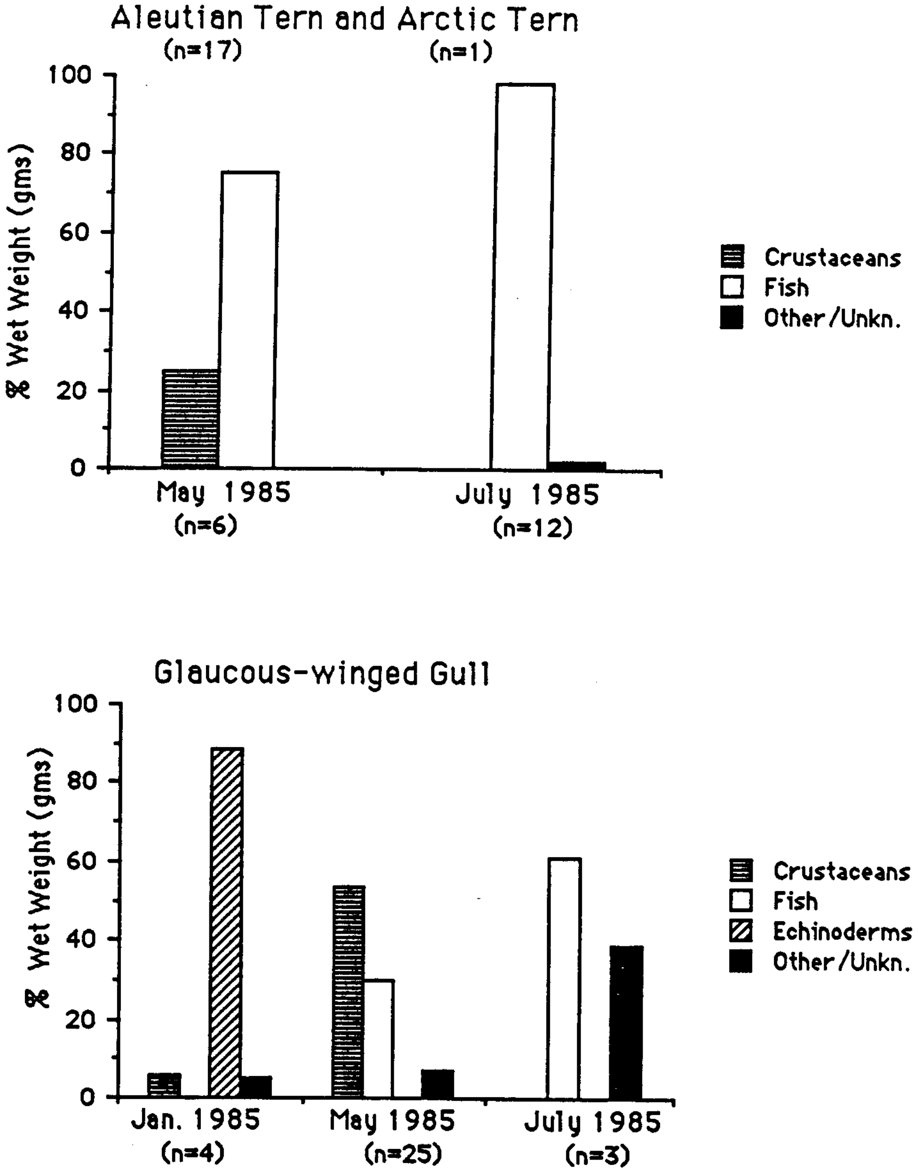


Figure 6.21. Comparisons of stomach contents of terns and Glaucous-winged Gulls collected in the North Aleutian Shelf area, Bering Sea, Alaska, September 1984 to July 1985.

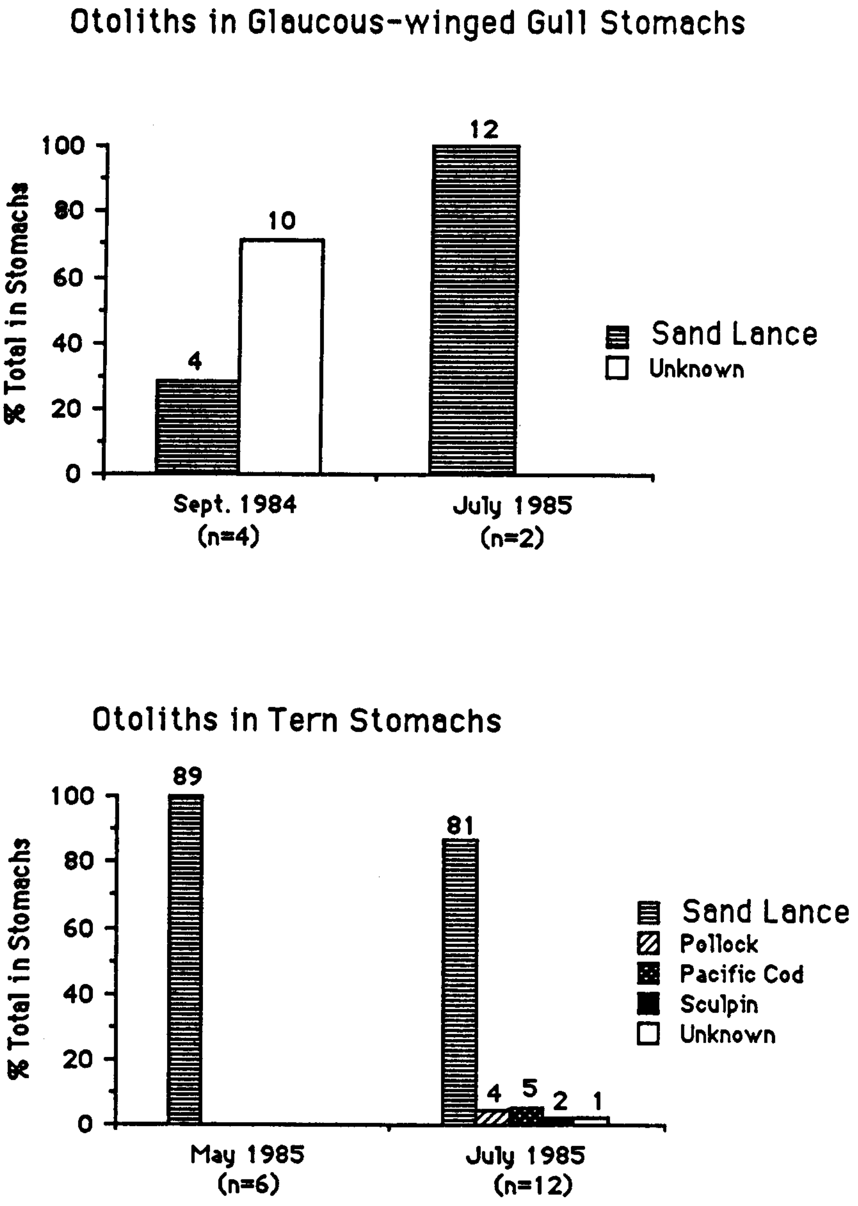


Figure 6.22. Identity of fish otoliths from stomachs of terns and Glaucous-winged Gulls collected in the North Aleutian Shelf area, Bering Sea, Alaska, September 1984 to July 1985.

Samples of terns (primarily Aleutian Terns, see Table 6.11) were collected only during cruises in May and July 1985 (Table 6.15). During those two months, and especially during July, fish (primarily sand lance; Fig. 6.22)comprised the largest proportion of the diet of terns (75% and 98.4%, respectively, of mean wet weight diets for May and July 1985).

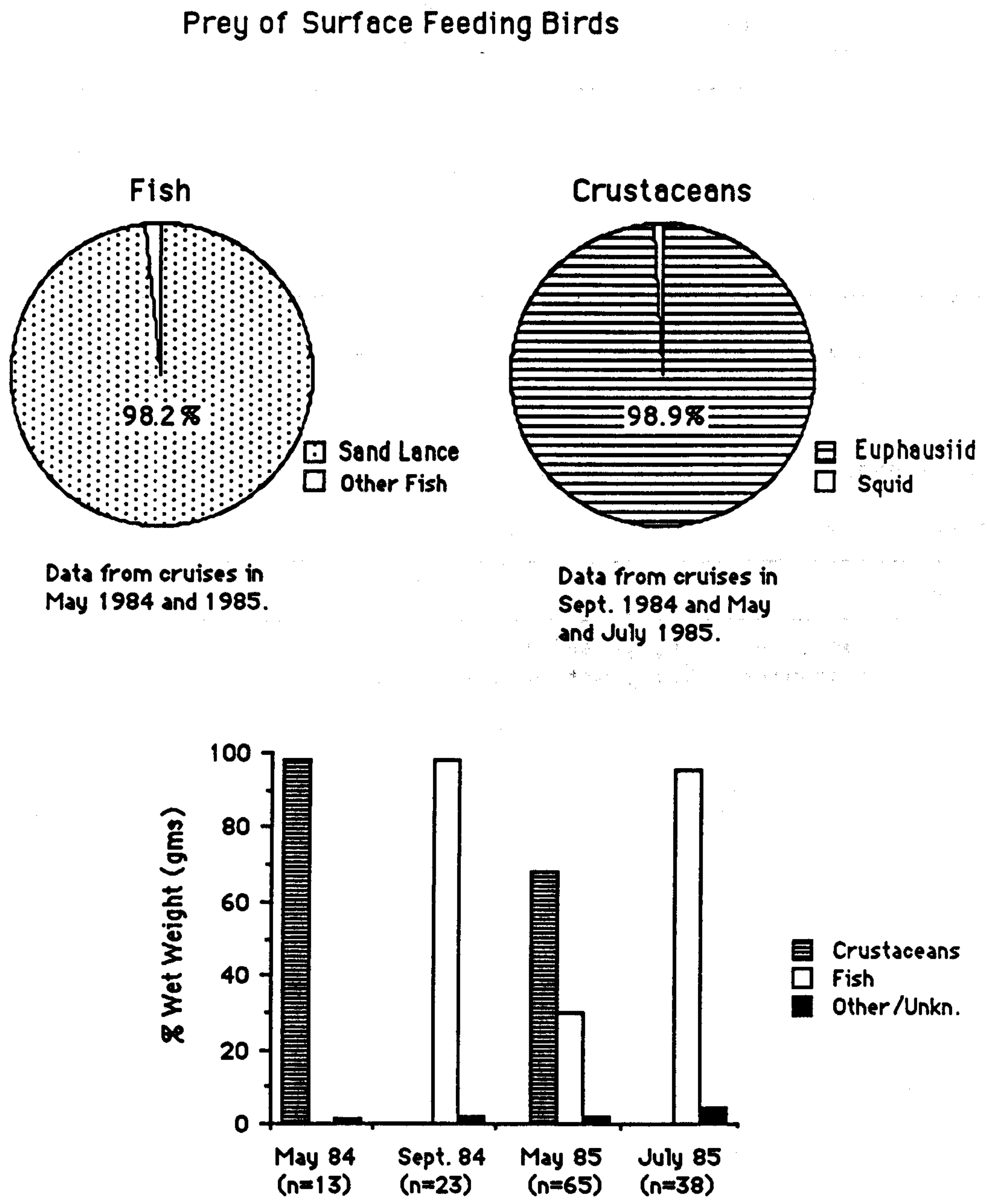
Thus, the diets of the four dominant species or species groups of surface-feeding birds using the NAS study area change drastically between spring (May) and summer-fall (July-September) sampling periods (Fig. 6.23). During May, diets were composed largely of euphausiid crustaceans and secondarily of fish (mainly sand lance in May 1985). By July, and continuing into September, all surface feeding birds that we collected had switched to sand lance as their main prey. Correlated with this finding, euphausiids swarm to the surface in late spring and early summer to breed, dispersing thereafter (at least in daylight hours) to water-column and benthic environments (Ponomareva 1966). Further, Craig (see Section 5.0, this report) found that sand lance were most abundant in the NAS study area during mid- to late summer (July and September cruise periods). Their distribution during these periods was very patchy, as illustrated by very erratic catches-per-unit-effort (CPUE): 0-180,000 fish hr^{-1} in July.

Our observations of surface-feeding seabirds, especially during the May 1985 cruise, indicated that Black-legged Kittiwakes, Short-tailed Shearwaters,and to a lesser extent Glaucous-winged Gulls, concentrated their feeding on patches of prey when the prey animals were near the surface. On 22 and 24 May especially, very dense concentrations of kittiwakes and shearwaters swarmed over surface concentrations of euphausiids and sand lance. Several birds collected from these feeding flocks had stomachs packed with sand lance and euphausiids; the sand lance in these stomachs were dissected and their stomachs were full of euphausiids. Thus, sand lance are present in the study area during spring (though apparently less abundant than in late summer) and apparently feed heavily on the surface swarms of euphausiids (see also 5.0, this report); they are available to surface-feeding birds when they approach the surface. Nevertheless, euphausiids are the most abundant prey of surface feeding seabirds during spring, as reflected in the diets of the birds. Later, during the summer-fall period, when euphausiids are less abundant

Table 6.15. Organisms eaten by terns (Sterna aleutica and Sterna paradisaea) in nearshore waters of the North Aleutian Shelf, Bering Sea, Alaska, 1985.

Major Taxa	May 1985 (n=6) Wet Weight (g)	May 1985 (n=6) Wet Weight (%)	July 1985 (n=12) Wet Weight (g)	July 1985 (n=12) Wet Weight (%)
Sand lance	5.6	42.4	0.0	0.0
Unidentified Fish	4.3	32.6	36.4	98.4
All Fish	9.9	75.0	36.4	98.4
Crustaceans	3.3	25.0	tr	tr
Other/Unknown*	tr	tr	0.6	1.6
TOTAL	13.2	100.0	37.0	100.0

* Blood clots, feathers, parasites, vegetation, sludge, etc.
tr = trace amounts (<0.1 g wet weight) of prey.



Data from cruises in May 1984 and 1985.

Data from cruises in Sept. 1984 and May and July 1985.

Figure 6.23. Stomach contents of surface-feeding birds (139 individuals of four species) collected during four cruises over the North Aleutian Shelf, Bering Sea, Alaska, May 1984 to July 1985. (Sample sizes of the four species are: 85 Black-legged Kittiwakes, 36 Short-tailed Shearwaters, 17 Aleutian Terns, and 1 Arctic Tern; forty-four Glaucous-winged Gulls were not included in this analysis).

and less available, sand lance are probably more abundant in the area and dominate the diets of surface-feeding seabirds.

These results contrast to some extent with other studies. Schneider et al. (1986) and others found that euphausiids (primarily *Thysanoessa raschii*) were the principal prey throughout the summer-fall period for important species of seabirds (primarily Short-tailed Shearwater) in the shallow, well-mixed inner domain (waters generally < 50 m deep). Hunt et al. (1981a) and Schneider et al. (1986) found fish (primarily walleye pollock, *Theragra chalcogramma*) to be the principal prey of seabirds only in outer domain and continental slope waters, close to the shelf-break and near the Pribilof Islands; these authors seldom mention sand lance as an important prey of seabirds near the Pribilofs. However, feeding studies near the Pribilof Islands by others (e.g., Bradstreet 1985) showed that sand lance formed a significant fraction of the diet of Black-legged Kittiwakes during July and August 1984. This was true especially near St. Paul Island (sand lance were 39% and 44.2% of the wet weight diets in July and August, respectively), which is situated in the middle domain some distance from the shelf break community.

In this study, euphausiids dominated the diets of all surface-feeding seabirds in spring and sand lance dominated their diets throughout the summer-fall period. Walleye pollock were conspicuous in their absence from diets of all surface-feeding seabirds during all cruise periods in the NAS study area.

Another unexpected result from this study was the virtual absence of salmonid prey in the diets of surface-feeding birds, even though very large numbers of the smolts of salmonids are reported to pulse through our study area annually (Straty 1981). However, the timing of our cruises and collections probably did not coincide with the major pulses of salmonids, which occur primarily in June (see Section 5.0, this report).

6.5.2.2 Water-Column-Feeding Birds

Red-faced Cormorants were collected during May and July 1985 and September 1984; the diets of these piscivorous birds were dominated by sand lance (Table 6.16, Fig. 6.24), which again suggests that this was the most abundant species of forage fish present in the study area during

Table 6.16. Organisms eaten by Red-faced Cormorants (<u>Phalacrocorax urile</u>) in nearshore waters of the North Aleutian Shelf, Bering Sea, Alaska.

	September 1984 (n=17)		May 1985 (n=9)		July 1985 (n=7)	
	Wet Wt.		Wet Wt.		Wet Wt.	
Major Taxa	(g)	(%)	(g)	(%)	(g)	(%)
Sand lance	154.8	94.8	317.9	93.5	102.4	88.4
All Fish	154.8	94.8	317.9	93.5	102.4	88.4
Crustaceans	0.6	0.4	11.6	3.4	5.1	4.4
Other/Unknown*	7.8	4.8	10.5	3.1	8.4	7.2
Total	163.2	100.0	340.0	100.0	115.9	100.0

* Sludge, rocks, otoliths, nematodes, blood clots, etc.

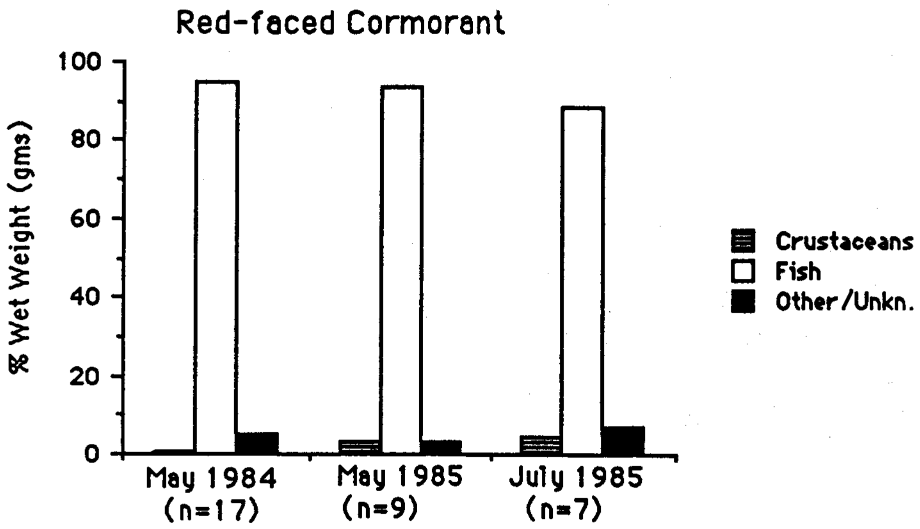


Figure 6.24. Composition of stomach contents of Red-faced Cormorants collected in the North Aleutian Shelf area, Bering Sea, Alaska, May 1984 to July 1985, Alaska.

these periods. The analyses of otoliths found in cormorant stomachs indicated that sand lance were virtually the only species of fish eaten by cormorants during our collection periods (see Fig. 6.25).

Murres, also typically piscivorous, were collected during cruises in May and July (see Tables 6.11 and 6.17). During these two months, the diets of both Common and Thick-billed murres were composed of over 90% fish (Fig. 6.26). Only during the May 1985 cruise did euphausiids form a relatively significant part of the diet of either of the two species of murre (8.8% of wet weight diet of Thick-billed Murre). In all other cruise periods (May 1984 and July 1985), fish comprised over 98.7% of the wet weight diet of each species. The analyses of otoliths taken from murre stomachs indicated that sand lance were virtually the only fish eaten by birds collected in waters 50 m deep or shallower (Fig. 6.25). However, one of the more remarkable results of this study was the finding that stomachs of five murres (one Thick-billed and four Common) collected during July 1985 in waters approximately 70 m deep, had otoliths (a total of 2039) from only walleye pollock. This suggests that the distribution of walleye pollock during the July cruise, and possibly during others, may have beeen restricted to waters beyond the 50-m depth contour. Thus, aside from the small proportion of the May 1985 diet of Thick-billed Murres that consisted of euphausiids (8.8%), sand lance comprised the bulk of the diet of water-column-feeding birds in waters shallower than 50 m (see Fig. 6.27). Otoliths from a sample of murres taken at a 70-m station during July 1985 indicates that pollock may be more common in deeper waters offshore from the NAS study area.

Although the July samples of murres from middle-domain waters are small, the fact that they contained pollock is consistent with the findings of others investigating food sources of seabirds in deeper waters of the Bering Sea shelf. Craig (Section 5.0, this report) confirms that pollock are "most abundant in the deeper portions of the NAS study area, paticularly from about July through September". Apparently after pollock reach sizes of around 35-50 mm, they descend to the bottom and take up a demersal existence, where they might escape being taken by water-column feeders. Craig found that large pollock were present in the demersal zone of the outer portions of the NAS study area. Schneider and Hunt (1982) found walleye pollock to be the principal fish prey of water-column-

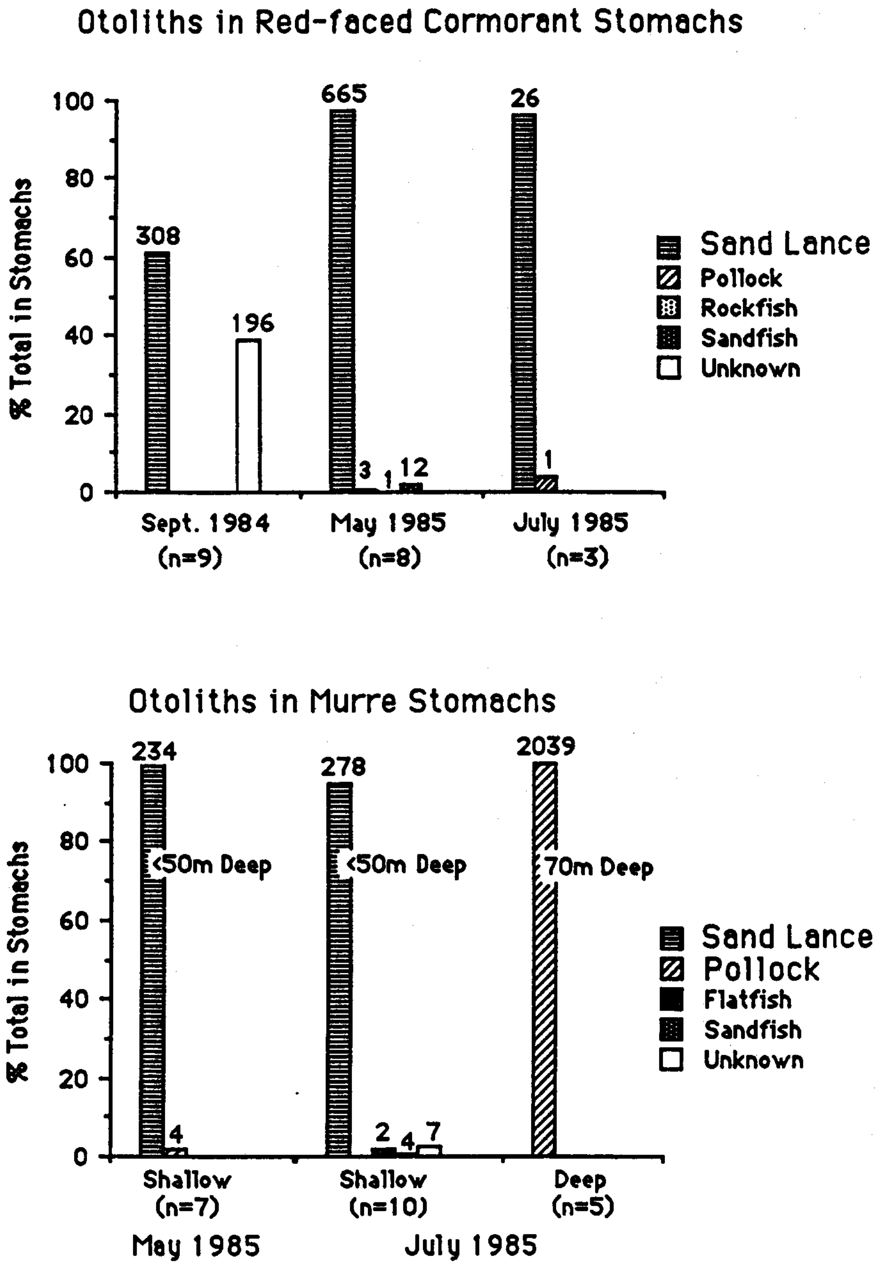


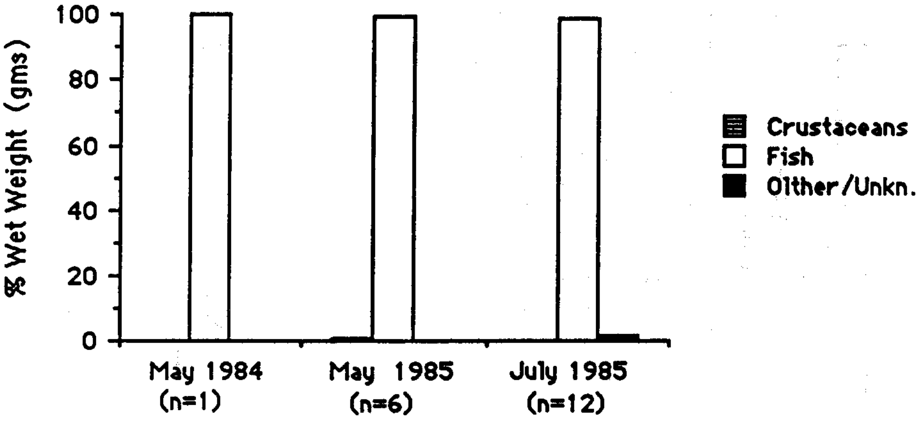
Figure 6.25. Identity of fish otoliths from stomachs of Red-faced Cormorants and murres collected in the North Aleutian Shelf area, Bering Sea, Alaska, September 1984 to July 1985.

Table 6.17. Organisms consumed by murres (Uria spp.) in nearshore waters of the North Aleutian Shelf, Bering Sea, Alaska.

	Common Murre						Thick-billed Murre			
	May 1984 (n=1)		May 1985 (n=6)		July 1985 (n=12)		May 1985 (n=8)		July 1985 (n=4)	
	wet wt.		wet wt.		wet wt.		wet wt.		wet wt.	
Major Taxa	(g)	(%)	(g)	(%)	(g)	(%)	(g)	(%)	(g)	(%)
Sand lance	0.0	0.0	79.2	85.6	44.9	31.5	0.0	0.0	0.0	0.0
Other Fish	0.0	0.0	2.2	2.4	0.0	0.0	0.0	0.0	0.0	0.0
Unid. Fish	4.7	100.0	10.5	11.4	95.7	67.2	24.8	91.2	13.1	100.0
All Fish	4.7	100.0	91.9	99.4	140.6	98.7	24.8	91.2	13.1	100.0
Euphausiids	0.0	0.0	0.5	0.5	0.0	0.0	2.4	8.8	tr	tr
Amphipods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Crustaceans	0.0	0.0	0.5	0.5	0.0	0.0	2.4	8.8	0.0	0.0
Other/Unknown*	0.0	0.0	0.1	0.1	2.0	1.3	0.0	0.0	0.0	0.0
Total	4.7	100.0	92.5	100.0	142.6	100.0	27.2	100.0	13.1	100.0

* Sludge, otoliths, nematodes, blood clots, etc.

Common Murre



Thick-billed Murre

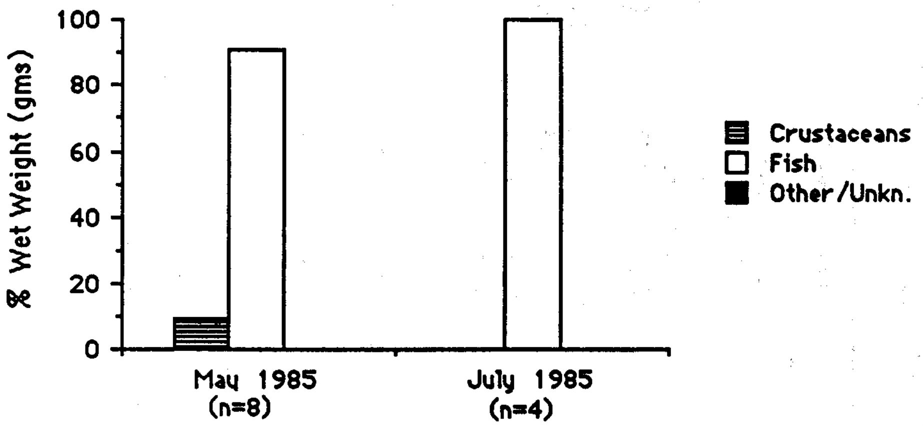


Figure 6.26. Composition of stomach contents of murres collected in the North Aleutian Shelf area, Bering Sea, Alaska, May 1984 to July 1985.

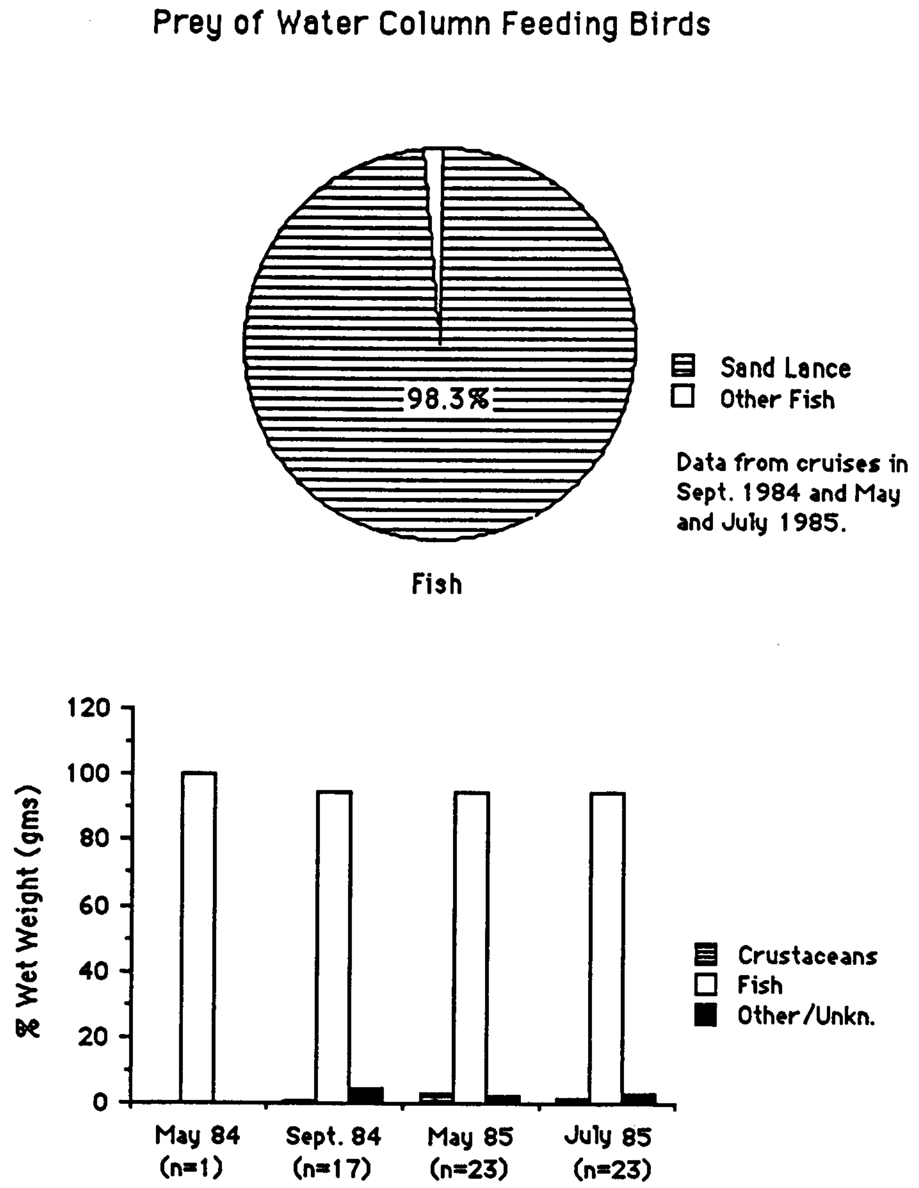


Figure 6.27. Stomach contents of water column feeding birds (64 individuals of three species) collected during four cruises over the North Aleutian Shelf, Bering Sea, Alaska, May 1984 to July 1985. (Sample sizes of the three species are 19 Common Murres, 12 Thick-billed Murres, and 33 Red-faced Cormorants.)

feeding seabirds in deeper waters away from the inner domain. Hunt et al. (1981a) found pollock by far the most important fish in the diet of murres collected near St. George Island, which is very near the deep waters associated with the shelf break community where many seabirds (especially kittiwakes) from St. George Island feed (see Schneider 1982). Sand lance formed only a very minor component of the diets of seabirds studied by Hunt et al. (1981a). In contrast, Bradstreet (1985) found sand lance to form a significant part (23% of the wet weight diets) of foods delivered to Thick-billed Murre chicks on St. Paul Island, which is located in the middle domain and is considerably farther from deep, outer domain and continental slope waters, where pollock are more abundant.

Little is known of the distribution and abundance of sand lance in the southeastern Bering Sea or elsewhere in the Pacific Basin. Dick and Warner (1982) give one of the best overall reviews of the life history of this species in the northeastern Pacific area. They described sand lance as abundant but variable in their distribution near the Kodiak Archipelago. Their distribution from May to October in this area was closely associated with warm, relatively shallow waters over substrates of coarse sand and fine gravel, where they bury themselves when inactive. Thus, the distribution and availability of this species in the NAS area, and possibly throughout the southeastern Bering Sea, is probably restricted by water temperature and the distribution of specific bottom substrate types (also see Macy et al. 1978).

6.5.2.3 Bottom-Feeding Birds

Six species of sea ducks comprise our samples of bottom-feeding birds collected during four cruises in the NAS study area. Scoters (White-winged and Black) were collected during cruises in September 1984 and January, May, and July 1985. Bivalve molluscs formed the largest proportion of the wet-weight diet of scoters during all cruises (Table 6.18). Only during September 1984 was the proportion of bivalve molluscs eaten by scoters less than 94% of the total wet-weight diet; crustaceans formed 21.7% of the diet of scoters during September 1984 (Fig. 6.28). Sanger and Jones (1984) found that White-winged Scoters feeding in Katchemak Bay, Alaska, during winter 1977/78 were generalists on molluscs.

Table 6.18. Organisms eaten by scoters (*Melanitta nigra* and *Melanitta deglandi*) in nearshore waters of the North Aleutian Shelf, Bering Sea, Alaska, 1984 and 1985

	September 1984 (n=27) wet weight		January 1985 (n=2) wet weight		May 1985 (n=5) wet weight		July 1985 (n=2) wet weight	
Major Taxa	(g)	(%)	(g)	(%)	(g)	(%)	(g)	(%)
Bivalves	61.5	66.6	15.9	91.4	9.8	100.0	30.2	99.7
Gastropods	5.9	6.4	0.6	3.4	0.0	0.0	0.0	0.0
Molluscs	67.4	73.0	16.5	94.8	9.8	100.0	30.2	99.7
Crustaceans	20.0	21.7	0.1	0.6	0.0	0.0	0.0	0.0
Polychaetes	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Fish (flesh)	4.8	5.2	0.0	0.0	0.0	0.0	0.0	0.0
Other/Unknown*	0.0	0.0	0.8	4.6	0.0	0.0	0.1	0.3
TOTAL	92.3	100.0	17.4	100.0	9.8	100.0	30.3	100.0

* Rocks, sludge, blood clots, etc.

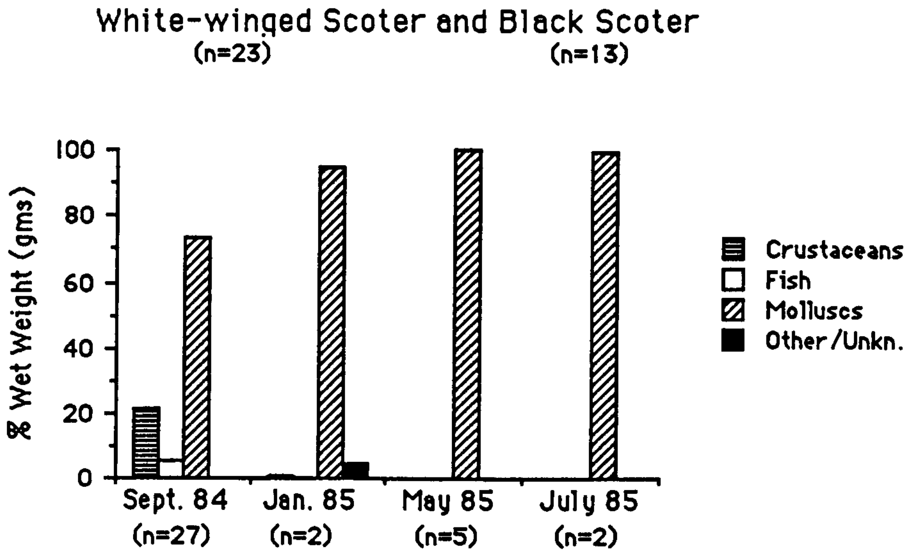


Figure 6.28. Compostion of stomach contents of scoters collected in the North Aleutian Shelf area, Bering Sea, Alaska, September 1984 to July 1985.

Although at least 22 species of molluscs were consumed, the bivalve Protothaca staminea (Pacific littleneck clam) was by far the most important prey consumed. Vermeer and Bourne (1984) also found that molluscs (primarily bivalves) dominated the diets of White-winged, Surf, and Black scoters in British Columbia waters. Large concentrations of scoters occurred at several nearshore locations along the NAS study area, especially during winter. No doubt very large quantities of bivalves are consumed at these locations, which suggests that very large standing stocks occur.

Steller's Eiders were collected during September 1984, when adult females were still in full wing molt, and during May 1985. During both periods bivalve molluscs formed the largest proportion of the diets of this species. In May, however, crustaceans formed a much larger fraction of the total diet (30.3%) than during September (2.4%; see Table 6.19, Fig. 6.29), when most Steller's Eiders preyed heavily on blue mussels Mytilus edulis. In fact, Petersen (1981:261) estimated that during periods of peak abundance (late summer-early fall) at Nelson Lagoon, Steller's Eiders consumed more than 7.3 metric tons of blue mussels-day^{-1} (119-127 g bird^{-1} day^{-1}). Lagoon locations (Nelson Lagoon, Moffet Lagoon, Izembek Lagoon, Bechevin Bay), where large numbers of bottom feeding waterfowl concentrate during fall through spring, are technically outside the main area of interest of this study. However, as mentioned in the discussion above, large concentrations of sea ducks (scoters and eiders) also occur in the shallow nearshore waters outside the lagoons (see also Section 6.1.1 Distribution and Abundance, this chapter), where many of the specimens taken for this study were collected. Information presented by Thomson (Section 4.0, this report) and Cimberg et al. (1984) shows large standing stocks of bivalves at several shallow-water stations along the NAS, especially north of Izembek Lagoon and north of Nelson Lagoon.

King Eiders were collected during cruises in September 1984 and during May and July 1985. The diet of this species varied considerably among these three cruises (Table 6.20, Fig. 6.29). In September, when most adult females were still in full wing molt, bivalve molluscs dominated the diets of King Eiders (this was the case for Steller's Eiders also); over 99% of the total wet-weight diet during this month was bivalves. In May, molluscs comprised almost 70% of the total diet (42.3%

Table 6.19. Organisms eaten by Steller's Eiders (Polysticta stelleri) in nearshore waters of the North Aleutian Shelf, Bering Sea, Alaska.

	September 1984 (n=17)		May 1985 (n=5)	
	Wet Wt.		Wet Wt.	
Major Taxa	(g)	(%)	(g)	(%)
Bivalves	166.0	90.7	32.7	67.4
Gastropods	3.6	2.0	1.1	2.3
Molluscs	169.6	92.7	33.8	69.7
Crustaceans	4.4	2.4	14.7	30.3
Polychaetes	2.8	1.5	0.0	0.0
Vegetation	6.2	3.4	0.0	0.0
Other/Unknown*	0.0	0.0	0.0	0.0
Total	183.0	100.0	48.6	100.0

* Rocks, sludge, cumaceans, nematodes, blood clots, etc.

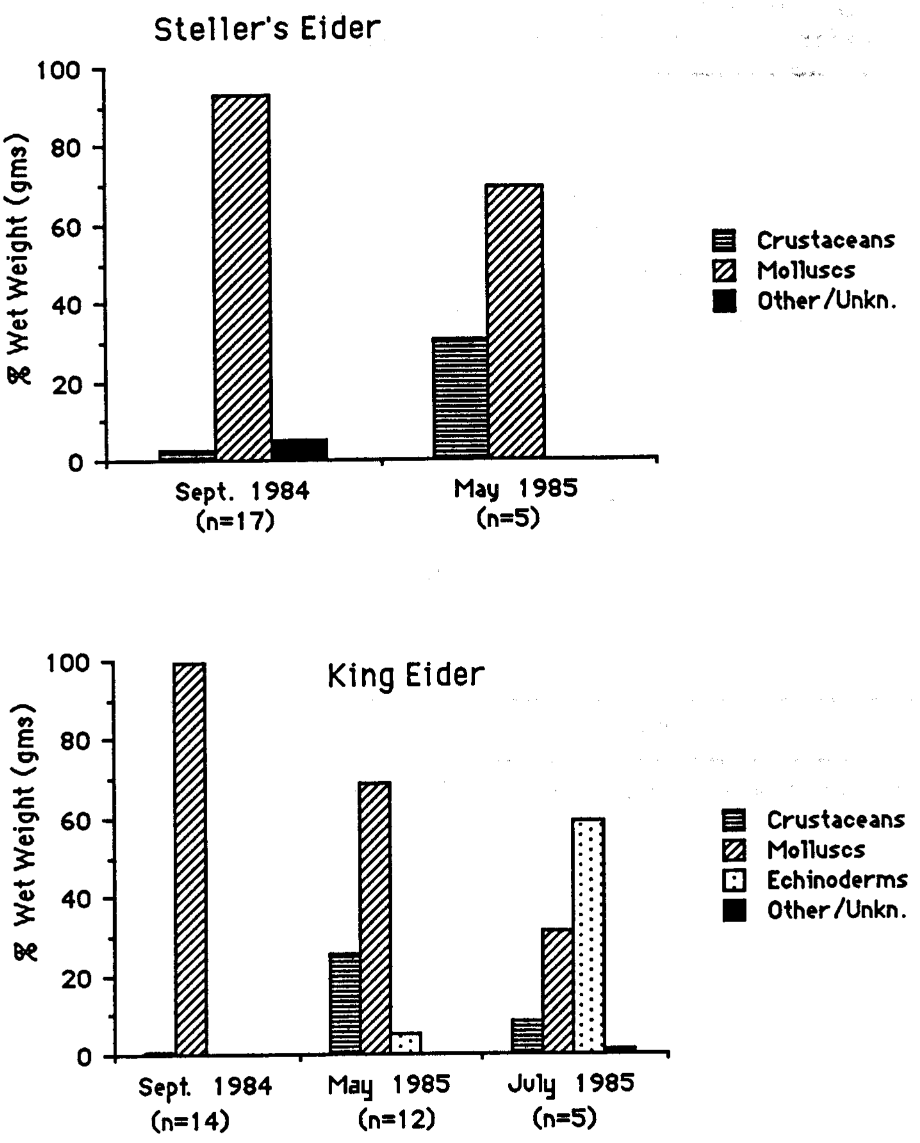


Figure 6.29. Composition of stomach contents of Steller's and King eiders collected in the North Aleutian Shelf area, Bering Sea, Alaska, September 1984 to July 1985.

Table 6.20. Organisms consumed by King Eiders (Somateria spectabilis) in nearshore waters of the North Aleutian Shelf, Bering Sea, Alaska.

Major Taxa	Sept. 1984 (n=14) Wet Wt. (g)	Sept. 1984 (n=14) Wet Wt. (%)	May 1985 (n=12) Wet Wt. (g)	May 1985 (n=12) Wet Wt. (%)	July 1985 (n=5) Wet Wt. (g)	July 1985 (n=5) Wet Wt. (%)
Bivalves	32.5	99.1	47.6	42.3	9.3	14.1
Gastropods	tr*	tr	29.9	26.6	11.2	17.0
Molluscs	32.5	99.1	77.5	68.9	20.5	31.1
Crustaceans	0.2	0.6	28.8	25.5	5.3	8.0
Echinoderm	0.0	0.0	5.9	5.2	39.2	59.4
Polychaetes	tr	tr	0.2	0.2	tr	tr
Fish (flesh)	tr	tr	0.0	0.0	0.0	0.0
Vegetation	0.1	0.3	0.2	0.2	1.0	1.5
Other/Unknown**	0.0	0.0	0.0	0.0	0.0	0.0
Total	32.8	100.0	112.6	100.0	66.0	100.0

* tr = trace amounts (<0.1%) of organisms.

**Rocks, sludge, cumacaens, nematodes, blood clots, etc.

bivalves, 26.6% gastropods), with crustaceans also forming a significant proportion (25.5%) (Fig. 6.29). In July, molluscs comprised only 31.1% of the total King Eider diet; echinoderms represented the largest fraction (59.4%).

Oldsquaws were collected during cruises in January and May 1985. During both of these periods, crustaceans represented the largest fractions of identifiable taxa eaten by Oldsquaws (Fig. 6.30); during January, fish and bivalve molluscs also formed significant fractions of the diet (Table 6.21). Oldsquaws collected during summer months in shallow coastal lagoons along the Alaskan Beaufort Sea coast ate a surprisingly narrow range of prey, primarily two species of mysids and one species of amphipod (Johnson 1984). However, Sanger and Jones (1984) found that Oldsquaws collected during winter 1977/78 in Katchemak Bay, Alaska, ate a wide variety of prey; two species of bivalve molluscs (Stimson's surf clam Spisula polynyma and blue mussel), and surprisingly, sand lance, were the most important prey consumed. Of the few otoliths found in Oldsquaw stomachs in this study, most also were from sand lance (see Fig. 6.31).

Harlequin Ducks were collected during cruises in September 1984 and May 1985. During both of these periods, gastropod molluscs comprised over 90% of the identifiable wet weight diet of this species (Table 6.22). The only other identifiable taxon found in Harlequin Duck stomachs was crustacea, which formed 3.7% of the diet in May (Fig. 6.30). No other recent studies have been conducted of the food habits of Harlequin Duck in the southeastern Bering Sea. However, Dzinbal and Jarvis (1984) found that Harlequin Ducks in Prince William Sound, Alaska, ate a much wider variety of prey (insects, echinoderms, decapods, eelgrass, many different gastropod molluscs) than we found in our study area.

In summary, the diets of the six dominant species of sea ducks that feed on benthos were composed largely of bivalve molluscs, but amphipod crustaceans and echinoderms also were strongly represented during some periods (Fig. 6.32). Several species appeared to specialize in preying on specific taxa, e.g., Harlequin Ducks on gastropod molluscs and scoters on bivalve molluscs. Other species appeared to feed on several different taxa, e.g., Oldsquaws on crustaceans, fish and molluscs, and King and Steller's eiders on bivalve molluscs during September and molluscs and

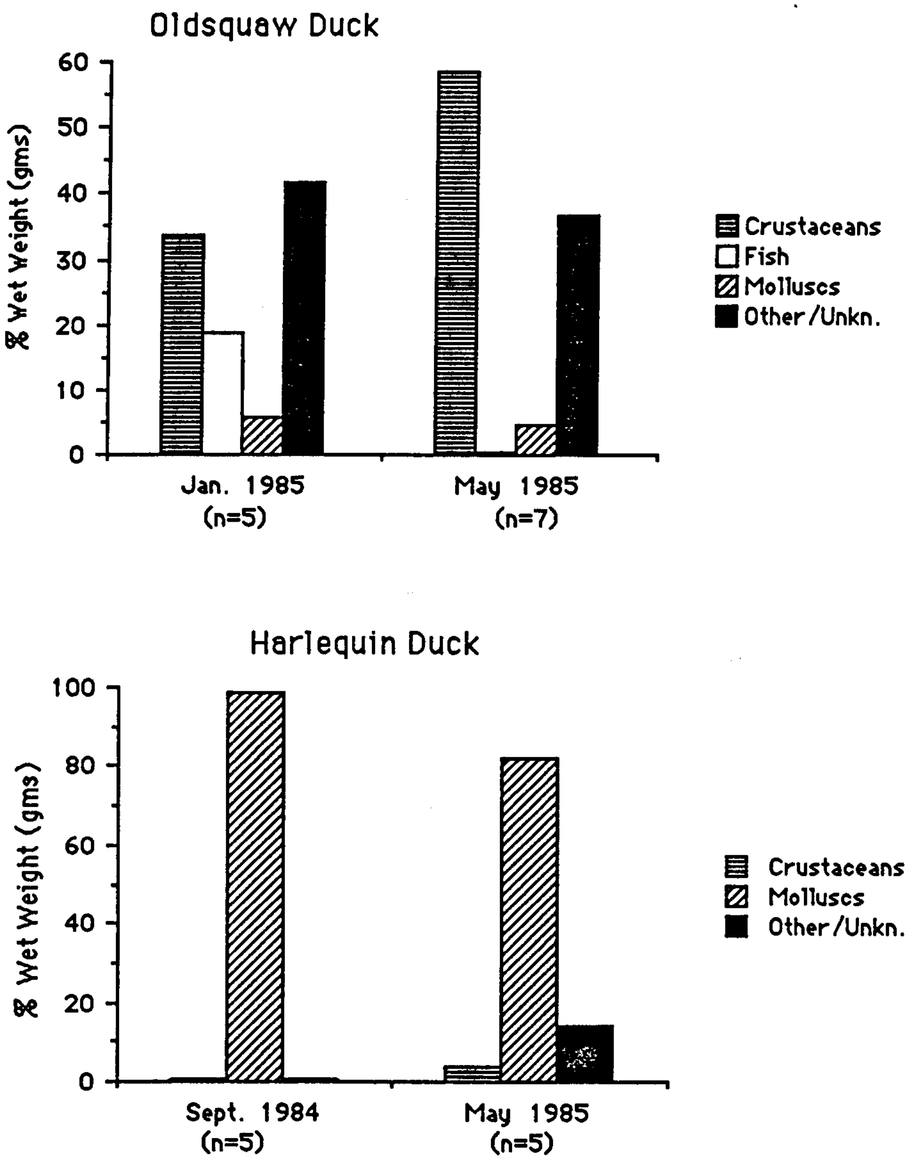
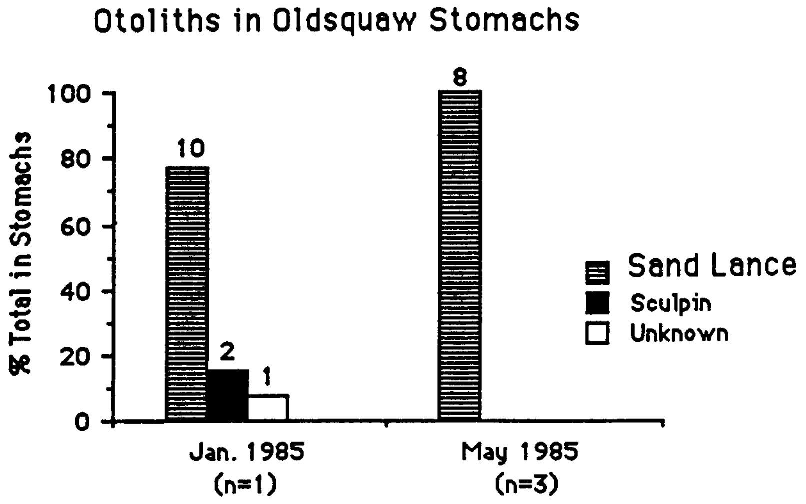


Figure 6.30. Composition of stomach contents of Oldsquaws and Harlequin Ducks collected in the North Aleutian Shelf area, Bering Sea, Alaska, September 1984 to May 1985.

Table 6.21. Organisms eaten by Oldsquaws (Clangula hyemalis) in nearshore waters of the North Aleutian Shelf, Bering Sea, Alaska, 1985.

	January 1985 (n=5) wet weight		May 1985 (n=7) wet weight	
	(g)	(%)	(g)	(%)
Bivalves	0.8	5.8	1.0	3.0
Gastropods	0.0	0.0	0.5	1.5
Molluscs	0.8	5.8	1.5	4.5
Crustaceans	4.7	33.8	19.8	58.6
Fish (flesh)	2.6	18.7	0.1	0.3
Unknown/Other*	5.8	41.7	12.4	36.6
TOTAL	13.9	100.0	33.8	100.0

* Rocks, sludge, blood clots, cumaceans, etc.



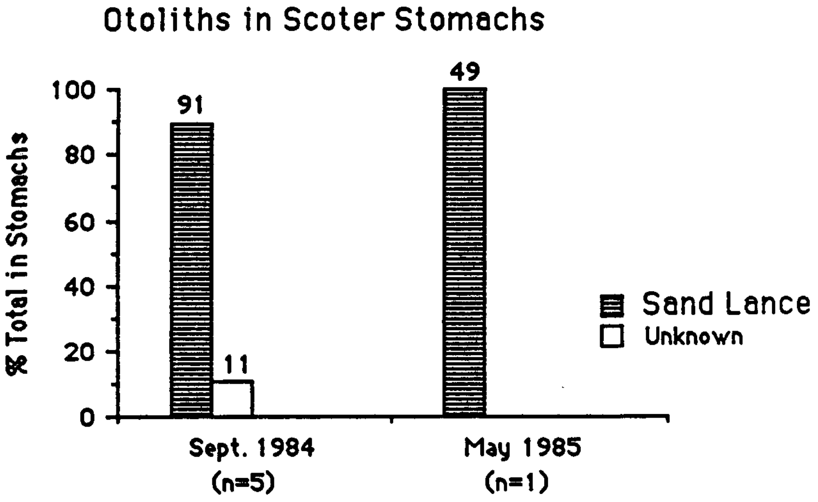


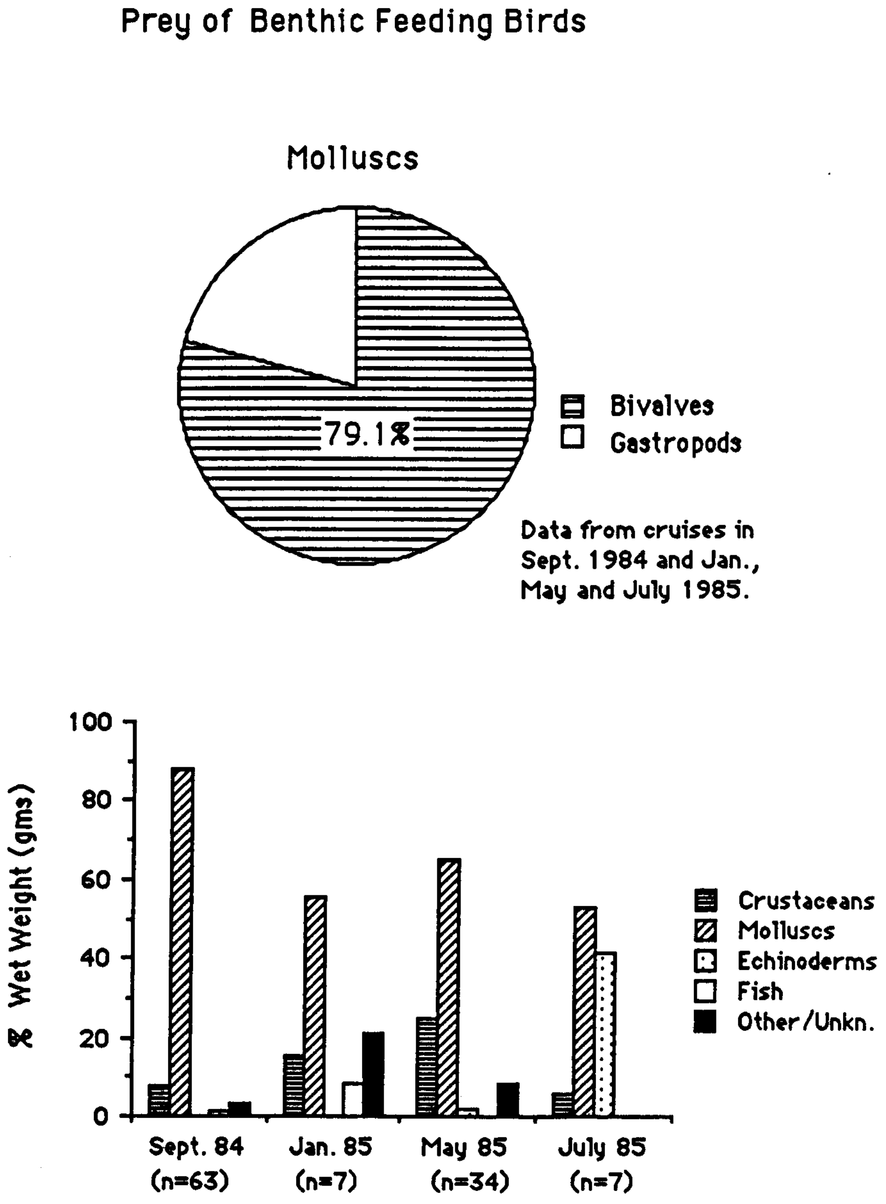
Figure 6.31. Identity of fish otoliths from stomachs of Oldsquaws and scoters collected in the North Aleutian Shelf area, Bering Sea, Alaska, September 1984 and May 1985.

Table 6.22. Organisms eaten by Harlequin Ducks (Histrionicus histrionicus) in nearshore waters of the North Aleutian Shelf, Bering Sea, Alaska, 1984 and 1985.

Major Taxa	September 1984 (n=5) wet weight (g)	September 1984 (n=5) wet weight (%)	May 1985 (n=5) wet weight (g)	May 1985 (n=5) wet weight (%)
Gastropods	5.7	98.9	48.9	82.2
Bivalves	tr	tr	tr	tr
Molluscs	5.7	98.9	48.9	82.2
Crustaceans	tr	0.4	2.2	3.7
Unknown/Other*	tr	0.7	8.4	14.1
TOTAL	5.8	100.0	59.5	100.0

tr = trace amounts (<0.1 g)

* Blood clots, stones, vegetation, feathers, etc.



Data from cruises in Sept. 1984 and Jan., May and July 1985.

Figure 6.32. Composition of stomach contents of benthic feeding birds (111 individuals of six species) collected during four cruises over the North Aleutian Shelf, Bering Sea, Alaska, Sept. 1984 to July 1985. (Sample sizes of the six species are: 12 Oldsquaws, 10 Harlequin Ducks, 22 Steller's Eiders, 31 King Eiders, 23 White-winged Scoters, and 13 Black Scoters.)

crustaceans during May and July. As a group, however, the sea ducks comprising the bottom-feeding birds in the NAS study area relied heavily on molluscan prey.

6.6 RECOMMENDED FURTHER RESEARCH

1. Replication of survey effort to assess the yearly (or shorter term) variability of marine bird use of the area. The present evaluation relies on point surveys (2-3 days) to describe each month.

2. Characterization of areas supporting large concentrations of birds, especially the region north of Unimak Island where major winter aggregations of murres and Crested Auklets have been found.

3. Surveys of the breeding colonies to ascertain the species composition and approximate numbers of attending birds. The seabird colony database reports a great many unidentified murres and cormorants as being present at the NAS colonies.

4. Study effort directed at evaluating the role of oceanographic features, especially the "inner front", in affecting marine bird distribution.

5. Study effort directed at evaluating the role of prey abundance and availability in affecting marine bird distribution.

6. Further studies of seabird trophics in waters offshore from the NAS study area (50-100 m depths), where walleye pollock may replace sand lance as the dominant fish prey of seabirds.

7. More detailed studies of sand lance in the NAS study area, with emphasis on the relationship between bottom substrate type and distribution and abundance of sand lance.

8. Larger collections of most species of sea birds in the NAS study area during the late fall-early spring period (September to April); little seabird trophics information is available for this area during this period.

6.7 ACKNOWLEDGEMENTS

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Section 7

MARINE MAMMALS

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Section 7

MARINE MAMMALS

7.1 SUMMARY

The most common marine mammals reported to occur in the North Aleutian Shelf (NAS) nearshore zone include Steller sea lion, harbor seal, sea otter, Dall porpoise, harbor porpoise, and gray whale. Gray whale populations migrate through the area in spring and fall; small proportions of the populations of each spend the summer there. Northern fur seals migrate through the adjacent Unimak Pass, and small numbers are found in western portions of the NAS study area. Sea otters and harbor seals are present year-round.

Ship surveys in this study in waters beyond about 20 m deep showed sea otters to be by far the most common marine mammal in these areas. Otters seemed to shift their center of abundance from shallow to deeper water in winter.

The mammal component of the biotic community includes both benthic and water-column feeders. Sea otter, the most abundant benthos consumer, eat primarily bivalves. The only other important benthic feeder is the gray whale; it may consume benthic amphipods or crangonid shrimp. The other species--Steller sea lion, northern fur and harbor seals, and porpoises--are mainly piscivorous.

7.2 INTRODUCTION

The southeastern Bering Sea is extremely rich in its marine mammal resources. Marine mammals common in the area include Steller sea lion (Eumetopias jubatus), northern fur seal (Callorhinus ursinus), harbor seal (Phoca vitulina), walrus (Odobenus rosmarus), sea otter (Enhydra lutris), gray whale (Eschrichtius robustus), beluga (Delphinapterus leucas), and harbor porpoise (Phocoena phocoena). Several of these species, however, are relatively scarce within the NAS study area and will not be considered in detail here; these are northern fur seal (found mainly to the west in Unimak Pass and perhaps in deeper waters offshore of the study area), and walrus and beluga (found mainly to the east in Bristol Bay). Walrus formerly hauled out on Amak Island but have not done so for several years.

Small numbers are occasionally found at the extreme east end of our study area at Cape Seniavin and in Port Moller.

A considerable volume of research, much of it sponsored through the OCSEAP program, has described the distribution and abundance of organisms in the study region as a whole. On a site-specific basis, however, relatively few quantitative data are available to describe the timing and abundance of marine mammals in the nearshore zone. Our objectives are to describe in a more quantitative way than was previously possible the timing, abundance, and distribution of marine mammals within this area. Trophic dependencies will also be addressed.

7.3 CURRENT STATE OF KNOWLEDGE

7.3.1 Gray Whale (Eschrichtius robustus)

The gray whale is the most numerous and most thoroughly studied whale occurring within the study area. It is a coastal species with regular, well-defined patterns of migration. Although classed as an endangered species (reduced to low populations by intensive whaling), gray whales in the eastern Pacific have recovered to population levels at or near their pre-exploitation stock size (Braham 1984b). Results of the numerous recent studies of this species have been summarized by Lowry et al. (1982b).

The majority of the estimated 17,000 eastern Pacific gray whales (Rugh 1984, Reilly 1984) migrate annually from breeding/calving lagoons off Baja California and mainland Mexico to feeding grounds that extend from the central Bering Sea northward and eastward into the Chukchi and Beaufort seas. All (or most) of the gray whales entering the Bering Sea travel through Unimak Pass (Braham et al. 1982, Hessing 1981). Scattered groups summer along much of the migration corridor, possibly including areas around Nelson Lagoon and Port Moller in our study area.

The northward migration occurs in two pulses, the first consisting of nonparturient adults and immature animals, the second principally of females and their calves of the year (Braham 1984a). These migrants move through Unimak Pass near the eastern shore (=west coast of Unimak Island) between March and June (Braham 1984a) and then continue along a narrow coastal corridor into Bristol Bay. A few may migrate directly northwestward to the Pribilof and St. Matthew islands.

The southbound migration has not been as clearly described. Based on shore censuses of gray whales migrating through Unimak Pass in fall 1977-79, Rugh (1984) concluded that the exodus from the Bering Sea occurs from late October through early January, with peak numbers passing during mid-November and mid-December. Again gray whales remain very close to shore as they transit the Unimak Pass area (Rugh and Braham 1979). Rugh (1984) found no whales more than 3.7 km west of Unimak Island; the observed animals moved by a median distance of 0.5 km from shore. Most gray whales that Leatherwood et al. (1983) saw in the Bering Sea were within 1 km of shore, many (45%) in waters less than 18 m deep. Gray whales feed almost exclusively on nektobenthic, epifaunal, and infaunal invertebrates (see Nerini 1984 for a complete list of known prey genera). Primary prey in certain parts of the northern Bering and Chukchi seas are ampeliscid and gammarid amphipods that form dense mats. Important amphipods in the summer diet include _Ampelisca_ _macrocephala_, _Lembos_ _arcticus_, _Anonyx_ _nugax_, _Pontoporeia_ _femorata_, _Eusirus_ sp., and _Atylus_ sp. (Tomilin 1957).

Gray whales (contrary to previous belief) apparently feed during migration (Braham 1984a), although the frequency and intensity of feeding during migration is much less than during the summer. Some feeding activity has been observed in the NAS area. Gill and Hall (1983), during an April aerial survey, classified 50% of the whales seen along Unimak Island as feeding. Gray whales these authors saw feeding in the Nelson Lagoon area were believed to be preying on shrimp (Gill and Hall 1983). Leatherwood et al. (1983) observed gray whale feeding behavior in the Port Moller/Nelson Lagoon area on their September 1982 survey.

The summer distribution of gray whales is undoubtedly strongly affected by the distribution of their favored prey. They probably feed where prey densities are unusually high (Lowry et al. 1982). In the northern Bering Sea, feeding activities of the whales are highest in areas with a higher than average standing crop of amphipods (Thomson and Martin 1983). Virtually nothing is known of the identity, distribution, or abundance of their prey in the NAS study area.

Gray whales in the eastern Pacific were once severely depleted by commercial whaling but have in recent years, in the absence of commercial hunting, recovered to what is probably near the pre-exploitation population size (Lowry et al. 1982b). Whether their population will continue to grow, and whether it will eventually become limited by shortages of food, are not known.

7.3.2 Dall's Porpoise (Phocoenoides dalli)

Dall's porpoise is present year-round in the Bering Sea but, because it is more characteristic of deeper waters, its status in the NAS is uncertain. It is distributed widely within the cool temperate to subpolar waters of the North Pacific; most sightings in the Gulf of Alaska have been made in waters in the 7^{o} to $14^{o}C$ range (Braham and Mercer 1978).

Dall's porpoises are most abundant in deep pelagic waters and in areas along the continental shelf break. Summer observations, particularly June and July (e.g., Wahl 1978), indicate that Dall's porpoise are abundant near the Aleutian Islands and along the edge of the continental shelf, particularly from the Pribilof Islands to Unimak Pass (Fig. 7.1).

Leatherwood et al. (1983) show Dall's porpoise being widespread in the Bering Sea but scarce or absent from the NAS and most other shallow areas. Migratory movements are not well understood but seasonal movements are evidently present (Braham et al. 1982). The distribution shifts southward in winter, with some animals leaving the Bering Sea (Fiscus 1980).

Dall's porpoises feed primarily upon a deepwater-based food web. Small meso- and bathypelagic fishes and cephalopods are the primary prey types. Squid, especially those of the family Gonatidae, are heavily utilized by Dall's porpoise. Myctophids constitute over 94% of all the fish consumed by Dall's porpoise (Crawford 1981), with capelin, herring, hake, sand lance, cod, and deep-sea smelts also constituents of their diet. Many of these prey species undergo a diel vertical migration toward the surface at night. Preliminary data suggest that Dall's porpoises take advantage of this movement by feeding primarily at night. Taxa occurring in stomachs of seven animals collected near Unimak Pass and in the Bering Sea were as follows (# stomachs in parentheses, 1 stomach was empty): squid (3), capelin (3), and pollock (1). Available data have not been

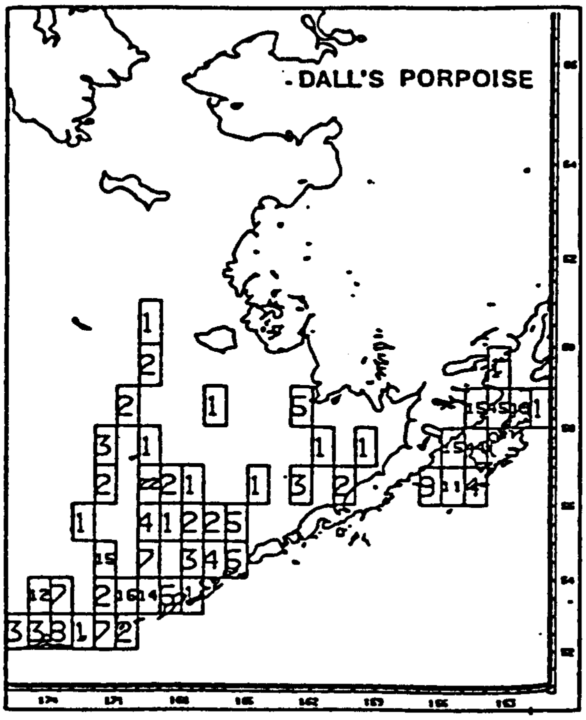

Figure 7.1. Distribution of Dall porpoise (individuals sighted) in 1° blocks in the southeastern Bering Sea (1982-1983). From Leatherwood et al. (1983).

examined for seasonal and regional feeding patterns. Since almost all samples have been collected during the summer months, they are probably not adequate to examine seasonal dietary differences.

7.3.3 Harbor Porpoise (Phocoena phocoena)

Little detailed information is available regarding the distribution of these small but common cetaceans. In southern portions of their range, they are generally seen near the coast in waters less than 20 m deep (Leatherwood and Reeves 1978). Seasonal shifts in abundance suggest that migrations of some sort occur (Leatherwood and Reeves 1978) but data are insufficient to detail the patterns. Leatherwood et al. (1983) report that harbor porpoises are almost entirely absent from the Bering Sea in winter. Leatherwood et al. (1983) frequently recorded harbor porpoises within Bristol Bay, generally (79%) nearshore of the 128 m contour. They show only two sightings within our NAS study area; these were off Izembek Lagoon during the spring.

Stomachs from only three harbor porpoises taken in the Bering Sea have been examined (Frost and Lowry 1981). All were animals caught in salmon nets in Norton Sound. Contents of all three consisted principally of small fishes and small amounts of benthic crustaceans. Based on identifiable remains (principally otoliths), 31 of 34 fishes eaten were saffron cod. In the Atlantic, herring, cod, and sand lance are major prey (Rae 1973, Smith and Gaskin 1974).

7.3.4 Steller Sea Lion (Eumetopias jubatus)

The Steller sea lion ranges north in the North Pacific Ocean from California and Japan to the Pribilof Islands in the Bering Sea (Fig. 7.2). The total Alaska population is about 200,000 (Braham et al. 1980). Sea lions haul out in the study area from mid-March to mid-October. Pupping occurs in June (Braham et al. 1977). Sea Lion Rock near Amak Island is the only large breeding rookery on the north side of the Alaska Peninsula (Fig. 7.3), and Amak Island is used as a haulout site. About 4000 animals may use Amak Island and Sea Lion Rock; a few males and subadults currently haul out at other locations in the study area, including sites on Unimak Island (Frost et al. 1983).

The total estimated population for the eastern Aleutians (including Amak Island and Sea Lion Rock) is 30,000. The number of sea lions within the area of interest has been changing markedly over the past couple of decades, therefore population estimates for the area and for particular colonies/haulout areas should not be relied on for more than general indices of current abundance. During winter there is apparently an influx of sea lions into the eastern Aleutians and northeastern Pacific Ocean.

Most studies of Steller sea lion food habits have been made in the Gulf of Alaska. Here, fish represented 73% of stomach contents, with walleye pollock accounting for 58% of total volume (Calkins and Pitcher 1983). Fiscus and Baines (1966) reported on a small sample (7) from the Unimak Pass area and found the prey ranking in order of importance to be capelin, sand lance, and sculpins. Pollock comprised the majority of stomach contents of four sea lions collected near the Pribilof Islands (Lowry et al. 1982b). In other areas as well, fish appear to be the main prey (Schusterman 1981). Major long-term diet changes in relation to changes in the composition of fish stocks have been documented in the Gulf of Alaska (Calkins and Pitcher 1983).

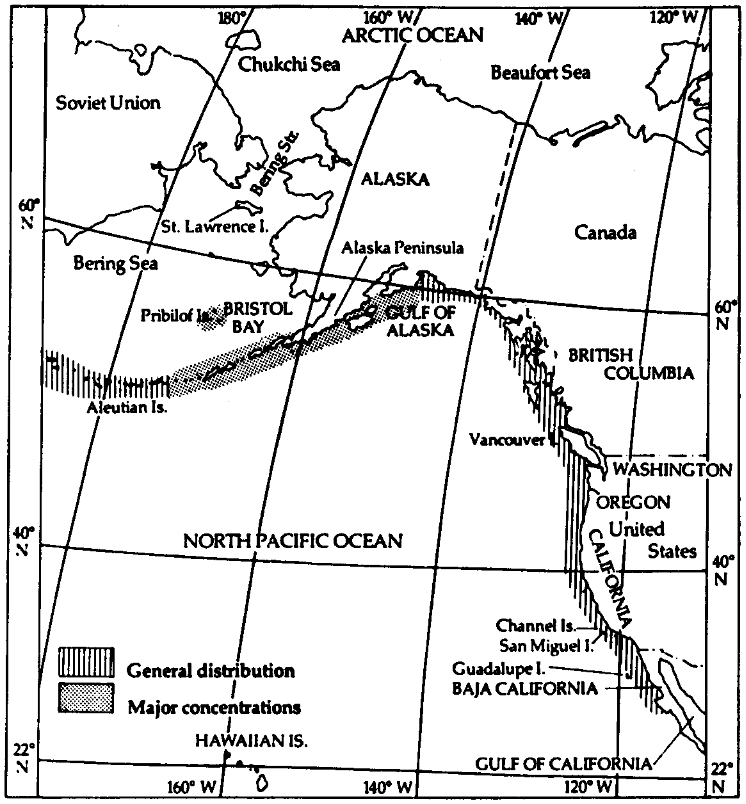

Figure 7.2. Steller sea lion distribution. From Gentry and Withrow (1978).

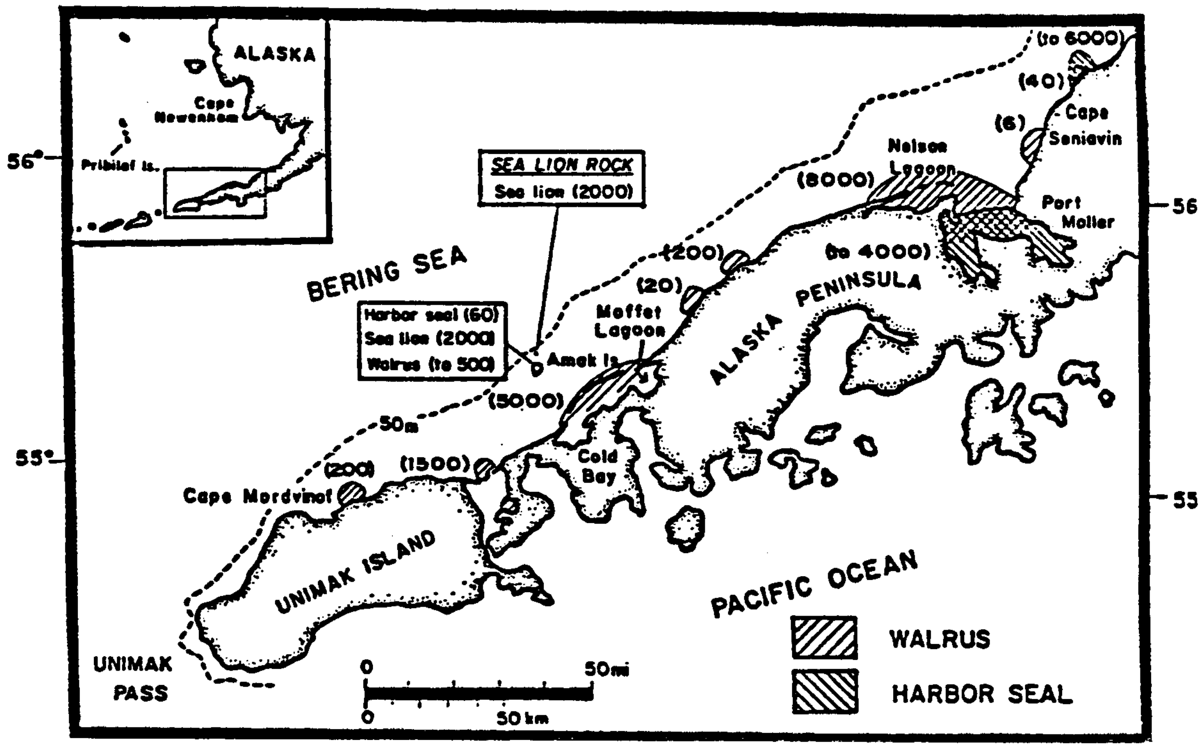

Figure 7.3. Haulout sites used by harbor seals, sea lions, and walrus on the North Aleutian Shelf, with approximate numbers in brackets. From Frost et al. (1983).

Generally, sea lions forage over the continental shelf in water depths of less than 90 m (Kenyon and Rice 1961) but Leatherwood et al. (1983) found some animals at and beyond the shelf break. They use traditional haulout sites for breeding and for resting (males, subadults) and it is near these areas that most sea lions appear to be concentrated. Fiscus and Baines (1966) reported that sea lions in Unimak Pass foraged 5 to 15 miles away from their haulout areas. Little is known about factors that regulate sea lion abundance. In the last 20 years, sea lion populations have declined about 50% in the study area (Braham et al. 1980, Gentry and Withrow 1978). Counts at the haulout areas on Umimak Island Island, including Sea Lion Point/Cape Sarichef, Oksenof Point, and Cape Mordvinof, have been as high as 4000 in the past (1960) but were less than 100 in 1975-77. Postulated causes of the sea lion decline in the study area include (1) migration to the west, (2) decrease in reproductive success due to pathogens, (3) commercial harvesting, and (4) increased competition with commercial fisheries for food. Off California, Ainley et al. (1982) have shown a relationship between the abundance of Pacific whiting and seasonal fluctuations in sea lion numbers. The apparent sea lion decline in the eastern Aleutians corresponds to a concurrent increase in commercial groundfish fisheries for preferred sea lion foods (Braham et al. 1980). Fowler (1982) has recently suggested that entanglement with net fragments in areas of intense foreign fishing may be a significant (>5%) source of mortality for fur seals, and the same may be true for sea lions. King (1983) lists the pathogen Leptospira pomona as possibly being responsible.

7.3.5 Harbor Seal (Phoca vitulina)

The harbor seal occupies ice-free coastal waters from the Bering Sea to Baja California (Newby 1978) (Fig. 7.4). The southeastern Bering Sea population of harbor seals is thought to number about 30,000 to 35,000 (Braham et al. 1977). Most of these are found along the north Alaska Peninsula and eastern Aleutian Islands (Frost et al. 1983).

Harbor seals occur in littoral waters throughout the area of interest. There are substantial seasonal movements but no large-scale migrations (Frost et al. 1983). During summer, local movements are made for the purposes of feeding and breeding (Bigg 1981). Major haul-out

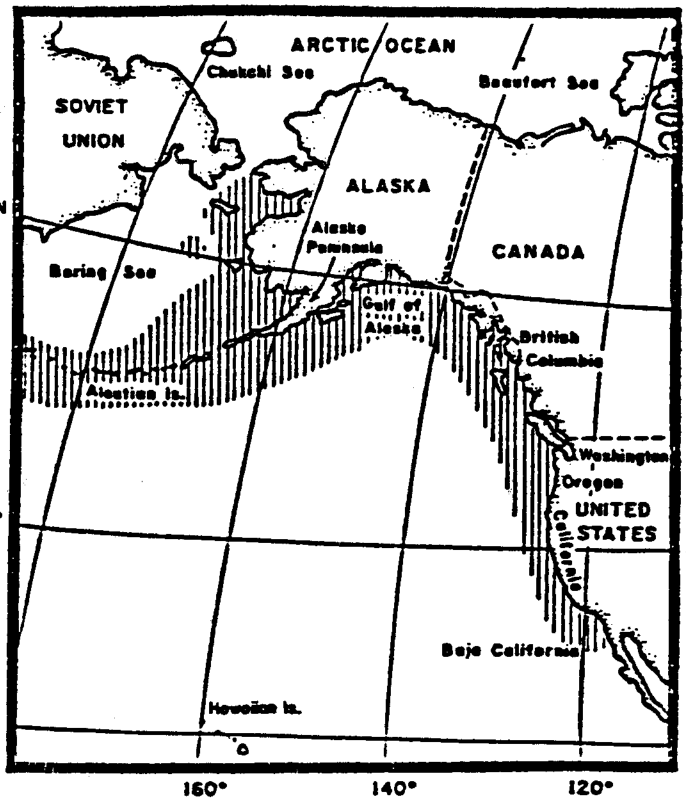

Figure 7.4. Pacific harbor seal distribution. From Newby (1978).

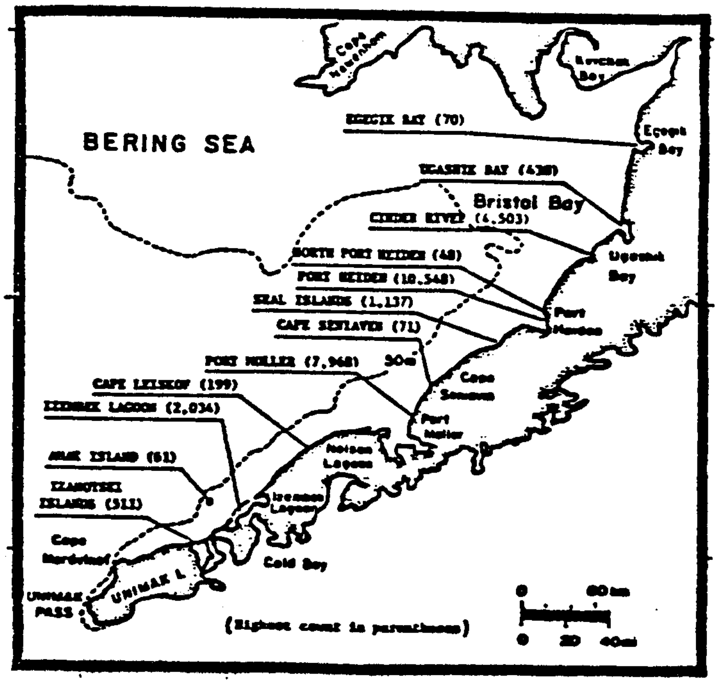

Figure 7.5. Locations of harbor seal concentration areas on the north side of the Alaska Peninsula with highest total sighted at each location by Everitt and Braham (1980) from 1975 to 1977. After Lowry et al. (1982b).

areas in the primary study area are in the False Pass region, Izembek Lagoon/Moffet Lagoon, and Nelson Lagoon/Port Moller regions (Fig. 7.5) (Frost et al. 1983); outside the study area large numbers are found at Port Heiden and Cinder River. Smaller numbers are found in other areas. Haulouts are used for resting, molting, and care of young. Seals haul out on sand bars and other areas exposed by the tides and more animals have been observed hauled out at low than high tides (Everitt and Braham 1980). Peak use of haulout areas occurs during the molt in June and July and apparently tapers off in September and October, after which seals spend more time in the water.

The harbor seal preys primarily on fish. In the Gulf of Alaska fish (mainly pollock and capelin) accounted for 75% of occurrences of all items in stomachs (Pitcher 1980). Off Amchitka Island, harbor seals had fed on Atka mackerel and to a much lesser extent on octopus (Kenyon 1965). Nineteen harbor seals collected in fall in the southeastern Bering Sea had eaten mainly sand lance, smelt, and sculpins (Table 7.1).

Major geographical differences sometimes exist in prey consumed (Lowry et al. 1982). Lowry et al. (1979) reported that seals collected in three different locations in the Aleutian Islands had different items in their stomachs. Pollock and cod were found in three stomachs from Unalaska Island. Five seal stomachs from Akun Island contained primarily Pacific cod, octopus, and pollock (Lowry et al. 1982b).

In summer, the harbor seal hauls out at traditional sites on offshore rocks and sand and gravel bars and spits (Frost et al. 1983). Its abundance and distribution may be dependent on the abundance and distribution of its principal prey (Calkins and Pitcher 1983) as well as the availability of haulout sites. It is restricted in its distribution northward in winter by the occurrence of sea ice.

7.3.6 Sea Otter (Enhydra lutris)

Most of the world's sea otters are found in Alaskan waters (Fig. 7.6). Sea otters were formerly widespread and abundant near land throughout the southern Bering Sea, but fur hunting reduced their population to a small colony near Unimak Island and perhaps a few individuals in the Fox Islands by the beginning of the present century. During the past 70 years, however, the number of sea otters has increased

Table 7.1. Rank order of importance of major items in stomachs of harbor seals collected in the southeastern Bering Sea, 4-12 October 1981. Numbers in parentheses indicate the estimated total number of fishes of each group consumed. Sample sizes include only stomachs containing food (from Lowry et al. 1982b).

Rank	Nunivak Island n=2	Cape Peirce n=3	Port Heiden n=5	Port Moller n=4	Akun Island n=5
1	Greenling (12)	Rainbow smelt(42)	Sculpins (87)	Sand lance (250)	Pacific cod (5)
2	Sculpins (1)	Greenling (2)	Sand lance (63)	Pollock (10)	Octopus
3		Lamprey (1)	Flatfishes (9)		Pollock (3)
4			Pollock (8)		Pacific Halibut(2)
5			Pacific cod (4)		Rockfishes (1)
6			Rainbow smelt (4)		Sculpins (1)

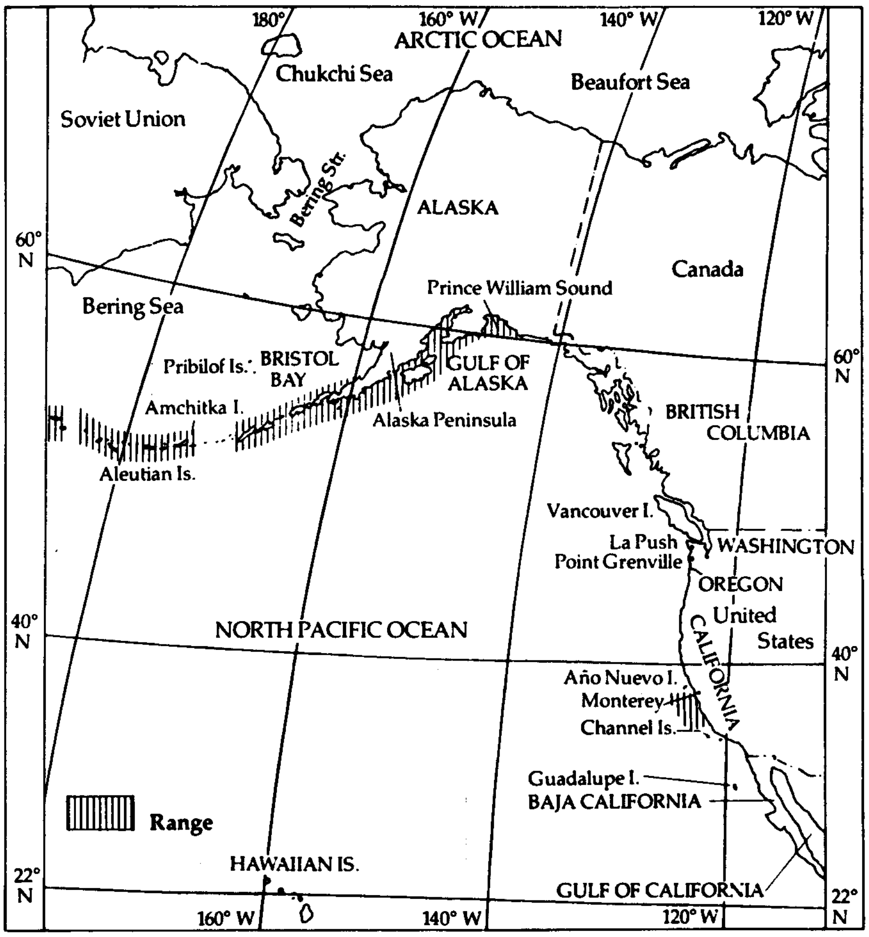

Figure 7.6. Sea otter distribution. From Kenyon (1978).

remarkably, though large areas of uninhabited or partly repopulated habitat remain (Schneider 1981).

The presently-growing Alaska population of sea otters may be over 100,000 (Lowry et al. 1982); 11,700 to 17,200 of these are found on the north side of the Alaska Peninsula (Schneider 1981, Frost et al. 1983). Sea otters occur all along the coast of the study area between Unimak Island and Port Moller, but most are found from Cape Mordvinof to the Moffet Lagoon area (Fig. 7.7) (Frost et al. 1983). From mid-June to mid-July large numbers are found in the Izembek/Moffet Lagoon area; highest densities are found within the 40-m isobath (Schneider 1981). Recent work (Cimberg et al. 1984) shows that a large proportion of this population probably migrates out of the area (south?) in winter. Leatherwood et al. (1983) found sea otters to be present year-round on the north side of the

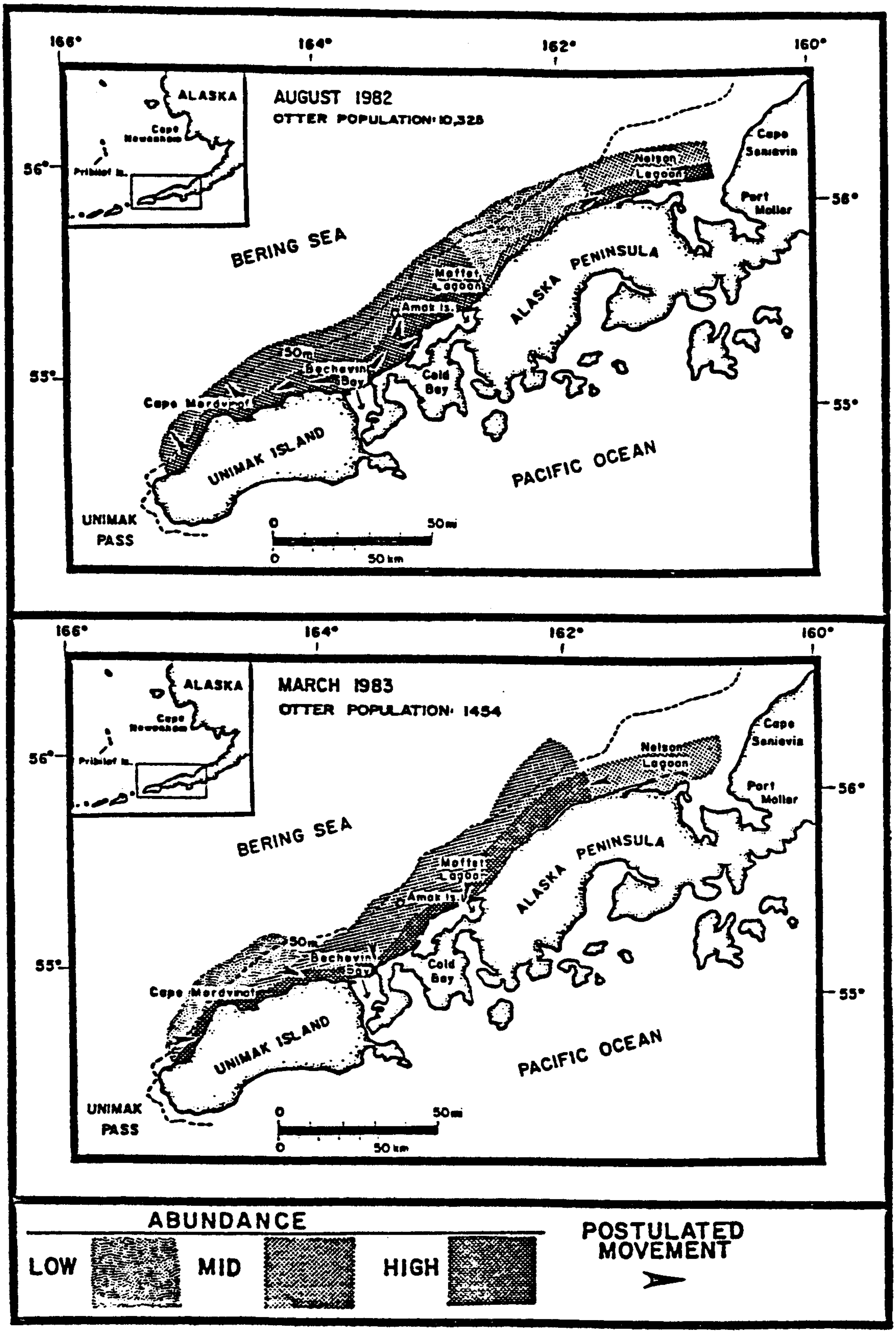

Figure 7.7. Sea otter distribution and abundance on the North Aleutian Shelf in winter (March) and summer (August). From Cimberg et al. (1984).

Alaska Peninsula, close to shore during winter and spring but more dispersed (occurring further offshore) during summer.

Sea otters are shallow-water animals rarely seen in water deeper than 55 m. Leatherwood et al. (1983) did find "significant" numbers of individuals to depths of 128 m. Distribution and movements within the Bering Sea have been described by Schneider (1981). The area of highest abundance is entirely within our area of interest, extending from mid-Unimak Island east to beyond Izembek Lagoon. Sea otters eat a wide variety of bottom-dwelling invertebrates (Calkins 1978), but also eat fishes when invertebrate populations are depleted. (Kenyon 1969, Estes et al. 1982). Sea urchins appear to be the preferred food of the sea otter (Estes et al. 1982). But as the sea otter population has increased in some areas in the Aleutian Islands, the diversity of prey has increased, sea urchins have decreased in relative importance (Estes and Palmisano 1974), and fish and molluscs have become more important. This and other evidence suggests that sea otters will often deplete favored prey, necessitating an eventual switch to less preferred items.

The few scat samples that have been collected from the NAS study area indicate that the otters there feed mainly on bivalves (mussels), crabs, echinoderms (sand dollars), and fish (yellowfin sole) (Cimberg et al. 1984). (Studies relying on scat analyses do not permit direct evaluation of the proportion each taxon contributes to the overall diet; e.g., sand dollars have much more indigestable material in relation to flesh than do flatfish.) Kenyon (1969) reported on three sea otters collected in 15-20 fathoms of water north of Unimak Island (July 1960). By volume, the stomachs contained predominantly clams, hermit crabs, and fish (greenling), all benthic species.

Sea ice apparently limits sea otter distribution northward, and unusually heavy ice has in some years caused large-scale mortality, or at least temporary displacement, of populations in the study area (Schneider and Faro 1975). Colder waters in the NAS in winter apparently displace some otter prey (flatfishes, crabs) to deeper waters farther offshore, perhaps causing the reported exodus of much of the otter population in winter (Cimberg et al. 1984). At present sea otters seem to have reached equilibrium density in some areas (e.g., Amchitka Island, Estes et al. 1982), where their populations are apparently regulated by food supply.

Their densities are higher in some coastal habitats (e.g., rocky areas with macroalgae, extensive shallow nearshore areas) than in others, presumably because of a better food supply.

7.4 METHODS

7.4.1 Distribution and Abundance

Information on distributions and abundances of marine mammals was collected by aerial and shipboard surveys, conducted simultaneously with marine bird surveys. A detailed description of these methods is presented in Section 6.4, this report.

7.4.2 Trophic Relationships

New information on trophic relations of mammals was collected only for sea otters. Scats (excrement) were collected in July and September 1984 and May 1985 from the beach on the northeast side of the Cape Glazenap entrance (most southwesterly entrance) to Izembek Lagoon; at least 100 sea otters have been recorded to haul out on the beach at this location, mainly during low tide. These samples no doubt indicate the general feeding habits of sea otters that forage primarily in the general area of this haul-out location, but otters may eat different foods farther offshore or at other coastal locations.

7.5 RESULTS AND DISCUSSION

7.5.1 Distribution and Abundance

7.5.1.1 Species Composition by Season

Densities of marine mammals observed during aerial surveys are summarized in Table 7.2. Relative to birds, most marine mammals occur at very low densities, thus many density estimates are zero, even when some animals are present and the data are presented to two decimal places.

Table 7.2. Average densities of marine mammals (#/km^2) on aerial survey transects east of Cape Mordvinof, North Aleutian Shelf, Alaska. Highest densities are shown in boldface; lowest in italics.

PECIES	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Brown Bear	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	**0.01**	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Sea Otter	*0.15*	0.35	0.19	0.52	0.28	0.30	*0.15*	0.57	0.21	**0.97**	0.26	0.57
Steller's Sea Lion	0.19	**0.22**	0.05	0.06	0.17	0.21	*0.01*	0.13	*0.01*	*0.01*	*0.01*	0.17
Northern Fur Seal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Walrus	*0.00*	*0.00*	*0.00*	**0.20**	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Harbor Seal	*0.00*	0.02	*0.00*	0.01	0.20	0.32	0.25	**0.44**	*0.00*	0.01	0.01	0.02
Killer Whale	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pac. Wh.-sided Dolph	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Harbor Porpoise	*0.00*	**0.02**	*0.00*	**0.02**	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	0.01
Dall Porpoise	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	**0.02**	*0.00*	*0.00*	*0.00*	*0.00*
Gray Whale	*0.00*	*0.00*	*0.00*	**0.02**	**0.02**	**0.02**	*0.00*	*0.00*	0.01	*0.00*	*0.00*	*0.00*
small whale	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	0.34	0.60	0.24	0.82	0.67	0.86	0.42	**1.17**	*0.23*	1.00	0.28	0.77

These low-density species are accounted for later, when actual population estimates are presented.

Twelve species of mammals were observed during aerial surveys of the nearshore zone. Species observed on the upper portions of the beach (red fox, wolf) are excluded. Brown bears, included in Table 7.2, were occasionally observed on or seaward of the beach (within the transect limits) scavenging marine mammal carcasses or fishing.

Sea otters were consistently the most numerous marine mammal seen during aerial surveys and were present year-round. Densities were not particularly low during winter (the December-Feburary density was similar to the June-August density); this provided little support for the reported winter exodus of otters from the area.

Steller sea lions were also relatively common and present year-round. Most sightings were along the coast at the western end of the study area. They were often encountered hauled out on low cliffs near Cape Mordvinof.

Harbor seals were most often seen during the summer months. The winter decline may indicate an exodus from the study area or simply a reduced sightability when they are not hauled out.

At least six species of cetaceans were seen during the aerial surveys in the study area. All the small whales identified were minke whales, those not specifically identified were likely this species as well. The most numerous cetaceans were harbor and Dall porpoises, the sightings demonstrating no particular seasonal pattern. Of interest were the sightings of Pacific white-sided dolphins. This species was not expected to occur in the eastern Bering Sea. We recorded them on three occasions, two aerial surveys and one cruise. Gray whales were present during 5 surveys--3 during spring migration (April-June) and two during fall migration (September and December). A probable gray whale was also seen in January west of Cape Mordvinof and just outside of the study area (Table 7.2). Spring sightings were more frequent than fall sightings.

Densities of marine mammals observed on each of the Miller Freeman cruises are shown in Table 7.3 (see also Fig. 7.8). Sea otters were seen in far higher densites than other species on all cruises; the highest densities recorded were in January, in contradiction to what might have been expected (see Cimberg et al. 1984). Densities of other species were, in addition to being relatively low, variable among survey periods. These

Table 7.3. Densities (#/km^2) of marine mammals by cruise, North Aleutian Shelf, Alaska. Highest densities are shown in boldface; lowest in italics.

SPECIES	May 84	Sept 84	Jan 85	May 85	July 85
Sea Otter	0.202	*0.147*	**0.313**	0.165	0.294
Steller Sea Lion	**0.023**	*0.000*	*0.000*	*0.000*	*0.000*
Northern Fur Seal	*0.000*	0.006	*0.000*	*0.000*	**0.008**
Harbor Seal	*0.000*	*0.000*	**0.015**	*0.000*	*0.000*
seal	*0.000*	**0.006**	*0.000*	*0.000*	*0.000*
Killer Whale	*0.000*	**0.006**	*0.000*	*0.000*	*0.000*
Harbor Porpoise	*0.000*	*0.000*	*0.000*	0.025	**0.032**
Dall Porpoise	*0.000*	*0.000*	*0.000*	0.007	**0.032**
Gray Whale	*0.000*	**0.003**	*0.000*	*0.000*	*0.000*
Minke Whale	*0.000*	*0.000*	*0.000*	0.007	**0.016**
whale	*0.000*	*0.000*	*0.000*	**0.004**	*0.000*
TOTAL	0.225	*0.167*	0.328	0.207	**0.381**

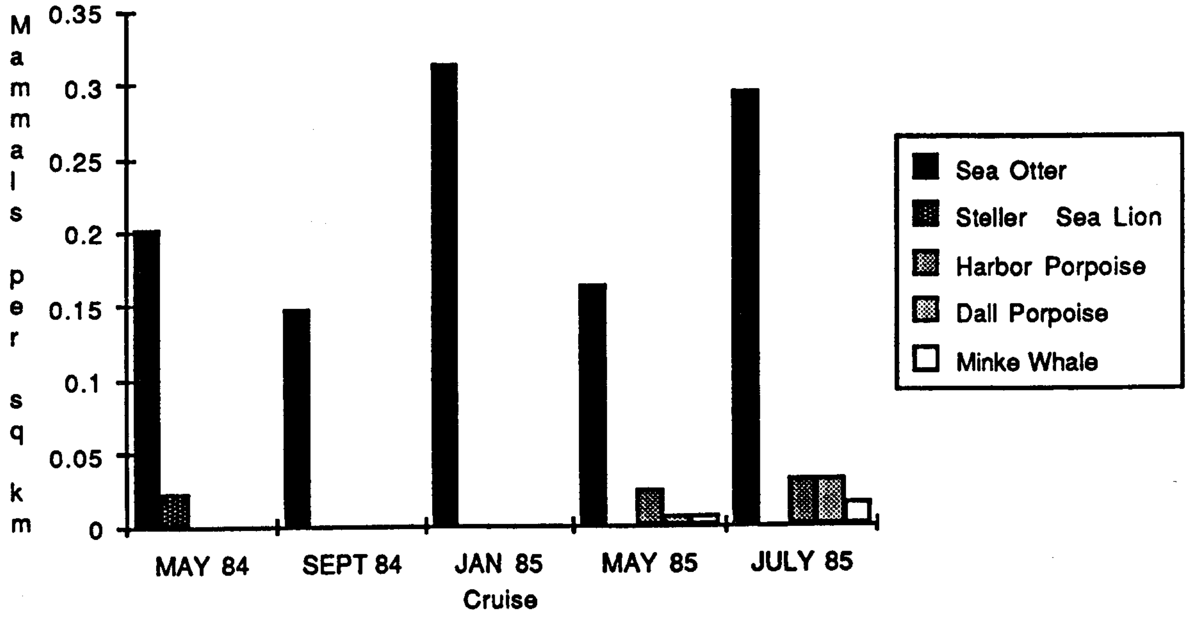

Figure 7.8. Density of marine mammals in the North Aleutian Shelf, Alaska by cruise. Highest densities are shown in boldface; lowest in italics.

cruise data demonstrate the near absence of Steller sea lion, harbor seal, and gray whale when the area surveyed does not include the strictly coastal band (virtually no sampling occurred from the Miller Freeman in waters less than 20 m deep.

7.5.1.2 Segregation By Depth

Marine mammal abundance along aerial survey bands parallel to shore are depicted in Figure 7.9 for 5 common species. (Depth ranges of survey bands are described in Section 6.5.1.2, this report.) Steller sea lion, walrus, harbor seal, and gray whale were all restricted to the coastal transects. (The Unimak sightings were also along the shore). Sea otters, although occurring at their highest densities along the coast, were found as far offshore as we surveyed; their abundance decreased with increasing distance from shore (and thus with depth).

The shipboard sightings, though more accurately described as to depth, do not include shallow-water observations (Table 7.4). Sea otters are relatively common to about the 50-m isobath (Fig. 7.10), peaking (on average) in the 30-40 m depth range. Gray whales and most Steller sea lions were found in the shallowest waters sampled, as would be expected based on the aerial survey results. In contrast, northern fur seals were restricted to the deeper areas, largely outside the area of focus for this study. During the July cruise, Dall porpoises were found in quite shallow waters (30-40 m) even though they are considered a deep-water species; previous sightings of this species, as in May 1985, were in areas > 60 m. These shallow-water observations coincided with the shoreward shift in distribution of several bird species and the inner front in July (see Sections 2.0 and 6.0, this report). Minke whale and harbor porpoise sightings in July were also in shallower waters than during prior cruises, although we have insufficient data to decide whether these sightings were atypical. Sea otter distribution was not noticably affected by the shoreward shift of the inner front in July.

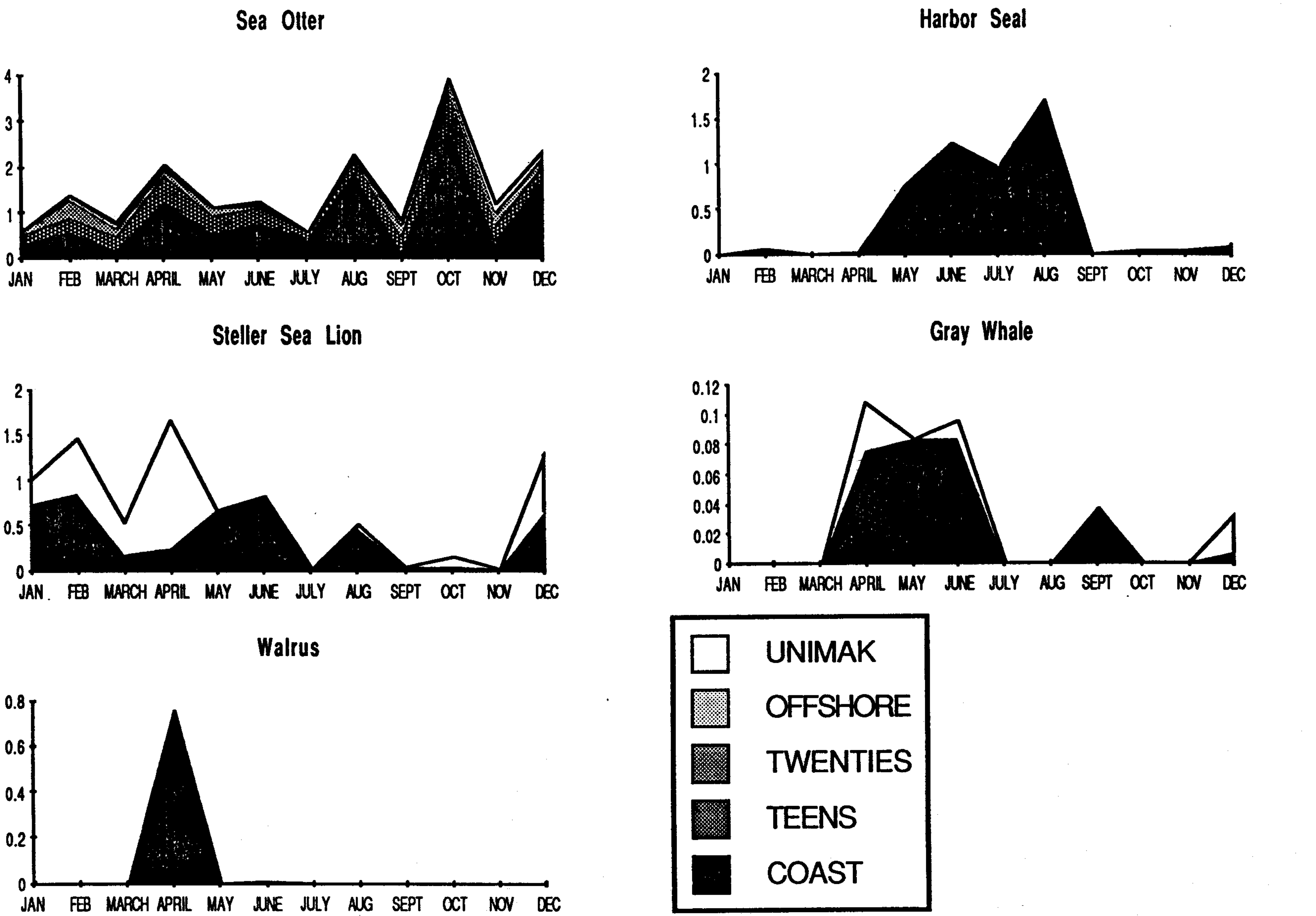

Figure 7.9. Monthly trends in abundance (#/km^2) of marine mammals by transect group (depth class) in the North Aleutian Shelf. "Unimak" was not sampled during the May, July, and September surveys.

Table 7.4. Densities of marine mammals (#/km^2) by water depth classes during cruises on the North Aleutian Shelf, Alaska. Highest densities are shown in boldface; lowest in italics.

SPECIES	≤ 30 M	30 - 40 M	40 - 50 M	50 - 60 M	≥ 60 M
May 1984					
Sea Otter	0.14	**0.48**	0.06	0.09	*0.00*
Steller Sea Lion	**0.09**	*0.00*	0.02	*0.00*	*0.00*
TOTAL	0.23	**0.48**	0.07	0.09	*0.00*
May 1985					
Sea Otter	**0.65**	0.44	0.15	0.02	*0.01*
Harbor Porpoise	*0.00*	*0.00*	**0.11**	*0.00*	*0.00*
Dall Porpoise	*0.00*	*0.00*	*0.00*	*0.00*	**0.02**
Minke Whale	*0.00*	*0.00*	**0.03**	*0.00*	*0.00*
whale	*0.00*	*0.00*	*0.00*	*0.00*	**0.01**
Total	**0.65**	0.44	0.29	*0.02*	0.05
September 1984					
Sea Otter	**0.23**	0.20	0.16	*0.00*	*0.00*
Northern Fur Seal	*0.00*	*0.00*	*0.00*	*0.00*	0.04
seal	**0.02**	0.01	*0.00*	*0.00*	*0.00*
Killer Whale	*0.00*	*0.00*	**0.02**	*0.00*	*0.00*
Gray Whale	**0.02**	*0.00*	*0.00*	*0.00*	*0.00*
TOTAL	**0.27**	0.21	0.18	*0.00*	0.04
January 1985					
Sea Otter	*0.00*	**0.60**	0.51	*0.00*	*0.00*
Harbor Seal	*0.00*	**0.04**	*0.00*	*0.00*	*0.00*
TOTAL	*0.00*	**0.64**	0.51	*0.00*	*0.00*
July 1985					
Sea Otter	0.37	**0.61**	0.36	*0.00*	0.08
Northern Fur Seal	*0.00*	*0.00*	*0.00*	*0.00*	**0.04**
Harbor Porpoise	**0.10**	*0.00*	*0.00*	*0.00*	*0.00*
Dall Porpoise	*0.00*	**0.16**	*0.00*	*0.00*	*0.00*
Minke Whale	*0.00*	**0.08**	*0.00*	*0.00*	*0.00*
TOTAL	0.47	**0.86**	0.36	*0.00*	0.12

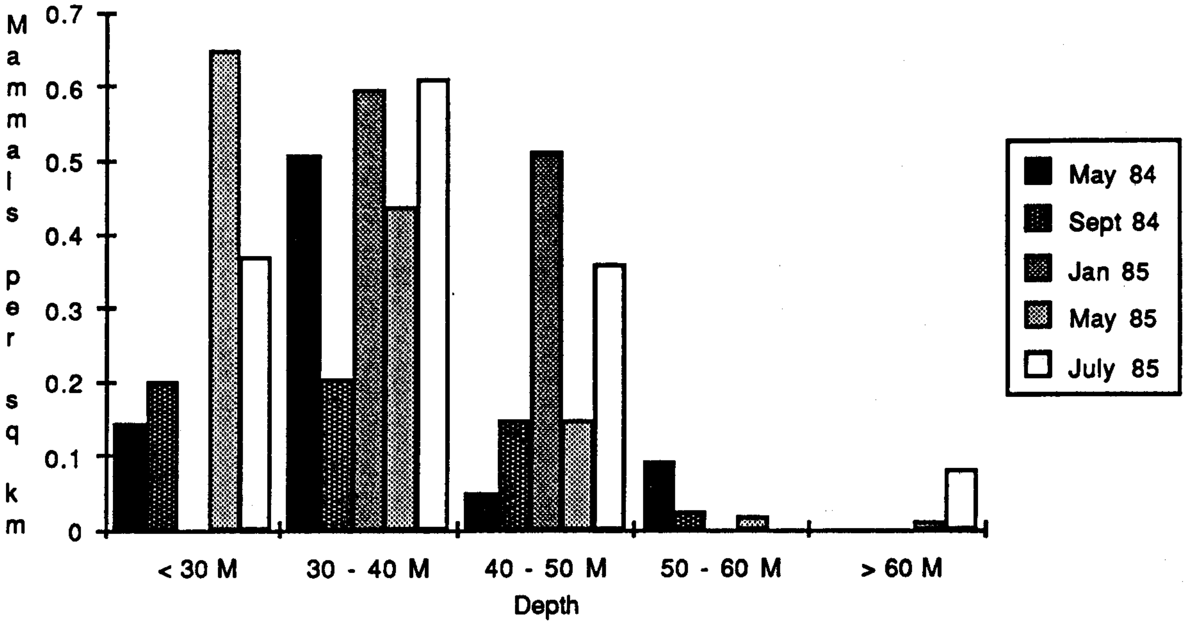

Figure 7.10. Abundance of sea otters by depth class in the North Aleutian Shelf, Alaska.

7.5.1.3 Population Estimates

Rough population estimates for use in the energy flow analyses (Section 8.0, this report) are presented in Table 7.5. The occurrence of rare species is more easily discerned here than in the density tables shown earlier. The period April-June is shown to be the portion of the year supporting the most diverse marine mammal fauna. Also evident is the numerical predominance of sea otter, Steller sea lion, and harbor seal; the latter was numerous only in the summer.

7.5.2 Trophic Relationships

Bivalve molluscs (primarily Mytilus edulis) comprised the largest component of the diet of sea otters (estimated by percent volume of items in scats) during all three sampling periods: 69%, 79%, and 64%, for July, September, and May, respectively (Table. 7.6, Fig. 7.11). Decapod crustaceans (primarily the crab Telmessus sp.), also were important prey during all three sampling periods. Although echinoderms (largely sand dollars) formed the second largest estimated component of the diet during summer and fall 1984, no evidence of this taxon was found in the small sample of scats taken in May 1985.

Kenyon (1978) found that fish comprised over 50% of the diet of sea otters in the Amchitka Island area of the Aleutians, where food may have been limiting sea otter populations that were at equilibrium densities. Most of the dead sea otters found along beaches in the central Aleutians were either very young or very old animals; Kenyon speculated that these animals may have been unable to catch fish and were forced to eat foods of lower quality (mainly echinoderms), thus causing starvation and death. Estes et al. (1982) similarly found that sea otters in the Amchitka Island area ate fish to supplement a poor quality diet of herbivorous macroinvertebrates. In other areas studied (Attu Island and coastal Oregon), where sea otters were apparently far below equilibrium density, macroinvertebrates made up their entire diet. Based on these findings, and considering (1) the apparent absence of fish bones and scales in the excreta of sea otters that we sampled, and (2) the obvious abundance of fish in the NAS study area, one could speculate that the sea otter

Table 7.5. Rough estimates of total mammal populations within the North Aleutian Shelf, Alaska study area at the time of each aerial survey. Estimates were derived by extrapolating average density on transects within each 10-m depth class to the total area of each depth class in the study area.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Brown Bear	0	0	0	0	0	0	3	1	0	1	0	0
Sea Otter	1,956	2,548	2,038	6,309	3,825	3,399	1,550	3,349	2,202	12,540	3,977	2,431
Steller Sea Lion	1,093	2,214	503	825	2,391	2,017	94	1,197	108	89	88	1,499
Walrus	0	0	0	100	0	1	0	0	0	0	0	0
Harbor Seal	1	59	0	67	231	2,641	1,147	3,459	1	83	4	108
Pacific White-sided Dolphin	0	0	0	0	0	107	0	0	0	0	0	0
Harbor Porpoise	0	38	0	220	0	0	20	0	0	0	0	0
Dall Porpoise	0	0	0	0	40	40	0	0	0	20	0	0
Gray Whale	0	0	0	215	297	141	0	0	186	0	0	27
small whale	0	0	0	0	0	0	0	0	0	20	0	0
TOTAL	3,050	4,860	2,541	7,736	6,785	8,347	2,814	8,006	2,497	12,753	4,069	4,065

Table 7.6. Estimated mean percent volume of sea otter (*Enhydra lutris*) scats collected in the vicinity of Izembek Lagoon, North Aleutian Shelf, Bering Sea, Alaska.

	July 1984 (n=100) % volume	September 1984 (n=17) % volume	May 1985 (n=2) % volume
Major Taxa			
Fish	1	0	0
Bivalve	69	79	64
Gastropod	0	1	0
Molluscs	69	80	64
Decapod	13	8	36
Crustaceans	13	8	36
Echinoderm	17	11	0
Other/Unknown*	0	1	0
TOTAL	100	100	100

* Polychaets, sludge.

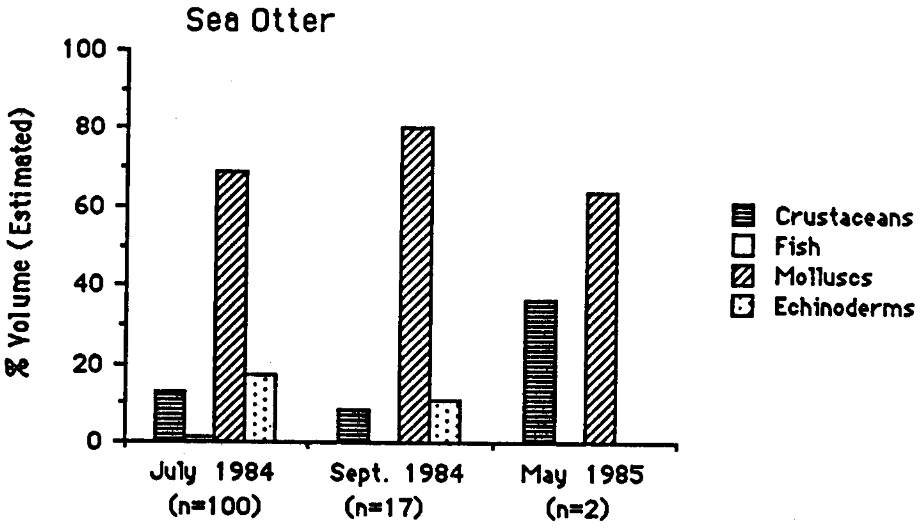

Figure 7.11. Contents of scats of sea otters feeding offshore near Izembek Lagoon, North Aleutian Shelf, Bering Sea, Alaska, July 1984 to May 1985.

population that we sampled was well below equilibrium density and survived almost solely on macroinvertebrates.

7.6 RECOMMENDED FURTHER RESEARCH

1. Replication of aerial survey effort is recommended to assess the temporal variability of marine mammal use of the area. The present evaluation relies on point surveys (2-3 days) to describe each month.

2. Specific attempts to ascertain gray whale use of the area are required if we are to determine the extent to which they are feeding in the area. Although low in numbers their massive size and (when feeding) large daily intake of food makes them potentially important consumers in the area.

3. Our survey efforts did not include censusing the Steller sea lion rookery and haulout areas on Sea Lion Rock and Amak Island. Reliable counts should be obtained in these areas especially considering the apparent decline this species has undergone in the eastern Aleutians.

4. Study effort should be directed at evaluating the role of prey availability in affecting marine bird distribution.

5. Given the apparent ease (at some low tides) in collecting sea otter scats at the haulout location at the southwest entrance to Izembek Lagoon, we recommend that further collections be made at this location. We further recommend that a careful survey be made near the entrance to Moffet Lagoon, Bechivan Bay and other lagoon and bay entrances between Nelson Lagoon and Unimak Island to see if sea otters haul out on the beaches there also; collections of scats should be made at several such locations if possible.

7.7 ACKNOWLEDGEMENTS

We thank R.H. Day, P.D. Martin, and G.W. Miller for their help in conducting shipboard censuses. The assistance of the officers and quarter masters and chief scientists of the Miller Freeman in recording the environmental and location data for each transect is greatly appreciated.

D.R. Herter has played a major role in the collection and coding of the aerial survey data and in maintaining our aerial survey equipment for the last minute decisions to take advantage of breaks in the weather. Many pilots from NOAA, ERA, and Seair have taken part in these surveys and we thank them all. We also thank G. LaPiene and M. Meyer of NOAA for managing to arrange for planes at the right times.

The massive job of data entry from both the shipboard and aerial survey programs fell in the hands of Lynn Maritzen and Virginia McCarter who have done a remarkable job in returning clean computer files. Joe C. Truett edited early versions of this report.

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Section 8

PATTERNS OF ENERGY FLOW: A CONCEPTUAL MODEL

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Section 8

PATTERNS OF ENERGY FLOW: A CONCEPTUAL MODEL

8.1 SUMMARY

This section attempts, by means of a conceptual model, to quantify energy flow through the biota of the NAS nearshore zone. Data used in development of the model are from samples collected during the present study (May, July, September, and January), from other studies in the southeastern Bering Sea (primarily PROBES), and from the general literature.

Pelagic primary production (phytoplankton) is by far the major source of energy to the invertebrate and vertebrate food web; eelgrass carbon reaches these consumers in insignificant amounts. Further, the estimated primary productivity far exceeds its estimated consumption by herbivores, both planktonic and benthic; the "excess" is possibly exported from the system and/or attenuated through benthic meiofaunal pathways.

A far greater proportion of the annual primary productivity is consumed by the benthos than by the zooplankton, but because the benthos are relatively inefficient producers, approximately equal amounts of zooplankton and benthos enter the vertebrate food web.

The measured availability of zooplankton was insufficient to feed the estimated abundance of zooplankton consumers. This undoubtedly represents some level of error in estimation, but at any rate suggests that the zooplankton are heavily cropped by the consumers. We postulate that this intensive predation on the zooplankton might depress their population growth, their standing stocks in summer, and ultimately their annual production, resulting in a phytoplankton biomass that is largely ungrazed in the water column, and ultimately settles or is exported.

Predation upon the benthos also appears to be intense. Though less well supported by measurements, it is possible that this predation is also sufficient to curtail standing stocks and annual productivity of the infauna and the epifauna.

The herbivorous invertebrates, both planktonic and benthic, thus appear to be (because of their scarcity) a weak link in the efficient transfer of primary production to the vertebrate community. Further, if the model we have constructed is valid, appreciable fluctuations in

abundance of these herbivores might affect the ability of the vertebrates to acquire sufficient food when they forage in the NAS nearshore area.

8.2 INTRODUCTION

The conceptual model described in this section depicts the flow of energy through the biota of the NAS. The area considered (approximately 8363 km^2) extends along the coast between Cape Mordvinof and Cape Seniavin, and from shore to the 50 m contour. The purpose of this model is to (1) quantify the major pathways by which biological energy flows from primary producers to vertebrates, (2) identify the key components in the food web, (3) describe the seasonal variability in 1 and 2, and (4) illustrate the relative importance of eelgrass detritus in this food web. Energy flow is considered for sampling periods in May, July, September, and January, and an annual summary model is produced.

8.3 METHODS

Many sources of information were used in the development of this model. Primary productivity levels on the NAS have been estimated by Schell and Saupe (Section 3.0, this report). Secondary productivity and food consumption by zooplankton were estimated by applying data obtained during the PROBES study and other relevant studies to this study's estimates of standing crop and taxonomic composition of the zooplankton. Secondary productivity and food consumption by the benthos were estimated by applying relevant productivity and respiration values obtained in the literature to our estimates of standing crop. The distributions and abundances of birds and marine mammals were determined through aerial surveys during each month of the year (Sections 6.0 and 7.0, this report). Feeding habits of each species were determined from data collected in the field (Section 6.0, this report) or from the literature. Feeding rates were determined from the literature. Distributions and abundances of fishes determined during five cruises in this study (Section 5.0, this report) were integrated with data found in the literature. Fish feeding habits were determined from data collected during this study (Section 5.0, this report) and feeding rates were taken from the literature.

Estimates used in constructing the energy flow model are subject to appreciable error. A subjective evaluation of the suspected accuracy of the data used in model construction shows considerable variability in data quality, as follows:

	Quality of Data (1 = poor to 5 = good)		
	Standing Crop	Productivity	Feeding
Zooplankton	4	3	3
Infauna	4	1	1
Benthic crustacea	1	1	1
Forage fish	2	NA[1]	4
Demersal fish	3	NA	4
Other fish	2	NA	4
Seabirds	4	NA	2
Marine mammals	4	NA	2

[1] NA means not applicable.

Some major sources of inaccuracy are described below. The peak in zooplankton standing crop may have been missed in our sampling, and zooplankton productivity data from the nearby PROBES study area may not be applicable in all cases to the NAS. Standing crop of infauna is well described from sampling conducted during this study and by Cimberg et al. (1984), but there are no data on feeding rates, productivity, or seasonal variability in standing crop. Data on feeding rates and productivity of infauna and benthic crustacea are little more than an educated guess. The standing crop of benthic crustacea is not well described. The abundances of forage fishes are not well described because of sampling limitations. Abundances of seabirds and marine mammals are well described through the monthly aerial surveys. Feeding habits of seabirds and fishes are well documented for some species and circumstances but not for others. Feeding habits of marine mammals are extrapolated from other areas, and thus are known only in a general way.

Estimates of average consumption rates for vertebrates have been extracted from the literature, and these may not always reflect actual consumption because nutritional requirements vary with activity (e.g., migration, resting, reproduction). Feeding rates for some species and circumstances are unknown. For instance, in the case of gray whales, the amount of feeding that actually occurs during their migration through the NAS is unknown.

All computations were done on an IBM AT microcomputer using the Lotus 123 spreadsheet.

8.3.1 Zooplankton

For each of six Miller Freeman cruises (May and September 1984; January, April, May, and July 1985), wet weight biomass of each taxon of zooplankton in each oblique Bongo net tow was converted to an equivalent biomass of carbon using values shown in Appendix 8.1. For each cruise, respiration was estimated using Ikeda's (1985) equation (see Appendix 8.2 for details). Growth, ingestion and assimilation were estimated using Dagg et al.'s (1982) and Vidal and Smith's (1986) data describing the spring bloom in the nearby PROBES study area (Appendix 8.2). Vidal and Smith (1986) suggested a weight-specific growth rate of 10 to 15% for the period June to October; we used the lower figure for this time period and a figure of 15% for the April/May spring bloom period.

Separate consumption estimates were made for herbivores (copepods, pteropods, euphausiids) and for carnivores (chaetognaths, hyperiid amphipods). Jellyfish were also treated separately because they consume both carnivorous and herbivorous zooplankton. Data were interpolated for months between cruises in order to produce annual estimates.

8.3.2 Benthos

Infaunal animals collected in grab samples were grouped according to their mode of feeding, and wet weights were converted to carbon using the values shown in Appendix 8.1. Biomasses of crustaceans in the grabs (mainly amphipods), starfish and crangoniids in trawls, and mysids in epibenthic sleds were also converted to carbon-equivalent biomasses. The values for respiration (0.3 µl O_2/mg dry wt/hr), for assimilation (0.64), and for productivity-to-biomass ratios (1.17) used by Walsh and McRoy (1986) for the infauna of the middle Bering Sea shelf were used in most cases. The productivity-to-biomass ratio of 2, determined for northern Bering Sea amphipods (Thomson 1984), was used to estimate productivity of crustacea. Productivity and consumption by mysids were estimated in the same manner as for zooplankton (Appendix 8.2).

8.3.3 Seabirds and Marine Mammals

The results of aerial surveys (Sections 6.0 and 7.0, this report) were used to estimate the abundances of seabirds and marine mammals. Body weights of seabirds were estimated using actual weights of birds collected during this study and from the literature. Weights of marine mammals were taken from the literature. Consumption rates of birds and mammals were taken from the literature (Appendix 8.3) and feeding habits were taken from the literature and from data collected in the field (Sections 6.0 and 7.0, this report) and the literature.

8.3.4 Fish

The standing crops, consumption rates, and timing of fish occurrence in the study area are shown in Appendix 8.4. Dietary information was collected in the field (Section 5.0, this report).

8.4 RESULTS

8.4.1 Zooplankton

Estimated ingestion rates of phytoplankton by herbivorous zooplankton ranged from 164 mg C/m^2/mo in September to 2037 mg C/m^2/mo in July; the total annual consumption rate was estimated to be 5380 mg C/m^2/yr (Table 8.1). These figures are very low compared with primary production levels of 30 to 60 g C/m^2/mo and an annual estimate of 225 g C/m^2/yr (Section 3.0, this report). Thus, it appears that, as in the case of many shallow

Table 8.1. Estimated average standing crop and rates of production and consumption for zooplankton on the NAS, Alaska. See Appendix 8.2 for methods of calculation.

	Monthly estimates (mg C/m^2/mo)*					Annual Estimates (mg C/m^2/yr)*
	Jan	April	May	July	Sept	
Herbivores						
Standing crop	28.2	33.9	47.1	284.4	21.9	72.2
Respiration	27.2	28.1	70.2	390.5	34.9	1141.7
Growth	0	152.5	212.0	853.2	65.7	2301.1
Winter storage	0	21.7	30.2	182.3	14.0	465.6
Total assimilated	0	202.4	312.4	1426.0	114.6	3766.6
Fecal production	0	86.7	133.9	611.2	49.1	1614.3
Total ingestion	0	289.1	446.2	2037.2	163.8	5380.9
Carnivores						
Standing crop	47.4	22.8	23.1	36.0	8.1	28.7
Respiration	42.6	17.0	19.3	39.5	9.9	320.7
Growth	0	102.6	104.0	108.0	24.3	550.4
Winter storage	0	13.4	13.6	21.2	4.8	94.4
Total assimilated	0	133.1	136.8	168.6	39.0	802.6
Fecal production	0	33.3	34.2	42.2	9.7	200.7
Total ingestion	0	166.3	171.0	210.8	48.7	1003.3
Jellyfish						
Standing crop	32.4	24.0	19.5	33.9	273.9	90.2
Respiration	7.6	4.7	4.5	10.1	92.4	229.2
Growth	0.0	3.6	2.9	3.4	27.4	76.6
Winter storage	0.0	4.0	3.3	5.7	46.0	125.0
Total assimilated	0.0	12.3	10.7	19.2	165.8	430.8
Fecal production	0.0	1.4	1.2	2.1	18.4	47.9
Total ingestion	0.0	13.7	11.8	21.4	184.2	478.7

* For standing crop, mg C/m^2; annual estimate is average of monthly estimates.

northern seas, much of the primary productivity was not utilized by the zooplankton and was therefore, available to the benthos.

The estimated consumption of zooplankton by carnivorous zooplankton and jellyfish accounts for about 1500 of the 2900 mg C/m^2 annual growth (production) by the herbivores and carnivores (Table 8.1), leaving about 1400 mg C/m^2 available for higher trophic levels.

On the NAS, the highest zooplankton biomass (thus, probably highest production) was found in the July sampling period, but the peak in biomass could have occurred in June, when sampling was not conducted. On the outer shelf and slope of the southeastern Bering Sea, Vidal and Smith (1986) found that zooplankton biomass and production peaked in mid-May. On the middle shelf, they found that both biomass and production were increasing in early June when their sampling ended; the timing of the peaks in growth and biomass were unknown. If the peak did occur in June on the NAS, then total annual productivity of herbivores could be as high as 5 g C/m^2. This is far lower than the 40-50 g C/m^2/yr produced by herbivores on the outer shelf and slope, or the 30 g C/m^2/yr produced on the middle shelf (Vidal and Smith 1986).

8.4.2 Benthos

Because most of the phytoplankton was not utilized by the zooplankton, it presumably sank and became directly available to benthic filter- and surface deposit-feeders as a high-quality food source. Consumption by filter- and deposit-feeding benthos, based on application of respiration, production and assimilation estimates to biomass, was about 136 g C/m^2/yr (Table 8.2). This is over half of the estimated 225 g C/m^2/yr produced annually by the phytoplankton.

Most of the annual production by deposit and filter feeders appears to be consumed within the benthic invertebrate food chain (Table 8.2). The estimated net availability of all benthos to higher trophic levels is about 1500 mg C/m^2/yr (production of filter feeders, deposit feeders and carnivores less consumption by invertebrate carnivores), which is approximately equal to the zooplankton available (see previous Section 8.4.1).

Table 8.2. Estimated annual respiration, growth and consumption by the benthos on the NAS, Alaska. See Section 8.3.2 for methods of calculation.

	Average Standing Crop (mg C/m^2)	Annual Carbon Budget (mg C/m^2/yr)				
		Respiration	Production	Total Assimilated	Fecal Production	Total Consumption
Filter and deposit feeders						
Filter feeders	393	1359	459	1817	1022	2839
Surf. dep. feeders	3267	76575	3812	80386	45217	125604
Deposit feeders	437	1833	510	2343	1318	3661
Other	331	519	386	906	509	1415
Crangonids	9	47	18	65	37	102
Other crustacea	229	680	458	1138	640	1778
Mysids*	10	67	44	156	67	222
Total	4676	81080	5686	86811	48810	135621
Carnivores						
Infaunal carnivores	606	2307	707	3014	1696	4710
Starfish	20	62	23	85	48	132
Total	626	2369	730	3099	1743	4843

*See Appendix 8.2 for methods of calculation; 'total assimilated' includes winter storage.

8.4.3 Flow of Primary Organic Matter

Over 50% of the estimated total organic input (carbon fixed by primary production) to the NAS cannot be accounted for (Table 8.3). A similar surplus of carbon appears to occur on the outer shelf, according to Walsh and McRoy (1986). On the outer shelf, however, zooplankton consumption of phytoplankton may be far higher than the 68 g C/m^2 estimated by these authors (see Vidal and Smith 1986).

There are three possible fates for this apparent surplus of organic carbon detritus on the NAS, as follows: (1) it is exported from the area, (2) it is consumed by bacteria, and (3) consumption by the benthos is higher than estimated. Evaluations of these possibilities follow.

1. Export from the NAS. The residence time of water in the NAS area is on the order of 10 to 20 days (Section 2.0, this report). Thus, a significant portion of the primary production could be exported to the middle shelf or, likely to a much lesser extent, to the coastal domain of inner Bristol Bay (see Walsh and McRoy (1986) and Walsh et al. (1985) for a discussion of the possible fate of this material).
2. Consumption by bacteria. Based on data provided by Griffiths et al. (1983), microbial respiration in Port Moller is about 100 g C/m^2/yr, and in the St. George Basin it is about 10 g C/m^2/yr. Thus, it appears that a high proportion of the unused detritus could enter a bacterial/meiofaunal food chain.
3. Increased consumption by benthos. The productivity-to-biomass ratio of the NAS benthos was assumed to be 1.17, the figure used by Walsh and McRoy (1986). Given the food availability and warm bottom temperatures in these shallow waters in summer (3°C in May to 9.5°C in September), productivity of the benthos could be much higher than estimated. A higher rate of productivity would require a higher rate of consumption.

Table 8.3. Sources and fate of primary production through the lower trophic levels of the southeastern Bering Sea (g $C/m^2/yr$). Except where noted, data are from Tables 8.1 and 8.2.

	Outer Shelf*	Middle Shelf*	North Aleutian Shelf
Phytoplankton production	162	166	225
Consumption by herbivorous zooplankton	68	36	5
To detritus pool	94	130	220
Detritus pool			
Phytoplankton not consumed	94	130	220
Zooplankton fecal pellets	20	8	2
Rivers and eelgrass			30**
Total	114	138	252
Detritus consumption			
Infaunal benthos	11	138	135
Meiofauna	29	22	22*
Total	40	160	157
Total detritus accumulation			
Not consumed	74	-22	95
Infaunal fecal production	5	50	51
Total	79	28	144

* from Walsh and McRoy (1986).
** From Schell and Saupe (this report).

On the NAS, all three of these factors likely account for the apparent surplus of carbon, but the relative importance of these factors remains unknown.

8.4.4 Seabirds and Marine Mammals

Estimated annual prey consumption by seabirds and marine mammals is shown in Table 8.4. In terms of biomass, benthic crustacea, infauna, fish and plankton appeared to be consumed in approximately equal quantities by

Table 8.4. Estimated annual consumption by seabirds and marine mammals on the NAS, Alaska. Crustacea eaten by surface and mid-water feeders are planktonic; those eaten by benthic feeders are benthic. See Appendix 8.3 and Section 8.3.3 for methods of calculation.

		Prey Consumed (mg C/m^2/yr)				
	Feeding Type*	Crustacea (Plankton, Benthos)	Fish	Benthic Invertebrates	Other	Total
Seabirds						
Shearwater-dark	S	100.32	3.60	0.00	3.47	107.40
Glaucous winged gull	S	13.49	22.75	5.43	9.27	50.95
Black-legged kittiwake	S	1.76	17.84	0.00	0.35	19.95
Northern fulmar	S	0.04	0.51	0.00	0.15	0.70
Mew gull	S	0.14	0.48	0.07	0.00	0.68
Jaeger	S	0.13	0.10	0.00	0.10	0.32
Tern	S	0.04	0.17	0.00	0.00	0.21
Phalarope	S	0.19	0.00	0.00	0.00	0.19
Bonapartes gull	S	0.00	0.00	0.00	0.00	0.01
Fork-tailed storm-petrel	S	0.00	0.00	0.00	0.00	0.01
Sabine's gull	S	0.00	0.00	0.00	0.00	0.00
Auklet	M	13.66	1.54	1.37	0.51	17.08
Murre	M	0.00	10.68	0.00	0.00	10.68
Cormorant	M	0.15	7.87	0.00	0.35	8.37
Tufted puffin	M	0.01	0.35	0.05	0.02	0.44
Loon	M	0.08	0.29	0.02	0.00	0.38
Red-breasted merganser	M	0.06	0.19	0.00	0.00	0.25
Alcid	M	0.00	0.05	0.01	0.01	0.07
Horned puffin	M	0.01	0.05	0.00	0.00	0.06
Murrelet	M	0.02	0.02	0.00	0.00	0.04
Grebe	M	0.01	0.03	0.00	0.00	0.04
Scoter	B	6.03	1.30	65.85	1.50	74.68
King eider	B	0.29	0.00	23.07	0.01	23.37
Steller's eider	B	0.46	0.00	19.26	0.60	20.32
Duck	B	1.79	0.30	3.88	0.00	5.97
Oldsquaw	B	1.30	0.50	0.19	1.34	3.33
Common eider	B	0.57	0.00	1.20	0.07	1.85
Harlequin duck	B	0.00	0.00	0.15	0.01	0.16
Pigeon guillemot	B	0.00	0.00	0.00	0.00	0.01
Marine Mammals						
Steller's sea lion	M	0.00	89.81	0.00	0.00	89.81
Harbor seal	M	0.52	9.89	0.00	0.00	10.41
Small (minke) whale	M	0.34	0.30	0.00	0.03	0.67
Harbor porpoise	M	0.00	0.15	0.00	0.15	0.31
Pac. white-sided dolphin	M	0.01	0.17	0.00	0.05	0.23
Dall porpoise	M	0.01	0.03	0.00	0.15	0.19
Grey whale	B	84.07	0.00	0.86	0.86	85.78
Sea otter	B	8.96	0.05	55.52	0.47	65.01
Walrus	B	0.05	0.00	0.99	0.00	1.04
Seabirds						
Surface feeders		116	45	6	13	180
Mid-water feeders		14	21	1	1	37
Benthic feeders		10	2	114	4	130
Total		141	69	121	18	348
Marine Mammals						
Mid-water feeders		1	100	0	0	102
Benthic feeders		93	0	57	1	152
Total		94	100	57	2	253
Total by surface feeders		116	45	6	13	180
Total by mid-water feeders		15	121	1	1	139
Total by benthic feeders		104	2	171	5	282
Grand total		235	169	178	19	601

* S = surface feeders; M= mid-water feeders; B = benthic feeders.

birds and mammals on the NAS, as shown below:

	Plankton	Benthos Crustacea	 Infauna	Fish	Other
Total consumption (mg C/m^2/yr)	131	104	178	169	19

An approximately equal biomass was consumed by seabirds and by marine mammals. For birds and marine mammals, pelagic (surface and mid-water) feeders consumed an amount similar to that eaten by benthic feeders. Major consumers were shearwaters, Steller sea lions, gray whales, sea otters, scoters, and glaucous-winged gulls. Together, these six species accounted for an estimated 79% of consumption by seabirds and marine mammals.

Table 8.5. Estimated annual consumption by fish on the NAS, Alaska. See Appendix 8.4 and Section 8.3.4 for methods of calculation.

	Consumption of prey (mg C/m^2/yr)				
	Plankton	Fish	Benthic Crustacea	Infaunal Benthos	Total
Pelagic feeders					
Salmon adults	14	0	0	0	14
Salmon juveniles	3	3	0	0	6
Herring/capelin	260	0	0	0	260
Sand lance	2617	0	26	23	2667
Other forage fish	13	13	4	1	32
Total	2907	16	31	24	2978
Benthic feeders	2060	2491	3299	3057	10907
Grand total	4967	2507	3330	3081	13885

8.4.5 Fish

Estimated annual consumption of various types of prey by fish is shown in Table 8.5. Benthic crustacea (3.3 g $C/m^2/yr$), zooplankton (5 g $C/m^2/yr$), infauna (3.1 g $C/m^2/yr$), and fish (2.5 g $C/m^2/yr$) were consumed in approximately equal quantities. In all, fish consume more than an order of magnitude more prey than do birds and marine mammals (14 g $C/m^2/yr$ *vs*. 0.6 g $C/m^2/yr$). Demersal fish (pollock, cod, and flatfish) consumed considerably more than the pelagic feeders (Table 8.5). Most of the pelagic feeding was by the sand lance and by the large pulse of herring and capelin that passes through the study area in midsummer.

8.4.6 Summary and Discussion

Two important aspects of food webs on the NAS need to be summarized. First, we need an overview of the prey groups important in the diets of the important vertebrates--fish, birds, and mammals. Second, we need to examine discrepancies within the energy flow model we have built, for example to see whether estimated biomasses of prey consumed exceed the estimated availability of the prey.

Table 8.6 summarizes the estimated biomasses of the various prey groups consumed by fish, birds, and marine mammals on the NAS. Several points are noteworthy. Nearly half (46%) of the total biomass consumed was benthic; half of this was epibenthic (mostly decapods and amphipods). The other half of the total consumed was either zooplankton (35%) or fish that eat mainly zooplankton (19%); the major zooplankton groups consumed were copepods and euphausiids (Table 8.6).

The energy flow model does not always "balance"; that is, the amount of energy estimated to be available to consumers does not always approximate the amount estimated to be consumed (Tables 8.7 and 8.8). Beginning at the lower end of the food web, we see that the estimated primary productivity far exceeds its estimated consumption by herbivores (Table 8.3). The "excess" primary productivity may have been exported or consumed by bacteria (which were not sampled). Alternatively, benthic herbivore biomasses or productivity may have been underestimated.

Another discrepancy relates to the zooplankton. The measured availability of the zooplankton was not sufficient to feed the zooplankton consumers (Table 8.7). Based on vertebrate diets and on estimated

Table 8.6. Estimated consumption of major prey by fish, seabirds and marine mammals on the NAS, Alaska.

	Consumption					
Prey Taxa	Birds and marine mammals		Fish		Total	
	mg C/m^2/yr	%	mg C/m^2/yr	%	mg C/m^2/yr	%
Plankton						
Copepods	4	0.7	2264	16.3	2268	15.7
Euphausiids	117	19.4	1275	9.2	1392	9.6
Mysids			864	6.2	864	6.0
Other zooplankton	10	1.7	563	4.1	573	4.0
Total	131	21.8	4967	35.8	5098	35.2
Nekton						
Squid	3	0.5			3	0.0
Sand lance	63	10.5	1247	9.0	1310	9.0
Other fish	106	17.6	1259	9.1	1365	9.4
Total	172	28.6	2507	18.1	2679	18.5
Infauna						
Bivalves	159	26.4	310	2.2	469	3.2
Gastropods	5	0.8			5	0.0
Echinoderms	12	2.0	1015	7.3	1027	7.1
Polychaetes	3	0.5	1333	9.6	1336	9.2
Other infauna			424	3.1	424	2.9
Total	179	29.7	3081	22.2	3260	22.5
Benthic Crustacea						
Decapods	9	1.5	1002	7.2	1011	7.0
Amphipods	84	14.0	1375	9.9	1459	10.1
Other Crustacea	10	1.7	953	6.9	963	6.6
Total	103	17.1	3330	24.0	3433	23.7
Other	17	2.8		0.0	17	0.1
Total	602	100.0	13885	100.0	14486	100.0

biomasses of vertebrates, we calculate that 5.1 g C/m^2 of zooplankton was consumed by vertebrates annually (Table 8.7). The total measured availability of zooplankton, however, was estimated to be only about 1.5 g C/m^2/yr (Table 8.7 and Section 8.4.1). If the peak of zooplankton biomass and growth occurred in June (when no sampling was done) rather than in July, and was relatively similar in magnitude to that occurring on the middle and outer shelf areas, then zooplankton availability might be

Table 8.7. Comparison of estimated prey availability vs consumption by vertebrates on the NAS.

	Monthly availability and consumption (mg C/m^2/mo)				Estimated Annual (mg C/m^2/yr)
	Jan	May	July	Sept	
Zooplankton					
Herbivores					
Standing crop	28	47	284	22	72
Production	0	212	853	66	2301
Carnivores					
Standing crop	47	23	36	8	29
Production	0	104	108	24	550
Gross availability	76	386	1282	120	2952
Consumption by invertebrates					
by carnivorous zooplankton	0	171	211	49	1003
by jellyfish	0	12	21	184	479
Total	0	183	232	233	1482
Net availability	76	203	1049	0	1470
Consumption by vertebrates					
Birds and marine mammals	10	26	<1	2	131
Fish	36	448	1071	338	4968
Total	46	474	1071	340	5099
Fish					
Standing crop	882	1992	3550	1902	1898
Consumption by vertebrates					
Birds and marine mammals	11	24	10	14	169
Fish	44	353	353	342	2507
Total	55	377	363	356	2676
Benthos					
Availibility					
Standing crop	*	*	*	*	5302
Productivity	*	*	*	*	6416
Gross availability	*	*	*	*	11718
Consumption by benthos	*	*	*	*	4843
Net benthic availability	*	*	*	*	6875
Consumption by vertebrates					
Birds and marine mammals	17	43	3	34	282
Fish	112	895	908	867	6411
Total	129	938	911	901	6693

* Data are insufficient for monthly estimates.

Table 8.8. Estimated biomasses of major food web components on the NAS, Alaska, in terms of how much is available and how much is consumed. Discrepancies between the amount available and the amount consumed suggest sampling biases or net influx or export of components.

	Food Biomass (g C/m /yr)							
		Consumed					Difference (Biomass and %, of Availability)	
Food Component	Available	Zoopl.	Benthos	Fish	Birds/Mamm.	Total	Surplus	Deficiency
Primary Production[1]	225.0	5.0	157.0	0.0	0.0	161.0	64 (28%)	
Zooplankton	7.9	1.5		5.0	0.1	6.6		3.6 (120%)
Benthos	11.7	0.0	6.4	3.5	0.3	11.5	0.2 (2%)	
Fish	1.9	0.0	0.0	2.5	0.2	2.7		0.8 (42%)
Birds & Mammals	0.03	No Significant Consumers				0.0	0.03 (100%)	

[1] Largely phytoplankton; eelgrass contribution to higher levels in the food web is negligible.

greater than the amount estimated by as much as 1.0 g C/m^2/yr, but would still be less than estimated consumption.

On the middle shelf a high biomass of zooplankton is maintained until October (Vidal and Smith 1986). From April to October, productivity of the herbivores is about 40-50 g C/m^2 on the outer shelf and about 30 g C/m^2 on the middle shelf. Water exchange between the NAS and offshore waters is rapid and all of the water in the NAS is exchanged every 10-15 d (see Section 2.0, this report). About 12.6 mg C/m^2/d or 2.7 g C/m^2/yr of zooplankton could be imported from offshore areas. This value is equivalent to herbivore production in the NAS and would increase net zooplankton availability to 4.2 g C/m^2/yr, a figure that is close to the total consumption of 5.1 g C/m^2/yr.

Net benthic prey availability to vertebrates (total benthic production less consumption by invertebrate predators) was about 6.8 g C/m^2/yr. Total consumption of benthos by vertebrates was approximately equivalent to that available (Table 8.7).

Among the infauna, polychaetes, bivalves, and echinoderms were consumed in approximately equal quantities (Table 8.6) that are equivalent to 20%-120% of the standing crop (or productivity). (Standing crop of polychaetes was 1.1 g C/m^2 and of bivalves was 2.4 g C/m^2; productivity = 1.17 x standing crop).

Estimated consumption of benthic amphipods and decapods far exceeded their standing crops or productivity (consumption was estimated at 3.4 g C/m^2/yr; standing crop was 248 mg C/m^2 and productivity was 500 mg C/m^2/yr; Table 8.2). It would appear that availability of benthic crustacea was underestimated. In order to balance their availability with consumption, the productivity-to-biomass ratio would have to be 14 (unlikely), or biomass has been underestimated by a factor of 7 (likely).

Total consumption of fish by predators was about 2.7 g C/m^2/yr (Table 8.6). However, the total standing crop of fish was estimated to be only 1.9 g C/m^2 (annual average, Table 8.9), and a good deal of this biomass consisted of cod, pollock, and flatfish too large to be consumed by seabirds and other fish. About half the fish consumed by seabirds and marine mammals consisted of sand lance (Table 8.6); the estimated consumption of sand lance by all vertebrates was about 1.3 g C/m^2/yr. The average estimated biomass of sand lance, however, was only 485 mg C/m^2 and

Table 8.9. Standing crop of invertebrates and vertebrates on the NAS, Alaska. Standing crop of vertebrates has been weighted to account for the time present in the area.

	Standing Crop (mg C/m^2)				
	Jan	May	July	Sept	Annual Average
Zooplankton					
Herbivores	28	47	284	22	72
Carnivores	47	23	36	8	29
Jellyfish	32	20	34	274	90
Benthos					
Filter feeders	393	393	393	393	393
Deposit feeders	4283	4283	4283	4283	4283
Carnivores	626	626	626	626	626
Fish					
Pelagic feeders	0	228	1786	138	535
Benthic feeders	882	1764	1764	1764	1363
Birds					
Pelagic feeders	1	3	1	1	2
Benthic feeders	1	1	0	1	1
Mammals					
Pelagic feeders	7	15	1	1	7
Benthic feeders	0	67	0	40	17
All vertebrates					
Pelagic feeders	8	246	1788	140	543
Benthic feeders	884	1831	1764	1806	1381

the maximum was 1742 mg C/m^2 (in July). Thus, there is a discrepancy between estimated availability of fish and estimated fish consumption by other vertebrates, especially in the case of sand lance. This discrepancy is likely attributable to underestimates of the standing stocks of forage fish on the NAS.

8.5 DISCUSSION

At the onset of this study, four hypotheses were generated to address study objectives. The results of the conceptual energy flow model assist in addressing two of these hypotheses.

> Hypothesis 1: Organic materials and nutrients derived from lagoons contribute significantly to food webs of fish, birds and marine mammals in adjacent marine waters. This hypothesis is not supported by the data. In the study area as a whole, input of eelgrass detritus is small relative to primary productivity (see Table 8.3 and Section 3.0, this report). Despite this, the eelgrass could theoretically important to vertebrates, because it becomes available to the benthos as detritus, and as demonstrated in this section, the benthos supplies about half the food for vertebrates. However, the benthos probably feeds mainly on settled phytoplankton because phytoplankton is underutilized by the zooplankton and this provides a continuous (for seven months) supply of high quality organic matter directly to the benthos. In contrast, eelgrass must be degraded by bacteria before it is of use to most benthic invertebrates. Indeed, results of stable and radioisotope studies (Section 3.0, this report) show that very little of the eelgrass is ultimately incorporated into the benthic invertebrate food chain.
>
> Hypothesis 2: The greatest vertebrate biomass and the largest number of vertebrate species in the study area depend mainly on a marine phytoplankton-epibenthos food chain. This hypothesis is partly invalidated by the data. It is true that marine phytoplankton provides the great majority of carbon fixed. But

on the whole, total consumption by vertebrates appears to be more or less equally divided between zooplankton and benthos. Furthermore, about half of the benthos biomass consumed by vertebrates is infauna, so only about a fourth at most of the vertebrate food supply is from the epibenthos.

The flow of biological energy on the NAS is summarized in Figure 8.1. Primary productivity by phytoplankton is probably lower on the outer and middle shelf areas of the southeastern Bering Sea than it is on the NAS, but total biomass of phytoplankton consumed by herbivorous zooplankton, and the standing stocks of zooplankton, appear to be an order of magnitude higher in the offshore waters than on the NAS (Table 8.10; Walsh and McRoy 1986). As a consequence, the production of zooplankton was also an order of magnitude higher on the outer and middle shelf (30-45 g C/m^2/yr; Vidal and Smith 1986) than on the NAS (2.9 g C/m^2/yr; this study).

The major difference in zooplankton between nearshore and offshore waters was that, in nearshore waters, biomass remained low in the presence of an abundant food supply. Differences in the seasonal dynamics of predation among areas may account for this. Walsh and McRoy (1986) estimated that total predation on zooplankton was 11.4 g C/m^2 on the outer shelf and 5.5 g C/m^2 on the middle shelf. These predation rates are much lower than the zooplankton availability (production 30.45 g C/m^2, see above). In May, July, and September on the NAS, estimated predation on zooplankton was equivalent to its estimated availability. In addition to continuous predation by demersal and forage fish, predation by the millions of shearwaters present in May and June was followed by a large pulse of herring and capelin that was, in turn, followed by an inundation of the area by jellyfish prior to September. This constant predation may not allow zooplankton biomass to accumulate, and thus, may limit the secondary productivity.

It is also possible that predation on benthos on the NAS is very high relative to benthic productivity; this could limit benthos standing crop and productivity. Although no data are yet available for infaunal mortality rates on the NAS, in the deeper shelf waters of the southeastern Bering Sea annual mortality of bivalves generally exceeds 20% and may reach 50%, and mean age of bivalves is on the order of three to five years

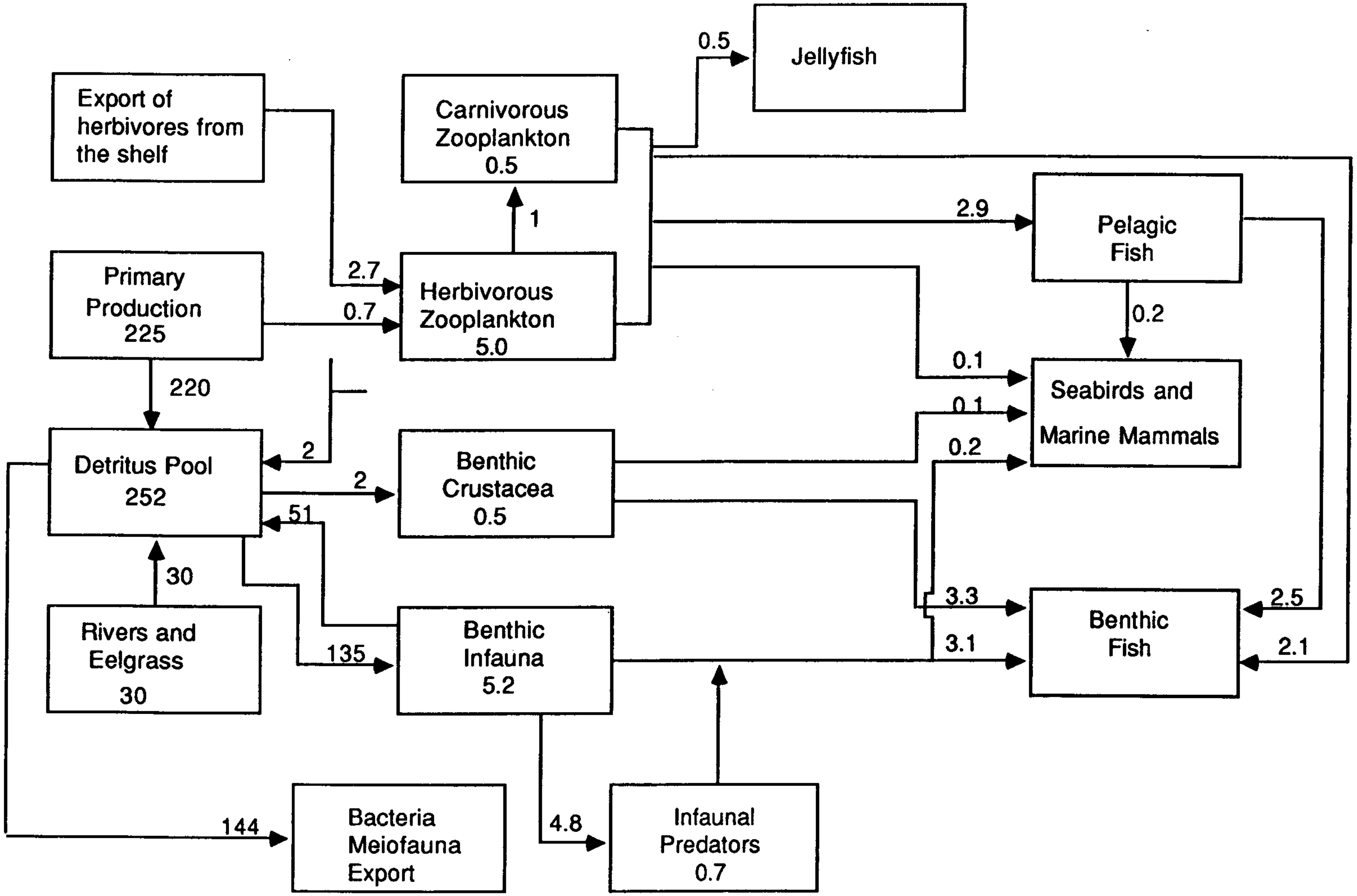

Figure 8.1 Schematic representation of energy flow (g/C/m^2/yr) on the NAS. Arrows indicate the direction of flow and associated numbers indicate the annual magnitude. Numbers within boxes are estimated annual production.

(McDonald et al. 1981). In contrast, near northern Baffin Island, where predation on the benthos is negligible, mortality of bivalves (Macoma, Mya, Astarte) is about 8% per year, and mean age is about 12 years at 10-m depth and >20 years at depths of 30 to 50 m (Thomson et al. 1986). Because of the low predation pressure in this high arctic environment, a high biomass (>1 kg/m^2) develops, consisting mainly of old individuals.

Thus predation on the zooplankton and benthos of the NAS appears to be intense. Because these invertebrate resources may be cropped to their annual net production limit, any factor that causes decreased availability of invertebrates could have a serious impact on higher trophic levels.

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8.7 APPENDIXES

Appendix 8.1. Values used to convert wet weight of zooplankton and benthos to equivalent weight of organic carbon.

Taxon	Dry weight as a % of wet weight	Carbon as a % of dry weight	References[a]
Jellyfish	4	10	1, 5
Copepods	17	46.5	2, 3
Hyperiids	19	38.4	2, 3
Euphausiids	21	46.6	2, 3
Mysids	17	43.9	2, 3
Decapod larvae	19	38.0	2, 3
Chaetognaths	10	40.7	1, 2
Larvaceans	10	40.7	Estimated from chaetognaths
Fish larvae	24.5	45	2, 3
Eggs	8	40	2
Nauplii	19	38	Estimated from Decapod larvae
Crangonid shrimp	18.6	29.3	4
Amphipods	15.6	47	4
Polychaetes	19.8	36	4
Bivalves	6.7	41	4
Gastropod	14.6	43	4
Ophiuroids	47.9	3	4
Echinoids	32.4	4	4
Sand dollars	51.4	2	4
Holothuroids	27.4	9	4
Sipunculids	18.0	25	4

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[a] 1. Percy and Fife (1980).
2. Harris (1985).
3. Griffiths and Buchanan (1982).
4. Stoker (1978).
5. Parsons et al. (1977).

Appendix 8.2. Data used in the computation of zooplankton respiration, growth, and consumption.

Respiration

Zooplankton respiration was estimated using Ikeda's (1985) equation:

$$\ln (1\ O_2/\text{indiv/h}) = 0.5254 + 0.8354 \ln (\text{mg C/indiv.}) + 0.0601 (\text{temp})$$

Mean wet weight (mg) of individuals was determined from zooplankton data taken during this study. Wet weight was converted to carbon using values shown in Appendix A.

Copepods	Mg wet wt/indiv.	Other Taxa	mg wet wt/indiv.
September	1.3	Euphausiids	17.5
January	1.8	Decapod larvae	3.6
April	1.9	Fish larvae	0.7
May	1.0	Chaetognaths	12.0
July	0.5	Mysids	12.0

Typical mid-water temperature °C (from 2.0 Physical Oceanography)

May 1984	2.75	April 1985	0.5
September 1984	9.5	May 1985	3.25
January 1984	3.5	July 1985	7.5

1 µl of Oxygen = 0.535 g carbon

Growth

April-to-May weight-specific growth rate, 15%; June-to-October weight-specific growth rate, 10% (from Vidal and Smith 1986).

Storage for Winter

It is assumed that zooplankton feed for seven months and store food for the remaining five months when food is not available. The respiration (as above) was calculated for those five months when they do not feed (November to March). In order to assimilate and store enough food to meet demands of winter respiration, it was estimated that additional monthly food requirements during the seven months when feeding occurs were 0.64 mg C/mg C/mo for herbivores, 0.59 mg C/mg C/mo for carnivores, and 0.17 mg C/mg C/mo for jellyfish.

Assimilation, Fecal Production, and Total Ingestion

Food assimilated by zooplankton was calculated as the sum of respiration, growth, and winter storage. Assimilation efficiencies of 70% for herbivores (Dagg et al. 1982), 80% for carnivores (Nagasawa 1985) and 90% for jellyfish (Alldredge 1984) were used to calculate total ingestion. Fecal production was the difference between assimilation and ingestion.

Appendix 8.3. Consumption rates for vertebrates used in computation of the energy flow model.

Seabirds (from Schneider et al. 1986)

Consumption (Kcal/bird/d) = (a) (b) (c) (M) (0.723)
a = 1.33 Ingested/assimilation ratio
b = 2.8 Active/resting ratio
c = 78.3 Kcal/d at rest
M = body weight in kg

Harbor Seal (from Ashwell-Erickson and Elsner 1981)

Mean body weight of 67 kg with average consumption of 3935 Kcal/d, based on the annual requirements of a population of 1000 seals using their Model I assumptions.

Walrus (from Fay 1982)

Total body weight 720 kg with average net food intake of 6.2% of body weight/d.

Sea Otter (from Estes and Palmisano 1974)

Body weight of 23 kg with consumption equal to 20 to 23% of body weight/d.

Minke Whale

Average weight of about 8000 kg (Brown and Lockyer 1984) with daily food intake equivalent to about 3.5% of body weight/d (Bushev 1986).

Gray Whale (from Thomson and Martin 1984)

Average body weight of 23,000 kg. Daily consumption while migrating is unknown. Average daily metabolic requirements are about 295,000 Kcal/d.

Steller's Sea Lion

Average body weight is about 636 kg. Consumption rates are unknown. However, fur seals consume from 7.5 to 14% of body weight/d (Swartzman and Hoar 1983) or from 5 to 10% of body weight/d (Spotte and Adams 1981).

Appendix 8.4. Daily ration (% of body weight/d), standing crop (g/m^2 wet weight), and timing of fish occurrence in the study area.

Species		Daily ration (%)	Standing Crop (g/m^2)	Days in study area											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Salmon adults		1	1.6					1	7	1					
Salmon juveniles		7	0.008						30	31	31	30			
Herring/Capelin	Spring	2	8.5					5	10						
	Summer	6	0.3						20	31					
	Summer	6	0.001								30	31			
Sand lance															
Jan		6	0.001	31	28										31
May		6	0.6			31	30	31							
July		2	15.8						30	31	31				
Sep		2	1.2									30	31	30	
Other forage fish		6	0.04					31	30	31	31	30			
Bottom fish															
Summer		4	16.0				26	31	30	31	31	30	21		
Winter		1	8.0	31	28	31	4						10	30	31

Sources of standing crop and daily rates data for fish.

Salmon Adults

An estimated 4.5 million adult salmon migrate through the NAS on their way into Bristol Bay (see text) at a speed of 60 cm/s, which equals seven days per fish in the NAS. A daily ration of 1% (Hartt 1966) may be high because sockeye had only 12 g of food (99% euphausiids) in their stomachs at that time. An additional 1.5 million adult salmon which spawn locally in the NAS (Shaul et al. 1983) are not included here, because they presumably had stopped feeding, being so close to their spawning streams.

Salmon Juveniles

Daily ration is estimated from Livingston and Goiney (1984); abundance estimates are from Isakson et al. (1986; their transects 4, 5 and 6).

Herring/Capelin

Few herring or capelin were caught, even though some spawning occurs near Port Moller. Estimates of spawner abundance (11K-100K tons) are rough, usually based on visual estimates of schools in the Port Moller vicinity (Gilmer 1983, McCullough 1984; Schwartz 1985). A mean value (70K tons) was used. Thereafter, estimates were based on midwater trawl data (g/m^3) x average water depth (30 m) of the study area. Best-guess estimates are that the fish have a moderate daily ration (2%) during spawning, and 6% thereafter.

Sand Lance

Daily ration is assumed to be 6% in winter and spring when most feeding occurs, and 2% at other times. Abundance estimates per sampling period = average BPUE in midwater trawls (g/m^3)*averge depth in the study area + average BPUE in bottom trawls (g/m^2).

Other Forage Fish

Abundance = average purse seine catch of all fish except salmon and sand lance (Isakson et al. 1986) x 3 to account for the average depth of the study area compared to the depth of the purse seine net.

Appendix 8.4. Concluded.

Bottom Fish

Daily ration is estimated from Livingston and Goiney (1984). Summer abundance estimates from various sources vary widely (1.5-50 g/m^2), depending on gear used and annual variation. The value used here is the average catch of small trawls (2.6 g/m^2) and large trawls in NMFS new subsea 1 (29.3 g/m^2) (see text). Winter abundance was taken as 1/2 summer abundance, which is the ration of the winter BPUE (January) to the summer BPUE (May-September) using our small trawl.

Section 9

SYNTHESIS

by

Joe C. Truett

Section 9

SYNTHESIS

9.1 INTRODUCTION

This synthesis presents an analysis of important aspects of the structure and function of the North Aleutian Shelf (NAS) ecosystem. It is based on existing data and on new data collected in this study. The structure of the synthesis reflects the primary objectives of the project: (1) to describe how the dominant fish, birds,and mammals use the NAS nearshore zone, (2) to clarify the important ecological components and processes on which these vertebrates depend, and (3) to evaluate the vulnerabilities of these vertebrates (and the factors on which they depend) to increased OCS-related activity in the area.

The synthesis has four main sections. Section 9.2 is a brief characterization of the NAS ecosystem from physical processes and lower trophic levels to top consumers. Section 9.3 focuses on Objective 1 (above), showing how the vertebrates are distributed in time and space and suggesting causes for the observed distributions. Section 9.4 addresses Objective 2, attempting to show how the important ecosystem processes and components regulate vertebrate use of the area in time and space. Section 9.5 evaluates the vulnerabilities of the important biota to OCS-related activities (Objective 3).

9.2 ECOSYSTEM CHARACTERIZATION

A general overview of important ecosystem processes and components on the NAS and how the biota depend on them is provided in point-form below.

1. In general, water appears to enter the NAS study area by advection from the west end (Schumacher and Moen 1983; Section 2.0, this report) and by dispersive exchange with shelf waters to the north (Section 2.0, this report). Minimal amounts are injected by stream discharge. Waters exit to the east by advection and to the north by dispersive exchange (Section 2.0, this report).

2. The spatial juxtaposition of the NAS study area relative to Unimak Pass, the shelf edge, and the outer and middle shelf domains, in combination with the circulation patterns, strongly influences the sources (and thus the quality) of its water. Water at the west end of the study area apparently contains substantial proportions of both (a) Alaska Coastal Current water that has come through Unimak Pass from the Gulf of Alaska shelf (Schumacher and Moen 1983), and (b) water that has recently upwelled from either the deep Pacific (through eastern Aleutian passes--Hood 1986) or the Bering Sea (Section 3.0, this report). By the time waters exit the east end of the study area, they probably come to resemble to some extent adjacent central domain waters because of the appreciable dispersive exchange that typically occurs between the NAS and the central domain during transit of water through the study area.

3. Most of the nutrients that fuel the NAS ecosystem appear to come from the deep Pacific/Bering basins, based on the radiocarbon abundances of NAS biota (Section 3.0, this report). These nutrients presumably come onto the Bering Sea shelf west or northwest of the NAS study area, as evidenced by the prevailing circulation patterns (see Kinder and Schumacher 1981, Whitledge et al. 1986). They may come into our study area either directly, by advection at the study area's western end, or indirectly, via dispersive exchange with the adjacent shelf waters to the north (which also receive nutrient-rich waters from off the shelf to the west--Kinder and Schumacher 1981, Whitledge et al. 1986). NOAA-sponsored studies now in progress near the eastern Aleutian Islands have obtained preliminary new evidence suggesting that large proportions of the nutrients for the NAS area may come from the Bering Sea basin (S. Saupe, Univ. of Alaska, pers. comm.).

4. The temperature of the NAS waters is more seasonally variable than that of either the shelf break waters to the west or the shelf waters to the north. NAS waters are up to several degrees warmer in summer than either shelf break or deeper shelf waters. In winter they are cooler than the shelf break waters but similar in temperature to other shelf waters (Kinder and Schumacher 1981; Schumacher and Moen 1983; Section 2.0, this report). These seasonal temperature patterns, especially when viewed in the context of temperature patterns of adjacent water bodies, imply much about the seasonal utility of the NAS to the fauna. This point will be discussed later in this section.

5. In summer a front normally exists between the coastal domain and the adjacent middle/outer shelf domains to the north. The location of this front is typically about the 50-m depth contour (the approximate outer boundary of the NAS study area) (Kinder and Schumacher 1981, Coachman 1986), but appears to be temporally variable, sometimes encroaching shoreward to about the 30-m contour and sometimes moving to beyond the 50-m contour (Section 2.0, this report). Regardless of its location, it is considerably wider than the water is deep (Coachman 1986), so any effect it has on concentrating zooplankton might be spread over a fairly broad band where the domains meet. Whether this front exists at all in winter is unclear (Schumacher et al. 1979, Coachman 1986).

6. Phytoplankton production accounts for the great preponderance of carbon that enters the vertebrate food web; eelgrass carbon provides a very small proportion (Section 3.0, this report). During winter, when phytoplankton production is reduced, nutrients move onto the shelf and tend to build up all along the NAS (and elsewhere on the shelf--Whitledge et al. 1986). When light and water-column conditions become optimum in spring, an

intense plankton bloom occurs, then declines as nutrients are stripped from the water column. But all through summer and into fall, blooms (usually much smaller than the initial spring bloom) may recur with weather events (storms) that inject nutrients into the system from the west or north (Section 3.0, this report).

7. Because of the large spatial and temporal variations in primary productivity and the uncertainties in measurement techniques, no clear differences in primary production levels with distance either parallel or perpendicular to the coast were observed in this study. But differences undoubtedly exist; total primary productivity and annual carbon fixation is probably considerably higher at the west end, near the main source of the nutrients (Section 3.0, this report).

8. Annual carbon fixation by primary production in the NAS is about 220 to 240 g C/m^2-yr, averaged over the study area (Section 3.0, this report). This is about the same as reported for deeper shelf waters by other studies in the southeastern Bering Sea (i.e., PROBES studies).

9. Phytoplankton produced in the NAS study area is very inefficiently grazed by water-column herbivores (copepods, euphausiids) (Section 8.0, this report); this same phenomenon has been reported to occur in deeper waters of the adjacent middle shelf. The excess production is presumably exported (primarily to the middle shelf, if the circulation model of Section 2.0 is any indication) or sinks and is consumed by the benthos. The relatively low standing stocks of benthic herbivores suggest that most of the excess is exported, unless most of that which sinks is consumed by meiofauna before it enters the other benthic consumers.

10. Presumably, the phytoplankton in the NAS study area is underutilized for the same reason that it is underused in the central domain--copepods (the principal grazers) are species that overwinter on the shelf in small numbers and cannot reproductively respond in spring to take advantage of the sudden plankton abundance. (Conversely, on the outer shelf, oceanic species of copepods, that overwinter at depth in large numbers, graze the phytoplankton very efficiently--Cooney 1981.) Our studies show that the NAS copepod community is a mixture of middle shelf and outer shelf (oceanic) copepod species; the relative abundances of the two groups vary in time and space, and apparently depend on the circulation patterns that bring water masses (and therefore copepods) into the area from various deep ocean and shelf sources (Section 4.0, this report). At no time do the copepods appear to normally be present in sufficient abundance to effectively crop the phytoplankton (Section 8.0, this report).

11. Excluding jellyfish, the major components of the zooplankton biomass on the NAS are grazers (copepods, euphausiids) and predators on other zooplankton (chaetognaths) (Section 4.0, this report). The zooplankton standing stock biomass per unit area in the study area, and in other nearshore Bristol Bay waters, is much lower than that reported to occur in middle and outer shelf domains of the southeastern Bering Sea (Section 8.0, this report). The relatively high consumption of zooplankton by vertebrate consumers in these nearshore waters could contribute to this low observed biomass.

12. Our sampling suggests that zooplankton groups have seasonal changes in relative abundance. Euphausiids seem to be the biomass dominant in late spring and early summer. Euphausiids decline in mid-summer, to be dominated thereafter by copepods and (in late summer and early fall)

by large jellyfish. Jellyfish comprised a very large proportion of the September zooplankton biomass in this study. By winter, chaetognaths are the dominant group (Section 4.0, this report). Seasonal changes in diets of zooplanktivorous birds and fish reflect this change in zooplankton abundance (Sections 5.0 and 6.0, this report). Second-year sampling suggested that this relative dominance pattern of zooplankton (and diets of birds and fish) might change somewhat from year to year--in May 1985 copepods were more abundant in relation to euphausiids (in samples and in bird and fish diets) than they were in May 1984 (Sections 4.0, 5.0, and 6.0, this report).

13. Distribution patterns of the benthos showed clear trends with depth (i.e., distance perpendicular from shore), and sometimes with alongshore locations. Benthic infaunal biomass was very low in waters less than 10 m deep (as would be expected because sea ice invades the area in some years); epifauna (principally shrimps and mysids) reached its highest biomass in these shallow areas. Total infaunal biomass was highest in western parts of the study area. Both infauna and epifauna tended to be abundant off the major inlets--Izembek Lagoon and Port Moller (Section 4.0, this report).

14. Some of these distributions of benthos could have been related to food availability. High infaunal biomass and high carbon fixation (by both phytoplankton and eelgrass) both appear in western parts of the study area (Sections 3.0 and 4.0, this report). Epifauna is most abundant where infauna (a probable competitor for food) is scarce (Section 4.0, this report).

15. Benthic infaunal biomasses between 20- and 50-m depths were similar to those reported for deeper parts of the southeastern Bering Sea shelf (Section 4.0, this report).

(Recall that primary productivity rates and the tendency for water-column grazers to be inefficient were also similar between the deeper parts of the NAS area and the middle shelf.)

16. The fish, bird, and mammal communities beyond about the 20-30-m depth contours appeared in large part similar to those in the deeper shelf waters beyond (Sections 5.0, 6.0, and 7.0, this report). Frequently the same species dominated, and were present in somewhat similar abundances. But there are a few obvious differences between the deep NAS and areas farther seaward. Pollock are probably much more abundant beyond the 50-m contour than inside; sea otters are the reverse.

17. The zone shoreward of the 20-30 m depth contour appeared to contain somewhat different assemblages of species than did waters beyond. Numerous species of resident inshore fishes, plus seasonally-spawning forage fishes, are largely absent beyond 20 m (Section 5.0, this report). Ducks, cormorants, and gulls were common within 30-m depths, but scarce beyond; the reverse was true for shearwaters, auklets, murres, and phalaropes (Section 6.0, this report). Gray whales, sea otters, harbor seals, and sea lions were relatively common within 20 m, but scarce beyond (Section 7.0, this report).

18. As is apparent from the previous several paragraphs, an ecosystem "boundary" in terms of distributions of many invertebrates and vertebrates, appeared to occur at the 20-30-m depth contour, or even nearer to shore, and not at the 50-m contour as initially postulated. Inside this rather nebulous boundary, the biological community was in many ways different from that farther offshore in the study area. And in the deeper, farther offshore parts of the

study area, the biological community was similar to that in the middle domain beyond 50 m.

19. Physical habitat constraints appeared responsible for making the biological community within the 20-30 m depth contour different from that farther offshore. Inshore fishes and spawning forage fishes were found only short distances away from bays, lagoons, sand substrates, benthic algal communities, and other shallow coastal habitats on which they depended (Section 5.0, this report). Shoreline nest sites combined with short foraging distances kept many birds (cormorants, gulls) nearshore in summer; preferences for shallow depths by benthic feeders (ducks) kept others near shore in winter (Section 6.0, this report). The benthic-feeding sea otter apparently prefers feeding in these shallow waters (Schneider 1981), and gray whales typically migrate and feed near shores throughout their range (Braham 1984). The nearshore infaunal community was, in comparison with that beyond 20 m, depauperate in terms of biomass and diversity, probably because of ice scour (Section 4.0, this report).

20. Use of the NAS study area by vertebrates appears to be highly seasonal partly because of the seasonality of food supplies in the water column. The spring bloom of phytoplankton occurs in May (Section 3.0, this report), followed by blooms of herbivorous zooplankton (copepods, euphausiids) in June/July (Section 4.0, this report). This, in turn, is followed by large-scale immigrations of plantivorous vertebrate consumers into the study area (Sections 5.0 and 6.0, this report), and they are abundant from spring through mid-summer. By August/September, the heavy grazing of zooplankton by vertebrates (and jellyfish) apparently depletes the supply, whereupon many birds, marine mammals, and forage fishes that feed in the water column move elsewhere, and levels of biological activity

remain relatively low until the next spring (Sections 4.0, 5.0, 6.0, and 7.0, this report). Animals that are abundant over winter (small flatfishes, sea ducks, sea otters, auklets) feed either on a seasonally stable infaunal food supply or near the shelf edge where planktonic food may be brought up from depth (Sections 5.0, 6.0, and 7.0, this report).

21. It is likely that many fishes use the NAS nearshore zone in summer in preference to adjacent areas because the water temperature is higher there. Species possibly influenced in their use of the area by the warm water include the forage fishes, the flatfishes, and juvenile salmon (Section 5.0, this report). The presence of some of these fishes (e.g., sand lance) may in turn attract piscivorous birds and mammals to the nearshore zone in summer.

9.3 DISTRIBUTION AND ABUNDANCE OF HIGHER TROPHIC LEVELS

In this section we summarize the distribution and abundance patterns that have been observed, and identify the physical and biological factors that appear to be responsible for these patterns. Section 9.4, to come later, will discuss in greater detail these causative factors.

9.3.1 Spatial Distribution

The NAS study area extends from the coast to the 50-m depth contour (and beyond in some cases), and from Cape Mordvinof on the west to Cape Seniavin on the east. Data from this study and others show that animal species composition and abundance often change with distance perpendicular to the coast (i.e., depth) and/or with location east-west along the coast.

Very few of the vertebrates sampled were distributed uniformly from the coast seaward to the deepest areas sampled. Fish, sampled mainly from late spring to early fall, showed depth preferences as follows: (1) sand lance, rainbow smelt, and yellowfin sole were most abundant at 20-m depths and shallower; (2) pollock, salmon, and rock sole were most abundant near the 50-m depth zone and beyond; and (3) herring and capelin (few of which were caught in this study) are known from other studies to be typically more abundant in the deeper waters except very briefly in late spring or summer when they come near shore to spawn (Section 5.0, this report). Among the birds, shearwaters, murres, auklets, and phalaropes concentrated in waters more than 30 m deep; cormorants, gulls, and sea ducks showed preferences for waters shallower than 30 m. Within these broad limits, some birds (shearwaters, murres) showed seasonal or annual differences in their depth zones of concentration (Section 6.0, this report). Among mammals, gray whales, Steller sea lions, walruses, and harbor seals were almost entirely restricted to shallow depths (<20 m) very near shore; northern fur seals were most common farthest from shore. Sea otters, generally most common near shore, became in winter more common in deeper water out to 50 m (Section 7.0, this report).

Reasons for the depth distributions observed appear to vary among species. Based on the present study and other investigations, the animals are probably responding to (1) the presence of the inner front (some birds), (2) the presence of specific shoreline or substrate types (fish, birds, and mammals), water temperature (fish), or prey availability (fish, birds, mammals).

Distributional abundances of some animals varied with east-west (coastwise) location in the study area. No clear pattern of coastwise abundances of fish emerged from the data in this study, but it is known that some fish are more abundant at the eastern end toward inner Bristol Bay (e.g., salmon, capelin) or near embayments such as Port Moller where spawning is concentrated (see Section 5.0, this report). Among birds, Crested Auklets (in winter) and shearwaters (in fall) were concentrated at the western end of the study area near Unimak Pass, and some others (e.g., Red-faced Cormorant, Glaucous-winged Gull) were concentrated in summer near known nesting colonies (Section 6.0, this report). Mammals showing marked coastwise concentrations included Steller sea lion and harbor seal (more abundant near haulout areas) and sea otters and fur seals (more abundant near the western end) (Section 7.0, this report).

Reasons for variability in coastwise abundances of animals include (1) the presence of coastal embayments attractive as feeding or spawning sites (birds, fish), (2) the presence of emergent coastal features unique as nesting or hauling-out sites (birds, mammals), and (3) the proximity of east or west ends of the study area to migration routes (i.e., Unimak Pass) or food concentrations (fish, birds, mammals).

9.3.2 Seasonal Patterns

All the important species varied seasonally in total abundance in the study area, and some showed seasonal shifts in distributions within the area. The best data on seasonal abundance exist for the spring, summer, and fall periods; winter data are sparse. The following information is taken from previous sections of this report.

Fish are, in general, much more abundant in the study area in late spring and summer than during other seasons (Section 5.0, this report). Forage fishes (herring, capelin, sand lance) began moving into the area in large numbers in late spring to spawn and/or feed; most were gone by late summer. Salmon juveniles leaving their natal streams in Bristol Bay traditionally move seaward (westward) through the area, and returning adults pass through eastward on their way to spawning areas in inner Bristol Bay streams. Most of these salmon movements take place in late spring and early summer, and most are concentrated mainly in deeper waters of the study area. Demersal fishes are most abundant in the area in summer; most (particularly large individuals) vacate the area in winter, though juvenile yellowfin and rock sole winter there. Water temperatures and perhaps food availability appear to promote this seasonal difference in fish distributional patterns.

Bird abundance overall, like that of fish, is greatest in summer (Section 6.0, this report). The main reason for the overwhelming summer abundance is the presence of several million Short-tailed Shearwaters, which nest in the southern hemisphere and spend their non-breeding period in the Bering Sea. Other species more abundant in summer than in winter are Black-legged Kittiwake and Glaucous-winged Gull; both species nest on nearby coasts. Birds more abundant in winter than in summer are Crested Auklets, scoters, eiders, murres, and cormorants. Note that, if shearwaters are excluded, winter bird densities are higher than summer densities. Seasonal differences in total bird abundance in the area, and distribution patterns within the area, are caused to some extent by the availability of nesting sites and migration passes nearby (e.g., for murres, gulls, cormorants, shearwaters), but also probably by food availability (e.g., for shearwaters, auklets, waterfowl, murres).

Mammals vary among species in their seasonal abundance and local distribution in the study area (Section 7.0, this report). Sea otters, consistently the most numerous mammals, shifted their distribution to deeper waters in winter but showed no marked seasonal difference in overall abundance in the study area. Steller sea lions and harbor and Dall porpoises showed no marked seasonal differences in abundance or in distribution within the study area (although would likely do so in years when sea ice invaded the study area). Harbor seals were most abundant in summer, and gray whales during spring and fall migrations. Most other mammals, though expected to be more common in summer, were seen too infrequently in this study to demonstrate any seasonal differences. Factors that account for seasonal differences in abundance include periodic intrusions of ice in winter (sea otters, harbor seals) and species migration patterns that bring mammals into or through the area from elsewhere (most whales).

9.3.3 Interannual Variability

Abundances of many vertebrates are known to vary among years in the southeastern Bering Sea (Wooster 1983). Because this study included only two years of field sampling, and for many vertebrate groups the sampling efforts were not made in the same months in each of the two years, few data to evaluate interannual variability were collected. Only for fish and birds could populations be reasonably compared among years.

Interannual variability in fish populations were inferred by viewing this study's data (Section 5.0, this report) in isolation as well as in the context of data from other studies. Capelin and herring, reported by others (Warner and Shafford 1981, Barton et al. 1977) to be abundant in late spring/early summer in some years in the NAS nearshore zone, were not caught in abundance in either 1984 or 1985 during this study. (Scarcity of these fishes in our catches was probably due, in part, to our failure to sample at optimum times.) Catches per unit effort (both numbers and biomass) of yellowfin and rock sole in this study were considerably higher in May 1985 than they were in May 1984. Large annual differences in salmon populations are known to occur, but were not measurable in the present study because sampling was not designed to catch salmon. Annual observed differences can be caused by several factors--(1) differences among years in sampling effort (e.g., for capelin and herring), (2) annual differences in regional distributions of fish as a consequence of water temperature or prey distribution differences (for yellowfin and rock sole), (3) real differences in regional population numbers, caused by one or more factors operating over much larger areas than the study area or (4) a combination of all these (and perhaps other) factors.

Among birds, interannual comparisons are based largely on data collected in the present study (Section 6.0, this report). Annual differences in both total numbers and distributional patterns within the study area were observed. For example, in May 1985 overall density estimates (of all species) were higher than in May 1984. Short-tailed Shearwaters appeared to occur at highest densities (based on shipboard surveys) in deeper water in 1985 than they did in 1984; conversely, Northern Fulmars peaked in density in shallower areas in 1985 than they did in 1984.

Reasons for these observed interannual differences are not clear. Because seabirds are long-lived, it is unlikely that large changes in total numbers occur between years. Higher shipboard estimates of total densities in May 1985 than in May 1984 may be partly a consequence of an inadequate survey technique. Shifts in depth preferences of shearwaters and fulmars among years could have been caused by shifts in hydrographic structure and, thereby, in prey distribution (e.g., horizontal changes in the location of the inner front), though this is not readily apparent from the oceanographic data. Because seabirds are highly mobile and can rapidly locate new prey sources and change their feeding locations accordingly, it is possible that distributional changes occur rapidly in response to short-term shifts in oceanographic conditions and prey availability. If this is so, observed annual differences in bird distribution cannot be interpreted as a between-year phenomenon.

9.4 FACTORS REGULATING DISTRIBUTION AND ABUNDANCE

The above discussion (Section 9.3) noted apparent causes for the observed distributions and abundances of biota. There seem to be two major causal factors--trophic and physical--involved in regulating these distributions and abundances.

9.4.1 Trophic Factors

Trophic dependencies and energy flow within NAS food webs have been depicted in a quantitative, conceptual model in the preceding chapter (Section 8.0, this report); a summary of the major points will help to introduce the following discussions. Pelagic primary production by phytoplankton provides nearly all the energy that supports the important vertebrates; eelgrass provides a relatively minor source of energy. The primary production supports both pelagic and benthic herbivores; vertebrates (in total) get approximately half their sustenance from the pelagic food web and half from the benthic. Primary production appears to be in excess of the needs of the herbivores. The excess carbon fixed by primary production is presumably exported, or used up in benthic meiofaunal food webs. The herbivorous zooplankton, and possibly the benthos, appear to be in short supply as food for the vertebrates that eat them. Predation by vertebrates may limit standing stocks and productivity of zooplankton and benthos.

The following sections expand upon these trophic factors (food supply, predation) as potential regulators of vertebrates on the NAS. Discussions proceed from lowest to highest trophic levels.

9.4.1.1 Primary Production, Nutrients, and Transport

Two sources of carbon--eelgrass transported from coastal lagoons and *in situ* phytoplankton production--are available to consumers in the NAS study area. It appears that eelgrass production contributes a very small part of the total, and that its greatest contribution is to the local benthic food web. Phytoplankton production is the major carbon source; it is apparently supported largely by deep-ocean nutrients (Section 3.0, this report). These nutrients may enter the NAS directly at its western end, or indirectly via water exchange with the middle shelf domain. The following paragraphs explain the apparent timing and manner of this nutrient supply to the NAS area and its use by the phytoplankton.

The general circulation and water exchange patterns that prevail in the southeastern Bering Sea and in the NAS study area (Kinder and Schumacher 1981; Schumacher and Moen 1983; Section 2.0, this report) suggest that materials are transported into the NAS area from the west (by advection) and from the north (by dispersive exchange). Part of the water and transported materials that come from the west appears to be derived from the Alaska Coastal Current that has moved into the area from the shelf south of the Alaska Peninsula (Schumacher and Moen 1983). Part could also be derived from deep Bering and/or Pacific water that has upwelled on the north side of the eastern Aleutians and moved eastward onto the shelf along the north side of Unimak Island (see Hood 1986). Radio-carbon signatures of organisms collected from the NAS study area reflect a deep-ocean based food-web (Section 3.0, this report), lending support to this possibility. Waters that enter the NAS from the north undoubtedly come from the middle domain (see map in Fig. 2.2), though the ultimate source of the middle domain water is the deeper Bering Sea, as we discuss further below.

Primary productivity is low in winter throughout the shelf, mainly because light is limited, but also because storms cause rapid mixing in the water column (even in the middle domain, which is stratified in most other seasons). This mixing dampens primary productivity by reducing the time that phytoplankton cells are in the euphotic zone (Sambrotto et al. 1986). During this period of low productivity, nutrients (nitrate) diffuse onto the Bering Sea shelf from the deeper waters to the west. This on-shelf flux of nutrients occurs not only in areas north of the NAS area, as reported by Whitledge et al. (1986), but also probably directly into the NAS from the west, as noted above.

As winter ends and spring progresses, the amount of daylight increases. At the same time, beginning in the eastern parts of Bristol Bay, the water column (at least in the middle domain) becomes stratified to some extent because the winter storm season terminates, fresh water is supplied to the surface by melting sea ice and river discharge, and surface waters warm (Sambrotto and Goering 1983). The longer days and (in the middle domain) the stratified water column expose phytoplankton cells longer to light, causing plankton blooms to commence (Sambrotto and Goering 1983). As nutrients (nitrate) that built up over the winter are assimilated from the euphotic zone by the phytoplankton, the loom diminishes. This pattern occurs both in the middle domain (Sambrotto and Goering 1983) and in the coastal domain (i.e., the NAS study area) (Section 3.0, this report). In both the coastal and middle domains, the bloom may periodically be rejuvenated during the summmer if the normally stratified middle domain is mixed by strong winds such that nutrients from its bottom waters are brought into the euphotic zone of both domains (Section 3.0, this report).

The timing of the phytoplankton bloom has strong implications for zooplankton abundance. During spring, particularly in eastern parts of the study area that are removed from the shelf edge, only small numbers of copepods are available from overwintered populations to take advantage of the bloom, and not until mid-summer do they reach near maximum numbers (see Section 4.0, this report). However, relatively large numbers of euphausiids may have overwintered on the shelf (Section 4.0, this report); thus, they may be the primary water-column grazers in the study area in spring. Apparently neither copepods nor euphausiids are ever sufficiently abundant in the NAS nearshore zone to crop a large percentage of the bloom before it settles to the bottom or is exported (Section 8.0, this report).

9.4.1.2 First-level Consumers

As noted above, the major zooplanktonic grazers are euphausiids and copepods. The euphausiids are typically dominant in late spring and early summer and the copepods typically dominate in late summer and fall (Section 4.0, this report). A brief look at some aspects of euphausiid and copepod seasonal abundance and behavior will help explain their seasonal abundances in samples (and in predator diets) on the NAS.

Among the euphausiids, it is probable that Thysanoessa raschii and T. inermis form the major portions of samples and predator diets (see also Ponomareva 1966, Dagg 1982). Both these species are abundant on Bering Sea continental shelves. In spring, coinciding in time more or less with the phytoplankton bloom, they collect in large swarms at the surface to breed (Ponomereva 1966), where they are easy prey to both birds and fish. Their swarms may be found from late April to June in the Bering Sea. By late summer, Thysanoessa becomes much less abundant to predators (and to sampling gear) because (1) they have dispersed from surface breeding swarms and are benthic in habit more of the time and (2) the numbers of adults have probably been cropped drastically by predators since early summer (see Ponomareva 1966).

In contrast to this pattern of seasonal abundance of euphausiids, the copepods in the coastal domain (similar to those in the adjacent middle domain) are at lowest abundance in winter and spring and increase to their highest abundance only by mid- to late summer (Lasker and Clarke 1982; Section 4.0, this report). Most of the time, the NAS is dominated by the small copepods that overwinter on the shelf and not by the large ones on the outer shelf that overwinter in the deep ocean environment, though the large copepods become more numerous when outer domain water intrudes into the NAS study area (Section 4.0, this report).

9.4.1.3 Top Consumers

Top consumers, as defined in this section, are second- and third-level consumers in the NAS food webs. With a few minor exceptions (e.g., the surf clam, Spisula), the species important to man are exclusively in these second and third consumer levels. Several food-web factors in relation to the distributions and abundances of these consumers are important, as follows:

(1) Many of these top consumers are more abundant in the study area in late spring and early summer than they are in late summer, fall, or winter. Included in this category are mainly birds (murres, shearwaters, kittiwakes, gulls), and fish (salmon, herring, capelin) that feed extensively on water-column invertebrates and to some extent on pelagic fish (Sections 6.0 and 5.0, this report). Nearly all these consumers feed heavily on euphausiids, or on fish that eat euphausiids (Section 8.0, this report). Most

species that are equally or more abundant in late summer, fall, or winter are mostly either year-round residents (harbor seal, cormorants, crabs, surf clam), and/or benthic feeders (sea otter, yellowfin and rock sole, crabs) (Sections 4.0, 5.0, 6.0, and 7.0, this report).

(2) Populations of most of the species that are seasonally abundant on the NAS in spring and early summer (excepting shearwaters) require large energy supplies preparatory to or during breeding, or for their young, at this time of year. This need means that each individual must acquire more food per day than at other times of the year; this may be particularly true for the fishes, which probably also require less food in winter because of low temperatures. This point and (1) above emphasize the need for water-column and surface feeders to find large quantities of readily available food at this time of year. The following point shows why food may be more available earlier in the year than later.

(3) Biomass of prey available to consumers that feed in the water column is much greater in late spring and early summer than it is in other seasons. Two main factors probably influence this greater availability. First, the lower the prey occurs in the food chain, the more abundant it tends to be (because each step up the food chain typically reduces the biomass about ten-fold). Euphausiids, the main spring/early summer prey base of pelagic top consumers (Section 8.0, this report) are primarily herbivorous (first-level consumer); sand lance, the main pelagic prey species for the same consumers later in the year, are second-level consumers. Second, primary productivity rates decline after the spring bloom, precipitating an eventual decline in herbivores, and finally in consumers of the herbivores. In combination, these differences between early-season and late-season prey on the NAS may have much to do with the seasonal abundances of their predators.

(4) The biomass of benthic-feeding vertebrates is more seasonally stable than that of pelagic species, probably reflecting the seasonal stability of the prey base. As noted earlier (Section 9.3), benthic feeders (as a group) are abundant in both summer and winter (e.g., demersal fishes and sea otters in summer; demersal fishes, sea otters, ducks in winter) in contrast to the scarcity of water-column feeders in fall and winter.

9.4.2 Physical Factors

Physical environmental factors that appear most effective in directly regulating animal abundance and distribution are three--(1) characteristics of shorelines or substrates, (2) extent of sea ice in winter, and (3) water temperatures. The first is a more or less fixed geological variable; the second and third are direct consequences of weather patterns and show great seasonal and annual variability.

9.4.2.1 Shorelines and Substrates

Figure 9.1 illustrates sites where some animal populations congregate on North Aleutian Shelf coasts and islands, based on information presented in previous sections of this report. Some of these concentrations are at oceanside cliffs (not discernible from the map), some are on islands, and some are associated with bay and lagoon systems. Very few occur along relatively featureless coasts. Other animal aggregations associated with physical features include juvenile crabs associated with rocky or cobble benthic environments off Port Moller and Cape Seniavin (McMurray et al. 1984) and surf clam concentrations between Port Moller and Ugaskik Bay where depths and salinities are optimum (Hughes and Bourne 1981) (these are not shown on the map). Perhaps some of these sites of aggregation are favored because of some trophic advantage offered (e.g., relatively abundant food in waters nearby); this cannot be evaluated from the data.

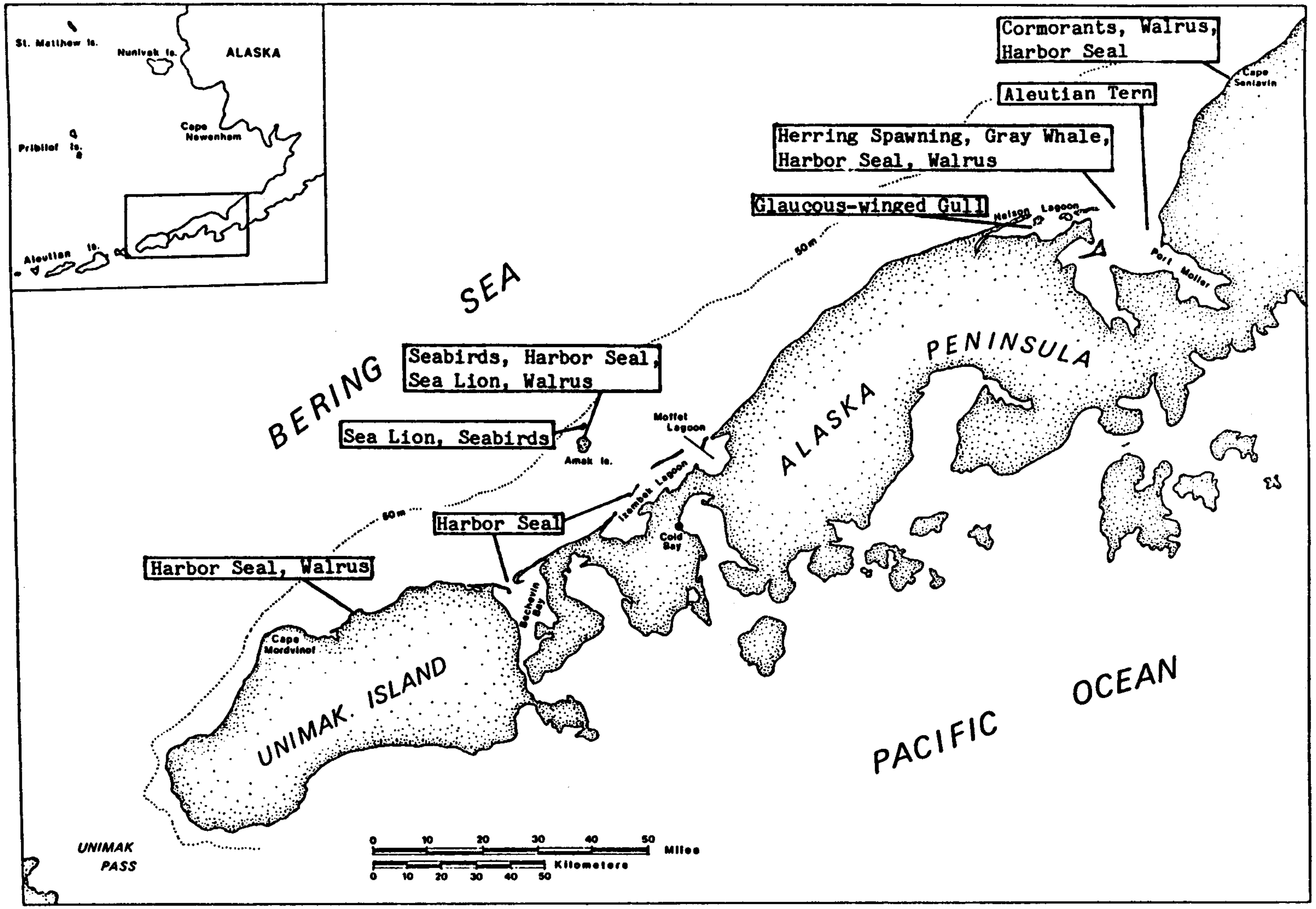

Figure 9.1. Areas where some of the animal populations in the NAS study area are concentrated.

9.4.2.2 Ice

Winter ice has positive effects on some species and negative effects on others. In most years, sea ice at its maximum extent approaches, but does not invade, the NAS study area from the northeast; in unusually cold years much of the area may be ice-covered in late winter and early spring (Niebauer 1981). Thus, walruses, which typically are associated with ice year-round, are near the southern limits of their distribution on the NAS. Conversely, sea otters, harbor seals, waterfowl and seabirds may be displaced to the south by encroaching ice, and are near their northern limits of winter distribution on the NAS (Sections 6.0 and 7.0, this report).

9.4.2.3 Water Temperature

Water temperature strongly affects the distribution and abundance of many, perhaps all, poikilothermic (cold-blooded) species (fishes and invertebrates) in medium to high latitudes (Laevastu 1984, Schumacher and Reed 1983). It is conceded to be one of the most important regulating factors for populations of fishes and invertebrates in the southeastern Bering Sea. It may also affect the homoeotherms (birds and mammals), because fishes and invertebrates are key components in the food webs of all of them.

It is well known that large annual variations in water temperature occur over the continental shelf of the southeastern Bering Sea. The differences are evidenced by such phenomena as differences in the extent of sea ice cover in winter, warming in spring or cooling in fall that are earlier or later than normal, and variations in seasonal maximum and minimum temperatures. Within the 100-m isobath, these variations seem to be caused mainly by annual differences in weather patterns, as has been discussed by Schumacher and Reed (1983). Less well known are the annual variations in temperature differences between the NAS nearshore zone and deeper shelf areas, which in some years (e.g., in summers when deeper waters are colder than normal) could create in the nearshore zone an important thermal sanctuary for fishes and inverterates (see Section 5.0, this report). The following paragraphs discuss how water temperature (and variability therein) affects fishes and invertebrates that use the NAS area, and what that implies about the seasonal distribution and abundance of these animals in the area.

Temperatures are known or suspected to affect the distributional abundances of salmon, forage fishes (sand lance, capelin, herring), demersal fishes (pollock, yellowfin sole, rock sole), and crabs. In addition, temperature has been shown to be an especially important factor in all aspects of fish energy budgets--it influences the amount of food ingested, the rate at which food is digested, and the general metabolic rate of the organism (e.g., Kinne 1960, Beamish 1964, Brett and Higgs 1970, Jobling et al. 1977, and many others).

Water temperature significantly affects the distribution of juvenile salmon as they migrate seaward into the Bering Sea (Straty 1981). Annual temperature differences can be expected to result in variations in the time juveniles reach the North Aleutian Shelf and the length of time they remain in this region. Sea temperatures may also influence the width of the seaward migration route of juveniles (Straty 1974), and thus influence what proportion of the migrants pass through the NAS area.

For forage fishes such as herring, capelin and sand lance, there are three general activities directly influenced by water temperatures: (1) reproduction, (2) rates of egg and larval development, and (3) population movements. Herring spawning, for example, is related to winter and spring water temperatures, i.e., it is early in warm years and late in cold years (Wespestad and Barton 1981). Herring, capelin, and sand lance have demersal eggs that generally require two or more weeks to hatch, with water temperature being the determining variable. The rate of larval development for these species is probably also related to temperature, but other environmental factors such as food supply for larval herring (Wespestad and Barton 1981) may be more consequential. Temperature may influence the seasonal distribution and movements of juvenile and adult herring more than any other environmental factor (Wespestad and Barton 1981). Temperature influences where herring overwinter in the central Bering Sea, when they migrate from offshore overwintering sites to coastal spawning grounds, when they spawn, and perhaps the length of time they remain in coastal waters before returning to offshore waters.

Temperature is also a key factor influencing the distribution and seasonal movements of demersal fishes such as pollock and yellowfin sole (Bakkala 1981, Smith 1981, Favorite and Laevastu 1981). In spring these fish tend to migrate from offshore overwintering areas to shallower portions of the continental shelf to feed and, in some cases, spawn, and in fall they retreat to deeper overwintering areas on the outer shelf and upper slope. The latter migration is thought to be an avoidance response to the cold bottom temperatures (0 to -1.8°C) existing over the eastern Bering Sea shelf in winter. The fish overwinter near the shelf break where water temperatures are about 5-6°C warmer. Movements in spring back into shallower water are probably influenced by increasing temperatures as well as other factors. Similarly, temperature may affect the year class strength of yellowfin sole, with above-average abundances occurring in warmer years (Maeda 1977, cited by Bakkala 1981).

Temperature affects both the distribution of adult red king crabs and the development and survival of their larvae (Armstrong et al. 1983). In late winter and early spring adult males apparently migrate from deeper, offshore areas to join females in shallow water for breeding; the nearshore, shallow water habitat is apparently selected in part for warmer water temperatures (and perhaps greater food supplies). Temperature is considered one of the most crucial physical factors affecting survival and growth of larvae (McMurray et al. 1984). Severe climatological changes could account for large fluctuations in survival of a year-class and later recruitment to the fishery. For example, both 1975 and 1976 were severely cold years and poor survival of larvae and juveniles then could account for low abundance of sublegal males five to six years later in 1981-82 (McMurray et al. 1984) and nine to ten years later in 1984-85 (this study).

Temperature undoubtedly also affects the recruitment, growth rates, and distributional patterns of invertebrates important in food webs. Timing of occurrence, and perhaps the distributions, of surface swarms of euphausiids may be temperature-related. The relative abundances of copepods and euphausiids in seasonal diets of vertebrates, as observed in this study, are perhaps temperature-related, though little is known of this subject.

9.5 VULNERABILITIES OF BIOTA TO OCS ACTIVITIES

This section discusses the vulnerabilities of the important fish, bird, and mammal populations to activities (herein called OCS activities) that might occur should oil exploration and development escalate in or near the NAS area. Emphasis will be on the potential effects of oil spills, but other activities such as those associated with oil well drilling and increased boat traffic will be considered in cases where they seem important. Impacts of OCS activities on the processes and components supporting the important vertebrates will be addressed in cases where these impacts may appreciably affect the vertebrates themselves.

In this discussion, "vulnerability" and "sensitivity" are two words used to describe the susceptibilities of animal populations to adverse impact from OCS activities. Vulnerability is defined as the likelihood that significant portions of regional populations will interact with OCS activities. Sensitivity is the level of response of individual animals to the activities with which they come in contact. Thus, a population that is highly concentrated in space might be highly vulnerable to an activity, particularly if that activity is likely to occur in the same places as the concentration; a population that is widely dispersed would not be particularly vulnerable to any localized activity. Populations whose members are highly sensitive to activities may suffer considerable adverse effects if the populations are vulnerable, but not if the populations are relatively invulnerable. Relatively invulnerable populations comprised of individuals not sensitive are secure from adverse effects.

Extensive reviews already exist of the known levels of sensitivity of Bering Sea fish, birds, and mammals to oil and other OCS activities, as follows: (1) fish and shellfish (Curl and Manen 1982; Thorsteinson and Thorsteinson 1982, 1984; Laevastu et al. 1985), (2) mammals (Braham et al. 1982, Davis and Thomson 1984, Armstrong et al. 1984, Pace 1984), and (3) birds (Strauch and Hunt 1982, Roseneau and Herter 1984, Armstrong et al. 1984, Pace 1984). All the species with which we are concerned have been included in one or more of these reviews, and the data collected in the present study do not provide significant new data on sensitivity. Thus our discussions will depend on existing information about species sensitivities, and will provide new information mainly on vulnerabilities of populations.

9.5.1 Relative Sensitivities of Important Species

Consensus in the literature about relative sensitivities of invertebrates, fish, birds, and mammals is generally as follows:

(1) Fish and Invertebrates--Eggs and larval stages of fish and invertebrates are relatively sensitive to oil in comparison with adults. Further, it is difficult or impossible for these early life stages to actively avoid oil with which they come in contact, which further enhances their sensitivity.

(2) Birds--Birds in general are the most highly sensitive group of vertebrates to being oiled. Oil may drastically impair the insulative and buoyancy values of feathers, frequently causing mortality if birds remain in water. Because marine birds are especially dependent on their use of the aquatic environment and the water surface, they are likely to come into direct contact with spilled oil. Birds also occasionally collide with ships, suffering dramatic mortalities on a very local scale. Nesting seabirds are very sensitive to some types of human activity, most obviously the taking of eggs or young from nests.

(3) Mammals--Sensitivity varies greatly among the mammal species. Mammals insulated largely with fur (fur seal, sea otter) respond more adversely to being oiled than do the other species, which are insulated with subcutaneous blubber. The literature also suggests that very young mammals, whether furred or otherwise, are generally more sensitive than older ones of the same species.

9.5.2 Vulnerabilities of Populations

General vulnerabilities of important vertebrate species and their food webs in the NAS and vicinity have been discussed by Pace (1984), Laevastu et al. (1985) and Truett and Craig (1986), based on existing literature. Conclusions of these authors, modified and supplemented as appropriate by findings of the present study, lead to the conclusions that follow.

9.5.2.1 Fish

Oil spills are assumed by most people to be the OCS activity of most concern with respect to fish. Laevastu et al. (1985) concluded that the largest oil spills conceivable would have only minor effects at most on the eastern Bering Sea populations of fish and shellfish, despite the sensitivity of larval stages. They point out that populations of all species are so widely dispersed, and potential oil spills so restricted in space, that only insignificant portions of the Bering Sea populations would even come into contact with the oil.

Several points about Laevastu et al.'s (1985) oil effects model should be noted in order to assess its applicability to fish populations in the NAS study area. Three hypothetical oil spill scenarios in the southeastern Bering Sea were considered, all spills at depths of less than 50 m. One was near the east end of the NAS study area (at a 45-m depth near Port Moller) and all were assumed to be very large spills. In general, the model assumed maximum adverse behavior of the spilled oil with respect to the various life stages of the species considered. Fishes and crabs important to the commercial fishery (demersal species, salmon, and pelagic species) were included in the evaluation, but evaluations of the effects of oil spills on beaches and on coastal spawning of herring and capelin were excluded. Thus it appears that the model is applicable to areas beyond the immediate subtidal zone of the NAS study area but not to bays, lagoons, intertidal, or very shallow subtidal areas.

On a local scale, some fish populations are vulnerable. The most vulnerable species are probably the littoral spawners such as capelin and Pacific herring. The next most vulnerable are probably the freshwater spawners such as boreal smelt and salmon, the juveniles of which spend some time in the shallow nearshore environment. Species that live year-round in shallow waters might be next most vulnerable. Most demersal and pelagic species are relatively invulnerable. On a very local basis, capelin could be highly vulnerable because they spawn in intertidal or shallow subtidal areas, where spilled oil might likely be deposited. Newly-hatched larvae tend to accumulate in surface water. But in the final analysis, capelin populations are so regionally dispersed and mobile that the effects of the worst imaginable oil spill could probably not be measured.

Herring would probably be the most vulnerable of the commercially-important species to an oil spill because their spawning, incubation and nursery stages all occur in shallow shoreline environments where oil might collect and persist for relatively long periods. But spawning stocks of herring in the NAS area are small compared with other stocks in the eastern Bering Sea. As summer progresses, juvenile herring move offshore where they are less vulnerable. Post-spawning adult herring from Bristol Bay stocks migrate into the study area to feed in summer and fall, but they are expected to be relatively secure from large-scale population losses (see Laevastu et al. 1985).

The most vulnerable stage in the life cycle of salmon occurs in late spring and early summer when smolts migrate downstream and inhabit coastal waters. Smolts are dependent on estuarine habitats for feeding and adjustment to new salinity regimes as they leave fresh water and enter the ocean. As summer progresses, these juveniles disperse farther offshore where they are less vulnerable to in the nearshore zone disturbances.

Bax (1985) and Laevastu et al. (1985) examined the vulnerabilities of Bristol Bay sockeye salmon juveniles and adults to oil spills. Their worst-case estimates of mortality from a large spill in Bristol Bay were 13% of Bristol Bay juveniles and 5% of the adults. Six percent of the juveniles and 2% of the adults could be tainted. At no time does the NAS study area harbor a very large proportion of Bristol Bay salmon juveniles or adults.

Resident inshore fishes of the NAS, especially those restricted to lagoons and bays, are relatively vulnerable in the sense that their populations are concentrated in habitats where spilled oil may accumulate and/or persist for relatively long periods. Included are species such as rockfish, greenling, and sculpins. (Note that these bays and lagoons are largely outside the NAS area as it was defined in this study.)

Groundfish are probably less vulnerable to OCS effects than are other fishes because they inhabit subtidal benthic environments, where oil is unlikely to accumulate. It is possible that an oil spill could damage the pelagic eggs, larvae, and/or juvenile stages of these species in surface waters, particularly in the case of pollock. But pollock populations are small within the study area in comparison with their populations farther offshore. For both pollock and other demersal fish, the widespread abundance of the early life stages suggest that population-level effects would be small on any except a very local basis.

9.5.2.2 Birds

We have seen that birds are, in general, more sensitive to oil spills than are fish or mammals. In some instances they are also quite vulnerable.

Birds can be vulnerable for one or both of two reasons--(1) large proportions of populations occur as local concentrations and/or (2) their intrinsic behavior exposes them to OCS activities (e.g., oil on water, human activity at nesting sites). Populations exhibiting both these traits are highly vulnerable; those exhibiting neither are relatively secure from appreciable impact.

Four species or species groups--Short-tailed Shearwaters, Crested Auklets, Glaucous-winged Gulls, and seaducks--concentrate themselves in space and also have behaviors that make them vulnerable. Short-tailed Shearwaters frequently occur in large concentrations (flocks of over 100,000 are common) and spend much time swimming on the water's surface where spilled oil can readily reach them. Crested Auklets were found in large concentrations in this study near the west end of the study area; this species spends virtually all its time swimming or diving. The largest colony of Glaucous-winged Gulls in Alaska is located adjacent to the study area on a spit in Nelson Lagoon; this colony is exposed to egg-gathering and other human activity that might occur in the area, or to a local oil spill (adults forage largely in the vicinity of the colony).

Seaducks occur in fairly large concentrations and are readily susceptible to floating oil.

Of these four species, the Crested Auklets are probably most vulnerable as a population, with seaducks next in order. The swimming and diving behavior of auklets insures that oil spilled near them would pose a high risk to the birds, and perhaps one-eighth or more of the Alaska population has been counted in one concentration area on the NAS. Large proportions of wintering populations of eiders, scoters, and Harlequin Ducks likewise occur in the NAS area in winter, and ducks are highly likely to be oiled if oil is present. In contrast, shearwater behavior enables them to normally avoid spilled oil, and, even though single flocks can be large, each is a small proportion of the perhaps tens of millions of birds that occupy the Bering sea. Likewise, Glaucous-winged Gulls are less likely to be affected by spilled oil on the water, and regulatory action should be sufficient to protect eggs and young at nests.

The other bird species appear to be relatively invulnerable, when NAS populations are viewed in the context of Bering Sea populations. Populations that use the NAS are either small proportions of Bering Sea populations (e.g., fulmars, cormorants, murres) and/or have behaviors that would likely enable them to avoid oil on the sea (e.g., kittiwakes, terns, phalaropes).

9.5.2.3 Mammals

Similarly to other vertebrates, the vulnerabilities of mammals depend on the proportions of regional populations harbored by the NAS, the tendency for the animals to congregate in areas where OCS activities might occur, and the probability that the animals could detect and avoid oil in the environment.

The most common marine mammals that occur in the NAS area appear to be sea otter, Steller sea lion, northern fur seal, harbor seal, and gray whale. Steller sea lion, northern fur seal, and gray whale populations migrate through the area in spring and fall; small proportions of the population of each spend the summer there. Sea otters and harbor seals are present year-round. Large proportions of the total population of gray whales use the area; significant proportions of sea lion and otter populations of the Bering Sea also occur in the NAS. Relative vulnerabilities of each of these populations to activities on the NAS are discussed below.

The NAS study area contains the highest densities of sea otters of any place in the Bering Sea (Schneider 1981). Frost et al. (1982) and the present study found highest densities in the west parts of the study area from Moffet Lagoon to Unimak Island. During most seasons, greatest densities occur near the coast within 10-20 m water depths (Section 7.0, this report). A haulout site near the southwest entrance to Izembek Lagoon attracted up to a hundred or more animals at various times during this study. But the majority are probaly dispersed over a broad area at all times and are thus relatively invulnerable as a population to localized effects of OCS activities.

The Steller sea lion probably exhibits the greatest tendency of any of these species to concentrate large proportions of its populations in restricted localities. Traditional haulout sites exist at Amak Island and on the north side of Unimak Island; there is a breeding rookery on Sea Lion Rock near Amak Island (Frost et al. 1982). During the present study, relatively high densities were observed near the Amak Island and Unimak Island haulout areas; densities tended to be low elsewhere. Because of this tendency to congregate near and on shores, sea lions are judged to be the most vulnerable of the mammals to potential effects of OCS activities.

Northern fur seal were seldom observed during this study, but they are known to concentrate in migratory passage in spring and fall in and near Unimak Pass near the west end of the study area (North Pacific Fur Seal Commission 1971). Based on the scarcity of observations during this study, and on the fact that most observations were of single animals, we judge that fur seal populations of the Bering Sea are highly invulnerable to OCS activities that occur within the study area.

Harbor seals occur in relatively high densities in coastal parts of the NAS study area, and the total number along the north side of the Alaska Peninsula is a significant portion of the Bering Sea population (Frost et al. 1982). Observations made during this study showed many to haul out on islands in the Port Moller vicinity. (Significant numbers probably hauled out also in Izembek Lagoon and farther inland reaches of Port Moller; these areas were not surveyed, since they were outside the study area.) Most animals observed were either hauled out or in very shallow waters near the coast, indicating a moderate level of vulnerability to oil spills or other localized activities that occur along coasts or in bays and lagoons.

The majority of the entire population of eastern Pacific gray whales is reported to migrate in spring in a very narrow coastal band through the NAS study area; a few of these apparently spend the summer in the Nelson Lagoon area near Port Moller (Braham et al. 1982). Some migrants apparently return through the area in fall (Leatherwood et al. 1983). Observations made during this study substantiate these reported observations. Because relatively small proportions of the migrants occupy the NAS at any one time, the vulnerability of the population to oil spills or other short-term activities is not as great as it might otherwise be. But the population would be extremely vulnerable to impacts from long-term activities in the shallow waters of the NAS.

9.5.3 Implications for Assessing the Effects of OCS Activities

The information presented above and in other parts of this report implies that certain animal groups are more likely to be adversely affected than are others. In general, we propose the following points.

(1) Seabirds, especially Crested Auklets, seaducks, Short-tailed Shearwaters, and Glaucous-winged Gulls (in approximately that order), are of greatest concern with respect to potential effects of OCS development in the NAS. Sea otters probably follow as a close second to this group of seabirds. The activity of major concern relative to impacts on these animals is oil spills.

(2) A secondary level of concern with respect to oil spills revolves around species that stand to exhibit less regionally important effects but might suffer local impacts. Included in this group are some fishes (e.g., capelin, herring, salmon), some birds (e.g., fulmars, cormorants, murres), and some mammals (e.g., northern fur seals, Steller sea lion).

(3) Other vertebrates in the study area appear relatively immune from even local adverse effects of OCS activities. Included are most pelagic and demersal fishes (excluding herring and capelin), birds that feed from the sea surface by dipping or seizing (kittiwakes, terns, phalaropes), and mammals that are widely dispersed and insulate themselves with blubber (e.g., porpoises, most whales).

(4) It seems unlikely that appreciable effects on the vertebrates will come mainly as a consequence of effects on their food webs. First, many of the important species, particularly the birds and mammals, are probably more susceptible to impact than are the prey species (largely fishes and invertebrates) they consume. Second, adverse impacts on food-web components are unlikely to be more than local, given the localized nature of most oil spills. With the rapid movement of zooplankton and other prey, and the high mobility of the consumers themselves, these local effects on food webs are not likely to substantially reduce food available to the consumers, much less to be measurable as changes in consumer populations. One possible exception might be severe reduction in infauna.

Information collected in this study also suggests something about the measurability, predictability, and consequences of impacts caused by OCS development. Important points follow.

(1) <u>The deeper parts (> 20 m) of the NAS appear to be in many ways similar in ecosystem structure and function to the middle shelf domain beyond the 50-m contour</u>. This implies that the kinds of impacts that might occur with OCS development are similar between the areas. It further suggests that information gathered on the NAS might be usefully extrapolated in some cases to other areas of the southeastern Bering Sea, and vice versa.

(2) <u>Large annual variations occur in distributions and abundances of many species</u>. Many of the important species

as well as the food-web components supporting them show large and sometimes unpredictable year-to-year variations in distribution and abundance of adults and/or recruitment of young. Such variability makes it very difficult to accurately predict, for any one year, how many organisms or what proportion of a population would be affected by a given OCS activity, or what the long-term effect on the population would be. Further, such unpredictable natural variability makes it very difficult to sort man-caused from natural change once a development-related impact has occurred.

(3) Distributions of most of the directly important species and the important components of their food chains are spatially patchy. Distributional patchiness has the same consequences for predicting or measuring man-caused impact as does annual variability--it greatly increases the difficulty of developing programs that will accurately predict, or measure, the effects of development activities in the area.

(4) Important pelagic species and their food-web components tend to be more highly mobile than benthic species. This mobility makes it very difficult in the pelagic system to either predict effects of a site-specific activity (because the organisms may be able to readily avoid the activity) or to measure the effects once they have occurred (because the affected organisms may quickly disperse themselves among unaffected organisms, or vice versa). Reliable predictions or measures of impact on infauna, or possibly on their predators, would probably be, in contrast, much simpler. (This generality might not hold in cases where impacts occur at nesting, breeding, or haul-out sites to which otherwise mobile organisms are tied by tradition or need.)

(5) A greater diversity and abundance of important species populations, particularly breeding populations, occupy the area in spring and summer than in fall and winter. This

implies that the chances for important adverse impacts are greater earlier in the year, particularly because eggs and young are generally more vulnerable to human-related activities than are adults. Crested Auklets and seaducks may be notable exceptions (particularly because of their susceptibility to oil), for few occupy the area in early summer and many congregate there in fall and winter.

(6) Evidence suggests that many of the species feeding on the pelagic food web may readily adapt to large changes in prey species availability. This implies that adverse impacts to only parts of the prey base may pose less of a problem to these consumers than it would if they were less versatile in dietary habits. Whether the benthic feeders are likewise adaptable is not clear.

(7) Because many of the animal populations on the NAS seem to exhibit great variability among years in response to natural environmental factors, it is very likely that they are "pre-adapted" to survive (over the long-term) man-caused disasters. In the short-term of a few months or years, however, it may still be possible for OCS activities to have substantial effects on some populations.

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