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Final Reports of Principal Investigators

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OUTER CONTINENTAL SHELF

ENVIRONMENTAL ASSESSMENT PROGRAM

FINAL REPORTS OF PRINCIPAL INVESTIGATORS

Volume 56

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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Outer Continental Shelf Environmental Assessment Program

Final Reports of Principal Investigators

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SEAL, SEA LION, WALRUS AND BELUGA WHALE SURVEYS

OF THE BERING SEA, 1979 AND 1982-1983

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Final Report
Outer Continental Shelf Environmental Assessment Program
Research Unit 669

May 1986

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ABSTRACT

Aerial and vessel surveys were conducted in the Bering Sea to determine pinniped and beluga whale density, distribution, and association with sea ice during 1979, 1982, and 1983. The 1982 surveys were conducted with a single helicopter flown over open water from a ship. The 1979 and 1983 surveys were conducted from one or two helicopters flown over the pack ice from an icebreaker. Because pinnipeds are difficult to observe in open water and most beluga whales are north of the Bering Sea during the seasons of open water, this report primarily addresses the 1979 and 1983 late winter to early spring surveys when pinnipeds haul-out on the pack ice and belugas are present. The 1979 surveys included the area from the marginal ice front north to St. Lawrence Island, while the 1983 surveys were restricted to the marginal ice front.

A total of 1,670 pinnipeds were recorded along 2,410 nm surveyed in 1983, and 2,909 pinnipeds were recorded along 4,342 nm in 1979. The Pacific walrus was the most abundant of the seven pinniped species recorded and also the most widespread. Walrus densities were particularly high in the pack ice south and west of St. Lawrence Island and in the marginal ice front between St. Matthew Island and the US-USSR Convention Line. Bearded, spotted, ribbon, and ringed seals and northern sea lions were considerably less abundant and more specific in their distribution. Bearded and ringed seal densities were highest in the central pack ice and spotted and ribbon seal densities were highest in the marginal ice front. Northern sea lion distribution was limited to the southern extreme of the marginal ice front.

The distribution of pinnipeds in the marginal ice front was variable. Spotted seals and northern sea lions primarily occurred in the western section of the front and ribbon seals in the central section of the front. Walruses occurred across the front, but were particularly high

in abundance in the central front. The distance pinnipeds were found in the front from its southern extreme was also variable. Walruses were on the average farthest from the southern extreme of the front, sea lions nearest, and ribbon and spotted seals intermediate. These results and those for the pack ice in general show that pinniped species partitioned their distribution in the project area to reduce competition for food and space.

In addition to pinnipeds, 886 and 598 beluga whales were recorded in 1979 and 1983, respectively. Belugas were widespread in the pack ice, but large numbers of belugas were observed along the western fringe of the St. Matthew Island polynya and in the central pack ice along the US-USSR Convention Line. Belugas were primarily encountered in narrow leads or areas of thin but extensive ice coverage.

Lastly, our studies provide estimated densities for beluga whales and pinnipeds in the project area. Estimates for most species were relatively consistent with those reported by other investigators for areas in or near the study area. Estimates for walrus in the marginal ice front were, however, higher than previously reported anywhere in the front. Furthermore, we report the first estimates of beluga whale and northern sea lion numbers in the Bering Sea pack ice.

INTRODUCTION

Information on pinniped use of the northcentral Bering Sea is limited. Most information is derived from studies in the eastern (Kenyon 1960; Burns 1970; Kenyon 1972; Fay 1974; Burns and Harbo 1977; and Fay 1982) and to a lesser degree the western (Tikhomirov 1964; Shustov 1965; and Kosygin 1966) Bering Sea during spring when pinnipeds haul out on the pack ice. While these and other surveys (Braham et al. unpublished) have entered into the central Bering Sea, very little effort has been devoted to the northcentral Bering Sea ice front. Even less effort has been given to this area during ice-free seasons (Consiglieri and Bouchet 1981). Studies of marine mammals in the northcentral Bering Sea, particularly during winter, have been few primarily because of its remoteness, high logistical costs to access it, and harsh weather.

The results of these published studies identify that seven species of pinnipeds inhabit the northcentral Bering Sea seasonally: northern fur seal (Callorhinus ursinus); northern sea lion (Eumetopias jubatus); Pacific walrus (Odobenus rosmarus); and the spotted (Phoca largha), bearded (Erignathus barbatus), ribbon (Phoca fasciata), and ringed (Phoca hispida) seals (Burns and Harbo 1977). Pinnipeds are most abundant during winter and spring when pack ice provides a platform for resting, breeding, birthing, and molting. Most species migrate either passively on the ice as it retreats northward or actively (swimming) to the Chukchi Sea to summer, except for spotted seals, sea lions, and fur seals, which move to coastal areas of the Bering Sea. Varying sex and age components of these pinniped populations adopt a pelagic existence in the Bering Sea during the ice-free seasons. The densities and movement patterns of pinnipeds in the northcentral Bering Sea, however, are poorly known.

The purpose of this report is to document and compare the results from pinniped and beluga whale surveys conducted in the Bering Sea during 1982-1983 and 1979. This report was prepared in order to document the results of two dedicated research projects for use by MMS in managing petroleum activities in the Navarin Basin and adjacent planning areas of the Bering Sea. The report is divided into three sections:

1. 1982-1983 survey of the Bering Sea.
2. 1979 survey of the Bering Sea.
3. Comparison between the 1982-1983 and 1979 survey results.

The purpose of the 1982-1983 survey was to determine the seasonal use of the Bering Sea by marine mammals during the spring, summer, fall, and winter. The objectives were to:

1. assess winter habitat use of the Navarin Basin by cetaceans, emphasizing the seasonal population size and distribution of bowhead whales relative to ice and other environmental parameters;

2. identify and enumerate the endangered species of whales in the Basin during the ice free period, assess habitat use, and correlate their temporal and spatial distribution with environmental parameters; and

3. document sightings of other species of marine mammals observed during the surveys, and provide estimates of their abundance and distribution within the region.

Objective 3 is addressed in this report, which examines pinniped and beluga whale abundance and distribution in the Basin during the spring (May-June), summer (July-August), fall (October-November), or winter (February-March). Because of the difficulty in detecting and identifying pinnipeds in open water, the report concentrates on winter when pinnipeds haul out on the ice and are most visible to survey. The other two objectives are addressed in an earlier report (Brueggeman et al., 1984).

The purpose of the 1979 survey was to determine marine mammal use of the Bering Sea pack ice during early spring. The objectives were to:

1. identify the distribution and density of bowhead whales and their association to sea ice in the Bering Sea and

2. document sightings of other marine mammals observed during the survey, and provide estimates of their distribution, density, and association with sea ice.

Objective 2 is addressed in this report, which documents information collected on seals, sea lions, walruses, and beluga whales. The bowhead whale results are reported by Brueggeman (1982). For both the 1979 and 1982 through 1983 surveys, the beluga whale results are reported in Appendix C.

Acknowledgements: We thank the 1982-83 field team of Dr. A. Erickson, Dr. T. Newby, J. Joyce, J. Harley, B. Troutman, and W. Everett. L. Consiglieri, M. Dahlheim, B. Kelly, D. Rugh, J. Taggart, and D. Wencker were the 1979 field team. Dr. D. Chapman, Dr. T. Quinn, and R. Fairbanks provided advice on statistical procedures. Dr. T. Loughlin and M. Athey reviewed the report. Logistical support was provided by the staffs of the NOAA ship SURVEYOR during the 1982 seasonal surveys and by the USCG icebreaker POLAR SEA during the 1983 and 1979 surveys of the pack ice. The National Marine Mammal Laboratory of the National Marine Fisheries Service was responsible for the operation, administration, and management of the 1979 survey. Funding for both studies and the analysis we present in this report was provided by the Outer Continental Shelf Environmental Assessment Program.

STUDY AREA

The 1982-1983 study area is located in the northcentral Bering Sea, approximately 200 nautical miles (nm) off the coast of Alaska in the Navarin Basin (Figure 1). It covers over 54,000 nm^2, an area approaching the size of the State of Michigan, and is bound by the

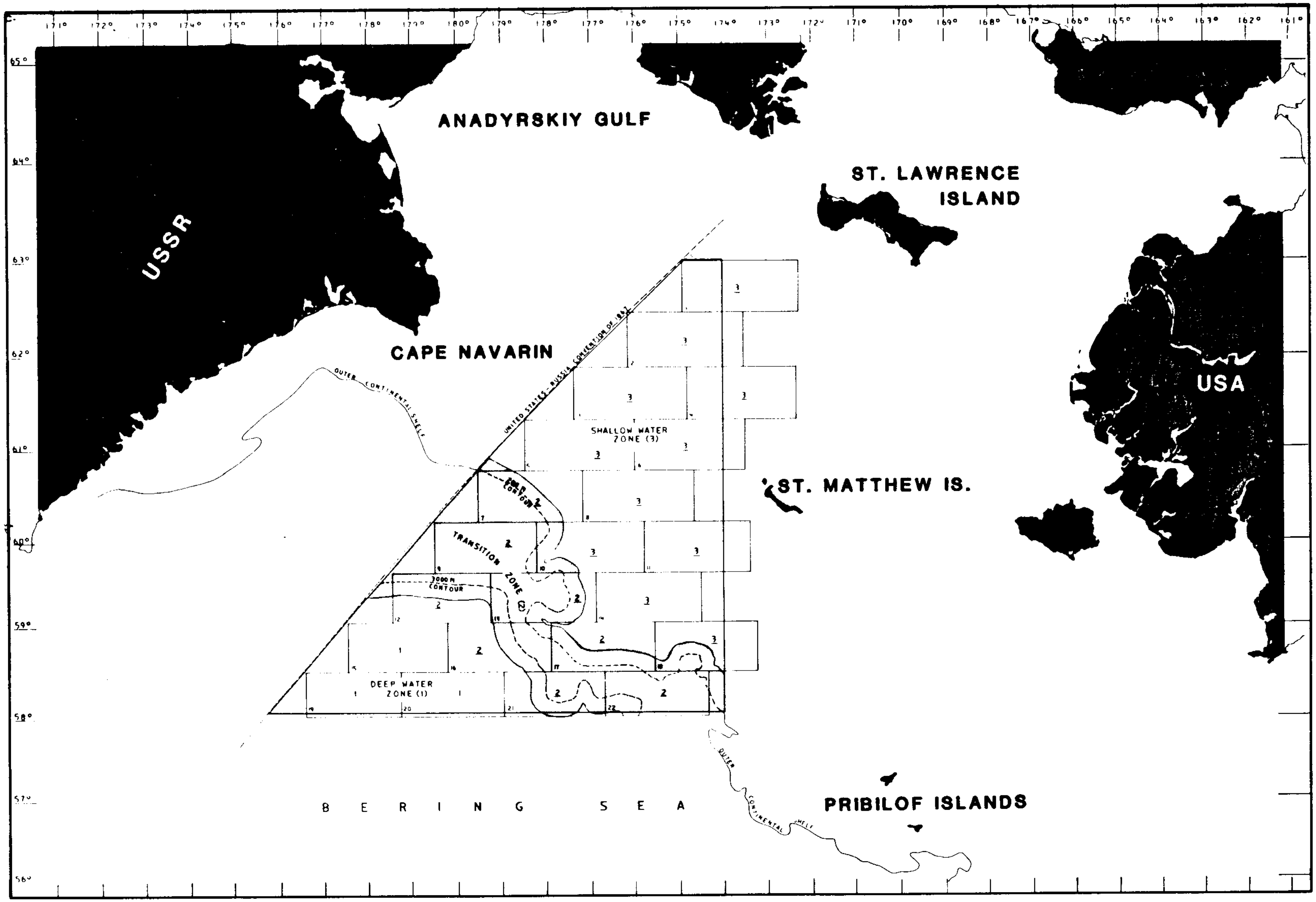

FIGURE 1 STUDY AREA AND SAMPLING DESIGN IN THE NAVARIN BASIN FOR SPRING THROUGH FALL SURVEY PERIOD, 1982.

US-USSR Convention Line to the west, 174°W longitude to the east, and latitudes 63°N and 58°N to the north and south. Water depth in the Basin ranges from about 44 m on the outer continental shelf to over 3000 m outside the shelf. The shelf comprises approximately half of the area in the Basin, while the continental slope and rise comprise 36 percent and 14 percent, respectively. The study area was extended to 171°W longitude during the 1983 winter survey period (Figure 2).

The 1979 study area is also located in the northcentral Bering Sea (Figure 3). It covers approximately 47,380 km^2 and is bound by longitudes 170°W and 180°W to the east and west and latitudes 59°N and 65°N to the south and north. The study area is on the outer continental shelf, where water depths are less than 200 m. The southern boundary was the approximate edge of the pack ice where it meets the open ocean. The 1979 study area overlapped parts of the Navarin Basin, Norton Basin, and the St. Matthew-Hall planning areas. Since the 1982-83 surveys were in the Navarin Basin and also crossed into the St. Matthew-Hall planning areas, the surveys of the two study periods are comparable. In addition, the longitudinal span of the marginal ice front surveyed for both years was largely identical.

The climate of the study area features harsh environmental conditions that promote the seasonal development of sea ice (Figure 4). Environmental conditions typically consist of cold temperatures, high wind speeds, low visibility, and extreme ranges in day length (Brower et al. 1977). Average annual air temperature and wind speed are 0°C and 14 kt, and visibility <2 nm persists approximately 14 percent of the time during the year. Sea ice persists in the Navarin Basin from December through June and ice coverage is greatest from February through April (Potocsky 1975). It seldom extends south of the outer continental shelf and is typically <1 m thick. Breakup of the ice begins in mid-April, and the Basin is generally ice-free by late June.

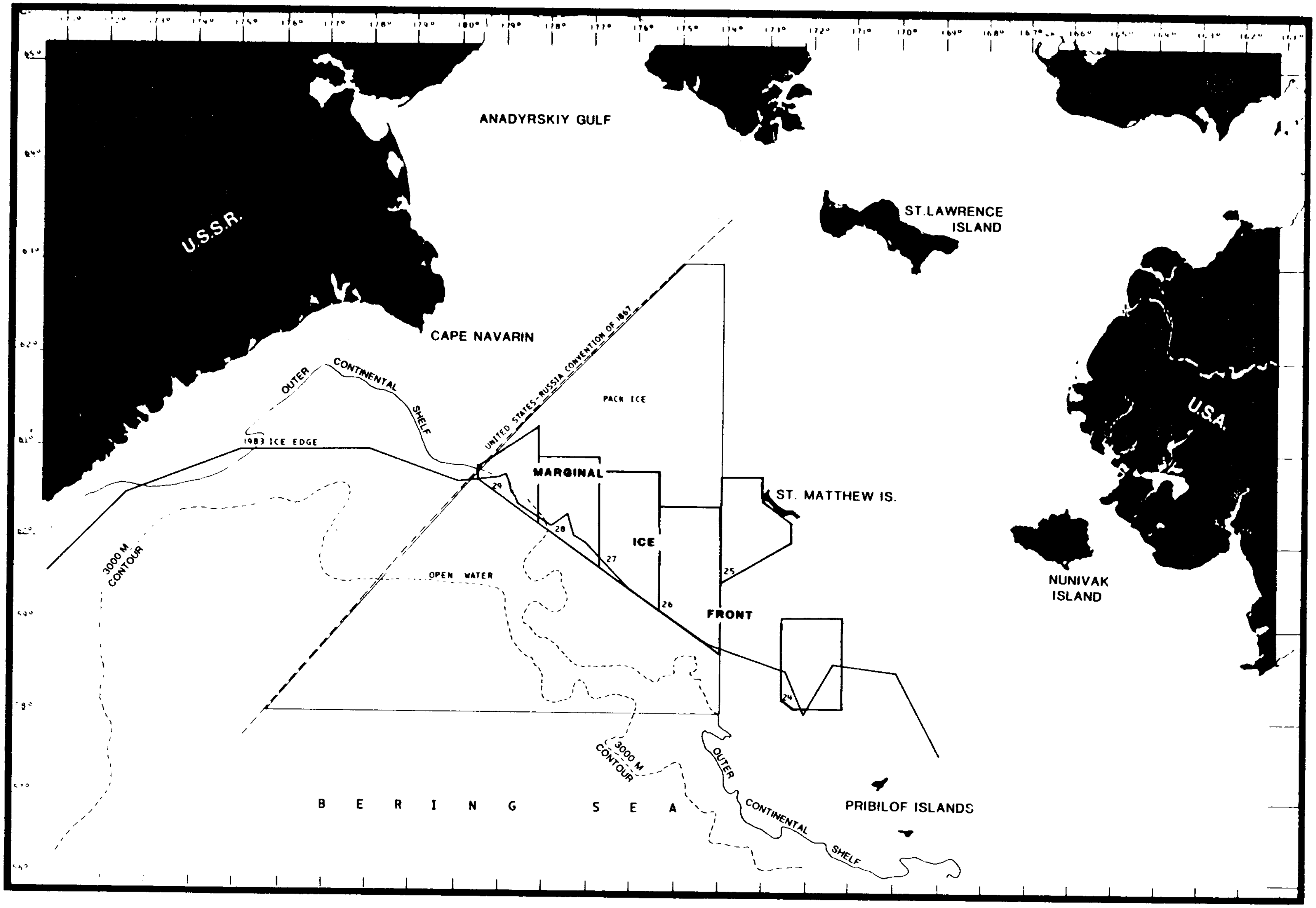

Figure 2 STUDY AREA AND SAMPLING DESIGN IN THE NAVARIN BASIN DURING WINTER SURVEY PERIOD, 1983.

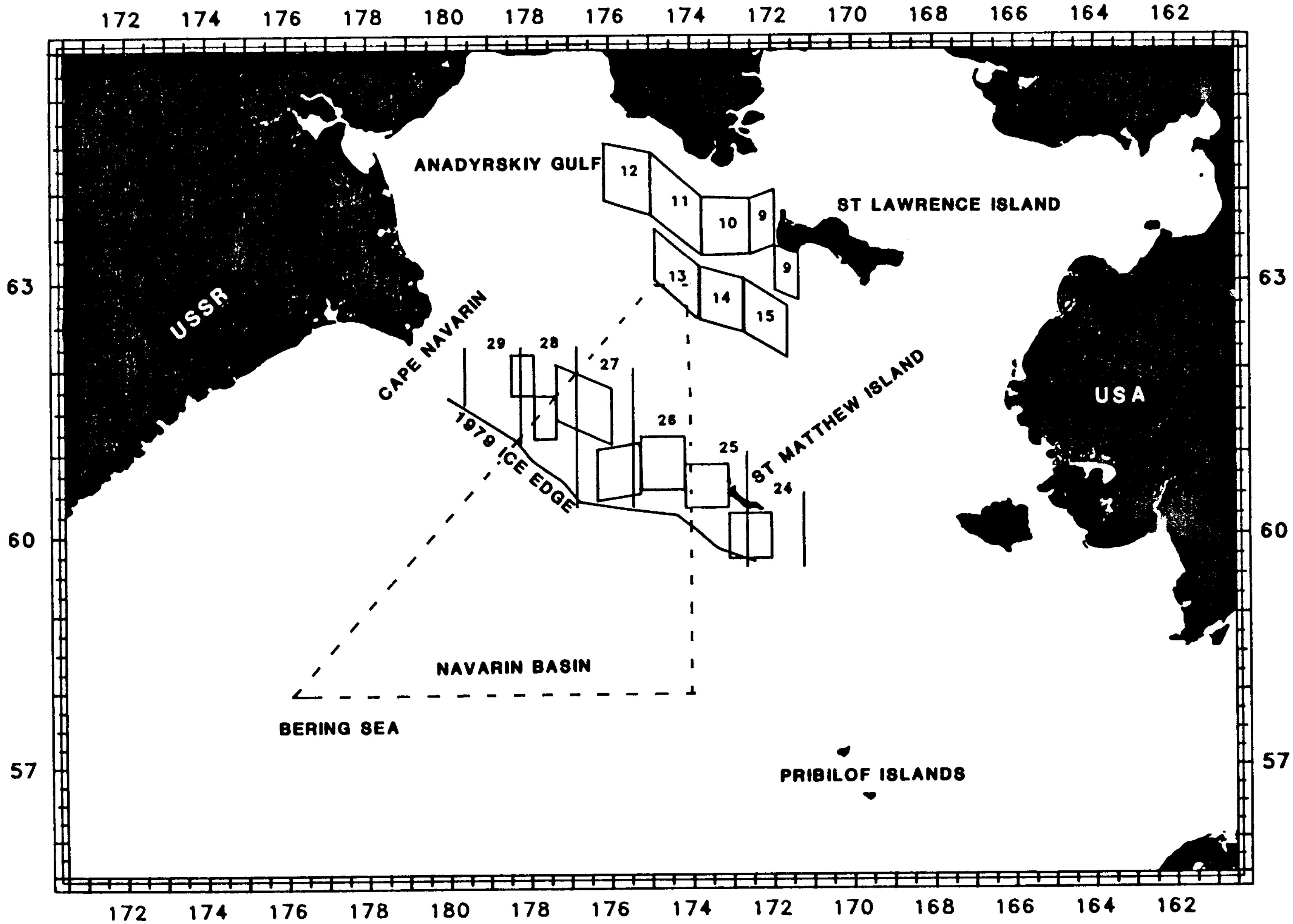

FIGURE 3 STUDY AREA AND SAMPLING DESIGN IN THE BERING SEA FOR THE EARLY SPRING AERIAL SURVEY PERIOD, MARCH-APRIL 1979.

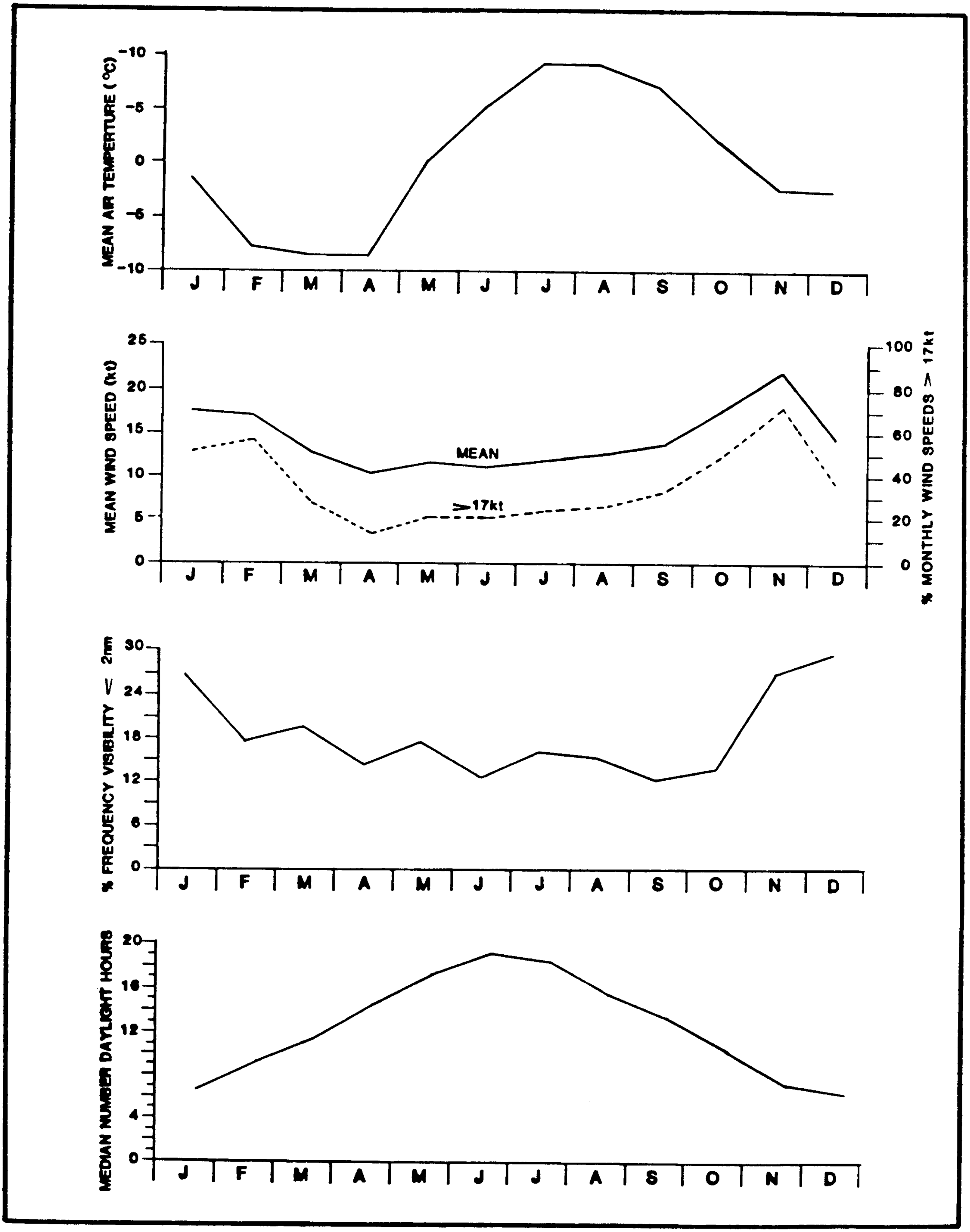

FIGURE 4 HISTORIC ENVIRONMENTAL CONDITIONS OF THE NORTH CENTRAL BERING SEA (BROWER ET AL. 1977)

METHODS

SURVEY PROCEDURES

1982-1983 Surveys

Two sampling designs were developed for aerial and vessel surveys of marine mammals in the Navarin Basin. One design was for surveys during the ice-free period from late spring to early fall. This design was modified for surveys during the late winter-to-early spring when sea ice was in the Basin.

ICE-FREE PERIOD - SPRING, SUMMER, AND FALL: The Basin was stratified into three survey zones (Figure 1). The shallow water zone coincided with the outer continental shelf, while the transition and deep water zones corresponded to the outer continental slope and rise, respectively. The former zone was the area northeast of a point 10 nm northeast of the 200 m contour line, and the latter zone was the area southwest of a point 10 nm southwest of the 3000 m contour line. The area between these points was the transition zone, which featured the greatest topographic relief. The Basin was stratified in this manner to account for distributional differences of marine mammals relative to major changes in water depth. Moreover, areas of potential petroleum development in the Basin may be closely linked to the feasibility of extracting petroleum in various water depths.

Twenty-two sampling units were distributed over the three zones (Figure 1). The shallow water zone contained 11 units, the transition zone 8 units, and the deep water zone 3 units. Each unit was approximately 34 nm by 72 nm and comprised about 2,450 nm^2. Nine transect lines, 30 nm long, were equidistantly spaced every 8 nm corresponding to the longitude lines in each sampling unit (Figure 5). This configuration provided thorough coverage of a sampling unit and prevented double surveying of adjacent lines or units.

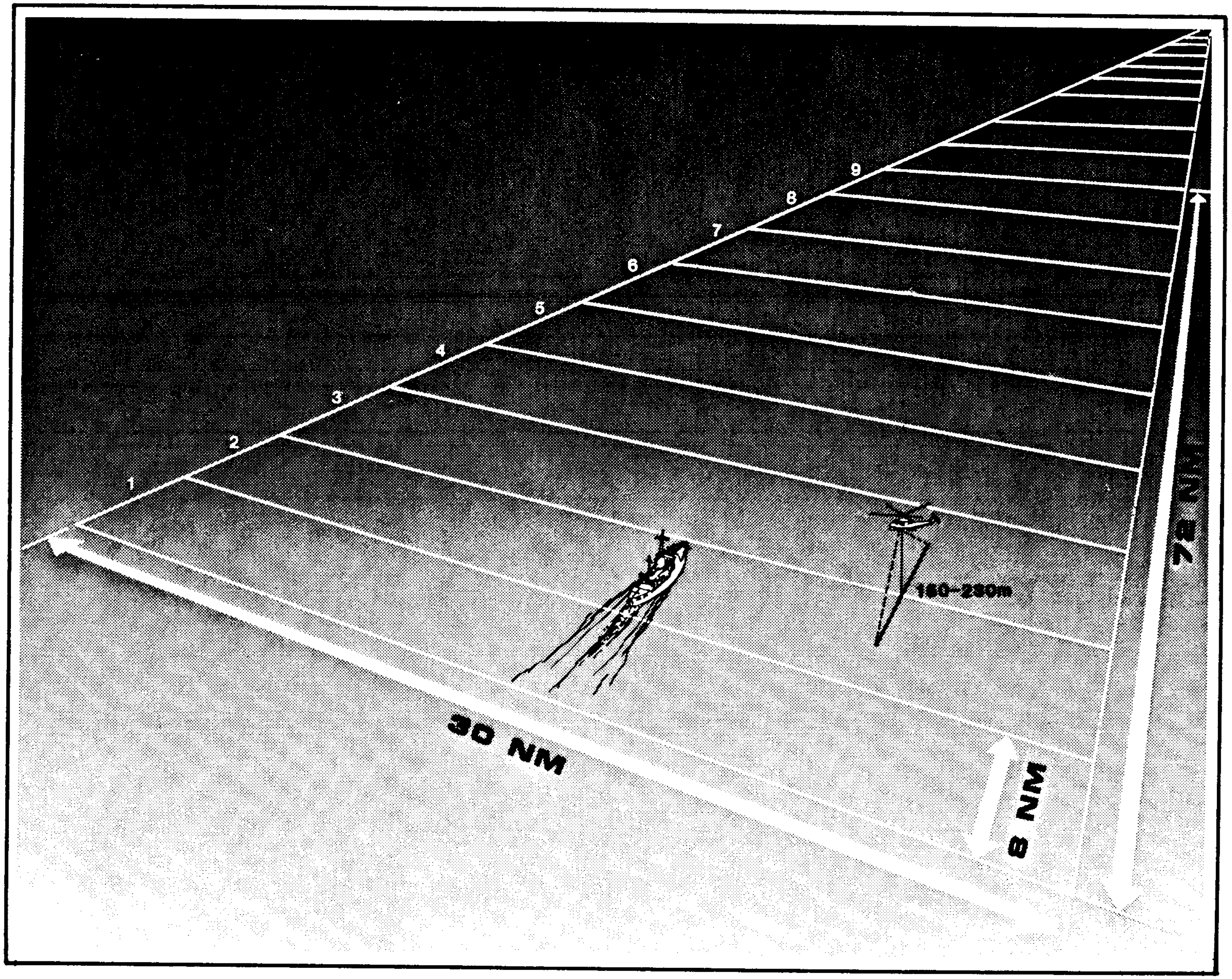

FIGURE 5 TRACKLINE ORIENTATION OF AERIAL AND VESSEL SURVEYS DURING SPRING THROUGH FALL PERIOD, 1982.

Aerial and vessel surveys were conducted along the transect lines of randomly selected sampling units (Figure 5). Survey effort in a given zone was allocated in proportion to the relative amount of area in each zone. Consequently, we attempted to allocate 50 percent of the survey effort in the shallow water zone, 36 percent in the transition zone, and 14 percent in the deep water zone. This approach assumed that marine mammals were distributed in proportion to the amount of area available in each zone, an assumption that was the best available at the initiation of the study from the marine mammal literature for the Basin.

Aerial surveys were conducted from a UH1M helicopter based on the NOAA ship SURVEYOR. Surveys were flown at altitudes of 150-230 m and at speeds of 65-75 kt. Two observers, one positioned in the copilot's seat and one in the right-aft section of the helicopter, provided data on marine mammals and environmental conditions to a data recorder; all data were recorded on computer-ready forms. Data collected on marine mammals during a survey were number, species, vertical angle when an animal was perpendicular to the trackline, group size, time, and position. Environmental conditions including visibility (Appendix A, Table A-1), Beaufort Wind Scale, air temperature, and glare were evaluated at the start of each transect line surveyed, or whenever the conditions changed. Vertical angles were taken with clinometers and positions were recorded from a GNS-500 every 3 nm along a transect line. The pilot was responsible for providing positions of the aircraft to the data recorder, maintaining a constant altitude and airspeed, and when possible, searching for marine mammals.

When the wind speed was greater than a Beaufort 4, the visibility <2 nm, or the ceiling below 150 m, vessel surveys were conducted along the transect lines in place of aerial surveys. Surveys were performed from the flying bridge, approximately 18 m above the water, and at a vessel speed of 12 kt. Two observers, individually stationed on the port and starboard sides of the vessel, recorded marine mammal and environmental data on the same variables described for the aerial surveys. Radial angles, instead of vertical angles, were taken with a sighting board or 10 minute surveyors transit and animal distances from the vessel were estimated by observers who generally had substantial experience with this estimation procedure. Water depth was recorded every 3 nm. Vessel surveys were terminated when wind speed exceeded a Beaufort 6.

Vessel surveys were also conducted in conjunction with the aerial surveys (Figure 5). The ship traveled an east-west route along the mid-latitudinal points of the north-south transect lines. One observer, positioned on the flying bridge, recorded marine mammals encountered along the trackline. The use of the ship during the aerial surveys was for the purpose of collecting distributional information on marine mammals and providing safeguards to the helicopter crew.

SEASONAL ICE PERIOD - WINTER: During the seasonal ice period, the Basin was stratified into three zones identified as the open water, marginal ice front, and heavy pack ice zones (Figure 2). The former zone occurred entirely in open water, while the heavy pack ice zone was primarily in areas of 90 to 100 percent ice coverage; the marginal ice front zone was intermediate between these two strata and consisted chiefly of 10 to 90 percent ice coverage and the fringe of ice along the southern margin of the pack. The size of each zone varied according to the movement of the sea ice during the course of the study. Although this stratification procedure was developed, the open water was not surveyed because of persistent high seas, nor was the heavy pack ice surveyed since the icebreaker had difficulty penetrating the dense, and at times thick, pack ice. Consequently, the entire survey effort was devoted to the marginal ice zone, where the largest number and greatest diversity of marine mammals were expected to be found (Burns et al. 1980, Brueggeman 1982).

Six sampling units were equidistantly distributed across the marginal ice front between longitudes 171°12'W and 179°36'W (Figure 2). The survey area extended beyond the boundaries of the Basin in order to increase coverage of the front. Although each unit was 36 nm wide, the north and south boundaries varied since they corresponded to the edge of the ice and the start of heavy pack ice; boundaries that are governed by wind and currents. The average sampling unit size was 2,730 nm^2, with a range of 1,474 to 3,731 nm^2.

Aerial and vessel surveys were conducted along seven paired transect lines established in each sampling unit (Figure 6). The paired transect lines were spaced every 4 nm and corresponded to the longitude lines. Individual transect lines comprising each pair were separated by 2 nm and extended 30 nm into the pack ice from the interface of the marginal ice front with the open water; the exact length of the transect lines varied depending on ice conditions and a combination of logistical factors influencing opportunities for surveys.

Aerial surveys were conducted from two Sikorsky H-52-A helicopters based on the U.S. Coast Guard icebreaker POLAR SEA (Figure 6). The helicopters flew transect lines parallel to each other or singly at speeds of 65-75 kt and at altitudes of 150-230 m. Observer and data collection procedures were largely the same as those reported for aerial surveys during the ice-free period. The only difference was that navigation was determined from Loran-C systems on each helicopter, and ice thickness, size, and concentration were visually evaluated every 3 nm along the transect line by the observer occupying the copilot's seat in each helicopter; ice characteristics were evaluated by the same two observers for every survey to maintain data consistency (Appendix A, Table A-2 defines ice characteristics). Single helicopter surveys were flown along the transect lines when one helicopter was inoperable. Under these circumstances, the Coast Guard restricted the helicopter range to 8 nm from the ship. To maximize the use of a single helicopter, the ship traveled a predetermined course, while the helicopter flew a transect line 8 nm both north and south of the ship. A similar vessel travel pattern was followed during the two-helicopter surveys but the aircraft traveled longer distances from the ship.

FIGURE 6 TRACKLINE ORIENTATION OF AERIAL AND VESSEL SURVEYS DURING WINTER, 1983.

When winds exceeded 25 kt, ceiling was below 91 m, visibility was <2 nm, or both helicopters were inoperable, vessel surveys were conducted along the transect lines in place of aerial surveys. Vessel surveys followed the same data collection procedures as described for surveys during the ice-free period except for the location of the observers and the angle measurement to an observed animal. Observations of marine mammals were made from the loft-conning tower, 34 m above the water. Each observer recorded all marine mammals occurring in a 90° arc on either side of the bow of the ship for the port and starboard sides. Angles to animals were taken in combination with a sighting board for the radial angle and a clinometer for the vertical angle. This approach provided an accurate way of determining animal distances from the ship. Vessel surveys were also conducted during aerial surveys if survey team members were available to observe due to one helicopter being inoperable; data collected during these surveys were used to describe marine mammal distribution and species composition.

1979 Survey

The study area was stratified into three survey zones (Figure 3). Fifteen sampling units, each approximately 55 km long by 59 km wide, were distributed systematically within these zones. The southern zone or marginal ice front contained 7 sampling units, the northern zone 5 units, and the central zone 3 units. The southern zone or marginal ice front is defined on page 12. The central and northern zones were in the heavier, consolidated pack ice north of the front. These three zones were selected because they characterize the wide range of habitats, ice conditions, and geographic areas used by pinnipeds and cetaceans in the pack ice. The ice conditions of the zones are described on page 45.

Aerial surveys were conducted from two Sikorsky H52-A helicopters based on the icebreaker, POLAR SEA. The helicopters were flown parallel at altitudes of 150 and 230 m, respectively, which was similar to the survey pattern followed in 1983 (Figure 6). Helicopters were simultaneously flown at different altitudes so that pinnipeds could be surveyed from the lower flying helicopter while whales were surveyed from both helicopters. In each sampling unit, 8 paired-strip transects, 55 km long and 1.8 km apart, were aligned with longitudinal lines and spaced every 5.5 km. A directional radio-navigational system (TACAN) was used between helicopters and the ship to guide the aircraft along the transects. Single helicopter surveys were flown (Units 11-15) when one helicopter was inoperable. All marine mammals were counted during the single-helicopter surveys.

Two observers, one positioned in the copilot's seat and one in the right-aft section of the helicopter, provided data on marine mammals and environmental conditions to a data recorder; all data were recorded on computer-ready forms. Data collected on marine mammals included species, number, group size, sex and age composition, time, and geographic location. Environmental conditions, including visibility (Appendix A, Table A-1), and glare (percent of viewing area) were evaluated at the start of each transect line surveyed, or whenever conditions changed. Ice concentration and floe size were visually evaluated every three minutes along the transect line by the observer occupying the copilot's seat (Appendix A, Table A-2). Ice nomenclature followed that of the World Meteorological Organization (1970).

When winds exceeded approximately 25 kt, ceiling was below 91 m, visibility was <2 nm, or both helicopters were inoperable, limited vessel surveys were conducted along the transect lines. Too few data were collected, however, during these surveys for analysis.

DATA ANALYSIS PROCEDURES

Standard statistical procedures were used in the analysis of the 1982-1983 and 1979 data. Population estimates were derived from the strip-transect method (Eberhardt 1978). The strip-transect method involves calculating abundance from the density of animals in a survey strip. Although this method assumes that all animals in the designated strip are counted, confirmation of this assumption is impossible and probably violated for marine mammals since animals below the surface of the water can be not counted. However, this method provided the best relative index of abundance of pinnipeds hauled out on the pack ice for this study.

Estimates of the density and abundance of pinnipeds and associated variances were calculated from methods described by Estes and Gilbert (1978) for strip-transect analysis. Density and abundance were calculated by summing the sampling unit estimates for the project area.

The estimator has the following form:

Estimated density is:

$$D_i = \Sigma y_i / \Sigma x_i$$

where D_i = the density of pinnipeds per nm^2 for a sampling unit
y_i = the number of pinnipeds in the i^{th} transect strip, and
x_i = the area of the i^{th} transect strip

Estimated variance of D_i is:

$$S^2_{D_i} = [\Sigma(y^2_i / x_i) - D \ \Sigma y_i] / (n-1)(\Sigma x_i)$$

where n = number of transects

Estimated abundance for a unit is:

$$T_i = D_i A_i$$

where: T_i = abundance of pinnipeds in a sampling unit, and
A_i = total area of that sampling unit

Estimated abundance for all zones is:

$$T = \Sigma T_i$$

Estimated variance of T is:

$$V(T) = A (A - \Sigma x_i) S^2_{D_i}$$

The 95 percent confidence interval for T is:

$$T \pm 1.96 \sqrt{V(T)}$$

Pinniped abundances were estimated from systematic aerial (1979, 1982-1983 surveys) and vessel (1982-1983 surveys) surveys. Pinniped estimates were made from observations occurring in a strip width of 0.5 nm (0.25 nm per side of the trackline) for both surveys. This strip width best fit the observed distribution of perpendicular distances of pinnipeds from the transect line. Other investigators (Burns and Harbo 1977, Braham et al. unpublished) have found this strip width to be suitable for estimating pinniped population sizes. The number of pinniped observations recorded from the two survey platforms (1983 data) did not indicate an observation bias for either side of the aircraft or vessel, so the observations for the two sides were treated equally in estimating abundance. No density estimates were made for pinniped populations during the ice free season because of the difficulties of accurately counting pinnipeds in open water.

Other statistical procedures used in the analysis were Chi-square goodness-of-fit for testing animal abundance among units, animal use of ice types, and interaction of time of day and wind chill on haul out patterns of pinnipeds (1982-83 data only). These procedures test the hypothesis that animals are uniformly distributed in space or time. Significant animal occurrence in a particular ice type was identified by procedures developed by Nue et al. (1974). Analysis of variance was applied to data delineating species distance from the ice edge. All tests were performed at the 0.05 level of significance.

RESULTS

1982-1983 SURVEY

Four hundred and fifty groups of pinnipeds representing seven species and 1,852 individuals were observed during four seasonal surveys of the Navarin Basin (Table 1). Over 50 percent of the animals were walruses, while northern sea lions comprised approximately another 25 percent. Spotted seals were the most abundant seal species encountered, followed by ribbon, bearded, ringed, and fur seals. Approximately 90 percent of the pinnipeds were recorded during the winter survey period (February-March), when pinnipeds haul out on pack ice and are most visible. Conversely, counts made during the other three seasons were generally much lower because of the difficulty of seeing pinnipeds in open water. More animals were recorded during spring than summer or fall, however, because bands of remnant ice (Burns et al. 1980) in the northern third of the Basin provided a platform for pinnipeds to haul out on. Over 75 percent of the animals recorded for all four seasons were observed during aerial surveys, which accounted for 69 percent of the 8,057 nm censused.

ICE FREE PERIOD

Ten percent of the pinnipeds recorded in the Basin were observed during the spring through fall seasons (Table 1). The greatest number and highest diversity of species were recorded in the spring, primarily on remnant ice. Walruses and sea lions comprised over 70 percent of the 161 pinnipeds encountered during this time, while 41 ribbon, spotted, and bearded seals were recorded. Mean group sizes were largest for walruses (5.6 ± 2.4 standard error) and smallest for bearded seals (1.0 ± 0.0); mean sizes of northern sea lion (4.3 ± 1.2), spotted seal (1.2 ± 0.1), and ribbon seal (1.0 ± 0.04) groups were intermediate (Figure 7). During the summer and fall seasons, 17 fur seals and 4 northern sea lions were observed primarily as singles. Most of the

TABLE 1

NUMBER OF SEALS, SEA LIONS, AND WALRUSES RECORDED DURING THE FOUR SEASONAL SURVEYS OF THE NAVARIN BASIN, 11 MAY-10 JUNE, 20 JULY-19 AUGUST, 29 OCTOBER-12 NOVEMBER 1982, AND 19 FEBRUARY-18 MARCH, 1983

	Spring				Summer				Fall				Winter				Total			
	No.	No. Individuals			No.	No. Individuals			No.	No. Individuals			No.	No. Individuals			No.	No. Individuals		
Species	Groups	Aerial	Vessel	Total	Groups	Aerial	Vessel	Total	Groups	Aerial	Vessel	Total	Groups	Aerial	Vessel	Total	Groups	Aerial	Vessel	Total
Spotted seal	13	14	1	15	--[a]	--	--	--	--	--	--	--	42	225	16	241	55	239	17	256
Ribbon seal	21	22	--	22	--	--	--	--	--	--	--	--	22	46	12	58	43	68	12	80
Bearded seal	4	4	--	4	--	--	--	--	--	--	--	--	8	6	2	8	12	10	2	12
Ringed seal	--	--	--	--	--	--	--	--	--	--	--	--	2	2	--	2	2	2	--	2
Fur seal	--	--	--	--	9	--	10	10	6	--	7	7	1	1	--	1	16	1	17	18
Northern sea lion	11	42	5	47	4	2	2	4	--	--	--	--	69	361	45	406	84	405	52	457
Walrus	12	65	2	67	--	--	--	--	--	--	--	--	147	574	294	868	159	639	296	935
Unidentified pinniped	6	--	6	6	--	--	--	--	--	--	--	--	73	72	14	86	79	72	20	92
TOTAL	67	147	14	161	13	2	12	14	6	--	7	7	364	1287	383	1670	450	1436	416	1852

a/ Dash (--) signifies no animals were observed.

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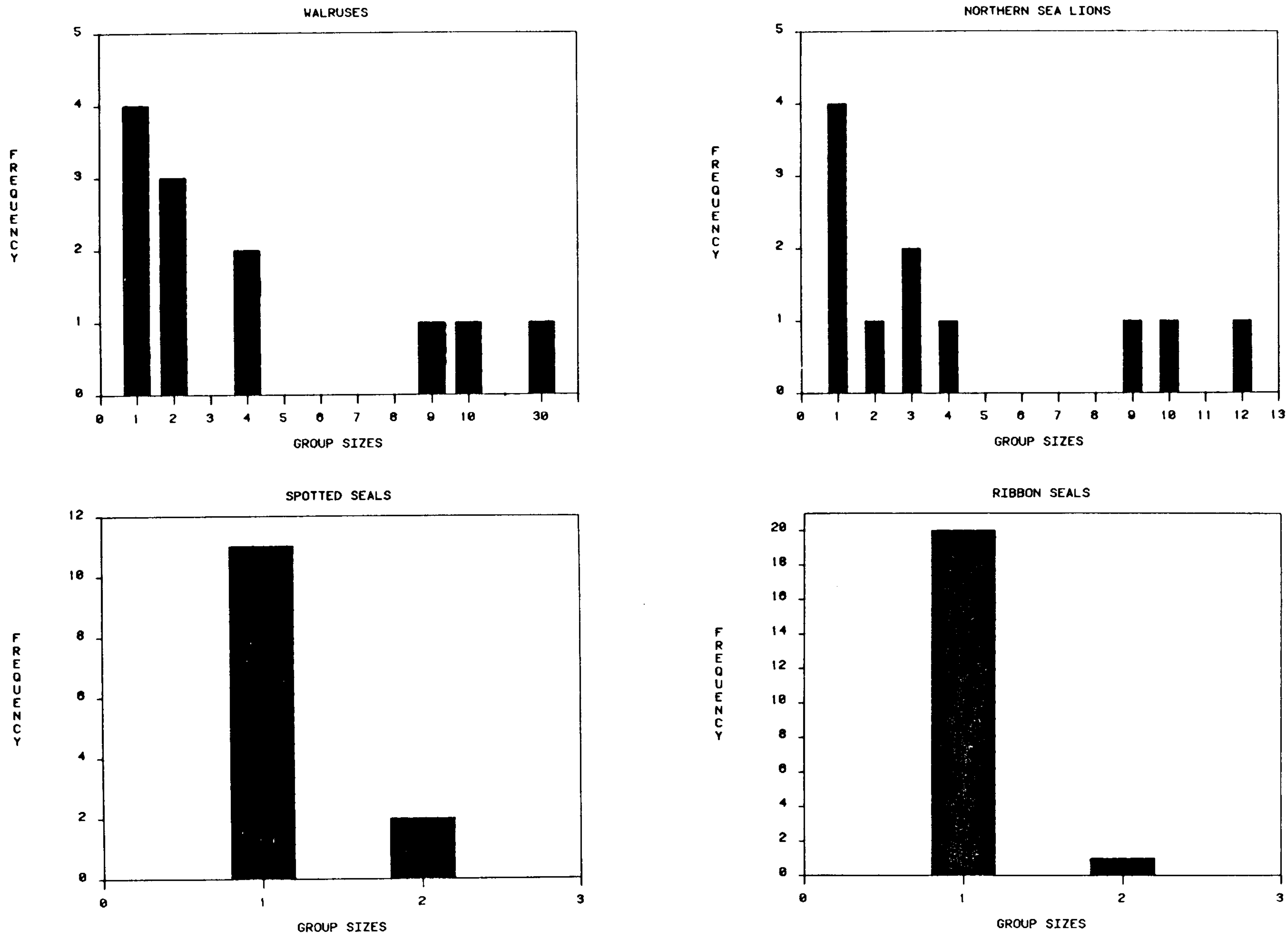

FIGURE 7 FREQUENCY DISTRIBUTION OF GROUP SIZES FOR THE FOUR MOST COMMON SPECIES OF PINNIPEDS OBSERVED IN THE NAVARIN BASIN DURING SPRING 1982.

animals were observed from the vessel in open water, compared to the spring when almost all of the animals were observed from the helicopter on ice. A total of 5,647 nm were surveyed from vessel and helicopter over these three seasons (Appendix Figures 1-6 illustrate the locations of the survey tracklines and animals).

SEASONAL ICE PERIOD

Composition and Relative Abundance

The seven species of pinnipeds found in the Bering Sea were observed in the marginal ice front of the Navarin Basin during the winter survey (Table 2, Figure 8). Over 75 percent of the 1,670 animals recorded along the 2,410 nm censused were walruses (52 percent) and northern sea lions (24 percent). Of the 310 seals encountered, 78 percent were spotted seals, followed by ribbon, bearded, ringed, and fur seals in their order of decreasing relative abundance. Eighty-six animals, primarily seals, were not identified to species because most of them were briefly seen in the water. Approximately 65 percent of the pinnipeds were recorded during aerial surveys, which represented 68 percent of the total survey effort.

Group sizes of pinnipeds were quite variable (Figure 9). Average group sizes were largest for walruses (6.9 ± 1.4 standard error) and smallest for ribbon seals (1.3 ± 0.2). Spotted seals and northern sea lions were recorded in groups averaging 6.3 ± 3.6 and 5.9 ± 0.8 animals, respectively. Spotted seal groups were the most variable, occasionally occurring in large but loose aggregations, while ribbon seal group sizes were consistently small. Spotted seal group sizes were considerably smaller (1.2 ± 0.1) in the spring during the birthing period. Although the large groups of walruses typically associated with the spring (Fay 1981) were not observed, group sizes of the other pinnipeds were similar to those reported by Burns and Harbo (1977). The sex or age composition of the groups was not determined, but eight newborn walruses, recorded between 25 February and 7 March, were observed primarily with single adults, presumably their mothers. The

TABLE 2

NUMBER OF SEALS, SEA LIONS, AND WALRUSES OBSERVED DURING THE WINTER AERIAL AND VESSEL SURVEYS OF THE NAVARIN BASIN, 19 FEBRUARY-18 MARCH, 1983

Sampling Unit	Trackline distance surveyed			Spotted seal		Ribbon seal		Bearded seal		Ringed seal		N. fur seal		N. sea lion		N. Pacific walrus		Unidentified pinniped		Total	
	Aerial (%)	Vessel (%)	Total (nm)	No. Groups	No. Indiv.	No. Groups	No. Indiv.	No. Groups	No. Indiv.	No. Groups	No. Indiv.	No. Groups	No. Indiv.	No. Groups	No. Indiv.	No. Groups	No. Indiv.	No. Groups	No. Indiv.	No. Groups	No. Indiv.
24	0	100	147	2	4	-- a/	--	1	1	--	--	--	--	3	7	25 c/	42	7	12	38	66
25	82	18	462	1 b/	1	5	5	--	--	--	--	--	--	-- b/	--	43 c/	198	17	18	66	222
26	71	29	613	4 b/	15	12 c/	45	6	6	--	--	--	--	8 b/	26	64 c/	556	24	26	118	674
27	83	17	482	4	37	3 b/	6	--	--	--	--	1	1	10	34	5 b/	33	3	3	26	114
28	80	20	466	3 b/	3	2 b/	2	--	--	--	--	--	--	36	324	-- b/	--	7	7	48	336
29	23	77	240	28 c/	181	-- b/	--	1	1	2	2	--	--	12	15	10	39	15	20	68	258
TOTAL	68	32	2410	42	241	22	58	8	8	2	2	1	1	69	406	147	868	73	86	364	1670

a/ Dash (--) signifies no animals.
b/ Significantly fewer observed than expected (p<0.05).
c/ Significantly more observed than expected (p<0.05).

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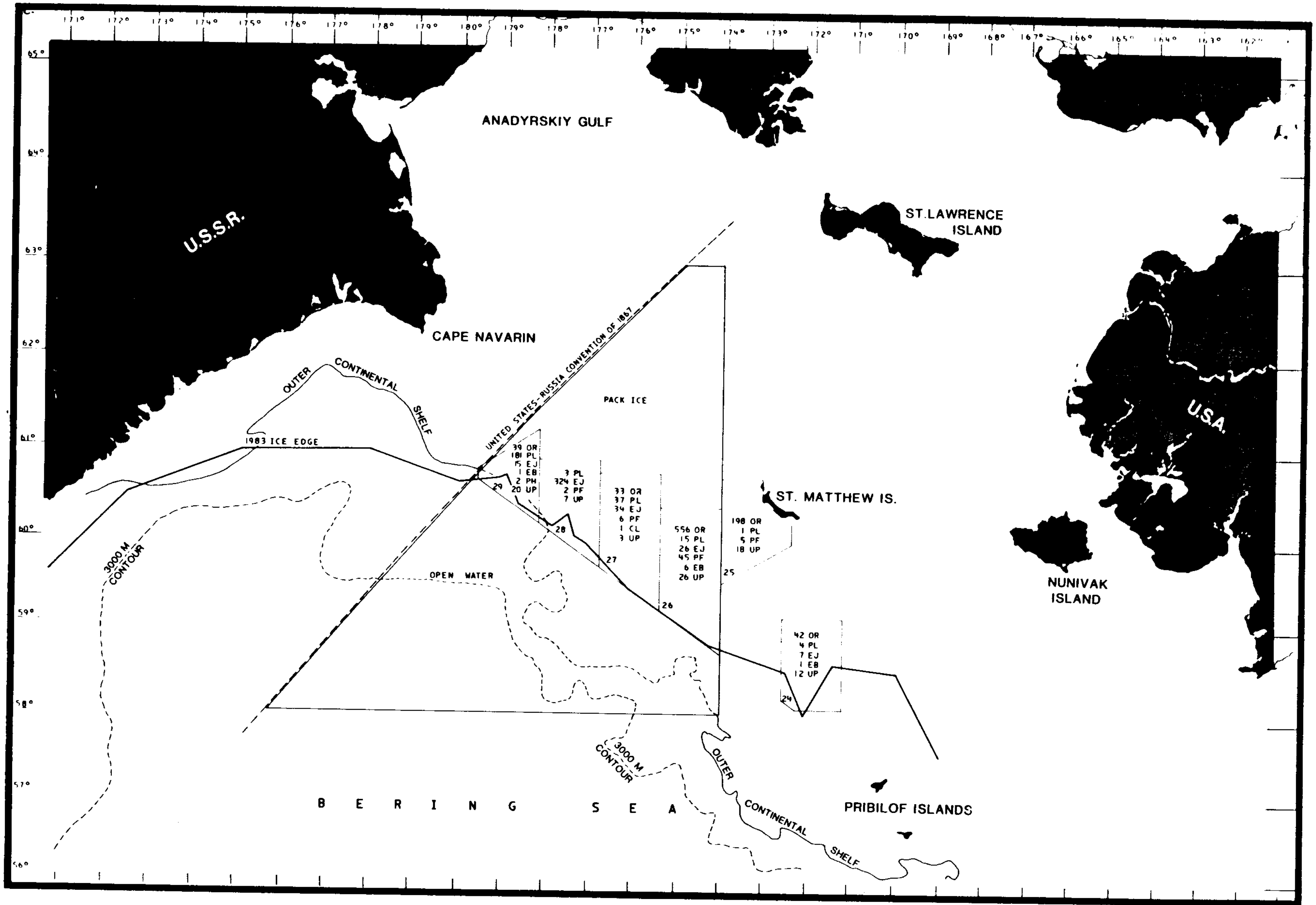

Figure 8 **DISTRIBUTION OF PINNIPEDS RECORDED IN NAVARIN BASIN DURING WINTER, FEBRUARY 19–MARCH 18, 1983.** (In appendices see Figures A-8 through A-11, Figures B-7 through B-11, and Table B-1.)

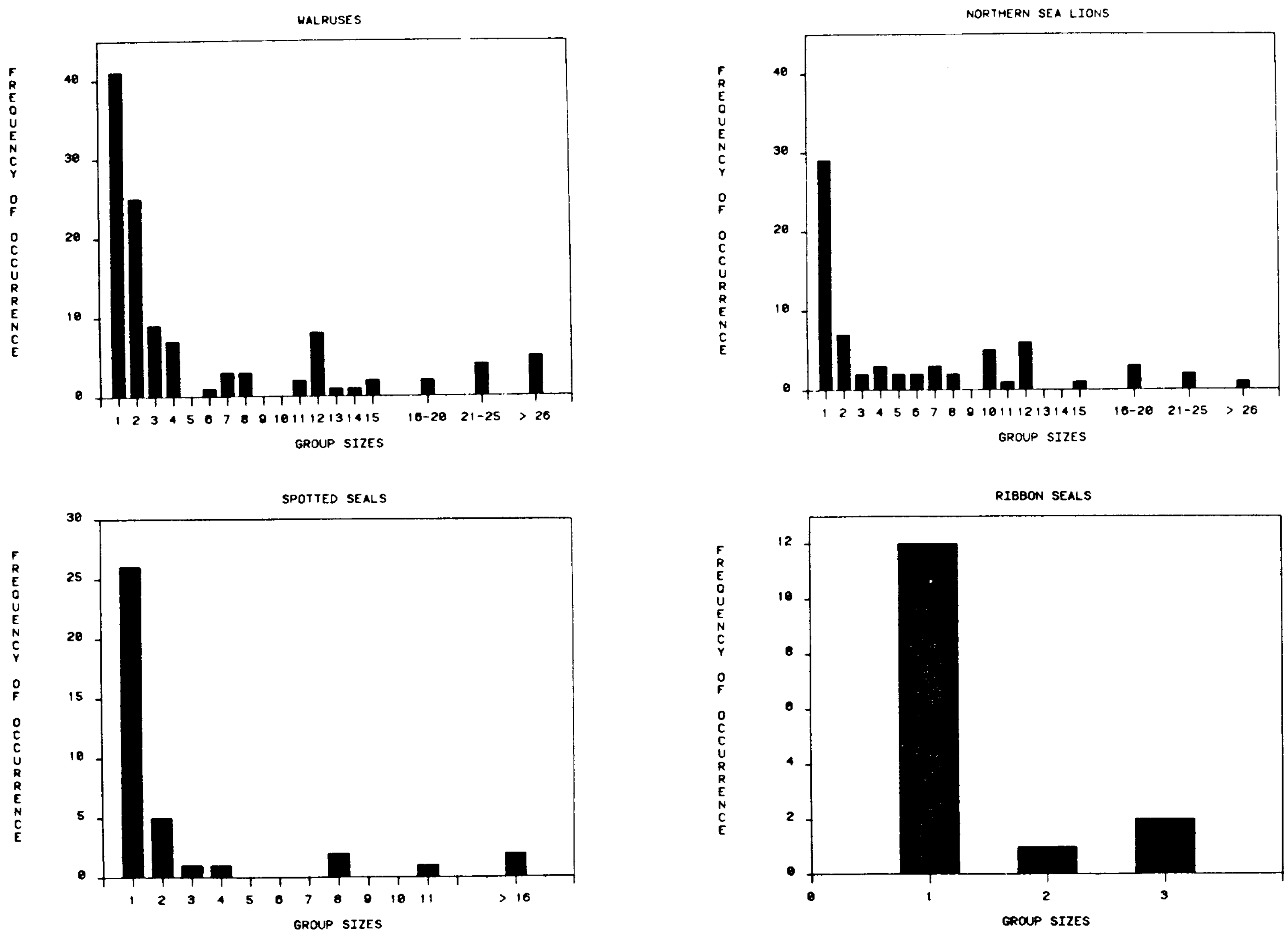

FIGURE 9 FREQUENCY DISTRIBUTION OF GROUP SIZES FOR THE FOUR MOST COMMON SPECIES OF PINNIPEDS OBSERVED IN THE NAVARIN BASIN DURING WINTER, 1983.

earliest previously recorded birth date of walruses was 15 April (Fay 1981). However, the pups may have been yearlings since the two age classes are difficult to distinguish without close physical inspection. No other species of newborn seals were observed because birthing periods of ice seals occurred after completion of our surveys and sea lions or fur seals birth on land outside the Basin. Group characteristics of the other species were not examined because too few animals were recorded, and only animals observed on the ice were included for the four species analyzed.

Distribution

Pinnipeds differed in their spatial distribution across the ice front and into the pack ice from the ice edge or open water (Figure 10). Spotted seals were the most widely distributed species in the ice front. They occurred in every unit, but were especially abundant in Unit 29, where observed numbers significantly ($p<0.05$) exceeded expected numbers (Appendix A, Table A-4). Ribbon seals, the most narrowly distributed species, occurred in the four units centrally located in the ice front. They were particularly abundant in Unit 26, where the number observed was significantly ($p<0.05$) greater than expected. Although walruses and northern sea lions were encountered in 5 of the 6 units, the distribution of each species spanned the entire front. Walrus use was significantly ($p<0.05$) greater than expected in the three eastern units, as was sea lion use ($p<0.05$) in Unit 28 of the front. Although there were too few observations of the other species to assess distribution, bearded seals were sporadically observed across the entire ice front. These results identify that pinnipeds were widespread in the ice front, and furthermore, certain areas were preferentially used by each species, which generally did not overlap.

In addition to having specific distribution patterns across the ice front, pinnipeds were differentially spaced from the ice edge (Figure 11). The average distance from the ice edge was significantly different ($P<0.05$; 3,274 df; $F=149.40$) among northern sea lions, walruses, spotted seals, and ribbon seals. Northern sea lions were

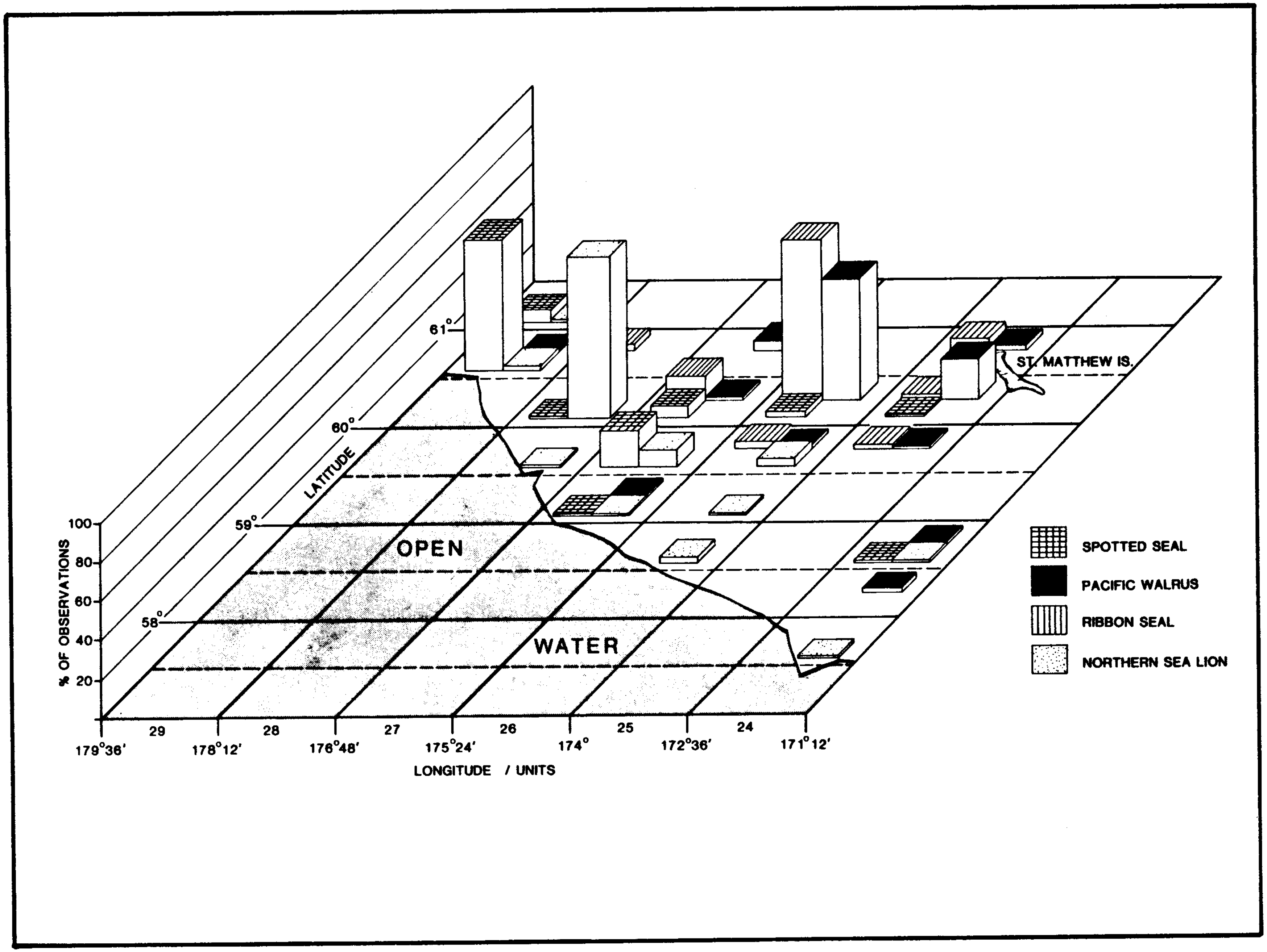

FIGURE 10 DISTRIBUTION OF THE FOUR MOST COMMON PINNIPEDS OBSERVED IN THE MARGINAL ICE FRONT DURING WINTER, 1983.

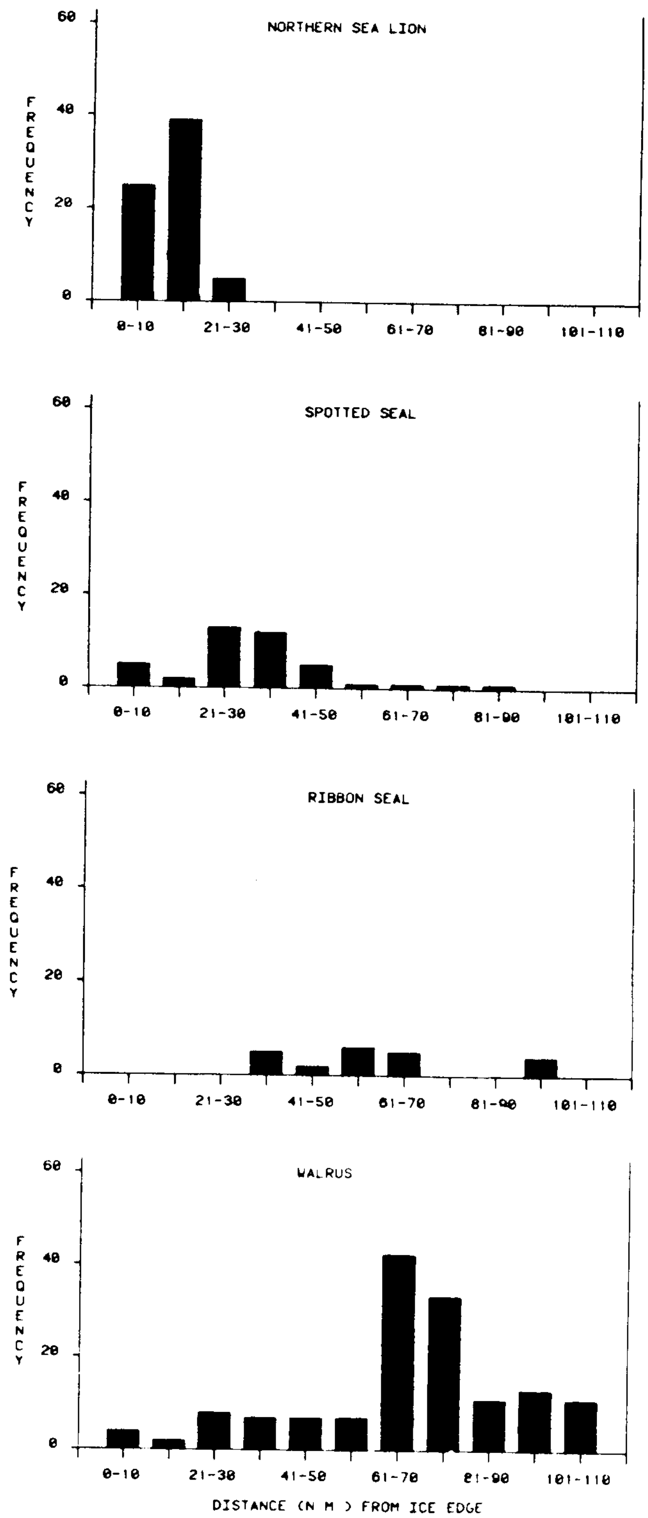

FIGURE 11 DISTANCE FREQUENCIES OF NORTHERN SEA LIONS, SPOTTED SEALS, RIBBON SEALS, AND WALRUSES INTO THE PACK ICE FROM THE EDGE OF MARGINAL ICE FRONT DURING WINTER 1983.

closest (12.5 nm±0.8 standard error) and walruses farthest (67.4 nm±1.9) from the ice edge. Distributed between these two species were the spotted (30.5 nm±2.7) and ribbon (60.5 nm±4.2) seals, although ribbon seals were considerably deeper into the pack ice. Walruses were found over the greatest range of distances and sea lions the narrowest range, suggesting that while each species concentrated at certain distances from the edge, the adaptability of sea lions to penetrate into the pack ice is more limited than for walruses or the other pinniped species examined. Too few sightings were recorded of the other species to analyze.

Ice Characterization and Use

The spatial distribution of pinnipeds is influenced by ice. Ice provides pinnipeds a platform for birthing, breeding, and molting (Burns et al. 1980). Pinnipeds may select certain ice conditions to accomplish these biological events. In order to evaluate the role of ice in the life cycle of pinnipeds, measurements were made of ice coverage, floe size, and ice thickness. A description of these ice conditions and their use by pinnipeds is provided below.

Ice coverage in the Basin was more extensive than average (Figure 12). The approximate ice edge, which was located south of the 1954-70, 16 year mean (Potocsky 1975), followed the outer continental slope. This resulted in pack ice covering approximately half of the Navarin Basin. The marginal ice front, a transition zone between the irregular southern margin of the main pack ice and the heavier consolidated pack ice (Burns et al. 1980), ranged between 30 and 100 nm in width in the study area. Ice coverage in the marginal ice front was 76 percent during the winter survey (Table 3). Pack ice coverage increased from 68 percent in the most western Unit 29 to approximately 80 percent in the eastern Units 24 and 25. One-way ANOVA (following arcsine transformation) indicated that ice coverage among units was significantly different ($p<0.001$; 5,837 df; $F=14.78$). Ice in the western units was more broken and featured relatively large proportions of area in the lower ice concentration and floe size classes but the

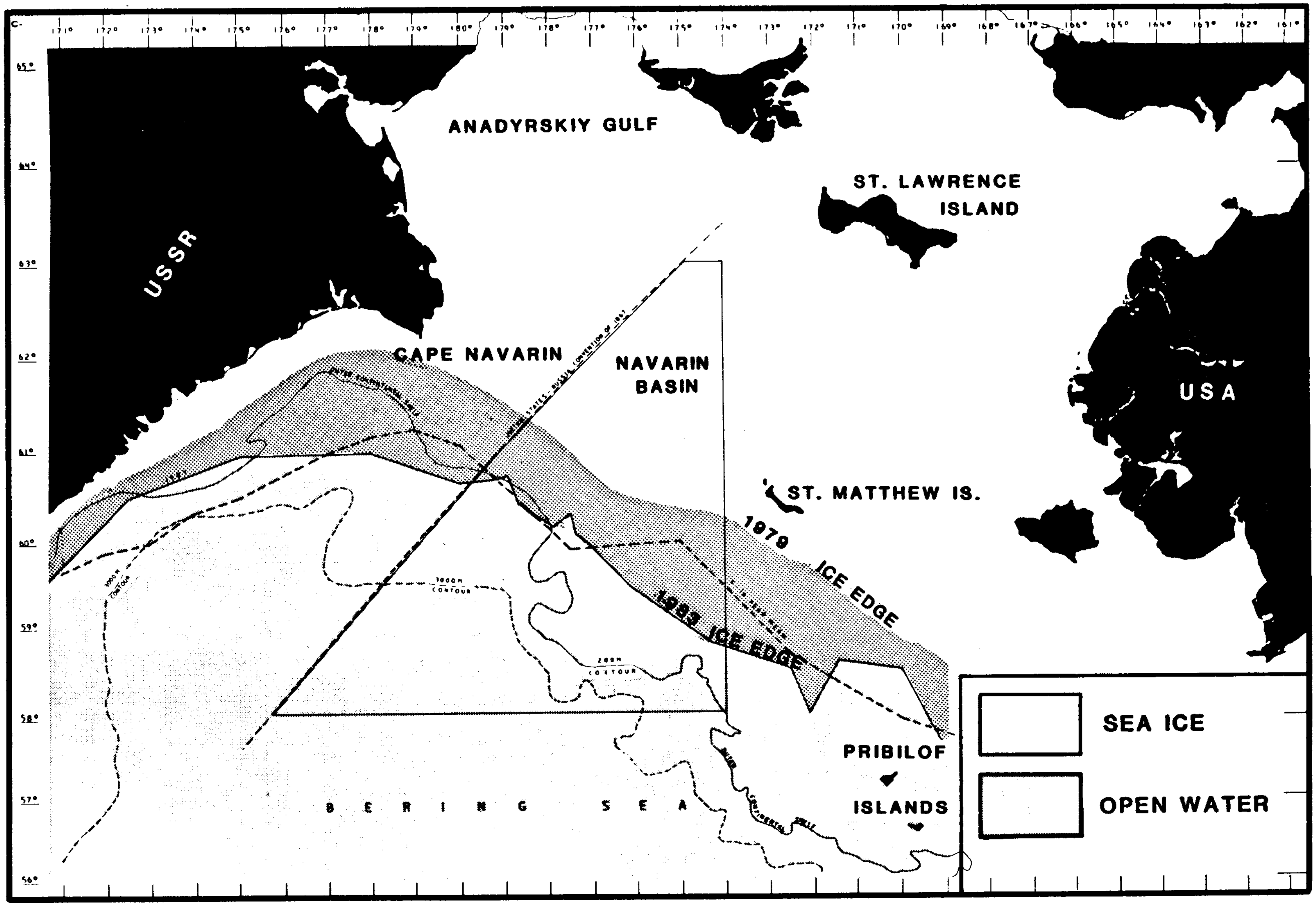

Figure 12 APPROXIMATE LOCATION OF ICE EDGE DURING 1979 AND 1983 STUDY PERIODS COMPARED TO A 5-16 YEAR MEAN (Potocsky 1975) IN THE NAVARIN BASIN.

TABLE 3

ICE CHARACTERISTICS OF STUDY AREA, 19 FEBRUARY - 18 MARCH, 1983[a]

Sampling unit	Percent area coverage of ice	Percent area (nm^2) coverage of each ice concentration category					Percent area coverage[b] of each ice size category				Percent area coverage of each ice thickness category			Total area surveyed (nm^2)
		0-20	21-40	41-60	61-80	81-100	Grease-slush	Pancake-small	Medium-large	Vast-giant	New	Young	First year	
24	79.0	2.0	7.1	15.1	25.3	50.5	4.8	4.5	5.6	85.1	19.1	11.7	69.2	73.4
25	80.5	0.6	4.5	12.8	35.7	46.4	17.3	0.0	8.8	73.9	28.2	45.6	26.2	231.2
26	78.5	2.0	3.8	19.4	25.9	48.9	17.1	5.2	15.7	62.0	17.9	55.6	26.5	306.4
27	71.5	9.3	3.9	21.9	23.8	41.1	2.7	59.2	20.0	18.1	1.9	30.3	67.8	240.9
28	75.7	3.0	3.5	18.1	38.4	37.0	4.1	24.0	30.8	41.1	0.6	29.5	69.9	233.0
29	68.2	11.7	13.5	12.2	24.2	38.4	3.9	40.2	15.8	40.1	1.7	35.0	63.3	119.9
TOTAL	75.9	4.4	5.1	17.3	29.6	43.6	10.0	21.0	17.4	51.6	11.8	38.8	49.4	1204.8

a/ Ice characteristics are defined in Appendix Table A-2.

b/ Ice size was calculated as a proportion of total ice coverage.

ice was thick. Conversely, ice in the eastern units was relatively thin but more concentrated, as evidenced by the presence of large amounts of areas in the higher ice concentration and floe size classes.

Pinnipeds occurred in a variety of ice conditions (Figure 13). Chi-square analysis (Appendix A, Table 5) identified that walruses preferred ($p<0.05$) areas of new ice and grease to slush floes, but indiscriminately ($p>0.05$) used areas of 20 to 100 percent ice coverage. Seventy-five percent of the animals, however, were recorded in the higher ice coverage areas (60 to 100 percent). Significantly fewer ($p<0.05$) walruses were associated with the intermediate floe sizes (pancake to large floes) and first year ice. Northern sea lions used areas of different ice thicknesses in proportion to their availability, but they were more abundant than expected ($p<0.05$) in areas with grease to small floes (pooled) and 0 to 60 percent ice coverage (pooled); use was particularly high in the areas with pancake to small floes (pooling of certain ice classes was necessary to obtain sample sizes sufficient to perform Chi-square analysis for sea lions and spotted seals, Appendix A, Table 6). Conversely, areas of high ice coverage (80-100 percent) and large floe sizes (medium to giant) received significantly ($p<0.05$) low use by sea lions. Spotted seal occurrence in ice was most similar to northern sea lions. Areas of 20 to 60 percent (pooled) ice coverage and first year ice were preferred ($p<0.05$) by spotted seals, while they occurred in areas of new and young ice (pooled) and 81 to 100 percent ice coverage in numbers significantly ($p<0.05$) less than expected (Appendix A, Table 7). Although there was no significant ($p>0.05$) use of specific floe sizes, spotted seals were most abundant in areas with pancake to small floes. Similar comparisons for the other pinniped species were not made because sample sizes were insufficient for analysis. These results suggest that while the species examined displayed wide use of pack ice, each species generally tended to have preferences and avoidances for particular ice conditions in the areas surveyed.

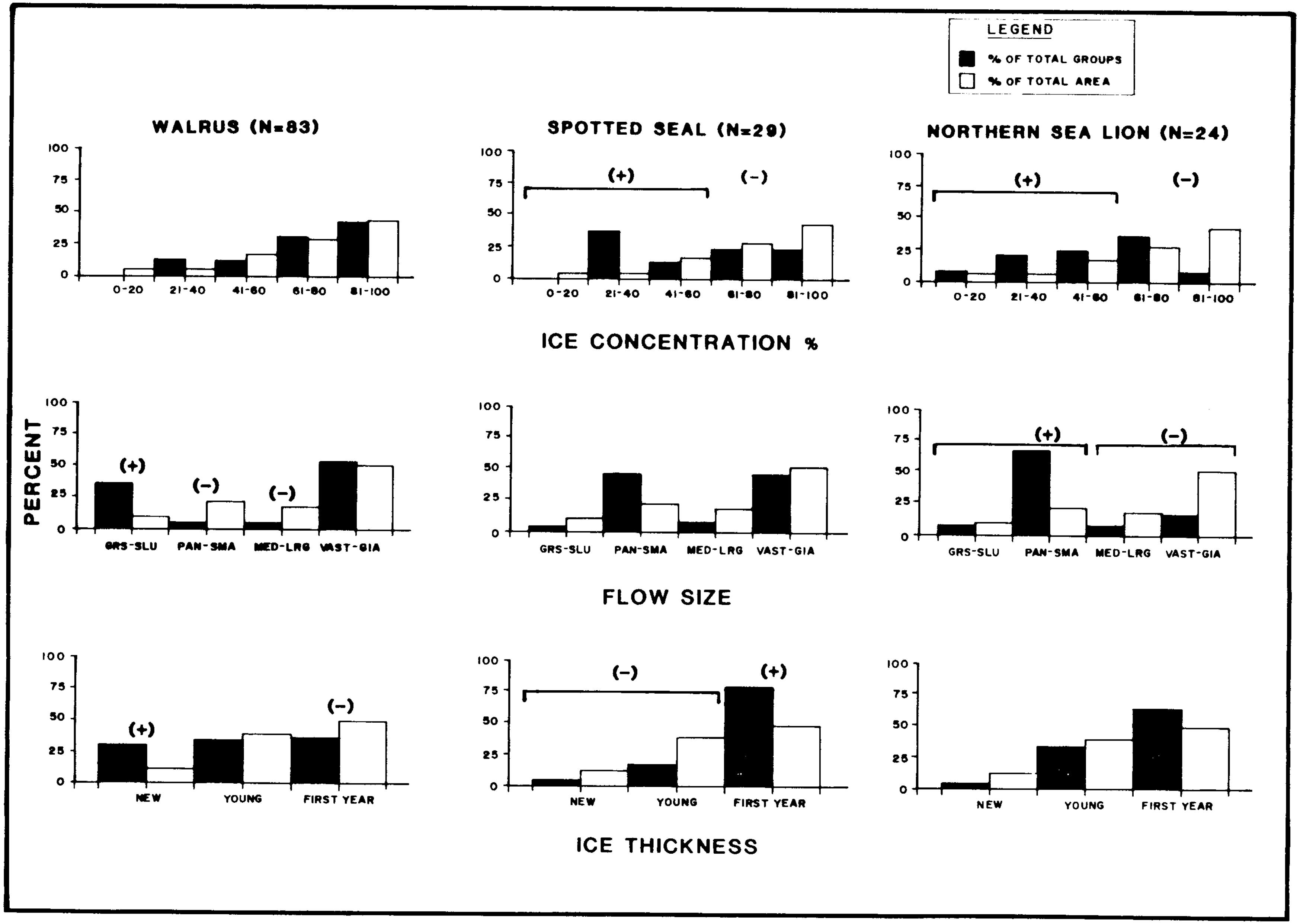

FIGURE 13 PERCENT OCCURRENCE OF PINNIPEDS RELATIVE TO PERCENT AVAILABILITY OF ICE TYPES IN THE MARGINAL ICE FRONT : PLUS (+) SIGNIFIES SIGNIFICANT PREFERENCE, MINUS (-) SIGNIFIES SIGNIFICANT AVOIDANCE, BRACKET (⌐¬) SIGNIFIES POOLED DATA, 1983.

Density

Density estimates of pinnipeds may be influenced by environmental conditions at the time of survey. Withrow (1982), Everett and Jeffries (1979), and others have shown that harbor seals and northern sea lions have definite haulout patterns correlated to time of day. Surveys conducted at off times produce biased estimates of density. Since ice-related pinnipeds may also show a similar pattern to time of day and be further influenced by wind chill during winter, we examined the influence of these environmental factors on our counts. Counts may also be influenced by vessel or helicopter noises; however, most of the animals we observed were counted before they reacted to the survey platforms.

The number of pinnipeds we observed on the ice was influenced by wind chill and possibly by time of day (Table 4). Seals as a group were observed on the ice in significantly ($p<0.05$) lower numbers during wind chill conditions colder than -30°C, while sea lions and walruses did not significantly ($p>0.05$) respond to wind chills reaching -50°C. Conversely, time of day did not significantly ($p>0.05$) influence number of seals seen on the ice but it was significantly ($p<0.05$) associated with sea lion and walrus counts. There was, however, no recognizable trend, suggesting sample size may have been too small or these species have no predictable haulout patterns during the winter season. Because of the effect of wind chill on seal counts, density estimates were derived for seals and areas surveyed under wind chills warmer than -30°C for all times of day, while sea lion and walrus densities were calculated without concern to wind chill or time of day.

The stratified estimated density of pinnipeds in the marginal ice front was 27.33 animals per 100 nm^2, representing an estimated 4,477 seals, sea lions, and walruses (Tables 5, 6). Walrus and spotted seal estimated densities were over 75 percent greater than for the other species. Walrus densities were highest in the eastern half of the ice front while spotted seals densities were highest in the western half of the front. Density estimates for the other species ranged between 0.09

TABLE 4

CHI-SQUARE GOODNESS-OF-FIT TEST COMPARING HAULOUT PATTERNS OF SEALS (SPOTTED, RIBBON, BEARDED, AND RINGED SEALS), SEA LIONS, AND WALRUSES TO TIME OF DAY AND WIND CHILL

Time interval	Distance surveyed (nm)	Seals: Observed number groups	Seals: Expected number groups	Sea lions: Observed number groups	Sea lions: Expected number groups	Walruses: Observed number groups	Walruses: Expected number groups
0800-1000	648	4	9.9	6	11.0	5	18.7
1000-1200	935	15	14.2	37	15.9	13	27.1
1200-1400	973	13	14.8	13	16.5	29	28.2
1400-1600	727	15	11.1	3	12.4	16	21.0
1600-1800	580	10	8.8	8	9.9	33	16.8
1800-1900	77	3	1.2	0	1.3	18	2.2
Total	3940	60	60.0	67	67.0	114	114.0
			$x^2=8.01$ $p>0.10$		$x^2=39.81$ $p<0.001$		$x^2=147.68$ $p<0.001$

Wind chill interval (°C)	Distance surveyed (nm)	Seals: Observed number groups	Seals: Expected number groups	Sea lions: Observed number groups	Sea lions: Expected number groups	Walruses: Observed number groups	Walruses: Expected number groups
-10 to -19	355	15	5.4	8	6.5	4	10.3
-20 to -29	1311	35	20.0	16	24.0	44	37.9
-30 to -39	1999	10	34.6	43	36.5	61	57.8
-40 to -49	275	—	—	—	—	5	8.0
Total	3940	60	60.0	67	67.0	114	114.0
			$x^2=42.89$ $p<0.001$		$x^2=4.17$ $p>0.10$		$x^2=6.14$ $p>0.10$

TABLE 5

ESTIMATED DENSITY (per 100 nm^2) OF SEALS, SEA LIONS, AND WALRUSES IN THE MARGINAL ICE FRONT OF THE NAVARIN BASIN DURING WINTER, FEBRUARY-MARCH 1983

Sampling unit	Total area (nm^2)	Area coverage: Aerial % a/	Aerial % b/	Vessel % a/	Vessel % b/	Total % a/	Total % b/	Spotted seal No. c/	Spotted seal Den.	Ribbon seal No. c/	Ribbon seal Den.	Bearded seal No. c/	Bearded seal Den.	Unidentified pinniped No. c/	Unidentified pinniped Den.	Northern sea lion No. c/	Northern sea lion Den.	Pacific walrus No. c/	Pacific walrus Den.	Total No. c/	Total Den.
24	2924	0.00	0.00	0.09	2.51	0.09	2.51	--d/	--	--	--	--	--	--	--	--	--	12	16.33	12	16.33
25	2381	0.71	7.98	0.00	1.73	0.71	9.71	--	--	--	--	--	--	--	--	--	--	60	25.95	60	25.95
26	3731	2.43	5.81	0.78	2.40	3.21	8.21	4	3.34	2	1.67	--	--	6	5.02	12	3.92	70	22.85	94	36.80
27	3429	5.83	5.84	0.66	1.19	6.49	7.03	34	15.27	6	2.70	--	--	2	0.90	1	0.42	31	12.87	74	32.16
28	2443	1.86	7.69	0.84	1.94	2.70	9.63	--	--	--	--	--	--	3	4.55	21	8.93	--	--	24	13.48
29	1474	1.91	1.91	5.26	6.27	7.17	8.18	25	23.65	--	--	1	0.95	4	3.78	2	1.66	11	9.12	43	39.16
Total	16,382	2.32	5.02	0.93	2.35	3.25	7.37	63	11.83±9.15	8	1.50±1.57	1	0.19±0.31	15	2.81±2.29	36	2.98±2.97	184	15.24±11.59	307	34.55
Stratified								63	6.09	8	0.95	1	0.09	15	2.35	36	2.45	184	15.40	307	27.33

a/ Percent area surveyed for seals and unidentified pinnipeds during wind chill conditions warmer than -30°C.
b/ Percent area surveyed for sea lions and walruses.
c/ Number of animals in strip.
d/ Dash (--) signifies no animals.

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TABLE 6

ESTIMATED ABUNDANCES AND 95% CONFIDENCE INTERVALS FOR SEALS, SEA LIONS, AND WALRUSES IN THE MARGINAL ICE FRONT OF THE NAVARIN BASIN DURING WINTER, FEBRUARY-MARCH, 1983[a/]

Sampling unit	Spotted seal	Ribbon seal	Bearded seal	Unid. seal	Northern sea lion	Pacific walrus	Total
24	- [b/]	-	-	-	-	477	477
25	-	-	-	-	-	618	618
26	125	62	-	187	146	853	1,373
27	524	93	-	31	14	441	1,103
28	-	-	-	111	218	-	329
29	349	-	14	56	24	134	577
Total	1,938±1474	246±253	31±50	460±371	488±468	2,497±1,827	5,660
Stratified	998±861	155±199	14±19	385±336	402±396	2,523±2,050	4,477

a/ Abundance was calculated for animals in the survey strip during acceptable wind chill conditions. Numbers were derived by multiplying the estimated density times the unit area (Table 5).

b/ Dash (-) signifies no animals.

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for bearded seals and 2.45 animals per 100 nm^2 for northern sea lions. Estimated densities for these species within the ice front were difficult to evaluate because of small sample sizes, except for sea lions, which were most dense in the western third of the front. In general, pinniped densities were highest in the portion of the ice front corresponding to the Navarin Basin proper (Units 26-29). Indices of abundance for the pinnipeds in the marginal ice front were estimated at 2,523 walruses, 998 spotted seals, 402 northern sea lions, 155 ribbon, and 14 bearded seals. These estimates were based on a survey coverage of 7.4 percent for sea lions and walruses and 3.3 percent for seals. Since they do not account for animals in the water or missed, the estimates should be considered conservative and as an index and not an absolute value of abundance. Confidence intervals around the estimates were wide because of small sample sizes.

1979 SURVEY

Composition and Relative Abundance

Six species of pinnipeds were observed in the Bering Sea pack ice during early spring (Table 7, Figure 14). Over 91 percent of the 2,909 pinnipeds recorded along the 4,342 nm censused were walruses. Of the remaining 238 animals observed, approximately 55 percent were bearded seals followed by spotted, ringed, ribbon, and northern sea lions. Sixty-three pinnipeds were not identified to species. All of these animals were recorded during aerial surveys.

Group sizes of pinnipeds were quite variable (Figure 15). Average group size was largest for walrus (10.0 ± 27.0, standard error) and nearly identical for spotted (1.5 ± 0.7), bearded (1.2 ± 0.7), ringed (1.1 ± 0.3), and ribbon (1.0 ± 0.0). Although walrus group sizes ranged between 1 and 280 animals over 70 percent of the walrus group sizes were between 1 and 5 animals. Too few sea lions were recorded

TABLE 7

NUMBER OF SEALS, SEA LIONS, AND WALRUSES OBSERVED DURING THE EARLY SPRING AERIAL SURVEYS OF THE BERING SEA, MARCH-APRIL, 1979 a/

Zone	Sampling Unit	Trackline Distance Surveyed (nm)		Spotted Seal		Ribbon Seal		Bearded Seal		Ringed Seal		Northern Sea Lion		N. Pacific Walrus		Unidentified Pinniped		Total	
				No. Group	No. Indiv.	No. Group	No. Indiv.	No. Group	No. Indiv.	No. Group	No. Indiv.	No. Group	No. Indiv.	No. Group	No. Indiv.	No. Group	No. Indiv.	No. Group	No. Indiv.
NORTHERN	9	278	(134)	--b/	--	--	--	9	9	--	--	--	--	12	28	1	1	22	38
	10	315	(243)	--	--	--	--	--	--	--	--	--	--	3	4	--	--	3	4
	11	414	(274)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	12	382	(287)	--	--	--	--	4	4	1	1	--	--	25	92	3	3	33	100
Subtotal		1,389	(938)	--	--	--	--	13	13	1	1	--	--	40	124	4	4	58	142
CENTRAL	13	353	(256)	3	3	1	1	80	97	6	6	--	--	47	566	12	13	149	686
	14	397	(312)	1	2	--	--	--	--	--	--	--	--	5	6	--	--	6	8
	15	384	(273)	5	8	--	--	14	18	7	8	--	--	21	235	18	21	65	290
Subtotal		1,134	(841)	9	13	1	1	94	115	13	14	--	--	73	807	30	34	220	984
SOUTHERN	24	174	(98)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	25	333	(217)	--	--	--	--	--	--	--	--	--	--	11	20	1	1	12	21
	26	456	(332)	--	--	6	6	4	4	--	--	1	2	85	387	7	7	103	406
	27	479	(284)	--	--	1	1	--	--	--	--	--	--	36	1,002	6	6	43	1,009
	28	377	(256)	2	4	1	1	--	--	--	--	--	--	22	331	5	11	30	347
Subtotal		1,819	(1,187)	2	4	8	8	4	4	--	--	1	2	154	1,740	19	25	188	1,783
TOTAL		4,342	2,966	11	17	9	9	111	132	14	15	1	2	267	2,671	53	63	466	2,909

a/ Distances and observations are for systematic and non-systematic surveys; systematic survey distances are in parentheses.
b/ Dash (--) signifies no animals

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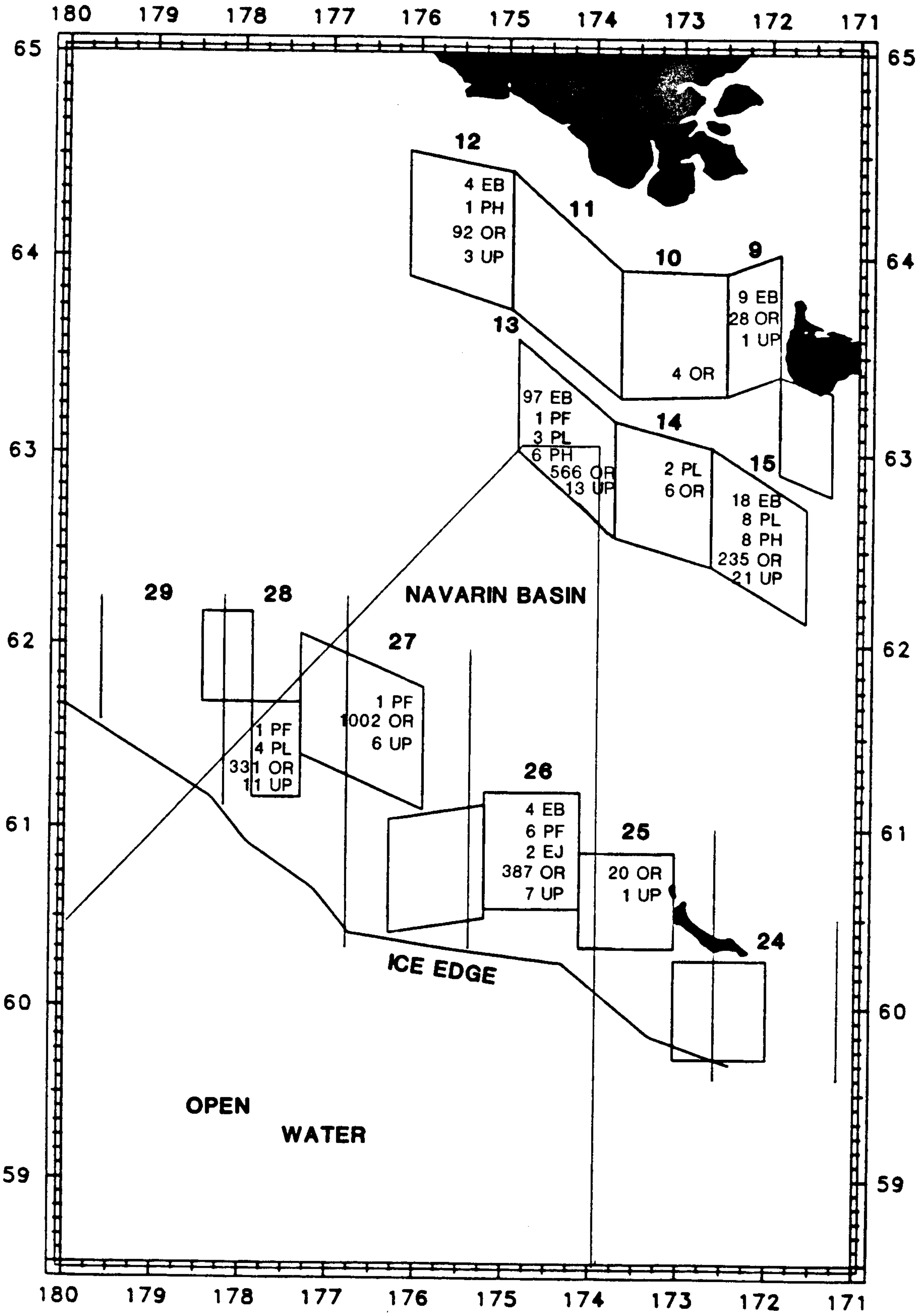

Figure 14 Distribution of pinnipeds recorded in the Bering Sea during early spring, 1979.

(SEE PAGE 93 FOR ABBREVIATION DEFINITIONS.)

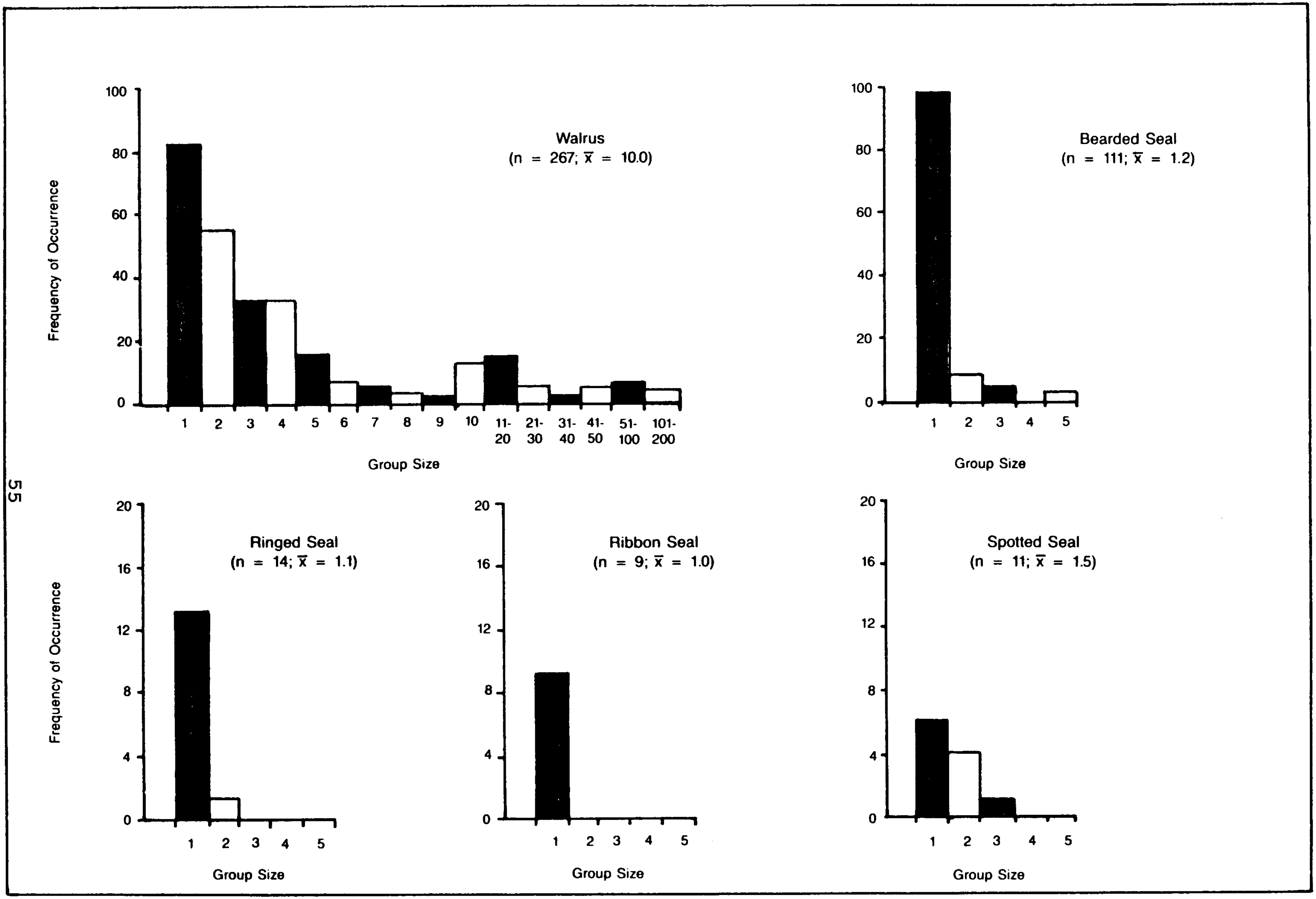

Figure 15 Frequency distribution of group sizes for the common species of pinnipeds observed in the pack ice during early spring, 1979.

to meaningfully determine the group size. Group sizes of these pinnipeds were similar to those reported by Fay (1981) and Burns and Harbo (1977). Ten newborns were recorded in these groups of which there were five walrus, three spotted, one ringed, and one bearded seal (Table 8). These newborns were observed between 15 March and 12 April which fall within the birthing period reported for these species (Burns, 1970). The walrus pups may have been yearlings since the two age classes are difficult to differentiate without physically inspecting the animals.

Distribution

The spatial distribution of pinnipeds was highly variable among zones (Figure 16). Walrus were the most widespread species. They occurred in 10 of the 12 units in the 3 zones which included: 3 of 4 units in the northern zone, the 3 units in the central zone, and 4 of 5 units in the southern zone. Walrus use was higher in the southern and central zones than in the northern zone. Walrus use of the southern zone or marginal ice front was greatest in the western Units 26, 27, 28, and particularly high in Unit 27. Use of all the other units was low except for Units 13 and 15 of the central zone where it was intermediate.

Bearded seals were the second most widespread pinniped species (Figure 16). They occurred in 5 of the 12 units in the 3 zones which included 2 of 4 units in the northern zone, 2 of 3 units in the central zone, and 1 of 5 units in the southern zone. Bearded seal use of these zones was highest in the central zone and lowest in the southern zone. Use was over five times greater in Unit 13 of the central zone than in the other units.

The distribution of the spotted, ribbon, ringed seal and northern sea lion was unclear because of the small number of observations. Spotted and ribbon seals, however, were entirely in the central and southern zones. Spotted seals were more prevalent in the central zone whereas

TABLE 8

NUMBER AND DATES OF NEWBORN PINNIPEDS OBSERVED IN THE BERING SEA PACK ICE DURING EARLY SPRING, 1979[a/]

Number	Species	Date
1	Walrus	March 15
1	Walrus	March 15
1	Walrus	March 24
2	Walrus	April 7
1	Bearded Seal	April 7
1	Spotted Seal	April 12
1	Spotted Seal	April 12
1	Spotted Seal	April 12
1	Ringed Seal	April 12

a/ Walrus pups were not physically inspected; therefore, they may have been yearlings, which are difficult to distinguish from pups during the spring.

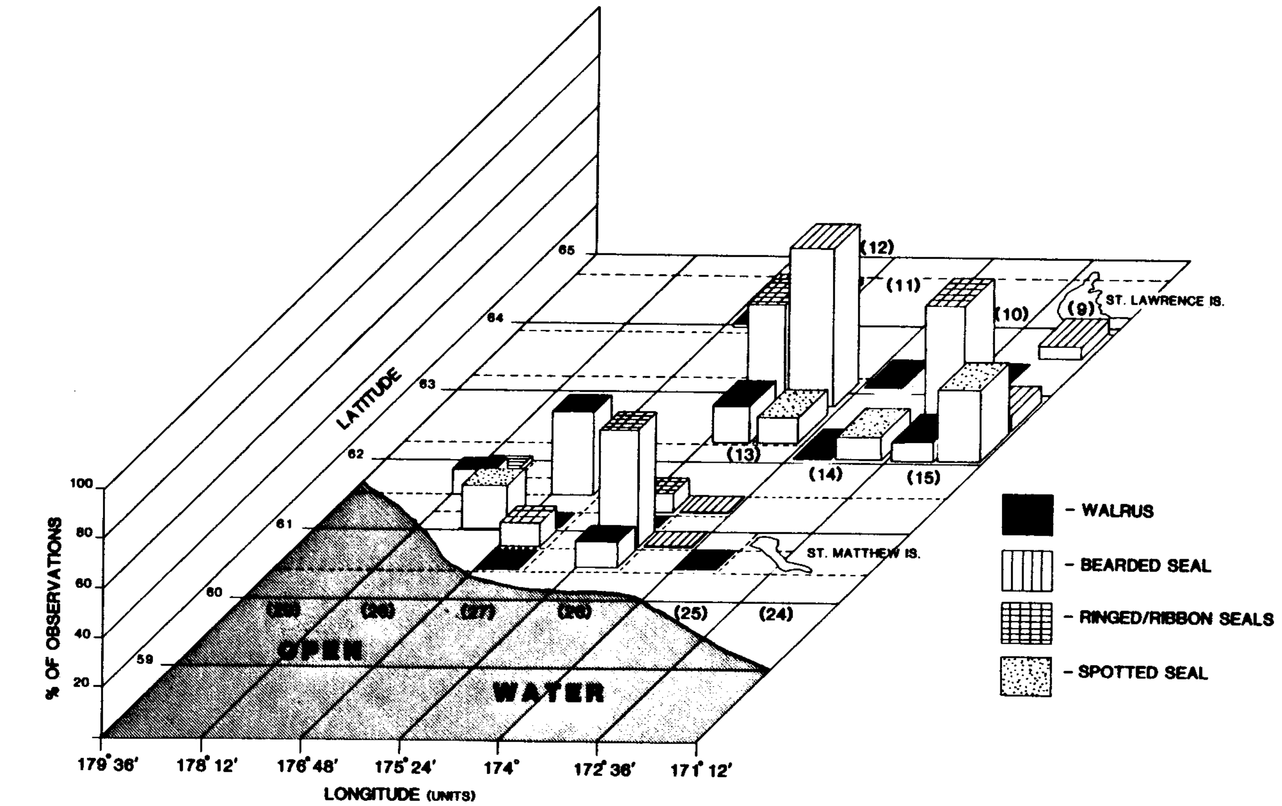

FIGURE 16 DISTRIBUTION OF PINNIPEDS MOST COMMONLY OBSERVED IN THE BERING SEA DURING EARLY SPRING, 1979.

ribbon seals were more abundant in the southern zone. Ringed seals were present in the northern and most abundant in the central zones. Two northern sea lions were observed in the southern zone.

These results identify that the central and southern zones supported the highest diversity of species. Walrus and bearded seals were the most widely distributed species. Walrus use was greatest in the southern and central zones, whereas bearded seal use was highest in the central zone. Use by the other species was less definite because of small sample sizes but in general, spotted and ringed seal use was highest in the central zone, and ribbon seal and northern sea lion use was highest in the southern zone.

Ice Characterization and Use

Ice coverage in the Bering Sea during 1979 was less extensive than average (Figure 12). The approximate ice edge, which was located north of the 1954-70, 16 year mean (Potocsky 1975), followed the outer continental slope.

Ice coverage in the three study area zones increased from approximately 64 percent in the southern zone to 75 percent and 85 percent in the northern and central zones, respectively (Table 9). Analysis of variance (following arcsine transformation) indicated that these differences were significant ($F=5.15$; 2, 9 df; $p < 0.05$). Correspondingly, ice in the southern zone was most broken, having large proportions of area in the lower ice concentration (0-25 percent, 26-50 percent) and size (grease-slush, pancake-small) categories. The northern zone contained moderately broken ice, with large proportions of area having medium to giant-sized floes in the higher ice concentration (51-75 percent) categories. In this zone ice concentration and size tended to increase from St. Lawrence Island west. The ice in the central zone was most compacted, having large amounts of area in the highest ice concentration (76-100 percent) and size (vast-giant) categories. Although pack ice during the study was farther north than usual, ice characteristics in the three zones were typical (Potocsky 1975).

TABLE 9

ICE CHARACTERISTICS OF STUDY AREA, 2 MARCH - 13 APRIL, 1979

Zone	Sampling Unit	Percent area coverage of Ice	Percent Area (nm^2) coverage of each ice concentration Coverage				Percent area coverage[a/] of each ice size Coverage				Total area surveyed (nm^2)
			0-25	26-50	51-75	76-100	Grease-Slush	Pancake-Small	Medium-Large	Vast-Giant	
NORTHERN	9	66.3	0.0	12.0	83.1	5.0	11.0	37.9	34.5	16.6	66.9
	10	65.2	1.2	13.6	80.1	5.0	29.5	36.1	27.8	6.6	121.4
	11	80.3	0.0	0.0	53.7	46.3	0.3	12.3	33.5	53.9	137.1
	12	82.6	1.8	0.0	30.4	67.8	6.5	6.8	23.7	63.0	143.5
	Subtotal	75.1	0.9	5.2	57.6	36.3	10.3	19.0	29.1	41.6	468.9
CENTRAL	13	82.9	0.0	0.0	30.7	69.3	0.0	0.2	15.3	84.5	127.9
	14	84.8	0.0	1.6	17.0	81.4	0.0	0.2	5.8	94.0	156.1
	15	86.1	0.0	0.0	20.3	79.7	1.5	5.4	11.0	82.1	136.5
	Subtotal	84.6	0.0	0.6	22.2	77.2	0.5	1.9	10.4	87.2	420.5
SOUTHERN											
(Marginal Ice Front)	24	81.5	0.0	0.0	47.7	52.3	0.0	26.6	45.4	28.0	48.9
	25	57.8	9.4	39.0	27.5	24.2	22.8	19.7	35.7	21.8	108.5
	26	66.8	2.4	31.3	34.3	32.1	21.4	72.5	5.7	0.4	166.1
	27	63.3	11.0	25.6	35.3	28.0	50.6	14.3	3.5	31.6	142.1
	28	59.3	11.4	27.0	55.3	6.3	2.4	22.7	31.9	43.0	128.0
	Subtotal	63.9	7.5	27.8	38.9	25.8	22.5	35.2	19.5	22.8	593.6

a/ Ice size was calculated as a proportion of total ice coverage.

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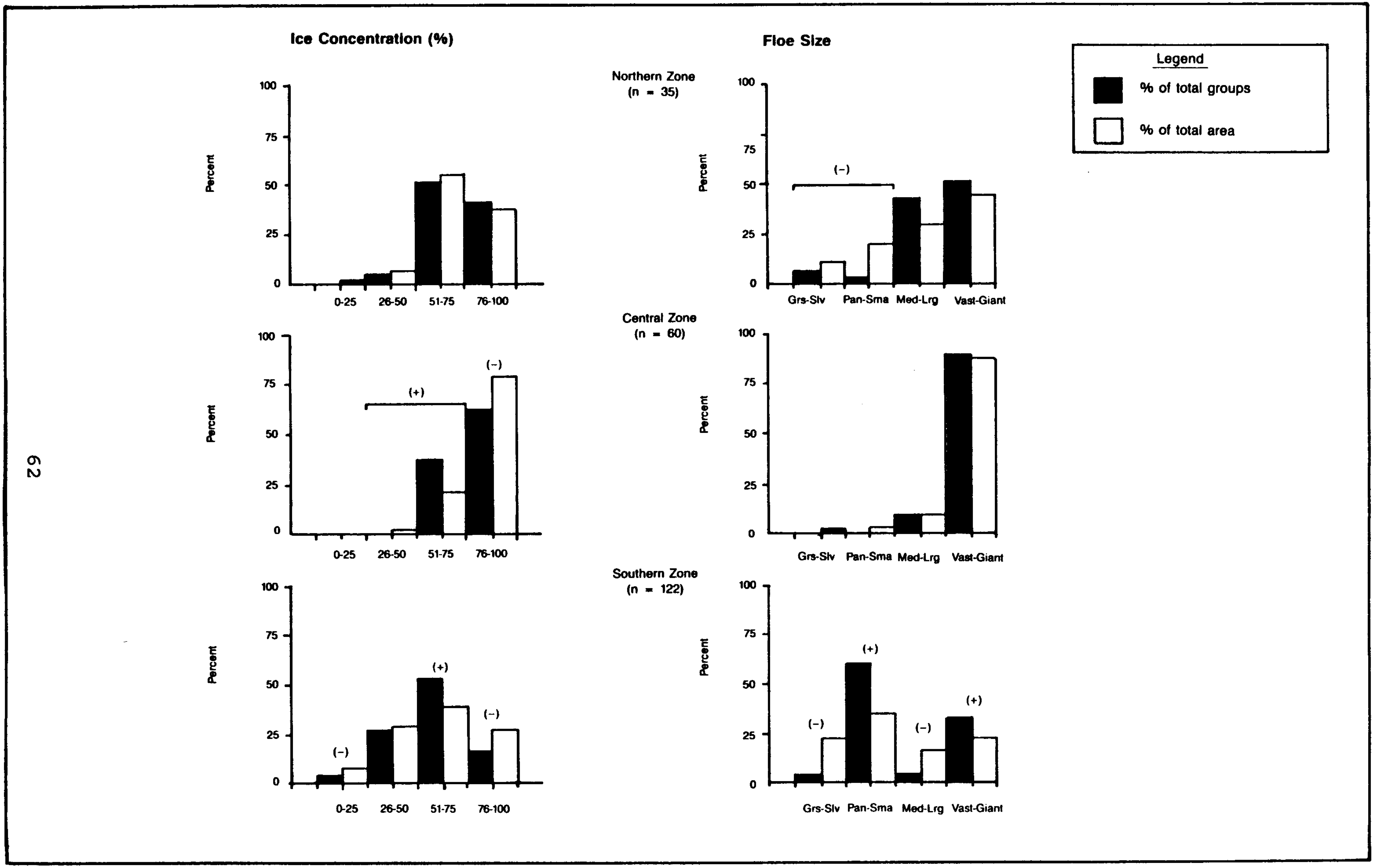
Pinnipeds occurred in a wide variety of ice conditions. Walrus were found in all ice concentration and floe size categories (Figure 17). Use was, however, higher than expected ($p<0.05$) in the intermediate ice concentration categories and lower than expected ($p<0.05$) in the other categories for the southern and central zones (Appendix B, Table 2). Walrus use of the different ice concentration categories in the northern zone was in proportion to their availability. Over 50 percent of the walrus were observed in areas of 50 to 100 percent ice coverage. The occurrence of walruses on floes of different sizes was statistically different but inconsistent among the zones (Appendix B, Table 3). Walrus numbers were, however, consistently high in the vast-giant floe size category except for in the southern zone where the highest numbers were in the pancake-small floe size category. These results show that walrus occurred in a wide variety of ice conditions but were most common in areas of higher ice concentrations and floe sizes typical of the inner pack ice. Similarly, the ice conditions primarily associated with walrus occurrences in the marginal ice front were characteristic of the interior of the front.

Bearded seals showed a preference for the intermediate ice concentration category (50-75 percent) and a slight avoidance for the 75-100 percent category (Figure 18). Almost 65 percent of the bearded seals were recorded in this latter category. There was no statistical significance associated with bearded seal use of different floe sizes, however, over 85 percent of the bearded seals were recorded in the vast-giant floe size (Appendix B, Table 4). These results substantiate the findings by other investigators that bearded seals inhabit the more concentrated pack ice where bigger floes are more prevalent. Similar comparisons for the other pinniped species were not made because sample sizes were insufficient for analysis. However, both the spotted and particularly the ringed seals were associated with areas in the higher ice concentration and floe sizes (Table 10). Ribbon seals were widespread in the different ice concentration and floe size categories but were more common in the higher ice concentrations and lower floe sizes.



Pinniped Project

Figure 17 Percent occurrence of walrus relative to percent availability of ice types in the Bering Sea, 1979: plus (+) signifies significant preference; minus (−) signifies significant avoidance, bracket (⌐¬) signifies pooled data.

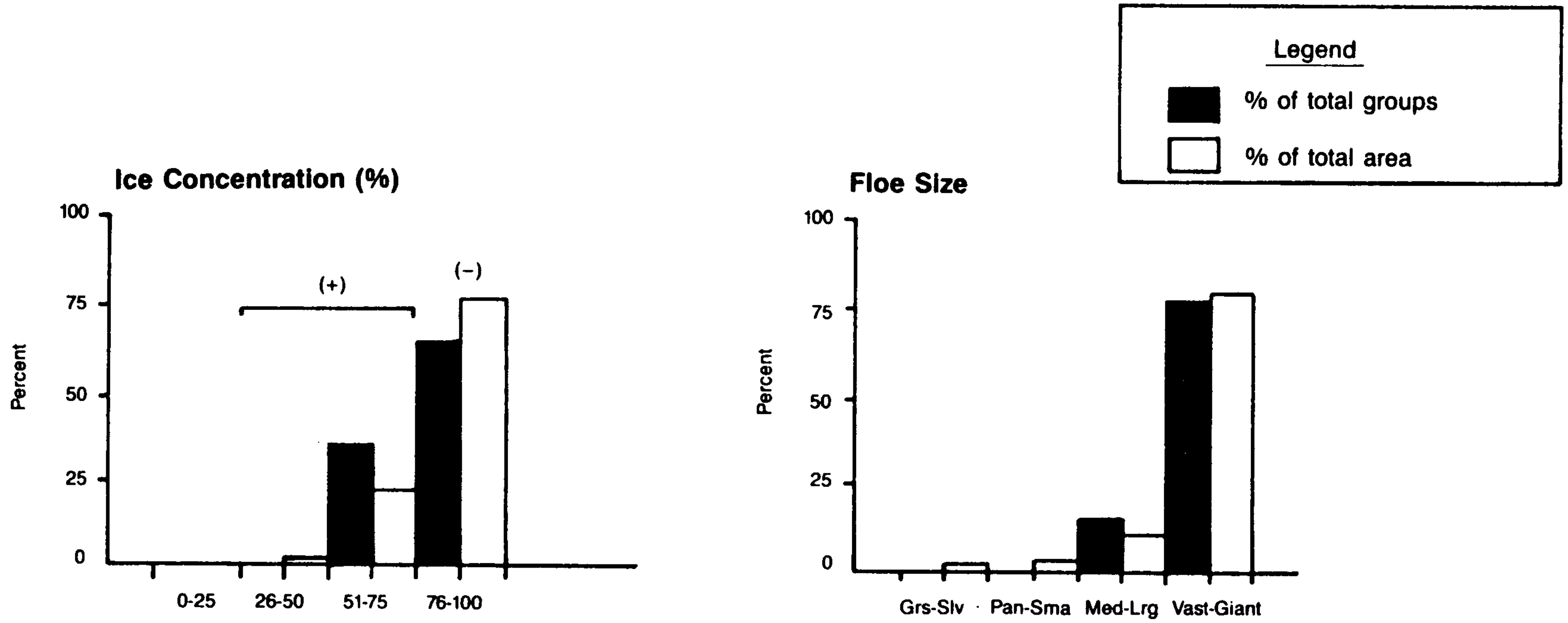


Figure 18 Percent occurrence of bearded seals relative to percent availability of ice types in the Bering Sea, 1979: plus (+) signifies significant preference; minus (–) signifies significant avoidance, bracket (⌐¬) signifies pooled data.

TABLE 10

NUMBER OF PINNIPED GROUPS OBSERVED IN EACH ICE CONCENTRATION AND FLOE SIZE CATEGORY OF THE PACK ICE IN THE BERING SEA DURING EARLY SPRING, 1979[a]

Species	Ice Concentration Category				Floe Size Categories				Total
	0-25%	26-50%	51-75%	76-100%	Grease-Slush	Pancake-Small	Medium-Large	Vast-Giant	
Ribbon seal	1	2	1	5	1	7	1	---	9
Ringed seal	--	--	1	8	--	--	1	8	9
Spotted seal	--	--	3	5	--	2	2	4	8

a/ Numbers are based on animal groups seen along systematic transect lines both in and out of strip.

b/ Dash (--) signifies no animal.

Density

The density of pinnipeds in the project area was estimated from 1,463 animals representing 192 groups encountered along 1,483 nm or 741 nm^2 surveyed (Table 11). Walrus densities were over 90 percent higher than any other species. They were highest in the central zone, lowest in the northern zone, and intermediate in the southern zone or marginal ice front. Walrus density was particularly high in Unit 27 of the marginal ice front and in Units 13 and 15 of the central zone. Densities for the other pinniped species were considerably lower and ranged from 0.39 ringed seals per 100 nm^2 to 4.20 bearded seals per 100 nm^2. Bearded, ringed, and spotted seals densities were highest in the central zone and ribbon seal densities were highest in the marginal ice front. Indices of abundance for the pinnipeds in the project area were estimated at 12,906 walruses, 512 bearded seals, 48 ringed seals, 40 spotted seals, and 27 ribbon seals (Table 12).

DISCUSSION

1982-83 SURVEY

Pinnipeds inhabited the Navarin Basin all year long. Use was greatest during the winter and spring when most pinnipeds are driven from more northern latitudes by the pack ice. The pack ice, particularly during the late winter and spring, provides pinnipeds a platform for resting, birthing, and molting. During the summer and fall when use of the Basin was lowest, the majority of pinnipeds had migrated northward or to coastal areas except for ribbons seals that probably summered over the shelf break (Burns 1970, 1981a). Although no ribbon seals were recorded in the Basin during these seasons, they may have been present but missed because phocid detection and identification in open water were difficult. The few sea lions and fur seals recorded were probably nonbreeding animals since these species occupy rookeries throughout the summer. Because of the low numbers of animals observed during the

TABLE 11

ESTIMATED DENSITY (PER 100nm2) OF SEALS AND WALRUSES IN THE PACK ICE OF THE BERING SEA DURING EARLY SPRING 1979 a/

Zone b/	Unit	Total Area (nm)2	Coverage	Spotted seal No.	Spotted seal Den.	Ribbon seal No.	Ribbon seal Den.	Bearded seal No.	Bearded seal Den.	Ringed Seal No.	Ringed Seal Den.	Unidentified pinniped No.	Unidentified pinniped Den.	North Pacific walrus No.	North Pacific walrus Den.	Total No.	Total Den.
NORTHERN																	
	9	960	6.97	--c/	--	--	--	--	--	--	--	--	--	--	--	--	--
	10	960	12.65	--	--	--	--	--	--	--	--	--	--	4	3.29	4	3.29
	11	900	15.23	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	12	900	15.83	--	--	--	--	1	0.70	--	--	2	1.39	23	16.03	26	18.25
Subtotal		3,720	12.60	--	--	--	--	1	0.21±0.40	--	--	2	0.43±0.59	27	5.76±5.27	30	6.40
CENTRAL																	
	13	900	14.20	2	1.56	--	--	56	43.79	4	3.13	5	3.91	439	343.32	506	395.93
	14	900	17.34	--	--	--	--	--	--	--	--	--	--	4	2.56	4	2.56
	15	900	15.17	4	2.93	--	--	17	12.46	3	2.20	14	10.26	224	164.12	262	191.90
Subtotal		2,700	15.57	6	1.43±1.50	--	--	73	17.36±11.62	7	1.66±1.70	19	4.52±3.64	667	158.65±124.70	772	183.64
SOUTHERNb/																	
	24	480	10.19	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	25	1,320	8.22	--	--	--	--	--	--	--	--	--	--	16	14.75	16	14.75
	26	1,200	13.84	--	--	1	0.60	--	--	--	--	--	--	2	1.20	3	1.81
	27	1,800	7.89	--	--	1	0.70	--	--	--	--	4	2.82	613	431.42	618	435.15
	28	960	13.33	--	--	1	0.78	--	--	--	--	1	0.78	22	17.19	24	18.75
Subtotal		5,760	10.31	--	--	3	0.51±0.52	--	--	--	--	5	0.84±0.89	653	110.00±161.21	661	111.31
TOTAL		12,180	12.17	6	0.40±0.44	3	0.20±0.22	74	4.99±3.56	7	0.47±0.50	26	1.75±1.14	1,347	90.83±74.60	1,463	98.70
Stratified				6	0.33	3	0.22	74	4.20	7	0.39	26	1.63	1,347	105.96	1,463	112.80

a/ Density is based on number of animals in a 0.5 nm wide strip for pinnipeds.

b/ Southern zone corresponds to the marginal ice front.

c/ Dash (--) signifies no animals.

TABLE 12

ESTIMATED ABUNDANCE AND 95 PERCENT CONFIDENCE INTERVALS FOR SEALS AND WALRUSES IN THE PACK ICE OF THE BERING SEA DURING EARLY SPRING, 1979 a/

Zone	Sampling Unit	Spotted Seal	Ribbon Seal	Bearded Seal	Ringed Seal	Unidentified Seal	Pacific Walrus	Total
NORTHERN	9	- b/	-	-	-	-	-	-
	10	-	-	-	-	-	32	32
	11	-	-	-	-	-	-	-
	12	-	-	-	-	13	144	163
	Subtotal	-	-	6	-	13	176	195
CENTRAL	13	14	-	394	28	35	3090	3561
	14	-	-	-	-	-	23	23
	15	26	-	112	20	92	1477	1727
	Subtotal	40	-	506	48	127	4590	5311
SOUTHERN	24	-	-	-	-	-	-	-
	25	-	-	-	-	-	195	195
	26	-	7	-	-	-	14	21
	27	-	13	-	-	51	7766	7830
	28	-	7	-	-	7	165	179
	Subtotal	-	27	-	-	58	8,140	8,225
TOTAL		49±50	25±25	608±407	57±57	214±130	11,064±8,515	13,731
Stratified		40±37	27±29	512±302	48±42	198±159	12,906±12,071	

a/ Dash (-) signifies no animals were observed.

b/ Numbers were derived by multiplying the estimated density times the unit area (Table 12).

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summer and fall and the limited survey effort of the fringe ice where pinnipeds almost entirely occurred in the spring, the discussion will concentrate on the winter survey results which we were able to more thoroughly analyze. Since these results do not reflect the peak period pinnipeds haul out on ice, biases may exist among interspecies comparisons, but the data represent a first detailed description of pinniped use of the central Bering Sea ice front during late winter and early spring.

During the winter survey period, walruses, sea lions, spotted seals, and ribbon seals partitioned their distributions in the pack ice. Walruses, although widespread, occurred principally deep in the pack ice in the eastern half of the ice front. They preferred areas of thin and grease-slush ice, avoided areas of thick ice and intermediate floe sizes, and displayed no association with ice concentration. Correspondingly, the eastern half of the front featured areas containing the highest proportion of grease-slush ice and new ice of the areas surveyed. Braham et al. (unpublished) also reported, but qualitatively, that walrus use was greater deeper in the pack than along the front. Furthermore, Fay (1981) reported that the northcentral concentration area (St. Lawrence Island vicinity) of walruses lies in an area of relatively thin, broken ice, surrounded by areas of heavier, more consolidated pack ice, and that walrus were conspicuously absent in areas of heavy ice. Walruses appear to select ice conditions that allow easy entry into shallow water feeding areas from haul out sites.

Sea lions, conversely, were very narrowly distributed in the ice front near the ice edge in the western third of the front (Unit 28). They preferred areas of grease to small floes (particularly pancake to small floes) and 0 to 60 percent ice coverage, avoided areas of high ice concentration and medium-giant floes, and exhibited no association with ice thickness. These conditions closely describe areas near the ice edge (Burns et al. 1980), and partially agree with ice conditions in

Unit 28, which featured somewhat lower proportions of area in high ice concentrations and larger floes than elsewhere in the front. Burns and Harbo (1977) also reported that sea lions haul out mainly on small floes at the extreme southern edge of the front or within a few miles of it, but are likely to be encountered at any location along the front. Consequently, sea lions appear to be poorly adapted to inhabiting the deeper pack ice.

Spotted seals, like walruses, were widespread but primarily occurred at locations from the ice edge that were intermediate to walruses and sea lions, and were predominantly in the westernmost unit of the front. They preferred areas of moderate ice coverage (20-60 percent and particularly 20-40 percent) and thick ice (first year), but avoided thin to moderately thick ice. They indiscriminately used ice floe sizes, although the highest proportion of seals was in the pancake to small floe size class. Correspondingly, the unit they occupied in greatest numbers was most similar to the ice condition they preferred. Spotted seals, according to Burns and Harbo (1977) are most abundant in the front, utilizing small floes near the southern terminus of the pack, generally within 30 miles of the open ocean, but are also encountered deeper in the pack where currents or wind keep the ice thin. Since spotted seals, like sea lions, do not maintain breathing holes in ice, they inhabit areas of pack ice where there is persistent open water.

Also intermediate in location to walruses and sea lions, but deeper than spotted seals from the ice edge, were ribbon seals. They primarily occurred in the central section, Unit 26, of the front which partially overlapped areas of high walrus use. Too few sightings were made to determine ice use, but Burns and Harbo (1977) reported that ribbon seals usually haul out on relatively thick, clear, rough, snow covered ice floes in the ice front, most often located between 20 and 50 miles north of the ice edge. The ribbon seals we observed were in somewhat similar ice conditions to these, but on the average they were deeper in the pack ice. Too few bearded and ringed seals were observed to evaluate their distribution patterns; these species primarily occur deep in the pack ice largely beyond the areas we surveyed (Burns and Frost 1979; Burns et al. 1980).

Consequently, the distribution of pinnipeds was influenced by sea ice. While ringed seals, and to a lesser degree bearded seals, maintain breathing holes in ice, the other species of pinnipeds do not. This precludes sea lions, spotted seals, and ribbon seals from occupying areas deep in the pack ice. Walruses, however, because of their much larger size, can inhabit areas of heavier pack ice than these species but not to the degree of ringed seals. Consequently, sea lions, spotted, and ribbon seals occurred chiefly in areas of broken ice toward the edge of the ice front where smaller floes were prevalent because of the influence of wave action from the open water. In addition, smaller floes provided the greatest amount of edge for these animals to use during haulout periods. Walruses, however, were deeper in the ice but generally near broken ice where openings were available for them to enter the water.

1979 SURVEY

Walrus were widely distributed in the pack ice in 1979. Walrus density was highest in the central zone and lowest in the northern zone. Although group size averaged 10.0 animals, almost 75 percent of the groups consisted of five or less animals. Most of the animals occurred deep in the pack ice away from the ice edge even in the zone comprising the marginal ice front. Walruses were primarily found in areas associated with the higher ice concentration and floe size categories except in the marginal ice front where they occurred in the more intermediate categories. Areas of high walrus use within the three zones tended to have more broken ice than other units, although the trend was not consistent among units. Braham et al. (unpublished) reported that surveys by Kenyon (1960, 1972) identified that the highest walrus concentrations in the northcentral Bering Sea were also southwest of St. Lawrence Island and in Anadyr Strait. In contrast to our findings, Braham et al. (unpublished) further reported that walruses were conspicuously absent in the central Bering Sea from 59°N to 63°N. Walrus densities in each zone of the project area were lower than reported by Braham et al. (unpublished) for areas near St. Lawrence Island (2.77 animals per nm^2) but higher in the central and southern zones than they reported for Bristol Bay (0.82 animals per nm^2).

Bearded seals, although widespread in the project area, were most abundant in the central zone and least abundant in the southern zone. Group sizes averaged 1.2 animals but almost 90 percent of the groups were of single animals. Bearded seals were most prevalent in the higher ice concentration and floe size categories. These conditions were most common in the central zone and least common in the southern zone. Braham et al. (unpublished) reported that bearded seal densities were 1.7 times higher in the northern than the southern section of the Bering Sea pack ice. Surveys by Burns and Frost (1979) showed high densities of bearded seals southwest of St. Lawrence Island in an area close to our central zone.

Ringed seals were almost entirely (14 of 15 animals) observed in the central zone. They were associated with areas of high ice concentrations and floe sizes which characterized the central zone pack ice. Thirteen of the 14 groups recorded consisted of solitary animals. One group of two animals, consisting of an adult with a pup, was recorded on April 12. Other investigators (Lowry et al. 1982) have reported that ringed seals occur throughout the Bering Sea pack ice but densities are highest in the shorefast ice. In areas where detailed ringed seal studies have been conducted, such as in the Chukchi Sea, seal densities were as much as 31 times greater in the shorefast ice than in the pack ice (Burns and Harbo 1977, Stirling et al. 1977, Burns and Eley 1978). Braham et al. (unpublished) reported that ringed seals were not numerous in the offshore pack ice of the Bering Sea except west of St. Lawrence Island, which generally corresponds to our results. Consequently, our results which are supported by those of other investigators, identify that ringed seal densities are highest southwest of St. Lawrence Island but are in general much lower in the Bering Sea pack ice than in the nearshore fast ice.

Ribbon seals were primarily encountered deep in the marginal ice front, although one was recorded in the central zone southwest of St. Lawrence Island. The seals were entirely observed west of 174°W where they were associated with a variety of ice concentrations and small floes characteristic of the front. Lowry et al. (1982) also reported that ribbon seals were most numerous in the ice front, particularly west of 173°W (Braham et al., unpublished). They further reported that isolated areas of abundance in the inner pack ice were west of St. Matthew Island and southwest of St. Lawrence Island. Ribbon seals according to Fay (1974) seem to be mainly solitary, which agrees with our findings where all eight ribbon seals we encountered were singles.

Spotted seals were most common in the central zone and there were none in the northern zone. Few were encountered in the ice front, which is reported to have the highest densities. Braham et al. (unpublished) found that densities decreased northward into the pack ice from the ice front. Densities were highest between 175°W and 180°W in the ice front (Braham et al. unpublished) and in Bristol Bay between 162°W and 165° 30'W (Burns and Harbo, 1977). This difference between results may be an artifact of our small sample size, but it is unclear why we saw so few spotted seals in the front. The three pups we observed on April 12 in Unit 15 agree with the late March and April pupping period reported by Fay (1974).

The 1979 results identify that pinniped distributions were influenced by ice conditions. Bearded and ringed seals were primarily associated with the areas of extensive ice coverage in the inner pack ice. These species are capable of maintaining breathing holes in the ice which provides a mechanism for them to inhabit heavy ice conditions.

Conversely, ribbon seals, which do not maintain breathing holes, were primarily encountered in the broken ice of the front. Walruses were widespread throughout the pack ice. Their wide distribution was partly the result of their capacity to break ice up to 22cm thick with their relatively large bodies (Fay 1974). Spotted seal association with the heavy ice of the inner pack is contrary to findings by other investigators. The reason for this association is unclear, but probably due to the small sample size. While the information for walrus and bearded seals was developed from relatively large numbers of observations, too few observations were obtained for ribbon, ringed, and spotted seals to draw firm conclusions.

Other factors beyond ice conditions undoubtedly influenced the distribution of pinnipeds. These probably include availability and accessibility of food, inter- or intra-specific competition or separation of sex and age groups. These factors or a combination of factors are probably responsible for explaining the site-specific distribution of the various species. Unfortunately, collection of these data was beyond the scope of this study.

COMPARISON BETWEEN THE 1982-1983 AND 1979 SURVEYS

The results of the 1983 and 1979 surveys are comparable because the study areas and methodologies were similar. The two study areas partially overlapped, particularly in the marginal ice front between St. Matthew Island and the U.S.-U.S.S.R. Convention Line (Appendix B Figure 8). While the 1983 study area was limited to the marginal ice front, the 1979 study area included areas of the deeper pack ice south and west of St. Lawrence Island. Consequently, marine mammal use of the marginal ice front is comparable between the two years and with other areas of the pack ice.

The methods used for the 1983 and 1979 surveys of the pack ice were also similar. Both surveys were flown at similar altitudes with identical helicopters along transect lines oriented in a north-south direction. Marine mammal data for the two periods were collected according to the strip transect procedure. Lastly, the study periods were similar, 19 February - 18 March, 1982, and 2 March - 13 April, 1979. Because of the similarity in methods and locations, the results of the 1983 and 1979 surveys are largely comparable.

The composition and relative abundance of pinnipeds in the marginal ice front differed between 1983 and 1979 (Table 13). Seven species of pinnipeds were recorded during the two survey periods. Only the fur seal was not encountered both years, but this species is an uncommon winter visitor in the pack ice. The most common species in the front both years was the North Pacific walrus. Walruses were almost twice as abundant in 1979 as in 1983, even though the effort was not double. Northern sea lions, spotted seals, and ribbon seals were, however, substantially more commonly recorded in 1983 than in 1979. Small numbers of ringed and bearded seals occurred in the front during both years. These species, however, are typically associated with the deeper pack ice as evidenced by the high numbers of bearded seals and to a lesser degree, ringed seals recorded south and west of St. Lawrence Island during 1979. While the reasons for the observed differences in abundances of the various species were unclear, the results show that the marginal ice front is important to walruses, northern sea lions, and ribbon and spotted seals, whereas bearded and ringed seals primarily inhabit the deeper pack ice.

The average group sizes of the six prominent pinniped species in the marginal ice front was generally consistent between the survey periods. Group sizes averaged approximately one for bearded, ribbon, ringed, and spotted (except in 1983) seals, while it was over four times higher for walruses and northern sea lions. Variation of group sizes between survey periods was greatest for walruses and spotted seals. Walrus group sizes were particularly high during the early spring 1979 survey in the marginal ice front (and the central zone of the pack ice). Spotted seal group sizes were substantially higher

TABLE 13

COMPARISON OF THE 1979 AND 1983 PINNIPED
DISTRIBUTIONS IN THE MARGINAL ICE FRONT OF THE BERING SEA a/

Sampling Unit	Distance Surveyed		Number Per Nautical Mile									
			Spotted Seal		Ribbon Seal		Bearded Seal		N. Sea Lion		N. Pacific Walrus	
	1979	1983	1979	1983	1979	1983	1979	1983	1979	1983	1979	1983
24	174	147	0	2.72	0	0	0	0.68	0	4.76	0	28.57
25	333	462	0	0.22	0	1.08	0	0	0	0	6.01	42.86
26	456	613	0	2.45	1.32	7.34	0.88	0.98	0.44	4.24	84.87	90.70
27	479	482	0	7.68	0.21	1.24	0	0	0	7.05	209.19	6.85
28	377	466	0	0.64	0.27	0.43	0	0	0	69.53	87.80	0
29	0	240	-	75.42	-	0	-	0.42	-	6.25	-	16.25
Total	1819	2410	0	10.00	0.44	2.41	0.22	0.33	0.11	16.85	95.66	36.02

a/ Too few ringed and fur seals were observed in the marginal ice front during both 1979 and 1983 to compare distributions.

during the 1983 winter survey, when they were occasionally observed in large but loose aggregations. The variation of group size for these species was probably associated with one or a combination of factors, including the social structure of spatially separated groups comprised of different sex and age compositions, availability of food, and character of sea ice (B. Fay and L. Lowry, personal communication).

The specific distribution of pinnipeds in the marginal ice front is difficult to compare between years because of the small numbers of animals encountered in 1979 except for the walrus. During both years, walruses were widely distributed. Use of the front was greatest in the western half during 1979 and in the eastern half during 1983. Highest concentrations of walruses were, however, near the center of the front. Walruses were also more common deeper in the ice front than along the edge during both years. Comparisons are less meaningful for the other species; however, observations from one or both years show that ribbon, spotted, and northern sea lions, and a few bearded seals, were widely distributed across the front in varying numbers. Moreover, sea lions primarily occurred along the southern boundary of the front while the other species were intermediate to sea lions and walruses in the front.

The distribution of marine mammals in the marginal ice front was influenced by the characteristics of the sea ice during 1979 and 1983. The ice front was considerably further north and the percent ice cover was lower in 1979 than in 1983 (Figure 12). The percent of area covered by ice in the front averaged 64 percent (58-82 percent) in 1979 and 76 percent (68-80 percent) in 1983 ($P<0.05$). Correspondingly, greater proportions of area were represented by the higher ice concentration and floe size categorizes in 1983 than in 1979. Lastly, the distribution of ice across the front tended to become more broken and less concentrated when going from the eastern to the western units during 1983, while there was no obvious trend in 1979. Consequently, pinniped distribution probably varies with the location and character of the sea ice each year.

Pinniped association with sea ice between 1979 and 1983 was only comparable in the marginal ice front for the walrus, since there were too few observations of the other species. Walruses occurred in virtually every type of ice condition during the two survey periods (Figure 19). Walrus association with the different ice concentration categories did not differ significantly ($P<0.05$) in 1983 but it did ($P<0.05$) in 1979. Walrus occurrence was higher than expected in the intermediate concentration category, and lower than expected in the other categories, except for the 26-50 percent category where it did not differ significantly. Walruses were, however, most abundant in the higher ice concentration, typical of areas deeper in the ice front. Burns (1970) also reported that walruses were widespread in the sea ice but that distribution was primarily influenced by prey availability while ice provided a platform for resting and birthing.

Estimated density of pinnipeds was variable between 1979 and 1983 in the marginal ice front (Table 14). Walrus densities were over 7 times higher in 1979 than in 1983. These values for the marginal ice front were, however, lower than in the central zone where walrus density was highest. Braham et al. (unpublished) reported that walrus densities were also much higher in the northern than in the southern Bering Sea or Bristol Bay. Walrus densities in the central Bering Sea were 1.7 times lower than Braham et al. (unpublished) reported for the northern Bering Sea. Densities which they and Burns and Harbo (1977) reported for the marginal ice front and Bristol Bay were, however, lower than we found in the front. This suggests that the marginal ice front and the areas southwest of St. Lawrence Island, associated with the central zone, are important to walrus.

Bearded seal densities were low in the marginal ice front during both 1979 and 1983 and were highest in the central zone. Braham et al. (unpublished) also found that bearded seal densities were considerably higher in the northern than in the southern Bering Sea pack ice. The

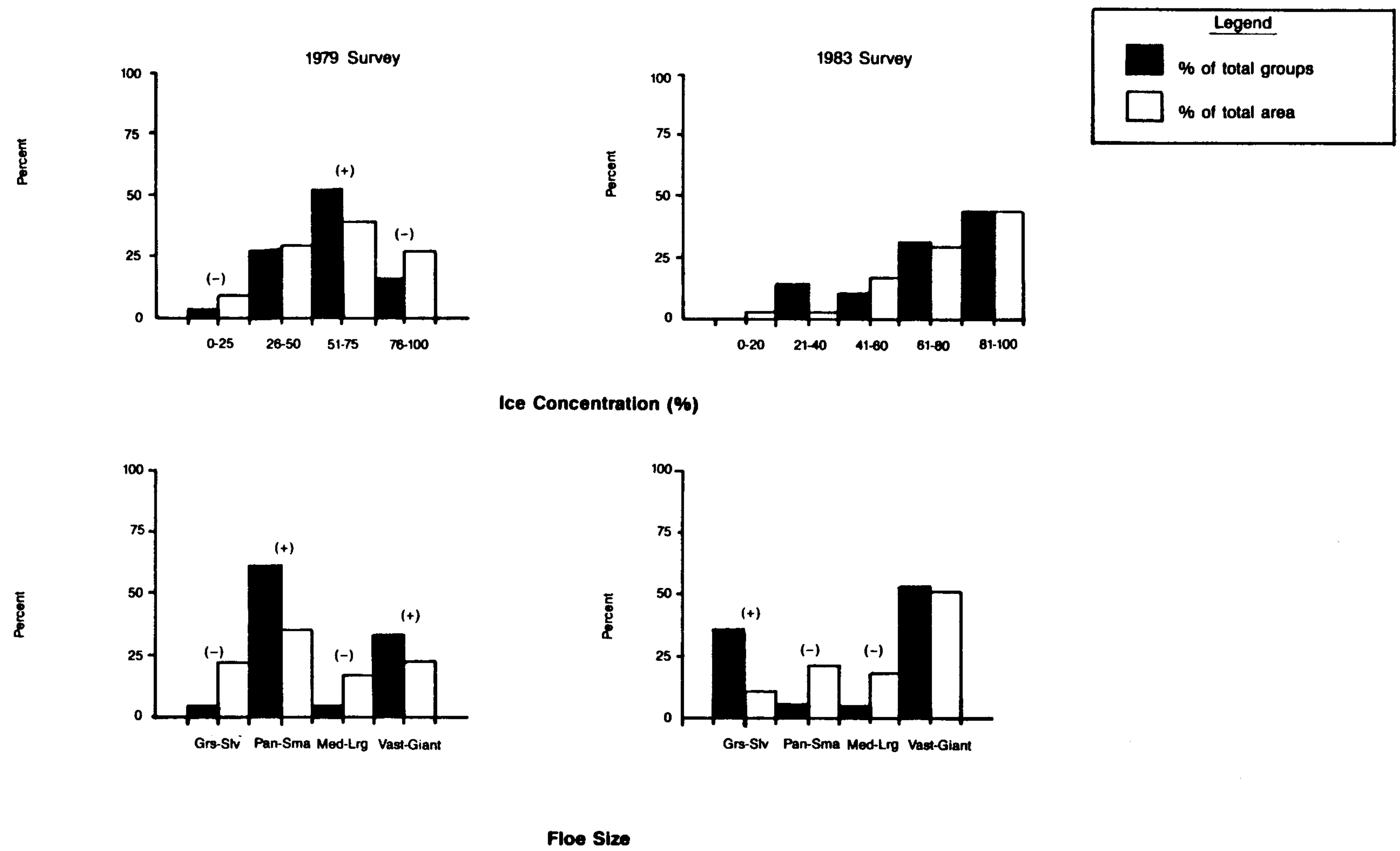

Figure 19 Percent occurrence of walrus in 1979 and 1983 relative to percent availability of ice types in the marginal ice front: plus (+) signifies significant preference; minus (–) signifies significant avoidance.

TABLE 14

COMPARISON OF PINNIPED DENSITIES (PER nm^2) REPORTED FOR THE CURRENT STUDY (1979, 1983) TO THOSE REPORTED BY OTHER INVESTIGATORS

Location[a]	Source	Pacific Walrus	Northern Sea Lion	Spotted Seal	Ribbon Seal	Bearded Seal	Ringed Seal
Marginal Ice Front							
Southcentral	1979 Study	1.100	0.000	0.000	0.005	0.000	0.000
Southcentral	1983 Study	0.152	0.030	0.120	0.015	0.002	0.000
Southcentral	Burns and Harbo (1977)	0.058	--	0.194	--	--	--
Southeastern	Burns and Harbo (1977)	0.118	--	0.614	--	--	--
Southeastern	Braham et al. (unpubl.)	0.820	--	0.370	0.006	0.083	0.017
Bristol Bay	Burns and Harbo (1977)	0.740	--	0.084	--	--	--
Central and Northern Bering Sea							
Central[b]	1979 Study	1.586	0.000	0.014	0.000	0.174	0.017
Northern[c]	1979 Study	0.057	0.000	0.000	0.000	0.002	0.000
Northern	Braham et al. (unpubl.)	2.770	--	--	0.000	0.141	0.059

a/ Southcentral Bering Sea = 169°W to 180°W; Southeastern Bering Sea = 163°W to 169°W; Bristol Bay = 157°W to 163°W; Northern Bering Sea = St. Lawrence Island vicinity.

b/ Southcentral in 1979 and 1983 studies corresponds to southern zone or marginal ice front.

c/ Central and northern in 1979 and 1983 studies corresponds to central and northern zone.

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densities we recorded in the central zone were 1.2 times higher than those reported by Braham et al. (unpublished). This suggests that the central zone, which is southwest of St. Lawrence Island, is an important area for bearded seals.

Ribbon seal densities were higher in the marginal ice front in 1979 and 1983 than in the areas surveyed deeper in the pack ice. Densities were not available for comparison in the area we reported but our results were similar to those reported by Braham et al. (unpublished) for the eastern section of the front. Furthermore, other investigators reported lower ribbon seal densities deeper in the pack ice than in the front.

Spotted seal densities were inconsistent between areas sampled for 1979 and 1983, but were highest in the marginal ice front. The densities we reported were however 5 times lower than these reported in the marginal ice front for the southeastern Bering Sea, where spotted seal densities are highest. These results suggest that the marginal ice front in the project area is of moderate importance to spotted seals.

Only two ringed seals were observed in the marginal ice front during both study periods. Densities were considerably higher in the deeper pack ice of the central zone, but lower than reported by Braham et al. (unpublished). Since ringed seals primarily inhabit the shorefast ice (Burns, 1970), densities were expected to be low in the pack ice.

Northern sea lion densities were extremely variable between 1979 and 1983. Densities for 1983, however, represent the first estimates for this species in the marginal ice front. Moreover, the absence of sighting deep in the pack in 1979 shows that northern sea lions only utilized the marginal ice front.

In summary, our results show that northern sea lion and spotted and ribbon seal densities were highest in the marginal ice front while walrus and ringed and bearded seal densities were highest in the central zone, an area of heavy pack ice southwest of St. Lawrence Island. These findings are consistent with those reported by other investigators (Burns and Harbo, 1977; Burns, 1970; Braham et al. unpublished), except for the density of walrus in the marginal ice front, which we found to be considerably higher than has been reported for the southcentral section of the front.

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APPENDIX A
1982-1983 SUPPLEMENTAL TABLES AND FIGURES

APPENDIX TABLE A-1
DEFINITION OF SURFACE VISIBILITY CATEGORIES
USED DURING AERIAL AND VESSEL SURVEYS[a]

Category	Definition
Excellent	Surface of water calm, a high overcast solid enough to prevent sun glare. Beaufort = 0, visibility greater than 5 km. Marine mammals will appear black against a uniform gray background.
Very good	May be a light surface ripple on the surface or slightly uneven lighting, but still relatively easy to distinguish animals at a distance. Beaufort = 1 or 2, visibility greater than 5 km.
Good	May be a light chop, some sun glare or dark shadows in part of survey track. Beaufort less than or equal to 3, visibility less than or equal to 5 km. Animals up close (300 m or less) can still be detected and fairly readily identified.
Fair	Choppy waves with some slight whitecapping, sun glare or dark shadows in 50 percent or less of the survey track. Beaufort less than or equal to 4, visibility less than or equal to 1 km.
Poor	Wind in excess of 15 kt, waves over 2 ft with whitecaps, sun glare may occur in over 50 percent of the survey track. Beaufort less than or equal to 5, visibility less than or equal to 500 m. Animals may be missed unless within 100 m of the survey trackline, identification difficult except for larger species.
Unacceptable	Wind in excess of 25 kt; waves over 3 ft high with pronounced whitecapping. Sun glare may or may not be present. Beaufort greater than or equal to 6 or visibility less than or equal to 300 m. Detection of any marine mammal unlikely unless observer is looking directly at the place where it surfaces. Identification very difficult due to improbability of seeing animal more than once.

a/ Surface visibility classification was taken from the National Marine Fisheries Service's Platform of Opportunities Program (Consiglieri and Bouchet 1981).

APPENDIX TABLE A-2

SEA ICE CLASSIFICATION USED DURING AERIAL AND VESSEL SURVEYS[a/]

Category	Description
Ice thickness	
New ice	less than or equal to 10 cm
Young ice	10-30 cm
1st year ice	greater than or equal to 30 cm
Ice type	
Grease ice	A later stage of freezing than frazile ice (fine spicules or plates of ice suspended in water) when the crystals have coagulated to form a soupy layer on the surface. Grease ice reflects little light, giving the sea a matt appearance.
Slush	Snow which is saturated and mixed with water on ice surfaces, or as a viscous floating mass in water after a heavy snowfall.
Pancake ice	Predominately circular pieces of ice from 30 cm-3 m in diameter, and up to about 10 cm in thickness, with raised rims due to the pieces striking against one another.
Floes	Any relatively flat piece of ice 10 m or more across.
Small floe	less than 10 m across
Medium floe	10-30 m across
Large floe	30-100 m across
Vast floe	100-200 m across
Giant floe	greater than 200 m across
Ice Concentration	The ratio of tenths of the sea surface actually covered by ice to the total area of sea surface, both ice-covered and ice-free, at a specific location or over a defined area.

a/ Ice description were taken from the World Meteorological Organization (1970). Ice floe sizes were modified from the World Meteorological Organization according to definitions of National Oceanic and Atmospheric Administration.

APPENDIX TABLE A-3
RECORD OF PINNIPEDS AND BELUGA WHALES ENCOUNTERED IN THE NAVARIN BASIN DURING THE FOUR SURVEY SEASONS, MAY-JUNE, JULY-AUGUST, OCTOBER-NOVEMBER, 1982 AND FEBRUARY-MARCH 1983

Date	Species[a]	Number[b]	Location
		SPRING SURVEY	
5/21/82	PF	1	59° 54', 174° 39'W
5/21/82	PL	1	60° 7', 174° 34'W
5/21/82	EB	1	60° 6', 174° 34'W
5/21/82	PF	1	60° 6', 174° 34'W
5/21/82	PF	1	60° 6', 174° 34'W
5/21/82	PF	1	60° 6', 174° 34'W
5/21/82	EB	1	60° 6', 174° 34'W
5/21/82	PF	1	60° 6', 174° 34'W
5/21/82	PL	1	60° 4', 174° 34'W
5/21/82	PL	1	60° 4', 174° 34'W
5/21/82	PF	1	60° 4', 174° 34'W
5/21/82	OR	1	59° 55', 174° 37'W
5/21/82	OR	9	59° 55', 174° 15'W
5/21/82	OR	2	59° 55', 174° 15'W
5/21/82	OR	2	59° 54', 174° 34'W
5/21/82	OR	4	59° 55', 174° 18'W
5/21/82	PL	1	59° 56', 174° 18'W
5/21/82	PF	1	59° 58', 174° 18'W
5/21/82	OR	1	60° 00', 174° 18'W
5/21/82	OR	30	60° 00', 174° 18'W
5/21/82	PF	1	60° 7', 174° 18'W
5/21/82	EJ	2	60° 7', 174° 18'W
5/21/82	PF	1	60° 7', 174° 18'W
5/21/82	PL	1	60° 7', 174° 18'W
5/21/82	PL	1	60° 7', 174° 18'W
5/21/82	PF	1	60° 7', 174° 18'W
5/21/82	PF	1	60° 7', 174° 18'W
5/21/82	PL	1	60° 8', 174° 18'W
5/21/82	PL	1	60° 8', 174° 18'W
5/21/82	PL	1	60° 10', 174° 18'W
5/21/82	PF	1	60° 10', 174° 2'W
5/21/82	PF	1	60° 10', 174° 2'W
5/21/82	PF	1	60° 7', 174° 2'W

a/ EJ = northern sea lion, CL = northern fur seal, PL = spotted seal, EB = bearded seal, PF = ribbon seal, PH = ringed seal, OR = Pacific walrus, DL = beluga whale

b/ Duplicate counts of beluga whales may have occurred during the 12 and 13 March surveys

APPENDIX TABLE A-3 CONT.
RECORD OF PINNIPEDS AND BELUGA WHALES ENCOUNTERED IN THE NAVARIN BASIN DURING THE FOUR SURVEY SEASONS, MAY-JUNE, JULY-AUGUST, OCTOBER-NOVEMBER, 1982 AND FEBRUARY-MARCH 1983

Date	Species[a/]	Number[b/]	Location
	SPRING SURVEY (Continued)		
5/21/82	PF	1	60° 7', 174° 2'W
5/21/82	OR	1	60° 5', 174° 2'W
5/21/82	OR	4	59° 59', 173° 46'W
5/21/82	OR	10	59° 59', 173° 46'W
5/21/82	EJ	9	60° 1', 173° 46'W
5/21/82	OR	1	60° 1', 173° 46'W
5/21/82	PL	2	60° 2', 173° 46'W
5/21/82	PF	2	60° 3', 173° 46'W
5/21/82	PF	1	60° 5', 173° 46'W
5/21/82	PL	1	60° 7', 173° 46'W
5/21/82	PF	1	60° 7', 173° 46'W
5/21/82	EB	1	60° 8', 173° 46'W
5/21/82	EJ	1	60° 10', 173° 44'W
5/21/82	PF	1	60° 5', 173° 30'W
5/21/82	PL	2	60° 5', 173° 30'W
5/21/82	EJ	10	60° 1', 173° 30'W
5/21/82	EJ	12	60° 1', 173° 30'W
5/21/82	EJ	3	60° 1', 173° 30'W
5/21/82	EJ	4	60° 1', 173° 30'W
5/21/82	EB	1	60° 1', 173° 30'W
5/23/82	PF	1	60° 43', 175° 20'W
5/23/82	PF	1	60° 43', 175° 20'W
5/23/82	EJ	1	60° 41', 175° 20'W
5/21/82	UP	1	59° 55', 174° 48'W
5/21/82	UP	4	59° 55', 174° 43'W
5/21/82	OR	2	59° 54', 174° 40'W
5/21/82	UP	1	59° 54', 174° 39'W
5/27/82	PL	1	60° 37', 174° 46'W
5/27/82	EJ	3	60° 41', 174° 46'W
5/27/82	EJ	1	60° 42', 174° 46'W
	SUMMER SURVEY		
7/28/82	EJ	2	60° 48', 178° 22'W
7/26/82	EJ	2	60° 53', 175° 1'W
7/29/82	CL	1	59° 46', 179° 8'W
8/04/82	CL	1	59° 52', 173° 30'W
8/07/82	CL	2	58° 26', 174° 39'W
8/07/82	CL	1	58° 19', 174° 39'W
8/07/82	CL	1	58° 18', 174° 39'W
8/07/82	CL	1	58° 16', 174° 39'W

APPENDIX TABLE A-3 CONT.
RECORD OF PINNIPEDS AND BELUGA WHALES ENCOUNTERED IN THE NAVARIN BASIN DURING THE FOUR SURVEY SEASONS, MAY-JUNE, JULY-AUGUST, OCTOBER-NOVEMBER, 1982 AND FEBRUARY-MARCH 1983

Date	Species[a/]	Number[b/]	Location
		SUMMER SURVEY (Continued)	
8/07/82	CL	1	58° 8', 174° 39'W
8/08/82	CL	1	58° 10', 174° 54'W
8/08/82	CL	1	58° 15', 174° 54'W
		FALL SURVEY	
11/6/82	CL	1	61° 03', 175° 33'W
11/6/82	CL	1	61° 03', 175° 24'W
11/10/82	CL	1	59° 55', 173° 38'W
11/10/82	CL	2	59° 55', 173° 53'W
11/10/82	CL	1	59° 55', 174° 47'W
11/10/82	CL	1	59° 55', 175° 28'W
		WINTER SURVEY	
02/21/83	PL	3	58° 36', 171° 25'W
02/21/83	OR	1	58° 10', 171° 32'W
02/21/83	UP	1	58° 27', 171° 43'W
02/21/83	UP	3	58° 25', 171° 48'W
02/21/83	OR	4	58° 22', 171° 48'W
02/21/83	OR	3	58° 22', 171° 48'W
02/21/83	OR	1	58° 20', 171° 48'W
02/21/83	OR	1	58° 19', 171° 48'W
02/22/83	OR	2	58° 10', 171° 48'W
02/22/83	OR	2	58° 08', 171° 48'W
02/22/83	UP	1	58° 03', 171° 48'W
02/22/83	EJ	1	57° 59', 172° 05'W
02/22/83	UP	1	58° 07', 172° 11'W
02/22/83	EB	1	58° 14', 172° 17'W
02/23/83	UP	4	58° 27', 172° 32'W
02/23/83	EJ	1	58° 31', 172° 32'W
02/23/83	EJ	5	58° 31', 172° 32'W
02/23/83	OR	1	58° 39', 172° 33'W
02/23/83	UP	1	58° 45', 172° 32'W
02/23/83	UP	1	58° 48', 172° 32'W
02/23/83	OR	1	58° 51', 172° 33'W
02/23/83	OR	1	58° 53', 172° 32'W
02/23/83	OR	2	58° 58', 172° 32'W
02/23/83	OR	2	58° 58', 172° 32'W
02/23/83	OR	2	58° 58', 172° 32'W

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APPENDIX TABLE A-3 CONT.
RECORD OF PINNIPEDS AND BELUGA WHALES ENCOUNTERED IN THE NAVARIN BASIN DURING THE FOUR SURVEY SEASONS, MAY-JUNE, JULY-AUGUST, OCTOBER-NOVEMBER, 1982 AND FEBRUARY-MARCH 1983

Date	Species[a/]	Number[b/]	Location
		WINTER SURVEY (Continued)	
02/24/83	EJ	2	59° 33', 176° 12'W
02/24/83	CL	1	59° 33', 176° 10'W
02/24/83	EJ	4	59° 32', 176° 04'W
02/24/83	UP	1	59° 44', 175° 54'W
02/24/83	PL	1	59° 54', 175° 52'W
02/25/83	EJ	1	59° 29', 176° 04'W
02/25/83	EJ	1	59° 28', 176° 04'W
02/25/83	OR	2	59° 28', 176° 04'W
02/25/83	EJ	4	59° 29', 176° 03'W
02/25/83	PL	1	59° 31', 176° 03'W
02/25/83	PL	34	59° 31', 176° 03'W
02/26/83	PL	1	60° 07', 177° 27'W
02/26/83	EJ	1	60° 16', 177° 34'W
02/26/83	UP	1	60° 18', 177° 41'W
02/26/83	EJ	1	60° 19', 177° 41'W
02/26/83	UP	1	60° 27', 177° 42'W
02/26/83	EJ	1	60° 21', 177° 52'W
02/27/83	PL	1	60° 35', 178° 13'W
02/28/83	PL	1	60° 54', 178° 14'W
02/28/83	PL	1	60° 54', 178° 15'W
02/28/83	PL	1	60° 55', 178° 17'W
02/28/83	OR	4	60° 55', 178° 18'W
02/28/83	PL	1	60° 55', 178° 19'W
02/28/83	PL	1	60° 55', 178° 19'W
02/28/83	PL	1	60° 55', 178° 19'W
02/28/83	PL	1	60° 55', 178° 19'W
02/28/83	PL	1	60° 55', 178° 19'W
02/28/83	PL	1	60° 56', 178° 21'W
02/28/83	PL	1	60° 57', 178° 23'W
02/28/83	OR	2	61° 02', 178° 19'W
02/28/83	UP	1	61° 01', 178° 17'W
02/28/83	UP	1	61° 01', 178° 17'W
02/28/83	OR	1	61° 04', 178° 16'W
02/28/83	UP	1	61° 05', 178° 16'W
02/28/83	OR	1	61° 11', 178° 20'W
02/28/83	PL	2	61° 13', 178° 25'W
02/28/83	OR	1	61° 12', 178° 27'W
02/28/83	PL	1	61° 12', 178° 29'W
02/28/83	PH	1	61° 11', 178° 30'W
02/28/83	UP	1	61° 11', 178° 30'W
02/28/83	OR	1	61° 04', 178° 40'W
02/28/83	OR	1	61° 04', 178° 40'W

APPENDIX TABLE A-3 CONT.
RECORD OF PINNIPEDS AND BELUGA WHALES ENCOUNTERED IN THE NAVARIN BASIN DURING THE FOUR SURVEY SEASONS, MAY-JUNE, JULY-AUGUST, OCTOBER-NOVEMBER, 1982 AND FEBRUARY-MARCH 1983

Date	Species[a]	Number[b]	Location
		WINTER SURVEY (Continued)	
02/28/83	OR	23	61° 01', 178° 41'W
02/28/83	PL	1	61° 01', 178° 41'W
02/28/83	OR	2	61° 01', 178° 41'W
02/28/83	PH	1	61° 01', 178° 35'W
03/01/83	UP	1	61° 00', 178° 30'W
03/01/83	PL	1	60° 59', 178° 28'W
03/01/83	OR	3	60° 56', 178° 28'W
03/01/83	EB	1	60° 39', 178° 28'W
03/02/83	PL	1	60° 41', 178° 51'W
03/02/83	UP	1	60° 43', 178° 51'W
03/02/83	PL	1	60° 55', 178° 54'W
03/02/83	PL	2	60° 56', 178° 52'W
03/02/83	PL	1	60° 56', 178° 52'W
03/02/83	PL	2	60° 56', 178° 52'W
03/02/83	PL	35	60° 58', 178° 53'W
03/02/83	PL	99	60° 58', 178° 53'W
03/02/83	UP	4	61° 00', 178° 52'W
03/02/83	UP	1	61° 00', 178° 52'W
03/02/83	UP	1	61° 00', 178° 58'W
03/02/83	PL	4	61° 01', 179° 02'W
03/02/83	PL	8	61° 01', 179° 02'W
03/02/83	PL	2	61° 01', 179° 02'W
03/02/83	PL	8	60° 59', 179° 04'W
03/02/83	UP	1	60° 58', 179° 04'W
03/02/83	PL	1	60° 55', 179° 04'W
03/02/83	UP	1	60° 55', 179° 04'W
03/03/83	EJ	1	60° 44', 179° 04'W
03/03/83	UP	2	60° 44', 179° 04'W
03/03/83	EJ	1	60° 44', 179° 04'W
03/03/83	EJ	1	60° 44', 179° 04'W
03/03/83	EJ	1	60° 43', 179° 05'W
03/03/83	EJ	1	60° 41', 179° 15'W
03/03/83	EJ	1	60° 41', 179° 15'W
03/03/83	EJ	2	60° 44', 179° 16'W
03/03/83	EJ	1	60° 49', 179° 16'W
03/03/83	UP	1	60° 47', 179° 24'W
03/03/83	UP	2	60° 49', 179° 24'W
03/03/83	PL	1	60° 49', 179° 15'W
03/03/83	EJ	2	60° 47', 179° 14'W
03/03/83	EJ	1	60° 51', 179° 18'W

APPENDIX TABLE A-3 CONT.
RECORD OF PINNIPEDS AND BELUGA WHALES ENCOUNTERED IN THE NAVARIN BASIN DURING THE FOUR SURVEY SEASONS, MAY-JUNE, JULY-AUGUST, OCTOBER-NOVEMBER, 1982 AND FEBRUARY-MARCH 1983

Date	Species[a/]	Number[b/]	Location
		WINTER SURVEY (Continued)	
03/03/83	EJ	2	60° 47', 178° 51'W
03/03/83	EJ	1	61° 00', 178° 38'W
03/03/83	UP	1	60° 58', 178° 36'W
03/04/83	EJ	4	60° 18', 177° 37'W
03/04/83	EJ	10	60° 20', 177° 37'W
03/04/83	EJ	10	60° 18', 177° 26'W
03/04/83	EJ	35	60° 18', 177° 26'W
03/04/83	EJ	25	60° 18', 177° 24'W
03/04/83	EJ	12	60° 18', 177° 24'W
03/04/83	EJ	10	60° 18', 177° 24'W
03/04/83	EJ	25	60° 20', 177° 25'W
03/04/83	EJ	12	60° 20', 177° 25'W
03/04/83	EJ	1	60° 20', 177° 25'W
03/04/83	EJ	8	60° 19', 177° 28'W
03/04/83	EJ	8	60° 17', 177° 24'W
03/04/83	EJ	7	60° 17', 177° 24'W
03/04/83	EJ	12	60° 17', 177° 24'W
03/04/83	EJ	11	60° 16', 177° 23'W
03/04/83	EJ	19	60° 16', 177° 23'W
03/04/83	EJ	18	60° 15', 177° 23'W
03/04/83	EJ	10	60° 13', 177° 22'W
03/04/83	EJ	12	60° 13', 177° 22'W
03/04/83	EJ	16	60° 11', 177° 21'W
03/04/83	EJ	2	60° 08', 177° 19'W
03/04/83	EJ	2	60° 05', 177° 15'W
03/04/83	PL	1	60° 30', 177° 20'W
03/04/83	PL	1	60° 27', 177° 20'W
03/04/83	EJ	7	60° 15', 177° 20'W
03/04/83	EJ	1	60° 13', 177° 20'W
03/04/83	EJ	1	60° 11', 177° 20'W
03/04/83	EJ	15	60° 09', 177° 16'W
03/04/83	EJ	1	60° 09', 177° 20'W
03/04/83	EJ	5	60° 09', 177° 16'W
03/04/83	EJ	7	60° 09', 177° 20'W
03/04/83	EJ	12	60° 09', 177° 20'W
03/04/83	EJ	1	60° 27', 177° 16'W
03/04/83	UP	1	60° 30', 177° 16'W
03/04/83	EJ	1	60° 05', 177° 08'W
03/04/83	EJ	1	59° 57', 176° 58'W
03/04/83	UP	1	60° 24', 176° 52'W
03/04/83	OR	15	60° 47', 176° 44'W
03/04/83	OR	13	60° 47', 176° 44'W

APPENDIX TABLE A-3 CONT.
RECORD OF PINNIPEDS AND BELUGA WHALES ENCOUNTERED IN THE NAVARIN BASIN DURING THE FOUR SURVEY SEASONS, MAY-JUNE, JULY-AUGUST, OCTOBER-NOVEMBER, 1982 AND FEBRUARY-MARCH 1983

Date	Species[a/]	Number[b/]	Location
	WINTER SURVEY (Continued)		
03/04/83	OR	1	60° 43', 176° 44'W
03/04/83	UP	1	60° 39', 176° 44'W
03/04/83	PF	1	60° 25', 176° 44'W
03/04/83	PF	2	60° 26', 176° 40'W
03/04/83	PF	3	60° 26', 176° 40'W
03/04/83	PF	1	60° 38', 177° 05'W
03/04/83	PF	1	60° 37', 177° 09'W
03/04/83	UP	1	60° 52', 177° 16'W
03/04/83	UP	1	60° 53', 177° 16'W
03/04/83	UP	1	60° 56', 177° 08'W
03/05/83	EJ	3	59° 37', 176° 08'W
03/05/83	EJ	1	59° 33', 175° 52'W
03/05/83	EJ	6	59° 42', 175° 44'W
03/05/83	EJ	10	59° 42', 175° 44'W
03/05/83	EJ	2	59° 32', 175° 51'W
03/05/83	UP	1	59° 55', 175° 32'W
03/05/83	EJ	12	59° 35', 175° 20'W
03/05/83	OR	1	59° 45', 175° 20'W
03/05/83	PL	2	60° 09', 175° 20'W
03/05/83	OR	1	60° 05', 175° 23'W
03/05/83	PL	11	60° 04', 175° 25'W
03/05/83	EB	1	60° 04', 175° 25'W
03/06/83	PF	1	59° 56', 174° 53'W
03/06/83	PF	1	60° 07', 174° 52'W
03/06/83	UP	1	60° 16', 174° 44'W
03/06/83	OR	2	60° 23', 174° 44'W
03/06/83	OR	1	60° 22', 174° 48'W
03/06/83	UP	1	60° 22', 174° 48'W
03/06/83	OR	1	60° 22', 174° 50'W
03/06/83	UP	1	60° 22', 174° 51'W
03/06/83	UP	1	60° 20', 175° 05'W
03/06/83	OR	1	60° 19', 175° 05'W
03/06/83	UP	1	60° 19', 175° 05'W
03/06/83	UP	1	60° 16', 175° 04'W
03/06/83	UP	1	60° 11', 175° 04'W
03/06/83	UP	1	60° 11', 175° 04'W
03/06/83	PL	1	60° 10', 175° 06'W
03/06/83	OR	1	60° 10', 175° 06'W
03/06/83	UP	1	60° 09', 175° 06'W

APPENDIX TABLE A-3 CONT.
RECORD OF PINNIPEDS AND BELUGA WHALES ENCOUNTERED IN THE NAVARIN BASIN DURING THE FOUR SURVEY SEASONS, MAY-JUNE, JULY-AUGUST, OCTOBER-NOVEMBER, 1982 AND FEBRUARY-MARCH 1983

Date	Species[a/]	Number[b/]	Location
	WINTER SURVEY (Continued)		
03/07/83	PL	1	60° 23', 175° 08'W
03/07/83	OR	1	60° 26', 175° 10'W
03/07/83	UP	1	60° 26', 175° 08'W
03/07/83	PF	1	60° 23', 175° 06'W
03/07/83	OR	1	60° 23', 175° 05'W
03/07/83	OR	1	60° 23', 175° 00'W
03/07/83	OR	1	60° 23', 174° 58'W
03/07/83	OR	3	60° 22', 174° 56'W
03/07/83	OR	2	60° 21', 174° 56'W
03/07/83	OR	1	60° 21', 174° 56'W
03/07/83	OR	1	60° 21', 174° 56'W
03/07/83	OR	3	60° 21', 174° 56'W
03/07/83	OR	2	60° 21', 174° 56'W
03/07/83	OR	1	60° 20', 174° 56'W
03/07/83	OR	15	60° 20', 174° 56'W
03/07/83	OR	8	60° 20', 174° 56'W
03/07/83	OR	3	60° 20', 174° 56'W
03/07/83	OR	1	60° 20', 174° 56'W
03/07/83	OR	8	60° 19', 174° 56'W
03/07/83	OR	1	60° 19', 174° 56'W
03/07/83	OR	2	60° 19', 174° 56'W
03/07/83	OR	7	60° 19', 174° 56'W
03/07/83	OR	2	60° 19', 174° 56'W
03/07/83	OR	2	60° 19', 174° 56'W
03/07/83	OR	4	60° 19', 174° 56'W
03/07/83	OR	11	60° 19', 174° 56'W
03/07/83	OR	12	60° 19', 174° 56'W
03/07/83	OR	2	60° 19', 174° 56'W
03/07/83	PF	1	60° 17', 174° 56'W
03/08/83	PF	1	59° 53', 174° 28'W
03/08/83	EJ	1	59° 27', 174° 40'W
03/08/83	UP	1	59° 26', 174° 49'W
03/09/83	EJ	1	58° 59', 174° 32'W
03/09/83	EJ	3	58° 57', 174° 32'W
03/09/83	EJ	6	58° 56', 174° 32'W
03/09/83	EJ	1	58° 53', 174° 31'W
03/09/83	UP	1	58° 57', 174° 16'W
03/09/83	EJ	1	59° 04', 174° 16'W
03/09/83	EJ	1	59° 09', 174° 14'W
03/10/83	UP	1	60° 16', 173° 06'W
03/10/83	OR	1	60° 28', 173° 08'W

APPENDIX TABLE A-3 CONT.
RECORD OF PINNIPEDS AND BELUGA WHALES ENCOUNTERED IN THE NAVARIN BASIN DURING THE FOUR SURVEY SEASONS, MAY-JUNE, JULY-AUGUST, OCTOBER-NOVEMBER, 1982 AND FEBRUARY-MARCH 1983

Date	Species[a/]	Number[b/]	Location
		WINTER SURVEY (Continued)	
03/10/83	OR	1	60° 28', 173° 08'W
03/10/83	OR	3	60° 28', 173° 08'W
03/10/83	OR	1	60° 27', 173° 08'W
03/10/83	UP	1	60° 27', 173° 08'W
03/10/83	UP	1	60° 23', 173° 09'W
03/10/83	UP	1	60° 18', 173° 08'W
03/10/83	UP	1	60° 17', 173° 08'W
03/10/83	PF	1	60° 15', 173° 07'W
03/10/83	UP	1	60° 14', 173° 06'W
03/10/83	UP	1	60° 11', 173° 07'W
03/10/83	UP	2	60° 08', 173° 08'W
03/10/83	UP	1	60° 06', 173° 08'W
03/10/83	UP	1	60° 02', 173° 08'W
03/10/83	UP	1	60° 01', 172° 56'W
03/10/83	UP	1	60° 04', 172° 56'W
03/10/83	PL	1	60° 06', 172° 56'W
03/10/83	UP	1	60° 08', 172° 56'W
03/11/83	UP	1	60° 19', 172° 52'W
03/11/83	OR	3	60° 19', 172° 52'W
03/11/83	OR	1	60° 14', 172° 35'W
03/11/83	OR	1	60° 15', 172° 34'W
03/11/83	OR	1	60° 15', 172° 34'W
03/11/83	OR	3	60° 16', 172° 33'W
03/11/83	OR	1	60° 16', 172° 33'W
03/11/83	OR	2	60° 16', 172° 32'W
03/11/83	OR	1	60° 16', 172° 32'W
03/11/83	OR	3	60° 16', 172° 32'W
03/11/83	OR	1	60° 09', 172° 32'W
03/11/83	PL	1	60° 04', 172° 28'W
03/11/83	OR	3	60° 05', 172° 29'W
03/11/83	OR	1	60° 05', 172° 29'W
03/12/83	OR	1	60° 34', 173° 37'W
03/12/83	OR	2	60° 33', 173° 42'W
03/12/83	OR	1	60° 31', 173° 44'W
03/12/83	OR	1	60° 29', 173° 46'W
03/12/83	OR	1	60° 25', 173° 44'W
03/12/83	OR	2	60° 26', 173° 47'W
03/12/83	OR	6	60° 25', 173° 48'W
03/12/83	OR	3	60° 24', 173° 48'W
03/12/83	OR	15	60° 23', 173° 52'W
03/12/83	OR	1	60° 17', 173° 54'W
03/12/83	OR	1	60° 17', 173° 54'W

APPENDIX TABLE A-3 CONT.
RECORD OF PINNIPEDS AND BELUGA WHALES ENCOUNTERED IN THE NAVARIN BASIN DURING THE FOUR SURVEY SEASONS, MAY-JUNE, JULY-AUGUST, OCTOBER-NOVEMBER, 1982 AND FEBRUARY-MARCH 1983

Date	Species[a/]	Number[b/]	Location
	WINTER SURVEY (Continued)		
03/12/83	OR	1	60° 20', 173° 54'W
03/12/83	OR	5	60° 18', 173° 55'W
03/12/83	OR	1	60° 14', 173° 54'W
03/12/83	UP	1	60° 14', 173° 54'W
03/12/83	OR	5	60° 17', 173° 56'W
03/12/83	OR	4	60° 15', 173° 53'W
03/12/83	OR	3	60° 15', 173° 53'W
03/12/83	OR	2	60° 22', 173° 56'W
03/12/83	OR	1	60° 18', 173° 56'W
03/12/83	UP	1	60° 16', 173° 56'W
03/12/83	OR	12	60° 16', 174° 08'W
03/12/83	PF	4	60° 07', 174° 08'W
03/12/83	PF	24	60° 02', 174° 13'W
03/12/83	OR	2	60° 01', 174° 16'W
03/12/83	UP	1	60° 01', 174° 18'W
03/12/83	EB	1	60° 00', 174° 19'W
03/12/83	OR	1	59° 59', 174° 23'W
03/12/83	UP	1	59° 59', 174° 23'W
03/12/83	UP	1	59° 59', 174° 23'W
03/12/83	OR	2	60° 03', 174° 28'W
03/12/83	EB	1	59° 59', 174° 26'W
03/12/83	EB	1	59° 59', 174° 29'W
03/12/83	UP	1	60° 00', 174° 31'W
03/12/83	UP	2	60° 01', 174° 31'W
03/12/83	DL	11	59° 58', 174° 11'W
03/12/83	DL	4	59° 57', 174° 13'W
03/12/83	DL	5	59° 58', 174° 16'W
03/12/83	DL	2	59° 58', 174° 16'W
03/12/83	DL	25	60° 04', 174° 20'W
03/12/83	DL	2	60° 04', 174° 20'W
03/12/83	DL	2	60° 04', 174° 20'W
03/12/83	DL	6	59° 54', 174° 20'W
03/12/83	DL	2	59° 54', 174° 20'W
03/12/83	DL	8	59° 56', 174° 20'W
03/12/83	DL	4	59° 55', 174° 28'W
03/12/83	DL	1	59° 55', 174° 28'W
03/12/83	DL	2	60° 00', 174° 28'W
03/12/83	DL	12	59° 57', 174° 28'W
03/12/83	DL	6	59° 55', 174° 32'W
03/12/83	DL	7	59° 55', 174° 32'W

APPENDIX TABLE A-3 CONT.
RECORD OF PINNIPEDS AND BELUGA WHALES ENCOUNTERED IN THE NAVARIN BASIN DURING THE FOUR SURVEY SEASONS, MAY-JUNE, JULY-AUGUST, OCTOBER-NOVEMBER, 1982 AND FEBRUARY-MARCH 1983

Date	Species[a]	Number[b]	Location
		WINTER SURVEY (Continued)	
03/12/83	DL	6	59° 54', 174° 32'W
03/12/83	DL	6	59° 56', 174° 33'W
03/12/83	DL	2	59° 56', 174° 33'W
03/12/83	DL	3	59° 56', 174° 33'W
03/12/83	DL	1	59° 57', 174° 33'W
03/12/83	DL	3	59° 58', 174° 32'W
03/12/83	DL	3	59° 58', 174° 32'W
03/12/83	DL	6	59° 55', 174° 32'W
03/13/83	PF	4	60° 10', 174° 38'W
03/13/83	PF	1	60° 10', 174° 38'W
03/13/83	PF	3	60° 12', 174° 23'W
03/13/83	OR	1	60° 19', 174° 32'W
03/13/83	OR	2	60° 17', 174° 28'W
03/13/83	UP	2	60° 08', 174° 29'W
03/13/83	OR	1	60° 07', 174° 27'W
03/13/83	OR	1	60° 12', 174° 21'W
03/13/83	EB	1	60° 12', 174° 21'W
03/13/83	OR	23	60° 11', 174° 20'W
03/13/83	OR	37	60° 11', 174° 20'W
03/13/83	OR	2	60° 17', 174° 20'W
03/13/83	OR	16	60° 16', 174° 20'W
03/13/83	OR	12	60° 17', 174° 20'W
03/13/83	OR	2	60° 17', 174° 20'W
03/13/83	PF	3	60° 11', 174° 15'W
03/13/83	OR	12	60° 13', 174° 09'W
03/13/83	OR	11	60° 13', 174° 09'W
03/13/83	OR	4	60° 13', 174° 09'W
03/13/83	OR	3	60° 13', 174° 09'W
03/13/83	PF	1	60° 08', 174° 04'W
03/13/83	OR	42	60° 13', 174° 10'W
03/13/83	OR	4	60° 12', 174° 08'W
03/13/83	OR	6	60° 21', 174° 07'W
03/13/83	OR	1	60° 21', 174° 08'W
03/13/83	OR	35	60° 18', 174° 08'W
03/13/83	OR	38	60° 15', 174° 03'W
03/13/83	OR	7	60° 15', 174° 08'W
03/13/83	OR	99	60° 15', 174° 03'W
03/13/83	OR	3	60° 12', 174° 08'W
03/13/83	OR	23	60° 16', 174° 06'W
03/13/83	OR	36	60° 16', 174° 06'W
03/13/83	OR	22	60° 17', 173° 55'W

APPENDIX TABLE A-3 CONT.
RECORD OF PINNIPEDS AND BELUGA WHALES ENCOUNTERED IN THE NAVARIN BASIN DURING THE FOUR SURVEY SEASONS, MAY-JUNE, JULY-AUGUST, OCTOBER-NOVEMBER, 1982 AND FEBRUARY-MARCH 1983

Date	Species[a]	Number[b]	Location
		WINTER SURVEY (Continued)	
03/13/83	OR	14	60° 17', 173° 55'W
03/13/83	OR	1	60° 16', 173° 52'W
03/13/83	OR	2	60° 17', 173° 45'W
03/13/83	OR	2	60° 16', 174° 01'W
03/13/83	OR	12	60° 16', 174° 01'W
03/13/83	OR	1	60° 16', 173° 58'W
03/13/83	OR	12	60° 16', 173° 55'W
03/13/83	OR	12	60° 17', 173° 53'W
03/13/83	OR	3	60° 17', 173° 53'W
03/13/83	OR	8	60° 20', 173° 35'W
03/13/83	OR	20	60° 19', 173° 20'W
03/13/83	OR	7	60° 20', 173° 20'W
03/13/83	DL	433	60° 19', 174° 22'W
03/14/83	OR	1	60° 35', 173° 44'W
03/14/83	OR	4	60° 35', 173° 44'W
03/14/83	UP	1	60° 26', 173° 40'W
03/14/83	OR	6	60° 40', 173° 41'W
03/14/83	PF	1	60° 38', 173° 53'W
03/14/83	PF	1	60° 38', 173° 53'W
03/14/83	PF	1	60° 38', 173° 53'W
03/14/83	OR	1	60° 26', 173° 49'W
03/14/83	DL	13	60° 44', 173° 50'W
03/14/83	DL	3	60° 44', 173° 50'W
03/14/83	DL	18	60° 44', 173° 50'W
03/14/83	DL	2	60° 44', 173° 50'W
03/15/83	OR	12	60° 01', 173° 20'W
03/15/83	OR	1	59° 59', 173° 20'W
03/15/83	OR	2	59° 53', 173° 25'W
03/15/83	OR	4	59° 58', 173° 32'W
03/15/83	PF	1	59° 47', 173° 48'W
03/15/83	UP	1	59° 49', 174° 08'W
03/15/83	UP	1	59° 47', 174° 08'W
03/15/83	UP	1	59° 37', 174° 20'W
03/15/83	EB	1	59° 46', 174° 26'W
03/15/83	UP	1	59° 35', 174° 42'W
03/15/83	UP	1	59° 36', 174° 47'W
03/15/83	UP	1	59° 36', 174° 52'W
03/16/83	OR	1	60° 43', 175° 22'W
03/16/83	PL	1	60° 26', 176° 02'W
03/16/83	OR	2	60° 25', 176° 03'W

APPENDIX TABLE A-4

CHI-SQUARE ANALYSES OF PINNIPED OCCURRENCE IN SAMPLING UNITS OF THE MARGINAL ICE FRONT

Sampling unit	Distance surveyed (nm)	Proportion of total distance	Walrus				Northern sea lion			
			No. obs.	No. exp.	Prop. obs.	95% confidence interval	No. obs.	No. exp.	Prop. obs.	95% confidence interval
24	147	0.061	25	9.0	0.170	$0.088 \le p \le 0.252$ [a]	3	4.2	0.043	$-0.021 \le p \le 0.107$
25	462	0.192	43	28.2	0.293	$0.194 \le p \le 0.392$ [a]	0	13.2	0.000	[b]
26	613	0.254	64	37.4	0.435	$0.327 \le p \le 0.543$ [a]	8	17.6	0.116	$0.014 \le p \le 0.218$ [b]
27	482	0.200	5	29.4	0.034	$-0.005 \le p \le 0.073$ [b]	10	13.8	0.145	$0.033 \le p \le 0.257$
28	466	0.193	0	28.4	0.000	[b]	36	13.3	0.522	$0.364 \le p \le 0.680$ [a]
29	240	0.100	10	14.6	0.068	$0.013 < p < 0.123$	12	6.9	0.174	$0.054 < p < 0.294$
Total	2410	1.000	147	147.0	1.000	$x^2 = 105.23$	69	69.0	1.000	$x^2 = 62.34$

Sampling unit	Distance surveyed (nm)	Proportion of total distance	Spotted seal				Ribbon seal			
			No. obs.	No. exp.	Prop. obs.	95% confidence interval	No. obs.	No. exp.	Prop. obs.	95% confidence interval
24	147	0.061	2				0	5.5	0.227	$0.027 \le p \le 0.427$
25	462	0.192	1	11.7	0.072	$-0.309 \le p \le 0.175$ [b]	5			
26	613	0.254	4	10.7	0.095	$-0.022 \le p \le 0.212$ [b]	12	5.6	0.546	$0.308 \le p \le 0.784$ [a]
27	482	0.200	4	8.4	0.095	$-0.022 \le p \le 0.212$	3			
28	466	0.193	3	8.1	0.071	$-0.031 \le p \le 0.173$ [b]	2	10.9	0.227	$0.027 \le p \le 0.427$ [b]
29	240	0.100	28	4.1	0.667	$0.479 < p < 0.855$ [a]	0			
Total	2410	1.000	42	42.0	1.000	$x^2 = 155.39$	22	22.0	1.000	$x^2 = 10.55$

a/ Significant preference.

b/ Significant avoidance.

APPENDIX TABLE A-5

CHI-SQUARE ANALYSIS OF PACIFIC WALRUS OCCURRENCE IN DIFFERENT ICE CONCENTRATION, SIZE, AND THICKNESS CATEGORIES

Ice Concentration Category	Area (nm^2)	Proportion of total area	Number observed	Number expected	Proportion observed	95% confidence interval
0-20	53	0.045	0	4	0.000	
21-40	62	0.051	11	4	0.132	$0.039 \le p \le 0.225$ (0-20 and 21-40 combined)
41-60	208	0.173	10	14	0.121	$0.032 \le p \le 0.210$
61-80	357	0.296	26	25	0.313	$0.186 \le p \le 0.440$
81-100	525	0.436	36	36	0.434	$0.298 \le p \le 0.570$
Total	1205	1.000	83	83	1.000	$x^2 = 2.31$

Ice Size Category	Area (nm^2)	Proportion of total area	Number observed	Number expected	Proportion observed	95% confidence interval
Grease-slush	91	0.100	30	8	0.361	$0.230 \le p \le 0.493$ [a]
Pan-small	192	0.210	4	18	0.048	$-0.011 \le p \le 0.107$ [b]
Med-large	159	0.174	4	15	0.048	$-0.011 \le p \le 0.107$ [b]
Vast-giant	472	0.516	45	42	0.542	$0.406 \le p \le 0.679$
Total	914	1.000	83	83	1.000	$x^2 = 79.67$

Ice Thickness Category	Area (nm^2)	Proportion of total area	Number observed	Number expected	Proportion observed	95% confidence interval
New (<10 cm)	142	0.118	25	10	0.301	$0.180 \le p \le 0.422$ [a]
Young (10-30cm)	468	0.388	28	32	0.338	$0.214 \le p \le 0.462$
First year (>30 cm)	595	0.494	30	41	0.361	$0.235 \le p \le 0.487$ [b]
Total	1205	1.000	83	83	1.000	$x^2 = 25.95$

[a] Significant preference.
[b] Significant avoidance.

APPENDIX TABLE A-6

CHI-SQUARE ANALYSIS OF NORTHERN SEA LION OCCURRENCE IN DIFFERENT ICE CONCENTRATION, SIZE, AND THICKNESS CATEGORIES

Ice Concentration Category	Area (nm^2)	Proportion of total area	Number observed	Number expected	Proportion observed	95% confidence interval
0-20	53	0.045	2	1	0.083	
21-40	62	0.051	5	1	0.208	$0.298 \leq p \leq 0.785$ a/
41-60	208	0.173	6	4	0.250	
61-80	357	0.294	9	7	0.375	$0.138 < p < 0.612$
81-100	525	0.437	2	11	0.083	$-0.052 < p < 0.218$ b/
Total	1205	1.000	24	24	1.000	$x^2 = 16.10$

Ice Size Category	Area (nm^2)	Proportion of total area	Number observed	Number expected	Proportion observed	95% confidence interval
Grease-slush	91	0.100	2	3	0.083	
Pan-small	192	0.210	16	5	0.667	$0.552 \leq p \leq 0.948$ a/
Med-large	159	0.174	2	4	0.083	
Vast-giant	472	0.516	4	12	0.167	$0.052 < p < 0.448$ b/
Total	914	1.000	24	24	1.000	$x^2 = 18.75$

Ice Thickness Category	Area (nm^2)	Proportion of total area	Number observed	Number expected	Proportion observed	95% confidence interval
New (<10 cm)	142	0.118	1	3	0.042	$0.154 \leq p \leq 0.596$
Young (10-30cm)	468	0.388	8	9	0.333	
First year (>30 cm)	595	0.494	15	12	0.625	$0.404 < p < 0.846$
Total	1205	1.000	24	24	1.000	$x^2 = 1.50$

a/ Significant preference.
b/ Significant avoidance.

APPENDIX TABLE A-7

CHI-SQUARE ANALYSIS OF SPOTTED SEAL OCCURRENCE IN DIFFERENT ICE CONCENTRATION, SIZE, AND THICKNESS CATEGORIES

Ice Concentration Category	Area (nm^2)	Proportion of total area	Number observed	Number expected	Proportion observed	95% confidence interval
0-20	53	0.045	0	1	0.000	
21-40	62	0.051	11	1	0.380	$0.296 \leq p \leq 0.740$[a]
41-60	208	0.173	4	5	0.138	
61-80	357	0.294	7	9	0.241	$0.024 \leq p \leq 0.431$
81-100	525	0.437	7	13	0.241	$0.024 \leq p \leq 0.431$[b]
Total	1205	1.000	29	29	1.000	$x^2 = 12.36$

Ice Size Category	Area (nm^2)	Proportion of total area	Number observed	Number expected	Proportion observed	95% confidence interval
Grease-slush	91	0.100	1	3	0.034	
Pan-small	192	0.210	13	6	0.448	$0.260 \leq p \leq 0.705$
Med-large	159	0.174	2	5	0.069	$-0.044 \leq p \leq 0.182$
Vast-giant	472	0.516	13	15	0.448	$0.227 \leq p \leq 0.670$
Total	914	1.000	29	29	1.000	$x^2 = 4.84$

Ice Thickness Category	Area (nm^2)	Proportion of total area	Number observed	Number expected	Proportion observed	95% confidence interval
New (<10 cm)	142	0.118	1	4	0.035	$0.038 \leq p \leq 0.376$[b]
Young (10-30cm)	468	0.388	5	11	0.172	
First year (>30 cm)	595	0.494	23	14	0.793	$0.624 < p < 0.962$[a]
Total	1205	1.000	29	29	1.000	$x^2 = 11.19$

a/ Significant preference.
b/ Significant avoidance.

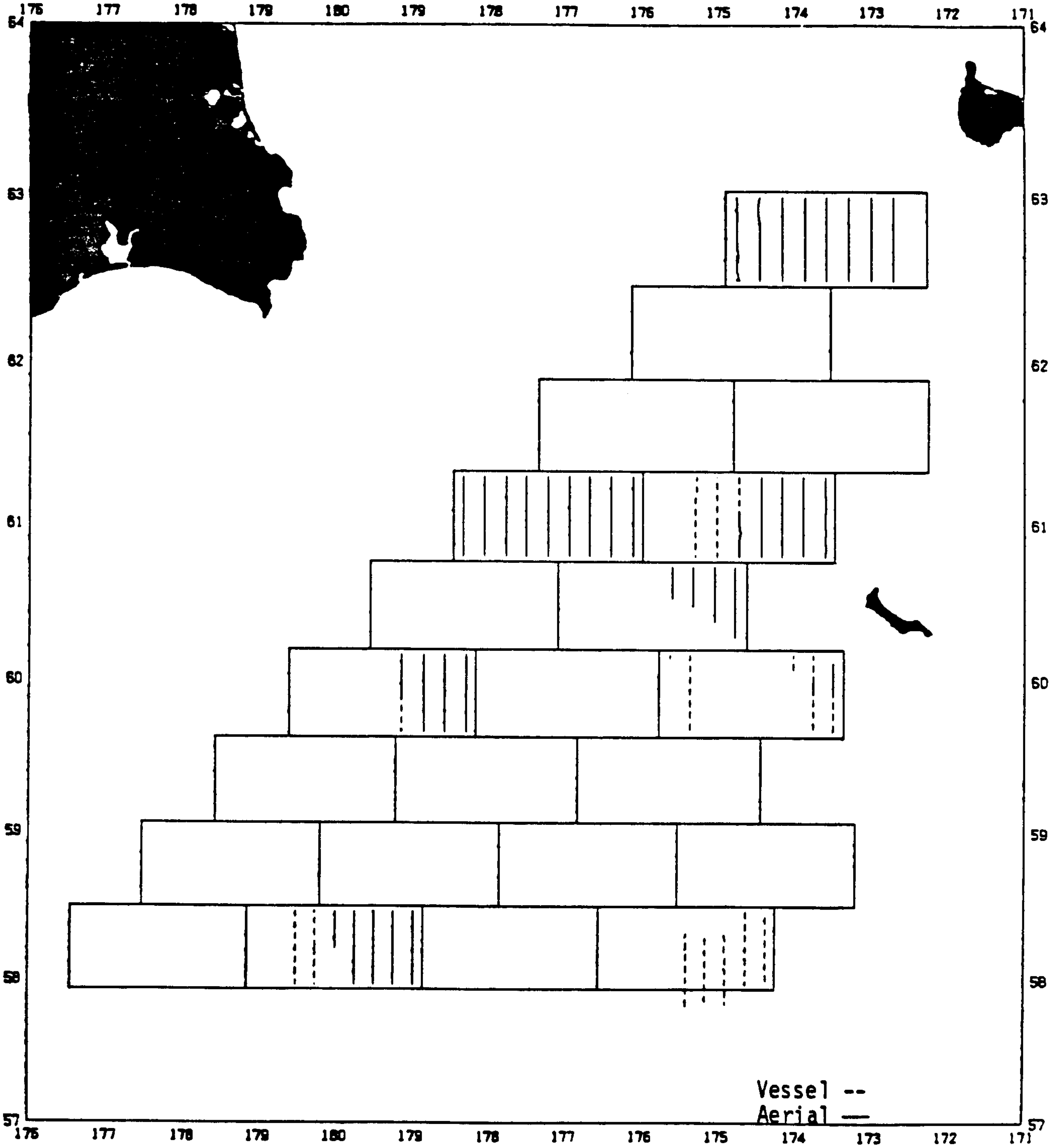

FIGURE A-1 LOCATION OF AERIAL AND VESSEL TRACKLINES SURVEYED IN THE NAVARIN BASIN DURING SPRING, MAY - JUNE, 1982.

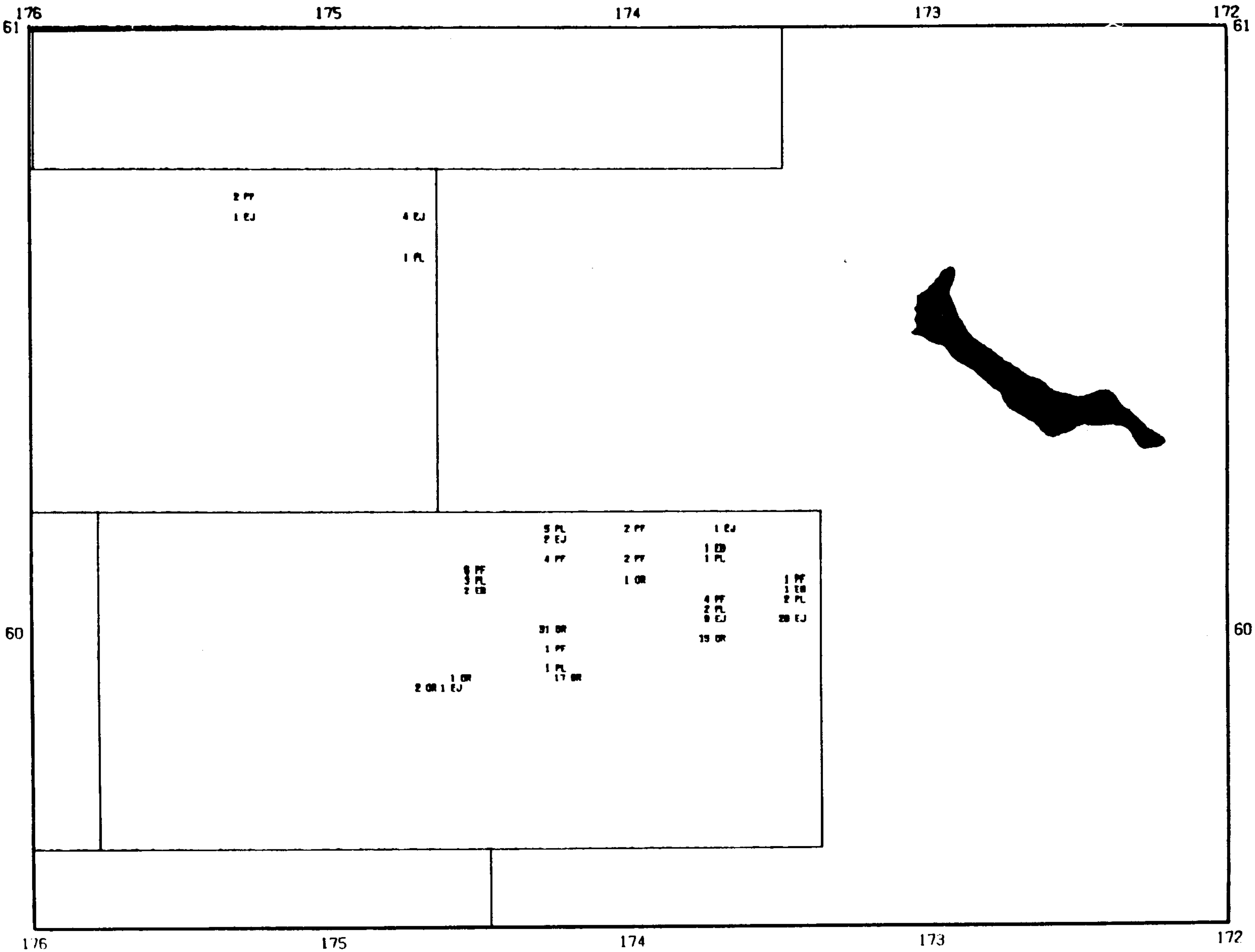

FIGURE A-2 **LOCATION OF PINNIPEDS OBSERVED IN THE NAVARIN BASIN DURING THE SPRING SURVEY, MAY-JUNE 1982. (Abbreviations are defined in Appendix Table).**

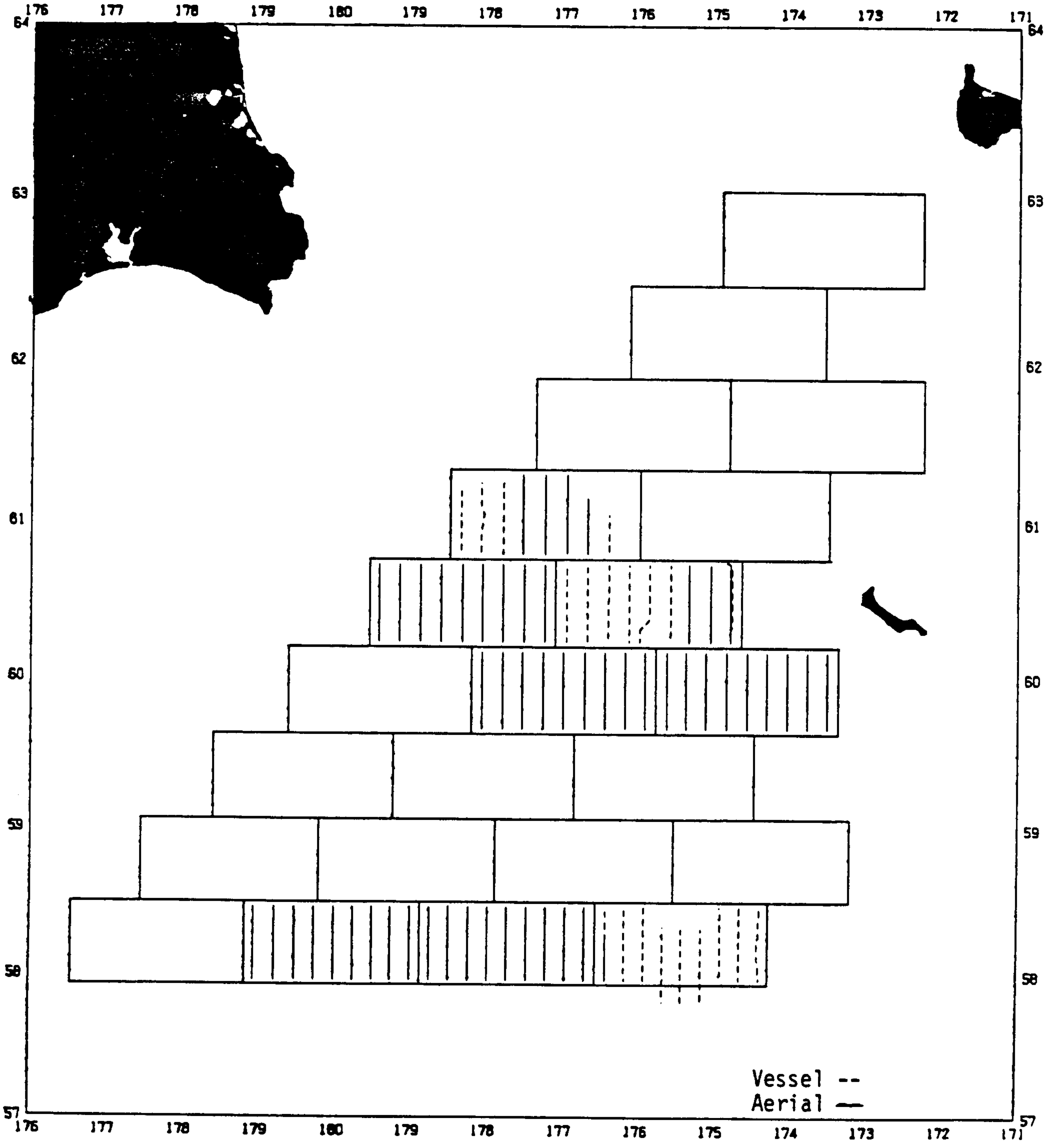

FIGURE A-3 **LOCATION OF AERIAL AND VESSEL TRACKLINES SURVEYED IN THE NAVARIN BASIN DURING SUMMER, JULY - AUGUST, 1982.**

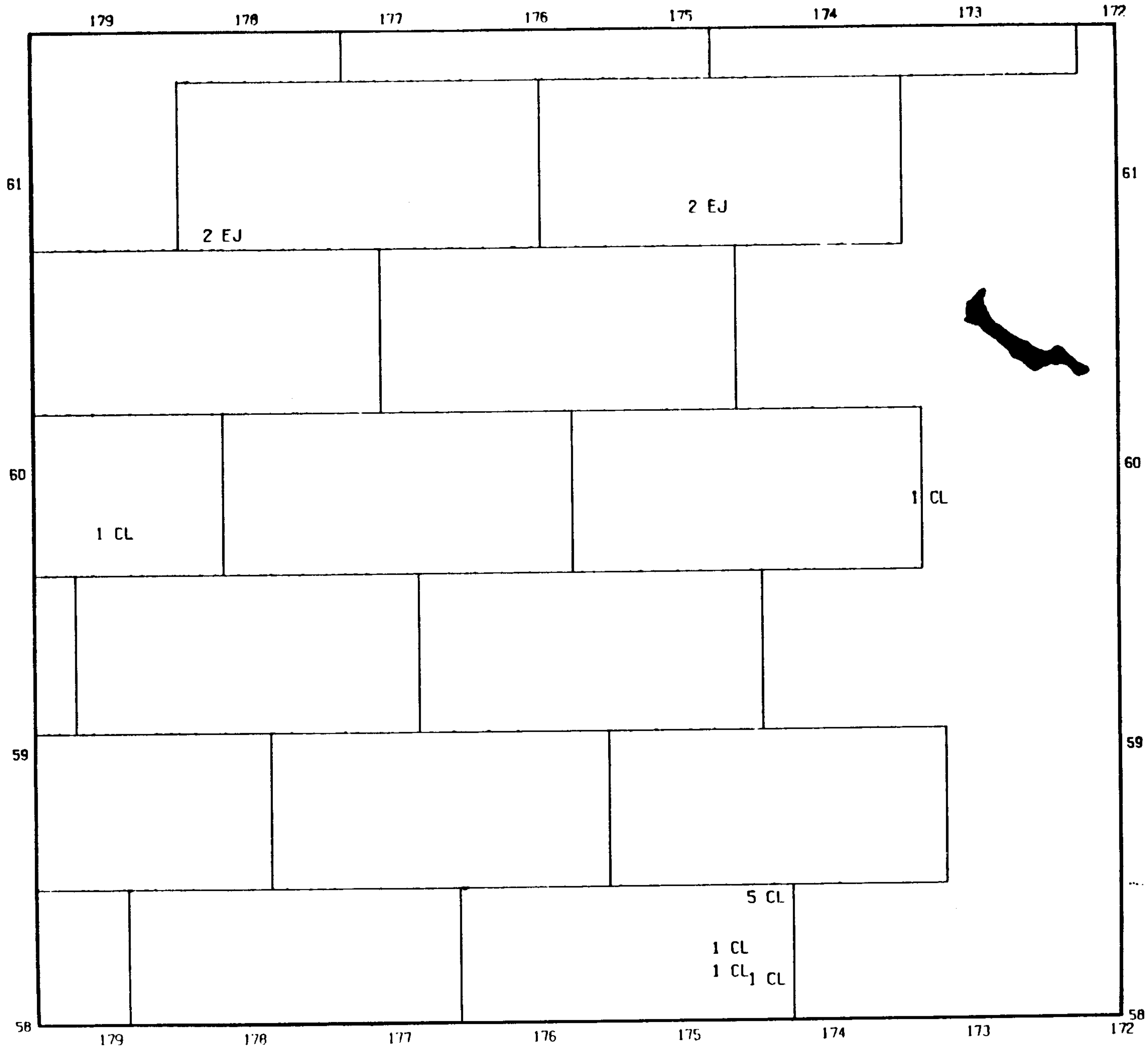

FIGURE A-4 **LOCATION OF PINNIPEDS OBSERVED IN THE NAVARIN BASIN DURING THE SUMMER SURVEYS, JULY–AUGUST 1982. (Abbreviations are defined in Appendix Table).**

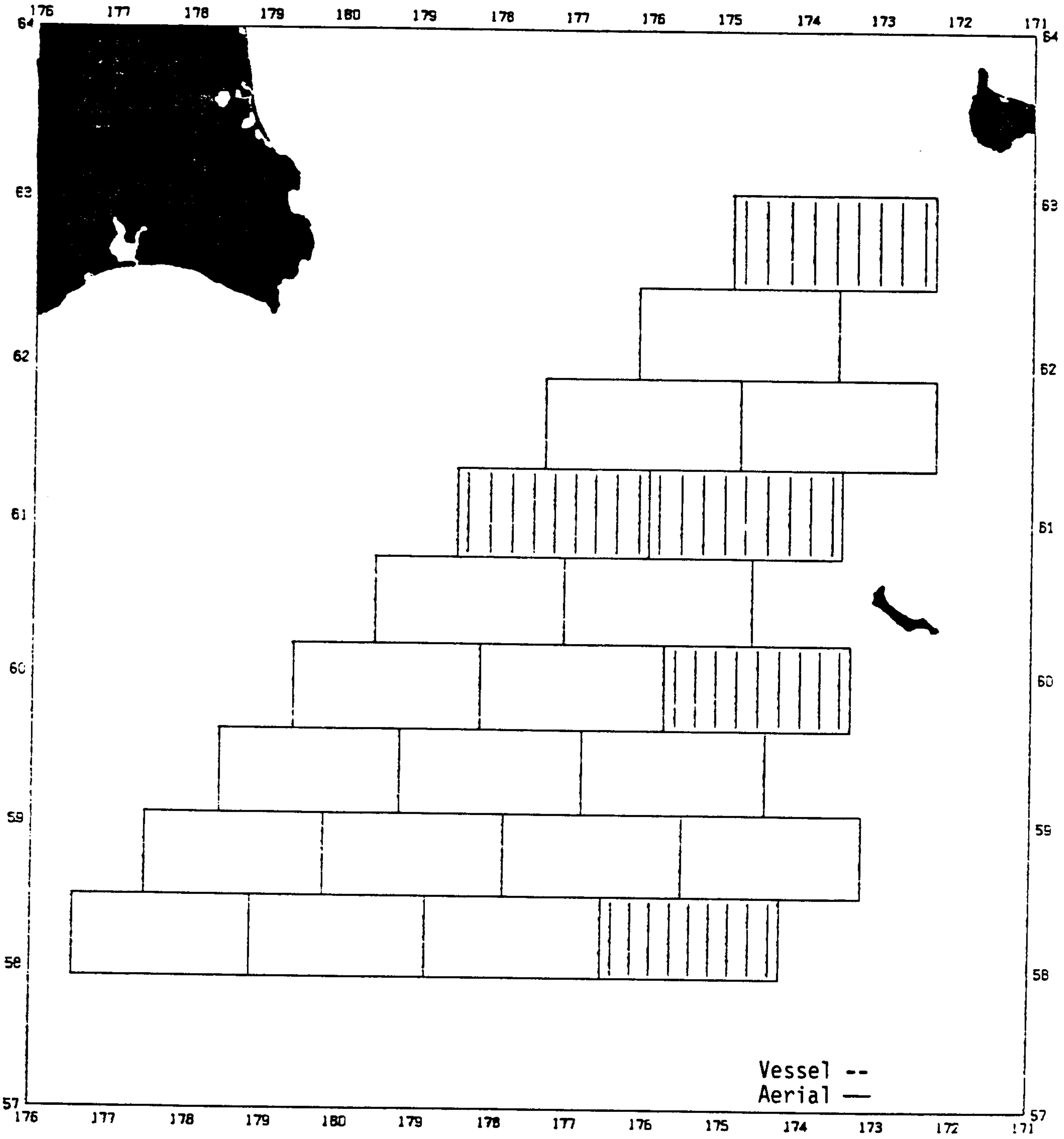

FIGURE A-5 **LOCATION OF AERIAL AND VESSEL TRACKLINES SURVEYED IN THE NAVARIN BASIN DURING FALL, OCTOBER – NOVEMBER, 1982.**

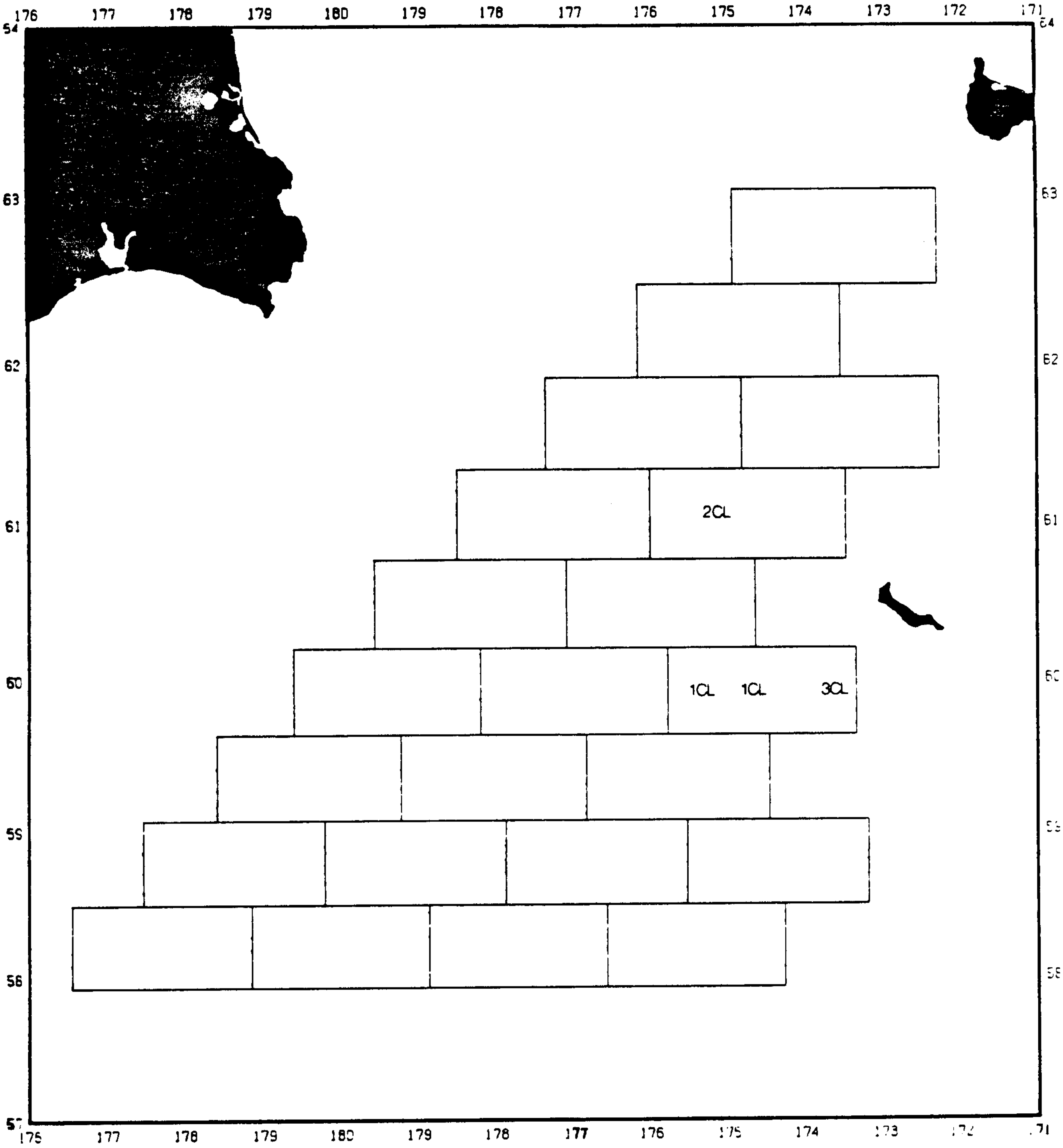

FIGURE A-6 **LOCATION OF PINNIPEDS OBSERVED IN THE NAVARIN BASIN DURING THE FALL SURVEYS, OCTOBER-NOVEMBER 1982. (Abbreviations are defined in Appendix Table).**

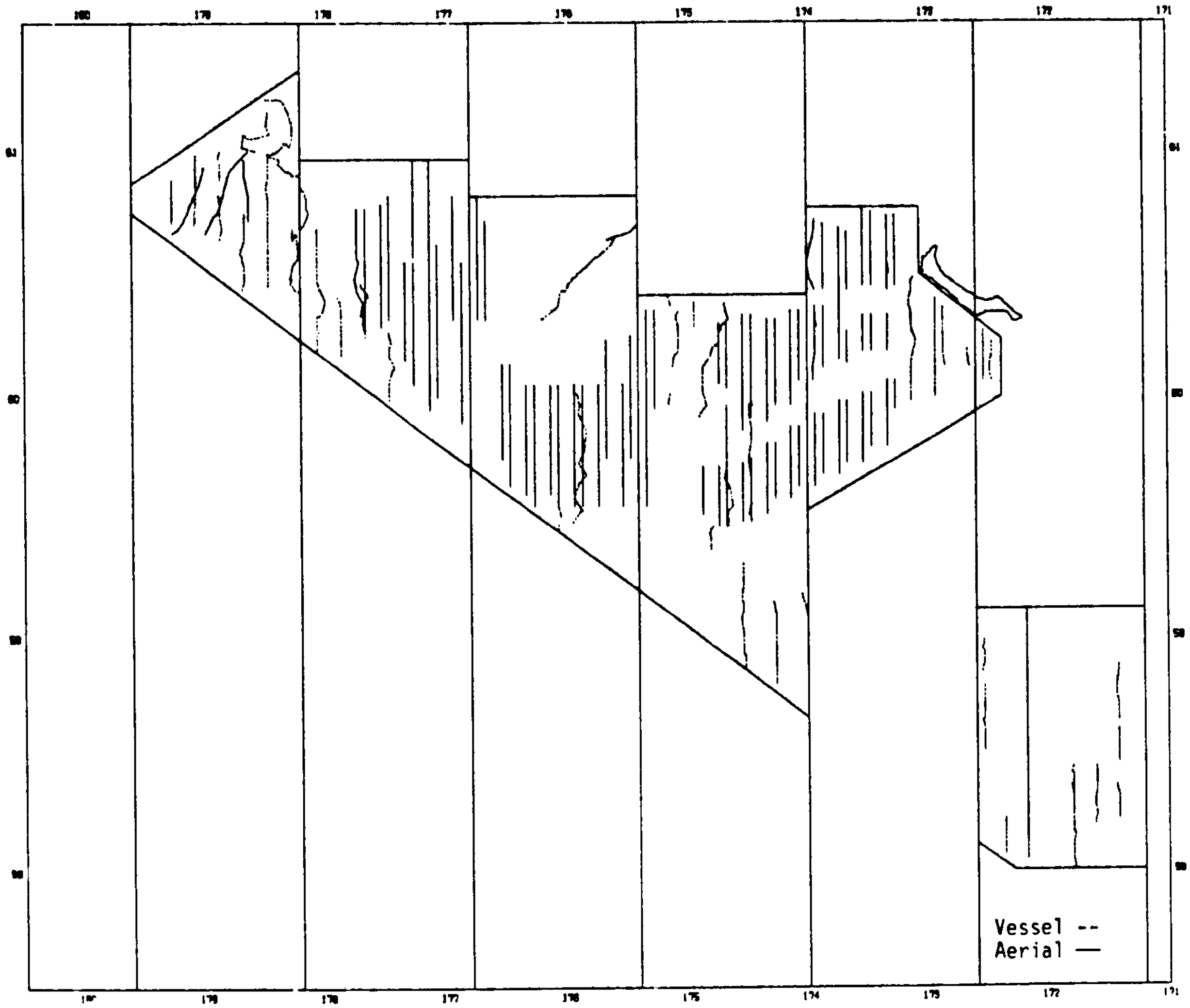

FIGURE A-7 **LOCATION OF AERIAL AND VESSEL TRACKLINES SURVEYED IN THE NAVARIN BASIN DURING WINTER, FEBRUARY - MARCH, 1983.**

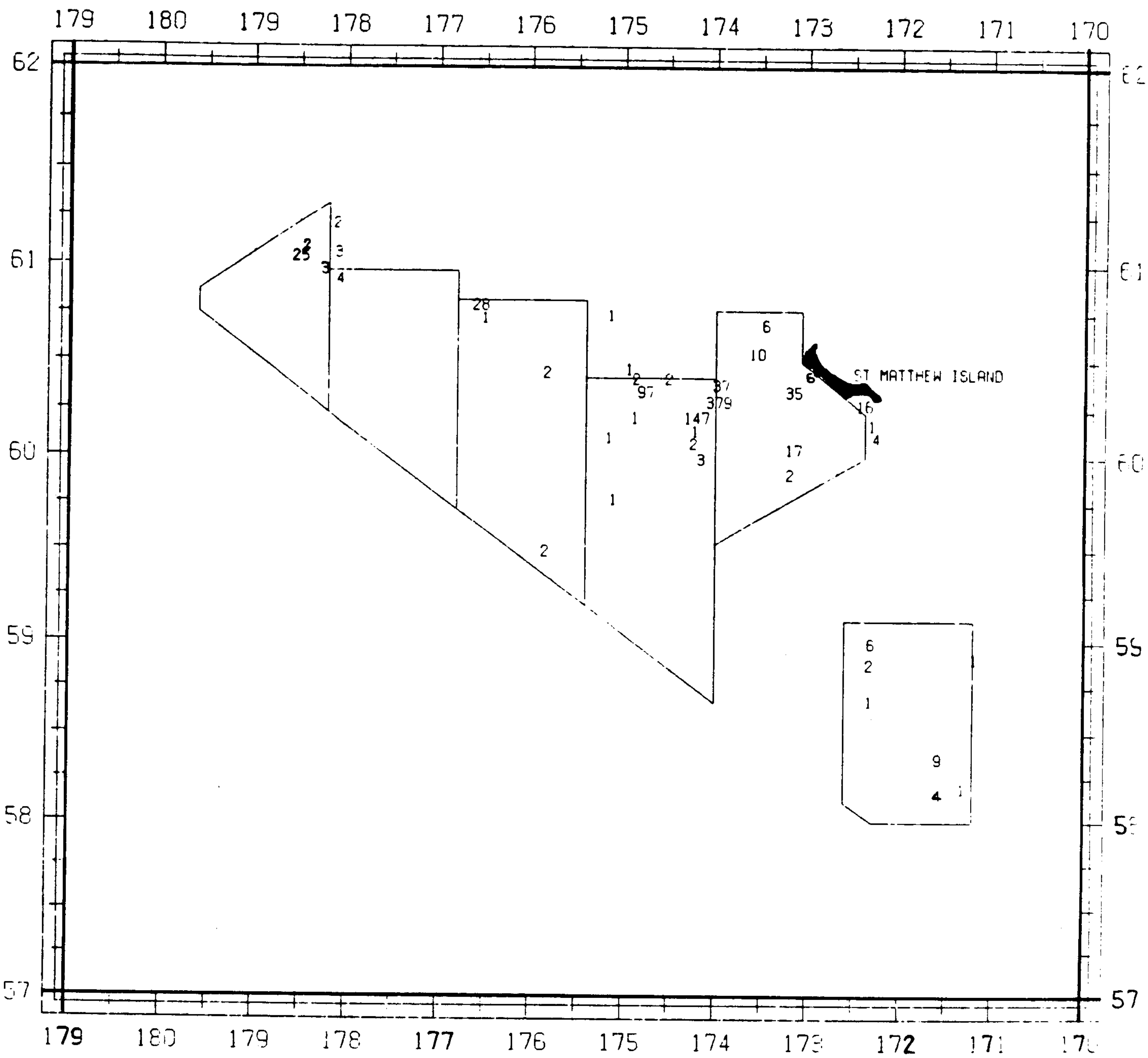

FIGURE A-8 **LOCATION OF WALRUSES OBSERVED IN THE NAVARIN BASIN DURING THE WINTER SURVEYS, FEBRUARY-MARCH 1983**

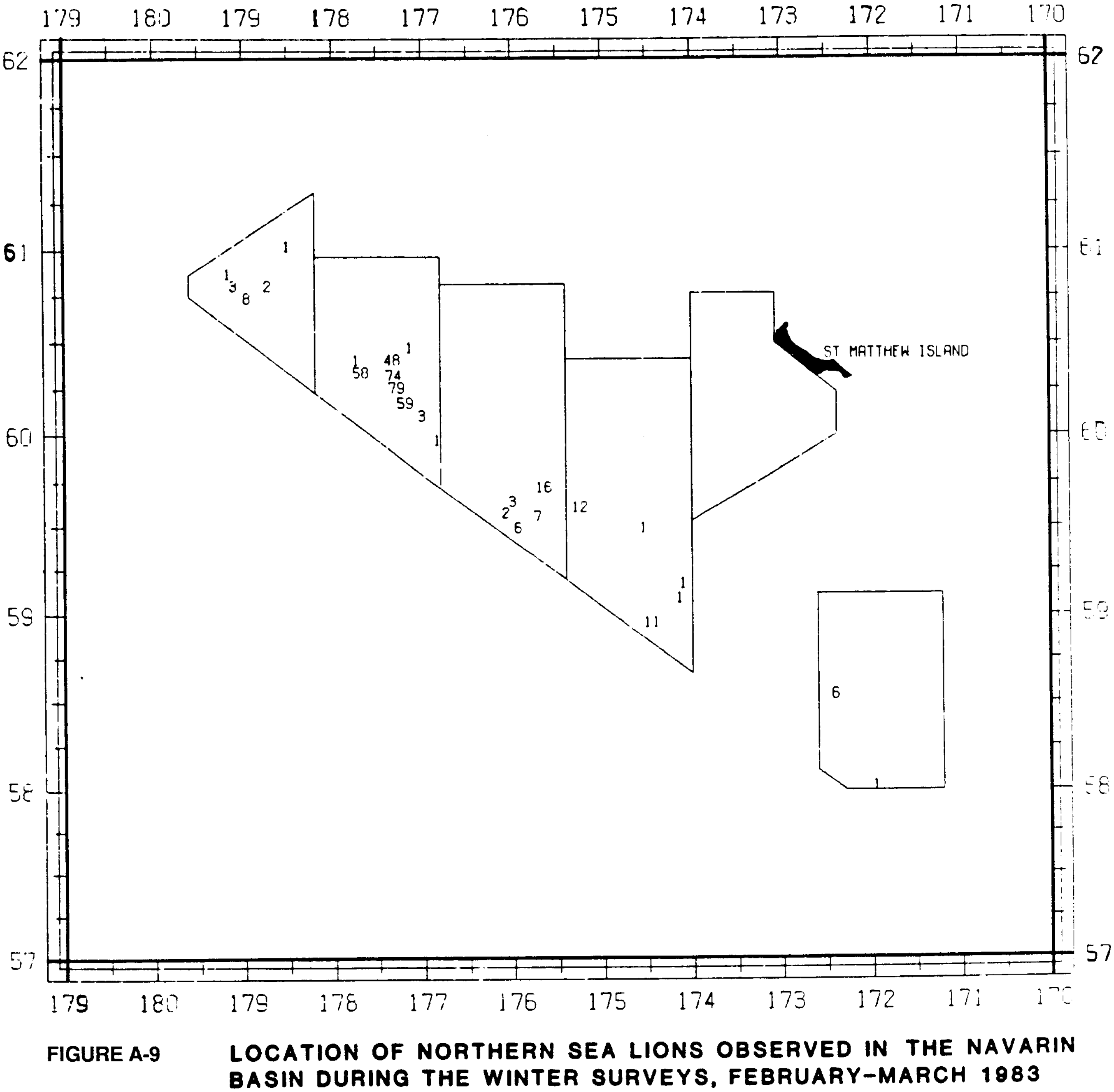

FIGURE A-9 **LOCATION OF NORTHERN SEA LIONS OBSERVED IN THE NAVARIN BASIN DURING THE WINTER SURVEYS, FEBRUARY-MARCH 1983**

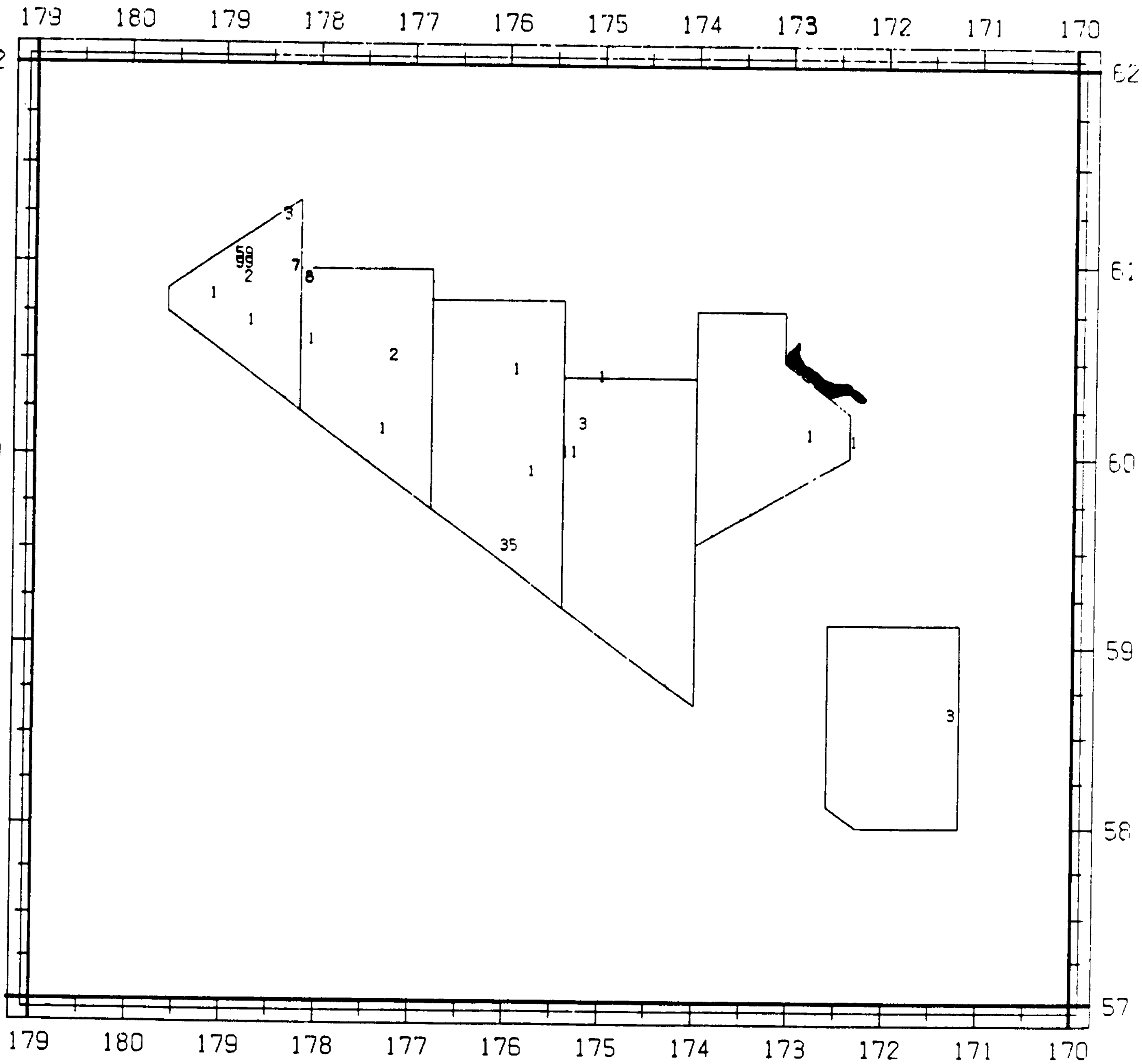

FIGURE A-10 **LOCATION OF SPOTTED SEALS OBSERVED IN THE NAVARIN BASIN DURING THE WINTER SURVEYS, FEBRUARY-MARCH 1983.**

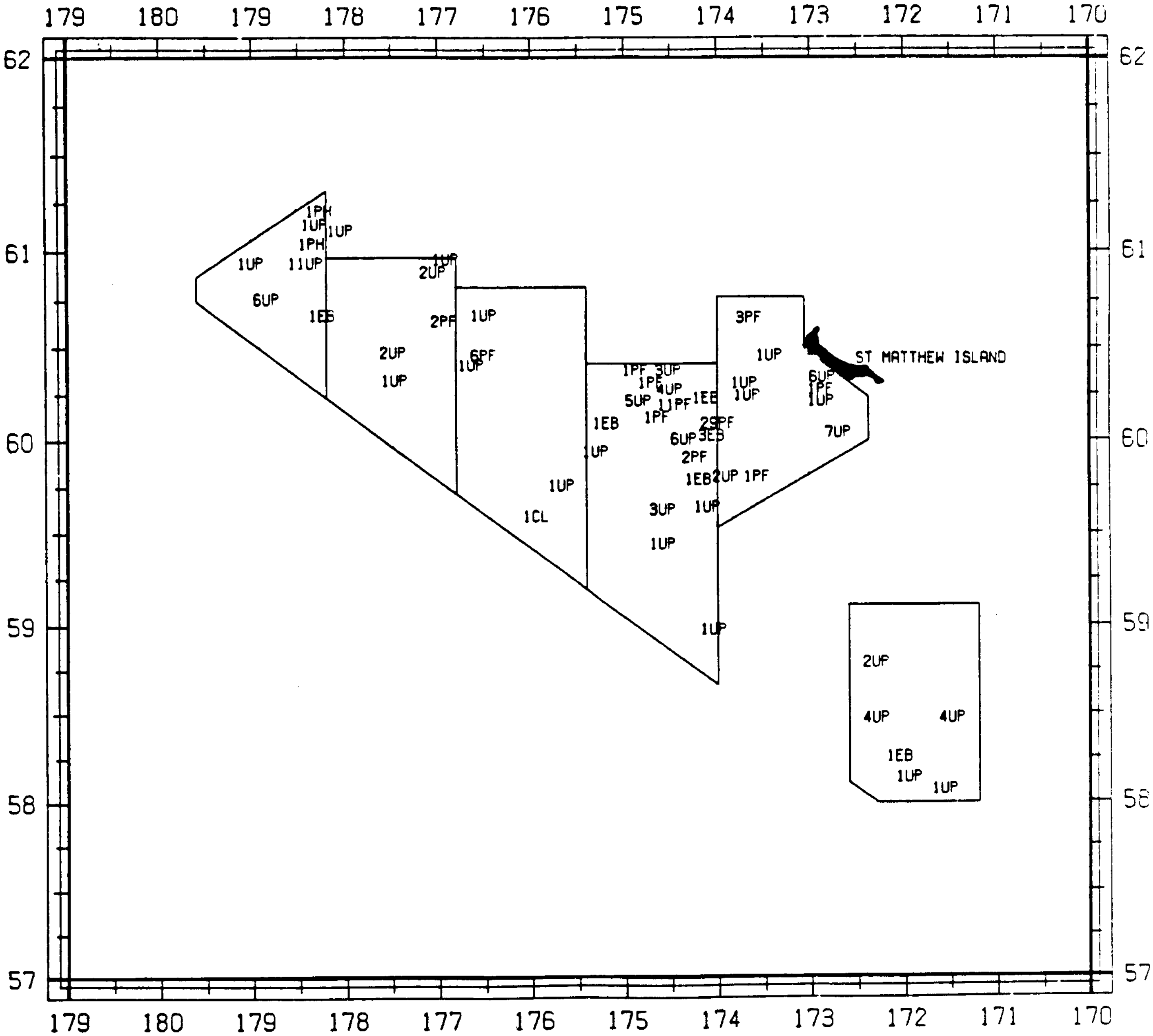

FIGURE A-11 **LOCATIONS OF BEARDED(EB), FUR(CL), RIBBON(PF), AND RINGED(PH) SEALS AND UNIDENTIFIED PINNIPEDS(UP) OBSERVED IN THE NAVARIN BASIN DURING WINTER, FEBRUARY-MARCH 1983**

APPENDIX B

1979 SUPPLEMENTAL TABLES AND FIGURES

APPENDIX B

APPENDIX TABLE B-1
RECORD OF PINNIPEDS AND BELUGA WHALES ENCOUNTERED IN THE PACK ICE OF THE BERING SEA DURING EARLY SPRING, MARCH-APRIL 1979.

Date	Species	Number	Location
3/5/79	DL	15	62°25', 176°30'W
3/5/79	DL	23	62°23', 176°35'W
3/5/79	DL	50	62°23', 176°35'W
3/5/79	DL	4	62°23', 176°35'W
3/5/79	DL	5	62°23', 176°35'W
3/5/79	DL	15	62°23', 176°35'W
3/5/79	DL	120	62°23', 176°35'W
3/5/79	DL	10	62°23', 176°35'W
3/5/79	DL	5	62°23', 176°35'W
3/5/79	DL	25	62°23', 176°36'W
3/5/79	DL	6	62°22', 176°36'W
3/5/79	DL	1	62°22', 176°36'W
3/5/79	DL	46	62°22', 176°36'W
3/5/79	DL	123	62°22', 176°36'W
3/5/79	DL	28	62°21', 176°34'W
3/5/79	DL	14	62°21', 176°34'W
3/5/79	DL	120	62°20', 176°31'W
3/5/79	DL	11	62°19', 176°27'W
3/5/79	DL	15	62°21', 176°39'W
3/5/79	DL	2	62°18', 176°43'W
3/5/79	DL	3	62°18', 176°45'W
3/5/79	DL	7	62°18', 176°45'W
3/5/79	DL	1	62°18', 176°37'W
3/5/79	DL	1	62°19', 176°37'W
3/5/79	DL	49	62°21', 176°34'W
3/5/79	DL	42	62°21', 176°34'W
3/5/79	DL	20	62°21', 176°36'W
3/5/79	DL	6	62°21', 176°36'W
3/5/79	DL	10	62°21', 176°36'W
3/5/79	DL	30	62°21', 176°36'W
3/5/79	DL	1	62°22', 176°31'W
3/5/79	DL	35	62°22', 176°30'W
3/5/79	DL	25	62°22', 176°30'W

APPENDIX TABLE B-1 CONT.
RECORD OF PINNIPEDS AND BELUGA
WHALES ENCOUNTERED IN THE PACK ICE OF
THE BERING SEA DURING EARLY SPRING,
MARCH-APRIL 1979.

Date	Species	Number	Location
3/ 7/79	UP	1	61°38', 176°50'W
3/ 7/79	OR	55	61°46', 176°45'W
3/ 7/79	OR	3	61°48', 176°45'W
3/ 7/79	OR	2	61°48', 176°45'W
3/ 7/79	OR	2	61°49', 176°44'W
3/ 7/79	OR	1	61°47', 176°40'W
3/ 7/79	OR	30	61°41', 176°42'W
3/ 7/79	OR	50	61°41', 176°42'W
3/ 7/79	OR	3	61°30', 176°41'W
3/ 7/79	OR	7	61°22', 176°41'W
3/ 7/79	OR	10	61°44', 176°18'W
3/ 7/79	OR	10	61°37', 176°24'W
3/ 7/79	OR	1	61°37', 176°24'W
3/ 7/79	OR	1	61°37', 176°24'W
3/ 7/79	OR	1	61°37', 176°32'W
3/ 7/79	OR	99	61°39', 176°32'W
3/ 7/79	OR	51	61°39', 176°32'W
3/ 7/79	OR	99	61°42', 176°33'W
3/ 7/79	OR	99	61°42', 176°33'W
3/ 7/79	OR	82	61°42', 176°33'W
3/ 7/79	OR	1	61°45', 176°34'W
3/ 7/79	UP	1	61°48', 176°34'W
3/ 7/79	OR	1	61°48', 176°34'W
3/ 7/79	OR	1	61°47', 176°31'W
3/ 7/79	OR	4	61°47', 176°31'W
3/ 7/79	OR	3	61°47', 176°29'W
3/ 7/79	OR	1	61°47', 176°26'W
3/ 7/79	OR	1	61°47', 176°26'W
3/ 7/79	OR	3	61°45', 176°26'W
3/ 7/79	OR	6	61°45', 176°26'W
3/ 7/79	OR	1	61°30', 176°18'W
3/ 7/79	OR	2	61°36', 176°17'W
3/ 7/79	OR	15	61°40', 176°16'W
3/ 7/79	OR	99	61°39', 176° 8'W
3/ 7/79	OR	51	61°39', 176° 8'W
3/ 7/79	UP	1	61°37', 176° 8'W
3/ 7/79	OR	1	61°37', 176° 8'W
3/ 7/79	OR	99	61°35', 176° 8'W
3/ 7/79	OR	1	61°35', 176° 8'W
3/ 7/79	OR	99	61°33', 176° 8'W
3/ 7/79	OR	26	61°33', 176° 8'W
3/ 7/79	OR	30	61°32', 176° 8'W

APPENDIX TABLE B-1 CONT.
RECORD OF PINNIPEDS AND BELUGA
WHALES ENCOUNTERED IN THE PACK ICE OF
THE BERING SEA DURING EARLY SPRING,
MARCH-APRIL 1979.

Date	Species	Number	Location
3/ 7/79	OR	1	61°28', 176° 8'W
3/ 7/79	UP	1	61°23', 176° 9'W
3/ 7/79	UP	1	61°22', 176° 9'W
3/ 7/79	OR	4	61°20', 176° 9'W
3/ 7/79	OR	3	61°18', 176°10'W
3/ 7/79	OR	1	61°17', 176° 2'W
3/ 7/79	OR	2	61°17', 176° 2'W
3/ 7/79	OR	1	61°16', 175°56'W
3/12/79	PF	1	61°49', 178° 6'W
3/12/79	UP	1	61°53', 177°50'W
3/13/79	OR	3	61°41', 177°45'W
3/13/79	OR	2	61°41', 177°29'W
3/13/79	OR	20	61°41', 177°27'W
3/13/79	OR	99	61°41', 177°24'W
3/13/79	OR	1	61°41', 177°24'W
3/13/79	OR	10	61°41', 177°24'W
3/13/79	OR	3	61°38', 177°22'W
3/13/79	UP	3	61°18', 177°23'W
3/13/79	PL	3	61°16', 177°23'W
3/13/79	PL	1	61°16', 177°23'W
3/13/79	UP	3	61°16', 177°23'W
3/13/79	UP	3	61°14', 177°22'W
3/13/79	OR	10	61°34', 177°31'W
3/13/79	OR	5	61°35', 177°38'W
3/13/79	OR	2	61°35', 177°38'W
3/13/79	OR	15	61°35', 177°38'W
3/13/79	OR	5	61°35', 177°38'W
3/13/79	OR	10	61°35', 177°38'W
3/13/79	OR	5	61°35', 177°38'W
3/13/79	OR	10	61°34', 177°39'W
3/13/79	OR	4	61°34', 177°39'W
3/13/79	OR	45	61°36', 177°49'W
3/13/79	OR	5	61°36', 177°49'W
3/13/79	OR	15	61°40', 177°55'W
3/14/79	UP	1	60°50', 175°46'W
3/14/79	PF	1	60°50', 175°46'W
3/14/79	OR	1	60°52', 175°46'W
3/14/79	UP	1	60°55', 175°48'W
3/14/79	PF	1	60°56', 175°24'W
3/14/79	OR	1	60°54', 175°12'W
3/15/79	UP	1	60°42', 174°47'W
3/15/79	OR	2	60°40', 174°48'W
3/15/79	OR	4	60°39', 174°49'W
3/15/79	UP	1	60°37', 175° 8'W

APPENDIX TABLE B-1 CONT.
RECORD OF PINNIPEDS AND BELUGA
WHALES ENCOUNTERED IN THE PACK ICE OF
THE BERING SEA DURING EARLY SPRING,
MARCH-APRIL 1979.

Date	Species	Number	Location
3/15/79	OR	5	60°42', 175° 7'W
3/15/79	OR	15	60°43', 175° 7'W
3/15/79	OR	2	60°44', 175° 7'W
3/15/79	OR	2	60°46', 175° 7'W
3/15/79	OR	2	60°46', 175° 7'W
3/15/79	OR	3	60°46', 175° 7'W
3/15/79	OR	3	60°48', 175° 7'W
3/15/79	OR	3	60°49', 175° 7'W
3/15/79	OR	1	60°49', 175° 7'W
3/15/79	UP	1	60°49', 175° 7'W
3/15/79	OR	1	60°52', 175° 8'W
3/15/79	OR	1	61° 4', 175°10'W
3/15/79	EB	1	61° 6', 175°10'W
3/15/79	PF	1	61° 0', 174°59'W
3/15/79	OR	25	61° 0', 174°59'W
3/15/79	PF	1	61° 0', 174°59'W
3/15/79	OR	15	60°51', 175° 0'W
3/15/79	OR	1	60°49', 174°59'W
3/15/79	OR	2	60°48', 174°58'W
3/15/79	OR	1	60°46', 174°58'W
3/15/79	OR	15	60°46', 174°58'W
3/15/79	OR	2	60°46', 174°58'W
3/15/79	OR	1	60°44', 174°57'W
3/15/79	OR	20	60°42', 174°57'W
3/15/79	OR	10	60°40', 174°57'W
3/15/79	OR	5	60°40', 174°57'W
3/15/79	OR	6	60°40', 174°52'W
3/15/79	OR	2	60°45', 174°52'W
3/15/79	OR	6	60°50', 174°52'W
3/15/79	OR	1	60°50', 174°52'W
3/15/79	OR	2	60°50', 174°52'W
3/15/79	OR	1	60°50', 174°52'W
3/15/79	OR	8	60°51', 174°52'W
3/15/79	OR	2	60°53', 174°53'W
3/15/79	OR	3	60°55', 174°53'W
3/15/79	OR	3	60°55', 174°53'W
3/15/79	OR	2	60°57', 174°53'W
3/15/79	OR	2	60°57', 174°53'W
3/15/79	OR	1	60°57', 174°53'W
3/15/79	OR	7	60°58', 174°53'W
3/15/79	OR	1	60°59', 174°53'W
3/15/79	OR	1	60°59', 174°53'W
3/15/79	PF	1	61° 0', 174°53'W
3/15/79	UP	1	61° 4', 174°54'W

APPENDIX TABLE B-1 CONT.
RECORD OF PINNIPEDS AND BELUGA
WHALES ENCOUNTERED IN THE PACK ICE OF
THE BERING SEA DURING EARLY SPRING,
MARCH-APRIL 1979.

Date	Species	Number	Location
3/15/79	EJ	2	61°10', 174°47'W
3/15/79	UP	1	61°10', 174°42'W
3/15/79	OR	2	60°58', 174°42'W
3/15/79	OR	2	60°54', 174°43'W
3/15/79	OR	2	60°54', 174°43'W
3/15/79	OR	4	60°51', 174°45'W
3/15/79	OR	3	60°48', 174°43'W
3/15/79	EB	1	60°48', 174°42'W
3/15/79	EB	1	60°49', 174°40'W
3/15/79	OR	1	60°45', 174°43'W
3/15/79	OR	3	60°45', 174°43'W
3/15/79	OR	2	60°41', 174°44'W
3/15/79	OR	6	60°41', 174°44'W
3/15/79	OR	3	60°41', 174°44'W
3/15/79	OR	8	60°41', 174°44'W
3/15/79	OR	7	60°41', 174°44'W
3/15/79	OR	5	60°40', 174°43'W
3/15/79	OR	5	60°40', 174°43'W
3/15/79	OR	5	60°40', 174°43'W
3/15/79	OR	10	60°40', 174°43'W
3/15/79	OR	2	60°40', 174°43'W
3/15/79	OR	10	60°40', 174°43'W
3/15/79	OR	3	60°38', 174°42'W
3/15/79	OR	2	60°38', 174°42'W
3/15/79	OR	3	60°38', 174°42'W
3/15/79	OR	5	60°34', 174°40'W
3/15/79	OR	5	60°34', 174°40'W
3/15/79	OR	5	60°34', 174°40'W
3/15/79	OR	10	60°34', 174°40'W
3/15/79	OR	2	60°34', 174°40'W
3/15/79	OR	2	60°37', 174°36'W
3/15/79	OR	50	60°40', 174°35'W
3/15/79	OR	1	60°40', 174°35'W
3/15/79	OR	2	60°40', 174°35'W
3/15/79	OR	1	60°40', 174°35'W
3/15/79	OR	1	60°42', 174°35'W
3/15/79	OR	2	60°52', 174°34'W
3/15/79	OR	2	60°52', 174°34'W
3/15/79	EB	1	61° 7', 174°26'W
3/15/79	PF	1	61° 4', 174°25'W
3/15/79	UP	1	60°58', 174°27'W
3/15/79	OR	2	60°53', 174°26'W
3/15/79	OR	1	60°52', 174°26'W

APPENDIX TABLE B-1 CONT.
RECORD OF PINNIPEDS AND BELUGA
WHALES ENCOUNTERED IN THE PACK ICE OF
THE BERING SEA DURING EARLY SPRING,
MARCH-APRIL 1979.

Date	Species	Number	Location
3/15/79	OR	1	60°41', 174°26'W
3/15/79	OR	1	60°41', 174°26'W
3/15/79	OR	1	60°41', 174°26'W
3/15/79	OR	1	60°41', 174°26'W
3/15/79	OR	6	60°39', 174°22'W
3/15/79	OR	1	60°39', 174°22'W
3/15/79	OR	1	60°40', 174°19'W
3/15/79	OR	1	60°45', 174°18'W
3/15/79	OR	3	60°46', 174°18'W
3/15/79	PF	1	61° 0', 174°19'W
3/15/79	UP	1	60°46', 174°10'W
3/15/79	OR	1	60°40', 174° 9'W
3/18/79	OR	2	60°38', 173°13'W
3/18/79	OR	1	60°38', 173°11'W
3/18/79	OR	1	60°46', 173°10'W
3/18/79	OR	8	60°51', 173°10'W
3/18/79	OR	2	60°51', 173°10'W
3/18/79	OR	1	60°52', 173°19'W
3/18/79	OR	1	60°49', 173°20'W
3/18/79	OR	1	60°46', 173°19'W
3/18/79	OR	1	60°49', 173°25'W
3/18/79	OR	1	60°50', 173°25'W
3/18/79	UP	1	60°49', 173°53'W
3/18/79	OR	1	60°49', 173°53'W
3/18/79	OR	1	60°32', 174° 8'W
3/24/79	DL	4	63°23', 172°11'W
3/24/79	OR	1	63°28', 172° 8'W
3/24/79	OR	7	63°31', 172° 9'W
3/24/79	OR	3	63°33', 172° 9'W
3/24/79	OR	2	63°33', 172° 9'W
3/24/79	OR	1	63°36', 172° 4'W
3/24/79	DL	4	63°34', 172° 4'W
3/24/79	EB	1	63°24', 172° 5'W
3/24/79	UP	1	63°52', 171°53'W
3/24/79	EB	1	63°50', 171°51'W
3/24/79	EB	1	63°24', 171°51'W
3/24/79	EB	1	63°24', 171°51'W
3/24/79	OR	3	63°23', 171°50'W
3/24/79	EB	1	63°19', 171°50'W
3/24/79	EB	1	63°19', 171°50'W
3/24/79	EB	1	63°19', 171°50'W
3/24/79	OR	1	63°18', 171°52'W
3/24/79	EB	1	63°18', 171°52'W
3/24/79	OR	2	63°17', 171°49'W

APPENDIX TABLE B-1 CONT.
RECORD OF PINNIPEDS AND BELUGA
WHALES ENCOUNTERED IN THE PACK ICE OF
THE BERING SEA DURING EARLY SPRING,
MARCH-APRIL 1979.

Date	Species	Number	Location
3/24/79	OR	1	63°14', 171°50'W
3/24/79	OR	2	63°12', 171°50'W
3/24/79	OR	3	63°10', 171°51'W
3/24/79	EB	1	63° 6', 171°52'W
3/24/79	OR	1	63°15', 171°56'W
3/24/79	OR	1	63°15', 171°56'W
4/ 4/79	OR	2	63°48', 173°28'W
4/ 4/79	OR	1	63°35', 173°40'W
4/ 4/79	OR	1	63°35', 173°40'W
4/ 5/79	DL	1	63°53', 174° 1'W
4/ 6/79	PH	1	64° 5', 175°26'W
4/ 6/79	UP	1	64° 1', 175° 4'W
4/ 6/79	OR	1	64° 1', 175°25'W
4/ 6/79	EB	1	64° 7', 175°32'W
4/ 6/79	DL	6	64°22', 175°33'W
4/ 6/79	DL	3	64°22', 175°33'W
4/ 6/79	OR	1	64° 4', 175°38'W
4/ 6/79	OR	5	64° 1', 175°38'W
4/ 6/79	OR	1	64° 0', 175°46'W
4/ 6/79	OR	10	64° 2', 175°46'W
4/ 6/79	OR	1	64° 6', 175°47'W
4/ 6/79	UP	1	64°10', 175°47'W
4/ 6/79	OR	1	64°16', 175°46'W
4/ 6/79	OR	1	64°18', 175°46'W
4/ 6/79	EB	1	64°18', 175°52'W
4/ 6/79	OR	4	64°17', 175°53'W
4/ 6/79	OR	6	64°14', 175°53'W
4/ 6/79	OR	3	64°14', 175°53'W
4/ 6/79	OR	3	64°12', 175°53'W
4/ 6/79	OR	6	64° 8', 175°52'W
4/ 6/79	OR	1	64° 3', 175°59'W
4/ 6/79	OR	3	64° 8', 175°59'W
4/ 6/79	OR	2	64° 8', 175°59'W
4/ 6/79	OR	20	64° 8', 175°59'W
4/ 6/79	OR	2	64° 9', 175°59'W
4/ 6/79	OR	2	64°11', 175°59'W
4/ 6/79	OR	1	64°13', 175°59'W
4/ 6/79	EB	1	64°17', 175°59'W
4/ 6/79	EB	1	64°20', 175°59'W
4/ 6/79	OR	4	64°21', 175°59'W
4/ 6/79	UP	1	64°14', 176° 7'W
4/ 6/79	OR	1	64°14', 176° 7'W
4/ 6/79	OR	9	64°14', 176° 7'W
4/ 6/79	OR	3	64°12', 176° 7'W

APPENDIX TABLE B-1 CONT.
RECORD OF PINNIPEDS AND BELUGA
WHALES ENCOUNTERED IN THE PACK ICE OF
THE BERING SEA DURING EARLY SPRING,
MARCH-APRIL 1979.

Date	Species	Number	Location
4/ 6/79	OR	1	64° 1', 175°52'W
4/ 7/79	PH	1	63° 4', 174°47'W
4/ 7/79	OR	15	63°21', 174°47'W
4/ 7/79	OR	30	63°21', 174°47'W
4/ 7/79	OR	99	63°29', 174°48'W
4/ 7/79	OR	1	63°29', 174°48'W
4/ 7/79	OR	2	63°29', 174°48'W
4/ 7/79	OR	50	63°29', 174°48'W
4/ 7/79	OR	5	63°29', 174°48'W
4/ 7/79	OR	1	63°30', 174°47'W
4/ 7/79	OR	1	63°30', 174°47'W
4/ 7/79	OR	3	63°30', 174°45'W
4/ 7/79	OR	1	63°30', 174°45'W
4/ 7/79	OR	15	63°30', 174°45'W
4/ 7/79	OR	2	63°29', 174°43'W
4/ 7/79	OR	75	63°27', 174°42'W
4/ 7/79	OR	2	63°26', 174°42'W
4/ 7/79	OR	25	63°26', 174°42'W
4/ 7/79	OR	3	63°26', 174°42'W
4/ 7/79	OR	2	63°24', 174°41'W
4/ 7/79	OR	4	63°21', 174°40'W
4/ 7/79	EB	1	63°15', 174°40'W
4/ 7/79	OR	1	62°59', 174°33'W
4/ 7/79	EB	1	63° 1', 174°34'W
4/ 7/79	EB	1	63° 6', 174°36'W
4/ 7/79	EB	1	63° 7', 174°36'W
4/ 7/79	EB	1	63° 8', 174°35'W
4/ 7/79	EB	1	63° 8', 174°35'W
4/ 7/79	EB	1	63°14', 174°34'W
4/ 7/79	EB	1	63°15', 174°34'W
4/ 7/79	PH	1	63°15', 174°34'W
4/ 7/79	EB	1	63°15', 174°34'W
4/ 7/79	EB	1	63°15', 174°34'W
4/ 7/79	PH	1	63°17', 174°34'W
4/ 7/79	OR	1	63°18', 174°34'W
4/ 7/79	EB	1	63°20', 174°34'W
4/ 7/79	PH	1	63°23', 174°34'W
4/ 7/79	EB	1	63°25', 174°35'W
4/ 7/79	EB	1	63°26', 174°33'W
4/ 7/79	EB	1	63°26', 174°30'W
4/ 7/79	EB	1	63°26', 174°30'W

APPENDIX TABLE B-1 CONT.
RECORD OF PINNIPEDS AND BELUGA
WHALES ENCOUNTERED IN THE PACK ICE OF
THE BERING SEA DURING EARLY SPRING,
MARCH-APRIL 1979.

Date	Species	Number	Location
4/ 7/79	EB	1	63°26', 174°30'W
4/ 7/79	EB	1	63°24', 174°28'W
4/ 7/79	EB	1	63°24', 174°28'W
4/ 7/79	EB	1	63°24', 174°28'W
4/ 7/79	EB	1	63°24', 174°28'W
4/ 7/79	EB	1	63°19', 174°29'W
4/ 7/79	EB	1	63°19', 174°29'W
4/ 7/79	OR	1	63°19', 174°29'W
4/ 7/79	EB	1	63°17', 174°29'W
4/ 7/79	EB	1	63°14', 174°28'W
4/ 7/79	UP	2	63°14', 174°28'W
4/ 7/79	EB	1	63°10', 174°28'W
4/ 7/79	EB	1	63° 9', 174°28'W
4/ 7/79	UP	1	63° 7', 174°28'W
4/ 7/79	OR	1	63° 6', 174°28'W
4/ 7/79	EB	1	63° 4', 174°28'W
4/ 7/79	EB	1	63° 4', 174°28'W
4/ 7/79	EB	1	63° 4', 174°28'W
4/ 7/79	EB	1	63° 4', 174°28'W
4/ 7/79	EB	1	63° 4', 174°28'W
4/ 7/79	EB	1	63° 1', 174°29'W
4/ 7/79	EB	1	63° 1', 174°29'W
4/ 7/79	EB	1	63° 1', 174°29'W
4/ 7/79	EB	1	62°59', 174°29'W
4/ 7/79	OR	2	62°56', 174°28'W
4/ 7/79	EB	1	62°55', 174°26'W
4/ 7/79	EB	1	62°55', 174°26'W
4/ 7/79	EB	1	62°54', 174°24'W
4/ 7/79	EB	1	62°54', 174°22'W
4/ 7/79	EB	1	62°57', 174°22'W
4/ 7/79	OR	4	62°57', 174°22'W
4/ 7/79	EB	1	62°57', 174°22'W
4/ 7/79	EB	1	62°57', 174°22'W
4/ 7/79	EB	1	62°59', 174°22'W
4/ 7/79	EB	1	63° 0', 174°21'W
4/ 7/79	EB	1	63° 1', 174°21'W
4/ 7/79	EB	3	63° 6', 174°20'W
4/ 7/79	EB	1	63° 6', 174°20'W
4/ 7/79	EB	1	63°11', 174°20'W
4/ 7/79	EB	1	63°13', 174°20'W
4/ 7/79	EB	1	63°13', 174°20'W

APPENDIX TABLE B-1 CONT.
RECORD OF PINNIPEDS AND BELUGA
WHALES ENCOUNTERED IN THE PACK ICE OF
THE BERING SEA DURING EARLY SPRING,
MARCH-APRIL 1979.

Date	Species	Number	Location
4/ 7/79	EB	1	63°10', 174°20'W
4/ 7/79	EB	3	63° 7', 174°21'W
4/ 7/79	EB	1	63° 7', 174°21'W
4/ 7/79	EB	5	63° 3', 174°22'W
4/ 7/79	EB	3	63°10', 174°22'W
4/ 7/79	UP	1	63°12', 174°22'W
4/ 7/79	OR	6	63°14', 174°23'W
4/ 7/79	EB	2	63°15', 174°23'W
4/ 7/79	OR	7	63°18', 174°22'W
4/ 7/79	EB	1	63°16', 174°14'W
4/ 7/79	EB	1	63°16', 174°14'W
4/ 7/79	EB	1	63°15', 174°14'W
4/ 7/79	OR	15	63°13', 174°14'W
4/ 7/79	UP	1	63°13', 174°14'W
4/ 7/79	EB	1	63°12', 174°14'W
4/ 7/79	EB	1	63°10', 174°15'W
4/ 7/79	EB	1	63°10', 174°15'W
4/ 7/79	UP	1	63° 1', 174°15'W
4/ 7/79	PF	1	62°57', 174°16'W
4/ 7/79	EB	5	62°57', 174°16'W
4/ 7/79	EB	1	62°57', 174°16'W
4/ 7/79	OR	4	62°55', 174°16'W
4/ 7/79	PL	1	62°52', 174°16'W
4/ 7/79	UP	1	62°52', 174°16'W
4/ 7/79	EB	1	62°52', 174°16'W
4/ 7/79	EB	1	62°52', 174°16'W
4/ 7/79	OR	2	62°52', 174°16'W
4/ 7/79	PH	1	62°50', 174°16'W
4/ 7/79	UP	1	62°50', 174°16'W
4/ 7/79	EB	1	62°50', 174°16'W
4/ 7/79	PH	1	62°50', 174° 8'W
4/ 7/79	PL	1	62°51', 174° 7'W
4/ 7/79	EB	1	62°52', 174° 7'W
4/ 7/79	EB	1	62°55', 174° 8'W
4/ 7/79	EB	1	62°57', 174° 8'W
4/ 7/79	UP	1	63° 0', 174° 9'W
4/ 7/79	EB	1	63° 3', 174° 9'W
4/ 7/79	OR	25	63° 6', 174° 9'W
4/ 7/79	OR	3	63° 6', 174° 9'W
4/ 7/79	OR	4	63° 6', 174° 9'W
4/ 7/79	OR	2	63° 6', 174° 9'W
4/ 7/79	OR	12	63° 6', 174° 9'W
4/ 7/79	OR	10	63° 6', 174° 9'W

APPENDIX TABLE B-1 CONT.
RECORD OF PINNIPEDS AND BELUGA
WHALES ENCOUNTERED IN THE PACK ICE OF
THE BERING SEA DURING EARLY SPRING,
MARCH-APRIL 1979.

Date	Species	Number	Location
4/ 7/79	OR	2	63° 8', 174° 9'W
4/ 7/79	PL	1	63° 8', 174° 9'W
4/ 7/79	OR	4	63° 9', 174° 9'W
4/ 7/79	OR	1	63°12', 174° 9'W
4/ 7/79	EB	1	63°12', 174° 9'W
4/ 7/79	EB	1	63°13', 174° 9'W
4/ 7/79	EB	1	63°16', 174° 7'W
4/ 7/79	OR	2	63° 9', 174° 2'W
4/ 7/79	OR	2	63° 9', 174° 2'W
4/ 7/79	OR	1	63° 8', 174° 2'W
4/ 7/79	UP	1	63° 8', 174° 2'W
4/ 7/79	UP	1	63° 6', 174° 2'W
4/ 7/79	OR	4	63° 4', 173°55'W
4/ 7/79	OR	35	63° 5', 173°56'W
4/ 7/79	EB	1	63° 8', 173°55'W
4/ 7/79	EB	1	63°11', 173°54'W
4/ 7/79	OR	60	63°11', 173°54'W
4/ 7/79	EB	1	63° 8', 173°48'W
4/ 7/79	EB	1	63° 6', 173°49'W
4/ 7/79	OR	2	63° 6', 173°49'W
4/ 7/79	OR	8	63° 6', 173°49'W
4/ 7/79	OR	4	63° 6', 173°49'W
4/ 7/79	OR	5	63° 6', 173°49'W
4/ 7/79	UP	1	63° 3', 173°49'W
4/ 7/79	EB	1	62°51', 173°55'W
4/ 7/79	EB	1	62°56', 174°10'W
4/ 7/79	UP	1	62°59', 174°16'W
4/ 7/79	EB	2	63° 1', 174°21'W
4/ 9/79	OR	2	62°32', 173° 5'W
4/ 9/79	OR	1	62°32', 173° 5'W
4/ 9/79	OR	1	62°46', 173° 3'W
4/ 9/79	OR	1	63° 1', 173° 4'W
4/ 9/79	OR	1	62°45', 172°56'W
4/ 9/79	PL	1	62°31', 172°48'W
4/ 9/79	PL	1	62°31', 172°48'W
4/12/79	OR	1	62°43', 172°39'W
4/12/79	OR	1	62°35', 172°40'W
4/12/79	PH	1	62°36', 172°32'W
4/12/79	OR	1	62°39', 172°34'W
4/12/79	EB	1	62°58', 172°31'W
4/12/79	EB	1	62°54', 172°32'W
4/12/79	OR	1	62°46', 172°32'W
4/12/79	OR	1	62°28', 172°30'W

APPENDIX TABLE B-1 CONT.
RECORD OF PINNIPEDS AND BELUGA
WHALES ENCOUNTERED IN THE PACK ICE OF
THE BERING SEA DURING EARLY SPRING,
MARCH-APRIL 1979.

Date	Species	Number	Location
4/12/79	PH	1	62°25', 172°26'W
4/12/79	EB	1	62°32', 172°16'W
4/12/79	PH	1	62°49', 172°14'W
4/12/79	OR	2	62°49', 172°10'W
4/12/79	UP	1	62°45', 172° 8'W
4/12/79	EB	1	62°42', 172° 9'W
4/12/79	UP	1	62°42', 172° 9'W
4/12/79	OR	2	62°20', 172°12'W
4/12/79	PH	1	62°25', 172°12'W
4/12/79	UP	2	62°25', 172° 7'W
4/12/79	PL	1	62°24', 172° 7'W
4/12/79	PL	1	62°24', 172° 7'W
4/12/79	UP	1	62°19', 172° 4'W
4/12/79	UP	1	62°19', 172° 4'W
4/12/79	PH	1	62°19', 172° 4'W
4/12/79	PH	1	62°19', 172° 4'W
4/12/79	OR	1	62°24', 172° 2'W
4/12/79	EB	1	62°29', 172° 2'W
4/12/79	OR	3	62°29', 172° 2'W
4/12/79	OR	2	62°39', 172° 3'W
4/12/79	EB	2	62°41', 172° 3'W
4/12/79	EB	2	62°41', 172° 3'W
4/12/79	OR	1	62°41', 172° 3'W
4/12/79	OR	55	62°48', 172° 3'W
4/12/79	UP	1	62°44', 171°57'W
4/12/79	UP	1	62°43', 171°57'W
4/12/79	OR	40	62°43', 171°57'W
4/12/79	OR	1	62°41', 171°57'W
4/12/79	OR	99	62°38', 171°58'W
4/12/79	OR	11	62°38', 171°58'W
4/12/79	UP	1	62°36', 171°58'W
4/12/79	UP	1	62°26', 171°57'W
4/12/79	OR	2	62°25', 171°56'W
4/12/79	PH	1	62°22', 171°56'W
4/12/79	EB	1	62°20', 171°56'W
4/12/79	UP	1	62°19', 171°56'W
4/12/79	UP	1	62°19', 171°56'W
4/12/79	UP	1	62°19', 171°56'W
4/12/79	UP	1	62°31', 171°48'W
4/12/79	EB	1	62°37', 171°51'W
4/12/79	OR	3	62°41', 171°51'W
4/12/79	PL	1	62°41', 171°51'W
4/12/79	PL	1	62°41', 171°51'W

APPENDIX TABLE B-1 CONT.
RECORD OF PINNIPEDS AND BELUGA
WHALES ENCOUNTERED IN THE PACK ICE OF
THE BERING SEA DURING EARLY SPRING,
MARCH-APRIL 1979.

Date	Species	Number	Location
4/12/79	EB	2	62°44', 171°50'W
4/12/79	UP	1	62°43', 171°48'W
4/12/79	EB	2	62°39', 171°45'W
4/12/79	EB	1	62°38', 171°44'W
4/12/79	OR	3	62°38', 171°44'W
4/12/79	EB	1	62°33', 171°45'W
4/12/79	UP	1	62°28', 171°44'W
4/12/79	UP	1	62°11', 171°40'W
4/12/79	UP	1	62°18', 171°37'W
4/12/79	PH	1	62°18', 171°37'W
4/12/79	UP	1	62°24', 171°37'W
4/12/79	UP	1	62°27', 171°37'W
4/12/79	PL	1	62°30', 171°36'W
4/12/79	PL	1	62°33', 171°36'W
4/12/79	EB	1	62°34', 171°37'W
4/12/79	OR	3	62°41', 171°45'W
4/12/79	OR	1	62°41', 171°45'W
4/12/79	PL	1	62°41', 171°48'W
4/12/79	PL	1	62°41', 171°48'W
4/12/79	OR	1	62°40', 171°55'W
4/12/79	UP	1	62°36', 172° 3'W

APPENDIX TABLE B-2

CHI-SQUARE ANALYSIS OF NORTH PACIFIC WALRUS OCCURRENCES IN DIFFERENT ICE CONCENTRATION CATEGORIES, 1979

Ice Concentration Category	Area (nm^2)	Proportion of Total Area	Number Observed	Number Expected	Proportion Observed	95 Percent Confidence Interval
NORTHERN ZONE						
0-25	4	0.009	0	<1	0.000	
26-50	24	0.052	1	2	0.029	
51-75	271	0.576	19	20	0.543	
76-100	170	0.363	15	13	0.428	
Total	469	1.000	35	35	1.000	$X^2 = 0.28$ a/
CENTRAL ZONE						
0-25	0	0.000	0	0	0.000	
26-50	3	0.006	0	<1	0.000	- $0.5064 \le p \le 0.2276$ b/
51-75	93	0.222	22	13	0.367	
76-100	324	0.772	38	46	0.633	$0.7724 \le p \le 0.4936$ b/
Total	420	1.000	60	60	1.000	$X^2 = 5.24$ b/
SOUTHERN ZONE						
0-25	45	0.075	3	9	0.025	$0.0603 \le p \le -0.0103$ b/
26-50	165	0.278	32	34	0.262	$0.3615 \le p \le 0.1625$ a/
51-75	231	0.389	68	47	0.557	$0.6694 \le p \le 0.4446$ b/
76-100	153	0.258	19	32	0.156	$0.2381 \le p \le 0.0739$ b/
Total	594	1.000	122	122	1.000	$X^2 = 18.78$ b/

a/ Significant avoidance.
b/ Significant preference.

1191a

APPENDIX TABLE B-3

CHI-SQUARE ANALYSIS OF NORTH PACIFIC WALRUS OCCURRENCES
IN DIFFERENT ICE SIZE CATEGORIES, 1979

Ice Size Category	Area (nm^2)	Proportion of Total Area	Number Observed	Number Expected	Proportion Observed	95 Percent Confidence Interval
NORTHERN ZONE b/						
Grease-Slush	36	0.103	2	4	0.057	$0.1993 \le p \le -0.0273$ a/ (Grease-Slush and Pan-Small combined)
Pan-Small	67	0.190	1	7	0.029	
Med-Large	102	0.291	14	10	0.400	$0.5979 \le p \le 0.2021$ b/
Vast-Giant	147	0.416	18	14	0.514	$0.7159 \le p \le 0.3121$ b/
Total	352	1.000	35	35	1.000	$X^2 = 8.56$ a/
CENTRAL ZONE a/						
Grease-Slush	2	0.005	0	<1	0.000	
Pan-Small	7	0.019	0	1	0.000	
Med-Large	37	0.104	6	6	0.100	
Vast-Giant	309	0.872	54	52	0.900	
Total	355	1.000	60	60	1.000	$X^2 = 0.32$ b/
SOUTHERN ZONE b/						
Grease-Slush	85	0.225	5	27	0.041	$0.0812 \le p \le -0.0010$ a/
Pan-Small	134	0.352	73	43	0.598	$0.6974 \le p \le 0.4986$ a/
Med-Large	74	0.195	4	24	0.033	$0.0692 \le p \le -0.0032$ a/
Vast-Giant	87	0.228	40	28	0.328	$0.4232 \le p \le 0.2328$ a/
Total	380	1.000	122	122	1.000	$X^2 = 60.67$ a/

a/ Significant preference.
b/ Significant avoidance.

1191a

APPENDIX TABLE B-4

CHI-SQUARE ANALYSIS OF BEARDED SEALOCCURRENCES
IN DIFFERENT ICE CONCENTRATION AND SIZE CATEGORIES, 1979 a/

Ice Concentration Category	Area (nm^2)	Proportion of Total Area	Number Observed	Number Expected	Proportion Observed	95 Percent Confidence Interval
0-25	0	0.000	0	0	0.000	
26-50	3	0.006	0	1	0.000	$-0.4815 \le p \le 0.2305$ a/
51-75	93	0.222	26	16	0.356	
76-100	324	0.772	47	56	0.644	$0.7695 \le p \le 0.5185$ a/
Total	420	1.000	73	73	1.000	$X^2 = 5.54$ a/

Ice Size Category	Area (nm^2)	Proportion of Total Area	Number Observed	Number Expected	Proportion Observed	95 Percent Confidence Interval
Grease-Slush	2	0.005	0	0	0.000	
Pan-Small	7	0.019	0	1	0.000	
Med-Large	37	0.104	11	8	0.151	
Vast-Giant	310	0.872	62	64	0.849	
Total	356	1.000	73	73	1.000	$X^2 = 0.51$ b/

a/ Analysis was performed only on central zone of study area, since 87 percent of total sightings were in this zone. Ice categories were combined to increase sample sizes.
b/ Significant preference.
c/ Significant avoidance.

1191a

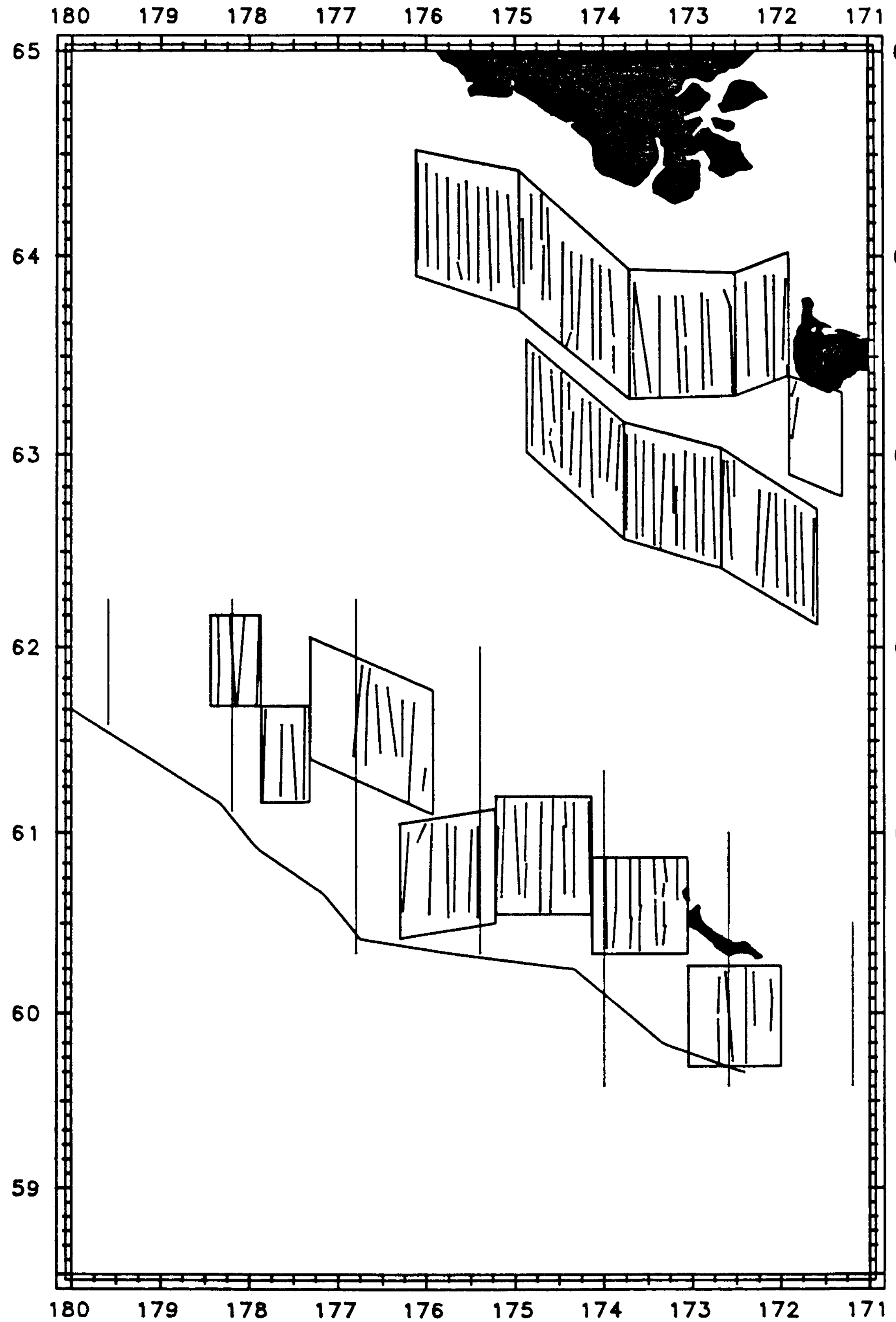

Figure B-1 Location of aerial tracklines surveyed in the pack ice of the Bering Sea during early spring, March - April 1979.

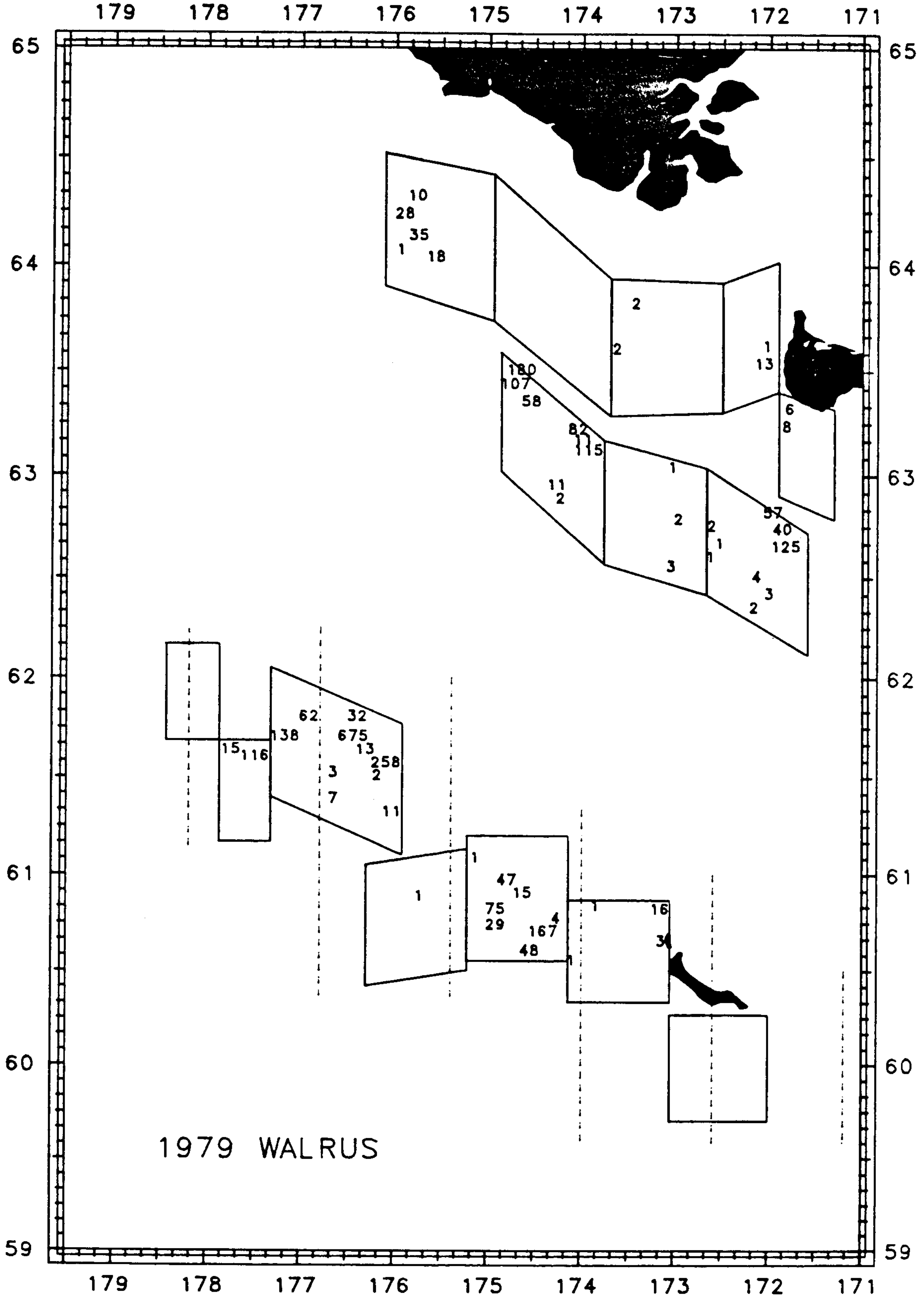

Figure B-2 Location of walruses observed in the pack ice of the Bering Sea during early spring, March - April 1979.

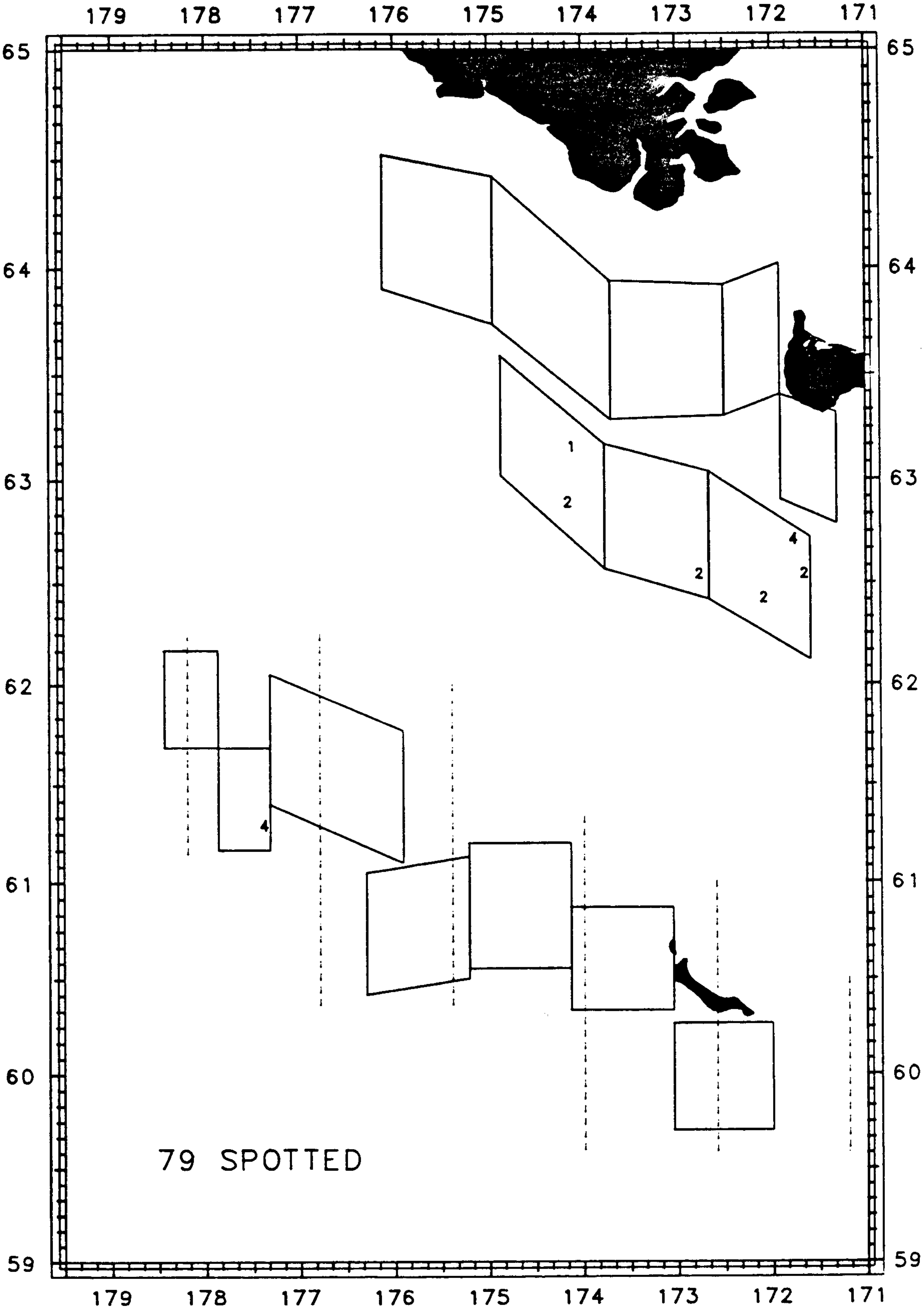

Figure B-3 Location of spotted seals observed in the pack ice of the Bering Sea during early spring, March - April 1979.

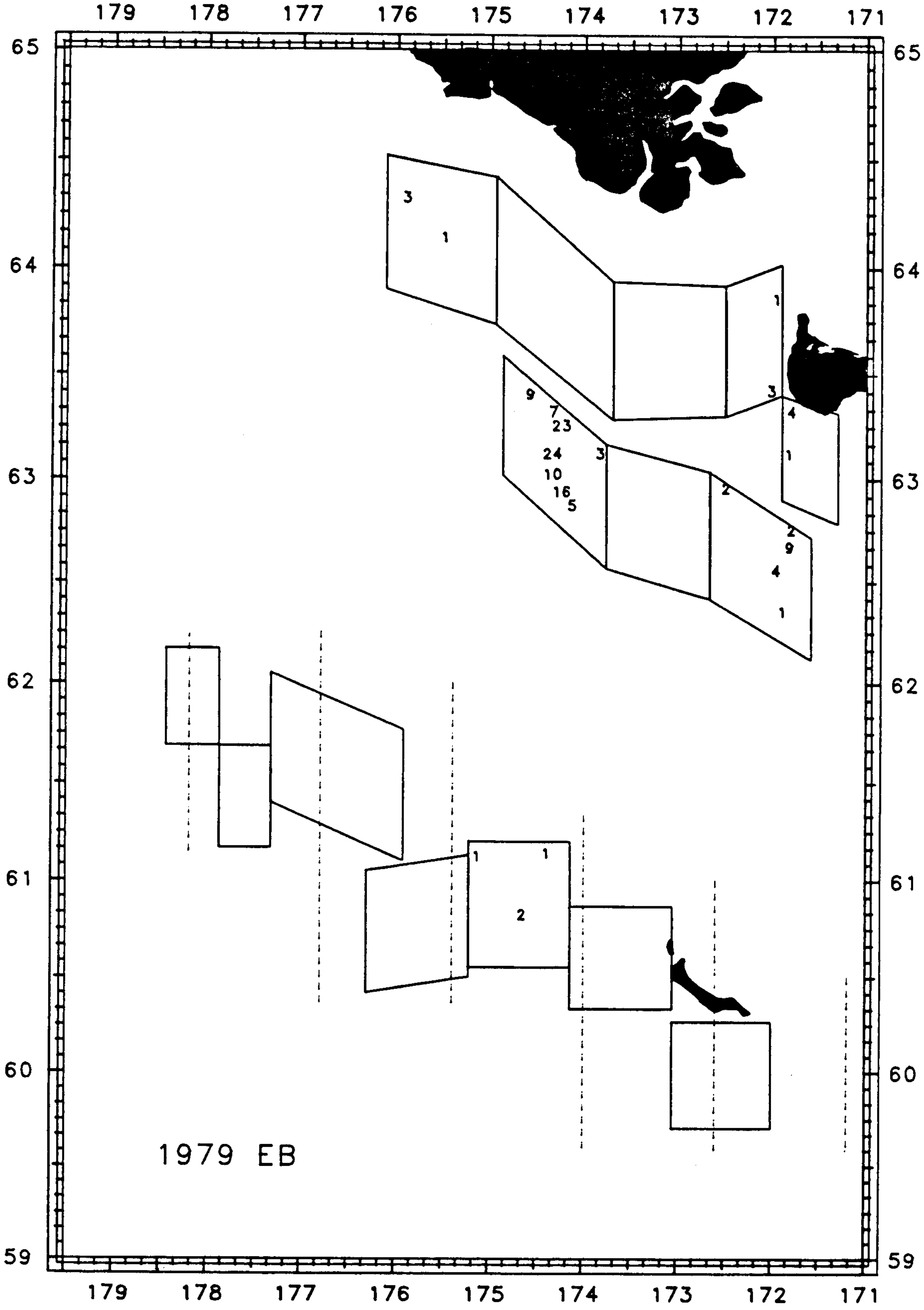

Figure B-4 Location of bearded seals observed in the pack ice of the Bering Sea during early spring, March - April 1979.

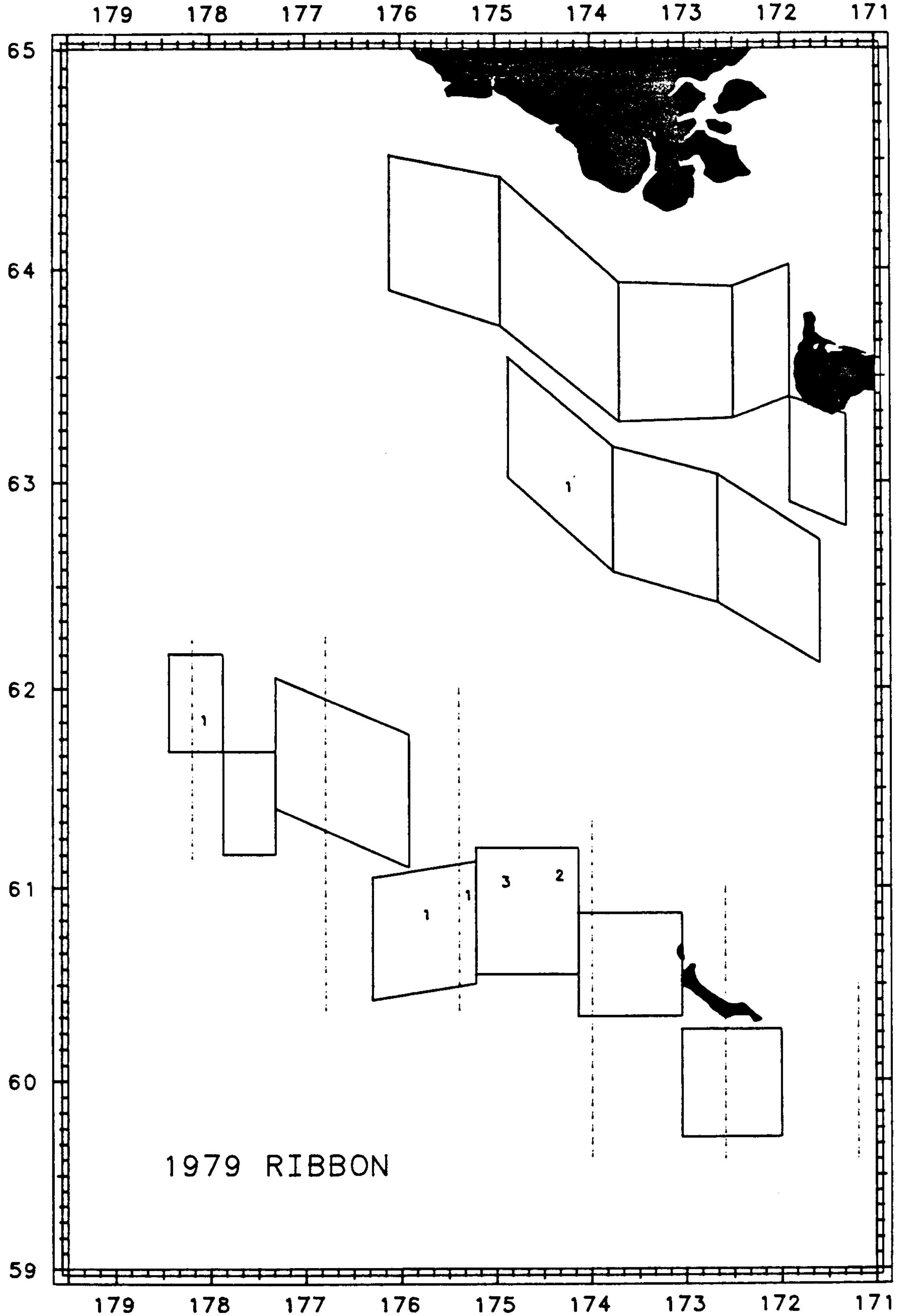

Figure B-5 Location of ribbon seals observed in the pack ice of the Bering Sea during early spring, March - April 1979.

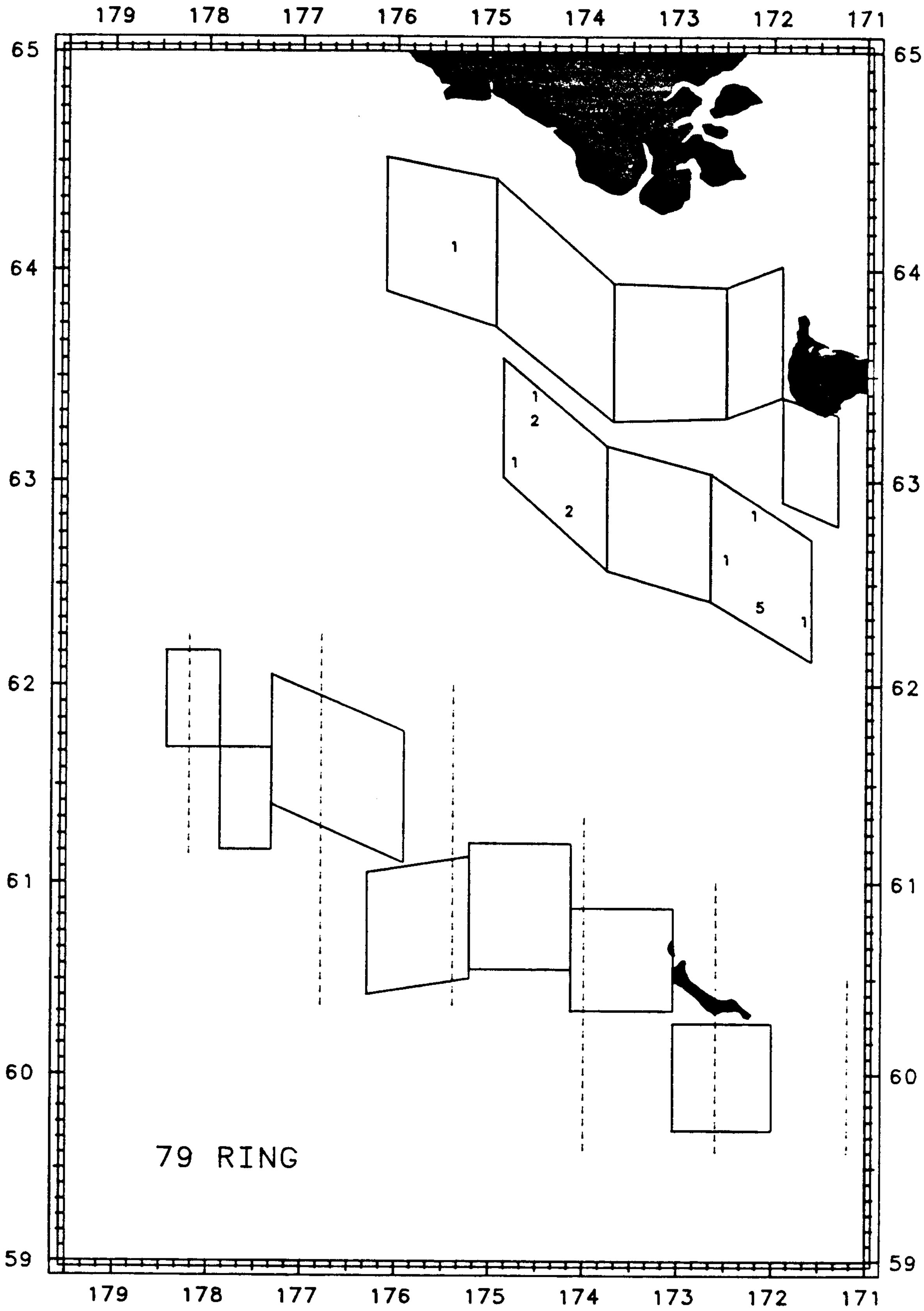

Figure B-6 Location of ringed seals observed in the pack ice of the Bering Sea during early spring, March - April 1979.

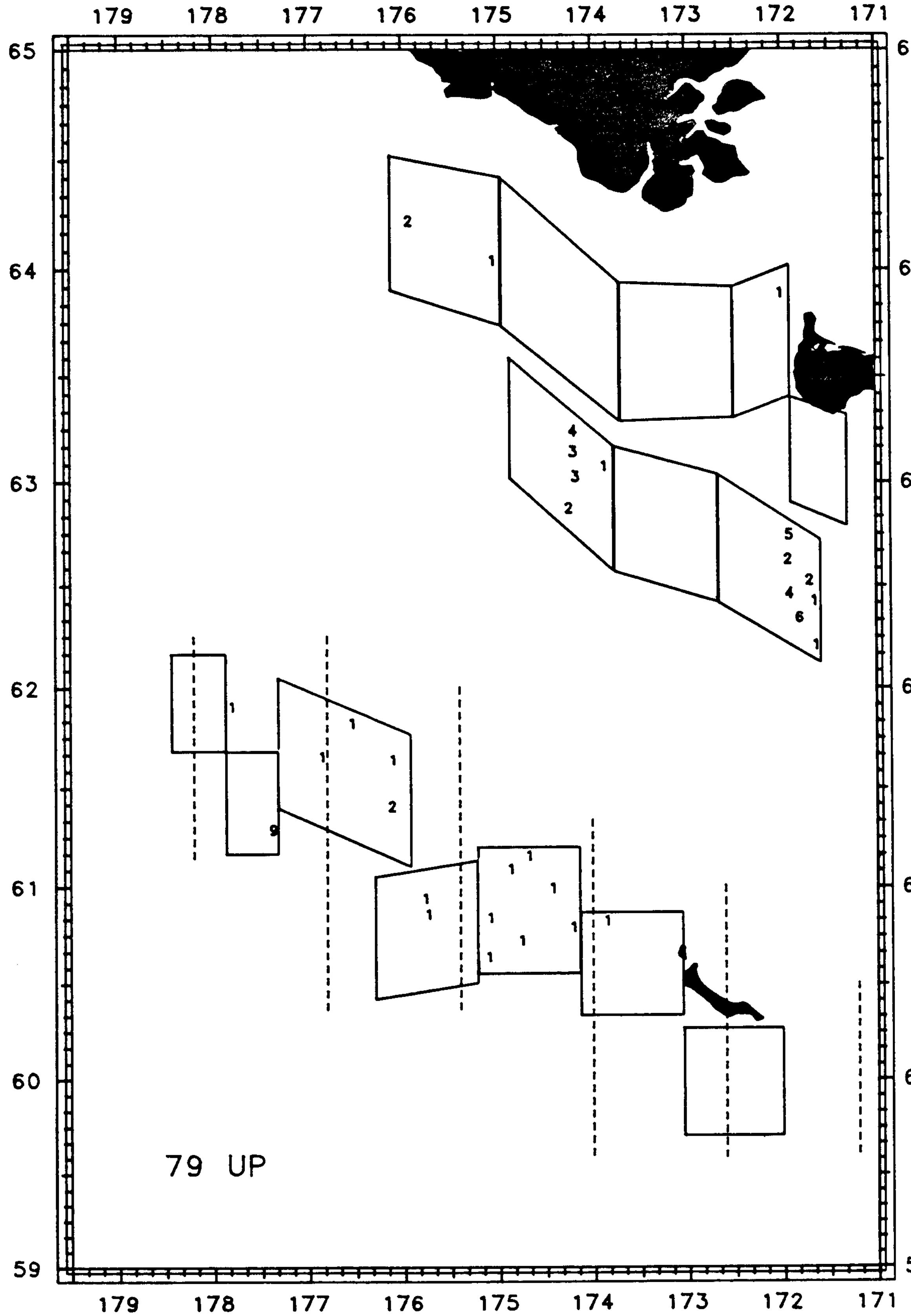

Figure B-7 Location of unidentified pinnipeds observed in the pack ice of the Bering Sea during early spring, March - April 1979.

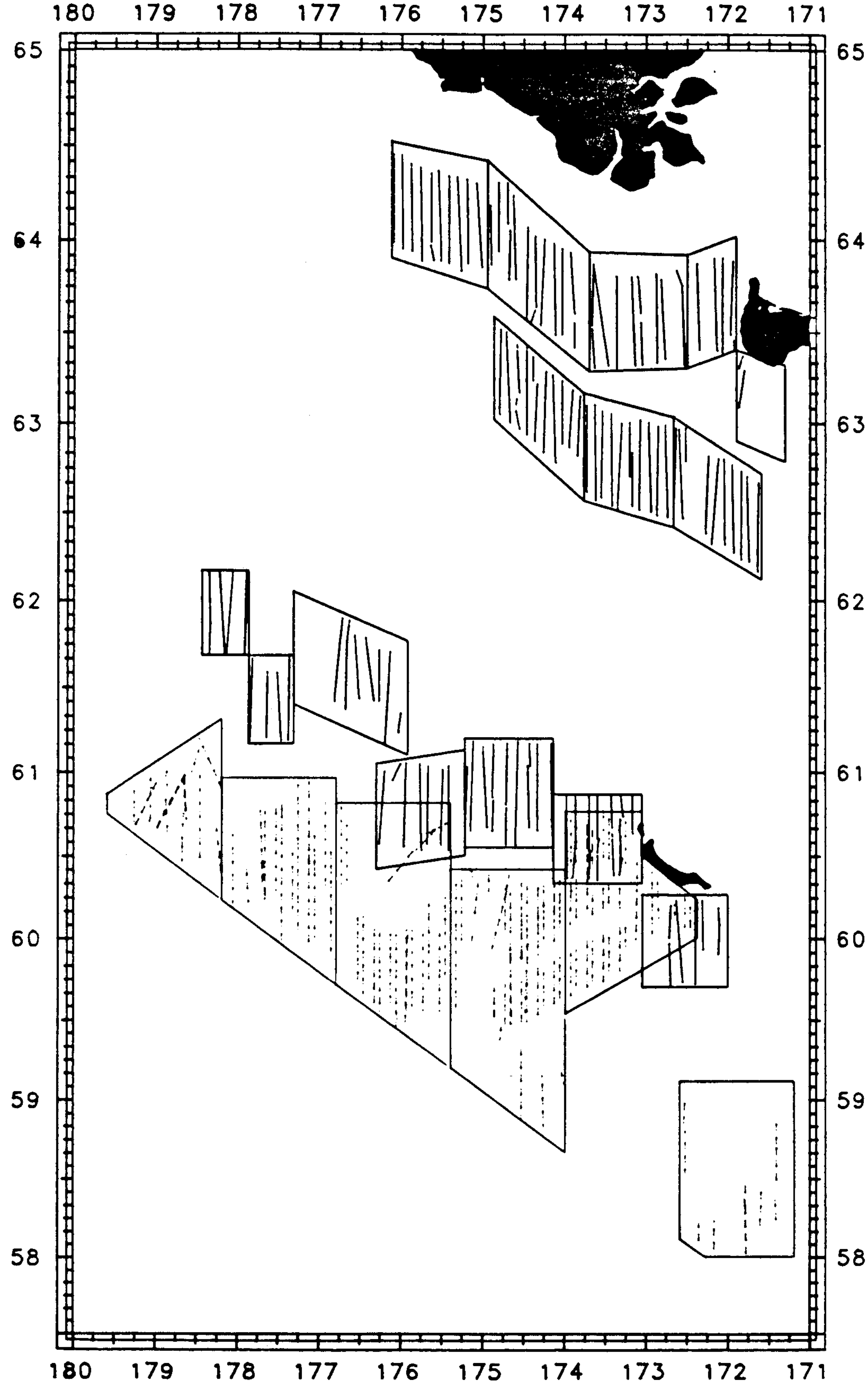

Figure B-8 Location of February - March 1983 (¦) and March - April 1979 (|) tracklines surveyed in the pack ice of the Bering Sea.

APPENDIX C

BELUGA WHALE STUDY REPORT

Beluga (Delphinapterus leucas) whales of the eastern North Pacific Ocean occur from the Gulf of Alaska westward to the Bering Sea, northward through the Chukchi Sea, and eastward into the Beaufort Sea (Brooks, 1963; Klinkhart, 1966; Scheffer, 1972). A minimum of 15,000 belugas are estimated to occupy these waters (Alaska Dep. Fish Game, 1975).

The Gulf of Alaska beluga population is largely located in Cook Inlet (Scheffer, 1972). The herd, estimated at 300 to 500 animals, appears to remain in the inlet the year-round (Klinkhart, 1966; Alaska Dep. Fish Game, 1975). The Alaska peninsula is evidently a barrier to the northward movement of these animals into the Bering Sea.

Beluga whales occurring in the Bering Sea consist of resident and migratory stocks. An estimated 1,000 to 1,500 (Klinkhart, 1966; Sergeant and Brodie, 1975; Alaska Dep. Fish Game, 1975) and possibly as many as 8,000 (DEIS in Braham and Krogman, 1977) animals remain in Bristol Bay throughout the year. An additional but unknown number of belugas are thought to winter in the Bering Sea and migrate to their summering grounds in eastern Siberian and Canadian waters (Brooks, 1954; Kleinenberg et al., 1964; Sergeant and Hoek, 1974; Alaska Dep. Fish Game, 1975). Part of this migratory stock summers in Norton Sound, Yukon Delta, and the Kuskokwim River, while the other animals continue north through the Bering Strait (Scheffer, 1972; Fay, 1974). Sergeant and Brodie (1969) suggest further that belugas in the Yukon Delta and Kuskokwim River may be resident.

The purpose of this section of the report is to document the number and distribution of beluga whales recorded in the pack ice of the Bering

Sea during our 1979 and 1983 surveys. The study area location and data collection procedures are largely identical to those described for pinnipeds. The main exception is that beluga whale surveys in 1979 were conducted from two helicopters compared to the one helicopter used to survey pinnipeds. Consequently, over 25 percent more trackline distance was surveyed for beluga whales than pinnipeds in 1979.

A total of 886 beluga whales were recorded in 1979 compared to 598 in 1983 (Table C-1). Group size averaged 26.8 (range = 1 to 123) animals in 1979 and 20.6 (range = 1 to 433) animals in 1983. The group sizes ranged widely because beluga whales were generally encountered as clusters of animals in large congregations. Kleinenberg et al. (1964) also reported that beluga whales congregate in large groups of variable size in the Canadian Arctic during early spring.

Beluga whales were widespread in the pack ice during 1979 and 1983 (Table C-1, Figure C-1). They occurred in the southern, central, and northern sections of the study area. Particularly large numbers of belugas were observed near the US-USSR Convention Line in 1979 and along the western fringe of the polynya, south and west of St. Matthew Island in 1983. In both areas, belugas were in areas occupied by concentrations of bowhead whales.

The span of time we observed belugas in the pack ice was from 5 March to 6 April. This identifies that belugas occur in the Bering Sea at least until early April. Other investigators (Braham and Krogman, 1977; Johnson et al., 1966; Kleinenberg et al., 1964; Bailey and Hendee, 1926) have postulated that belugas move north from the Bering Sea in March and April and return between November and January, and on occasion as early as September and October (D. Harry, Gambell, AK, Personal Communication).

Beluga whales we observed were primarily in thin but extensive ice coverage in 1983 and in leads in 1979. Almost 90 percent of the beluga

APPENDIX TABLE C-1

NUMBER AND DISTRIBUTION OF BELUGA WHALES
RECORDED IN THE PACK ICE OF THE BERING SEA
DURING LATE WINTER TO EARLY SPRING, 1979 AND 1983

Location	Distance Surveyed		1979		1983	
	1979	1983	No. Group	No. Indiv.	No. Group	No. Indiv.
Northern	1,749	--	5	18	--	--
Central	1,134	--	28	868	--	--
Southern	3,006	2,410	--	--	29	598
TOTAL	5,889	2,410	33	886	29	598

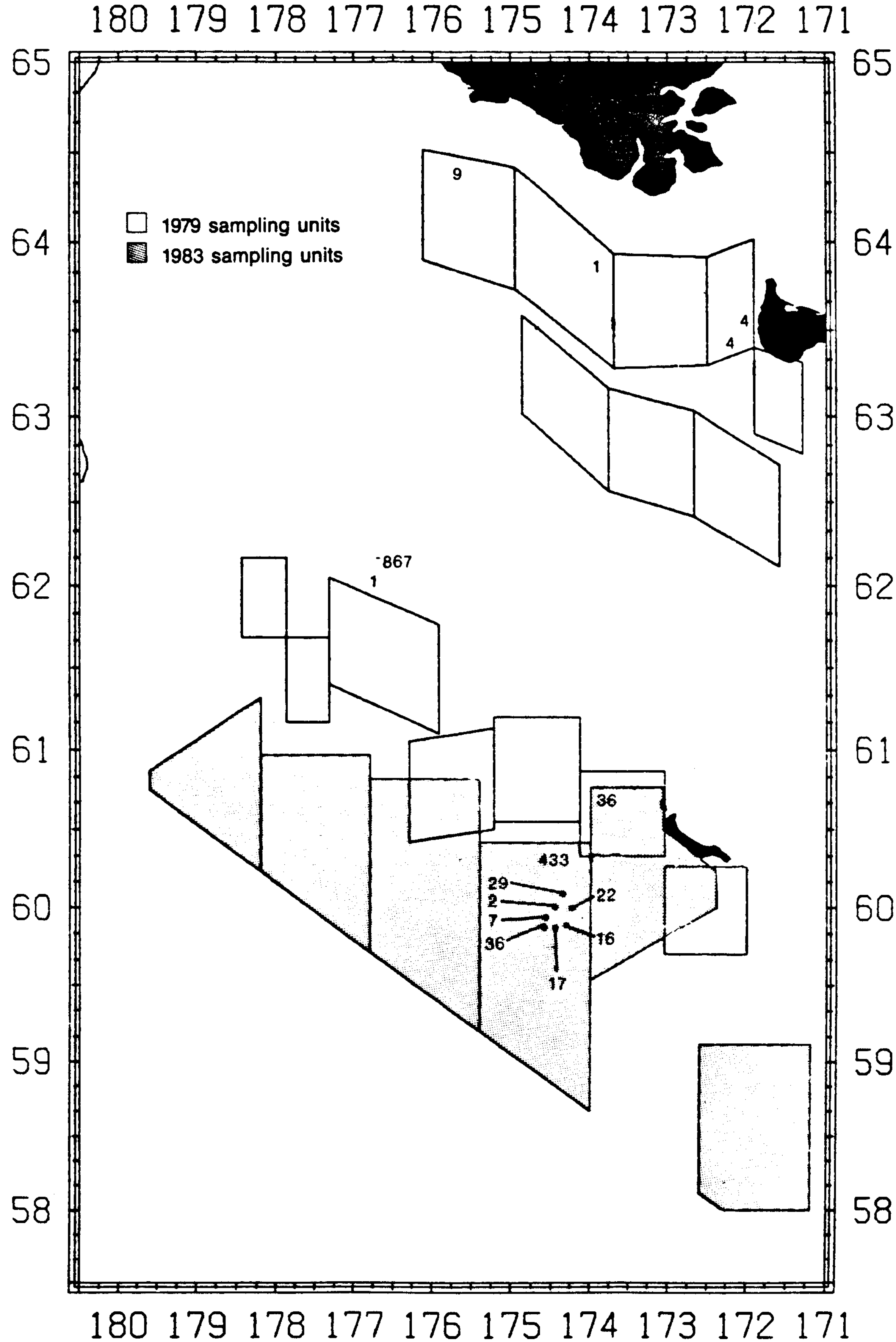

Figure C-1 Locations of beluga whales observed in the Bering Sea pack ice during March - April 1979 and February - March 1983.

observations in 1983 were in areas of 80-100 percent ice concentration predominated by new and young ice (Figure C-2). Few whales were observed in the lower ice concentrations, particularly the 0-40 percent categories, and there were no whales encountered in areas of first-year ice. In 1979, almost all of the belugas were observed in long narrow leads north of the marginal ice front. Floe size did not appear to influence beluga whale distribution.

Beluga whale densities were estimated for 1983 but not 1979 because too few animals were observed during systematic surveys. An estimated 0.028 belugas per nm^2 representing 462 $\pm$ 578 animals occurred in the marginal ice front in 1983 (Brueggeman et al., 1983). This estimate is based on 6.7 percent coverage of 16,382 nm^2 involving observations of 37 belugas. Since the estimated abundance is below the actual number observed, the actual observed value of 886 animals is the best estimate of abundance. This estimate is above the 598 animals observed in 1979 and it represents a minimum estimate since it does not account for animals below the surface that were missed.

The results of the 1979 and 1983 surveys showed that an estimated 886 beluga whales occurred throughout the pack ice from winter to early spring. Most of the whales occurred in areas of higher ice concentrations and in leads. Particularly high occurrences of belugas were in an area along the US-USSR Convention Line and along the fringe of the St. Matthew Island polynya.

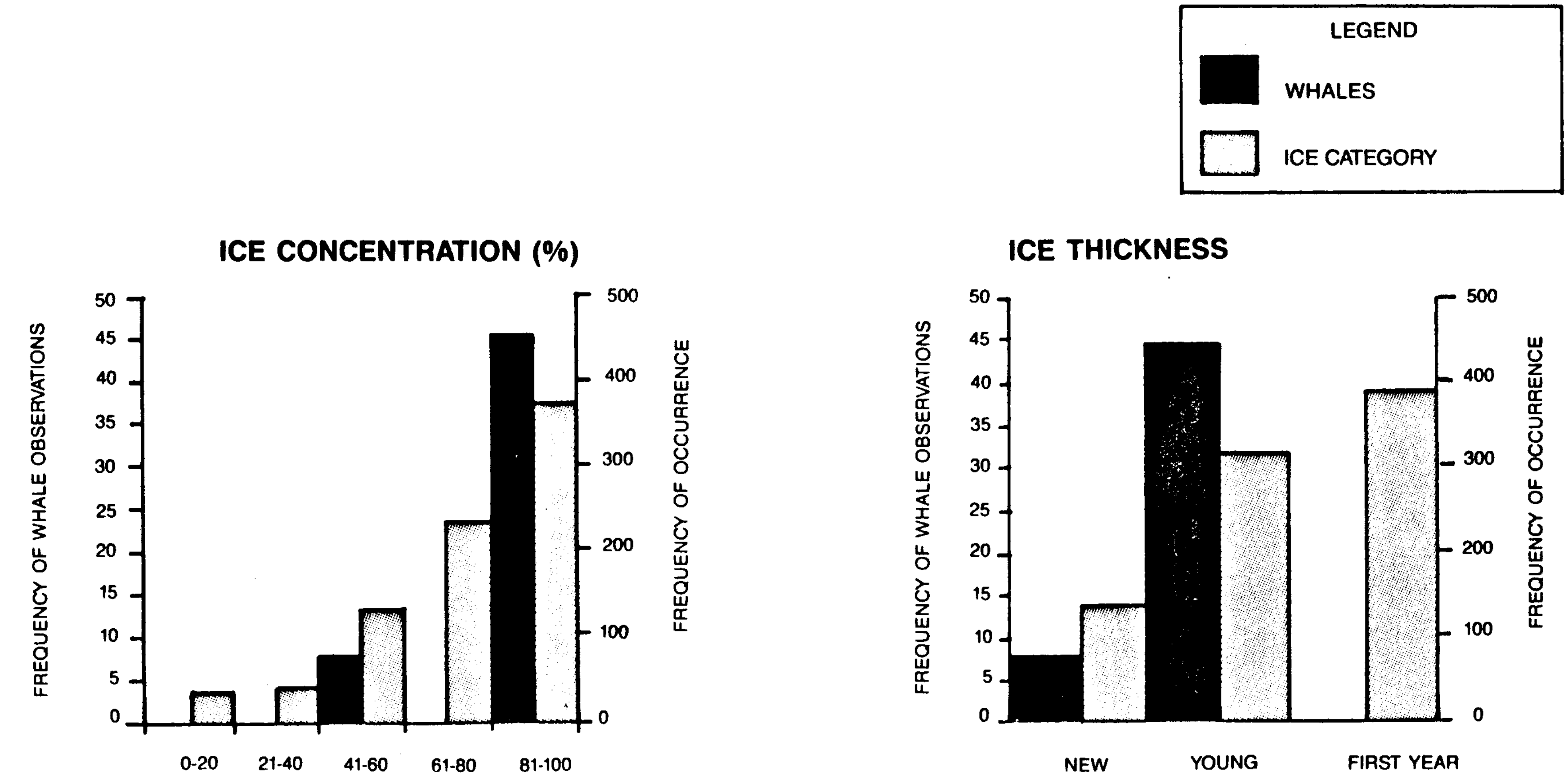

Figure C-2 Frequency of beluga whale observations relative to frequency of ice concentration and thickness.

INVESTIGATIONS OF BELUKHA WHALES IN COASTAL WATERS OF WESTERN AND NORTHERN ALASKA

I. DISTRIBUTION, ABUNDANCE, AND MOVEMENTS

by

Glenn A. Seaman, Kathryn J. Frost, and
Lloyd F. Lowry

Alaska Department of Fish and Game
1300 College Road
Fairbanks, Alaska 99701

Final Report
Outer Continental Shelf Environmental Assessment Program
Research Unit 612

November 1986

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SUMMARY

Belukha whales are widely distributed in the marine waters of western and northern Alaska. Seasonal movements are pronounced. During winter belukhas occur principally in the seasonal ice of the Bering Sea, although some may overwinter in the southern Chukchi Sea. Optimal habitat occurs in areas with leads, polynyas, or other areas of predictably open water. The spring migration begins in March and April. Some whales move eastward appearing in coastal waters of Bristol Bay in early April. Others move northward through Bering Strait and through the lead system which extends along the Chukchi Sea coast from Point Hope to Barrow. They then continue north and eastward to Banks Island and Amundsen Gulf where they arrive in May and June. Some of these whales summer in the Mackenzie Delta while others are found offshore in the eastern Beaufort Sea.

Groups of belukhas appear at many locations along the coast of western Alaska shortly after the ice breaks up and moves offshore. Large concentrations are regularly seen near the mouths of the Yukon River, in inner Norton Sound, in Kotzebue Sound, and near Kasegaluk Lagoon. Belukhas have been seen in the Yukon River more than 1200 km upstream from the river mouth.

The abundance of belukhas in coastal waters decreases markedly after August. Large numbers of whales are seen moving westward in the Beaufort and northeastern Chukchi seas in late August and September. During this westward, fall migration the belukhas are associated with the pack ice which is usually 50-100 km north of the Beaufort Sea coast. The path of the migration southward through the Chukchi Sea is poorly known. Whales pass south through Bering Strait during October and November.

Belukhas occur in all proposed Outer Continental Shelf (OCS) lease areas. The Saint Matthew-Hall, Saint George, Navarin, and North Aleutian basins include much of the winter habitat. The spring migration passes through the Norton Basin, Hope Basin, Barrow Arch, and Diapir Field lease areas. Major summer concentrations occur in the North Aleutian Basin, Norton Basin, Hope Basin, and Barrow Arch. During the fall migration very large numbers of belukhas pass through the Diapir Field and Barrow Arch.

Although belukhas still occur in all areas where they were known to occur historically, some distributional shifts have occurred. These are particularly evident in Kotzebue Sound. Increased human activity in the coastal zone may be, in part, responsible for these changes.

The abundance and interrelationships among groups of belukhas are poorly known. Based on available sightings, it appears that belukhas seen in Norton Sound and near the mouths of the Yukon River comprise a single group. Provisionally, the belukhas which summer in the eastern Chukchi Sea are also considered a single group which is seen sequentially at several locations. It is suggested that belukhas in western and northern Alaska comprise four stocks as follows: Bristol Bay - 1,000-1,500 animals; Norton Sound - 1,000-2,000 animals; eastern Chukchi

Sea - 2,500-3,000 animals; eastern Beaufort Sea - 11,500 animals. The minimum total number of animals which pass through the waters adjacent to Alaska is estimated as 13,500-18,000. Considering that belukhas also occur in waters of the USSR, the actual abundance of whales in the Bering, Chukchi, Beaufort, and East Siberian seas may be in excess of 25,000.

ACKNOWLEDGEMENTS

This study was funded primarily by the National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program. Additional support was provided by the Alaska Department of Fish and Game (ADF&G), and the Federal Aid in Wildlife Restoration Program.

This study of belukha distribution did not have the benefit of funding for systematic surveys. Our results and conclusions therefore result from a compilation of many observations from various sources. We thank all the pilots, hunters, fishermen, biologists, and Alaskan residents who have recorded their observations of belukhas and made them available to us. Major contributions were made by John J. Burns, Francis H. Fay, Don K. Ljungblad, and Robert R. Nelson. John Burns was responsible for most aspects of project management and provided editorial comments on the report. Figures were prepared by Jesse Venable.

WORLD DISTRIBUTION

Belukha whales (Delphinapterus leucas) are widely, though not uniformly distributed throughout most seasonally ice-covered waters of the northern hemisphere (Figure 1). They are circumpolar, occurring off North America, Europe, and Asia (Kleinenberg et al. 1964). Based on a knowledge of seasonal patterns of movement and concentration areas, the presence of major though not complete geographical barriers, and differences in size of adult animals in different areas, it is likely that belukhas occur in a number of somewhat discrete populations and stocks in various parts of their range (Sergeant and Brodie 1969; Gurevich 1980).

In general, belukhas spend the winter in ice-covered offshore waters. They are unable to make and maintain breathing holes in ice more than about 8 cm thick so are found in areas where geographic, oceanographic, or meteorologic factors cause ice motion and the formation of openings (Kleinenberg et al. 1964; Burns et al. 1981). In spring, as soon as the ice begins to break up and move offshore, belukhas move toward the coast, some making extensive migrations in excess of 2,000 km and some moving relatively short distances toward shore. Most belukhas appear to spend most of the summer in coastal waters, especially in shallow bays or estuaries of large rivers, although an unknown proportion of some populations may remain associated with offshore pack ice. In late summer to late autumn they move generally away from the coast, ahead of or with advancing pack ice (Kleinenberg et al. 1964).

In the eastern hemisphere belukhas occur regularly and in substantial numbers in the White, Barents, Kara, Laptev, East Siberian, and Okhotsk seas (Bel'kovich 1960; Kleinenberg et al. 1964; Ognetov and Potelov 1982). They are sometimes present off the coasts of Norway, Holland, Denmark, and West Germany, and in cold winters have been sighted as far south as Great Britain (Tomilin 1957; Gurevich 1980).

Belukhas regularly occur throughout the north Atlantic and eastern Canadian Arctic north to 82°30'N near Ellesmere Island, western Greenland, and Spitsbergen and south to the Gulf of Saint Lawrence. They are occasionally present near the coast of Nova Scotia in the Bay of Fundy, and are rare off Labrador and Newfoundland. They are most abundant in Davis Strait, Baffin Bay, Ungava Bay, Hudson Bay, Hudson Strait, Foxe Basin, Lancaster Sound, Prince Regent Inlet, Barrow Strait, Peel Sound, Cumberland Sound, and Jones Sound and have also been observed near Iceland and Jan Mayen (Kleinenberg et al. 1964). The most southern extralimital record along the east coast of North America is from Avalon, New Jersey (38°55'N). Locations of other extralimital sightings from the east coast include Maine, Massachusetts, and Long Island (Reeves and Katona 1980).

In the western arctic belukhas are found in the Beaufort Sea, Amundsen Gulf, and M'Clure Strait, and westward to the East Siberian Sea (Kleinenberg et al. 1964). Western arctic belukhas are apparently separated from those to the east by heavy pack ice which occurs in the western Canadian arctic islands (Sergeant and Brodie 1975). Belukhas are also found in the Chukchi, Okhotsk, and Bering seas, the latter including the Gulf of Anadyr and Bristol Bay. A small apparently

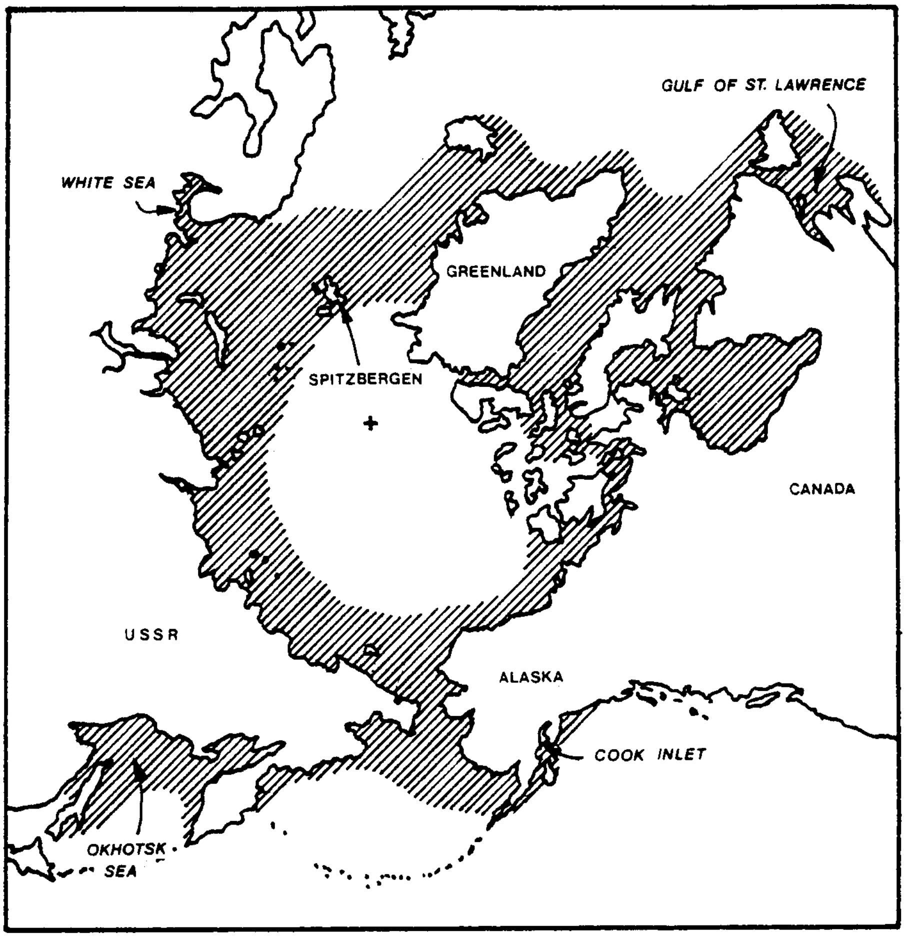

Figure 1. Current world distribution of belukha whales, not including extralimital occurrences.

separate stock occurs in Cook Inlet (Seaman and Burns 1981). In the eastern North Pacific region, extralimital occurrences have been reported from as far south as Tacoma, Washington (47°15'N) (Scheffer and Slipp, 1948).

GENERAL DISTRIBUTION IN ALASKA

Belukhas in Alaska are considered to comprise two populations. One has a center of abundance in Cook Inlet where they are numerous throughout the year (Klinkhart 1966). They are known to range into the northern Gulf of Alaska from at least Kodiak Island to Yakutat Bay (Harrison and Hall 1978). Seasonal movements are poorly known; however, concentrations occur each summer near mouths of rivers flowing into Cook Inlet from the north and east. This project has not dealt with the Cook Inlet population and it will not be considered in the remainder of this report.

The second, much larger group of belukhas ranges seasonally through the Bering, Chukchi, Beaufort, and at least parts of the East Siberian seas. During winter these whales occur throughout the ice fringe and front from the Alaska coast to Siberia, as well as in more northerly regions of the Bering and Chukchi sea pack ice where open water regularly occurs (Kleinenberg et al. 1964; Fay 1974; Seaman and Burns 1981). As the ice recedes in spring, a large segment of the population moves north, some of them passing Point Hope and Point Barrow during April to June (Braham and Krogman 1977; Fraker 1979). Those belukhas are thought to mostly migrate eastward through offshore leads in the Beaufort Sea, then south along the west coast of Banks Island to Amundsen Gulf, then west to the Mackenzie River estuary where they appear in late June (Sergeant and Hoek 1974; Fraker et al. 1978; Fraker 1980). Ice conditions allow late migrants to utilize a more direct route to the estuary. Other belukhas migrate less extensively and are seen in coastal waters of the Bering and Chukchi seas shortly after ice breakup in spring. During the summer months belukhas occur in the Bering, Chukchi, and Beaufort seas, primarily in coastal waters and the broad margin of pack ice. Major concentrations in western North American waters occur in Mackenzie Bay, Kugmallit Bay, off Kasegaluk Lagoon, in Kotzebue Sound, Norton Sound (including the Yukon River estuary), and Bristol Bay. They have been recorded in major river systems several hundred kilometers from the ocean (Kleinenberg et al. 1964; Gurevich 1980; ADF&G, unpublished). Belukhas leave the coastal zone in late summer to late autumn. Animals in the northern part of their range move southward ahead of and with the advancing ice pack, most of them passing through Bering Strait and into the Bering Sea (Fay 1974; Seaman and Burns 1981).

SEASONAL DISTRIBUTION IN ALASKA

We have compiled available distribution information for belukhas in the Bering and Chukchi seas, the Beaufort Sea, including Mackenzie Bay, and the eastern part of the East Siberian Sea (see also Gurevich 1980 for a review of the seasonal distribution of belukhas in Siberian waters). Data have been compiled by two-month periods beginning in January and are summarized in Figures 3-8. Major locations are shown in Figure 2.

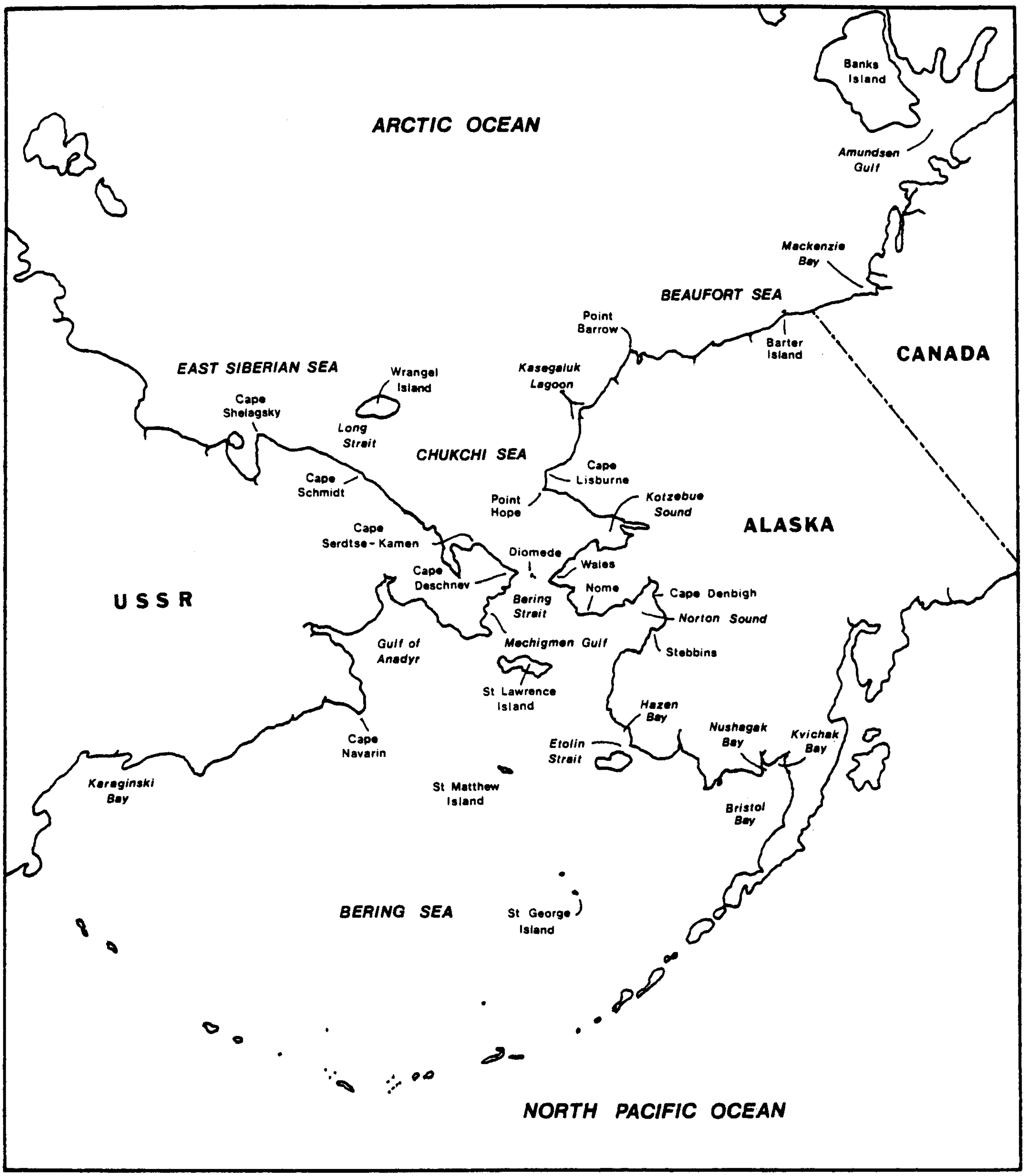

Figure 2. Map of the Bering, Chukchi, and Beaufort seas showing major locations mentioned in the text.

January-February (Figure 3)

Belukhas overwinter in both the Bering and southern Chukchi seas. Most midwinter sightings have been made from Point Hope and coastal villages to the south. Belukhas probably do not regularly overwinter in the Beaufort or northern Chukchi seas since the ice cover there is heavy, without extensive leads, polynyas, or other areas of predictably open water (Fay 1974). They may occasionally become entrapped by ice, however, and be forced to remain in unsuitable regions (Freeman 1968). Mortality in such instances is probably high (Porsild 1918; Freeman 1968).

During January-February in the southeastern Chukchi Sea, belukhas have been observed from Point Hope to Bering Strait. Sightings have been by residents of Point Hope, Shishmaref, Wales, and Diomede. Winter distribution in the Chukchi Sea is probably variable depending on annual severity of ice conditions. Along the southwestern Chukchi coast they have been reported during winter from Cape Dezhnev (East Cape) and Serdtse Kamen Cape (Kleinenberg et al. 1964). In the Bering Sea they occur in Mechigmen Gulf and Provideniya Bay on the Siberian coast, south and west of Saint Lawrence Island, and occasionally along the Alaskan coast from Norton Sound to Bristol Bay. In Bristol Bay belukhas are rarely seen by coastal residents during the coldest winter months (Brooks 1954; ADF&G, unpublished). They generally occur in the outer regions of Bristol Bay and the Bering Sea at that time (Lensink 1961).

March-April (Figure 4)

Observations from March and April indicate that belukhas are widely distributed in the Bering and Chukchi seas. They are present along the southern edge of the seasonal sea ice from Bristol Bay westward (Seaman and Burns 1981). Although sightings are widely dispersed throughout ice-covered regions of Bristol Bay and the Bering Sea, the greatest number of sightings has been in western Bering Sea from the ice edge to Bering Strait, including southeast of Saint George Island, south and southwest of Saint Matthew Island, around Saint Lawrence Island, and around the Diomede Islands and Cape Prince of Wales (Kenyon 1972; Braham et al. 1984; ADF&G, unpublished). On the Siberian side they have been observed from Cape Navarin, Mechigmen Gulf, Serdtse Kamen Cape, and Cape Dezhnev (Kleinenberg et al. 1964; Seaman and Burns 1981).

Belukhas in large numbers are first seen in nearshore waters of Bristol Bay in April as areas become ice-free, frequently congregating at or near the mouths of large rivers to feed and sometimes ascending the rivers until their upstream movements are impeded by ice (Brooks 1956; Frost et al. 1983a; Frost and Lowry, unpublished). They appear north of Bristol Bay along the coast in Etolin Strait and Hazen Bay in April, and are also commonly sighted off the shore ice in Norton Sound near Saint Michael, Shaktoolik, Cape Denbigh, Cape Nome, and the city of Nome.

Sightings in the Chukchi Sea in March and April occur mainly near the coast from Bering Strait to Cape Schmidt on the Siberian side and Point Barrow on the Alaskan side (Seaman and Burns 1981). The first sightings of belukhas off Point Hope are in March with larger numbers observed in

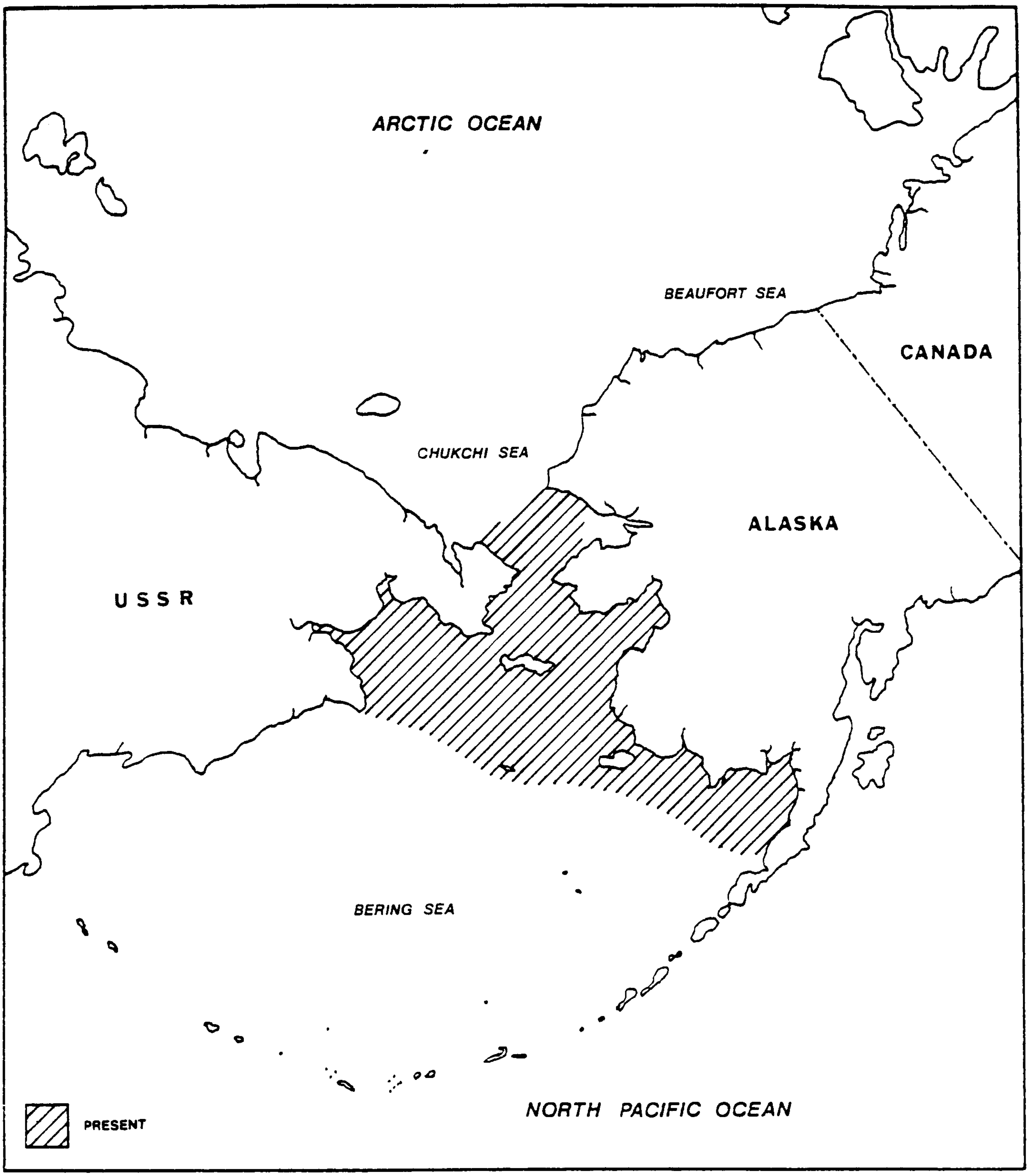

Figure 3. Distribution of belukha whales in January and February.

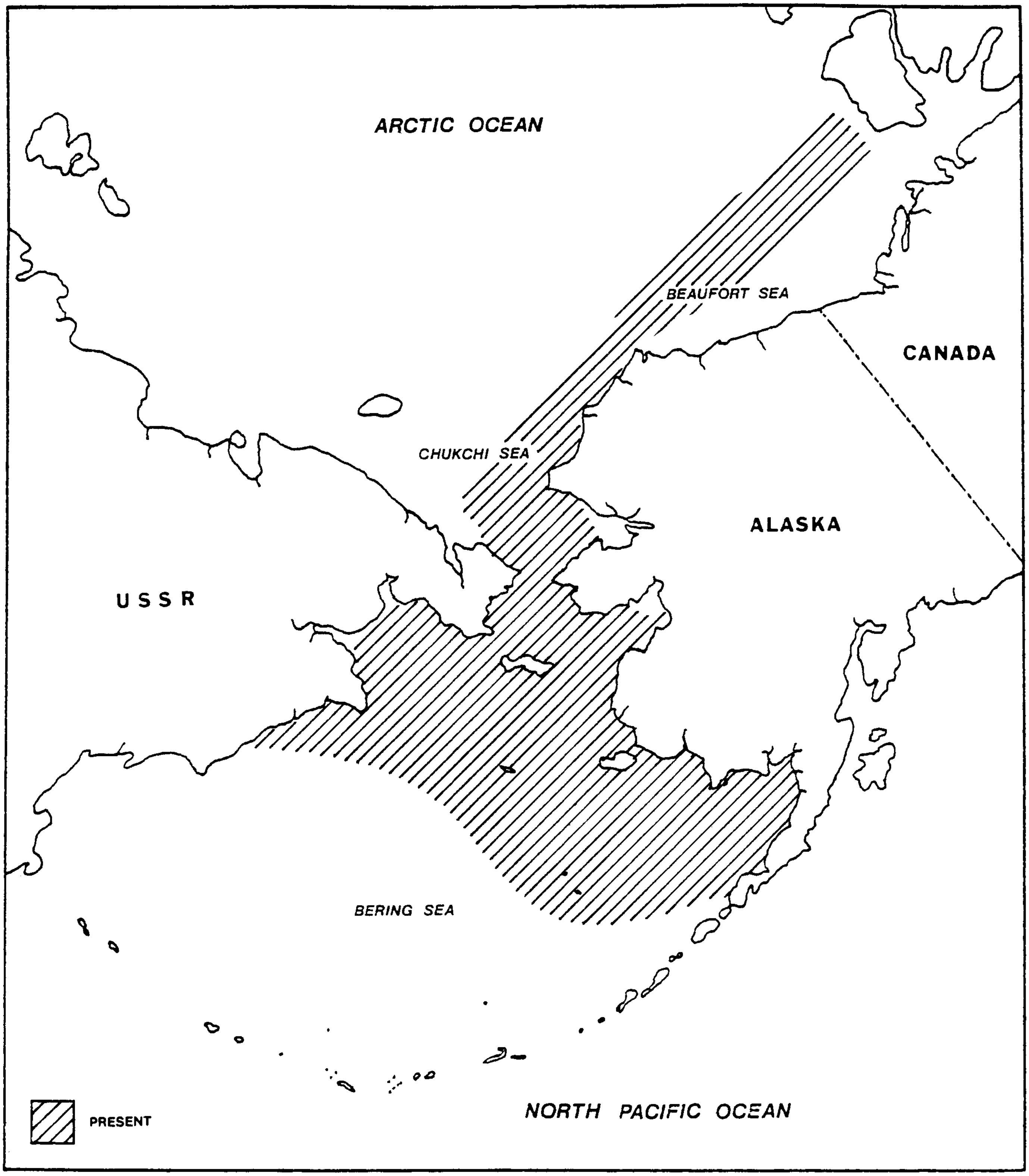

Figure 4. Distribution of belukha whales in March and April.

April and May (Marquette 1976, 1977, and 1979; Braham and Krogman 1977; Frost et al. 1983b). Belukhas first appear off Barrow in early to mid-April but most pass by in May (Braham and Krogman 1977; ADF&G, unpublished).

May-June (Figure 5)

In May and June belukhas are still reported throughout the northern Bering Sea. However, there are fewer offshore sightings and the majority of sightings are relatively near shore. On the Siberian coast sightings occur along the coast from Cape Navarin to Cape Dezhnev (Tomilin 1957; Kleinenberg et al. 1964). In Alaskan waters belukhas occur from southeastern Bristol Bay to Bering Strait and northward past Point Barrow. Most sightings are from Bristol Bay and Norton Sound (Brooks 1954, 1955; Lensink 1961; Klinkhart 1966; Seaman and Burns 1981; Frost et al. 1983a).

By June many belukhas have moved northward into the Chukchi Sea and arrived in the eastern Beaufort Sea where they congregate near Banks Island and Amundsen Gulf before moving into the Mackenzie River estuary. Most sightings in the Chukchi Sea are from the Alaskan side, extending from Kotzebue Sound well into the Beaufort Sea northeast of Barrow (Childs 1969; Seaman and Burns 1981; Braham et al. 1984). Sightings during this period have also been made on the Siberian side near Serdtse Kamen and along the coast as far west as Cape Schmidt (Kleinenberg et al. 1964).

July-August (Figure 6)

July and August are the months during which peak use of coastal waters occurs in most areas. Along the Siberian coast belukhas are apparently rare in Karaginski Bay and common in the Gulf of Anadyr, western Bering Strait, and along the northern coast of the Chukchi Peninsula to the vicinity of Long Strait. There are few sightings during these months from the East Siberian Sea (Tomilin 1957; Kleinenberg et al. 1964). The distribution in Alaska during this period is generally continuous from Bristol Bay to the western Beaufort Sea and into Canadian waters of the eastern Beaufort Sea (Seaman and Burns 1981; Davis and Evans 1982).

The largest number of sightings, and generally the largest groups of belukhas, are seen in inner Bristol Bay, particularly in Nushagak and Kvichak bays (Brooks 1955; Lensink 1961; Frost et al. 1983a); in Norton Sound near the Yukon River estuary, near Stebbins, Unalakleet, Shaktoolik, Koyuk, and Elim; in Kotzebue Sound; between Cape Lisburne and Point Barrow (mainly in and adjacent to Kasegaluk Lagoon); north of Barrow in late August and September (Seaman and Burns 1981; Frost et al. 1983b; ADF&G, unpublished); and in Canadian waters of the eastern Beaufort Sea (Fraker 1977). Groups of whales have also been sighted along the margin of the pack ice from Barrow southwest to Icy Cape and east to Barter Island (Harrison and Hall 1978; Braham et al. 1984; ADF&G, unpublished).

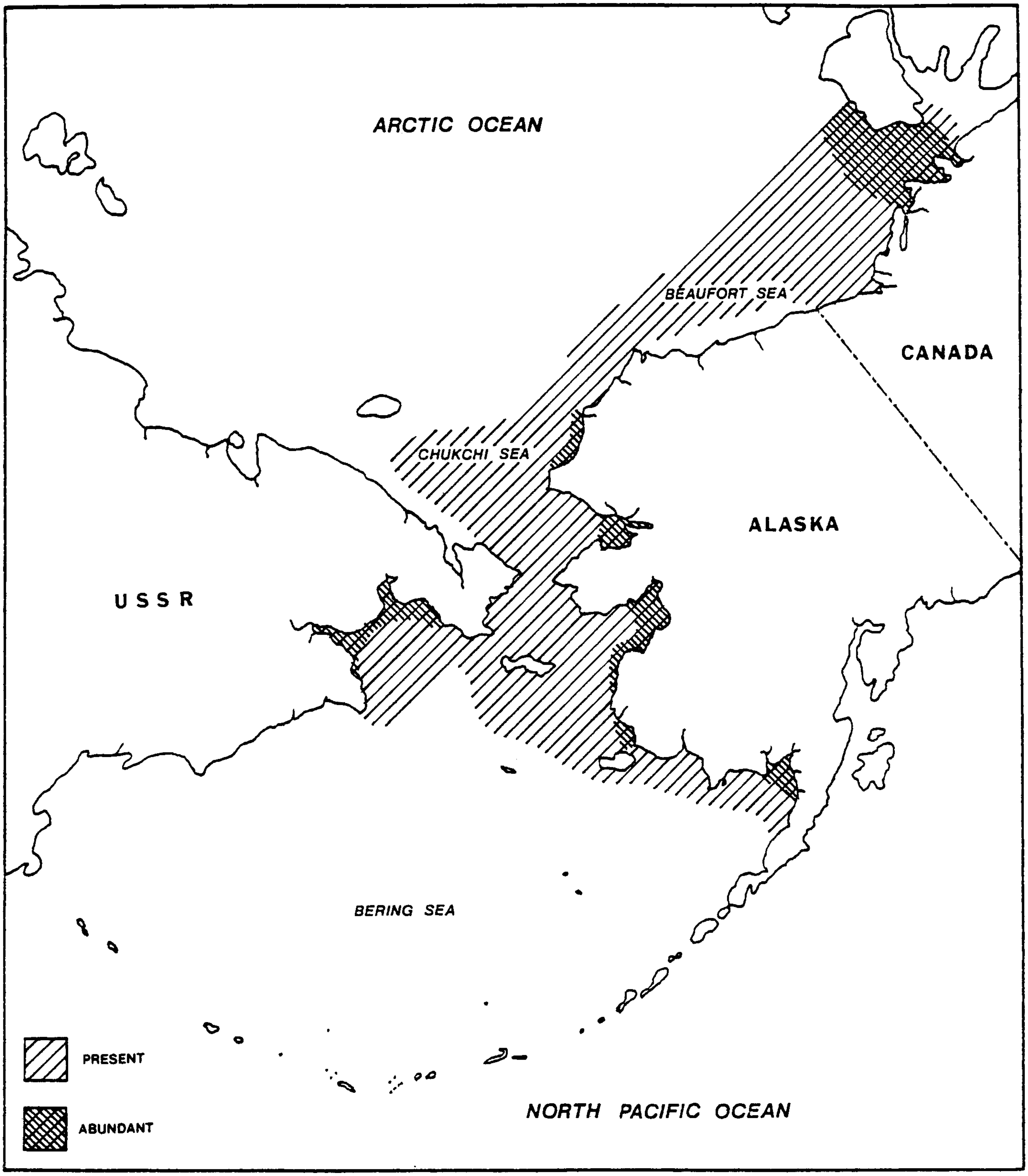

Figure 5. Distribution of belukha whales in May and June.

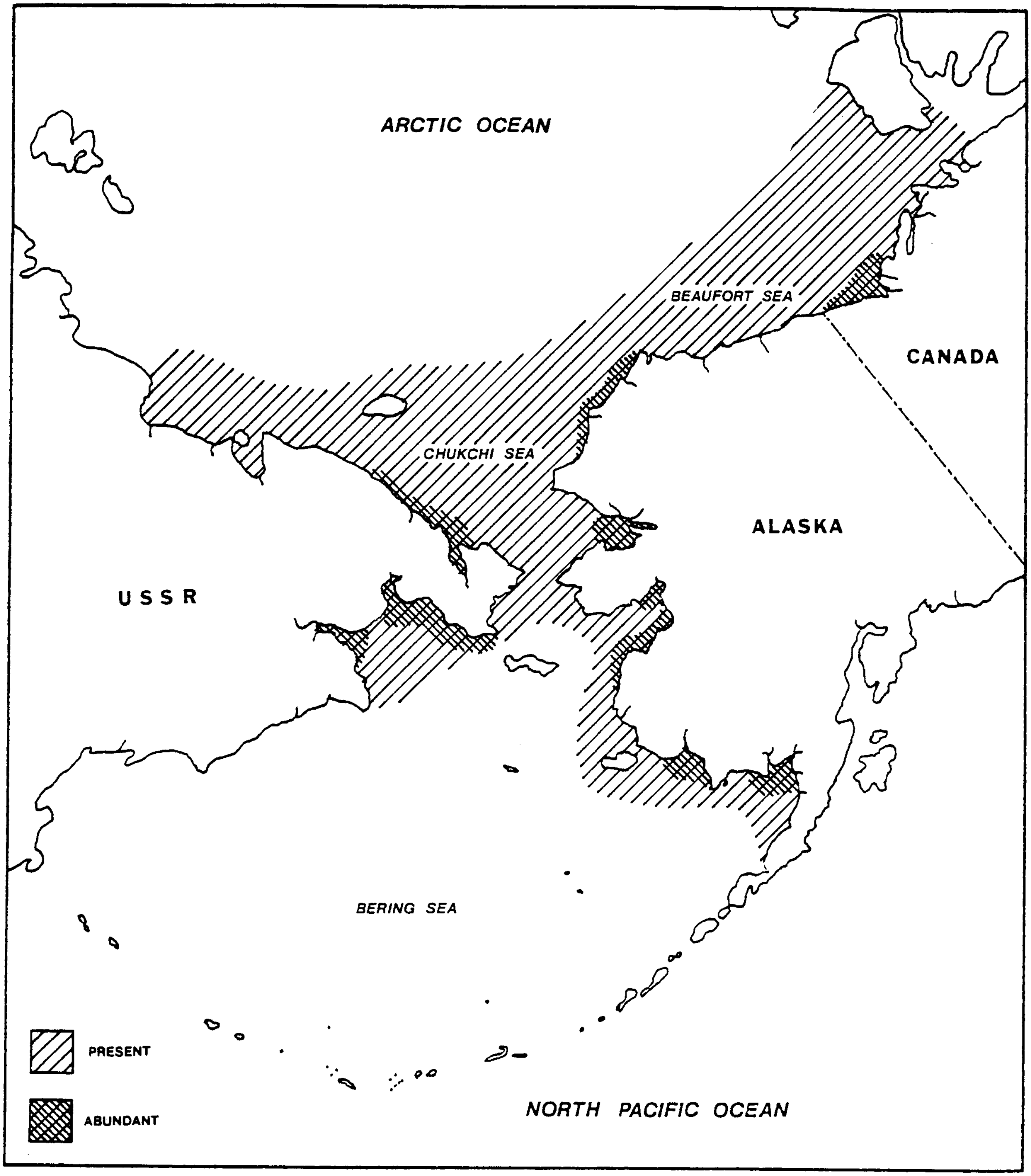

Figure 6. Distribution of belukha whales in July and August.

September-October (Figure 7)

The pattern of whale distribution changes markedly in September and October. Fewer whales are observed in coastal waters, and there is a general increase in offshore sightings. In the far north, animals from Siberia move east and seaward, while those from the eastern Beaufort move westward. Consequently, most sightings in September and October have been from the northern Chukchi Sea between Wrangel Island and northeast of Point Barrow (Seaman and Burns 1981).

Very large aggregations of belukhas have been seen at this time of year; sightings of 500 to more than 1,000 whales were made northeast of Barrow in September 1978 and October 1979 (J. Bitters and L. Zimmerman, personal communication) and of several thousand (perhaps more than 5,000) in the central Chukchi Sea in September 1974 (G. C. Ray and T. Dohl, personal communication).

Some sightings have also been made in the area from south of the pack ice to Bering Strait. Coastal residents of Bering Strait report belukhas moving southward in advance of the ice in October (Kleinenberg et al. 1964; ADF&G, unpublished). Sightings along the Alaskan coast from Cape Prince of Wales to Bristol Bay become progressively less common as winter approaches.

November-December (Figure 8)

There are few sightings of belukha whales in November and December. Most have been in the Bering Sea with a few in the Chukchi Sea from Point Hope southward (Seaman and Burns 1981). In general, sightings have been by coastal hunters and commercial airline pilots since survey efforts have been minimal during these months. Sightings of belukha whales from villages in Bering Strait indicate a predominently southward movement (Kleinenberg et al. 1964; F. Fay, personal communication; ADF&G, unpublished). The southward movement characteristically peaks in November and early December with or in advance of the appearance of seasonal pack ice, but continues through midwinter (Kleinenberg et al. 1964).

It appears that belukhas maintain an association with sea ice in winter, and that the timing of their southward migration is closely related to the timing of freezeup and southward advance of the pack ice. Their distribution in March and April suggests that they winter throughout the Bering Sea from the ice front to Bering Strait and in the southern Chukchi Sea.

REGIONAL DISTRIBUTION AND ABUNDANCE

North Aleutian Basin

For the purpose of this discussion the North Aleutian Basin is defined as the waters of Bristol Bay from Cape Newenham to Unimak Pass (Figure 9).

Our information on belukha whales in Bristol Bay comes from a variety of sources. From 1954 to 1958, J. Brooks conducted extensive studies on

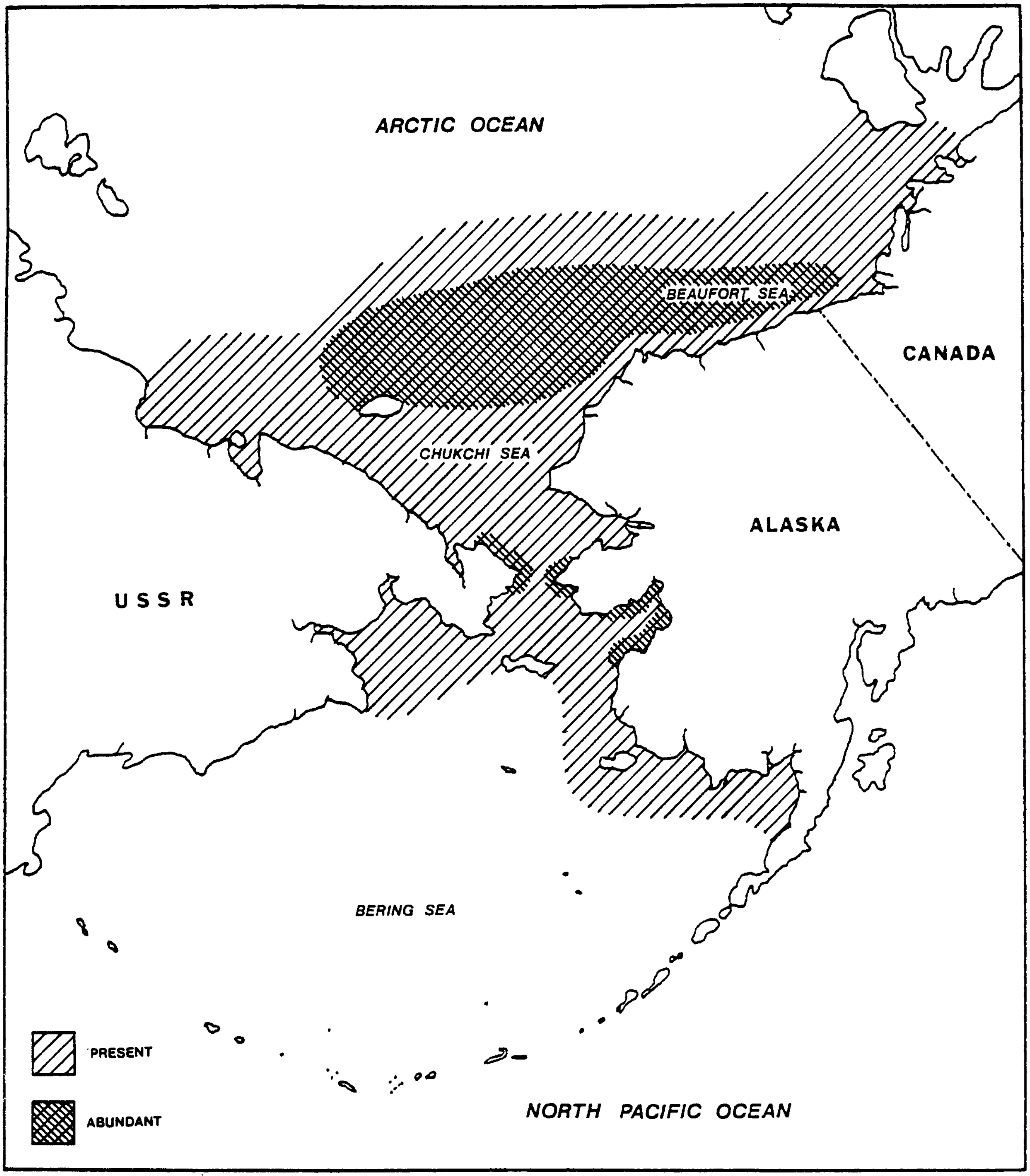

Figure 7. Distribution of belukha whales in September and October.

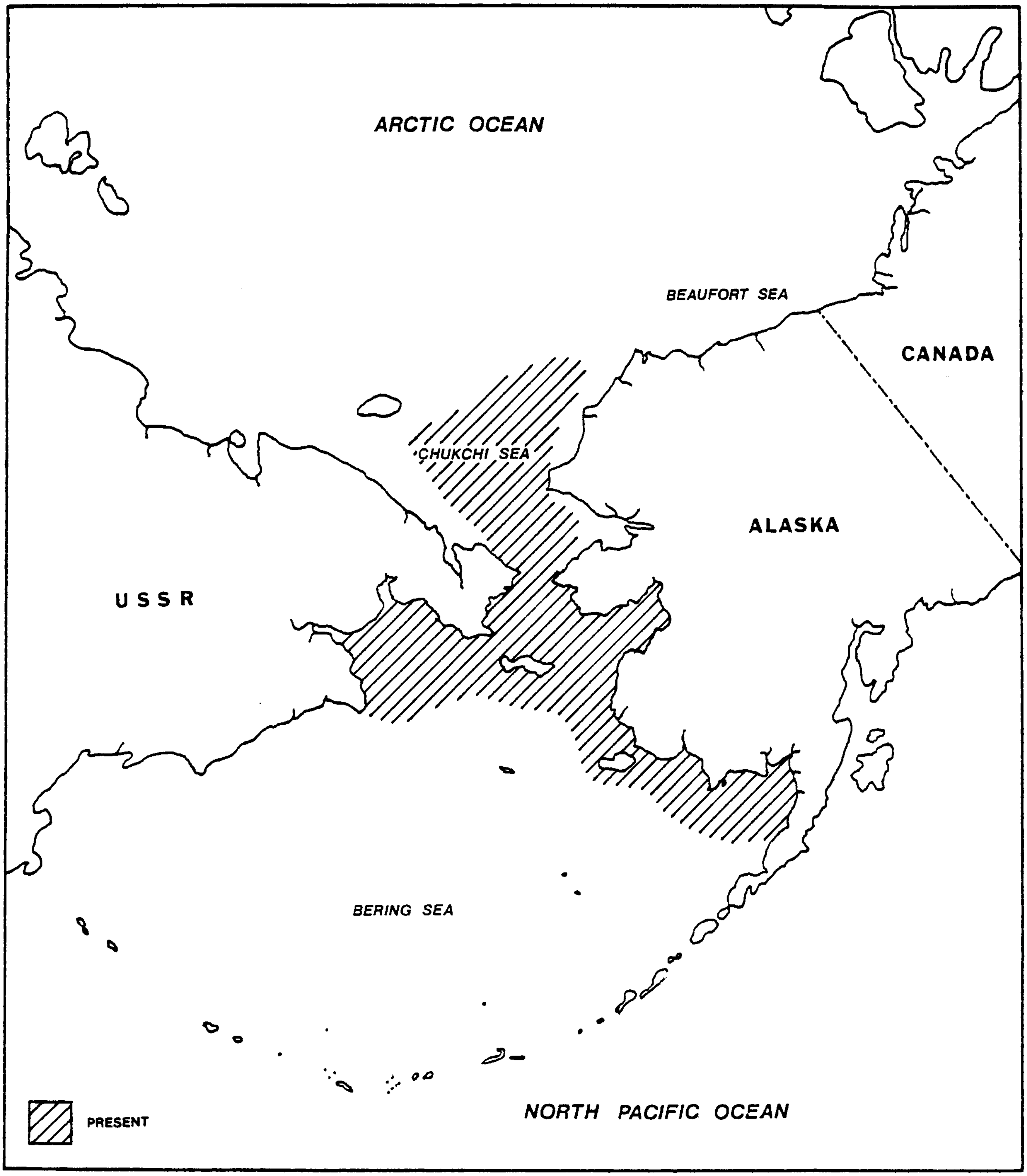

Figure 8. Distribution of belukha whales in November and December.

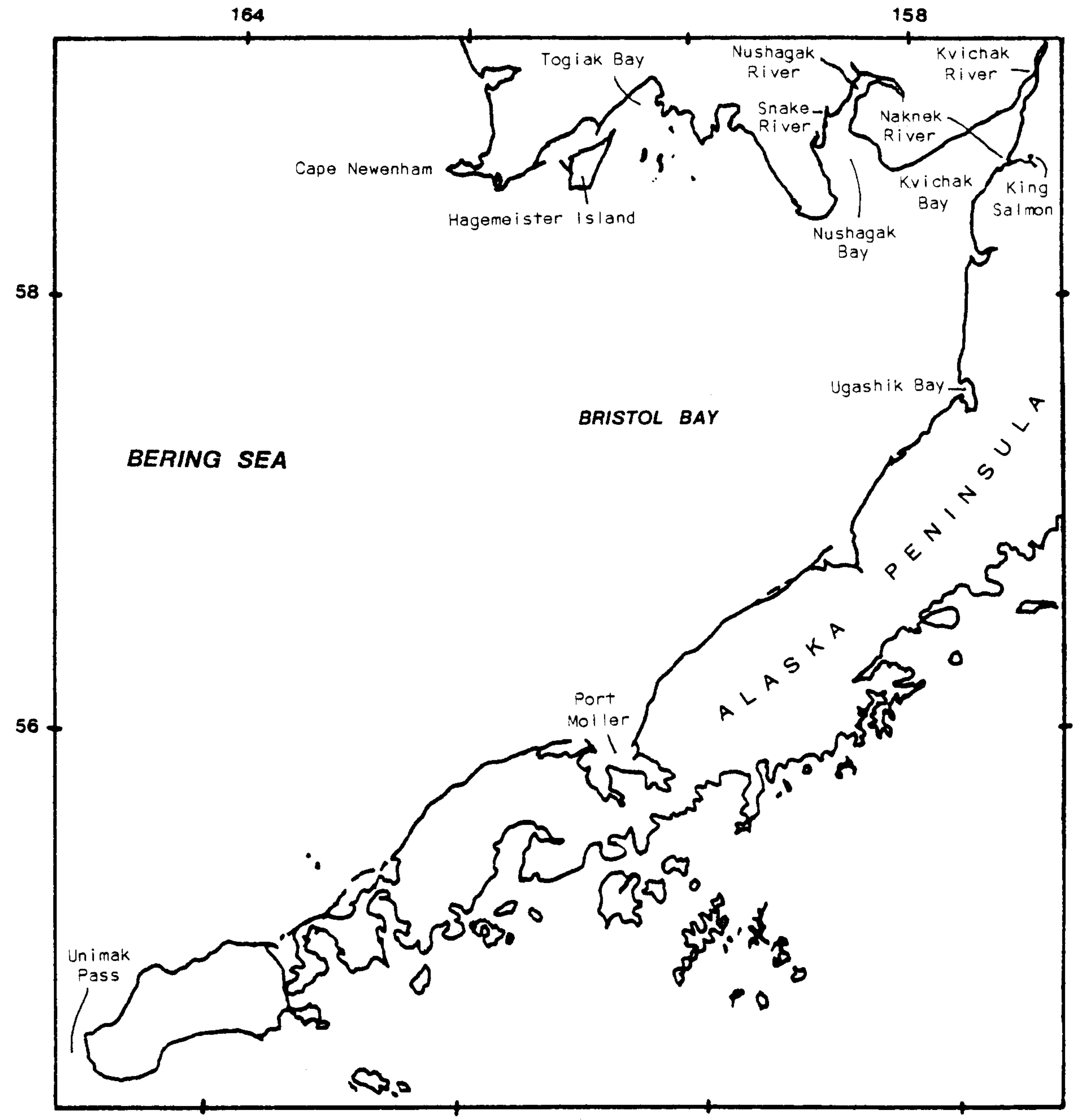

Figure 9. Map of the North Aleutian Basin showing locations mentioned in text.

the distribution, movements, and feeding of belukhas in inner Bristol Bay. Lensink (1961) summarized Brooks' work and added information for areas north of Bristol Bay. More recent studies include the work of Harrison and Hall (1978) primarily in the Bering Sea, and Fried et al. (1979); Lowry, Frost, and Nelson (1982); Frost, Lowry, and Nelson (1983); and Frost et al. (1984) in Nushagak and Kvichak bays. Other information is from the authors' unpublished observations, ADF&G unpublished data, interviews with area residents, and correspondence with biologists working in the area.

Belukhas utilize the Bristol Bay area throughout the year. They are most common and occur in the largest concentrations in nearshore waters during ice-free months (Frost et al. 1983a). Although small groups are occasionally observed near shore in inner Bristol Bay during winter, they are considered uncommon there at that time (Brooks 1954, 1955; Lensink 1961; ADF&G, unpublished).

In general, during winter-early spring belukhas are widely distributed in outer Bristol Bay and the southeastern Bering Sea (Lensink 1961; ADF&G, unpublished) and are believed to occur in close association with seasonal sea ice. They are probably more common during relatively heavy ice years, when the seasonal ice extends south into the Bay, than in years of less extensive ice cover. Leatherwood et al. (1983) sighted belukhas in Bristol Bay on surveys conducted in September, late October-early November, January, and February. Most sightings at this time of year are of groups of one to five whales. A notable exception occurred on 13 April 1976 when over 300 whales were sighted northwest of Port Moller (Braham and Krogman 1977). Examination of satellite imagery indicates that this sighting occurred close to the southern edge of the seasonal pack ice, which extended unusually far to the south at that time (Burns et al. 1981).

In April, as the seasonal ice starts to disintegrate and recede northward, belukha whales begin to move into coastal regions (Brooks 1956; Frost et al. 1983a). Whales are found both offshore and near shore at this time with sightings recorded from Hagemeister Island, Togiak Bay, and eastern Bristol Bay (Kenyon 1972). In April and May, concentrations of up to several hundred animals occur at the river mouths in Kvichak Bay (Brooks 1956; Frost et al. 1983a, 1984). The first concentrations usually occur in mid-April in and at the mouth of the Naknek River where the whales feed on smelt (Osmerus mordax). Belukhas, sometimes in groups of up to several hundred, ascend the Naknek River as soon as the ice goes out, moving at least as far upstream as King Salmon (30 river km from the mouth). When the ice in the Kvichak River breaks up (usually several weeks after breakup in the Naknek) belukhas move to the Kvichak River where, twice daily, groups of whales move upriver on flooding tides and downriver on ebbing tides. The period during which belukhas make daily movements up and down the Kvichak River coincides with the seaward migration of post-spawning smelt and with the peak outmigration of red salmon (Oncorhynchus nerka) smolts. Belukhas remain in Kvichak Bay during the adult salmon runs in June-August, when they are most often found between the western side of the bay and the Kvichak River mouth (Frost, Lowry, and Nelson 1983, 1984). Belukhas also occur in Nushagak Bay where they are first seen in mid-April in and near the Snake and Igushik rivers, along the west side of the bay, and off Etolin Point (Brooks 1956; Frost et al. 1983a; Frost, Lowry, and Nelson 1983, 1984). In May-July, whales are most commonly seen between the mouth of the Snake River and Clarks Point, and in the northern part of the bay near the junction of the Wood, Little Muklung, and Nushagak rivers (Lowry, Frost, and Nelson 1982; Frost, Lowry, and Nelson 1983, 1984).

Prior to the mid-1960's belukhas moved into several of the major rivers of Bristol Bay from breakup until mid-June (Lensink 1961). Beginning in 1965 tape recorded sounds of killer whales (Orcinus orca) were used to repel belukha whales from the mouth of the Naknek River and later the Kvichak River (Fish and Vania 1971; N. Steen and D. Bill, personal communication). This effort was designed to reduce belukha whale predation on outmigrating red salmon smolt by keeping the whales away from areas with the highest smolt concentrations. The belukha "spookers" were normally in operation from the end of May through the first two weeks of June and effectively displaced belukhas from the Naknek and Kvichak rivers during that period. When the use of spookers was discontinued in late June, belukhas again ascended these rivers but in low numbers. Attempts were made to extend the program to the Nushagak River but tides and other hydrological conditions prevented the establishment of a permanent program. After 1978 the belukha spooker program was discontinued, and belukhas have since resumed use of these river systems during the smolt outmigration (D. Bill and R. Randall, personal communication; Frost, Lowry, and Nelson 1983, 1984).

Belukhas are abundant in inner Bristol Bay through the remainder of the summer, but become progressively less common in autumn (Brooks 1954; Frost et al. 1983a). They are observed there with some degree of frequency until October when the whales are presumed to move offshore and westward. They have been reported east of Hagemeister Island in September (G. C. Ray, personal communication) and near Ugashik Bay in October (Harrison and Hall 1978). Local fishermen suggest they frequent the outer portions of the Bay. An October sighting near the Pribilof Islands confirms that belukhas do occur offshore over the continental shelf at this time (Harrison and Hall 1978). The degree to which belukhas utilize these offshore waters during summer and autumn is unknown. Sightings and changes in coastal abundance suggest that offshore habitats are not utilized extensively during the summer, but that they may be utilized during autumn. These changes correspond with the sharp decrease in abundance of anadromous fish in coastal waters during autumn.

The spring and summer movements of belukhas in Kvichak Bay are reported to be closely related to tidal movements. Brooks (1954) and Lensink (1961) found that belukhas generally swam up the Kvichak River and over the tidal flats on flooding tides. They usually returned to the bay on ebb tide, although they occasionally remained in the deeper portions of the river through the tidal cycle. Recent observations confirm this movement pattern in the Kvichak River and Kvichak Bay (Frost, Lowry, and Nelson 1983). In Nushagak Bay, Fried et al. (1979) observed belukhas a considerable distance up the Nushagak River on all phases of the tidal cycle. Other recent observations (Frost, Lowry, and Nelson 1983 and unpublished) also indicate that in the lower portions of the Snake River movements of whales are not closely correlated with tides although the direction of tidal flow has a major influence on river currents. The reason for this apparent difference in behavior of belukhas in Kvichak and Nushagak bays is unknown.

It has been suggested that belukhas avoid areas of heavy boat traffic during the commercial salmon fishing season. For example, Lensink (1961) attributed the decreased numbers of belukhas ascending the Kvichak River in mid-June to increased boat traffic in the river. However, since the early 1970's when salmon canneries located up the Kvichak closed down, boat traffic upriver no longer increases markedly during the salmon fishery, yet few belukhas use the upper river after mid-June. Frost, Lowry, and Nelson (1983 and unpublished) concluded that decreased use of the river coincides with the end of the red salmon smolt outmigration. In 1983, belukhas were last seen in large numbers in the Kvichak River on 6 June, by which time 90% of the smolt outmigration had occurred.

Fried et al. (1979) and others have suggested that whales gather near the Snake River to avoid boat activity since that area is closed to commercial fishing. However, Frost, Lowry, and Nelson (1983) observed that the same group of whales moved regularly between the Snake River mouth and the east side of Nushagak Bay near Clarks Point, where there was constant boat activity and where most of the processing fleet was anchored. On several occasions, they observed a large group of belukhas swimming among the boats at Clarks Point. Local biologists also have reported that belukhas are frequently numerous around Clarks Point (K. Taylor, personal communication). Thus, it seems unlikely that the absence of boat activity entirely explains the whales' preference for the Snake River mouth. Topography may be one of the factors affecting the suitability of the area. Although several rivers flow into Nushagak Bay, the most extensive mud flats begin at the mouth of the Snake River and extend south to the mouth of the Igushik River. The red salmon run in the Snake River is smaller than in any of the three other major rivers, but the extensive shallows may make those salmon easier to catch. In Kvichak Bay, belukhas are also frequently seen swimming near fishing boats and nets, and it is probable that the availability of salmon, tidal stage, and bottom topography rather than the presence or absence of vessels, determines distribution of the whales.

Belukha whales calve in Bristol Bay in June and July. Although Fried et al. (1979) did not see neonates during late May and June surveys of the lower Snake River and its mouth, they noted that local residents and fishermen reported calving to occur there. Neonates may have been present during the surveys, but due to their small size, dark coloration, and poor survey conditions they could not be seen (S. Weston, personal communication). In 1982, neonates were observed near the Snake River mouth during early July. In late June-early July of both 1982 and 1983 there was a substantial increase, thought possibly to be a calving concentration, in the number of belukhas using the Snake River mouth area; an estimated 400+ whales were present in mid-July of both years (Lowry, Frost, and Nelson 1982; Frost, Lowry, and Nelson 1983). In addition, beachcast neonates and floating afterbirth were observed in the area at that time. Calving also occurs in Kvichak Bay during late June or early July. Lensink (1961) reported seeing the first newborn calves in the lower Kvichak on 14 June. In 1983, females with new calves were observed near the Kvichak River mouth on 7 July (Frost, Lowry, and Nelson 1983). Afterbirths and several dead neonates were found in late June and early to mid-July.

It is difficult to determine the abundance of whales in Bristol Bay; survey conditions are poor due to turbid water, and dark-colored juveniles are particularly difficult to see. Sergeant (1973) in Hudson Bay and Fraker (1980) in the Mackenzie Estuary surveyed belukhas under similar hydrological conditions. Sergeant thought that belukhas spend a third of the time at the surface and the remainder of time underwater and thus multiplied his actual counts by 3 to account for unseen animals. Fraker assumed, since his view of an area was not instantaneous but lasted over 15 seconds, that he would see a higher proportion; he multiplied the number of whales sighted by 2 to obtain the total number present. Frost, Lowry, and Nelson (1983) used surface-time to dive-time information obtained from radio-tagged whales to calculate an average correction factor of 2.75 at a survey speed of 183 km/hr. Comparison of simultaneous aerial and boat counts yielded a similar multiplier of 2.4-2.8.

The abundance of belukhas in Bristol Bay has been estimated by Brooks (1955, 1956) and Frost et al. (1984). Brooks estimated that at least 1,000 belukhas were present in Bristol Bay in 1954, and approximately half that number in 1955 and 1956 (Table 1). In the late 1970's fishermen reported belukhas to be moderately abundant (R. Baxter and M. Nelson, personal communication). Sightings of up to 100-200 whales were regularly made in the Naknek River in April and May (D. Bill and N. Steen, personal communication). In late June 1979, during a flight over the north side of Kvichak Bay, R. Randall (personal communication) counted at least 250 belukhas and estimated that half the animals present were counted. During another flight in summer of 1979, he counted 400 to 500 whales in Kvichak and Nushagak bays combined. Lowry, Frost, and Nelson (1982) estimated that 400-600 whales were in the vicinity of the Snake River mouth in early July 1982. During April to August 1983, Frost et al. (1984) conducted twice-monthly surveys of Kvichak and Nushagak bays and estimated that approximately 1,000 belukhas older than neonates were in the area (Table 2). Based on recent and historical observations, we estimate that approximately 1,000-1,500 belukhas summer in Bristol Bay and the North Aleutian Basin.

Saint Matthew-Hall Basin

The proposed Saint Matthew-Hall OCS lease area, as discussed here, includes the coastal region of western Alaska from the southern Yukon Delta to Cape Newenham and westward to 174°W longitude (Figure 10). Use of the Yukon River estuary by belukha whales is discussed in detail in the section dealing with the Norton Basin.

In winter and early spring belukhas occur throughout the Saint Matthew-Hall lease area except in the immediate nearshore region where they may be excluded by shorefast ice. During occasional episodes of

Table 1. Estimated numbers of belukha whales in inner Bristol Bay in 1954 and 1955 (Brooks 1955). Estimates were based on surface and aerial observations and interviews with fishermen and local residents.

1954	May	June	July	August
Kvichak Bay	250	250-400	?	600
Nushagak Bay	?	250-400	400	400
Total, both bays, about 1,000				
1955				
Kvichak Bay	100	150-250	?	50-100
Nushagak Bay	?	250	250-500	450
Total, both bays, about 525				

Table 2. Estimated numbers (# counted x correction factor) of belukha whales in Nushagak and Kvichak bays, April-August 1983 (from Frost et al. 1984). Neonates are not included.

Date	Nushagak Bay	Kvichak Bay	Total	Adjusted Total[1]
15 April	218	474	692	747
2/5 May	41	584	625	675
17 May	85	274	359	388
31 May	27	212	239	258
14 June	49	259	308	333
24 June	182	55	237	286
29 June	347	572	919	993
14 July	496	181	677	731
14 Aug	0	309	309	334

[1]Total increased by 8% for yearlings which are not seen during aerial surveys (Brodie 1971).

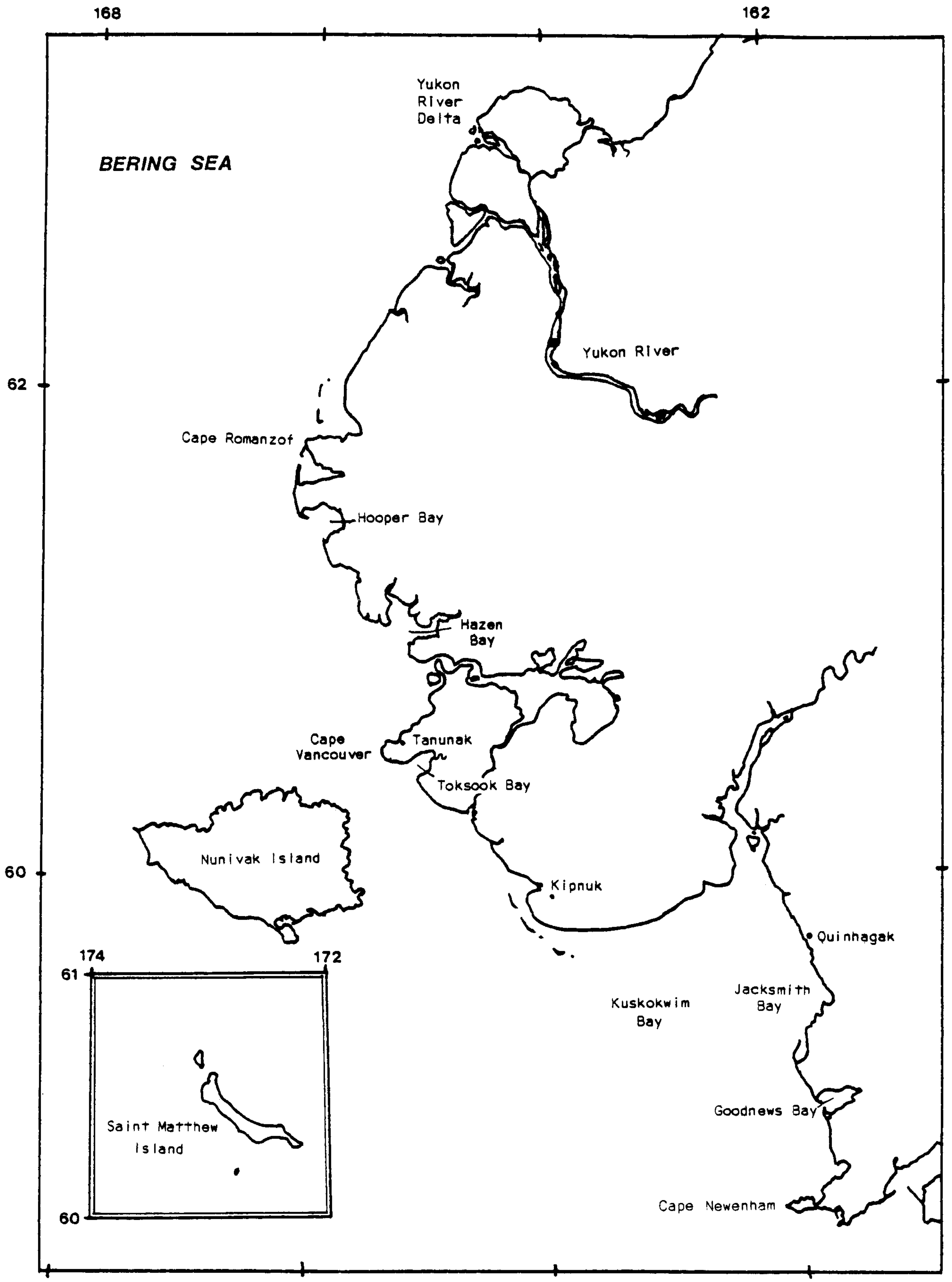

Figure 10. Map of the Saint Matthew-Hall Basin showing locations mentioned in text.

strong easterly winds which may break up the shorefast ice and move it offshore, belukhas have been seen near the mouths of the Yukon River, off Cape Romanzof, near Hooper Bay, and in Kuskokwim Bay (Nelson 1887; Seaman, unpublished). Residents of Hooper Bay report that such sightings occur during most winters (Seaman, unpublished). Nelson (1887) reported that large numbers of belukha whales utilized the coastal regions south of Cape Vancouver during winter. Recent interviews with residents of coastal villages in that area generally confirm Nelson's observations (ADF&G, unpublished).

Most winter and early spring observations of belukhas in the offshore portion of this basin during March and April have been west of 170°W. This is at least partially a result of the distribution of survey efforts. Belukhas are quite abundant in the large polynya and pack ice west and south of Saint Lawrence Island and are commonly sighted along the west and south shores of Saint Lawrence Island (see section on Norton Basin). They have also been frequently sighted in polynyas south and southwest of Saint Matthew Island in March and April (ADF&G, unpublished; Brueggeman, et al. 1984). Leatherwood et al. (1983) made sightings of belukhas south and east of Saint Matthew Island and between Saint Matthew and Saint Lawrence in February and March.

From breakup in May or June until freezeup in October or November belukhas occur throughout coastal waters between the Yukon River estuary and Cape Newenham. Their appearance and abundance is frequently associated with the availability and movements of various anadromous and marine fishes. In recent years their appearance in Kuskokwim Bay is reported by local residents to be irregular and of short duration. Sightings have been reported from Quinhagak, Toksook Bay, and Kipnuk (ADF&G, unpublished). Belukhas were considerably more common in Kuskokwim Bay earlier in the century (R. Baxter, personal communication). The last year belukhas were reportedly seen in large numbers near Quinhagak was around 1955. Belukhas have not been seen for many years in Goodnews Bay where they were previously very common (ADF&G, unpublished). Formerly, belukhas regularly entered the shallow waters of the Bay during the summer and were hunted by local residents.

Belukhas were formerly very abundant in the shallow waters of Jacksmith Bay (R. Baxter, personal communication). A village was located near there which depended to a large extent on an annual summer belukha hunt. It is said that in the early 1920's a large vessel came to Kuskokwim Bay and traded motor boats for king salmon (Oncorhynchus tshawytscha). The next year, about 1925, a very large belukha hunt took place in Jacksmith Bay in which it was reported that "all" the whales were killed. Belukhas failed to return to Jacksmith Bay in subsequent years and the settlement there was abandoned (R. Baxter, personal communication). This may have been a cause and effect situation, but there is also the possibility that, as in other parts of Kuskokwim Bay, there was a general consolidation of many small settlements during this period.

Belukhas frequent the coastal waters between Cape Vancouver and the Yukon River estuary during the spring, summer, and autumn. Observations by residents of Tanunak and local pilots indicate that belukhas are common in the Hazen Bay area where small groups are sighted every year during late spring and early summer. They are present but less common there in autumn. Belukhas also occur around Nunivak Island during the ice-free months but the degree of use at different times of the year is unclear. Historically, residents of Nunivak Island caught belukhas in nets during the autumn (Curtis 1930).

Belukhas are occasionally observed near and inside of Hooper Bay during the ice-free period, particularly during the late spring and early summer when their presence is closely tied to runs of king and chum (Oncorhynchus keta) salmon (Frost et al. 1983a). The number of whales in the area varies greatly from year to year. Belukhas are also common just north of Hooper Bay near Cape Romanzof where they are often seen in May in association with schools of herring (Clupea harengus) (Frost et al. 1983a). By early summer most whales leave this area and are believed to move to the Yukon River estuary where they are very commonly seen during summer and autumn.

Based on available information about seasonal movements of belukhas in Norton Sound, Bering Strait, and the Saint Lawrence Island region, it appears that a large portion of the whales that seasonally migrate through the Bering Strait to summer in the Arctic Ocean spend the winter in the Saint Matthew-Hall lease area. However, the actual number of belukhas either wintering in the area or passing through it during migration is unknown.

Saint George Basin

The Saint George Basin lease area encompasses a large portion of the southeastern Bering Sea (Figure 11). The northern portion of this area is on the continental shelf. The southern portion is off the shelf, with depths ranging from 200 m to more than 1,500 m. The extent and characteristics of seasonal ice cover are highly variable from year to year (Burns et al. 1981). During the "average" year, ice is usually present in the northern and northeastern portions, generally north of the Pribilofs. During cold winters and "heavy" ice years the ice may extend southward to approximately the continental shelf break, while in light ice years it may be entirely absent from the lease area.

It is difficult to assess the distribution and abundance of belukha whales in the Saint George Basin due to the scarcity of surveys and belukha sightings there. Most sightings have been made in conjunction with aerial and ship surveys directed at other species such as bowhead whales (Balaena mysticetus), walruses (Odobenus rosmarus), and ice-associated seals. Since these surveys are frequently restricted to particular habitats (ice front, shelf edge, etc.) where the target species are more likely to occur, they may not provide a reliable indication of the use of the area by belukhas.

We know of only one sighting of belukha whales in the Saint George Basin during the summer. Leatherwood et al. (1983) reported seeing a single animal southeast of the Pribilof Islands on 8 August 1982. This was the only belukha they sighted in four surveys conducted in the Saint George Basin between late May and September 1982. Harrison and Hall (1978) and Braham et al. (1984) surveyed a large portion of the Saint George Basin

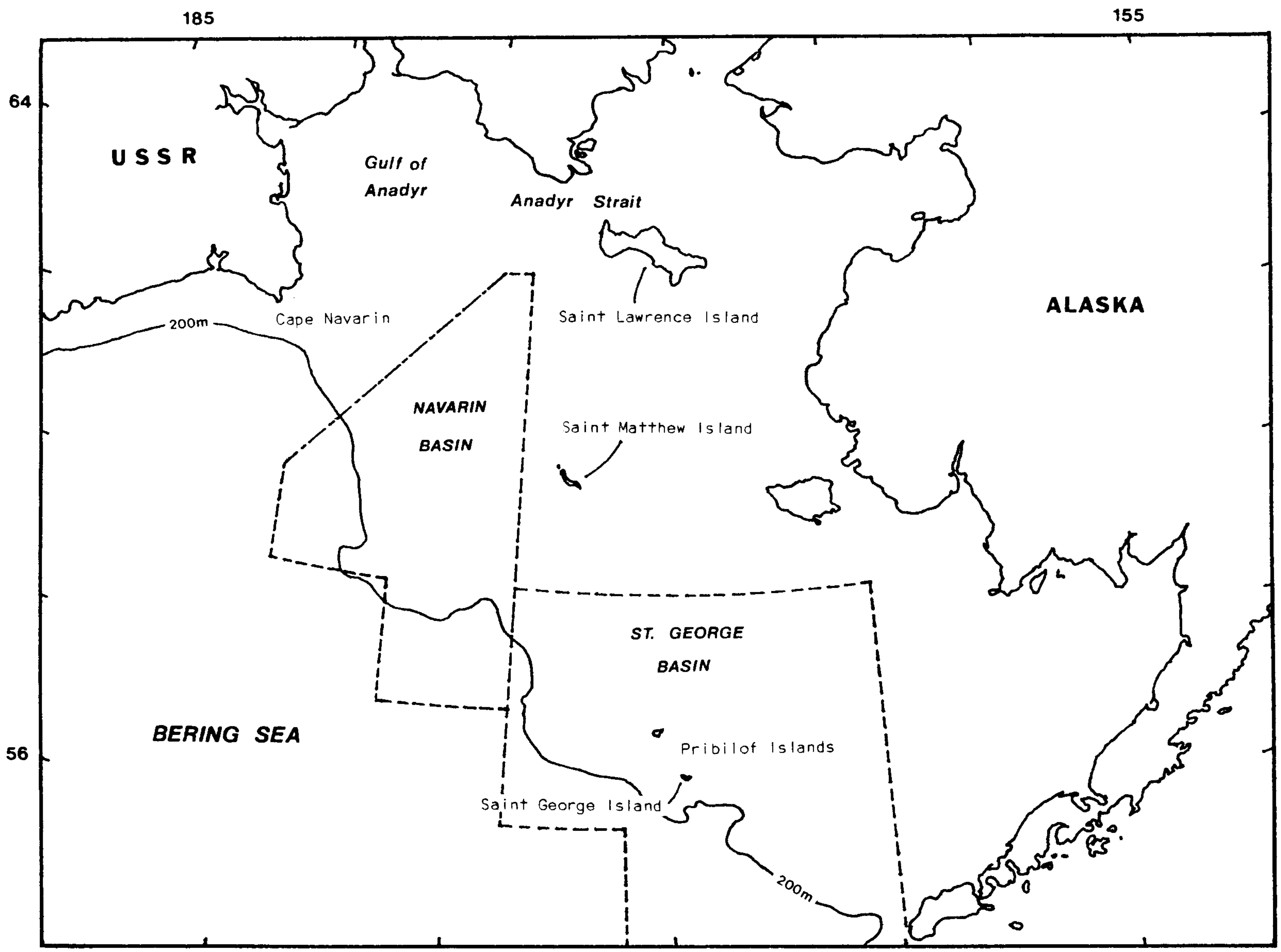

Figure 11. Map of the Saint George and Navarin basins showing locations mentioned in text.

during summer and saw no belukhas. It is possible that they occur in small numbers since they have been seen in the area during the spring and autumn (Harrison and Hall 1978; ADF&G, unpublished). When present, belukhas are probably restricted to the relatively shallow waters overlying the continental shelf and may be somewhat more common in the northeastern portion of the lease area which is closest to the coast.

In late summer and early autumn, belukhas start to leave the Bering Sea coast and by mid to late autumn there is a clear decrease in abundance in some nearshore areas, including in Bristol Bay. This decrease frequently parallels a decrease in the abundance of primary prey species. It is unclear where these whales go at this time, but since there is little evidence of a shift to neighboring coastal areas, it is likely that at least some utilize the more offshore regions of the Bering Sea including the northern portion of the Saint George Basin. Harrison and Hall (1978) observed two belukhas on 11 October 1976, approximately 110 km southeast of Saint George Island. Several species of suitable prey are abundant in this area (Pereyra et al. 1976).

Belukhas probably occur in greatest abundance in the lease area during winter and spring when seasonal ice excludes them from many nearshore regions. They may be most common in Saint George Basin during heavy ice years when they have been observed in March and April near the Pribilof Islands, in western Bristol Bay, and south of Nunivak Island. They are probably less common when seasonal ice in Saint George Basin is minimal or absent. A significant but unknown proportion of the whales that winter in the Saint George Basin lease area probably summer in the coastal waters of the eastern Bering Sea and Bristol Bay.

We cannot presently estimate the number of belukhas utilizing the Saint George Basin. Based on limited sightings, the availability of apparently suitable habitat, and the area's proximity to coastal areas regularly used by belukhas, the Saint George Basin lease area may be important to a large number of whales. We expect that the use of the lease area varies annually with peak use during winter and spring when sea ice is present.

Navarin Basin

The Navarin Basin includes a large portion of the central Bering Sea west of the Saint Matthew-Hall and northwest of the Saint George Basin lease areas (Figure 11). The northern portion is on the continental shelf, while the southern part occurs over very deep water. Navarin Basin is remote; the closest land masses are Saint Matthew Island to the east, Saint Lawrence Island to the northeast, and the coast of the USSR to the west.

It is difficult to assess utilization of the Navarin Basin by belukha whales due to the lack of settlements in the area and the near absence of sightings from any months except March, April, and early May. Aerial sightings of belukhas here have been on an opportunistic basis in conjunction with surveys for other species.

It appears that the portion of the Navarin Basin overlying the continental shelf is an important part of belukha winter range. In the autumn and early winter large numbers of belukhas are consistently observed moving south into this region through Anadyr Strait (Kleinenberg et al. 1964; F. Fay, personal communication; Seaman, unpublished). In March and April belukhas have frequently been sighted during the course of survey flights over the Navarin Basin (H. Braham, personal communication; ADF&G, unpublished). Brueggeman et al. (1984) observed several hundred belukhas west of Saint Matthew Island in March 1983. Belukhas are also common east and west of the Navarin Basin during the same period. Although there are no sightings available for January and February, distribution then is probably similar to that in March and April although generally more northerly. As winter progresses the whales move southward with the advancing pack ice. Belukhas are thought to be rare or uncommon south of the continental shelf because they are generally shallow water feeders, and the ice with which they are usually associated in winter rarely extends south of the shelf break (Burns et al. 1981).

Belukhas appear to move inshore or northward out of the Navarin Basin in spring. Residents of Gambell see these whales passing through Anadyr Strait in March and April, with the numbers diminishing in May (Seaman, unpublished). Kleinenberg et al. (1964) observed several hundred whales in late May moving northward by Cape Navarin into the Gulf of Anadyr. Some belukhas may remain until June in association with an ice remnant which predictably occurs in the northern Navarin Basin each year (Burns et al. 1981), then move west to coastal areas of the Gulf of Anadyr where they are common until freezeup (Tomilin 1957; Kleinenberg et al. 1964). Belukhas are probably uncommon in the ice-free waters of the Navarin Basin in summer and early autumn when they are abundant in coastal areas, but return in autumn when coastal areas freeze over.

Many of the belukhas which summer in the Chukchi, Beaufort, and East Siberian seas probably occur seasonally in the Navarin Basin. Some may utilize the area for a major portion of those months when ice is present, while others may occur there for only a few days. The abundance of belukhas in Navarin Basin is probably highly variable depending on ice and feeding conditions, but is likely to be greatest during years of extensive ice cover.

Norton Basin

For the purpose of this discussion Norton Basin includes Norton Sound, the southwest coast of the Seward Peninsula, and the Chirikof Basin including Saint Lawrence Island (Figure 12).

Belukha whales are uncommon during the coldest winter months in inner Norton Sound due to the usual presence of an extensive, comparatively unbroken ice cover. Hunters from Elim have reported sightings and occasional entrapment of belukhas in openings in the ice south of that village (Seaman, unpublished), but such sightings are uncommon since leads in the ice are not regularly present in areas accessible to local hunters.

Belukhas utilize the coastal areas of Norton Sound including the Yukon River estuary during the entire ice-free period from breakup in May or June until freezeup in October or November. Belukhas have often been sighted as early as April off the shorefast ice near Shaktoolik and Cape

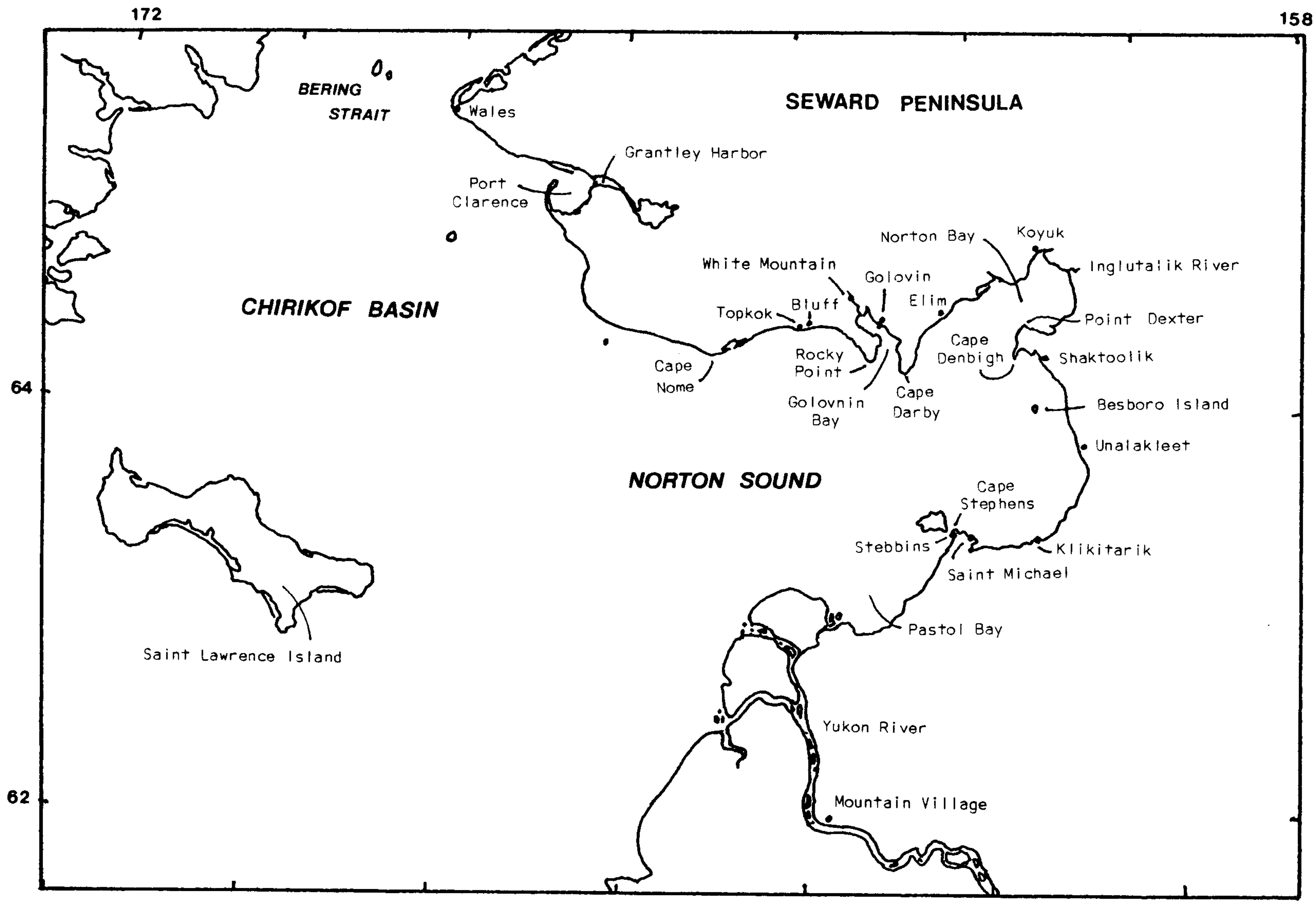

Figure 12. Map of the Norton Basin showing locations mentioned in text.

Denbigh. They are most common near the eastern Norton Sound villages of Stebbins, Saint Michael, Unalakleet, Shaktoolik, Koyuk, and Elim from late May through June and from September until November, although they are present throughout the summer (Frost et al. 1983a). People from Stebbins, Saint Michael, and Elim believe that belukhas seen in spring frequent the mouths of and nearshore waters off the Yukon River during the summer. Ray (1964 and 1975) identified the historically important belukha hunting areas in Norton Sound as Pastol Bay, the mouth of the Inglutalik River (Norton Bay), and Golovnin Bay. Nelson (1887) found that belukhas were very common in southern Norton Sound near Saint Michael and near the mouths of the Yukon River. Residents of Golovin and White Mountain confirm that belukhas were historically common in Golovnin Bay and Golovnin Lagoon (ADF&G, unpublished).

Belukhas begin to utilize the coastal areas of Norton Sound at the same time that migratory and anadromous fishes arrive there. During herring spawning, which commences in late May or early June as breakup occurs (Barton 1979), belukhas are regularly seen following schools of herring, particularly near Golovnin Bay, Cape Denbigh, Point Dexter, and near Saint Michael (Nelson 1887; Giddings 1967; L. Barton, personal communication; Frost et al. 1983a). Local pilots have also seen belukhas feeding on herring in mid-June near Besboro Island. In 1981, belukhas were seen chasing and eating herring off Klikitarik in late April and Cape Stephens in mid-May (ADF&G, unpublished). At least 100 were present and feeding on herring in the shallows near Point Dexter in late May 1981. Runs of herring are followed slightly later by capelin (Mallotus villosus) and salmon, which are also important prey of belukhas.

Throughout the summer and autumn belukhas are found near and in the mouths of the Yukon River where they feed on salmon. In 1980, they were common near the southern mouth in late May and June; and in early July over 150 were seen regularly near Big Eddy, just upstream from Emmonak (J. Burns Jr., personal communication). In July 1981 over 100 belukhas were seen feeding just off the northern mouth of the Yukon and another smaller group was sighted to the east in outer Pastol Bay (Ljungblad et at. 1982). King, chum, red, and silver (Oncorhynchus kisutch) salmon enter the Yukon River from late May to early September (Geiger and Andersen 1978). There are numerous historical accounts of belukhas swimming upriver several hundred kilometers above tidal waters, probably following salmon. They have been reported from Nulato and Koyukuk, over 800 kilometers from the river mouth, both historically and as recently as 1981 (Nelson 1887; Collins 1945; Lensink 1961; ADF&G, unpublished). Residents of Tanana remember seeing belukhas near their village in the early 1900's. A group of four or five belukhas was reported several km upriver from Tanana (1,200 km from the river mouth) in June 1982 and at the same general time a single large adult was reported 130 km further upriver above Rampart (F. Andersen, personal communication). In recent years belukhas have been observed occasionally at Mountain Village, 110 km upriver.

In general, belukhas appear to move up the Yukon River less frequently than they did 50-75 years ago. They are still very common, however, around the mouths of the river where they feed in the shallows. Although the use of those waters may have been altered to some extent by increased fishing and related motorboat activity, the changes are not reported to be great (ADF&G, unpublished).

Near Saint Michael from midsummer to freezeup Nelson (1887) found that belukhas fed extensively on saffron cod (Eleginus gracilis). He observed that feeding occurred mainly at night and in the early morning in the bay near Saint Michael and in the many tidal creeks south to Kuskokwim Bay. In late September and October of 1976 and 1981 groups of 30-60 belukhas were feeding during daytime on schools of saffron cod near Cape Darby and Rocky Point at the entrance of Golovnin Bay (Lowry, Frost, and Burns 1982). About 150 belukhas were seen between Topkok and Bluff in early September 1981 (R. Nelson, personal communication).

Along the coast of the Seward Peninsula from Cape Nome to Wales, belukhas are seen from spring through autumn. They are sometimes seen in the pack ice off Cape Nome and the city of Nome as early as April. They were seen in early May of 1979 by Eskimos hunting walrus between Nome and Sledge Island. Cape Woolley and Cape Nome were once productive hunting sites for belukhas, with whales present throughout the ice-free periods but most common in early summer and again in autumn (Ray 1964; Seaman, unpublished). In November 1977, 150-200 belukhas were seen moving by Cape Nome; in November 1979, approximately 250 were seen there; and in November 1980, 75-100 whales were observed feeding just offshore (R. Nelson, personal communication).

During spring and summer, belukhas appear to move through the area from Cape Nome to Wales, sometimes foraging along the way, but not forming any major local concentrations. Near Cape Nome in spring and early summer they feed on schools of saffron cod and later have been observed following schools of herring (L. Barton, personal communication). The relationship between the belukhas of Norton Sound and those seen along the outer coast between Cape Nome and Wales is unknown, but they may be the same whales moving back and forth, or animals passing through the area. Historically large numbers of belukhas occurred in Port Clarence and Grantley Harbor, but today they are seen only occasionally and in small numbers (Ray 1964 and 1975; Seaman, unpublished). In previous years when belukhas were common in Port Clarence and Grantley Harbor their appearance coincided with that of spawning herring.

Near Wales, belukhas are reportedly most common from mid-March through mid-May when movement is generally northward, and in October and November when most movement is southward (Curtis 1930; Thornton 1931; Van Valen 1941; Ray 1964; Seaman unpublished). Sightings in March and early April are probably of whales migrating to the Beaufort Sea, while later spring sightings may be of whales headed for the Chukchi coast. During summer, belukhas are not common and may be seen moving to either the north or the south.

Near Saint Lawrence Island belukhas are seen commonly in the spring, and occasionally in autumn and winter, particularly when saffron and arctic (Boreogadus saida) cod are abundant (Seaman, unpublished). In April, large groups of belukhas (some of over 100 whales) have been observed moving north by Gambell, Southwest Cape, Southeast Cape, and East Cape. G. C. Ray (personal communication) and Braham et al. (1984) reported many belukhas in this area in spring, particularly north and northwest of the Island. Belukhas are rarely observed during the summer, usually as single animals or in very small groups of both gray and white individuals (F. Fay, personal communication; Seaman, unpublished).

In some years large numbers of belukhas are seen along the north and west shores of Saint Lawrence Island prior to freezeup. Occasional whales are seen in late October but most arrive from the north in November and December. Local residents report that belukhas are seen more often in the autumn at Gambell than at Savoonga; whales seen at Savoonga are usually following the coast of the island toward the west, occasionally remaining in the area for several days. Either before or shortly after the ice appears, belukhas move southward, at least some of them moving into the Gulf of Anadyr (Kleinenberg et al. 1964). F. Fay (personal communication) reported at least a thousand animals north of Saint Lawrence Island in late November and early December 1957. This group followed the north coast past Gambell, headed toward the Gulf of Anadyr. Sightings of equal or greater numbers were made north and west of Saint Lawrence Island in November of 1974 and 1976 (Seaman, unpublished). Smaller groups (15-25) are seen in December-March along the western and southern shores in areas of open water created by strong ocean currents and prevailing northwesterly winds. Groups of up to 250-300 have been reported near Southwest Cape (Seaman, unpublished).

There have been no systematic surveys directed toward determining the abundance of belukhas in Norton Sound or adjacent areas of Norton Basin. The best available information on abundance is based on the observations of local residents and biologists working in the area. In combination, those sources suggest that the number of belukhas utilizing the coastal waters of eastern Bering Sea from Bering Strait south to Kuskokwim Bay during summer at least equals and probably exceeds the number in Bristol Bay. A conservative estimate is 1,000-1,200 whales, possibly as many as 2,000. Although calving occurs in Norton Sound, specific calving areas have not been identified.

Hope Basin

Hope Basin includes the southeastern Chukchi Sea from Bering Strait north to Cape Lisburne (Figure 13). Most of our information on the distribution and movements of belukha whales in the coastal regions of the Hope Basin is based on field studies undertaken by the Alaska Department of Fish and Game at Point Hope and in Kotzebue Sound, and on interviews and conversations with long-time residents of coastal villages. Most of this information is reported in Frost et al. (1983b). There is little other published information regarding belukhas in this area.

During winters of years with "light" ice conditions, belukhas are not uncommon in the southern Chukchi Sea. Eskimo hunters from Wales see them in nearshore leads throughout the winter. In the 1950's when seal hunting was still a major winter occupation at Shishmaref, belukhas were occasionally seen by hunters traveling to the shore lead. On 5 March 1976, hunters reported a group of 35 belukhas trapped in the ice about 45 km southwest of Shishmaref (ADF&G, unpublished).

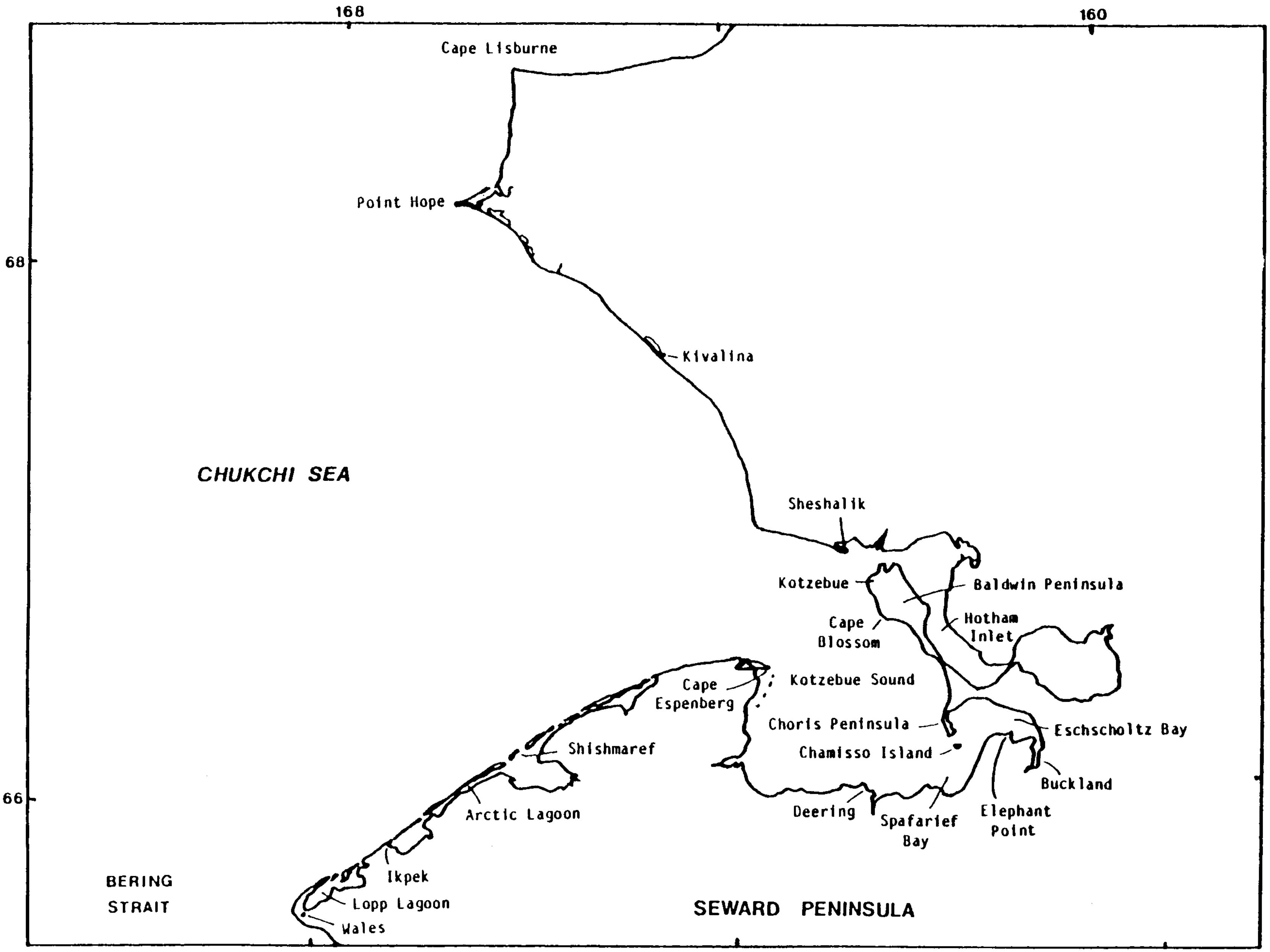

Figure 13. Map of the Hope Basin showing locations mentioned in text.

According to older residents of Shishmaref and Wales, belukhas were once common along the northern Seward Peninsula from Ikpek to Cape Espenberg during breakup and throughout the summer (Seaman, unpublished). In the early 1900's, reindeer herders from Shishmaref and Wales saw from a few to several hundred belukhas inside Lopp and Arctic lagoons in late June and July. If left undisturbed, whales would remain in the lagoons for extended periods. Belukhas occasionally entered Shishmaref Lagoon in July during periods of high water, and occurred along the nearby coast until freezeup when they were sometimes caught in nets set in the drifting ice near the village (Seaman, unpublished). At one time some of the people from Kotzebue Sound spent their summers fishing and hunting seals, caribou, and belukhas along the coast from Shishmaref to Cape Prince of Wales (Nelson 1887; Curtis 1930; Hall 1975; ADF&G, unpublished).

Belukhas have been infrequently sighted near Shishmaref in recent years. One group of about 20 was sighted in the ice 7 km west of the village on 4 June 1979 (Frost et al. 1983b). Residents of Shishmaref think there have been fewer whales near their village since the introduction and increased use of outboard-powered boats. Undoubtedly, large numbers of belukhas pass along the north side of the Seward Peninsula in spring on their way to Kotzebue Sound and locations further to the north, but this migration is probably far enough offshore to pass unnoticed by coastal residents.

Belukhas have been reported as common summer residents of Kotzebue Sound for as long as there are published records for the area (Nelson 1887; Curtis 1930; Foote and Cooke 1960; Ray 1964 and 1975; Foote 1965; Foote and Williamson 1966; Saario and Kessel 1966; Hall 1975; Giddings 1967; Seaman and Burns 1981; Frost et al. 1983b). Belukhas arrive in Kotzebue Sound in late May to mid-June, usually during or shortly after breakup when ice is still present but is broken and scattered. They are often first seen in pockets of open water in the northern Sound from Sheshalik to Cape Blossom. In 1978 the first confirmed sighting in Kotzebue Sound was made on 11 June southeast of Chamisso Island by a Kotzebue hunter enroute to Elephant Point. In 1979, a pilot from Kotzebue reported a group of about 30 whales on 1 June south of Cape Blossom. A group of 80-100 was seen at the same location on 6 June, and was observed approaching Sheshalik spit from the southwest shortly thereafter (G. Barr, personal communication). These first sightings in 1978 and 1979 were probably somewhat earlier than usual, since in both years the winters and springs were unusually warm and breakup occurred early. Foote and Cooke (1960) found that the first belukhas usually appeared near Sheshalik in mid- to late June.

Eschscholtz Bay is a large shallow bay in the southeastern corner of Kotzebue Sound about 85 km southeast of Kotzebue. It is presently the most productive belukha hunting site in the Kotzebue Sound area. Belukhas normally appear in Eschscholtz Bay in mid-June, slightly later than in northern Kotzebue Sound. In 1978, hunters from Deering sighted a group of at least 50 on 12 June, 6 km west of Elephant Point, and in 1979 over 200 were seen on 8 June along the northwest shore (N. Lee, personal communication). Belukhas appeared somewhat later in 1982 with the first whales seen on 21 June. When in the area, belukhas normally move into Eschscholtz Bay each day on the flood tide and leave on the ebb tide, but sometimes remain in the bay through the tidal cycle. They follow a deep channel which extends from Chamisso Island and parallels the north shore toward the Buckland River. On high tide and the first part of ebb tide, the whales commonly disperse along the north and east shores of the bay. On some flood tides they do not deeply penetrate the bay but concentrate in the shallow waters along the northeast shore. This may be due in part to avoidance of boat traffic near Elephant Point and the Buckland River. In June they are usually intercepted by hunters who herd or drive them into shallow waters of the inner bay. In June 1978, 1979, 1981, and 1982 belukhas continued to move in and out of the bay for a week to 10 days, presumably until hunting activity disturbed them to the the point they would no longer enter (Seaman and Burns, unpublished). In some years after hunting ceases and all hunters leave, some whales return to Eschscholtz Bay and remain until at least mid-July (Seaman, unpublished).

There appears to be considerable local movement of belukhas in Kotzebue Sound. The whales seen near Sheshalik, Kotzebue, and Cape Blossom are almost certainly part of the same group seen in Eschscholtz Bay. In 1979, during times when belukhas were not seen in Eschscholtz Bay, many whales were seen off Sheshalik, in Kotzebue Sound proper, and in Spafarief Bay just west of Eschscholtz Bay. On several occasions when there was much boat activity near both Sheshalik-Kotzebue and Eschscholtz Bay, belukhas were seen near Cape Blossom and seaward of Sheshalik. The residents of Deering say that belukhas are not seen near their village. Historically as well as in recent years the whales seem to have preferred the northern and eastern parts of the Sound.

The utilization patterns and movements of belukhas in Kotzebue Sound appear to be markedly different today than in the early 1900's (Seaman and Burns 1981; ADF&G, unpublished). Residents of Noatak and Kotzebue have noted that the greatest change occurred shortly after the introduction of outboard-powered boats in the 1920's and early 1930's. Foote and Cooke (1960) stated that before motorboats were used belukhas came very close to shore and often entered the shallows behind Sheshalik spit as well as Hotham Inlet. In the 1940's and 1950's there was a large increase in both the number and size of motorboats near Kotzebue and Sheshalik. Hunting became more difficult as fewer belukhas came into the shallows near these sites. By the 1960's boat traffic in northern Kotzebue Sound was heavy, traditional hunting methods gave way to less organized hunts, and fewer belukhas were seen in these shallow areas. With few exceptions, belukhas are now even less common near Sheshalik than in the 1960's although they are still common offshore. Many people from Kotzebue believe that the noises associated with modernization, such as electrical generation, construction, barge traffic, and low-flying aircraft have compounded the problem.

Noticeable changes in utilization patterns and movements of belukhas have also occurred in Eschscholtz Bay. Traditionally only the people from the small village of Buckland and occasionally Deering hunted belukhas in Eschscholtz Bay. In the early 1900's the village was located on the lower Buckland River, and residents seasonally moved downriver to Eschscholtz Bay for the belukha hunt. The whales, which were present in large but variable numbers every year, were hunted from umiaks and kayaks for one or two weeks in late June or July, or until enough meat was obtained. After the boat hunt was over (usually mid-July) belukhas returned to the bay and frequently stayed for days at a time moving over the tidal flats on flood tide and to the deep water at ebb tide. The older people remember that very large numbers of whales were present after the hunt in July in the shallows east of Elephant Point and along the north shore. Belukhas frequented these areas until early August, after which time they were more commonly seen in western Eschscholtz Bay, near Chamisso Island and the Choris Peninsula, or in Spafarief Bay.

In the early 1920's a reindeer processing plant was established at Elephant Point. About the same time the Buckland people moved their summer hunting camp from the north side of the bay to this location and by the late 1930's the village of Buckland was situated at Elephant Point year-round. With the increase in noise and activity, belukhas spent more time on the northern side of the bay and came less frequently into the shallows east of Elephant Point. However, boat traffic was generally moderate prior to the 1950's since the village was located very near the hunting area. Boat traffic increased somewhat about 1954 when the village was relocated up the Buckland River to above tidewater and people began moving regularly back and forth. In the late 1960's a few hunters from other areas began to come to Eschscholtz Bay to hunt and by 1975 there were many additional boats, particularly from Kotzebue. Hunters are of the opinion that uncontrolled boat traffic in June and early July, particularly during flooding tides, acts to reduce the number of belukhas entering Eschscholtz Bay and to decrease hunting success (ADF&G, unpublished).

Belukhas are known to both feed and calve in Kotzebue Sound. As in Norton Sound, the whales probably follow local movements of fish, feeding on species which are particularly abundant at certain times (Seaman and Burns 1981; Seaman et al. 1982). In Eschscholtz Bay there are substantial runs of herring, smelt, char (Salvelinus alpinus), and salmon, in addition to large numbers of saffron cod (Barton 1979; Burns, Frost, and Seaman, personal observation).

Calving has been reported in all coastal regions of the Sound; however, it is unknown whether calves are born only in shallow coastal regions or whether calving also occurs offshore. Most observations of calving are from near Sheshalik and from the eastern end of Eschscholtz Bay. Sheshalik may be of lesser importance at present due to avoidance by whales as discussed above.

The actual number of whales using the Kotzebue Sound area during the ice-free months is poorly known. Our estimate of abundance is based on our field studies, interviews with local residents, and occasional observations of local pilots and biologists working in the area. In July 1962, Burns (unpublished) saw 900-1,200 belukhas north of Chamisso Island, moving northward along the Choris and Baldwin peninsulas. On 8 July 1978 a resident of Buckland (N. Lee) saw an estimated 900-1,000 belukhas scattered in the shallows along the northwest shore of Eschscholtz Bay. At least 500 whales were seen from boats in Eschscholtz Bay on the first hunt in June 1978 and, based on hunting success, that is a very conservative estimate of the numbers of belukhas in the area that year. Local hunters reported that belukhas were also very abundant in 1977. In

1979 and 1981 hunters reported low numbers of whales which was reflected in very low harvests. In 1982 belukhas were very abundant in southeastern Kotzebue Sound and were also common near Sheshalik. Considering all observations we estimate that the peak number of whales in Kotzebue Sound during summer ranges from 500 to perhaps 2,000+ with considerable year-to-year variability which cannot at present be explained. This estimate is based primarily on observations made in southeastern Kotzebue Sound and may poorly reflect whale abundance in other portions of the Sound. Systematic surveys of the area are needed in order to refine these estimates.

Belukhas appear off Kivalina and Point Hope, which are along the migratory route of whales headed to the eastern Beaufort Sea, much earlier than they do in Kotzebue Sound. The northward spring migration past Point Hope has been documented by Foote (1960), Fiscus and Marquette (1975), Marquette (1976, 1977, and 1979), and Braham and Krogman (1977). At Point Hope belukhas are seen moving north through leads in the ice as early as March. The earliest recent sighting was on 21 March 1976 when two groups of approximately 80 and 120 whales were seen moving north through a lead southeast of Point Hope (Seaman, unpublished). In late March 1978 more than 100 were seen moving through the leads near Point Hope and about 1,000 were seen on 19 May 1980 (D. Smullin, personal communication). Belukhas are commonly seen and hunted throughout April and May, although hunting for belukhas takes place primarily when bowhead whales are not available (Marquette 1977; Braham and Krogman 1977). During spring most belukhas are seen swimming north, although in May 1976 several small groups were seen swimming south. Most sightings near Kivalina are in April and May and again in late June and early July (Frost et al. 1983b; Seaman, unpublished).

Hunters from Point Hope frequently see belukhas while hunting seals among the ice floes in late June and early July. During July, August, and early September, many belukhas are occasionally seen along the coast between Kotzebue Sound and Point Hope (Nelson 1887; Foote 1960; Frost et al. 1983b; Seaman, unpublished). Residents of Kivalina commonly see belukhas during the first part of September, usually swimming northwest along the coast toward Point Hope; they are rarely seen after that time. Seal hunters from Point Hope report seeing belukhas moving southward by the village during September and October. Belukhas are uncommon off Point Hope during midwinter, although they are occasionally seen south of there in January and February, following periods of strong northerly winds that form leads and polynyas in the ice.

Barrow Arch

The Barrow Arch area includes the Chukchi Sea coast from Cape Lisburne to Point Barrow (Figure 14). Most of the information presented below is based on our field studies conducted from 1978 to 1981, including interviews with local residents of Barrow, Wainwright, and Point Lay, and aerial surveys of the coast between Barrow and Cape Sabine. Specific sighting information is presented in Frost et al. (1983b). There is little published information on belukhas in this area.

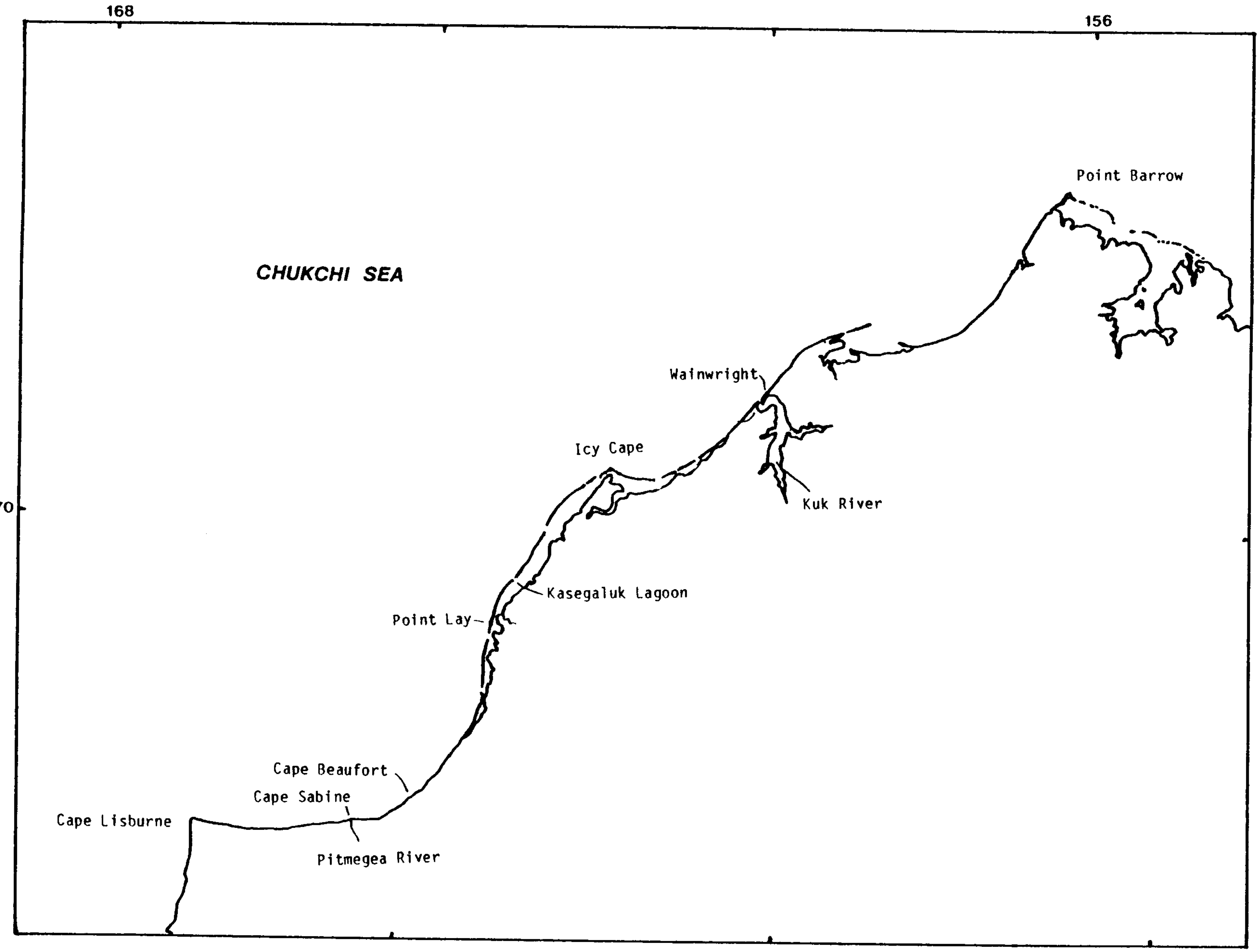

Figure 14. Map of the Barrow Arch region showing locations mentioned in text.

Belukhas are present in two "waves" along the northern Chukchi Sea coast. The first comprises whales migrating northward through leads in the pack ice during March-June and the second consists of whales that move into the coastal zone in June or July after the ice moves offshore. The timing of breakup is variable from year to year, with the ice moving out of the southern regions such as Ledyard Bay earlier than Peard Bay and Point Barrow to the north. On the average, the shore ice leaves Cape Sabine and Cape Beaufort regions in mid-June and Point Barrow about one month later.

Northward migrating belukhas move by Wainwright through leads in the ice as early as March (Nelson 1969; ADF&G, unpublished). However, the peak of the spring migration past Wainwright and Barrow occurs in April and May (Braham and Krogman 1977; Seaman and Burns 1981). Groups of from 10 to several hundred whales have been seen in the flaw zone between Cape Lisburne and Barrow. The spring migration is largely complete by late May with most whales moving into the eastern Beaufort Sea to summer in coastal waters off the Mackenzie River estuary (Fraker 1979).

The coastal area of the northern Chukchi Sea used most intensively by belukhas in June and July is Kasegaluk Lagoon and, particularly, the adjacent marine waters. Belukhas characteristically appear in the southern part of this region near Ledyard Bay in mid- to late June, then move gradually northward following the retreat of seasonal ice. Childs (1969) reported a group of 50 or more belukhas near the Pitmegea River on 24 June 1958. On 3 July 1982 an estimated 2,000-2,500 whales were observed in a loose aggregation moving northward along the coast in the area between Cape Sabine and Cape Beaufort (R. Quimby, personal communication). Calves were observed within the aggregation. Residents of Point Lay regularly see whales near Cape Beaufort prior to their arrival at Kasegaluk Lagoon.

Belukhas first appear near the village of Point Lay in late June or early July. In 1978 the people of Point Lay saw the first "summer" belukhas (as opposed to spring migrants on their way to the Mackenzie River estuary which may be seen in April and May) of the year in Naokok Pass on 2 July. At least 100 whales were moving northward close to the shore. In 1979 the first summer whales, a group of at least 100, were seen at Kukpowruk Pass on 22 June. This is one of the earliest recorded sightings in this area and was probably due to a very early breakup that year.

Although belukhas sometimes use the deeper portions of Kasegaluk Lagoon, they are most often seen in the nearshore waters outside the barrier islands (Figures 15-17). The whales are usually concentrated near major passes, particularly Kukpowruk, Utukok, Icy Cape, and Akoliakatat, and to a lesser extent, Akunik. At a given time, most of the whales in the area usually concentrate at the same pass, either in or just outside of the pass itself, or in the downstream plume of lagoon water. Most have been observed within 1/2-3/4 km from shore, usually with a few small groups or solitary animals (mostly adults) farther offshore in deeper water. On 10 July 1978 a large group of whales observed near Kukpowruk Pass was concentrated in and south of the pass; the nearshore current was moving south that day. Whales seen at Akoliakatat Pass on 13 and 15 July 1979 were in and to the northeast of the pass; the current was moving to the

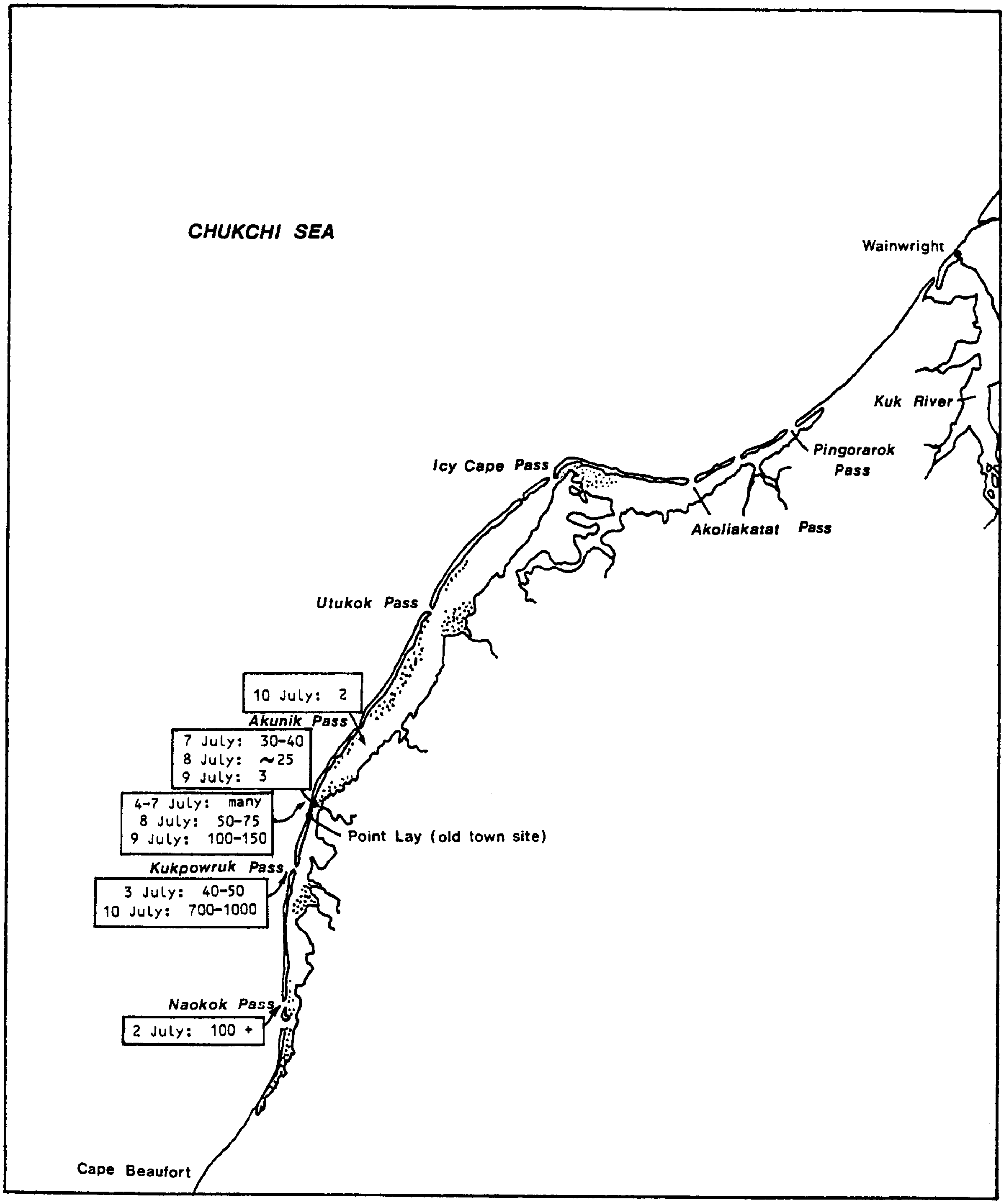

Figure 15. Sightings of belukha whales near Kasegaluk Lagoon, 1978.

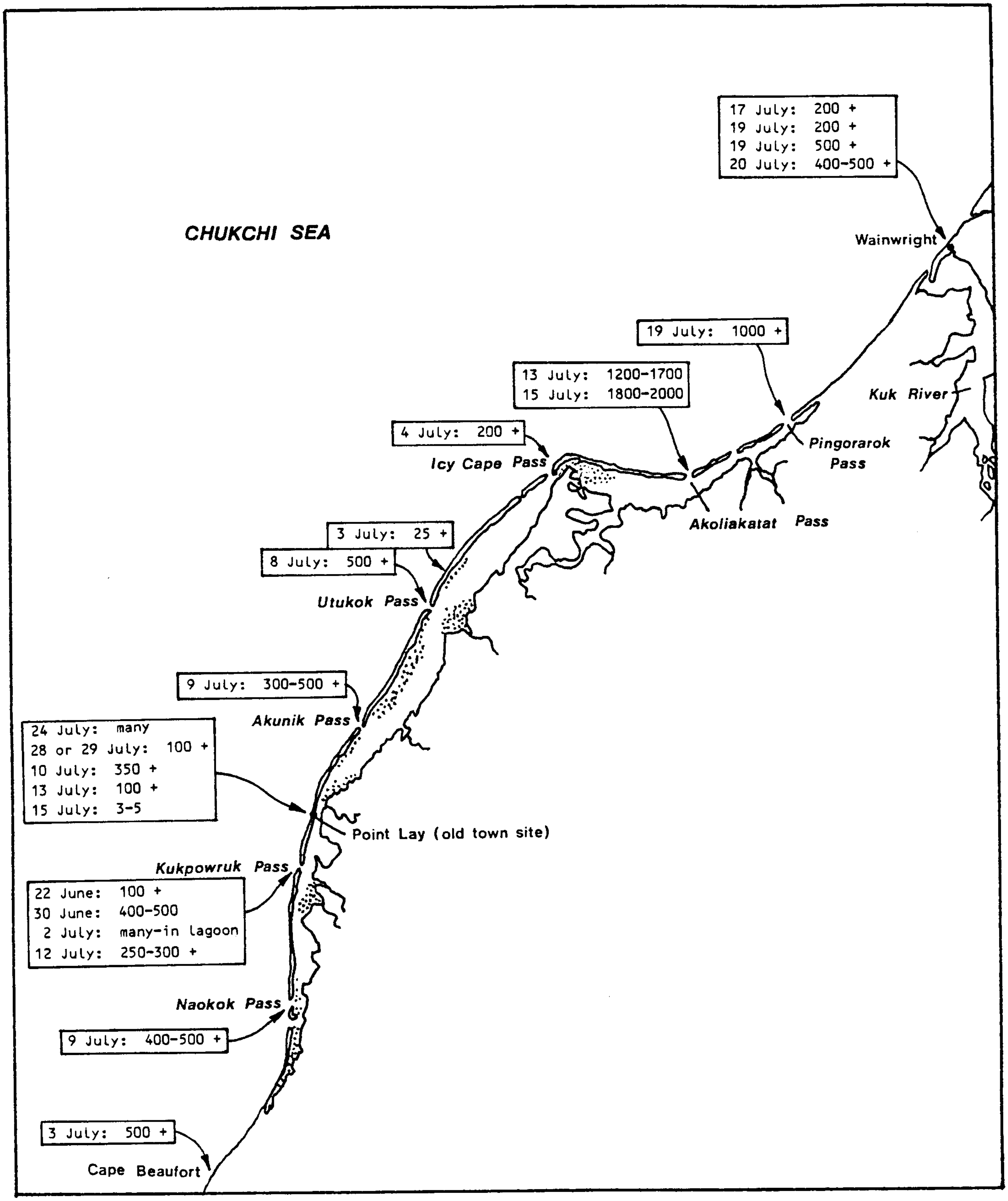

Figure 16. Sightings of belukha whales near Kasegaluk Lagoon, 1979.

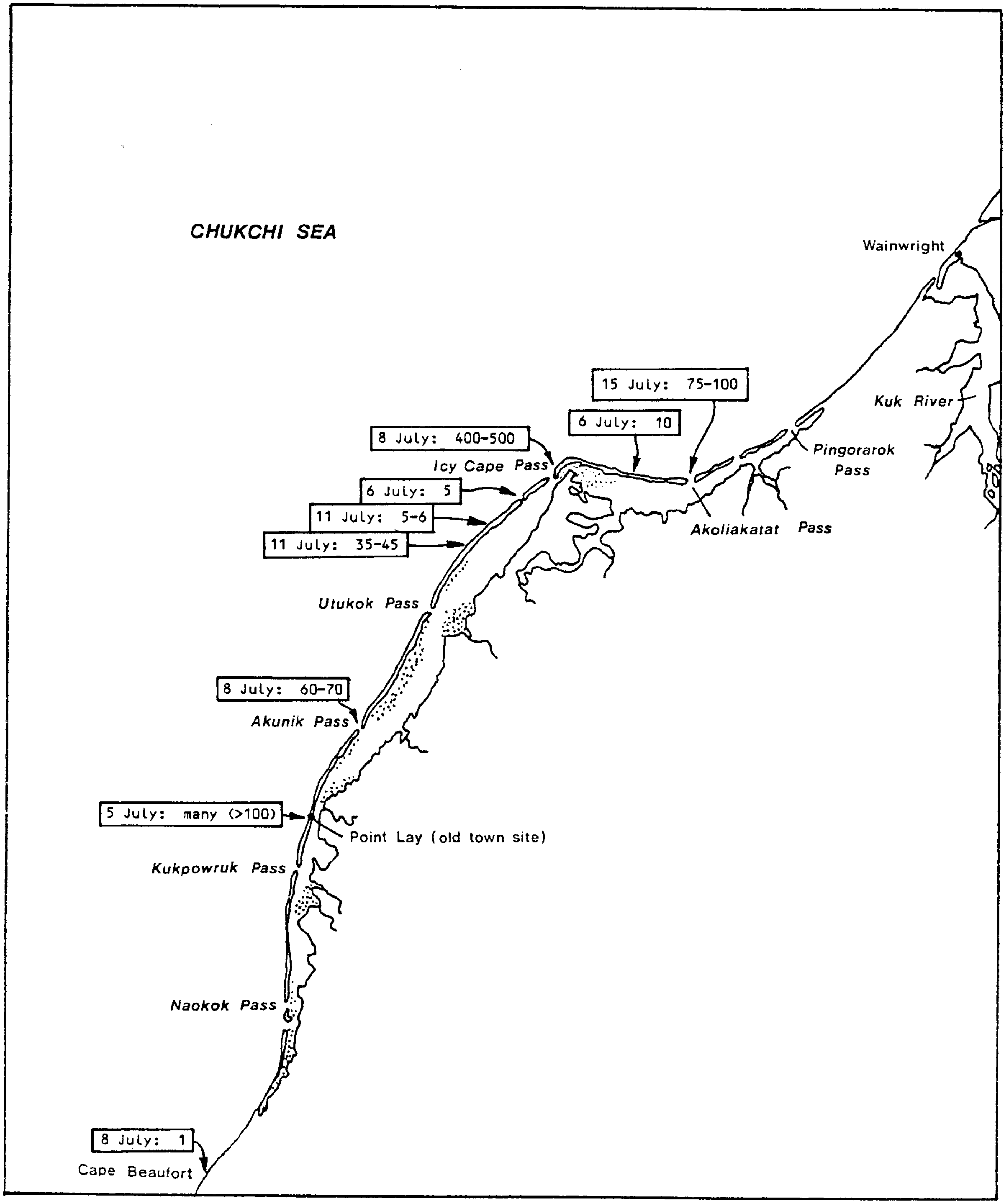

Figure 17. Sightings of belukha whales near Kasegaluk Lagoon, 1981.

northeast. Water temperatures in these lagoon plumes were as much as 2°C warmer than nearby marine waters (Seaman, unpublished).

Belukhas also occur in the deeper channels inside Kasegaluk Lagoon. Point Lay residents report that whales only enter the lagoon when water is moving out a pass. They often enter by one pass and leave by another. In some years, many whales enter the lagoon, while in others very few do so. The reason for this variability is unknown.

Sightings from 1979, the year for which our data are most complete, illustrate some aspects of the movement of belukhas within the area. By late June the shore ice had moved offshore along the southern third of the lagoon; the pack ice remained close to shore near Utukok Pass and Solivik Island. The first belukhas were seen and hunted on 22 June at Kukpowruk Pass, after which they reportedly moved northward and offshore. They were next seen on 24 June moving southward along the beach near Point Lay and at the same location on 28 June moving northward. A pilot estimated 400-500 whales near Kukpowruk Pass on 30 June. None were seen on 1 July but many were present near shore and inside of the lagoon near Kukpowruk Pass on 2 July. There appeared to be some movement of whales between the coast and the edge of the ice pack a short distance to the north.

On 3 July the coast was surveyed from Naokok Pass to Point Barrow. The pack ice extended south parallel to the coast to approximately midway between Utukok and Icy Cape passes. Several small groups of belukhas were seen along the ice edge north of Utukok Pass. At approximately the same time, over 500 were reported by a hunter about 125 km to the south at Cape Beaufort. No whales were seen between the two points. On 4 July a southwest wind blew the ice to just north of Icy Cape and a pilot saw approximately 200 whales near Icy Cape Pass. On 8 July over 500 whales were seen at Utukok Pass and on 9 July sightings of 300-500 animals were made in the vicinity of both Akunik and Naokok passes.

The last large sighting of belukhas made at Point Lay in 1979 was on 13 July. Over 100 whales were moving northward from Kukpowruk Pass where whales were seen the day before. At Akoliakatat Pass, approximately 1,600-2,400 belukhas were present from 13 to 18 July, at which time they moved farther east and north. Whales were sighted at Pingorarok Pass (1,000+ animals) on 19 July moving northward, and at Wainwright, 40 kilometers to the northeast between 17 and 20 July, with peak numbers late on the 19th (500+) and on the 20th (400). No whales were seen at Akoliakatat Pass on 19 July. Based on the timing of observations, the belukhas seen at Wainwright on the 19th and 20th were the same animals that were observed at Akoliakatat Pass a few days earlier.

According to the residents of Point Lay, belukhas left the Kasegaluk Lagoon region unusually early in 1979. They are usually seen at Point Lay until at least the end of July and sometimes, as in 1978, until the middle of August. In 1981, however, no belukhas were seen on aerial surveys flown after 15 July (Frost et al. 1983b). The whales usually depart to the north, occasionally following the coast where they are seen at Wainwright and, less commonly, at Barrow. The factors affecting the timing of belukha movements are poorly known, but may include ice conditions, water temperature, food availability, human disturbance in the form of hunting or aircraft overflights, and the presence of killer whales (*Orcinus orca*) (Bel'kovich 1960; Fish and Vania 1971; Sergeant 1973; ADF&G, unpublished).

Belukhas are known to calve in the Kasegaluk Lagoon area. On aerial surveys in July 1978 and 1979, neonates were observed among the adult and subadult whales. Twice, on 8 and 10 July 1978, belukhas were observed giving birth in the lagoon (Seaman, unpublished).

Our best estimates of the abundance of belukhas along this sector of the coast come from aerial photographic counts of whales at concentration areas. At Kukpowruk Pass on 10 July 1978, 703 whales were counted. At Akoliakatat Pass in 1979, 1,104 were counted on 13 July and 1,601 on 15 July. There are many problems associated with deriving an estimate of the total number of whales in concentration areas from aerial counts (Brodie 1971; Sergeant 1973; Fraker 1977). Some of the animals are underwater at any given time and, depending on turbidity of the water and the depth to which the belukhas dive, they may or may not be visible to an observer. Animals outside the main concentration areas (farther offshore) were more widely dispersed and appeared to remain underwater longer and therefore were not adequately represented in aerial photographs. Neonates and yearlings are also undoubtedly under-represented because their small size and dark color makes them difficult to see. By applying correction factors to account for the above problems in sightability, we estimate the total number of belukhas at Kukpowruk Pass on 10 July 1978 as 1,138, and at Akoliakatat Pass on 13 and 15 July 1979 as 1,575 and 2,282 (Table 3). Based on the above observations and those of local residents, we estimate that 2,000-3,000 belukhas may occur near Kasegaluk Lagoon in most years, although in some years the abundance of whales in the area may be considerably less.

Belukhas appear only occasionally at Wainwright and Barrow during the ice-free periods. Van Valin (1941) described a belukha hunt in "late spring" (presumably July) at Wainwright after the ice had gone out. Belukhas were seen and hunted there on 17 and 18 July 1979. Nelson (1969) noted that during the ice-free season, belukhas were most commonly seen in late July and August, and were usually moving northeast along the coast. Informants from Wainwright confirmed that information, and added that "long ago" belukhas sometimes congregated at the mouth of Wainwright Inlet and moved into the Kuk River during summer. They are occasionally seen near Wainwright in September. They were reported to be numerous off Wainwright on 3 September 1975 and small groups were seen off the coast between Wainwright and Barrow on 11 and 13 September of that same year (Fiscus et al. 1976).

Hunters near Barrow occasionally see belukhas moving along the shore in summer and early autumn. Murdoch (1885) reported that in 1881, 1882, and 1883 large groups of belukhas passed by Barrow as soon as there was open water near the beach and appeared again a week to 10 days later. He saw 100 or more whales pass by Barrow within 200 yards of the shore on 28 September 1881 but noted that September sightings were uncommon. Several older residents of Barrow indicated that belukhas were once commonly seen near the village every summer. Boat traffic and noise

Table 3. Counts from photographs, correction factors and total estimated numbers of belukhas, excluding neonates, seen near Kasegaluk Lagoon on survey flights in 1978 and 1979.

	Kukpowruk Pass	Akoliakatat Pass	
	10 July 1978	13 July 1979	15 July 1979
Photographic count	703	1104	1601
Correction factor for whales underwater and therefore not observed[1]	(140) 20%	(221) 20%	(320) 20%
Correction factor for areas where whales were not included in photos[2]	(211) 25%	(133) 10%	(192) 10%
Correction factor for yearlings not observed[3]	(84) 8%	(117) 8%	(169) 8%
Total estimated number of belukhas in concentration	1138	1575	2282

[1] Brodie (1971) working in clear water in Cumberland Sound estimated that he missed counting 40% of the animals because they were underwater and too deep to see. He did not use aerial photographs. Sergeant (1973) believed that he saw only 33% of the total animals while working in the murky waters of Hudson Bay. Seaman is of the opinion that he was able to count a much greater proportion of the total animals present in and adjacent to Kasegaluk Lagoon through the use of aerial photographs. On the average, whales were observed for 15-20 seconds and appeared on as many as three or four frames.

[2] Outside of the main concentration areas--the area covered by photographs--there were widely scattered individuals or small groups of whales that could not be included in photos taken on a single pass of the airplane. We assume that the age composition of those whales was similar to the main concentration.

[3] We used Brodie's (1971) estimate of 8% yearlings. Neonates are not included in the total estimates.

from large generators, vehicles, aircraft, etc., or other unknown factors may have discouraged whales from passing by near shore in recent years.

There is little information on the distribution and numbers of belukhas in the Barrow Arch portion of the northwestern Chukchi Sea. Burns (unpublished) recorded 13 whales in five scattered locations from 74°20'N to 74°41'N and 160°54'W to 167°24'W on 12 September 1974. On aerial survey flights conducted 10 through 20 September 1980, belukhas were sighted at four locations from 72°35'N to 73°00'N and 164°00'W to 169°00'W (Burns, unpublished). Recent detailed observations of autumn distribution in the northern Chukchi and western Beaufort seas are discussed in Burns and Seaman (1985).

Diapir Field

The Diapir Field planning area includes the Alaskan Beaufort Sea and a portion of the northeastern Chukchi Sea east of 162°W longitude (Figure 18). The continental shelf is quite narrow in the Beaufort Sea, generally extending offshore less than 100 km. Nearly continuous ice cover exists through much of the winter with a few offshore leads developing in the spring (Fraker 1979; Burns et al. 1981). Shorefast ice usually persists through June. In most years the pack ice retreats northward in mid to late summer leaving the coastal waters ice-free until freezeup in late September to early November (Burns et al. 1981). In some years the ice never leaves the coastal waters of the Beaufort Sea, while in other years the southern edge may be a hundred kilometers or more north of the coast.

Belukha whales are absent from the Diapir Field during most of the winter, from late November through March. Ice and weather conditions do not produce areas with predictable open water, and favorable wintering conditions for belukhas generally do not occur. Small numbers of whales may become entrapped by ice during the autumn migration, but the incidence of this is probably low. Observations of entrapped belukhas in the eastern Canadian Arctic (Porsild 1918; Freeman 1968) suggest that attempts to overwinter under these conditions frequently result in high mortality.

Belukha whales are common and at times very abundant in the Diapir Field during the spring, summer, and autumn. The majority of belukhas that seasonally occur in the Beaufort Sea are part of a group of at least 11,500 whales that summer in the Canadian Beaufort Sea and overwinter in the Bering and southern Chukchi seas (Braham and Krogman 1977; Fraker 1979; Davis and Evans 1982). The spring migration of belukha whales in the Chukchi Sea past Point Hope commences in mid- to late March (see Hope Basin and Barrow Arch planning area discussions). The earliest recorded sighting of belukha whales passing Point Barrow was on 2 April 1977 when a Barrow hunter, Arnold Brower (personal communication), sighted over 60 animals moving through a narrow lead off the shorefast ice. Four days later several hundred whales were seen. It is possible that belukhas occasionally pass by Barrow as early as late March. Belukhas are known to utilize offshore leads during the spring migration (Braham et al. 1984) and it is likely that some pass Point Barrow unnoticed by local hunters.

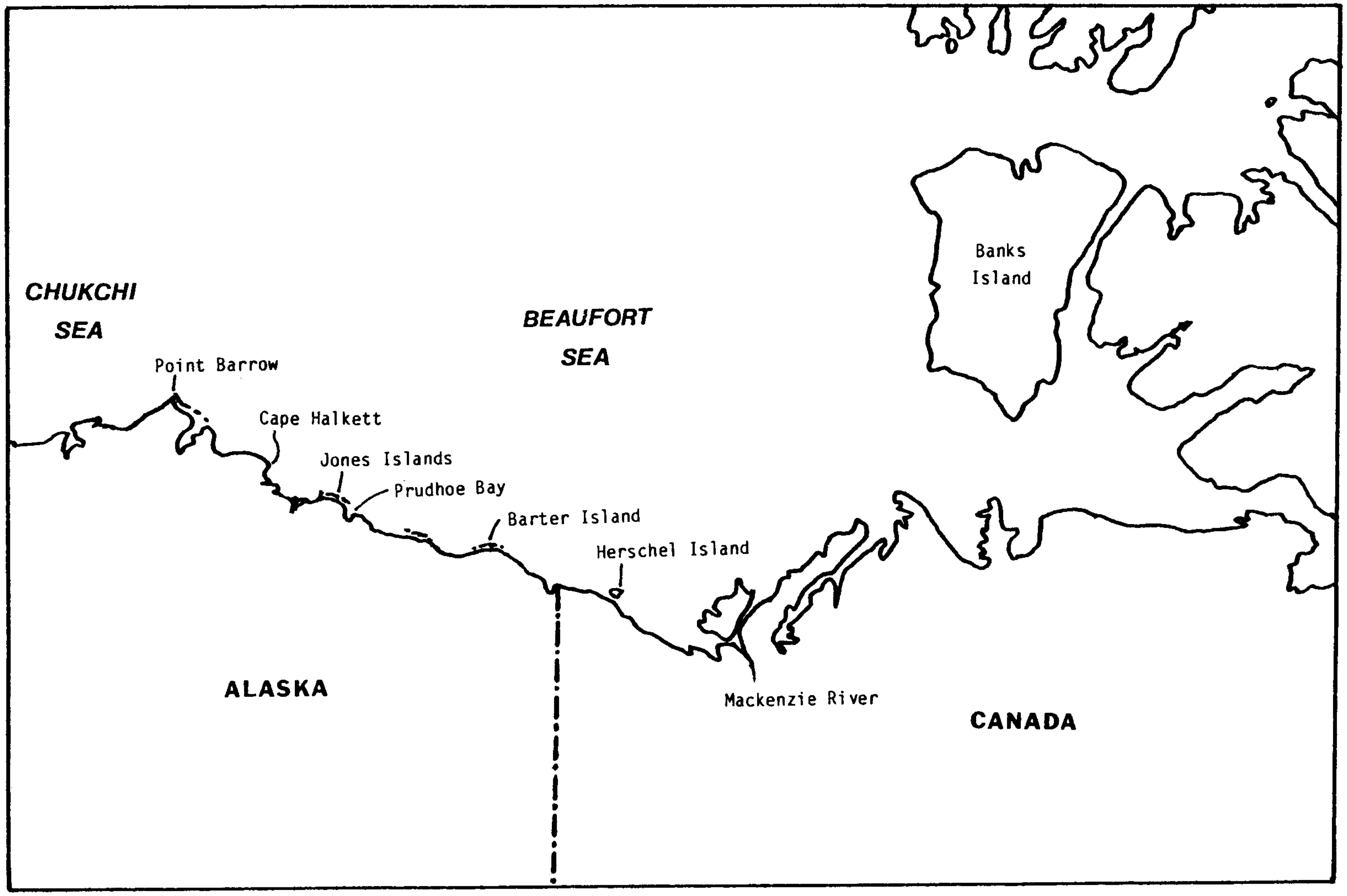

Figure 18. Map of the Diapir Field showing locations mentioned in text.

The peak of the spring migration past Point Barrow occurs from late April to the third week of May and varies in relation to ice conditions (Braham and Krogman 1977; G. Carroll, personal communication). The general north and east migration past Point Barrow continues through at least early July. Braham et al. (1984) observed belukhas north of Barrow up until their last aerial surveys in late June. Harrison and Hall (1978) observed two groups of 9 and 23 belukhas north of Barrow the first week of July and Murdoch (1885) reported whales along the coast at Barrow in the middle of July immediately following breakup.

The proposed migration route of belukha whales from Point Barrow to the eastern Beaufort Sea is described in detail by Fraker (1979). Observations by Ljungblad (1981) confirm that in late May and June migrating whales utilize offshore leads in pack ice which extend northeast from Barrow, into the Beaufort Sea. Many whales appear to congregate in the leads, polynyas, and open water west of Banks Island and in Amundsen Gulf in May and early June. By late June most of these whales have moved to the shallow, warmer waters of the Mackenzie River estuary where concentrations in excess of 2,000 whales are observed in some of the bays (Fraker et al. 1978). However, some belukhas have been seen moving eastward in Alaskan waters as late as 27 June and 15 July (Ljungblad 1981; ADF&G, unpublished).

Belukha whales have never been observed in large numbers during the summer in the coastal waters of the Alaskan Beaufort Sea. This is in marked contrast to the Canadian portion of the Beaufort Sea where up to 7,000 whales have been observed in the Mackenzie River estuary during July and August (Fraker 1980). Long-time residents of the Alaskan mid-Beaufort region, Jim and Harmon Helmericks (personal communication), indicate that belukhas are common off the shorefast ice until it moves away from the coast, usually between late June and mid-July. During the remainder of the summer, belukhas are rarely observed in the ice-free coastal waters of the Alaskan mid-Beaufort Sea.

During summer, belukhas are occasionally observed in the pack ice or ice-free waters near Barter Island. In July, these whales are typically observed moving eastward close to shore in small groups of 5 to 15. During August belukhas occur in groups of similar size, but are observed to move both east and west along the coast. Hunters of Kaktovik on Barter Island killed several belukhas on 19 August 1980.

There have been very few sightings of belukha whales within 120 km of the coast in the waters and pack ice of the Beaufort Sea during July and early August. Harrison and Hall (1978) saw four whales on 18 August 1976, approximately 75 km north of Cape Halkett, and Ljungblad et al. (1982) made three sightings of 26 animals at 96, 220, and 270 km north of Prudhoe Bay on 22 August 1981. Considering the substantial effort that has been devoted to offshore aerial surveys in this region north to about 71° N (e.g., Harrison and Hall 1978; Ljungblad et al. 1980, 1982; Ljungblad 1981), it appears that belukhas are uncommon in the open water areas of the Alaskan Beaufort Sea during July and early August.

Sightings of belukha whales in the eastern Beaufort Sea become increasingly infrequent in late August and September. Whales are seen headed west past Herschel Island during September; a group of 2,000 was sighted near there on 21 September 1972 (Fraker et al. 1978). It appears that most whales move offshore prior to entering the Alaskan Beaufort Sea since they are rarely reported in nearshore waters. Johnson (1979) reported two sightings of whales swimming westward just offshore of the Jones Islands; a group of 75-100 was seen on 15 September 1977 and approximately 35 were seen on 23 September 1978. Cummings (personal communication) heard vocalizations of belukha whales near Prudhoe Bay in September 1980. No belukha whales were seen during marine mammal research done from a small boat in the nearshore Alaska Beaufort Sea from 20 August to 21 September 1980 and 16 August to 11 September 1981 (Frost and Lowry 1981; Lowry et al. 1981). The majority of belukha whales seem to remain well offshore throughout their westward migration out of the Beaufort Sea. Large numbers of whales have been seen on several occasions in September and early October in the region 35-220 km north of Point Barrow. During September they may be dispersed over a wide area. For example, on 21 September 1977, 100 were seen north of Prudhoe Bay and 2,000 were seen near Herschel Island. On 20 September 1980, Burns and Seaman (1985) observed numerous belukhas in a 140 km long band of pack ice north and east of Barrow.

DISCUSSION AND CONCLUSIONS

While belukha whales are a widespread, abundant, and comparatively well-known species in arctic and subarctic regions, many aspects of their distribution and movements are poorly understood. A basic question of considerable practical significance is how various groups of belukhas, which are mostly observed, studied, and exploited in spring and summer, relate to one another in terms of population identity.

Although some researchers have implied that reproductive isolation occurs among summering groups by referring to them as populations or stocks, such assertions probably do not apply to belukhas in western Alaskan waters. Breeding activity occurs in spring, prior to the arrival at summering areas, at a time when considerable mingling of animals can occur. Unfortunately, virtually no research has been done in areas where belukhas are presumed to breed so that an assessment of population identity must be made based on geographical considerations, as well as the fragmentary results of tagging and morphometric studies. We use the term population to refer to groups of whales that probably have low genetic interchange with other groups due to isolation during the reproductive period. Other groupings or concentrations of whales should be called aggregations, within which there may be herds. In areas where aggregations have been shown to be resident and largely isolated from adjacent groups the term stock may be applicable.

Whales in the North Pacific region are divisible into three populations. Those occurring in the Okhotsk Sea and the Cook Inlet area are resident and geographically isolated from the group that ranges throughout much of the Bering, Chukchi, Beaufort, and East Siberian seas. We refer to this latter group as the Bering Sea population. Contrary to the implication of Figure 6 in Gurevich (1980), we know of no evidence to suggest that interchange occurs between the Bering Sea and Cook Inlet populations through Unimak Pass, though it is possible. The separation between the Eurasian and the Bering Sea populations occurs in the western part of the East Siberian Sea (Gurevich 1980). Heavy pack ice effectively separates the belukhas from the Bering Sea population that summer in the western Canadian arctic from those to the east (Sergeant and Brodie 1975).

Favorable wintering habitat for belukhas (i.e., seasonal pack ice with adequate leads and polynyas) occurs in much of the Bering and southern Chukchi seas and the few available sightings indicate that whales are dispersed throughout this area. Compressive forces resulting in tightly packed ice (see Burns et al. 1981) likely exclude belukhas from some areas north of large islands (i.e., St. Lawrence and St. Matthew) and immediately north of Bering Strait.

With the first loosening of pack ice in March, a large component of the belukha population begins an extensive migration that eventually brings them to the eastern Beaufort Sea-Amundsen Gulf area (Fraker 1979). Since the shorefast ice is still intact during the migration period, these animals are excluded from the coastal zone until late June when they reach the Mackenzie estuary. The remaining animals move to coastal areas of Alaska and the USSR at breakup, which can occur as early as April in southern locations such as Bristol Bay.

During late spring and summer, belukhas occur in most coastal regions of the eastern Bering and Chukchi seas (Frost, et al. 1983a, 1983b). However, they are not seen in all locations at the same time, nor do they necessarily occur in each area every year. In the Bering Sea, whales are resident throughout the summer in inner Bristol Bay and the Norton Sound/Yukon River mouth region but are seen only sporadically in the area from Cape Constantine to Cape Romanzof. Considerable local movements of whales may occur. For example, belukhas that are seen in eastern and northern Norton Sound chasing schools of herring in late May and June are thought to move to the Yukon River estuary in summer to feed on salmon. These may be the same animals seen near Nome and Golovnin Bay in October and November feeding on saffron cod. We estimate that a minimum of 2,000-3,500 belukhas summer in Alaskan waters south of Bering Strait.

Along the Chukchi coast, belukhas are seen in two "waves." The first moves through the shore leads and offshore pack ice, passing Point Hope mainly in late April and May and Point Barrow slightly later (Fraker 1979). The second wave entails groups of animals that appear in coastal areas shortly after breakup from mid-June through July and occasionally into August.

Although direct evidence is lacking, it is likely that the summer whales in the Chukchi Sea are part of a single group which occurs sequentially at various locations along the coast. The timing of occurrence of whales in recent years at several locations is shown in Table 4. These data are based mainly on opportunistic observations and may not in all cases reflect the peak period of abundance at each location. Nonetheless, a clear pattern is evident which shows whales appearing later in the summer at more northerly points, with little overlap between periods of occurrence at adjacent locations. On the average, this group of whales moves from southeastern Kotzebue Sound to the vicinity of Wainwright, a distance of approximately 625 km during a period of 30 days, much of which may be spent in concentration areas such as Kasegaluk Lagoon. Although the pattern is generally repetitive, considerable year to year variations in abundance and residence time in specific areas have been noted and are discussed in previous sections of this report. We estimate that this group consists of 2,500-3,000 belukhas.

Table 4. Dates of sightings of belukha whales at selected locations on the eastern Chukchi Sea coast (from Frost et al. 1983b and this report).

Year	Kotzebue Sound	Kivalina	Cape Sabine	Point Lay	Wainwright
1978	11 June-9 July	21-24 June		2-10 July	15 July
1979	8-25 June		3 July	22 June-19 July	17-20 July
1980	13-23 June			11 July	20 July
1981	12-19 June		8 July	5-15 July	
1982	7-23 June	29 June	3-6 July	5 July	

The whereabouts of this group of whales after they leave the Kasegaluk Lagoon region and move northward toward Barrow is poorly known. Sightings off Wainwright indicate that they sometimes follow the coastline toward Point Barrow. These whales probably move generally north to the pack ice and remain in the northeastern Chukchi/western Beaufort seas until the autumn migration occurs. During three aerial surveys made in mid-September, the largest numbers of belukhas were encountered in the region generally north of Point Barrow, though herds occurred sporadically along the entire ice margin in the Chukchi Sea and were seen regularly in the western Beaufort Sea (Burns and Seaman 1985).

However, there is also a possibility that belukhas which are in the coastal zone of eastern Chukchi Sea during June to early August may move eastward across the Beaufort Sea and become part of the groups which are in Amundsen Gulf and the Mackenzie Bay region in mid-August. Aerial surveys of the eastern Beaufort Sea and Amundsen Gulf in 1981 detected a major increase in numbers of belukhas between late July and mid-August (Davis and Evans 1982). For the period 5-17 August, the minimum estimated number of whales was 11,500, which was an increase of over 7,000 whales from the previous survey period (18-25 July). During the mid-August surveys, researchers noted whales moving into their study area from the north. For belukhas to move from Point Barrow to the eastern Beaufort Sea would require a movement of about 640 km over a period of 15-30 days, which is somewhat more rapid than their probable rate of movement along the Chukchi Sea coast. However, this possibility remains speculative since belukhas are occasionally present near Wainwright in early to mid-August and large herds of eastbound whales have not been seen in the Alaskan Beaufort in late July or early August.

As previously indicated, large groups of whales have been observed in September in offshore waters and pack ice of the western Beaufort and eastern Chukchi seas. These groups, which probably include both Chukchi Sea and eastern Beaufort Sea herds, may move westward and join whales which have summered along the coast of the Chukchi Peninsula prior to heading southward through Bering Strait. Large groups of belukhas have been seen near Wrangel Island in early October, headed eastward toward Bering Strait (Kleinenberg et al. 1964).

Based on our review of distributional information, we conclude that belukha whales that summer in the eastern Bering, the Chukchi, and the Beaufort seas probably comprise four summering groups (Table 5). A minimum population estimate of belukhas which pass through waters adjacent to Alaska, derived by summing the low estimate for each group and assuming that Chukchi Sea animals were counted during eastern Beaufort Sea surveys, is 13,500. The maximum estimate is 18,000. It must be noted that both of these estimates are conservative since surveys of the eastern Beaufort Sea did not include the entire area and no corrections were made for submerged animals which were not counted (Davis and Evans 1982). Considering these factors and the unknown number of whales summering in the northern Chukchi Sea as well as in waters of the USSR, the actual abundance of belukhas in the Bering Sea population may be in excess of 25,000.

Table 5. Estimated abundance of stocks of Alaskan belukha whales.

Stock Name	Estimated Abundance
Bristol Bay	1,000-1,500
Norton Sound	1,000-2,000
Eastern Chukchi Sea	2,500-3,000
Eastern Beaufort Sea	11,500

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INVESTIGATIONS OF BELUKHA WHALES IN COASTAL WATERS OF WESTERN AND NORTHERN ALASKA

II. BIOLOGY AND ECOLOGY

by

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Final Report
Outer Continental Shelf Environmental Assessment Program
Research Unit 612

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SUMMARY

Information from 617 belukhas, including fetuses, was obtained during two phases of this study; 1977 to 1979 and 1980 to 1983. The first phase involved harvest monitoring and sampling programs, mainly ancillary to other marine mammal studies, during which data were obtained from 249 belukhas. Preliminary results were reported by Seaman and Burns (1981). The second phase, funded by the NOAA Alaska Office of the Outer Continental Shelf Environmental Assessment Program included monitoring and sampling efforts in which data were acquired from an additional 368 animals, including fetuses. The second phase also included two aerial surveys in 1982, as well as expanded efforts to summarize available information about belukhas.

We consider belukhas in the Bering, Chukchi, Beaufort, and eastern East Siberian seas and Amundsen Gulf to be part of a single population that winters mainly in Bering Sea. We refer to it as the Bering Sea population. Based on samples from northwest Alaska, physical maturity of females is obtained between age 8 and 11 and in males between 10 and 14. Mean standard length of females 11 years and older was 355 cm. Mean length of males 14 years and older was 413 cm. Maximum standard lengths were 414 cm for a female and 457 cm for a male. Length at age in belukhas from Bristol Bay, Alaska and northwest Canada was the same as that in belukhas from northwest Alaska. Length and weight of newborn calves averaged 155 cm and 72 kg. Growth of fetuses from waters of Alaska, eastern Canada, and Greenland appeared similar.

The sex ratio was found to be 1:1. Breeding probably begins in midwinter and extends to June with a presumed peak, yet to be verified, during March. Births occur over a prolonged period from April to late July or early August with a peak in mid-June to mid-July. Gestation is a minimum of 14.5 months and more likely 15 to 16 months. First pregnancy occurs between ages 4 to 7 and first births at 5 to 8 years. Females were reproductively active throughout life, though about 50% of those older than 21 years were nongravid when taken. The oldest whales in our samples were two males at least 38 years and a female at least 35 years. Generation time was about 6 years.

Mature females comprise about 33% of the Bering Sea population and the annual rate of calf production is 0.104. Size of this population is unknown. A minimum of 16,000 to 18,000 belukhas occur in waters adjacent to western North America during summer. The entire population, including whales in waters of the Soviet northeast, northwest North America, and the ice front between, will probably be found to number more than 25,000 animals.

Annual landed harvests are on the order of 415 whales, of which 220 are taken in U.S. waters, 135 in northwest Canada, and 60 in Soviet waters. Instances of unusual availability, such as the occurrence of animals entrapped by ice, may substantially increase the take by hunters and predation by polar bears. Hunting loss in all regions combined is estimated to be about 0.44 and the combined total annual kill is estimated to average 735 animals. The combined total annual kill of 585 belukhas taken in waters of Alaska and northwest Canada is 3.3% to 3.7% of the minimum number of whales occurring in those waters.

Belukhas that occur in ice-free coastal waters of eastern Chukchi Sea during summer first aggregate in Kotzebue Sound. After departing Kotzebue Sound, usually in late June, they move generally northward along the coast, temporarily frequenting Kasegaluk Lagoon in late June to mid-July and arrive near Wainwright in late July to early August. Those whales depart coastal waters in August, presumably to the ice front north of Point Barrow, where they mingle with belukhas migrating from the eastern Beaufort Sea region.

Route of the westward late summer and autumn migration of belukhas that summered in the Amundsen Gulf-eastern Beaufort Sea regions is mainly offshore, along and through the ice front.

Other aspects of the biology of belukhas, as reported in the literature, are reviewed and summarized.

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Any small contribution to knowledge about belukhas that this report may make will have resulted largely from involvement of subsistence whalers, particularly those that hunted near Elephant Point, in Eschscholtz Bay. Their interest and cooperation affected all aspects of our field work there, from transportation of equipment, personnel, supplies, and specimens, to securing the whales that became subjects of study. Our experiences in the field, and hopefully our understanding of the small whale hunting culture, were greatly enhanced by the opportunity to live and work among the whalers and their families. We especially acknowledge the assistance of Beulah Ballot, Lawrence Thomas, Willie Thomas, Nathan Hadley, Lester Hadley, Louis Hadley, Raymond Lee, and Tommy Carter, all of Buckland; Elmer Armstrong, Willie Goodwin, Jr., Bob Uhl, and York Wilson of Kotzebue; the people of Point Lay, particularly Amos Agnasagga; and the hunters at Point Hope, particularly Amos Lane, Joe Frankson, and Henry Attunganna.

Several people assisted us in the acquisition of specimens and measurements in the field. Most of them are appropriately identified in Table 1 in the section on results of biological sampling efforts. Among those colleagues we are especially thankful to Robert Nelson, Kathryn Frost, and Lloyd Lowry, all with the Alaska Department of Fish and Game (ADF&G). Mr. Lowry was also constructively critical of this report. William Marquette of the National Marine Mammal Laboratory (Nat. Mar. Fish. Serv.) made it possible for the junior author to sample belukhas at Point Hope in 1977 and also provided some harvest records from other hunting sites.

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The burden of typing fell on Dawn Hoover and her efforts are appreciated. Jesse Venable willingly assumed many tasks including some of the data entry, all of the computer programming, analyses of data, and preparation of figures in this report. His efforts are greatly appreciated.

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INTRODUCTION

General Description

Belukha whales Delphinapterus leucas (Pallas) are one of two genera of cetaceans belonging to the Family Monodontidae. The other is the narwhal, Monodon monoceros Linnaeus, mainly of the north Atlantic-eastern Canadian Arctic regions.

Belukhas are a northern species that occurs in the seasonally ice-covered seas of temperate, subarctic, and arctic regions. According to Tomilin (1957), during the warmer part of the year, belukhas are in coastal waters. The proportion of various populations that frequent offshore waters during warmer months is not known. In the North Pacific region, belukhas are present in the Sea of Japan, the Okhotsk Sea, Cook Inlet (with sightings reported in adjacent waters of Prince William Sound and the Gulf of Alaska), Bering, Chukchi, and Beaufort seas, the eastern part of the East Siberian Sea, Amundsen Gulf, and adjacent waters of the Arctic Ocean. This report is primarily focused on the population or stocks that occur(s) in the Bering, Chukchi, East Siberian, and Beaufort seas and Amundsen Gulf.

Belukhas of this region have been referred to by various North American authors, including us, as the "Western Arctic" or the "Bering-Chukchi population." On reflection, neither name is appropriate. The name Western Arctic population is incorrect because (1) the whales are adapted to and primarily utilize northern boreal and subarctic marine habitats, escaping arctic conditions through migration, and (2) western Arctic has a different geographic reference in different countries. What a North American refers to as western Arctic is, for a Soviet and most other Europeans and Asians, the eastern Arctic. Therefore, we recommend against further reference to a western Arctic population of belukhas (and for the same reasons, bowhead whales, Balaena mysticetus).

The name Bering-Chukchi population is more acceptable though still misleading and inaccurate. Belukhas of the population we studied have a much larger total range that also includes the East Siberian and Beaufort seas, Amundsen Gulf, and adjacent parts of the Arctic Ocean. It is too cumbersome to designate this population by its total range. Therefore, we propose that the region within which the population normally winters, and most likely breeds, be used to designate it. We recommend the name Bering Sea population and will use it in this report.

As adult animals, belukhas appear white or near white with restricted fringes of grey to black on the posterior edges of flukes and occasionally the flippers. This white, adult coloration is attained after a number of years. Calves are blue-grey at birth, becoming progressively lighter colored with age. The white coloration accounts for this whale's common name in several languages: Marsouin blanc, French-French Canadian; white whale, English; and belukha, from Russian belii meaning white. Mainland Alaskan Eskimo common names include dialectal variants of situaq (Bering Strait Inupiat), sisuaq (north Alaskan Inupiat), and cetuaq (mainland Yupik). On St. Lawrence Island where Siberian Yupik is spoken, these whales are called puugzaq.

In western and northern Alaska, coastal people use either the appropriate Eskimo name or the borrowed Russian name. White whale is not a name in common use in this region, reportedly because it is not descriptive or indicative of the color of a significant proportion of the belukhas observed or caught.

A detailed discussion of belukha distribution and seasonal movements in waters adjacent to western and northern Alaska is presented by Seaman et al. (1985). In general, the Bering Sea population winters over a broad area in the drifting ice of Bering Sea. They are found in areas where the ice cover is broken, as for instance in the ice front and in regions of persistent polynyas or ice divergence. Belukhas can surface through relatively thin ice, as in newly refrozen leads and polynyas, but they are definitely limited by ice thickness. Several accounts of entrapment by surrounding heavy ice have been reported and will be discussed later. Numerous sightings of belukhas in thin ice areas indicate that they break the ice cover with their back. Excellent photos of belukhas surfacing through thin ice include those published by McVay (1973).

These whales have no dorsal fin, though a prominent well-developed dorsal ridge is present. They are fusiform in shape, have a comparatively small head with a prominent melon, and anteriorly extended jaws which form a short "beak." The flukes are moderately notched on the midline. Foreflippers are unlike those of other delphinoids, being relatively short, tapered at the proximate and distal ends, and broad across the middle approximately one-third. On older animals, particularly males, they are sometimes curved upward on the distal portion. Also, unlike other cetaceans belukhas have considerable lateral and vertical movement of the head, to the extent that they sometimes appear to be looking almost backward while swimming.

Tomilin (1957) reported that the most common complement of teeth is 34 to 38, with as few as 32 and as many as 40. Kleinenberg et al. (1964) indicate that the first teeth emerge through the gum line at about age one and that there are no deciduous "milk teeth." Our specimens confirm those reports. Teeth are uniformly simple, peg-like structures that have single roots and are deeply, though rather loosely received in the alveoli of both upper and lower jaws. The crowns are often well-worn with great individual variation in extent of wear and orientation of worn surfaces. Tooth wear results in underestimation of ages of older animals, as will be discussed later.

The homodont-type dentition (little differentiation in shape of teeth) appears well suited for grasping prey, though not for masticating it. Food is swallowed whole and includes a wide array of organisms that, in Alaskan waters, ranges in size from small benthic worms and shrimp to red salmon (Oncorhynchus nerka) and small chinook salmon (O. tshawytscha). In Bristol Bay, where adult red salmon are commonly consumed, average length and weight of these fish are 61 cm and 3.2 kg (6.6 lb.) (ADF&G file data). Other moderately large species of salmon, including chums (O. keta) and cohos (O. kisutch), are reported,by local residents of the Yukon and Kuskokwim river areas, to be eaten by belukhas. Average weight of adults of these species in the Kuskokwim River is 3.36 kg (7.4 lb.) and 3.45 kg (7.6 lb.) respectively (ADF&G data). About 100 different kinds of prey items have been reported as belukha food (Kleinenberg et al. 1964) though a relatively few species comprise the bulk of diet at a particular time and place. Results of a detailed study of belukha food habits in the eastern Bering and Chukchi seas are reported by Lowry et al. (1985).

These small whales have been, and remain, an important component of the marine mammal resource base available to coastal-dwelling subsistence hunters of northern Alaska. Availability to hunters varies at different locations and is directly related to seasonal movements of the whales. Those whales that move northward through the extensive lead system between Bering Strait and Point Barrow pass close to the settlements of Wales, Kivalina, Point Hope, Wainwright, and Barrow, mainly in late April and May. Point Hope and Kivalina normally account for the largest spring harvest of these migrants.

An unknown proportion of the belukha population moves into coastal waters of mainland Alaska, from Bristol Bay to Point Barrow, as soon as breakup of nearshore and river ice permits. This, of course, occurs progressively later at higher latitudes. As examples, belukhas enter the Naknek River in Bristol Bay in late March-early April, Kuskokwim Bay in late May-early June, coastal waters of Norton Sound normally in early June, Eschscholtz Bay (southeast Kotzebue Sound) in mid- to late June, and Kasegaluk Lagoon (near Point Lay) in late June to early July. Some whales remain, or return to, coastal waters throughout the open water period, though their presence in late summer-autumn is seemingly not yet predictable. Certain coastal locations appear to constitute preferred habitat as belukhas are present each year.

As can be inferred from the comments above, belukhas can be and are harvested at many different locations. However, the most predictably successful hunting sites during the open water seasons are in eastern Norton Sound (from the villages of Elim, Koyuk, Stebbins, St. Michael, and Shaktoolik), Eschscholtz Bay (mainly by hunters from Buckland and Kotzebue), and in Kasegaluk Lagoon (by hunters from Point Lay). Largest annual harvests are normally taken near Point Hope in April-May and in Eschscholtz Bay in June. The majority of specimens available to us are from these two locations.

Background

A list of early literature that includes mention of belukhas would be long and diverse. Explorers of the higher latitudes, as well as northern missionaries, teachers, entrepreneurs, scientists of various disciplines, and the numerous sojourners to shores of the seasonally ice-covered seas often included mention of these whales in their accounts. Certainly, Europeans that became associated, through commerce or scientific curiosity, with native residents of northern coastal regions were made aware of the importance of this small whale, the times of their availability to local hunters, and some of the more easily observed biological characteristics. The latter included coloration, food habits, local movements (especially occurrence in rivers), aboriginal hunting methods, etc. Some of this early literature is cited in the extensive monograph by Kleinenberg et al. (1964) and the summary paper on belukha distribution by Gurevich (1980).

Collectively, Soviet investigators made the first concerted efforts in the North Pacific region, starting in the 1920's, to obtain information about marine mammal resources of the Soviet north and far east. A number of workers began studies in different regions extending from the White and Kara to the Okhotsk and Bering seas. These initial assessments of resources, including belukhas, were in line with a renewed, post-revolutionary interest in developing and exploiting resources in the "frontier" regions. The 1920's and 1930's were, for instance, decades during which great expenditures of money and manpower were devoted to opening up the Soviet northern sea route from Leningrad and Murmansk to Bering Strait and developing a more vigorous economic base. An interesting account of one such effort, which includes frequent mention of the potential importance of marine mammals, is a narrative of the voyage of the Chelyuskin (Anonymous 1935).

Soviet scientists that significantly contributed to a knowledge of belukhas during the 1920's and 1930's included V. A. Arsen'ev, K. K. Chapskii, S. V. Dorofeev, V. G. Heptner, S. K. Klumov, B. A. Zenkovich, and others. Degerbøl and Nielsen (1930) also provided some of the earliest detailed biological information about belukhas from waters of West Greenland.

Major monographs about the species include those by Vladykov (1944), based on studies he conducted in the Gulf of St. Lawrence (eastern Canada), and the comprehensive account by Kleinenberg et al. (1964). The latter is a compendium of virtually all of the available information about belukhas up to that time. Tomilin (1957), in his work on cetaceans of the U.S.S.R. and adjacent countries, also presented an important compilation of available knowledge.

More contemporary studies of belukhas usually have focused less on the economic potential of belukha hunting, though in general, biological material examined has come from commercial or subsistence harvests.

To the extent possible, we have tried to utilize original sources of information about belukhas. However, this was not possible with respect to older works, particularly those in the Russian language that were not available to us. The major secondary sources of earlier writings we utilized included Degerbøl and Nielsen (1930); Vladykov (1944); Tomilin (1957); and Kleinenberg et al. (1964).

Much of the current information about belukhas in western North American waters is contained in "grey literature." Our treatment of that literature may seem overly detailed. However, it includes important data and information that, in our opinion, require integration and broader exposure to persons interested in these whales.

STUDY AREA

The area in which our studies were conducted includes the Bering, Chukchi, and Beaufort seas (Figure 1).

The Bering Sea is a well-defined body of water that is almost completely surrounded by land. Zenkevitch (1963) presents a very useful resume of some major characteristics of this sea, as follows.

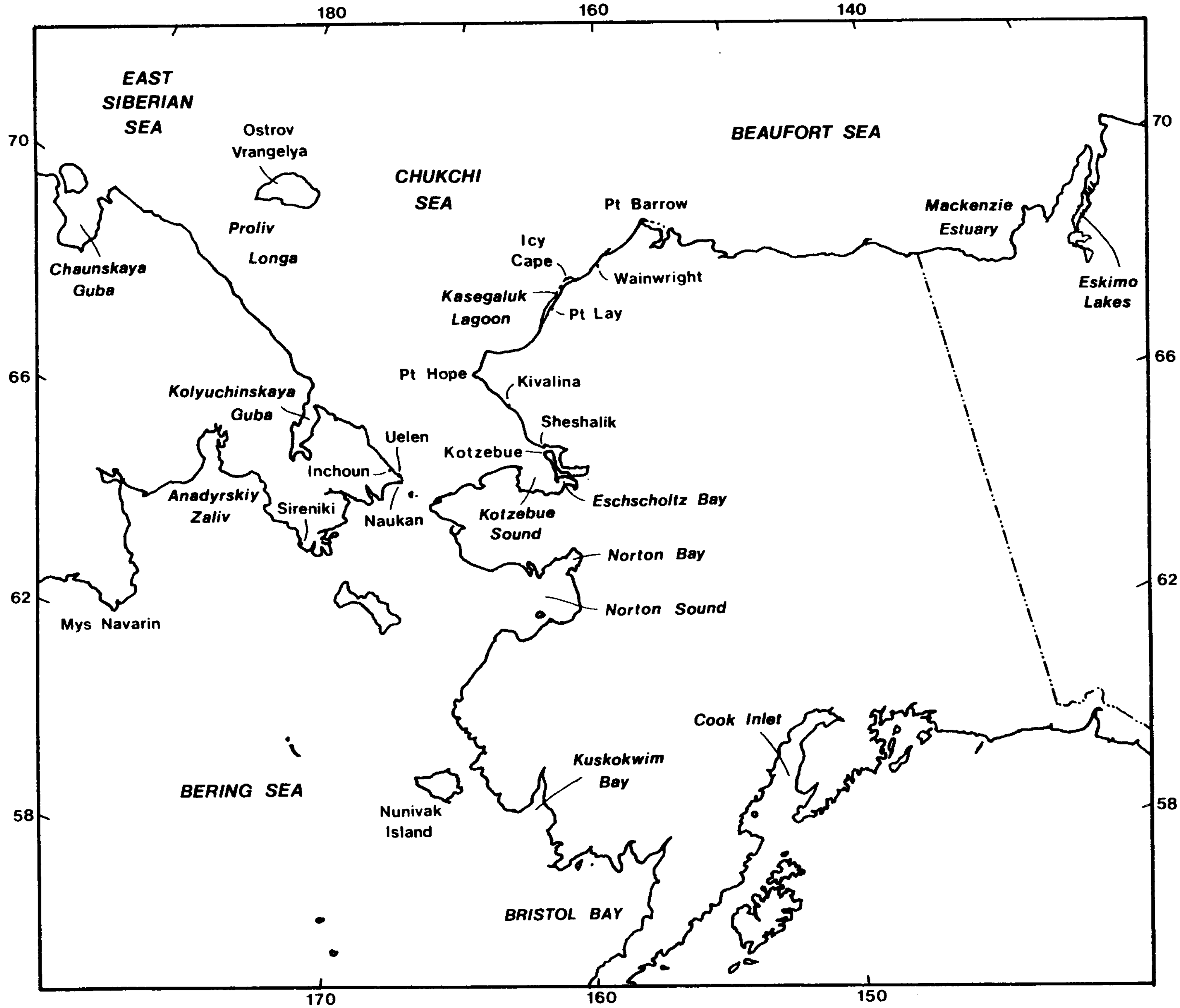

Figure 1. Location map showing the study area and most of the place names referred to in the study area.

The surface approximates 2,304,000 km^2 and its volume approximates 3,683,000 km^3. Greatest depth is in the region of Kamchatka Strait, reaching 4,420 m. Mean depth for the entire sea is 1,598 m. Of great importance, from the standpoint of belukhas, is the fact that the Bering Sea is divided by the 200 m isobath into two approximately equal parts; the southwestern part with depths greater than 3,500 m and the northern and eastern shelf regions of less than 200 m depth. Belukhas mainly occur in the shelf region.

The few soundings available suggest that the continental shelf of the northeastern Bering Sea is a flat plain with gentle slope gradients (Creager and McManus 1966). Minor relief features are present. Major relief features in the Bering Sea are the fjords of the Chukchi Peninsula and the discontinuous trough paralleling the Chukchi Peninsula north of Northwest Cape, St. Lawrence Island (Udintsev et al. 1959).

Of the confined seas, the Bering Sea is exceeded in size only by the Mediterranean Sea. It is connected with the Pacific Ocean by the deep Kamchatka Strait (4,420 m) as well as by numerous, deep passages through the Aleutian Islands.

In the north, Bering Strait connects the Bering and Chukchi seas. This Strait is very shallow (not exceeding 55 m, according to U.S. Coast and Geodetic Survey, chart number 9400) with a width of 85 km and a cross-section of approximately 2.5 km^2 (Zenkevitch 1963). Throughout most of the year movement of water is north through Bering Strait. Zenkevitch (1963) indicates that about 20,000 km^3 of Bering Sea water passes north through Bering Strait each year. South-setting currents have been recorded (Bloom 1964) and are usually produced by meteorological factors. The magnitude and occurrence of such currents are only poorly known as they occur mainly during the late fall and winter months. South-setting surface currents dominate during November through March and result in a net southward transport of ice during that period.

The Chukchi Sea is somewhat more difficult to delineate as it is not completely surrounded by land. It is frequently considered, especially in the Soviet literature, as an embayment of the Arctic Ocean that is bounded on the south by the Bering Strait, on the west by the Chukchi Peninsula and the eastern shores of Wrangel Island (approximately 176°42'W longitude), on the north by the edge of the continental shelf, and on the east by the shores of Alaska as far as a line extending north from Point Barrow (approximately 156°13'W longitude). All of this area is underlain by the Chukchi Platform.

According to Zenkevitch (1963), the area of the Chukchi Sea is 582,000 km^2. The continental shelf of the Chukchi Sea is a flat, almost featureless plain having average depths of 45 to 55 m and regional slope gradients ranging from 2 minutes to immeasurably gentle (Creager and McManus 1966). Local maximum gradients range up to 1°55'. Excluding the slope between the land and the sea floor, the major relief features in the Chukchi Sea are Herald Shoal, Hope Sea Valley, and the Cape Prince of Wales Shoal (Udintsev et al. 1959).

The Beaufort Sea is a less discrete body of water than either the Bering or the Chukchi Sea. Generally, it is considered as an integral part of the Arctic Ocean extending from Banks and Prince Patrick islands in northwest Canada to Point Barrow in Alaska. Its southern margin is the shoreline of mainland Canada and Alaska. There is no discrete northern boundary.

Biological and physical features of belukha whale habitat within the three seas are different. The Bering Sea is a northern extension of the North Pacific Ocean. It is a biologically rich and diverse region within which upwelling of nutrient-rich deep water, forced upward by the Aleutian Chain of islands and the continental shelf edge, is a major contributor to the high biological productivity that occurs. Several major rivers, frequented by belukhas, also contribute significantly to the nutrient regime. Climate in the Bering Sea (strongly influenced by the Pacific Ocean) is temperate, grading into subarctic in the northern one-third. Prevailing winds are out the south (mainly southeast) during May through September and from the north (mainly northeast) during November through April. There are great annual differences in climate that result in major annual differences in, for instance, extent and characteristics of the seasonal ice cover. Ice is normally present from late November through June. It includes two major components--ice that forms during winter in the Bering Sea, and ice that is transported south through the Bering Strait. It appears that most ice is of the former component.

On average, the southern extent of ice, at the time of maximum coverage (March-April), coincides with the edge of the continental shelf. However, annual differences in location of the southern ice margin in the central Bering Sea are as much as 450 nautical miles (nm) (from approximately 60 nm south of St. George Island to about 60 nm south of St. Lawrence Island). Shifting and movement of the relatively thin ice cover is significant and produces extensive areas where the ice is fragmented and openings are present. This shifting, together with the extensive leeward coastlines of several large islands as well as the coasts of Alaska and Siberia, produce local conditions that may accommodate a relatively high abundance of belukhas during winter.

The Chukchi Sea is mainly subarctic in its characteristics. Much of the North Pacific influence is lost as water flowing north through the narrow constriction of Bering Strait has become altered in the Bering Sea. Biological productivity of the Chukchi Sea is less than that of the Bering Sea.

Ice conditions are more severe due to average lower winter temperatures, a longer freezing period, incursions of multi-year ice during the fall-spring period, constraints of surrounding land masses that are largely exposed to prevailing winter winds (mainly northeast), and the frequent occurrence of persistent "arctic" high pressure systems. Water depths in all parts of the Chukchi Sea are relatively shallow.

The Beaufort Sea is a transition area between the subarctic and arctic provinces. The northward trend of decreasing biological productivity continues and, in comparison to the Chukchi Sea, productivity is significantly lower.

Multi-year ice is a significant feature of the northern part of this sea and the areal coverage of this ice shows extreme annual variations. Seasonal sea ice develops near shore, its extent depending on the amount of multi-year ice that is present. The coastline of the Beaufort Sea north of Alaska has a northeasterly exposure and it is therefore ice-stressed by the shoreward advance of ice during the seasons of freezing. Prevailing winds are northeast and, at least in the eastern part, there are weak cyclonic surface circulations of air and water (Wilson 1974).

Seasonal and multi-year ice can occur in the Beaufort Sea throughout the year. In most years the nearshore zone is ice-free during August through October but there is great annual variation in the extent of open water. It is mostly ice-covered from late October through mid-July. During the late summer-early fall "open water" period multi-year ice is present at varying distances from shore. Usually it is situated north of the shelf break.

METHODS

Harvest Enumeration

The magnitude of annual harvests of belukhas taken in Alaska from 1977 to 1984 were determined on the basis of many different sources of information. Sampling efforts at major hunting sites provided personnel of ADF&G the opportunity to obtain direct counts of whales harvested during the sampling periods. Public awareness of the belukha investigations was promoted during the course of this and other studies of belukhas, and an extensive network of contacts established. Many of the local contacts reported the seasonal catch of belukhas by hunters in villages where they resided. When a take of whales was reported but the magnitude was unknown, a Department employee stationed close to the hunting site often personally visited that site and determined the take on the basis of direct interview of village residents. At other locations harvests were reported by resident teachers, local pilots, resource managers, or investigators involved with socio-economic studies.

Field personnel of the National Marine Fisheries Service, and later of the Alaska Eskimo Whaling Commission, that were involved in investigations of bowhead whales (*Balaena mysticetus*), provided us with records of belukha catches made during the bowhead whaling seasons, mainly at Point Hope and Barrow.

Harvest data were also obtained during routine visits to villages by ADF&G personnel and by interview of village residents during their visits to communities in which Department offices were located.

Biological Sampling

Most biological sampling was accomplished by an ADF&G employee specifically detailed to known productive hunting sites during periods when successful hunting normally occurs. Usually a single department employee worked at the sampling sites as a means of minimizing both support requirements and intrusions into the closely knit temporary hunting encampments. Productive sites included Eschscholtz Bay, Point Hope, and Point Lay. Eschscholtz Bay was the major sampling area and produced 68% of all whales we examined.

Conditions existing at the time whales were landed determined procedures used for data acquisition and biological sampling, as well as the thoroughness of sampling efforts. Within Eschscholtz Bay whales are mostly taken by driving pods into shallows and then killing as many as possible. Actual timing of each hunting foray is based on the tide conditions; hunting begins shortly after the tide starts to ebb. If whales are seen and a successful drive takes place within reasonable distance of Elephant Point, where whalers and their families camp, the whales are towed to the Point. Butchering begins immediately and continues until all the whales are cut up or, occasionally, until the next ebbing tide when, weather permitting, the hunters again go out. Very often, a large number of whales are landed at one time. As an example, in June 1982, 75 whales were landed after a single drive and the total catch of 121 whales was secured in three drives during a period of approximately 40 h.

As boats returned with whales, each landed animal was numbered and its sex, color, standard length, and other notations recorded. Standard length is the straight line distance between the notch of the fluke and the anterior tip of the lower jaw with the whale lying on its stomach. The collection of specimens, including mandibles (occasionally complete skulls), reproductive tracts, and samples of stomach contents, was accomplished as the whales were processed. Whales were landed and butchered along a stretch of beach approximately 0.7 km long. Thus, to initially process whales as they are landed at different points along the beach and to subsequently obtain specimens from them when the butchering process had been sufficiently completed, required continuous movement of the sampler up and down the beach. Traditionally, remains are towed to sea by the hunters prior to initiation of another drive, if possible.

The pace of sampling activity after a successful drive is frenetic, becoming exhausting when successful drives occur during successive tidal cycles. As an accommodation to our sampling effort, the hunters at Elephant Point left unsampled whale remains on the beach until we could examine them and obtain specimens. Reproductive tracts of as many females as possible were obtained. Those of males were obtained only in the first years of this project.

Mandibles and skulls were cleaned and air-dried in the field. Soft parts, including stomach contents, were preserved in 10% formalin. Testes and epididymides from which micro-slides were to be made were sliced for better preservation. Ovaries were usually left attached to the uteri, the latter having been cut off 5-10 cm posterior of the cervix, tied, and the lumen injected with 10% formalin to ensure fixation of the uterus and preservation of a small fetus, if present. Uteri were not obtained from those whales that had a near-term fetus. Most near-term fetuses were measured in the field. A few were brought to the laboratory.

Lactation was noted at the time whales were landed (either based on the presence of exuding milk or by palpating the teats) or, if not externally obvious, during subsequent inspection of mammary tissue left as part of carcass remains.

Payment of 10-20 dollars (the latter after 1979) was made to each hunter that secured a whale from which we obtained specimens and supporting data.

A similar sampling procedure was utilized at other locations by ADF&G personnel. Non-departmental cooperators, mainly engaged in bowhead whale studies at Point Hope, provided what data and specimens they could secure. Those specimens were frozen and shipped to our laboratory in Fairbanks.

Laboratory Procedures

Male Reproductive Organs

Laboratory procedures varied somewhat over the course of this study. The volume of one intact testicle, with and without the epididymis attached, was determined by water displacement for a small sample. Tissue samples from testicles and epididymides which had been sliced and fixed were sent to a commercial laboratory for preparation of histological slides. Standard histological preparations were made using Hematoxalin-Eosin stain. These slides were examined to determine the state of spermatogenesis in testes and the presence or absence of sperm in tubules of the epididymides.

Female Reproductive Organs

For females, ovaries were separated from uteri. Examination of these two organs was done separately and the subsequent findings regarding appropriate aspects of reproductive status were compared. Length of a "nongravid" uterine horn was measured from the level of the medial, externally recognizable junction of the horns to the anterior end, over the curvature of the preserved horn. General assessment of surficial rugosity and whether or not the whale was parous or nulliparous was noted. Each uterine horn was then opened. Notations were made of general internal appearance, presence of mucus, debris, blood, a cervical plug, and presence or absence of a small fetus. Anomalies were also noted.

Thus, based on examination of uteri, females were categorized with respect to relative age (juvenile, sexually mature and relatively young, or sexually mature and relatively old) and reproductive status (nongravid, gravid, or postpartum).

Ovaries were trimmed of connective tissue, and weighed to the nearest 0.1 g. A two-dimensional diagram of paired ovaries was made on a 5" x 7" index card along with depictions of obvious surficial features. The paired ovaries were then serially sectioned (parallel to the longest axis) by hand. Sections were, on average, about 2 mm thick. Ovarian structures, including follicles larger than 5 mm, corpora lutea, corpora albicantia, calcified bodies, and other noteworthy internal features were drawn based on the serial sections. Several sections of those ovaries that contained multiple structures were drawn. The position of each section was noted on the diagram of the intact ovary from which it was taken. Other notations were included on the diagram cards, including correlations of results of ovarian and uterine examinations.

Age Determinations

Age determinations were based on the number of dentinal layers counted on longitudinal sections of teeth (Laws 1953; Sergeant 1959; Klevezal' and Kleinenberg 1967; Brodie 1971).

Examination of our first collected specimens showed great variation in size and wear of mandibular teeth from an individual and among individuals. Teeth were removed from the mandibles in several different ways depending on the difficulty encountered. Some were rotated in the alveolar socket and pulled using dental pliars, or they were pried out with the aid of a dental elevator. In some instances, the mandibles were boiled or macerated in water until the teeth became loose and could be easily removed with pliars or forceps. The method employed depended on several factors, including size and curvature of the teeth, extent of eruption, or whether the mandibles were stored in water to prevent desiccation and checking of teeth.

Epoxy glue was used to attach the two or three largest mandibular teeth to small wooden blocks which could be clamped on the turntable of a precision lapidary saw. Orientation of glued teeth was important in order to obtain longitudinal sections from the midline portion. Sections from the central portion of one or two teeth were cut to a thickness of 0.001" to 0.012" using a diamond-impregnated blade. Dentinal layers were counted using a microfiche reader or a binocular microscope. In both cases transmitted light was used. When dentinal layers were not sufficiently distinguishable in the tooth sections initially cut, additional teeth were sectioned for examination.

When the neonatal line was evident, the number of dentinal layers was considered to represent the total complement deposited. When absent, an unknown and variable number of layers had been worn away and counts represented some minimum number. In odontacete whales the neonatal line is a distinctive dentinal layer laid down shortly after birth. It separates prenatal from postnatal dentine (Nishiwaki and Yagi 1953; Sergeant 1959). We based the age (or minimum age) of whales on the assumption that two dentinal layers are deposited each year, in accordance with the findings of Brodie (1971).

Aerial Observations

Seasonal distribution and relative abundance of belukhas in the study area are subjects addressed by Seaman et al. (1985). We report here only an interpretation of late June-August movements of belukhas within or from Kotzebue Sound to Point Barrow, and characteristics of the westward, autumn migration of whales in the northeastern Chukchi and Beaufort Seas.

Most available records of belukha sightings during summer in coastal waters between Kotzebue Sound and Point Barrow have been compiled and summarized by Frost et al. 1983. Those, together with additional sightings, were reviewed to determine possible patterns of movement in that region and the relationship between groups of whales summering in the eastern Chukchi and those in the eastern Beaufort seas.

Additionally, on June 29, 1982, when belukhas were no longer available to hunters, an extensive aerial reconnaissance of nearshore Kotzebue Sound was made. This reconnaissance was after the period of successful hunting in southeastern Kotzebue Sound (Eschscholtz Bay and near Chamisso Island) that occurred from 22 to 26 June and after the period of successful netting in northeastern Kotzebue Sound which occurred between 17 and 26 June.

Flights were made in a float-equipped Piper Super Cub flown at an altitude of 3,000 ft and an average speed of 90 mph. Time of the flights was such that they occurred during the period 2 h before to 3 h after high tide at Kotzebue. State of the tide was considered a principal factor as the whales usually are in the bays and closest to shore at about high tide. Flight path was maintained by visual reference to the coastline and was 1½ to 2 mi seaward on flights outbound from Kotzebue and about ½ mi seaward on those inbound to Kotzebue. A deviation from this pattern was made to search Eschscholtz Bay and its entrances.

An intensive search of the southern margin of drift ice in the Beaufort Sea was made during 17-21 September 1982. Previous aerial surveys for Pacific walruses (Odobenus rosmarus divergens) during this period in the northern Chukchi and western Beaufort seas had suggested that during September belukhas likely were strongly associated with the ice fringe and that the route of the autumn migration may be mainly determined by location of the drift ice margin. Location of the summer-autumn ice margin in relation to the Beaufort Sea coastline is annually quite variable but usually at some considerable distance. Experience during previous years indicated that weather for flying was normally poor along the coast and over open water but was marginal to good over the pack ice. To deal with these conditions a fully instrumented aircraft capable of sustained flight in severe icing conditions was required.

A Conquest (Cessna 441) was selected for our search effort. This aircraft was capable of takeoffs and landings in bad weather, could climb to 30,000 ft through severe icing conditions, and had a high altitude cruising speed of up to 290 knots. Once the pack-ice ice margin was located visually or by on-board radar, descent to desired search altitude was made and the cruising speed reduced to 120-140 knots. Although suitable for a general search for belukhas, the aircraft was less than ideal for making a reliable census because the main observers, located in the passenger cabin, had only limited forward visibility and no capability of taking photographs while the aircraft was in level flight. We made counts and photographed the larger pods and aggregations of whales by closely circling them.

A 500-ft altitude and cruise speed of 120-140 knots were used during search efforts. Occasionally, descents to 200 ft were necessitated by low clouds. A transect width of ½ nm, ¼ nm on either side of the aircraft, was used for counting whales and maintained with the aid of inclinometers. Three observers were utilized: one in the co-pilot's seat and two in the passenger cabin. The pilot and forward observer counted whales within that portion of the transects close to the airplane that were not visible to observers in the passenger cabin. The forward observer also recorded all sightings as well as time, position, other navigational information, ice conditions, and weather. Data were recorded mainly for each 1-min time interval though occasionally the record interval was as long as 3 min.

Survey flights were made on 17, 19, 20, and 21 September. Those on the first three days were along, or north of and parallel to, the ice margin between 141°W and 160°W. On 21 September transects deeply penetrated the pack ice along alternate N-S and S-N lines. Length of transects flown on the 21st was determined by the distance between the open water/ice margin interface and the point at which a solid ice cover was encountered. Total alloted time for all flights, including ferry time from Fairbanks to Prudhoe Bay and Prudhoe Bay to Anchorage was 25 h.

Two concurrent studies in the Beaufort Sea north of Alaska were of particular relevance to our autumn survey effort. Ljungblad et al. (1983) were engaged in extensive aerial reconnaissance over a very broad area of open water, for bowhead whales. S. Johnson (personal communication) repeatedly flew a grid of pre-selected transects from shore, seaward to a distance of 20 nm, in the area between the Alaska/Canadian border and 143°45'W. These surveys were for purposes of recording all marine mammal and bird sightings. Both Ljungblad and Johnson provided us with information about belukha sightings.

Data Management

Data acquired in this study were put into two basic formats (files) suitable for analysis utilizing a "mini" computer (Digital Equipment Corp., VT/78, with associated printer and plotter). The first file was of whale sightings and associated information such as number of animals, time, date, geographic coordinates, ice conditions, begin and end points of survey transects, and pertinent comments about sightings and/or transects.

The second file was of biological data about sampled whales including specimen number, date and location of capture, sex, color, length, weight (mostly of fetuses of neonates), age, and reproductive status.

A variety of programs, prepared by Mr. Jesse Venable, were utilized for data analysis. These included tabulation of harvest data, determination of various biological parameters, tests of statistical significance between or among samples, construction of a life table and age-specific mortality estimates, plots of whale sightings and of transects flown during aerial surveys, and general mapping of the study area.

RESULTS

Biological Sampling

In total, 491 belukhas older than newborn calves, 68 fetuses in the first trimester of development, and 58 term fetuses and newborn calves were sampled in 1977 to 1983 (Table 1). Most were landed by subsistence hunters and were mainly taken in Eschscholtz Bay during June of various years. The Eschscholtz Bay samples amounted to 68% of the whales older than calves and 62% of the fetuses and newborns. Fifteen of the whales, including an abortus and nine neonates, were found beachcast in the Bristol Bay region by L. Lowry and/or K. Frost (personal communication; Frost et al. 1983).

Subsistence hunting during June-July is during part of the prolonged birth period. At most locations where hunting occurs in these months, belukhas are driven into shallow water where they are relatively easy to follow and kill. Knowledge and observation of hunting techniques employed during whale drives suggest that the younger, smaller whales are under-represented, to an unknown extent, in our samples. Larger whales are preferred because of the higher yield. Their size, lighter color, and more obvious wake make them easier to pursue and hit with rifle fire.

Table 1. Field collection efforts and a summary of belukha whales examined, or from which specimens were obtained and included in this study, 1977 to 1983.

		No. of belukhas				No. of fetuses or newborn calves accounted for			
Field location	Dates	males	females	undetermined	total	recently implanted	near-term or newborn	total	Field collector
Point Hope	Apr-May 77	19	20	0	39	5	9	14	G. Seaman/ ADF&G
Elim	Jun 77	3	0	0	3	0	0	0	G. Seaman/ ADF&G
Point Hope	Apr 78	11	5	0	16	1	2	3	G. Seaman/ ADF&G
Eschscholtz Bay	Jun 78	38	38	2	78	15	7	22	G. Seaman/ ADF&G
Point Lay	Jul 78	5	4	0	9	0	1	1	G. Seaman/ ADF&G
Wainwright	Jul 78	0	1	0	1	1	0	1	R. Tremaine/ ADF&G
Eschscholtz Bay	Jun 79	2	1	0	3	0	0	0	G. Seaman/ ADF&G
Point Hope	May 79	5	1	0	6	0	1	1	P. Field/ NMFS
Wainwright	Jul 79	28	12	1	41	4	5	9	R. Tremaine & G. Seaman/ ADF&G
Barrow	May 79	1	1	0	2	0	0	0	Unknown collector/ NMFS
Eschscholtz Bay	Jun 80	51	40	2	93	16	5	21	J. Burns & K. Frost/ ADF&G
Point Hope	May 80	4	4	1	9	1	1	2	D. Smullin/ NMFS
Eschscholtz Bay	Jun 81	5	34	0	39	8	6	14	J. Burns/ ADF&G
Nushagak Bay	Jul 82	3	0	0	3	0	2	2	L. Lowry & K. Frost/ ADF&G
Eschscholtz Bay	Jun 82	53	68	0	121	11	9	20	J. Burns/ ADF&G
Point Hope	Apr-May 83	3	5	0	8	2	1	3	R. Clarke/ North Slope Borough
Bristol Bay	May-Jul 83	0	2	0	2	0	8	8	L. Lowry & K. Frost/ ADF&G
Point Lay [a]	Jul 83	8	10	0	18	4	1	5	R. Nelson/ ADF&G
Totals		239	246	6	491	68	58	126	

[a] Only fetuses from this collection are included in results of this report.

Sex Ratio

Of 533 specimens including 47 term fetuses or newborn calves, 265 (49.7%) were females. Although the sex ratio of the entire sample was 1:1, there were great deviations in some subsamples. At Point Hope, 16 whales sampled in April 1978 included 11 males (69%). At Wainwright, in July 1979, 28 (70%) of 40 whales taken were males. In Eschscholtz Bay during June 1981, the entire annual catch, which amounted to 39 belukhas, was taken in a single drive. Thirty-four (87%) of those whales were females.

Differences in sex ratios of these subsamples suggest some degree of segregation among different pods and groups of belukhas, and beg the general questions of sampling biases and the sampling effort required to deal with such biases.

Growth

Age-Body Length Relationship

Age-body length data were obtained from 126 belukhas, not including fetuses. This sample was of 58 males and 68 females. Two other data sets from whales that were taken in, or are known to pass through waters adjacent to Alaska were available for comparison. The first was from 18 belukhas taken in Bristol Bay (Lensink 1961) and the second from 45 animals taken in the Mackenzie estuary (eastern Beaufort Sea) and sampled by Sergeant (1973).

Growth curves for male and female belukhas, based on data obtained during our study, are shown in Figure 2. In Figure 3 the data reported by Lensink (1961) and Sergeant (1973) are plotted in relation to the growth curves for males and females from northwest Alaska.

Age-length relationships of the Bristol Bay and Mackenzie estuary samples appear to be essentially the same as those from whales taken in northwest Alaska. It is noteworthy that the sample from Bristol Bay included a large proportion of belukhas less than 12 years old, based on the assumption of two dentinal layers per year of life.

Maximum standard lengths of belukhas in our sample were of a 30-year-old male 457 cm and a 31-year-old female 414 cm. In comparison, maximum lengths in the smaller samples from Mackenzie estuary were of an approximately 445-cm, 20-year-old male and a 387-cm, 20-year-old female. Maximal lengths in the Bristol Bay samples were 417 cm for a 16-year-old male and 356 cm for a 5-year-old female.

Figure 4 shows growth of belukhas, based on animals from northwest Alaska, ages 0 to 4 years. The increase in SL during the first year of life was found to be 46.3 cm or 26.8%, based on comparison of means of six neonates and four 1-year-olds. This compares to a length increase of 56.4 cm (35.3%) between the same age cohorts, as found by Brodie (1971) for belukhas in Cumberland Sound. Values for annual growth increments are presented in Table 2.

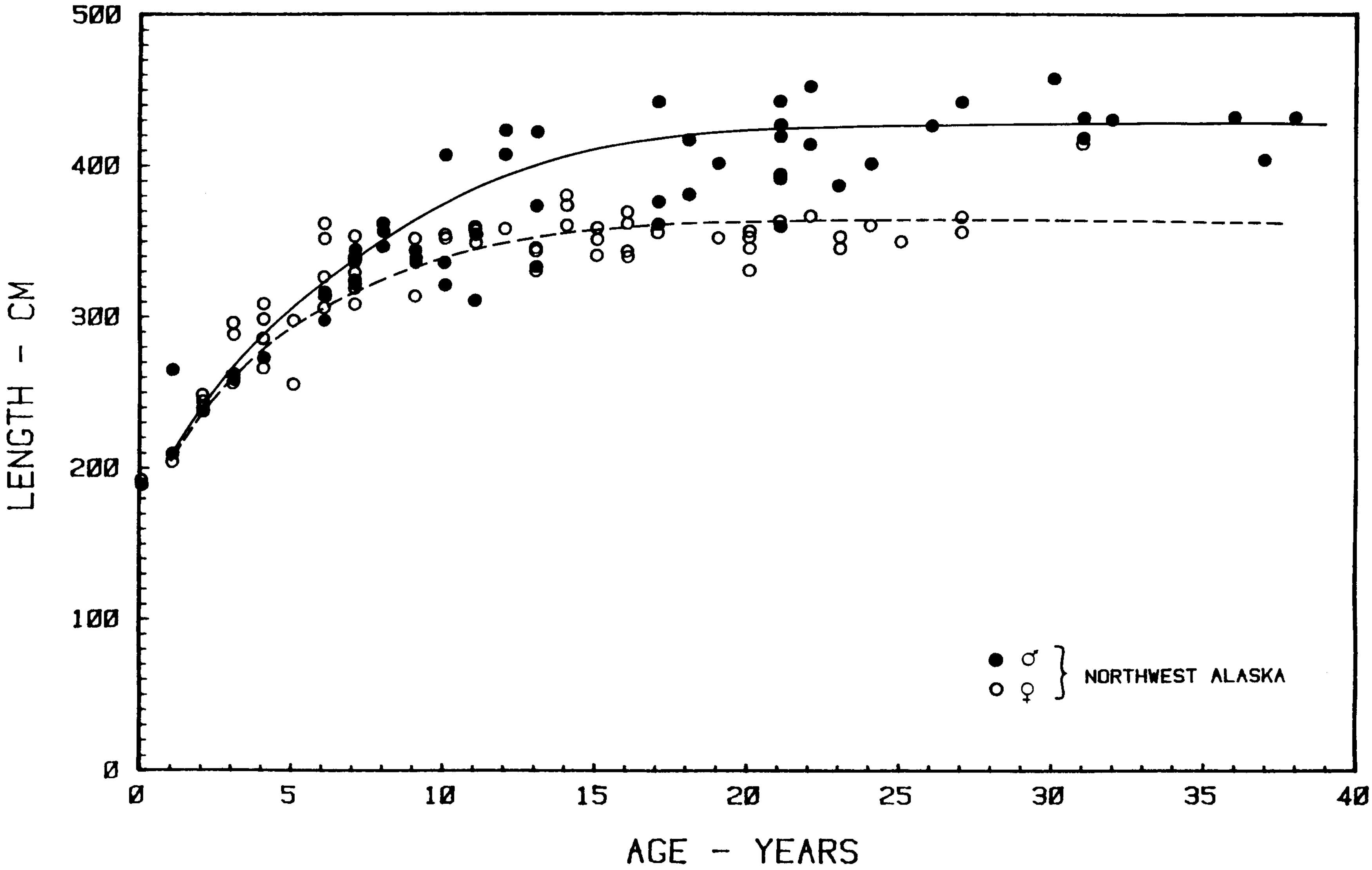

Figure 2. Age-length relationships of 126 belukhas sampled in northwest Alaska, 1977 to 1982. Growth curves were fitted by eye.

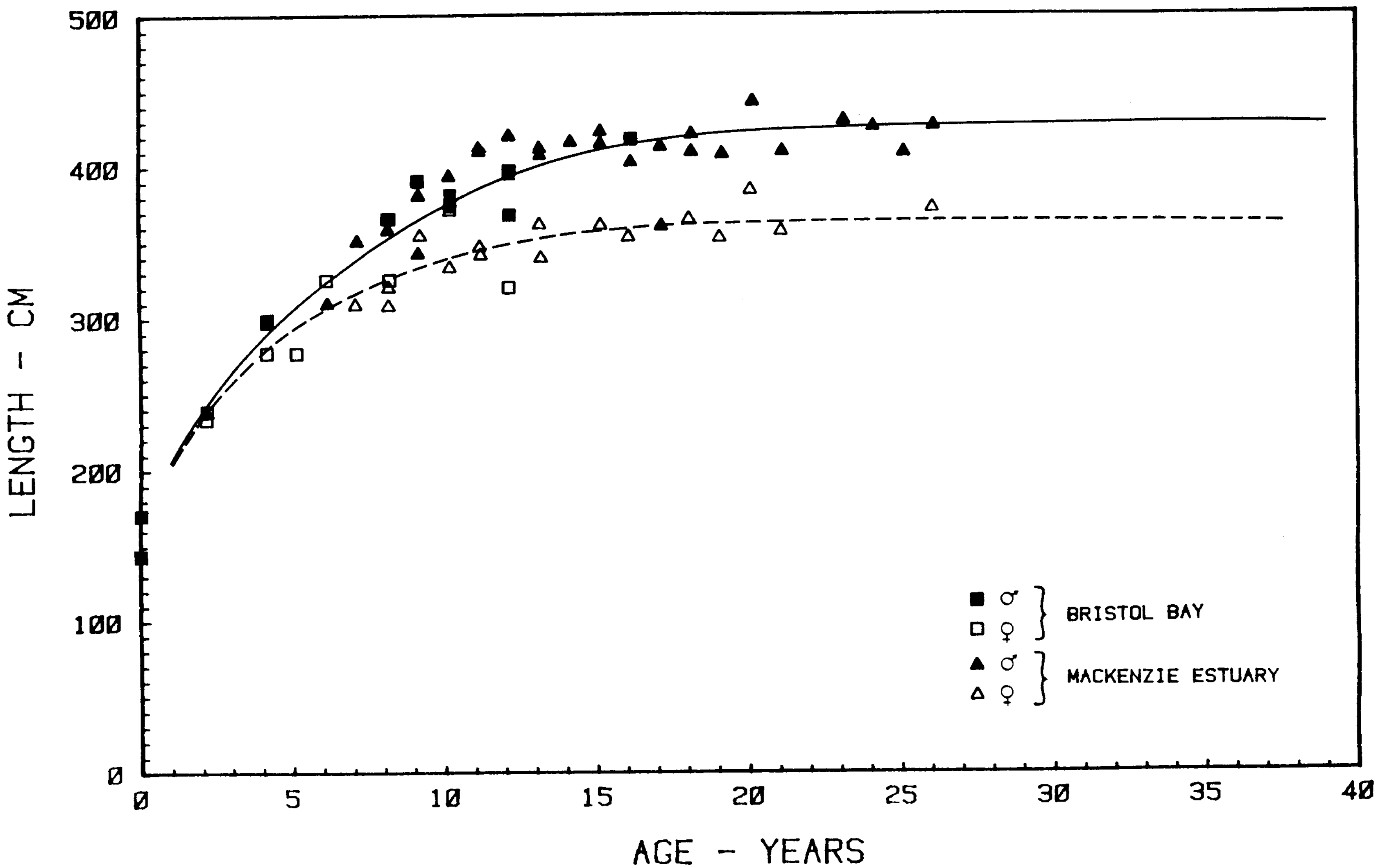

Figure 3. Age-length relationships of 18 belukhas from Bristol Bay, Alaska and 45 from Mackenzie estuary, Canada, plotted on growth curves for whales from northwest Alaska, as shown in Figure 2.

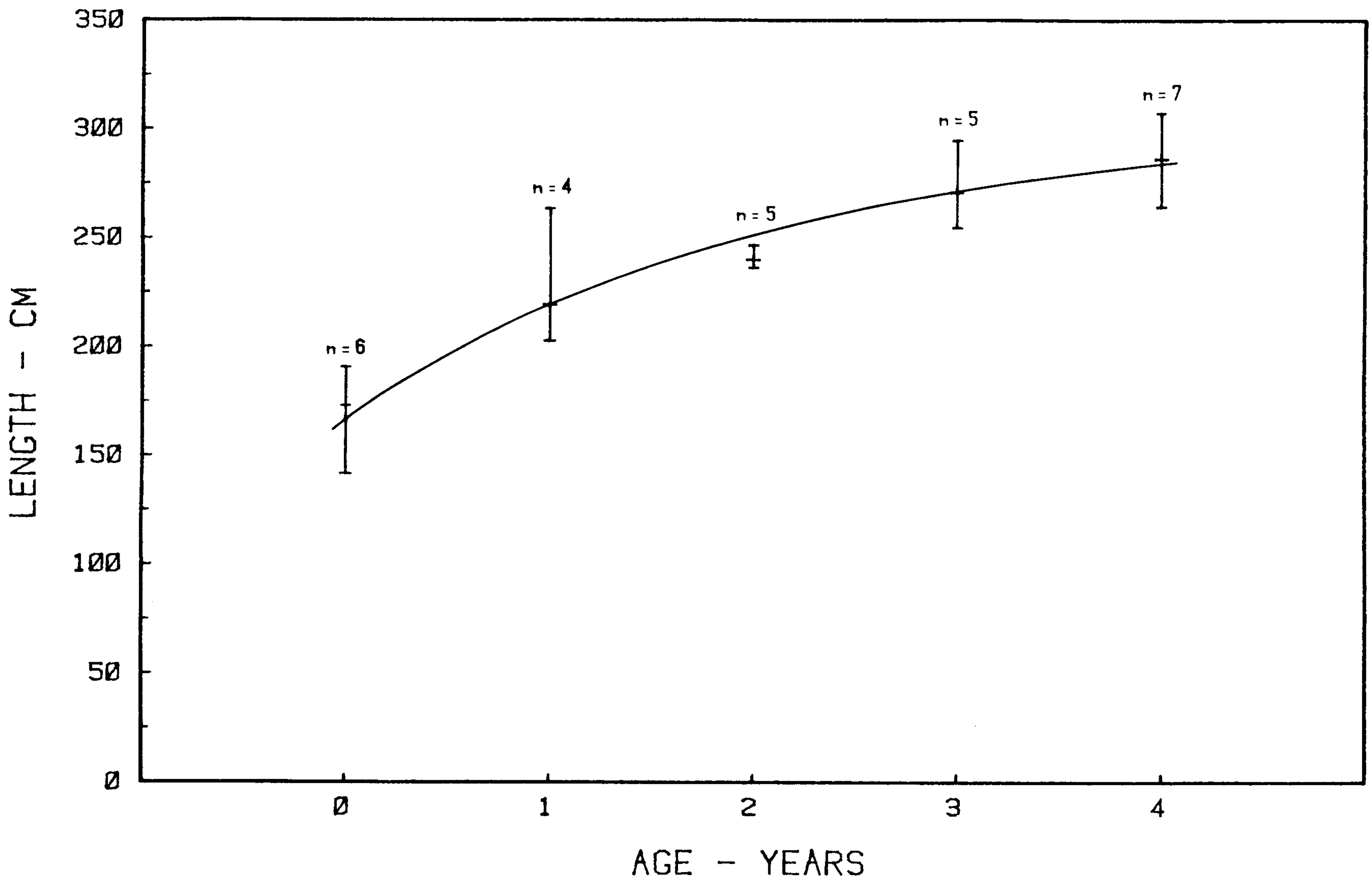

Figure 4. Age-length relationships of belukhas, ages 0 to 4 years, from northwest Alaska.

Table 2. Parameters of age/length relationships for belukhas ages 0 to 4 years, from northwest Alaska; males and females combined.

	Age (yr)				
Parameter	0	1	2	3	4
Sample size	6	4	5	5	7
Mean length (cm)	173.1	219.4	239.8	270.7	286.1
Minimum length	142.2	202.6	236.2	254.6	264.2
Maximum length	190.5	263.5	246.4	294.6	307.3
Increase from preceding year (cm)	-	53.3	20.4	30.9	15.4
Percent increase from preceding year	-	32	9	13	6

Our sample is inadequate to determine the increase in length during the first few months of life, though it is suggested by two calves of the year killed by hunting (as compared to beachcast) in Bristol Bay (Lensink 1961). These included a newborn, 142 cm long, taken in mid-June and an approximately 3-month-old calf, 168 cm long, taken in mid-September. The difference in length was 26 cm or 18.3%. Though such an increase in length in the first three months of life is highly probable, many more specimens would have to be measured and their age determined to adequately estimate growth during early life.

The matter of growth during the first several months of life is important, given the techniques of aerial observation and/or photogrammetry that have been utilized by some investigators to determine the proportion of calves of the year in various aggregations of belukhas. In our opinion, such methods are reasonably accurate during June-July when neonates are small and exhibit little overlap in length when compared with 1-year-old animals. However, aerial observation and photogrammetry may be much less useful by late August to October, when some calves of the year are probably as large as some yearlings.

If aerial observation and/or photogrammetry procedures are to be used as a means of determining birth rate or the proportion of calves present at times other than close to the peak birth period, much more data about growth during the first two years of life will be required.

Fetal Growth

Sample size for embryos and fetuses from waters of northern Alaska was 99 and includes 5 from Bristol Bay collected by J. W. Brooks (unpublished), and 94 obtained during this study. Specimens were collected from April to July and include 59 embryos and small fetuses and 40 near-term and term fetuses. We have no data about fetal growth during the eight-month period, August to March.

Three length measurements were recorded as appropriate for condition of an embryo or fetus. Five embryos were straight and rod-like in appearance. Greatest length of these was used. Forty fetuses were large, near-term or term, and were measurable in a manner similar to larger belukhas. On these, standard length (SL) was measured. On the remaining 54 small fetuses, nose to tail length (NTL), SL, or both were taken, depending on whether the fetus was tightly curled or relatively straight. NTL is a measurement from the anterior end of the jaw to the tip of the developing fluke along the dorsal curvature of the body. A fluke notch is not present on small fetuses in May to July. Of the 54 small fetuses, only NTL was obtainable on 41, and both NTL and SL on 13. NTL is an exaggeration of SL and when used, resulted in a discontinuity when making comparisons with embryos or with larger fetuses. A regression equation was developed, based on the 13 fetuses for which both NTL and SL were recorded. The resulting equation showed that $SL = 0.737 (NTL) - 4.57$, with $r = 0.941$. The derived SL of small fetuses was used to plot progressive increase of fetal length over time (Figure 5).

Mean length of 26 near-term fetuses collected in June was 155.5 cm (range = 127.3 to 180.3) and is our best indicator of length at birth. The

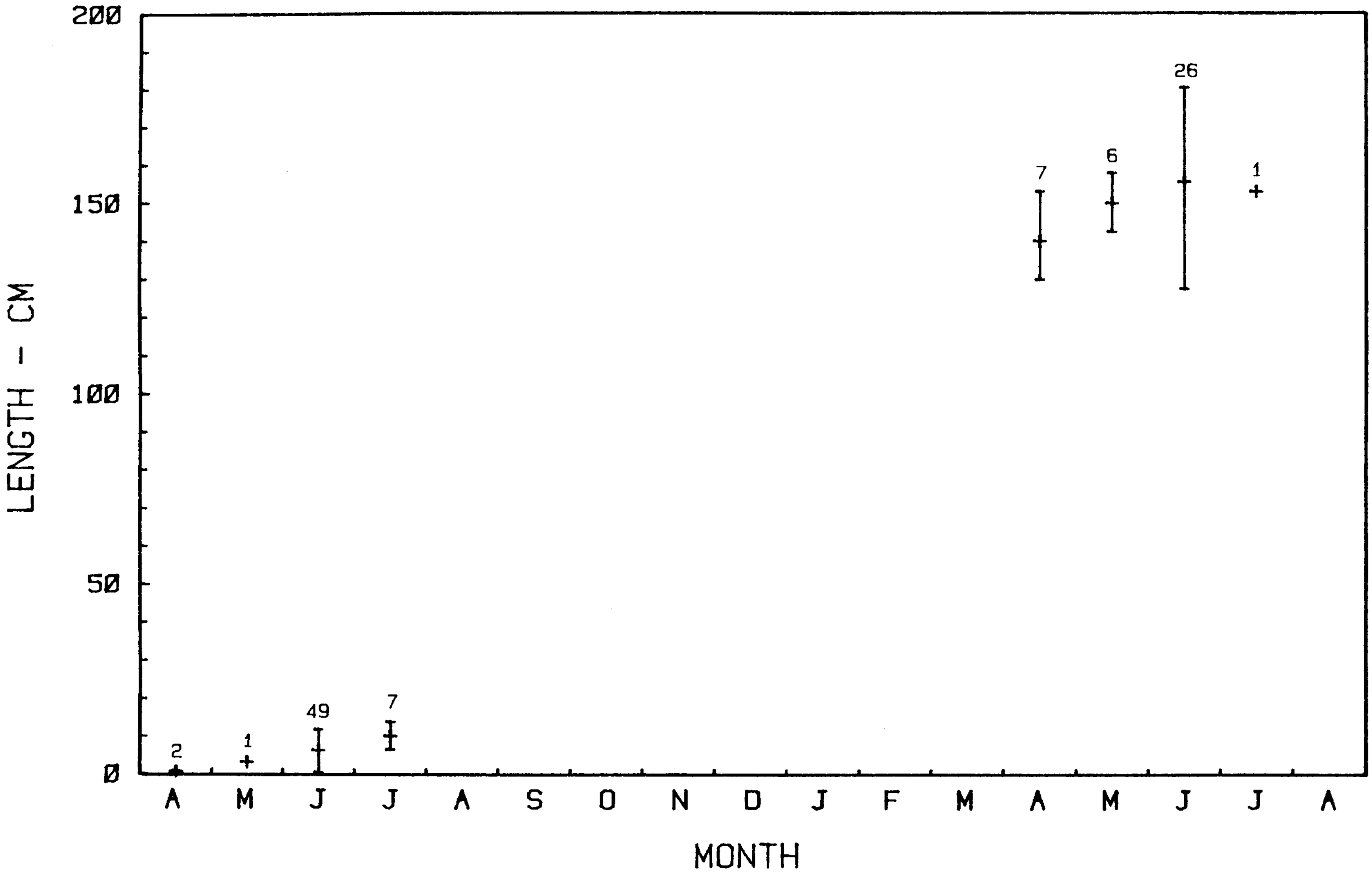

Figure 5. Progressive increase in length of prenatal belukhas from Bristol Bay (N = 5) and northwest Alaska (N = 94). No specimens were available for the period August to March.

increase in weight over time is shown in Figure 6. Average weight of six near-term fetuses taken in mid- to late June was 71.8 kg.

The data from belukhas taken in Alaskan waters show that during late pregnancy from April to June, the increase in fetal length is comparatively small, whereas increase in weight is considerable. Compared to near-term fetuses taken in June, those obtained in April were only 10% shorter, but 45% lighter.

Length of Neonates

Standard length of four newborn calves from northwest Alaska taken in June averaged 164.9 cm with a range of 137 to 175 cm. Nine neonates obtained in Bristol Bay during July included one taken by hunting (J. W. Brooks unpublished) and eight found beachcast. That taken by hunting was 175.3 cm long. Those found beachcast averaged 143.0 cm, with a range of 137 to 152 cm.

Beachcast neonates from Bristol Bay were appreciably smaller than term fetuses from that area. Five term fetuses from Bristol Bay, obtained by Brooks (unpublished), had an average SL of 154.9 cm (range = 134.6 to 170.2); a length approximating the mean of 155.5 cm for other term fetuses from waters of northern Alaska.

Excluding the beachcast neonates from Bristol Bay, average length of four newborn calves obtained in June-July was 174.0 cm.

Reproduction

Interpretation of Female Reproductive Tracts

Extensive examination of female reproductive tracts from ice-associated pinnipeds of Bering Sea indicated the validity of recognizing nulliparous, primaparous, and most multiparous females on the basis of size and external condition of uterine horns (Burns 1981a, b; Burns and Frost 1983). Exceptions were multiparous females in which successive pregnancies occurred only in the same horn. These could not be discerned from primaparous animals. Differences among the three categories of females were that uterine horns of nulliparous animals were narrow, smooth in external appearance, and relatively thin-walled. When a pregnancy went to late term or birth, the uterine horn became greatly thickened, rugose, and internally a placental scar was often evident. Correlations of reproductive status based on gross examination of uterine horns and on ovarian analysis were very useful in identifying animals that had ovulated but not given birth, those that were primaparous, and those that had two or more pregnancies alternately involving both horns.

In belukha whales, nulliparous females were easily distinguished from parous animals based on gross external examination of uteri. This, in combination with ovarian features, permitted recognition of young animals that had ovulated but had not supported a fetus. However, primaparous and multiparous animals were indistinguishable. Even when a belukha had supported only one fetus to late term or birth, both uterine horns appeared similar.

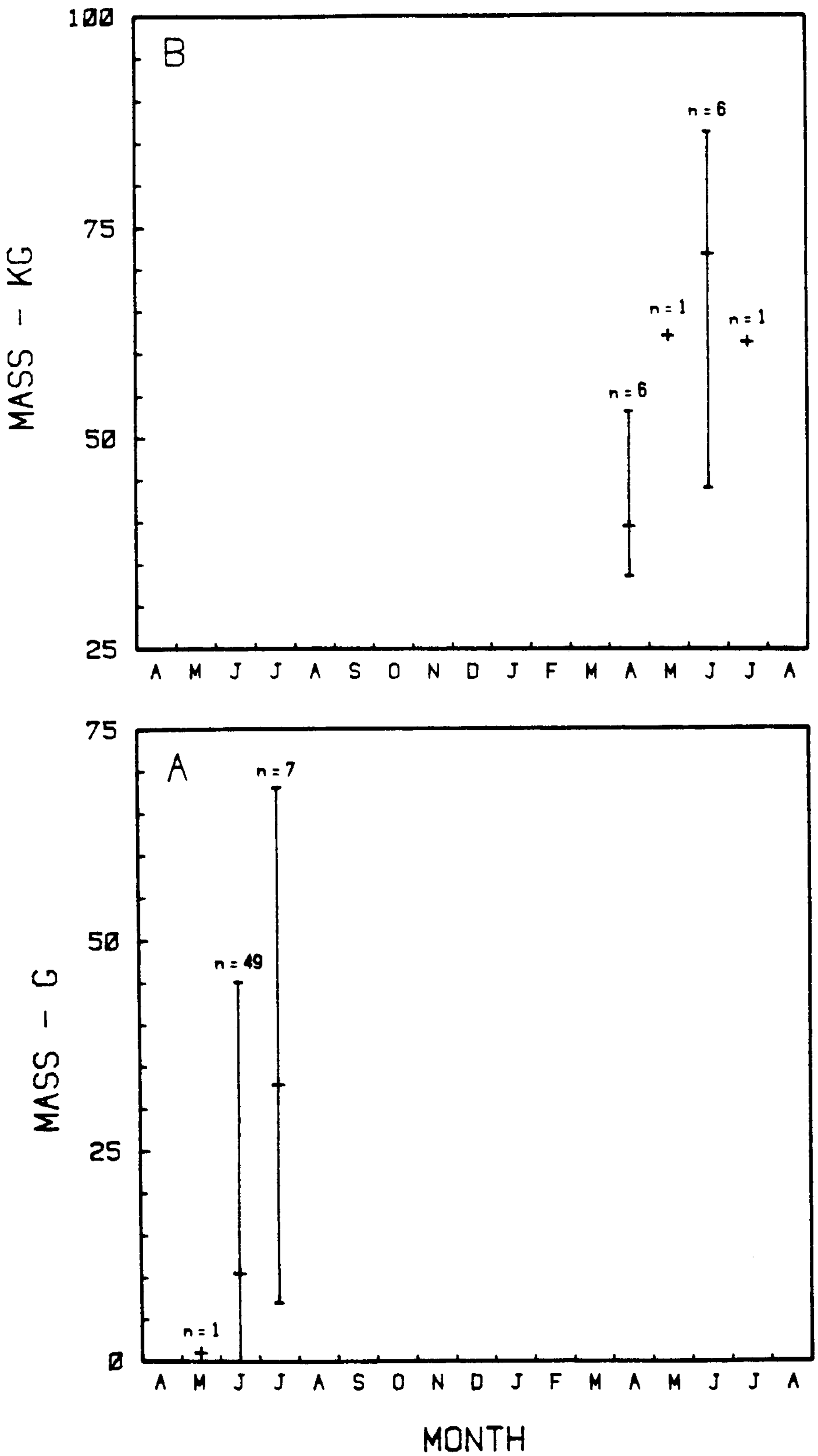

Figure 6. Progressive increase in weight of prenatal belukhas from northwest Alaska; A is of fetuses in the first trimester of development with weight in g, and B is in the third trimester with weight in kg.

We attribute this to involvement of both uterine horns in a pregnancy. Field examination of belukhas with term fetuses, taken in Eschscholtz Bay in 1981 and 1982, showed that in seven of 11 instances the fetus extended into both uterine horns. The head and torso were in the horn where the placenta was and extensive, fluid-filled fetal membranes with the enclosed caudal portion of the fetus extended into the other uterine horn.

In the four instances where a term fetus was within a single horn, the caudal portion was tightly recurved and laid along the ventral surface of the abdomen as described by Doan and Douglas (1953). In one instance, the head was toward the cervix. Caudal presentation was probable in the other three instances. Caudal presentation appeared probable in all instances where the caudal part of a fetus extended into the nongravid uterine horn. In the four instances in which a near-term fetus was completely within one uterine horn, part of the fluid-filled membranes intruded into the other horn.

Perhaps of greater significance was the finding that in seven of 11 early pregnancies noted in our 1982 sample from Eschscholtz Bay, fetal membranes extended into the nongravid uterine horn. Field collections of examined uteri were from 22 to 24 June and the fetuses were small. None exceeded 160 mm in length. Gross appearance of the epithelial tissue in both horns of newly pregnant females appeared similar. No comparisons based on histologic preparations were made.

The apparent frequent involvement of both uterine horns in a single pregnancy is probably facilitated by the broad connection between the horns, the relatively large cavity of the uterus, a single cervical canal, and presence of a mucus plug in the cervical canal during pregnancy. These anatomical features were consistent with findings reported by Kleinenberg et al. (1964), though in our samples there was considerable variation in characteristics of the cervical plug. Kleinenberg et al. (1964) indicated that these mucus plugs were, "thick, rubbery, and semitransparent," and that they were only present in pregnant females, occurring at all stages of pregnancy.

In our samples the mucus plugs varied from gelatinous and amber-colored to rubbery and nontransparent whitish in color. It is not known if the duration of specimen storage in 10% formalin affected appearance of this mucus substance. We found mucus plugs in all pregnant females examined for it and also in a few nongravid adults.

The presence of accessory corpora in the ovaries of belukhas have been noted by several investigators. Brodie (1971) discussed problems of interpretation of ovarian examination resulting from the presence of accessory corpora lutea in pregnant belukhas. Kleinenberg et al. (1964) concluded that such accessory corpora indicated postpartum breeding, an occurrence disproved by Brodie (loc. cit.). Multiple corpora lutea from a single pregnancy result in multiple corpora albicantia. Normal interpretation of these structures, as would be done for instance in the walrus or phocid seals, to obtain an indication of the approximate number of ovulations or, less precisely, the number of young born to a female, is not applicable to belukhas. Our earliest samples, obtained in 1977, included females supporting a single fetus (we encountered no multiple pregnancies) but exhibiting more than one corpus luteum. The work of Brodie (1971), combined with our earliest findings, encouraged us to disregard numbers of corpora albicantia as being indicative of the actual number of ovulations or pregnancies. Instead it prompted an effort to obtain a sufficiently large sample of females during the appropriate time of the reproductive cycle to base estimates of productivity on the presence of active corpora lutea in combination with the presence of a fetus. The number and frequency of corpora lutea in our samples of females containing such structures are presented in Table 3.

Our sample of females with at least one corpus luteum was 110. Of those, 87 (79%) had a single corpus luteum, 17 (15.5%) had two luteinized bodies, 5 (4.5%) had three, and 1 (1%) contained five well-developed luteinized bodies.

Subdivisions of this total sample were as follows:

47 females with a near-term fetus or newborn calf
- 34 (72.3%) with one corpus luteum
- 11 (23.4%) with two luteinized bodies
- 2 (4.3%) with three luteinized bodies

63 females with a small fetus
- 53 (84.1%) with one corpus luteum
- 6 (9.5%) with two luteinized bodies
- 3 (4.8%) with three luteinized bodies
- 1 (1.6%) with five luteinized bodies

Brodie (1971) reported that five of 39 (12.8%) term or postpartum females had accessory corpora lutea. In our sample as a whole, 110 pregnancies were associated with 141 corpora lutea, or 1.3 corpora lutea per pregnancy. The 1980 sample of 21 females obtained in Eschscholtz Bay is 19% of the females included in Table 3, though it includes 39% of the females with multiple corpora lutea. We have no explanation for the large annual variation in multiple corpora lutea evident in our samples.

There was a suggestion that more accessory corpora lutea were associated with later stages of pregnancy, though the differences in sample means ($t = 0.5462$, $df = 107$, $P > 0.5$) and distributions (chi-square = 4.57, $df = 3$, $0.5 > P > 0.1$) were not statistically significant. Mean number of corpora lutea in 47 females with a term fetus or newborn calf was 1.32, compared to 1.25 in 63 females supporting a small fetus.

Age at Sexual Maturity in Females

In this discussion, age at sexual maturity is the age at which a female conceives for the first time. Pregnancy may or may not result from the first ovulation. Our sample of known-age females ovulating for the first time includes 24 animals. In only two (8%) of these, ovulations did not result in a pregnancy. This was deduced by the presence of a corpus albicans in an ovary of those females, the uterine horns of which were clearly those of a nulliparous animal.

Table 3. Number of corpora lutea found in ovaries of pregnant and postparturient belukhas from northwest Alaska. Samples are separated into whales supporting a small fetus and those with a near-term fetus or newborn calf.

	With near-term fetus or newborn calf					With a small fetus				
		Number of luteinized bodies					Number of luteinized bodies			
Sample collection	N	1	2	3	>3	N	1	2	3	>3
PHD-77	9	8	1	0	0	5	4	1	0	0
PHD-78	2	2	0	0	0	1	1	0	0	0
PHD-78	7	6	1	0	0	15	15	0	0	0
PLD-78	1	1	0	0	0	0	0	0	0	0
PHD-79	1	1	0	0	0	0	0	0	0	0
WD-79	5	3	1	1	0	4	3	1	0	0
PHD-80	1	0	1	0	0	1	1	0	0	0
EPD-80	5	4	1	0	0	16	8	4	3	1
EPD-81	6	4	2	0	0	8	8	0	0	0
EPD-82	10	5	4	1	0	11	11	0	0	0
PHD-83	0	0	0	0	0	2	2	0	0	0
Totals	47	34	11	2	0	63	53	6	3	1

Determination of reproductive status for sexually immature females is straightforward. However, determination of the age of first pregnancy in the 22 females that had been pregnant only once is slightly confounded by the following considerations:

1. The duration of pregnancy is greater than a year.

2. Those pregnant only once were represented by females of three different conditions commensurate with a basically triennial breeding cycle; recently pregnant (with a small fetus), with a near-term fetus or neonate, or nongravid but having borne a calf prior to the year of capture.

3. Females were taken during the calving period or, stated differently, about the time of their own birthdays.

Thus, a female of age 6, pregnant for the first time and supporting a small fetus, was bred at age 5+ or during its sixth year of life. A female of age 6, pregnant for the first time and supporting a term fetus was bred at age 4+ or during its fifth year of life. The analysis becomes somewhat less accurate for nonpregnant, primiparous females with presumed 1-year-old calves. Such females bred for the first time some 26 to 27 (or more) months prior to capture. Our sample includes 10 such known-age primiparous, nongravid females, eight of which were taken near Elephant Point in 1982 again suggesting an interesting sampling bias operative at the particular location and at that time (in this instance, a high proportion of young females of the same reproductive status).

Correlation of age at sexual maturity (= initiation of first pregnancy) for 22 females, based on the considerations stated above showed that 12 females (54%) conceived at age 4+ (fifth year of life), 9 (41%) at age 5+ and 1 (5%) at age 6+.

Table 4 presents a slightly different approach to the question of age at sexual maturity and pregnancy rate for our entire sample of 207 known-age females. Again, it is important to note that we obtained most of the samples at the approximate time of their birth dates. Thus, 4-year-old females were not pregnant when taken during June, though some of them would have become so prior to their fifth birthday. These data show that all animals up to the age of 4 years (N = 28) were sexually immature, 33% of 5-year-olds were sexually mature, as were 94% of 6-year-olds. All animals beyond age 8 were sexually mature.

Pregnancy Rates

Our sample of 207 known-age females included 36 (17%) sexually immature animals. This proportion of immatures is lower than actually occurs in the population as a whole, for reasons which have already been discussed.

Of the entire sample of sexually mature females for which age was determined (N = 171), 35% were nongravid when taken, 35% were newly pregnant, and the remainder were with term fetuses or had recently given

Table 4. Reproductive status of 207 known-age female belukhas from northwest Alaska.

Age	No.	Number Immature	Number Mature Nongravid	Recent preg.	Near-term
0	1	1	0	0	0
1	4	4	0	0	0
2	6	6	0	0	0
3	6	6	0	0	0
4	11	11	0	0	0
5	9	6	0	3	0
6	16	1	6	4	5
7	11	1	4	4	2
8	7	0	1	2	4
9	7	0	1	4	2
10	5	0	0	3	2
11	9	0	3	3	3
12	4	0	2	1	1
13	8	0	5	0	3
14	8	0	2	5	1
15	9	0	2	4	3
16	8	0	1	3	4
17	8	0	2	3	3
18	6	0	2	3	1
19	5	0	1	2	2
20	8	0	1	4	3
21	5	0	3	0	2
22	9	0	1	5	3
23	10	0	5	2	3
24	5	0	4	1	0
25	3	0	1	0	2
26	5	0	3	0	2
27	5	0	4	1	0
28	1	0	0	1	0
29	3	0	2	1	0
30	1	0	1	0	0
31	1	0	0	1	0
32	1	0	1	0	0
33	1	0	1	0	0
34	0	0	0	0	0
35	1	0	0	0	1

birth (Table 4). These findings further support conclusions of a basically triennial breeding cycle as shown by Brodie (1971) and Seaman and Burns (1981).

Age-specific fecundity was examined in a general way (Table 5). Again, sampling bias and the triennial breeding cycle precluded meaningful comparisons among individual age classes of relatively small sample size. The trend for grouped age classes is evident. Nongravid females comprised 25% of those ages 8 to 20 years and increased to about 50% in animals older than age 20. Thus, the incidence of pregnancy is reduced in older age animals. The analysis by 3-year age groups shows a similar trend though it is confounded by attainment of sexual maturity over several years in young age groups and by the probability of encountering high proportions of females of specific reproductive condition in pods that are hunted in Eschscholtz Bay. As an example, 89% of all females in age group 8 to 10 in our samples were pregnant.

Age-specific birth rates, based on those females with term fetuses or neonates as shown in Table 4, by groups of age classes were: ages 0-5, 0.0; ages 6-10, 0.326; ages 11-22, 0.333; ages 23-25, 0.278; ages 26-28, 0.182; and ages 29-38, 0.125. Based on the age frequency of sexually mature females in our sample, as shown in Table 4, birth rate for the population was found to be 0.306. We consider this to be a slight under-estimation because of the inability to recognize those females that may have borne calves during the earliest part of the prolonged birth period in which they had been collected. Age-specific pregnancy rates, based only on inclusion of those females with a small fetus were: ages 0-5, 0.055; ages 6-10, 0.414; ages 11-22, 0.363; ages 23-28, 0.267; and ages 29-38, 0.190. Values for age cohorts 6 to 22 indicate that some females become pregnant more frequently than once in three years.

Birth Period

According to residents of coastal northwest Alaska, the time during which most belukha calves are born is from shortly after the middle of June to about mid-July. Our samples indicate an extended birth period beginning at least as early as mid-April and extending through July and possibly later. The peak period, however, is probably mid-June to mid- or late July. Determination of the latter part of the peak may be complicated if selective use of warmer coastal waters by whales about to, or having recently given birth, actually occurs. If, as suggested by Sergeant (1973) and Sergeant and Brodie (1975), such habitat selection does occur, samples would be biased toward females supporting a term fetus or newborn, even after the actual peak period of births.

Our aggregate sample of 195 sexually mature females included 171 for which age was determined and an additional 24 of unknown age. Of the 195, 54 were in the latter stages of pregnancy or were recently postparturient; 14 having been taken in the nearshore lead system of eastern Chukchi Sea during April-May and the remainder by driving them in embayments during June-July.

Postpartum females were determined based on an observed cow/calf pair or on the basis of meeting two or more of the following criteria: (1) presence

Table 5. Age-related fecundity in sexually mature female belukhas from northwest Alaska. Data are presented for, (A) groups comprised of 3-year classes and (B) for larger groups.

A			B		
Age groups (years)	N	Nongravid (%)	Age groups (years)	N	Nongravid (%)
5-7	28	36	8-20*	92	25
8-10	19	11			
11-13	21	48			
14-16	25	20			
17-19	19	26			
20-22	22	23	21-30	47	51
23-25	18	56			
26-28	11	64			
29-31	5	60	31-37	4	50
32-34	2	100			
35-37	1	0	TOTAL:	143	
TOTAL:	171				

* This cohort begins with whales in the age group at which all females were sexually mature.

of one or more corpora lutea/corpora albicantia in the early stages of degeneration; (2) distended uterine horns containing blood or debris; and (3) lactating with evidence of abundant milk production (colostrum in several instances). The inherent bias in this procedure is that females which may have given birth in April-May would not have shown indications of recent parturition by mid-June-July. They would be classified as supporting a calf because they were lactating, but not necessarily having been pregnant in the year taken. This tends to overestimate the number of nongravid females and underestimate those classified as having near-term fetus/newborn calves. Doan and Douglas (1953) reported that placental scars are not evident in belukhas. We found none, even in females known or judged to be recently postparturient. This may be explained by structure of the placenta, variously referred to as being of the epithelial (Kleinenberg et al. 1964) or indeciduate type (Doan and Douglas, loc. cit.).

Eight females taken between 25 and 29 April supported a near-term fetus, and one taken on 29 April was postpartum. Four females taken in May had a near-term fetus and none were postpartum. Samples obtained in June include 32 females taken in Eschscholtz Bay between 13 and 24 June, of which 19 supported a near-term fetus and 13 were postparturient. Between 1 and 18 July, eight females were obtained near Point Lay and Wainwright, of which three were recently postparturient and five bore a term fetus.

In Bristol Bay, 68 belukhas were collected between 26 May and 18 August 1954 (ADF&G 1969). These included 4 taken in May, 12 in June, 31 in July, and 24 in August. Three term fetuses were found in the June sample; the last one being on the 23rd. Three calves of the year were taken, the first one on 8 July. In 1961, also in Bristol Bay, Lensink (1961) found a newborn on 14 June and two term fetuses, one each on 11 and 17 June. Lowry et al. (1982) reported finding two beachcast neonates in that region, the first on 7 and the second on 10 July, 1982. Both had been dead for several days. Frost et al. (1983) indicated that in Bristol Bay births occur principally in June and July. During repetitive aerial searches for beach cast whales in 1983, the first belukha was found on 11 May 1983 and the first newborn on 4 July. Five dead newborns were found on 15 July. Additionally, four different masses of drifting afterbirth, identified as being from belukhas, were found and reported by local fishermen on 9 July 1983 (Frost et al., loc. cit.).

In Kasegaluk Lagoon, near Point Lay, a birth was recorded on 7 July 1978. In this instance an unaccompanied whale was observed for several hours after which a calf suddenly appeared beside it (Seaman, field notes).

Our findings indicate that in waters adjacent to Alaska, the birth period of belukhas is rather long, extending from April through July and possibly longer. However, most births occur between mid-June and late July.

Breeding Period

Brodie (1971) utilized a straight line method applied to fetal lengths and determined the gestation period to be 14.5 months. For the population of whales he studied near Baffin Island, the known birth period was late July-early August and he concluded that the peak breeding period was therefore in mid-May.

Application of the same procedure used by Brodie (1971) to our data from the Bering-Chukchi population of belukhas would indicate a peak of breeding in April. This is based on a 14.5 month gestation period and a peak of births during a month-long period from mid-June to mid-July.

However, our limited collection of biological samples suggests that breeding may occur earlier and that diapause (delayed implantation) cannot, as yet, be ruled out for belukhas. Our series of 20 early-caught, sexually mature females other than those with a near-term fetus or neonate (these are ruled out as breeders in the year of capture) includes 9 taken in April and 11 in May, as shown below:

Date	No. specimens	Date	No. specimens
April 25	2	May 7	1
26	1	10	1
27	2	17	4
29	4	19	3
		23	1
		24	1

Of the nine females from April, ovaries of four had a large, completely formed corpus luteum, the smallest of which was 39 mm in diameter. One of the females, taken on 27 April, had a 2.8-mm, rod-like, segmented embryo. No embryos were recovered from the other three, though they were, in all probability, pregnant. Another four females were apparently nonbreeders during the year of capture. They showed no indication of recent or impending ovulation. As is usual for most adult females, the ovaries of these nongravid females contained follicles, in one instance as large as 8 x 5 mm, but mostly less than 2 mm. None of these follicles protruded from the surface of the ovary. One female taken on 29 April 1977, contained a fully mature, ripe follicle, the greatest diameter of which was about 42 mm. The follicle mostly protruded above the surface of the ovary. This female was considered to be nearing ovulation. Thus, of the five females taken in late April that showed signs of breeding activity, four had ovulated enough in advance of collection that the corpora lutea were fully formed. One was approaching ovulation, indicating that some breeding was still occurring.

Of the 11 appropriate females obtained in May, five had ovulated earlier in the year as evidenced by a fully formed corpus luteum, the smallest of which was 41 x 30 mm. An embryo, 8.4 mm, was recovered from the female taken on 7 May. Recent or imminent ovulation was evidenced in one animal taken on 10 May. It had a large (>30 mm), though collapsed, follicular cavity which protruded above the ovary surface. This follicle may have been naturally ruptured, or burst when the whale was butchered on the ice. The remaining five females were apparently nonbreeders in the year of capture. None of the 112 females taken in June that were potentially capable of breeding during the year of capture showed signs of recent or impending ovulation. Fifty of them were already pregnant and supporting small fetuses and 62 were nongravid. In the July sample of 10 appropriate females, 2 were nongravid and 8 were pregnant. One of the eight had a large, 45-mm, incompletely formed corpus luteum, suggesting ovulation sometime in late June-early July. It was taken on 18 July.

This series of specimens indicates that some breeding occurs in late June-early July but most occurs prior to late April. Kleinenberg et al. (1964) noted the difficulty of finding very small embryos under field conditions. They indicated that some authors had recorded well-developed corpora lutea in belukhas, but were unable to find an embryo. That was the case in our series of newly pregnant females taken in April-May. The two embryos recovered were in uteri from two of three reproductive tracts obtained in 1980 and later, all of which were carefully examined under laboratory conditions. The third of these taken on 19 May, had a fully formed corpus luteum, the largest dimensions of which were 50 x 41 mm. Neither an implantation site nor an embryo was found. We cannot say with certainty that samples obtained prior to 1980 contained a small embryo or not. They did not have obvious implant sites, features which are apparent even with the smallest discernable embryos.

Small to moderate size follicles were found in ovaries of some females, regardless of either the month in which they were taken or their general reproductive condition. As an example, of 68 females taken in June 1982 in Eschscholtz Bay, 24% had one or more obvious follicles. The largest follicle in two recently postpartum females was 12 x 9 mm. In three females with a small fetus the largest follicle was 7 x 6 mm ($\bar{x}$ = 6 x 5.7 mm). Five females with follicles were subadults, being nulliparous and not pregnant. The largest follicle in these was 10 x 8 mm ($\bar{x}$ = 6.6 x 5.2 mm). In six nongravid, parous females, average size of follicles was 11 x 6.3 mm, and the largest was 17 x 12 mm. This large follicle was the only one in the June 1982 sample that might have matured later in the summer. Though it was situated near the surface of the ovary, it did not protrude.

Histological sections of testes and epididymides from 39 males were examined microscopically. This sample included 8 whales taken in late April, 2 in mid-May, 6 in late May, 18 in mid-June, and 5 in early July. Five whales were found to be adolescent. In the 34 sexually mature males, two (5.9%), both taken in mid-June, were judged to have been in breeding condition. In the testes of both, all phases of the maturation of germ cells, from spermatogonia to spermatoza, were evident. Also, spermatoza were moderately abundant in tubules of the epididymides of both whales.

In contrast, the other 32 adult males, including the 14 animals obtained in April and May, were in the early to mid part of the retrogression phase of the annual cycle of spermatogenesis. Within epididymides, spermatozoa were mostly absent (22 animals) or present only in trace amounts (10 animals). Contents of tubules mainly consisted of cellular debris. Seminiferous tubules of the testes showed various stages of degeneration of germ cells, presence of giant cells, and extensive debris. Presence of multi-nucleated spermatid giant cells is indicative of the retrogression phase.

These findings show that although a small proportion of males may remain in breeding condition through June and perhaps later, most are in nonbreeding condition by late April-May.

Evidence from reproductive organs of females and males indicate that the breeding season is long but that most breeding occurs during an unknown period prior to mid-April. We suggest that additional study will establish the peak period between late February and early April, when most belukhas are in the Bering Sea or beginning the spring migration.

Color Change

The color of term fetuses and very recently newborn calves seems quite variable. They appear to have a light greyish or silvery sheen that masks much darker pigmentation. Short-term exposure apparently changes or removes this surface coloration and the young calves become a dark brownish-grey or blueish-grey. Belukhas gradually become lighter as they mature and all (or most) are white, with a narrow blackish fringe on the posterior margins of the flukes as adults. Some adults, especially males, also have a narrow dark fringe along the posterior margins of the flippers. Sergeant and Brodie (1969) indicate that the white coloration is obtained when the animals become sexually mature, "but rather later in females than in males."

We classified belukhas into four general categories of color: dark brownish- to blueish-grey, grey, light grey, and white. Since categorization of such a color gradient is subjective, some differences in assigned coloration may have occurred both between the two principal investigators and among different years for the same investigator. The senior author classified 172 of 209 (82%) whales for which color as well as either age, standard length, or both were also determined. The greatest probability for discrepancy may be in classification of light grey- and white-colored animals.

Lengths and ages of males and females of the four color phases are presented in Table 6. For males, dark grey animals were mostly those in their first and second years of life, grey animals were mostly ages 2 through 7, light grey were mostly 6 to 9 years, and white-colored males were 9 years and older. The light grey phase was evident in some males and females by age 5. The mean age of light grey females indicated in Table 6 is misleading. Although the modal age of light grey females was 6 years, this color phase was evident in animals as old as 21, thus skewing the mean to an age significantly higher than either the mode or the median of 7 years. Apparently, in some females the light grey color phase persists well into adulthood while others become white as young as age 6.

Indicated mean ages of white-colored males and females are parameters of little value because of the great range in age of whales in this color cohort.

Reproductive status of females indicated that most reach sexual maturity before they become white. A comparison of coloration and reproductive history showed that none of the dark grey females were sexually mature. Of 29 grey females, three (10%) were sexually mature, having been pregnant once. They were judged to have bred at age 4+ (fifth year of life).

Sexual maturity in females was mainly obtained during the light grey color phase. Of 21 females in this category, 19 (90%) were sexually mature, including 7 (37%) that had been pregnant only once. The older, light grey animals were multiparous.

Table 6. Age (yrs) and standard length (cm) of belukhas from northwest Alaska, classified by color phase.

		Color phase							
		Dark grey		Grey		Light grey		White	
Sex	Parameter	Length	Age	Length	Age	Length	Age	Length	Age
Male	N	4	5	8	19	10	17	24	39
	Mean	217.6	1	299.4	5	333.2	7.5	408.3	22.9
	Range	188.0-256.5	0-3	236.2-335.3	2-9	297.0-355.6	5-11	345.4-452.1	9-38
Female	N	5	6	13	23	11	21	35	65
	Mean	214.8	1.2	274.3	3.9	329.7	8.8	350.8	19.3
	Range	190.5-241.3	0-2	238.8-307.3	2-6	304.8-361.3	5-21	312.4-373.4	6-33

Of 71 white-colored females, all were sexually mature and 31 (44%) were pregnant only once; one becoming so at age 4+ years, one at 5+ years, and two at 6+ years. Although they were white when collected, they were probably grey or light grey when they became pregnant.

Of 225 whales in our sample, for which color was recorded, 70% were light grey (whitish) or white.

Age Structure and Mortality Rates

Several sources of bias additional to those inherent in field sampling affect our analysis of population structure. Age determinations were based on counts of dentinal layers and the conclusion by Brodie (1971, 1982) that these layers are deposited at the rate of two per year. Our age determinations for small-sized whales also support Brodie's conclusion. There is great individual and sex-related variation in length and diameter of teeth. On average, those of males are considerably larger, in both dimensions, than those of females. We do not know if there is a general sex-related difference in rate of tooth wear, nor if the growth-to-wear relationships vary at different times of a whale's life. Accurate counts of the total number of dentinal layers actually deposited were possible only when the neonatal line was present. Loss of that important reference line was quite variable. It was worn away in 1 out of 21 (4%) whales 8 years old and all of 15 whales that were determined to be 17 years old (34 to 35 dentinal layers). However, it occasionally persisted in a very few individuals up to the age of 23+ years. For our purposes we used the minimal ages, as determined by the number of remaining dentinal layers, as if they were actual ages. Thus, the true age frequency distribution of older whales in our samples is biased toward younger cohorts and the maximum life span is underestimated.

The derived estimates of birth rate for the population as a whole and age-specific birth rates are also considered to be slightly lower than actual. Birth rates are based on those females that supported a term fetus or had recently given birth. The great majority of whales were sampled in June and July, at which time indications of a birth that may have occurred several weeks to months earlier were no longer obvious. Such whales would have been classified as nongravid. Actual birth rate for our sample was probably closer to 32% for females 6 years and older rather than the derived rate of 30.6%. However, we have used the 30.6% figure.

Age composition of 412 sampled whales from northwest Alaska is shown in Figure 7. Under-representation of age classes 0 to 5 is obvious. This is presumed to result from bias due to three factors: (1) a generally older-age composition of those whales comprising the early spring migrants (those taken in the lead systems near Point Hope in April-May); (2) a general hunter preference for larger whales; and (3) the greater ease with which larger, lighter-colored whales can be pursued in shallows. Age composition of our sample indicates that full recruitment into the catch occurs at about age 6. Various aspects of this sort of recruitment into the harvest are discussed, in detail, by Ricker (1958). The age frequency of sampled animals 6 years and older was "smoothed" using the probit regression (Caughley 1977) in order to generate the probable age structure of that

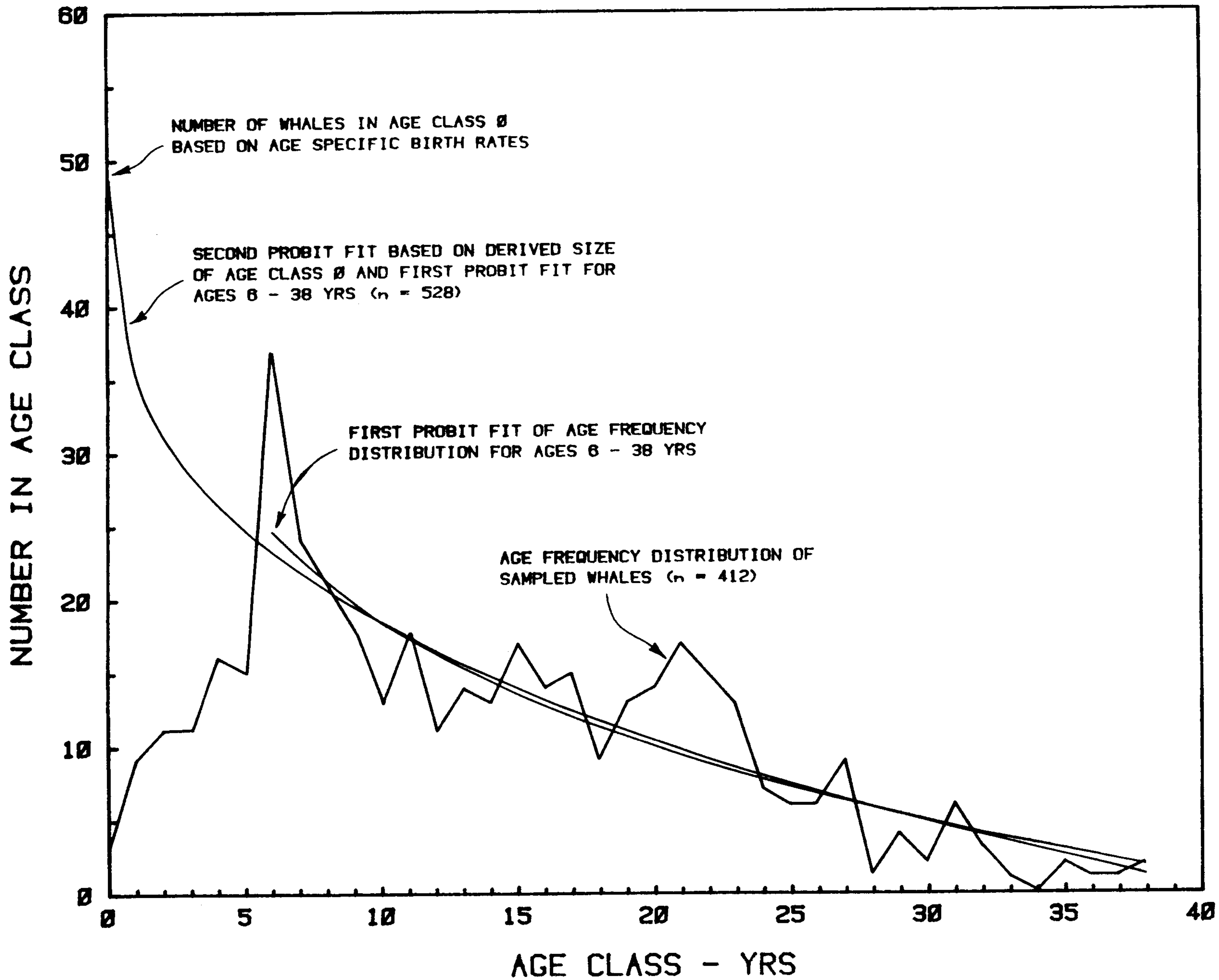

Figure 7. Age-frequency distribution of 412 belukhas sampled in northwest Alaska and the probable age-frequency distribution of model "population."

portion of the population. Then, based on our findings of a 1:1 sex ratio, age-specific birth rates as previously indicated and the fitted age frequency distribution of whales 6 years and older, the number of calves produced by a "population" of our sample size and composition was derived. The 332 belukhas, 6 years and older represented by the probit fit produced 50 calves. Using 50 as the size of age cohort 0, and the values that produced the probit fit for belukhas 6 years and older, another probable age frequency curve was generated. Our assessment is that the derived distribution curve for ages 0 to 38 appears to be a reasonable approximation of population structure.

This statistical exercise indicates that in the derived "population" of 528 belukhas, calves (age 0) represent 9.5%, ages 0 to 5 are 35% to 36%, and those 6 and older are 64% to 65%.

A life table for belukhas in our study area, based on the fitted age distribution is presented in Table 7. Procedures used for deriving that table generally follow those employed by Caughley (1966, 1977) and Smith (1973). Parameters included are age (x), smoothed age frequency distribution (N = 528), number per age class when the population size is 1,000, survivorship (l_x), deaths per age class (d_x), age-specific mortality rates (q_x), and mean life expectancy per age class (e_x). Mean annual mortality rate was found to be 0.0936.

Age-specific mortality (q_x) for a model population of 1,000 belukhas is shown in Figure 8. It suggests that the mortality rate for males, starting about age 4, becomes increasingly greater than for females.

Mortality

We have no data about mortality of belukhas caused by diseases or parasites. Three causes of mortality commonly mentioned in Eskimo lore are entrapment in ice and predation by polar bears and killer whales. Surprisingly, in many years of working with marine mammal hunters of northwestern Alaska, instances of either entrapment or predation by bears were reported from relatively few locations. Entrapment of belukhas by unfavorable ice conditions can certainly facilitate predation by bears and the two phenomena are often linked.

Entrapment

Belukhas normally winter in regions of active drift ice where they have easy access to air. The vast majority of the Bering Sea population apparently winters over a broad area in Bering Sea. Winter distribution is inadequately known. In other parts of the north there are aggregations, groups, and populations that winter in restricted and localized polynya areas in several parts of the Soviet Union (Kleinenberg et al. 1964), in Foxe Basin and James Bay in eastern Canada (Jonkel 1969, Sergeant 1973, Stirling et al. 1981), and in Bering Strait.

Throughout their range, belukhas occasionally become entrapped by extensive ice. Accounts of ice entrapments suggest to us that they most commonly result from two causes--failure of belukhas to migrate prior to or during

Table 7. Life table for belukha whales based on samples obtained in northwest Alaska from 1977 to 1982.

Age class (x)	Number per age class	Number per age class (pop. = 1000)	Survivors per 1000 (l_x)	Deaths per 1000 (d_x)	Age specific mort. rate (q_x)	Mean life expectancy (e_x)
0	50	94	1000	294	294	10.18
1	35	66	706	76	107	13.21
2	31	59	630	53	84	13.73
3	29	54	577	42	73	13.95
4	26	50	535	36	66	14.01
5	25	47	500	31	62	13.97
6	23	44	469	28	59	13.86
7	22	41	441	25	57	13.70
8	21	39	416	23	56	13.50
9	19	37	393	21	55	13.26
10	18	35	371	20	54	13.00
11	17	33	351	19	54	12.72
12	16	31	332	18	54	12.42
13	16	29	314	17	54	12.09
14	15	28	297	16	54	11.76
15	14	26	281	15	55	11.40
16	13	25	266	15	56	11.04
17	12	24	251	14	57	10.66
18	12	22	237	14	58	10.28
19	11	21	223	13	60	9.88
20	10	20	210	13	61	9.47
21	10	18	197	12	63	9.06
22	9	17	184	12	65	8.64
23	9	16	172	12	68	8.21
24	8	15	161	11	71	7.77
25	7	14	149	11	74	7.32
26	7	13	138	11	78	6.87
27	6	12	127	11	83	6.41
28	6	11	117	10	88	5.95
29	5	10	106	10	94	5.47
30	5	9	96	10	102	4.99
31	4	8	87	10	111	4.50
32	4	7	77	9	122	4.01
33	3	6	68	9	137	3.50
34	3	5	58	9	155	2.97
35	2	5	49	9	180	2.43
36	2	4	40	9	216	1.85
37	2	3	32	9	271	1.22
38	1	2	23	23	1000	0.50

Mean mortality rate = 0.09362

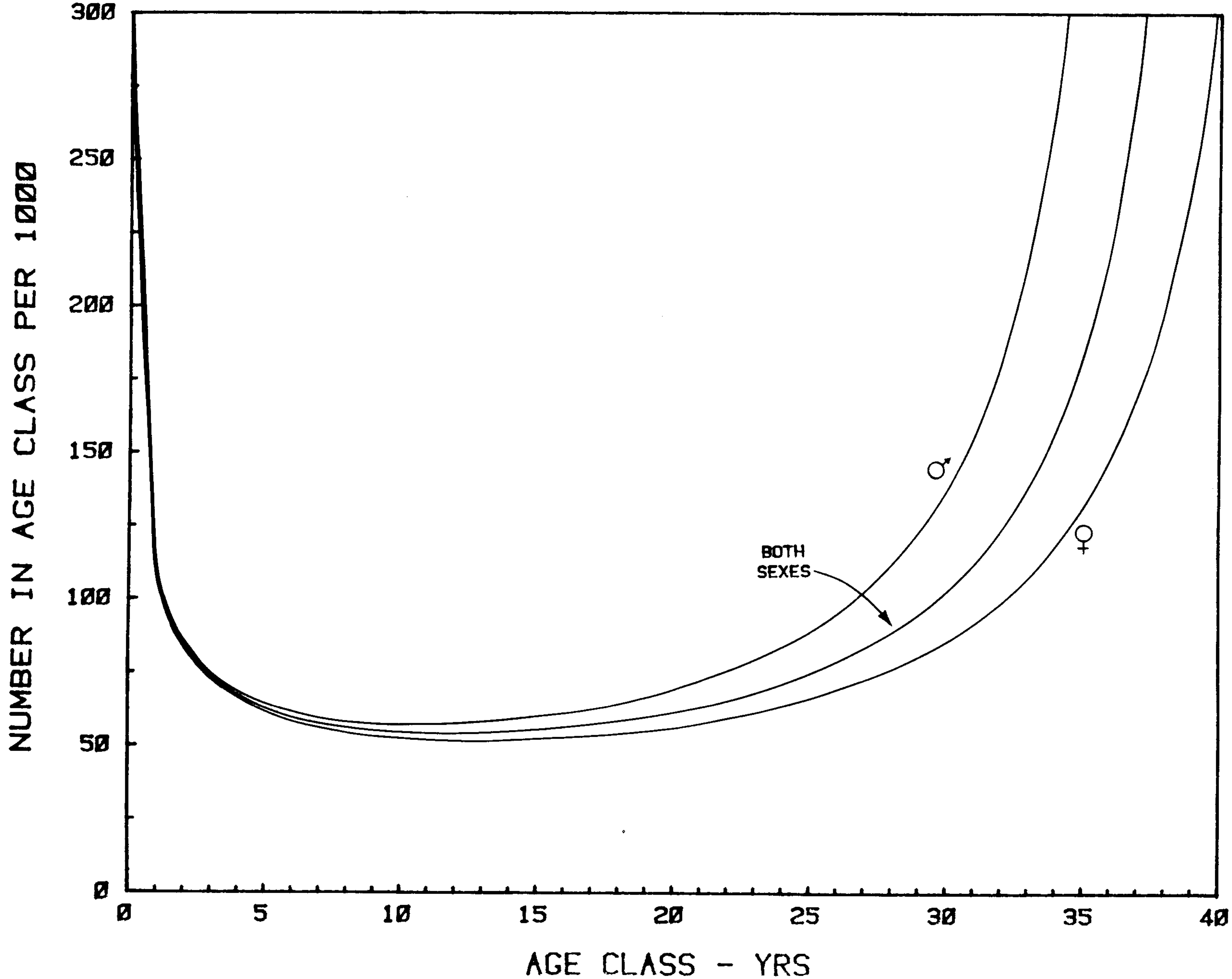

Figure 8. Age-specific mortality (q_x) for a model "population" of 1,000 belukhas, based on samples from northwest Alaska obtained in 1977 to 1982.

autumn freezeup, or deep penetration of the pack ice during spring migration with subsequent cold weather and extensive freezing of openings.

Porsild (1918) described entrapments of animals and introduced the anglicized Greenland Inuit term savssats into the biological literature. The term savssaq (or its dialectal variants), in its most general sense, means an animal whose way is blocked. In Greenland Inuit, savssaq usually means a single whale or seal locked in a hole in the ice and savssat refers to more than one whale or seal in similar circumstances. The term is less commonly used in reference to sea birds or fishes whose way is blocked by such man-made devices as a weir (Schultz-Lorentzen 1927). In Alaska there are exact equivalents used by coastal Inuit from Bering Strait to Point Hope: sapraq (sing.) and saprat (pl.; Bob Uhl, personal communication). We will use the more familiar Greenland word in reference to trapped belukhas.

In April 1984, two instances of entrapment were known to have occurred adjacent to Alaska (Lowry et al., in press). The first was near Fairway Rock, in Bering Strait, at approximately 65°38'N, 168°34'W. An unknown number of whales (savssat) became entrapped around the middle of the month. The opening and numerous dead whales were found by a pilot flying from Nome to Little Diomede Island and the site was subsequently seen, on occasion, for almost a month. Photographs acquired by Mr. Robert Nelson (Alaska Department of Fish and Game, Nome) that were taken on 24 April by Mr. John Fray (pilot, Seward Peninsula Flying Service) showed that a minimum of 40 and perhaps as many as 55 whales had been killed over a period of several days and dragged onto the ice by polar bears. By 6 May the dead whales had drifted to a location approximately two miles north of Little Diomede Island. On that date an estimated 31 polar bears were scavenging belukha remains that were spread over several acres of ice around the opening. Open water was then only several hundred meters away (Sister Joseph Alice, Fraternity of the Little Sisters of Jesus, Diomede Island, Alaska, personal communication, 8 August 1984). The second entrapment occurred in mid-April in southeast Chukchi Sea at approximately 67°49'N, 165°15'W. Numerous belukhas were seen at two small, closely adjacent holes in extensive refrozen leads. No other openings in the ice were visible. Several polar bears and several dead belukhas were seen (David Furber, pilot, Shellabarger Flying Service, Kotzebue, Alaska, personal communication 16 May and 4 September 1984).

Predation

The preceding comments about polar bear predation on savssat add to the existing record of such mortalities as reported by several writers, including Freeman (1973). Polar bears also take belukhas under different conditions. On 27 April 1984, near Cape Lisburne, Alaska, Lloyd F. Lowry, (biologist, Alaska Department of Fish and Game, Fairbanks, field notes; Lowry et al., in press) examined a kill site at which a polar bear took a young belukha in a narrow though continuous lead system. The first northward migrating belukhas moving through that general area were seen on 25 April. Thousands of whales were seen generally moving northward through the Cape Lisburne area, from 25 April to 13 May, when field study by Alaska Department of Fish and Game personnel was terminated. Dr. F. H. Fay (University of Alaska Fairbanks, personal communication) noted a report by a pilot, of a belukha caught and partially eaten by a polar bear in the southern Chukchi Sea on 27 March 1967. Mitchell and Reeves (1981) show an instance of predation by polar bear(s) in the eastern Beaufort Sea.

Killer whales have been reported as major predators on belukhas. Sleptsov (1952) described a predatory encounter involving those whales that was also recounted in Kleinenberg, et al. (1964). The latter authors also commented on predation by killer whales published by Kukenthal (1889) and Degerbøl and Nielsen (1930) indicating that belukhas are vulnerable when panicked. Kleinenberg et al. (1964) stated that killer whales do not occur in the Arctic Ocean of Siberia and North America. We are aware of three sightings of killer whales associated with the ice margin in waters north of Alaska. On 10 July 1967, at least five killer whales, in a single pod, closely approached a marine mammal hunting party operating in pack ice near Wainwright (70°39'N). The hunters indicated that game was very "nervous" for several hours after these whales had passed and that the occurrence of these whales was not especially unusual. The two other sightings were in September in western Beaufort Sea; 7 on 17 September 1974 near the ice margin where bowhead whales were present (Burns, field notes), and one large male in the ice front at 72°28.5'N, 153°06.7'W, on 17 September 1982. The latter sighting was made during our survey of belukhas and the killer whale was in loose ice (2/10) where belukhas were also abundant. Other killer whales may have been present, submerged in the openings, or under the ice.

Dr. F. H. Fay (personal communication) noted a report by an Eskimo hunter of St. Lawrence Island who found a dead adult belukha on 7 November 1967 which was killed by a killer whale(s). Fay (1982) concluded that killer whales were probably significant predators of walruses in the Bering and Chukchi seas. Predation on belukhas is also a logical occurrence in those seas when the two are present in the same area.

Accounts of harassment or predation by killer whales on belukhas, that have been observed or related to us, have occurred in the Kotzebue Sound area and near Point Lay. Most happened during June-July. During June 1979, belukha hunting success was unusually poor in Eschscholtz Bay and only three were taken. Failure of belukhas to enter the bay from Kotzebue Sound was attributed by local hunters to persistent presence of killer whales near the mouth of the bay (Seaman, field notes). Other interactions between killer whales and belukhas that have been recounted to us were as follows.

Mr. York Wilson, a hunter from Kotzebue, informed us of an incident that occurred during early July, sometime in the middle 1950's. A pod of belukhas was chased into shallow water near Sheshalik (northeastern Kotzebue Sound), by a pod of killer whales. The belukhas remained stationary for quite some time while the killer whales cruised back and forth in deeper water. After a time several of the smaller killer whales dashed toward the belukhas, apparently frightening a gray colored one away from the pod. This small belukha was seized by a large male killer and carried away from shore. A brief struggle occurred, the killer whale dove, and considerable blood and oil floated to the surface. The large killer whale swam seaward carrying the limp body of the belukha, with the posterior portion in its mouth. It was not observed to feed on the belukha before disappearing from view.

Two separate accounts were relayed to the senior author by Mr. Willie Goodwin, Jr., also an active belukha hunter from Kotzebue. Several years ago, while camped near Sheshalik in early July, Mr. Goodwin's mother watched a pod of killer whales chase a lone belukha toward shore. In its apparent attempt to escape, the belukha beached itself. Partial and complete strandings, with animals becoming free on the subsequent rising tide, were reported by Smith (1985). The second incident occurred in mid-June 1984, also near Sheshalik. A pod of four to six killer whales chased a much larger pod of belukhas under shorefast ice that was extensive at the time. Reportedly, the killer whales cruised about in the area near where the belukhas went under the ice and did not permit them to come out. These belukhas could have utilized the enlarged access holes of ringed seals to breathe. Basking ringed seals were common in the area at that time. Geptner (1930, cited in Tomilin 1957) indicated that belukhas can utilize seal holes for breathing.

Farther north, in the vicinity of Point Lay, there are three recent records of killer whales in the vicinity of belukhas. On 15 July 1979 the junior author saw at least two killer whales attack and kill a grey, subadult belukha. The event occurred close to the seaward shore of a barrier island and happened within 30 m of the observer. The sea was rough. The first sighting was of a "spyhopping" killer whale. The second was of the belukha, also spyhopping, between the shore and the killer whale. A second killer whale and a young (possibly calf) grey whale (Eschrichtius robustus) then briefly appeared. The next whale seen was the belukha. When it dove it was attacked by one of the killer whales and a bout of violent thrashing occurred, followed by 10 to 15 seconds of relative quiet. Then, the killer whale surfaced with the young belukha in its mouth. None of the whales were seen after that. It was not known if the killer whales were initially pursuing the grey whale or the belukha, nor the eventual fate of the grey whale. On 5 July 1981 a pod of killer whales was seen chasing a pod of belukhas. Outcome of that chase was not known (account by Point Lay hunters to G. Seaman, field notes). On 11 July 1981 a single killer whale was swimming about 50 m offshore (Seaman field notes).

Sergeant and Brodie (1969) indicated that in Cumberland Sound (eastern Baffin Island, Canada) killer whales have been reported to prey on belukhas. Steltner et al. (1984) report an eyewitness account of how killer whales preyed on narwhals in the eastern Canadian Arctic.

We are not aware of any accounts from the Bering or Chukchi Sea region that suggest predation on belukhas by walruses or sharks, as mentioned by Chapskii (1941) and Sleptsov (1952). Predation on marine mammals by sharks is not unusual (Brodie and Beck 1983). Pacific sleeper sharks, Somniosus pacificus, may be probable predators of belukhas in Alaskan waters. These sharks occur in Bering Sea (Wilimovsky 1958; Bright 1959; Hart 1973), and are known to prey on pinnipeds (Bright 1959). Their Atlantic counterpart, the Greenland shark (S. microcephalus) has been known to attack narwhals and belukhas caught in nets (Beck and Mansfield 1969).

Hunting

Seaman and Burns (1981) summarized the recent information about belukha hunting and netting in western Alaska and the harvests of these whales throughout Alaska from the late 1950's through 1979. Information from the late 1950's came from Lensink (1961) who estimated annual average harvests of 400 to 500 whales throughout all of western and northern Alaska; including a known directed take of 165 in Bristol Bay during the five-year period 1954-1958. In the Bristol Bay region the last significant, directed harvest of belukhas was in 1965, when seven whales were known to have been killed (ADF&G 1969). Though belukhas remain abundant in the bay hunting effort was drastically curtailed after 1959 for three reasons: cessation of lethal methods of controlling predation by belukhas on juvenile and adult salmon, greater participation of local residents in the intensifying salmon fishery, and a decrease in the demand and use of belukha whale meat and muktuk in that region. Several factors, mostly related to "modernization" including the virtual demise of working sled dog teams, contributed to that decrease in demand. Use of non-lethal methods of controlling presence of belukhas in major salmon spawning rivers, as reported by Fish and Vania (1971), eliminated that portion of the annual kill actually or subliminally encouraged by a desire to harass these whales and/or reduce their numbers in rivers flowing into Bristol Bay.

In Bristol Bay, the take of belukhas by directed hunting has remained comparatively low since 1961. Four were reported killed by hunting in summer 1983 (Frost et al. 1983). Most belukhas now taken in that region are accidentally entangled in salmon gillnets, with a kill on the order of perhaps 15 to 30 per year depending on characteristics of the salmon fishing season. In 1983, an incidental catch of 23 belukhas was reported (Frost et al. 1983).

Approximate average annual harvests of belukhas from the Bering Sea population, made in Alaska during different time intervals were as follows:

late 1950's	$\bar{x}$ 450/yr - Lensink 1961
mid-1960's	$\bar{x}$ 225/yr - Burns, unpublished
1968-1973	$\bar{x}$ 183/yr - Seaman and Burns 1981
1977-1979	$\bar{x}$ 187/yr - Seaman and Burns 1981
1980-1984	$\bar{x}$ 237/yr - this study

Harvests recorded for specific locations in the years 1977-1979 are reported in Seaman and Burns (1981, p. 571, Table 1). A similar presentation for the years 1980-1984 is included in Tables 8 to 12. In 1984 it was not possible to survey all of the coastal communities. Therefore, only part of the 1984 harvest is known. Based on that known harvest, take in 1984 was estimated to have been about 170 belukhas. This relatively low estimated take was mainly due to a total failure of the important annual hunt in Eschscholtz Bay and the lack of hunting effort near Point Lay, even though whales were present in early July.

It is noteworthy that near Kivalina in 1983 and 1984, harvests of belukhas have been significantly higher than the recent, long-term average take. In spring of 1983 and 1984, residents of Kivalina engaged the assistance of a local pilot to fly over the ice and locate leads through which bowhead whales and belukhas were passing. The hunters then established their ice camps near the most promising leads (R. Quimby, ADF&G, Kotzebue, personal communication; Burch 1984). Use of a small airplane to locate suitable openings in the extensive ice cover is a means of ensuring that open water

Table 8. Statewide (Alaska) belukha harvest, 1980, from records compiled by the Alaska Department of Fish and Game.[1]

Village or area	Number known	Number estimated	Source of information
Bristol Bay	8	15-20	Mainly incidental to fishing - K. Taylor - ADF&G and area fisherman
Yukon-Kuskokwim deltas	9	15	J. Burns, Jr. - Fisheries Biologist in region; summer of 1980
St. Michael	unknown	10[2]	estimated
Stebbins	unknown	10[2]	estimated
Shaktoolik	unknown	5[2]	estimated
Koyuk	unknown	15[2]	estimated
Elim	unknown	5[2]	estimated
Nome	0	0	J. Burns - ADF&G, correspondence w/ residents of Nome
Diomede Island	2	2	J. Burns - ADF&G, information from A. Iyahuk and P. Omiak, residents of Little Diomede
S.E. Kotzebue Sound incl. Eschscholtz Bay	101	101	J. Burns and K. Frost - ADF&G, field monitoring and hunter interviews
N.E. Kotzebue Sound incl. Sheshalik	13	13	J. Burns - ADF&G, personal interviews and Elmer Armstrong, resident of Kotzebue
Kivalina	3	3-5	J. Burns - ADF&G, interview of several residents of Kivalina
Point Hope	23	23-25	D. Smullin - biologist at Point Hope during bowhead whaling season
Point Lay	15	15-18	J. Burns - ADF&G, correspondence with residents of Point Lay
Wainwright	0	0	J. Burns - ADF&G, personal interviews with residents of Wainwright
Barrow	0	0	J. Burns - ADF&G, O. Ahkinga and W. Kaleak - residents of Barrow
Kaktovik	11	11	B. Bartels - USFWS, Kaktovik resident W. Marquette - NMFS
Totals	185	243-255	

1 An additional five to seven belukhas were taken in the separate "Cook Inlet" population, most incidental to commercial salmon fishing. K. Schneider - ADF&G, pers. commun.; J. Burns - ADF&G, interview of resident of Tyonek.

2 No unusual harvests of belukhas were reported by local travelers, residents of these villages, or hunters interviewed. Therefore, the average of known annual harvests for the location are used.

Table 9. Statewide (Alaska) belukha harvest, 1981, from records compiled by the Alaska Department of Fish and Game.[1]

Village or area	Number known	Number estimated	Source of information
Bristol Bay	unknown	10-20	K. Taylor - ADF&G, area fisherman
Yukon-Kuskokwim deltas	17	25-28	J. Hanson, Alakanuk, general comments of various village residents and travelers, includes three known taken in salmon nets[2]
St. Michael	11	11	G. Seaman - ADF&G, personal interview
Stebbins	10	10-20	R. Nelson - ADF&G, personal interview
Shaktooklik	7	7-15	R. Nelson - ADF&G, personal interview, L. Schwarz - ADF&G, aerial survey and estimate
Koyuk	21	21-25	R. Nelson - ADF&G, personal interview
Elim	3	3	R. Nelson - ADF&G, personal interview
Nome	1	1	R. Nelson - ADF&G, personal interview
Eschscholtz Bay	39	39	J. Burns - ADF&G, field monitoring
Northern Kotzebue Sound	4	4	J. Burns - ADF&G, personal interview and monitoring
Kivalina	3	10-15	E. Burch - anthropologist, G. Moore - ADF&G, and Kotzebue residents[3]
Point Hope	0	4-7	unverified pilot report
Point Lay	29	29-38	G. Seaman, field interview, and T. Smith - both ADF&G, R. Dronenberg - North Slope Borough
Point Barrow	5	5	O. Ahkinga - Barrow resident, R. Dronenberg - North Slope Borough
Kaktovik	0	0	B. Bartles - USFWS, Kaktovik resident
Totals	150	179-231	

[1] An additional three to six belukhas were taken in the separate "Cook Inlet" population, most incidental to commercial salmon fishing (K. Schneider - ADF&G, pers. commun.).

[2] 1981 has consistently been reported as a year when all marine mammals, including belukhas, were noticeably scarce near the Yukon River mouths during the open-water season.

[3] The 1981 harvest in Kivalina was estimated on the basis of an average catch of 10-15 whales as reported by informed village representatives.

Table 10. Statewide (Alaska) belukha harvest, 1982, from records compiled by the Alaska Department of Fish and Game.[1]

Village or area	Number known	Number estimated	Comments and sources of information
Bristol Bay	9	15-20	Mainly incidental to fishing. S. Behnke, K. Taylor, and L. Lowry - ADF&G
Kuskokwim Bay	4	4-10	R. Baxter - ADF&G, J. Hanson - resident of Alukanuk
Hooper Bay	5	5-7	R. Baxter - ADF&G
Yukon River Delta	20	20-30	J. Hanson - resident of Alukanuk
St. Michael	4	4-10	R. Nelson - ADF&G
Stebbins	6	6	F. Pete - resident of Stebbins, R. Nelson - ADF&G
Shaktoolik	16	16	C. Katchatag - resident of Shaktoolik, R. Nelson - ADF&G
Koyuk	13	15-20	K. Dewey - resident of Koyuk, R. Nelson - ADF&G
Elim	14	15-20	C. Sacceous - resident of Elim, R. Nelson - ADF&G
Diomede Island	1	1	P. Omiak - resident of Diomede, R. Nelson - ADF&G
S.E. Kotzebue Sound incl. Eschscholtz Bay	129	129	Harvest recorded directly by J. Burns - ADF&G, take at Choris Peninsula reported by W. Goodwin, Jr. - resident of Kotzebue
N.E. Kotzebue Sound incl. Sheshalik	25	25	Mostly taken in whale nets. B. Uhl and W. Goodwin, Jr. - residents of Kotzebue area, J. Burns - ADF&G
Kivalina	4	4-5	B. Adams and R. Adams - residents of Kivalina, G. Moore - ADF&G
Point Hope	17	17	R. Clark - Ak Eskimo Whaling Comm. field observer, J. Jacobson - resident of Kotzebue
Point Lay	28	28-33	G. Hittson and A. Agnassagga - residents of Point Lay
Wainwright	0	0	Many seen. None taken. B. Patkotak - resident of Wainwright
Barrow	3	3-5	T. Albert - North Slope Borough
Kaktovik	0	0	B. Bartels - USFWS, Kaktovik resident
Totals	298	307-354	

[1] An additional 3 to 6 belukhas were estimated to have been taken from the separate "Cook Inlet" population. Of these, one was reported taken by residents of Tyonek (D. Foster - ADF&G) and others incidental to commercial salmon fishing (K. Schneider - ADF&G).

Table 11. Statewide (Alaska) belukha harvest, 1983, from records compiled by the Alaska Department of Fish and Game.[1]

Village or area	Number known	Number estimated	Source of information
Bristol Bay	22	25-30	L. Lowry, K. Frost, and K. Taylor - ADF&G. Mostly incidental to fishing
Yukon-Kuskokwim deltas	6	15	J. Burns, Jr. - ADF&G Fisheries Biologist in region; summer of 1983
St. Michael	4	4	R. Nelson - ADF&G, interview of village residents
Stebbins	7	7	R. Nelson, same
Unalakleet	2	2	R. Nelson, same
Shaktooklik	7	7	R. Nelson, same
Koyuk	11	11	R. Nelson, same
Elim	10	10	R. Nelson, same
Golovin	2	2	D. Punguk - resident of Golovin
Nome	0	0	J. Burns - ADF&G, interview of Nome residents
Diomede Island	0	0	P. Omiak - resident of Little Diomede
S.E. Kotzebue Sound incl. Eschscholtz Bay	48	48	N. Hadley - belukha hunter from Buckland, W. Goodwin - resident of Kotzebue, pers. commun. with J. Burns
N.E. Kotzebue Sound incl. Sheshalik	19	19-24	J. Burns - ADF&G, personal interviews, B. Uhl - belukha netter and W. Goodwin - Kotzebue
Kivalina	24	24	E. Burch, Jr. - anthropologist working at Kivalina and R. Quimby - ADF&G, Kotzebue
Point Hope	30	31	K. Frost - ADF&G, from several informants R. Clarke - biologist, NMFS, bowhead whale project
Point Lay	18	18	R. Nelson - ADF&G, field monitoring of harvest
Wainwright	0	0	J. Burns - ADF&G, personal interviews with residents of Wainwright
Barrow	0	3	W. Kaleak - resident of Barrow
Kaktovik	0	0	B. Bartels - USFWS, Kaktovik resident
Totals	210	226-236	

[1] An additional three to six belukhas were taken in the separate "Cook Inlet" population, most incidental to commercial salmon fishing (K. Schneider - ADF&G, pers. commun.).

Table 12. Known and estimated harvests of belukha whales taken near selected locations in western and northern Alaska during 1984, from records compiled by the Alaska Department of Fish and Game.[1]

Village or area	Number known	Number estimated	Source of information
Bristol Bay	6	6-15	K. Taylor - ADF&G, Dillingham
Yukon-Kuskokwim deltas	5	20	S. Patten - ADF&G, Bethel, J. Hanson - resident of Alukanuk
Koyuk	38	38	R. Nelson - ADF&G, Nome, K. Dewey - resident of Koyuk
S.E. Kotzebue Sound incl. Ecshscholtz Bay	0	0	J. Burns - ADF&G, Fairbanks, N. Hadley - resident of Buckland
N.E. Kotzebue Sound incl. Sheshalik	31	31	J. Burns - ADF&G, Fairbanks, W. Goodwin - resident of Kotzebue
Kivalina	27	27	E. Burch, Jr. - anthropologist working at Kivalina
Point Lay	0	0	J. George - North Slope Borough

[1] On the basis of known and estimated harvests at hunting sites indicated above, the total 1984 harvest of belukhas in western and northern Alaska was estimated to have been about 170.

is found and if openings are numerous, that camps can be established near those that have been frequented by whales. The spring harvests of belukha whales by hunters from Kivalina in 1983 and 1984 were 24 and 27 respectively (R. Quimby, personal communication; Burch, personal communication, 1984). It is anticipated that if aircraft continue to be engaged by hunters from Kivalina for the purpose of choosing the most favorable locations for their whaling activities, catches of belukhas will continue at levels above the long-term annual average.

We did not make a systematic study of the helminth fauna in harvested belukhas. In the course of disarticulating mandibles and cleaning skulls, the senior author examined ear sinuses of 31 whales. Nematodes, identified by Dr. Murray Dailey (California State College, Long Beach, CA) as Otophocaenurus oserskoi, (Skrjabin 1942) were present in all. In their summary of marine mammal parasites, Dailey and Brownell (1972) listed 15 helminths in belukhas, including the nematode indicated above. Those helminths included five species of trematodes representing three genera, one cestode, seven species representing five genera of nematodes, and two species of a single genus of acanthocephalans.

Movements

Summer Movements in Eastern Chukchi Sea

Annual sea ice conditions strongly influence movements of marine mammals (Burns 1970, Fay 1974, Burns et al. 1980, 1981, Braham et al. 1984), including belukhas, throughout their range and especially in the eastern Chukchi Sea during spring and summer. During spring, belukhas often migrate in association with bowheads and may precede the bowheads by one to two weeks (Braham 1984). At Little Diomede Island, which is centrally located in Bering Strait, northward-migrating belukhas are occasionally taken as early as the first part of March. Usually, however, they are not seen by seal hunters there until late March. They generally arrive in association with bowheads near Point Hope in early to mid-April (Johnson et al. 1966) but have been seen as early as mid-March (Seaman et al. 1985). Foote (1960a) reported the first sighting of a bowhead from near shore on 10 April 1960 and the first belukhas on 11 April. Belukhas continued passing Point Hope, close to shore, until late July 1960 (Foote 1960b). Bowheads, and presumably belukhas, have been reported to arrive in the vicinity of Point Hope as early as 19 March (Foote 1960a).

Unusually heavy, close-packed ice conditions have been known to delay whale migrations. In 1980, an extraordinary blockage of Bering Strait by closely packed ice (Johnson et al. 1981, Ljungblad 1981) is reported to have delayed the spring migration of bowheads by approximately one month (Johnson et al. 1981). Presumably belukhas were similarly affected.

The northward migration of belukhas through the flaw zone in eastern Chukchi Sea is quite prolonged. Based on aerial surveys in the region between Wainwright and Barrow in 1976, Braham and Krogman (1977) reported sighting belukhas from 29 April to 19 June. Their surveys were terminated on 20 June. Of note was the finding (Braham and Krogman 1977, P. 20) that, "As many belukhas were seen during the last part of the season as during the first part." An average of 43.3 belukhas were seen per survey day in

May (12 survey days) and 42.0 in June (six survey days). There is no reason to believe that an end to the migration abruptly coincided with termination of the above-mentioned surveys.

Northward spring migration of belukhas off the northwest coast of Alaska is generally along the same route traversed by bowheads, with two variations. Belukhas are more broadly dispersed during spring migration (Braham et al. 1984), and some of the later migrants enter coastal waters as soon as nearshore ice conditions permit. When they begin to enter the bays, rivers, and estuaries, the directed path of their travels becomes more variable and they spend days or weeks in the same general area.

In March to May or June many belukhas passing northward from Bering Strait to Point Hope move to the west of Kotzebue Sound, beyond the margin of the extensive, unbroken ice cover. It has long been known that some of these early migrants approach land in the region between Kivalina and Point Hope, where a persistent polynyna is present. Kivalina is a settlement from which belukhas are often successfully taken by hunting in leads during April-May. So long as Kotzebue Sound remains icebound, the belukhas apparently continue northward. As ice in the Sound deteriorates, the newly arriving belukhas penetrate it. Annual variation in numbers of belukhas utilizing coastal estuaries is considerable (Anderson 1937; Lensink 1961; Sergeant and Hoek 1974; this study). Our studies in Kotzebue Sound support the Eskimo contention that, within the Sound proper, belukhas first occur in the northern part and work their way eastward and southward as seasonal disintegration of ice proceeds. This is graphically shown in Figure 9. They usually arrive in southeastern Kotzebue Sound and Eschscholtz Bay during the second 10 days of June, while other belukhas are still moving up the retreating flaw zone farther north.

The subsequent pattern of movement of those belukhas that enter Kotzebue Sound is suggested by sequential sightings in June to August in and near estuaries along the Chukchi Sea coast (Table 13). On average, after most whales depart Kotzebue Sound, they arrive in the vicinity of Point Lay in late June to early July and near Wainwright in mid- to late July or early August.

Nelson (1969), stated that belukhas may pass within sight of the coast near the village of Wainwright at any time during the summer, and that this may occur whether or not ice is present. Our information may help clarify Nelson's statement a bit more. During summers of severe ice conditions, Icy Cape is the geographic point along the northwest coast, north of which sea ice may persist relatively close to shore. Farther north, there is a higher probability of such an event happening. At Wainwright during years when ice moves far offshore, belukhas are apparently not seen after late July to early August. In years when the ice does not recede far from shore, these whales may appear sporadically in coastal waters throughout August and early September. The greater frequency of sightings in late summer during heavy ice years is thought to involve whales moving back and forth between the pack ice and coastal waters. Summer 1975 was unusual in that the pack ice extended south of Wainwright and was seldom far from land. In late August of that year, Ray and Wartzok (1980) reported sighting both belukhas and bowheads relatively close to shore in the region

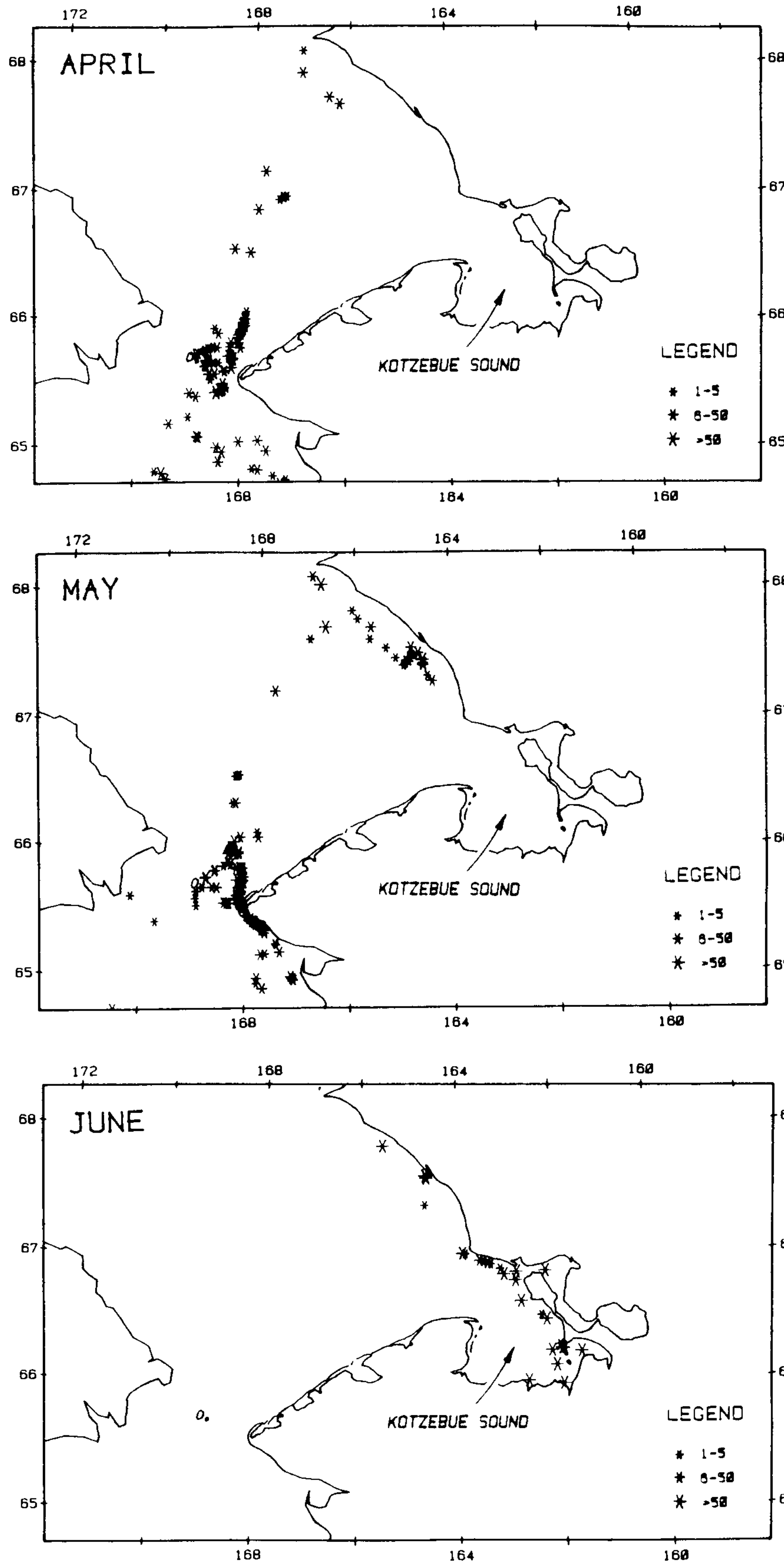

Figure 9. Occurrence of belukhas in or near the Kotzebue Sound region in April to June.

Table 13. Dates when belukhas were known to be present during breakup and ice-free months near selected locations in the eastern Chukchi Sea region.

	Locations				
Year	Kotzebue Sound	Kivalina	Cape Sabine	Point Lay	Wainwright
1958	--	--	24 Jun[1]	--	--
1960	--	1st week Jul[2]	--	--	--
1962	mid- to late Jun	--	--	--	--
1966	--	--	--	--	Early Aug[3]
1976	--	--	--	--	21-28 Jul
1978	11 Jun-9 Jul	21-24 Jun	--	2-10 Jul	15 Jul
1979	8-25 Jun	--	3 Jul	22 Jun-19 Jul	17-20 Jul
1980	13-23 Jun[4]	--	--	11 Jun	20 Jul
1981	12-19 Jun	--	8 Jul	5-15 Jul	--
1982	7-23 Jun	29 Jun	3-6 Jul	5 Jul	--
1984	--	--	4 Jul[5]	4 Jul[6]	--

1 Childs (1969).
2 Saario and Kessel (1966).
3 Nelson (1969).
4 K. Frost, Alaska Dept. of Fish and Game, Fairbanks, Field Notes.
5 J. Coady, Alaska Dept. of Fish and Game, Nome, Personal Communication.
6 Arthur Manning, Fairbanks, Alaska, Personal Communication.

between Icy Cape and Point Franklin. Our studies indicate that belukhas move northward after leaving Kasegaluk Lagoon and presumably, in 1975, they moved to the ice fringe near Wainwright.

The general picture of belukha migrations that emerges from this information is that from March to early June movements of these whales are comparatively rapid and directed; northward toward Point Barrow and thence mostly eastward across the Beaufort Sea. From about mid-June to early August the sustained, directional movement slows, with large numbers of whales entering warmer coastal waters from Kotzebue Sound to Mackenzie Bay and others remaining close to the retreating ice fringe between these points and also probably westward in the northern Chukchi Sea. By early to mid-August most belukhas move away from the coast toward the pack ice.

Those that entered coastal waters, starting in Kotzebue Sound in about mid-June, move slowly northward, some temporarily stopping at other embayments and estuaries enroute and, in August, mostly move off to the ice of the eastern Chukchi and western Beaufort seas.

A generally similar migration pattern is hypothesized as occurring along the coast of Chukhotka (see Discussion). By early September, belukhas north of Bering Strait are mostly associated with the late summer ice fringe and front over a very broad area extending from Wrangel Island to Amundsen Gulf. Observations in September suggest a late August distribution that includes large numbers of whales north of Chukhotka (Klumov 1936, in Kleinenberg et al. 1964) and from the northeastern Chukchi Sea to Amundsen Gulf. By late August the belukhas slowly begin a return migration that eventually brings most of them back into Bering Sea.

Autumn Migration in Beaufort Sea

Aerial surveys of the ice "front" in extreme northeastern Chukchi Sea and the Beaufort Sea were conducted from 17 to 21 September 1982. The eastern and western limits of this survey area were approximately 141°W and 161°W, respectively. Tracklines were determined during the survey flights and were predicated on location of the ice margin.

This survey was specifically intended to test the hypothesis that in autumn, the westward migration of belukhas across the Beaufort Sea is in close proximity to location of the pack ice margin and front zones. That hypothesis was based mainly on the paucity of reported sightings from shore and in ice-free waters of the Beaufort Sea during autumn, speculations of investigators that had studied summer distribution of belukhas in eastern Beaufort Sea and Amundsen Gulf, and the limited record of sightings for August to October obtained mainly in conjunction with surveys of other marine mammals, including bowhead whales and Pacific walruses. The background for formulation of this hypothesis evolved from results of several studies discussed as follows.

Sergeant and Hoek (1974) stated that belukhas depart the eastern Beaufort Sea during September, moving in open water. This conclusion appears to have been based largely on a sighting of 2,000 whales near Demarcation Point on 21 September 1972. These authors did not indicate how far from the pack ice those whales were. Fraker (1977) stated that knowledge of the westward autumn migration from the Mackenzie estuary was a major data gap. He suggested that some belukhas depart the estuary to the north to exploit food resources that may occur along the pack ice margin. Fraker et al. (1978) also indicated that little was known about fall migration in the Beaufort Sea. They suggested that it takes place in late August-September, that movement is toward the west, and that it was not known if migration occurred along the coast or offshore though it was "possibly along the pack ice." Those remarks appear to involve a reassessment of the conclusions previously expressed by Sergeant and Hoek (1974). Harrison and Hall (1978) reported results of 6,000 km of aerial survey tracklines flown in the western Beaufort Sea during July 1975 and August 1976. The majority of those survey lines appear to have been over ice-free waters. Only two sightings of belukhas were made in each month in the Beaufort Sea. These four sightings were of 36 belukhas, all of which were within the ice front. Johnson (1979) reported two sightings of belukhas made from islands of the Jones Islands group in southcentral Beaufort Sea. The first was a pod of 75-100, swimming westward within 300 m of the seaward side of Pingok Island on 15 September 1977, and the second was of 35, swimming westward, within 150 m of the seaward side of Thetis Island, on 23 September 1978. The first sighting was of belukhas in ice-free waters 10 to 20 km south of the pack ice. The second sighting was of whales moving along the edge of a small field of scattered ice some 16 to 20 km south of the main pack. Johnson (loc. cit.) concluded, based on these sightings and previously published records by Fraker et al. (1978), that the autumn migration occurs during the last half of September and is near the coast well south of the pack ice margin. Fraker (1980) again stated that the autumn migration had not been studied, and reiterated the sightings reported in Fraker et al. (1978) and Johnson (1979).

A series of aerial surveys, mainly for walruses and bowhead whales, began to strongly point to the ice front as the habitat through which the autumn migration of belukhas mainly occurred. In September 1974 and 1975, the senior author participated in surveys of Pacific walruses in the northern Chukchi and extreme western Beaufort Sea. Survey lines were over open water and from the ice margin northward until close-packed ice (9/10 to 10/10 cover) was encountered. A few sightings of small groups of belukhas were made, all within the ice front. Distribution of sightings during those September surveys indicated that some belukhas were present in the northern Chukchi as well as in the Beaufort Sea.

An extensive walrus survey in which the senior author also participated was undertaken during 10 to 20 September 1980 (Johnson et al. 1982). Tracklines, location of the pack ice margin, and general position of belukha sightings are shown in Figure 10. The indicated sightings are only of those whales within about 1/8 nm of the survey aircraft. Three important points about the autumn distribution of belukhas emerged from the 1980 walrus survey. These were: 1) belukhas occur well within the ice margin during mid-September, 2) they extended at least as far west as the northcentral Chukchi Sea, and 3) an area of very high abundance occurred north and east of Point Barrow. The last point is not particularly evident from Figure 10. However, on 11 September 1980, during the survey flights north and east of Barrow, several thousand belukhas were present, almost all beyond the pre-selected survey transects. Twenty-three sightings of a total of 124 belukhas occurred on the transects.

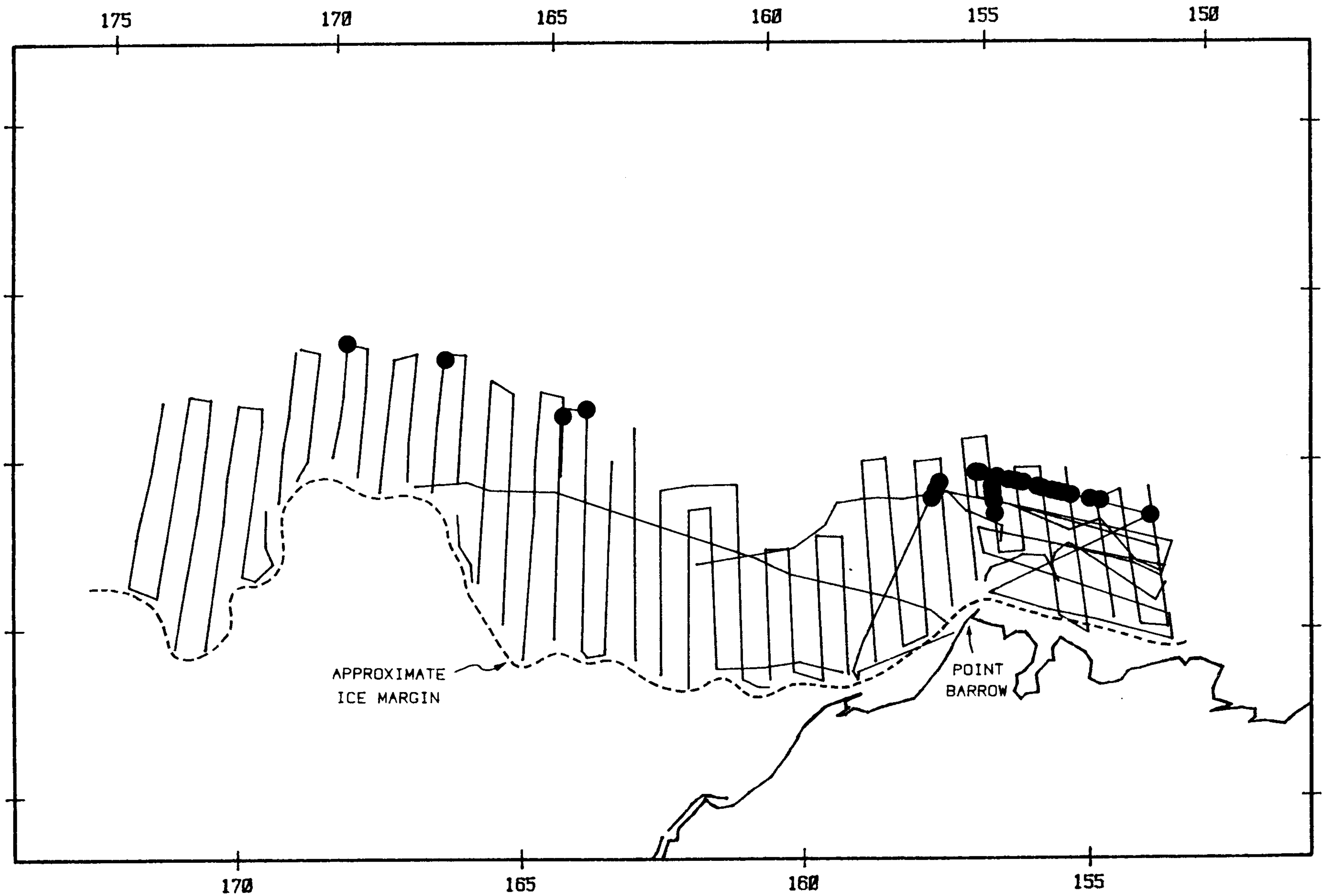

Figure 10. Tracklines flown during a walrus survey, 10 to 20 September 1980, showing locations of the pack ice margin and sightings of belukha whales (after Johnson et al. 1982).

Ray and Wartzok (1980) and Ray et al. (1984) reported sightings of belukhas also made during extensive flights with large aircraft for the purposes of determining the utility and capabilities of remote sensing techniques for study of marine mammals. In September 1974, they sighted belukhas in association with the ice front zone across the western Beaufort Sea and the Chukchi Sea west to approximately 177°W longitude (Ray and Wartzok 1980, Figure 2b). They also found a huge aggregation of belukhas of unknown total size that exceeded several thousand animals. This aggregation was seen on 18 September 1975 about 30 nm south of the pack ice margin in northeast Chukchi Sea. Their sightings led them to suggest the possibility, as had Fraker et al. (1978), that belukhas that summer in the eastern Beaufort Sea-Mackenzie Delta regions may first move north to the ice front, westward across the Beaufort Sea within the front, and then southward from somewhere in the east-central Chukchi. As an alternative possibility, they suggested that belukhas of the front may be a separate subpopulation (from those that supposedly occur near shore?) that may utilize the productivity of that habitat (Ray and Wartzok 1980).

Ljungblad et al. (1980) reported the results of a very intensive survey effort undertaken during autumn 1979. They reported results of 44 separate flights in the central Beaufort Sea region during September and October of that year. Until the onset of freezeup, most segments of the survey flights were over open water, south of the ice margin that prevailed. Belukhas were seen on only two occasions--on 1 October well into the pack north of Point Barrow and on 19 October in the advancing ice front north of Harrison Bay. The paucity of reported sightings during these extensive surveys over open water indicated that any subsequent searches for belukhas, by us, should be concentrated farther offshore and within the ice front. In autumn 1980, Ljungblad (1981) again conducted extensive surveys for bowhead whales in the Beaufort Sea during September and October. The primary study area during 4 September to 24 October was the near-shore central Beaufort between 146°W and 154°W. Some flights extended to Mackenzie Bay in the east and to Point Barrow in the west. He reported that in autumn 1980 pack ice remained close to the coast, some 8 nm north of the barrier islands that are generally east of the Colville River delta. Additionally, freezeup was underway early, the process being quite apparent by 16 September. No belukhas were reported seen during the 20 separate flights made in September 1980. One sighting of two belukhas was reported during 14 survey flights in October. The sighting was on 6 October and the whales were swimming west (Ljungblad 1981).

Aerial surveys, primarily for bowhead whales, were also undertaken during August-September 1980 in the eastern Beaufort Sea by Renaud and Davis (1981). These investigators flew extensive, largely replicate transects, mostly north of the Tuktoyaktuk Peninsula, over open water during three periods; 6-7 August, 21-24 August, and 3-4 September 1980. No belukhas were sighted during the September survey. During each of the two surveys in August, 82 belukhas were sighted. The whales were broadly distributed in ice-free waters. Based on the relatively low number of belukhas seen, Renaud and Davis (1981, p. 49) stated simply that, "These results also do not provide much information regarding the whereabouts of the Mackenzie estuary population of white whales in August and September."

The final set of survey data considered in the design of our 1982 search for migrating belukhas were results of surveys undertaken in September-October 1981 by Ljungblad et al. (1982). These investigators flew 134 hours, mainly between 140°W and 154°W and predominately south of the pack ice. The total survey effort included 21 flights in September and 11 in October. No belukhas were sighted on any of these flights, again indicating that if they were migrating westward during this period, they most likely had to be farther north, in or near the ice front.

Our surveys were conducted from 17 to 21 September 1982. Total time on survey transects was 13 hours 29 minutes. An additional eight hours were devoted to transit to and from the survey area and circling over aggregations of whales. We concentrated almost entirely on the ice front zone extending from open water 3 nm south of the margin, northward until the ice cover became complete. Transects paralleled the margin in the survey area east of 148°22'W. West of that longitude some tracks were parallel and others perpendicular to the general ice margin. The only survey effort over water farther than 3 nm south of the ice margin was during transit to or from the primary survey area. In total, 1,768.5 nm of linear tracklines were surveyed on five separate flights as shown in Figure 11. A transect width of ¼ nm on either side of the aircraft was further divided into inner and outer 1/8 nm strips. Boundaries of the transects were maintained by use of inclinometers. Sighting conditions were marginal on flight 1 and poor on the four subsequent flights. On 17 September the wind was less than 5 knots, permitting extensive formation of slush ice in openings between ice floes. On the 19th to 21st, winds in excess of 25 knots prevailed producing waves with whitecaps in ice-free waters and in openings north of the ice margin. Additionally, small ice floes and ice rafts were being blown away from the larger masses. The combination of waves, whitecaps, and abundant small floes in openings of water between the larger ice rafts made it difficult to sight and enumerate belukhas. Also, many of the whales we saw were starting to dive beneath or were emerging from under the ice. In spite of these difficulties, our surveys were very useful for determining the distribution of belukhas. The combination of poor sighting conditions and an unknown correction factor for whales below the surface and for whales under the ice did not permit any quantitative assessment of the total number that may have been present.

Belukhas were present in the ice front zone from the easternmost to westernmost points surveyed. Within the transects, 103 sightings of 224 belukhas were recorded. Sixty-three percent of the whales counted were within the first 1/8 nm of the transect, indicating a rapid decrease in sightability with distance from the aircraft. From the onset of this survey it was evident to us that the sighting of even a single whale within the transect usually meant that more were present. We temporarily deviated from a transect on 15 occasions to widely circle an area in search of additional whales. During these 15 instances of circling, 731 belukhas additional to those within transects were counted. Mean group size along transects was 2.2 whales (103 sightings of 224 belukhas). Mean size of the few aggregations over which we circled was 48.7 whales (15 aggregations of 731 belukhas). This great difference shows that if the objective of a survey in the front is to obtain a population estimate, a very intensive effort for animals that are mostly underwater, swimming beneath ice, widely distributed, and probably highly clumped would be required.

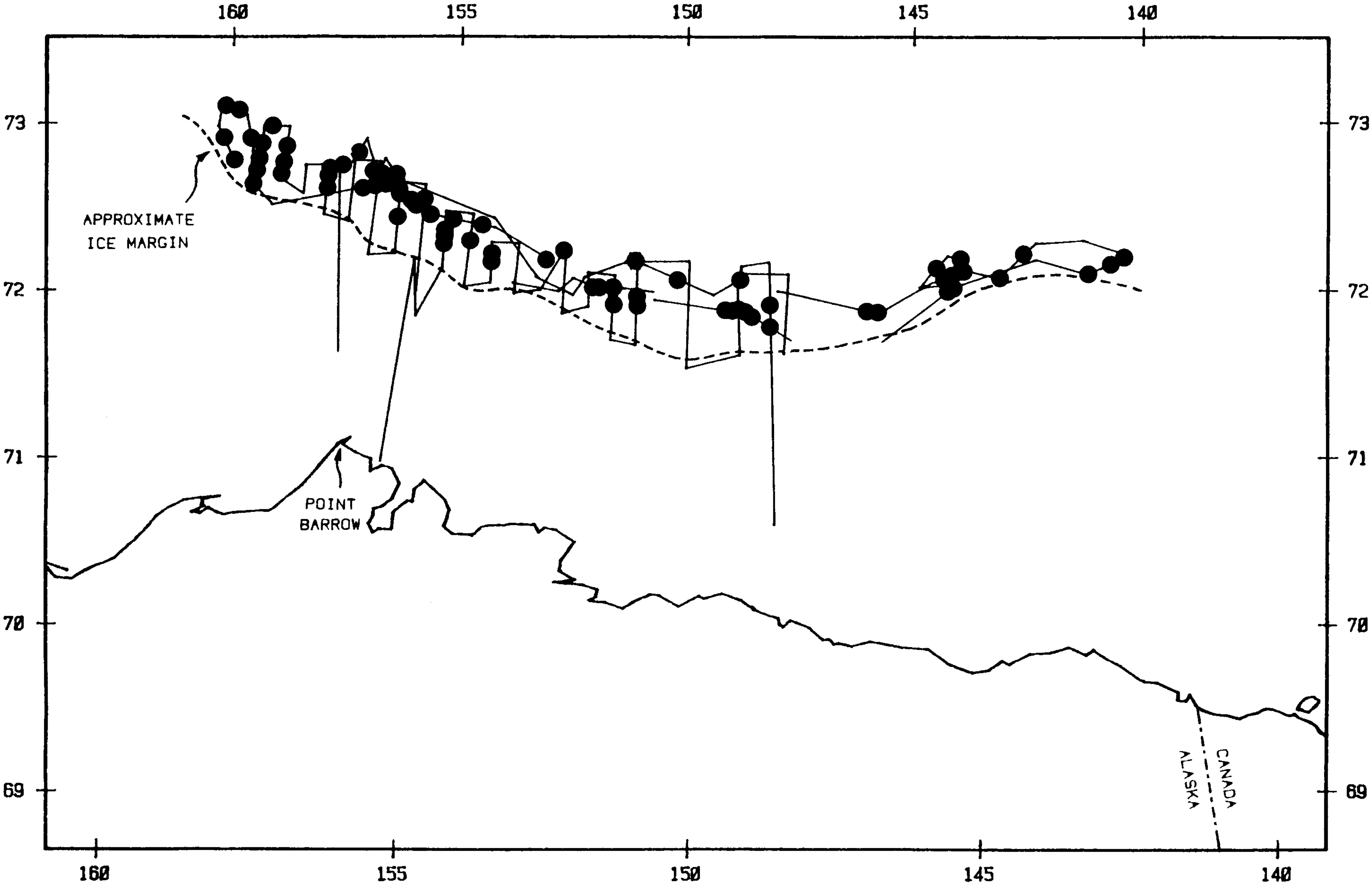

Figure 11. Location of aerial survey tracklines and sightings of belukhas within survey transects during 17 to 21 September 1982.

As was the case for belukhas sighted during the 1980 surveys of walruses (Johnson et al. 1982) and 1981 surveys of bowhead whales (Ljungblad et al. 1982), belukhas were most abundant to the north and northeast of Point Barrow (see Figures 10 and 11). Directional movement of the whales we saw within transects was basically to the west (98 of 103 sightings). Two sightings were of four whales swimming east, and three sightings were of six whales swimming south. The latter were on transects in the Chukchi Sea, northwest of Point Barrow. We did not record direction of movement of pods that were beyond the transects.

DISCUSSION AND CONCLUSIONS

Sex Ratios

Our findings show a sex ratio of whales in Alaskan waters to be 1:1 based on a sample size of 533. However, there was great annual variation (cf. annual samples from the same locations, as presented in Table 1, or samples indicated in Table 14. Tomilin (1957) also concluded that the sex ratio was approximately even, based on results of work by Vinogradov (1949, cited in Tomilin 1957) and Klumov and Dorofeev (1936). Though no sample sizes were indicated, Tomilin reported an extreme degree of selection in a sample in which 78.7% of the belukhas taken in the Gulf of Sakhalinskii (Okhotsk Sea) in 1930 were males. Kleinenberg et al. (1964), also citing Vinogradov (1949) as their source, say only that the sex ratio in belukha populations is 1:1.

Causes for the observed differences in sex ratio, even within the same geographic sampling area, are assumed to result from the factors stated by Tomilin (op. cit.); specifically, that it results from the differences in composition of pods that are captured. Tarasevich (1958) stated that sexual segregation of belukhas is common. Sergeant (in press) commented on differences in summer distribution of females with young calves and adult males in the St. Lawrence estuary.

According to Eskimos of Little Diomede Island, Alaska, the first groups of whales to pass north during the earliest phases of the annual spring migration are large adult males, based on the sex of those they occasionally kill and the size of those they see. We have not sampled these early migrants. Brodie (1971) indicated a selective bias toward females and neonates in the net capture of belukhas in shallow water. Sergeant and Brodie (1975) indicate that the long-term catches of whales near Churchill have been on the order of 500 per year, with a strong bias for males, that comprise about 66% of the harvests. Ognetov (1981) found that males were 75% of whales in a sample of 105 animals taken in the Barents Sea in 1973-74. Fraker (1978) similarly indicates a selective bias toward males, which are about 80% of the annual catches made in the Mackenzie estuary.

In Eschscholtz Bay, during the whale drives, the selective bias is toward larger whales that are more often light-colored and leave a larger wake in shallow water. Both characteristics, color and size, more readily focus attention of hunters in pursuit. Thus, hunting bias takes at least two forms: a disproportionate number of older, larger whales from those available, and non-random composition of pods. Notwithstanding, the kinds

Table 14. Sex ratios of belukhas sampled in various studies.

General location	Source of data	Sample size	No. males	No. females	Sex ratio
Bristol Bay Alaska	Brooks 1954 (unpubl.)	66	20	46	
	Lensink 1961	25	15	10	
	Lowry et al. 1982	5	4	1	
	Frost et al. 1983	20	13	7	0.81:1
Northwest Alaska	This study	533	268	265	1.01:1
Mackenzie Estuary, NW Canada	Fraker 1980	129	100	29	
	Hunt 1976	16	8	8	2.92:1
Hudson Bay, NE Canada	Doan and Douglas 1953 3 annual samples				
	1949	180	93	87	
	1950	293	176	117	
	1951	581	383	198	
	Sergeant 1973	590	279	311	
	Finley 1982	60	30	30	1.31:1
Greenland	Degerbøl and Nielsen 1930	190	104	86	1.21:1
White, Barents, and Kara seas	Medvedev 1970	99	66	33	
	Ognetev 1981	385	221	164	1.46:1
		3,172	1,780	1,392	$\bar{x}$ = 1.28:1

of different sampling biases associated with different times, locations, and methods of capture, the sex ratio of various belukha populations is apparently 1:1.

Growth

Age-Body Length Relationships

Increase in length of belukhas during the first few years of life is not well known. Kleinenberg et al. (1964) reported their findings about progressive increase in length of "sucklings" from Tugurskiy Gulf in southwestern Okhotsk Sea in the period from late June to late July. They reported a length increase of 62 cm (27%) between sucklings examined in late June when they averaged 230 cm (N = 6) and those measured on 26 July that had an average length of 262 cm (N = 5). We judged those data as not useful for indicating growth of calves. Measurements included in their analysis (Table 54, p. 255) strongly suggest that the broad category of "sucklings" probably included neonates as well as 1- and perhaps 2-year-olds. The numbers of each age cohort cannot be determined on the basis of data they presented. Brodie (1971) also commented on problems of accurately determining growth rate of calves based on the reported findings of Kleinenberg et al. (1964).

Of concern in this discussion are the probable relationships of belukhas that occur in three different geographical regions during summer; Bristol Bay (southwest Alaska), northwest Alaska and the Mackenzie estuary of eastern Beaufort Sea. Belukhas that summer in these three areas winter in Bering Sea, though it is not known if or to what extent they may intermingle.

Sergeant and Brodie (1969) examined geographical differences in body size of belukhas from 12 different regions of their range. They concluded that the smallest belukhas come from western Hudson Bay, the White Sea, and Alaska. In both males and females, those from Alaska were ranked fourth and those from Mackenzie Bay, eighth, in order of increasing length in a ranking from 1 (smallest) to 12 (Sergeant and Brodie 1969, Figure 8, p. 2567). Sergeant and Brodie's sources of data about whales from Alaska were those animals obtained in Bristol Bay by Brooks (1954b) and Lensink (1961). As previously indicated, samples of whales taken in Bristol Bay appear to be strongly biased toward younger-age cohorts (smaller-sized individuals) than those taken in other parts of Alaska. Based on an examination of Lensink's data, the modal and mean ages of 21 whales from Bristol Bay, were 5 and 6.2 years respectively. In our sample of 412 animals from northwest Alaska the mode and mean were 12 and 13.6 years respectively.

White-colored belukhas from northwest Alaska were, on average, shorter than those from the Mackenzie estuary (Table 15). This difference was statistically significant only for females ($t = -2.5689$, d.f. = 65; $0.01 < P < 0.02$). This comparison was based on length frequency of harvested "adult" whales and several significant sources of potential bias contributing to samples of different size composition in females are probably operative. These include different conditions in which hunting occurs, hunter selectivity and non-random composition of whale pods. Our

Table 15. Standard lengths (cm) of adult, white-colored belukhas from northwest Alaska and the Mackenzie estuary of northwest Canada.

	Northwest Alaska		Mackenzie estuary[1]	
Statistical parameter	Males	Females	Males	Females
Sample size	23	35	85	32
Mean	402.9	350.7	412.9	359.5
S.D.	33.9	12.3	21.9	15.3
Minimum length	327.8	312.4	377.1	346.5
Maximum length	452.1	373.4	460.0	386.5

1 Data were interpolated from Sergeant (1969) as follows: samples sizes of white-colored whales were derived from Figure 4, p. 2564 based on the assumption that males longer than 350 cm and females longer than 330 cm are white; means, ranges, and standard deviations are from Figure 8, p. 2567.

samples are almost entirely of whales pursued cooperatively by a large number of boats, driving large pods within enclosed embayments well inshore. The cooperative driving is terminated when the whales are in water shallow enough to be easily followed or can no longer be driven. At that point of a drive, the actual killing begins. In Mackenzie Bay belukhas are hunted in a less confined body of water and each boat (hunting crew) acts as an independent unit usually in pursuit of a single whale (Hunt 1979). According to Fraker (1980), hunters in the Mackenzie estuary select large individuals and avoid taking females with calves. Such selection is evident in the sex composition and length frequencies of harvested whales in that region, reported by Sergeant and Brodie (1969), in which 75% of the examined whales (N = 126) were males and there were no females less than about 310 cm.

We further approached the question of size differences among belukhas from Bristol Bay, northwest Alaska and eastern Beaufort Sea by comparing length at age rather than lengths of white-colored animals, using the growth curves derived from the sample from northwest Alaska. This non-statistical approach indicated that length at age for males and females from all three areas was similar (Figure 12). As an additional comparison, we used a chi-square test to determine if there was a statistical difference in length at age in females 10 years or older in samples from Mackenzie estuary (N = 12) interpolated from Sergeant (1973, Figure 10, p. 1077) and northwest Alaska (N = 27). No statistically significant difference was evident ($x^2 = 6.295$, d.f. = 5). Based on those data we conclude that length at age for these aggregations of summering whales is probably the same.

Brodie (1982) compared length at age of a captive male belukha from Alaska, maintained at the Vancouver Public Aquarium (Vancouver, B.C., Canada), with his findings from whales sampled near eastern Baffin Island, Canada. The captive whale was measured six times between 1.2 and 14 years of age. Growth of the captive whale closely approximated that of free-ranging animals examined by Brodie (op. cit., p. 446, Figure 1).

We queried Dr. Newman, Director of the Vancouver Public Aquarium (personal communication, December 27, 1984) about the origin of the whale and verified that it was captured in Bristol Bay. We then compared its growth with that of the male segment of our sample from northwest Alaska (Figure 13). Growth rate of the captive male from Bristol Bay was slightly faster than the average of our sample, though within the range of lengths for appropriate year classes. Its greatest length of 427 cm was 10 cm less than that of the largest male from northwest Alaska.

Fetal Growth

Our data about fetal growth of whales from waters adjacent to Alaska included specimens representing only the early and late stages of gestation. To this we added data from 131 fetuses examined by Degerbøl and Nielsen (1930) from waters of Greenland, 103 from eastern Hudson Bay summarized by Sergeant (1973), 17 from the St. Lawrence estuary reported by Vladykov (1944) and 9 from waters adjacent to Baffin Island, reported by Brodie (1971). The resulting composite growth curve is shown in Figure 14. It appears that fetal growth in belukhas from Greenland and eastern

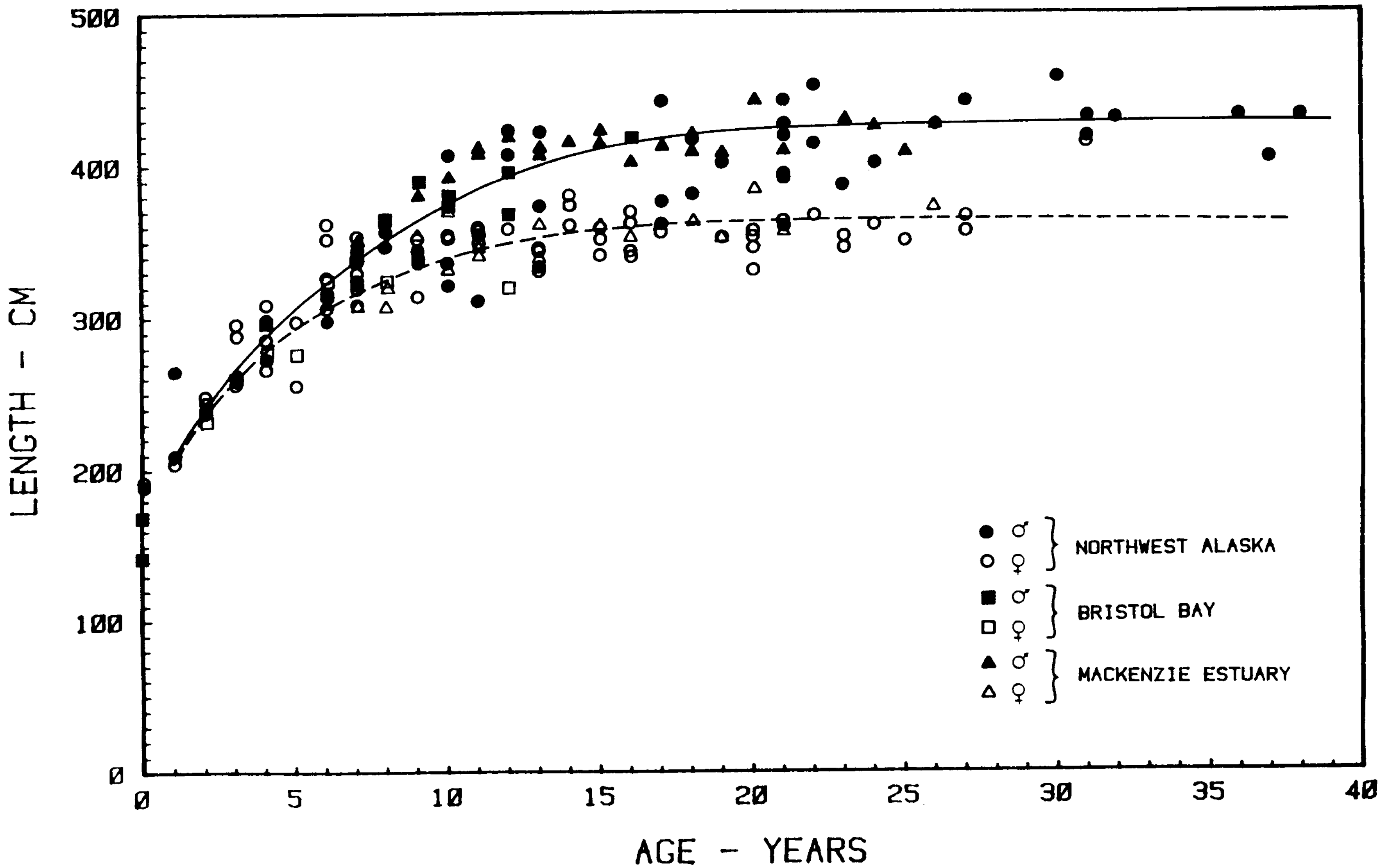

Figure 12. A composite illustration of length at age for belukhas from the three areas indicated and the growth curves for whales from northwest Alaska.

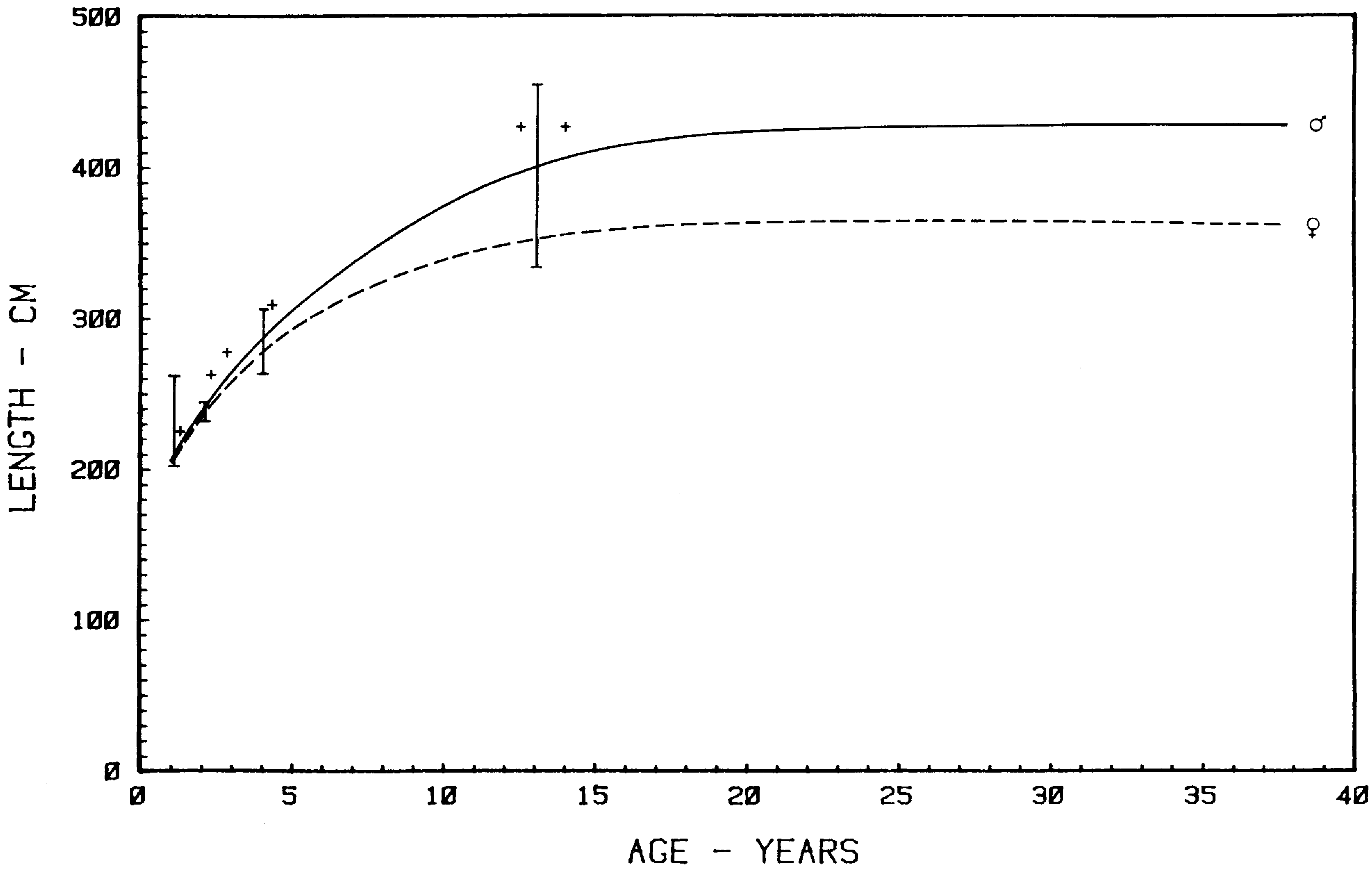

Figure 13. Length at age of a captive male belukha from Bristol Bay, Alaska, maintained at the Vancouver Public Aquarium (+) compared to the range for males and the growth curves for both sexes from northwest Alaska.

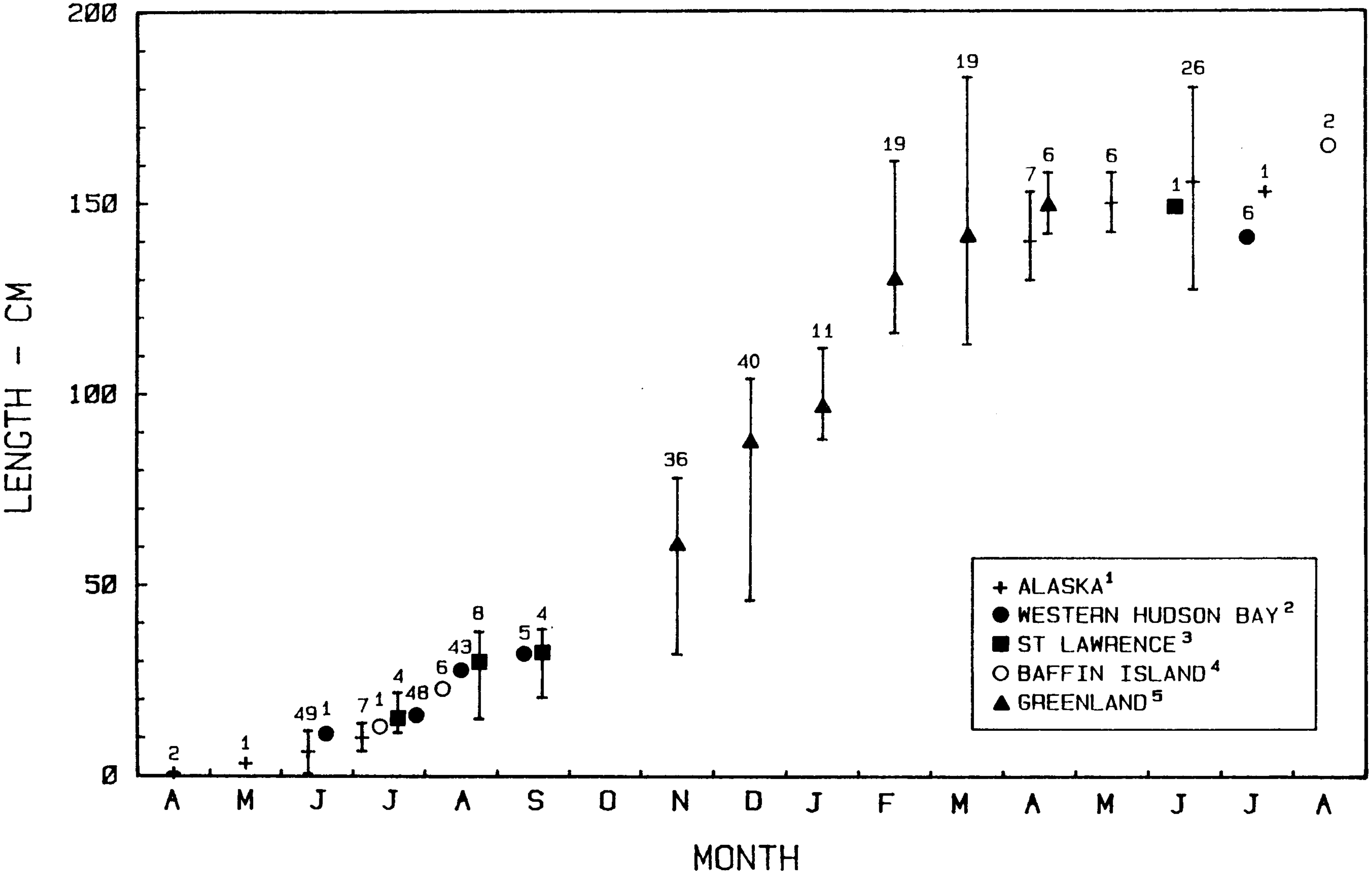

Figure 14. Increase in length of belukha fetuses. Sample size is indicated above symbols. Sources of data are: (1) this study; (2) Sergeant 1973; (3) Vladykov 1944; (4) Brodie 1971; and (5) Degerbøl and Nielsen 1930.

Canadian waters is generally similar to that for whales from Alaskan waters. In most locations, the peak period of births occurs in mid-June to mid-July. However, in Cumberland Sound on eastern Baffin Island, it is in mid-July to mid-August (Brodie 1971). A similarly later peak birth period may also occur in waters adjacent western Greenland, contrary to comments by Degergøl and Nielsen (1930) that most young in that region are probably born in March to May. Their conjecture was based on encountering the first neonates in mid-March and on the observation that fetal length did not increase after April. However, review of their work indicates that no whales were sampled after mid-April. Our findings verify that some early births do occur and that although there is little increase in fetal length after April, there is a considerable increase in weight.

Figure 14 does not include fetuses examined by Soviet scientists. Most of the Soviet data was summarized in graphic form by Kleinenberg, et al. (1964, p. 260, Figure 99). That graphic presentation also included data of Degerbøl and Nielsen (1930) and Vladykov (1944). The combined data plotted by Kleinenberg et al. (loc. cit.) were not separable by source or geographic location. Nonetheless, their summary showed that growth of fetuses in whale populations adjacent to the U.S.S.R. approximated that of whales from western Greenland and the St. Lawrence estuary, and those values were similar to North American groups illustrated by us. Collett (1911, in Degerbøl and Nielsen 1930) indicated lengths of six small fetuses as follows: one of 14 cm taken on 6 May 1903 near Vardø on the Norwegian coast of the Barents Sea, three taken near Spitzbergen on 14 August 1869 having lengths of 26.0, 27.5, and 29.0 cm, and two taken at an unidentified location in the Svalbard region on 15 August 1881 that were 23.5 and 28.0 cm. Those lengths are in line with the growth rate shown in Figure 14, though we have no way of determining how those fetuses were actually measured (SL or NTL).

Different authors determined probable size at birth in different ways. Our data indicate the average length (N = 26) and weight (N = 6) of term fetuses from Alaskan waters to be 155 cm and 71.8 kg. These values for other populations or groups of belukhas were: Baffin Island (Brodie 1971), 165 cm, 79 kg, N = 2; west Greenland (Degerbøl and Nielsen 1930, average of three fetuses taken on 12 April, 1926) 153 cm; west Hudson Bay (summarized by Sergeant 1973), about 150 cm. Various authors estimated size at birth to approximate an average of the length of the largest fetus and smallest neonate. Using this procedure, size at birth in the Barents Sea (Khuzin 1961, in Kleinenberg et al. 1964) was 158.5 cm; in the Kara Sea (Zaikov 1934, in Kleinenberg et al. 1964, Kleinenberg and Yablokov 1960) 148.5 cm and 149 cm. For the Okhotsk Sea, Sleptsov (1952) reported the smallest neonate and Kleinenberg et al. (1964) reported the largest fetus. Derived mean of these was 152.5 cm. Thus, size of term fetuses from Alaskan waters, 155 cm, is similar to that of other groups or populations of belukhas.

Weight-Gain of Calves

We were not able to weigh belukhas other than fetuses, thus we have no data about the rate of weight-gain. Lensink (1961) reported the weight of a newborn taken in mid-June to have been 45 kg and that of a 3-month-old calf to have been 106 kg. The difference of approximately 61 kg is an increase of 136% in the first three months of life for the two animals from Bristol Bay. Brodie (1971) reported the weight increase from birth to 1 year old for belukhas from Baffin Island based on 17 of the former and three of the latter. Average weight of the neonates was 78.3 kg and that of the yearlings was 187.8 kg; indicating a 140% gain during the first year of life. The average weight of neonates reported by Brodie (1971) was close to that of the six near-term fetuses from late June, obtained in northwest Alaska ($\bar{x}$ = 71.8 kg).

Birth Period

Determinations of the birth period for belukhas are based on two general types of information. The first and most useful is that derived by examination of whales including fetuses and verified newborns, observation of actual births, and rigorously acquired data about short-term changes in the proportion of calves. The second and more confusing type of information includes general comments mostly about such things as finding "large" fetuses (measurements unspecified) or the general sightings of dark-colored calves reported but not verified as newborn.

Sergeant (1973, p. 1080) commented appropriately about the difficulty of determining a peak period of births for belukhas when he stated, "It is strange that the peak could not be narrowed down more closely, since the size frequency of small fetuses . . . shows a very narrow season of matings, with no evidence of variation from year to year over three consecutive seasons . . . ."

Early studies in Alaskan waters indicated, as does our data, that calving occurs mainly in June-July. Nelson (1887) stated that calving occurs in mid-June in the vicinity of St. Michael (southern Norton Sound) and Lensink (1961) indicates a peak of calving in Bristol Bay during mid-June.

Though our data indicate a prolonged birth period extending from April through July and perhaps later, the incidence of births prior to about mid-June is comparatively low. Most seem to occur between mid-June and the second decade of July throughout waters adjacent to Alaska. In northern Alaska, most births that occur prior to about 15 June occur in cold, ice-covered waters. During the open water period (progressively later farther north) any selective utilization of warm, nearshore or estuarine waters by cows about to give birth, or cows accompanied by new calves, would tend to bias samples in such a manner that an apparent peak in the birth period would be suggested even after it actually occurred.

The peak birth period suggested by our data is generally supported by findings elsewhere. As determined by studies conducted in Alaskan waters, some females were still supporting a term fetus as late as mid-July, when our sampling efforts terminated. The first verified postparturient cow was taken on 21 April.

More subjective data, mainly from aerial surveys, suggest a slightly more confused picture. Braham et al. (1984) summarized the results of several years of study in which they were involved from 1975-1978. They reported that young of the year (short-yearlings?) and neonates were seen during the course of aerial surveys in April and May in each of four years. The sighting of neonates in these months is probably based on known births as early as April and the likelihood of being able, at least on occasion, to differentiate between newborns and short-yearlings. These authors (Braham et al. 1984, p. 29) also state that, "Small young of the year calves were observed by the senior author 100 km north of Barrow on 28 September 1979. Calving may therefore occur into late summer or early autumn." Although late summer-early autumn calving is certainly possible, the sighting reported above is inconclusive unless the observers could distinguish with certainty between neonates and calves of 2½ to 4 months age. It is certain that a large proportion of belukhas in the Beaufort Sea during September are returning from Amundsen Gulf and Mackenzie Bay where they calve earlier.

It is general knowledge among Eskimos that in more northern waters the appearance of large numbers of calves coincides with arrival of belukhas in bays and lagoons. Various investigators have also stated this to be the case (Sergeant 1973; Sergeant and Brodie 1975; Finley 1976, 1982; Fraker 1977, 1978). In Alaska, exceptions to this generalization are in Bristol Bay and Cook Inlet, where belukhas usually begin frequenting estuaries as early as late March in some years, though neonates have not been seen until June.

Belukhas that summer in eastern Beaufort Sea and Amundsen Gulf are considered by us to be of the same stock as those we sampled in northwest Alaska, and they usually arrive in the Mackenzie estuary in the last week of June (Fraker 1977, 1978). Based on extensive aerial surveys in that region in 1981, Davis and Evans (1982) reported that neonates comprised 13% of 615 belukhas sighted between 18 and 25 July and 12% of 875 whales sighted in the period 5 to 17 August. If neonates were correctly identified from an aircraft, this suggests little calving after late July in that region.

In most other northern areas births also occur mainly in June-July as reported for the Gulf of St. Lawrence (Vladykov 1944) and the White and Kara seas (Bel'kovich 1960). Zaikov (1934, in Tomilin 1957) recorded a catch of 247 whales taken in the Gulf of Ob (White Sea) between 15 July and 3 August 1932. Only one full-term fetus was found, though the catch also included 62 sucklings of which 20 still retained remnants of the umbilical cord. Kleinenberg et al. (1964) concluded that in most Soviet waters the birth period ends between the second half of June and early August. Medvedev (1970) writing about belukhas in southeastern Kara Sea made a general (and confusing) statement that the mating and birth periods end in August-September.

Findings of investigations carried out in the Okhotsk Sea by Arsen'ev (1939) and Nikol'skii (1936) were summarized by Kleinenberg et al. (1964). It was reported that in that region, unlike the situation farther north, belukhas calve in early spring.

In Hudson Bay, Canada, Doan and Douglas (1953) reported the last date of finding a term fetus was in the week ending 14 July. They further stated that the presence of a large fetus is rare in late summer. Brodie (1971) indicates the birth period as occurring in late July to mid-August in Cumberland Sound, near Baffin Island.

Breeding Period

As with several other aspects of reproduction, comments gleaned from the literature about the season of rut or breeding are inconsistent among accounts. Early literature on this subject includes accounts of belukhas in pursuit of each other, or otherwise involved in behaviors interpreted as being or associated with mating. Zhitkov (1904, cited in Kleinenberg et al. 1964) reportedly observed mating in late June-early July in the White Sea. Provorov (1957, in Kleinenberg et al., loc. cit.) reportedly also observed mating of these whales in the White Sea, on two occasions in mid-July. One of these observations, as recounted, strongly indicates that mating was occurring. That incident was on 10 July 1933.

Vladykov (1944) concluded that the period of mating in the St. Lawrence Estuary extended from early April to early June, with a marked peak at the beginning of May. This was determined on the basis of fetal growth and a presumed gestation period of about a year. In applying similar methodology to data from Greenland (apparently that of Degerbøl and Nielsen, 1930), Vladykov concluded that the period of mating there extended from February to August, with a pronounced peak also around early May. Doan and Douglas (1953) worked with samples of belukhas from the Churchill region of western Hudson Bay. Based on measurements of fetuses and following procedures established by Vladykov (1944), they determined that most conceptions occurred in May though some occurred from March to September.

Tomilin (1957), in his summary of available information, correctly stated that the breeding season is long, though he was in error that its onset is in August. Kleinenberg et al. (1964) recounted much of the reported information and incorporated some additional data. They based their determination of the breeding season on several considerations, though mainly on analysis of fetal growth curves also during an assumed gestation period of 12 months. They concluded that in all seas the mating period seems to be late April to early May, with isolated matings from late February to late August--over a period of six months. Brodie (1971) determined the gestation period to be 14.5 months as compared to all previous findings that it was about a year. This, in combination with a supposed peak birth period for belukhas in Cumberland Sound of late July-early August, placed the peak of breeding for that stock in mid-May.

Sergeant (1973) reported results of his work in western Hudson Bay. He concluded that gestation was most probably around 14 months. Mean date of birth, based on fetal length and length of calves at birth, was not established with certainty and could have been either in the first week of August or closer to mid-July. Thus, he concluded that conception could have been in mid-April or earlier for that stock or population of whales.

Based on the fetal growth curve of belukhas taken in Alaskan waters, the assumption that delayed implantation does not occur, a main birth period of mid-June to mid-July, and the currently assumed gestation period of 14.5 months, as found by Brodie (1971), breeding in belukhas of the Bering population would occur mainly in April. However, this does not in fact, appear to be the case, based on examination of ovaries or of testes.

Examination of ovaries indicated that although some breeding may occur in late April to perhaps mid-June, the peak of breeding is probably appreciably earlier than that. Four of five females taken in late April and judged to have been in breeding condition during the year of capture, had already bred. These four had fully formed corpora lutea and the other was about to ovulate. The time required for complete formation of a corpus luteum in belukhas is unknown. Nonetheless, these specimens indicate that although the peak breeding period cannot be determined, it occurs earlier than mid- to late April.

Examination of histological sections of testes and epididymides indicated, as did ovarian analysis, that the peak breeding period occurs at some unknown time prior to late April. Of 14 adult males taken in late April to late May, all were in the retrogression phase of the annual cycle of spermatogenesis. Retrogressive changes are probably not abrupt and it is assumed that retrogression was initiated significantly earlier than the dates on which those males were collected. Thus, although the peak breeding period cannot be established on the basis of specimens available to us, we suggest that it most likely occurs mainly between late February and early April.

Evidence from females and males suggests that some breeding could occur as late as June. That there is a definite peak is shown by the narrow range of fetal size at age in our sample.

At this time, we cannot rule out the possibility of delayed implantation in belukhas, with attachment occurring mainly in mid- to late April.

Vital Parameters

The sources of data about vital parameters for belukhas of the population we sampled in northwest Alaska are mainly derived from Table 4, which presents information on reproductive status of females and the life table (Table 7). Our presentation is made in the form of a list. There is considerable confusion among different authors with respect to definitions of vital parameters as they are presented in the literature and therefore, when the terms may be ambiguous, we have attempted to explain what we mean and/or provide the values from which an estimate was derived.

Reproductive Parameters

Sex ratio; 1:1.
Breeding season; late February to June with a presumed peak in March.
Birth period; March through July or August with a peak in mid-June to mid-July.
Gestation period; 14.5 mos. at minimum (Brodie 1971); more likely 15 to 16 mos.
First pregnancy; ages 4 to 7.
First birth; age 5 to 8.
Maximum age at last birth; about 35 years (maximum age is not known due to loss of dentinal layers in teeth of old animals).
Generation time; about 6 years.
Duration of dependent nursing period; 6 to 12 mos.

Pregnancy rates;

A. Proportion of sexually mature females age 5 years and older with either a newly implanted fetus, a term fetus, or a newly born calf, 112/179 = 0.626.

B. Proportion of sexually mature females age 5 years and older with a newly implanted fetus, 60/179 = 0.335.

C. Proportion of sexually mature females age 6 years and older with a term fetus or a newly born calf, 52/170 = 0.306. In view of bias inherent with interpretation of ovarian analysis, prolonged birth period, and pregnancies at a rate greater than once in three years for younger sexually mature females, a more reasonable estimate is on the order of 0.32 to 0.34. Note in Table 4 that 6 of 16 females, age 6 years, had given birth in a prior year.

Female reproductive life span; this is an ambiguous term. Our samples show that females are reproductively active throughout their adult life though there is a marked decline in pregnancy rates in old-age animals. Potential reproductive life span in our sample is on the order of 31 years, or during the span from age 4 to 35 years. Maximum potential reproductive life span is not known because of loss of dentinal layers in old animals.

Population Parameters

Maximum longevity; due to loss of dentinal layers in teeth, maximum longevity is not known. The oldest animals in our samples included two males 38+ years and a single female, 35+ years.

Proportion of mature females in population; best estimate is 32% to 33%. From the probit age structure, 322/528 (61%) of the whales were age 6 years or older and 357/528 (68%) were 5 years or older. The sex ratio is 1:1. Attainment of sexual maturity occurs when a female becomes pregnant. First pregnancy occurs between ages 4 and 7 years, mainly at ages 5 (33% to 38% of females were pregnant) and 6 (by which age 94% of the females were sexually mature).

Annual rate of calf production; best estimate is 0.104. This estimate is from the "smoothed" age structure derived through probit, and the resulting life table. The model population of 1,000 whales included 94 calves; 94/906 = 0.104.

Crude birth rate; the same as the rate for females supporting a term fetus or neonate. Best estimate is about 0.33. The range, as indicated by our data, is 0.31 (from probit age structure and age-specific reproductive rates) to 0.34 based on interpretation of ovarian features.

Survival (q_x); 0.094, derived from probit age structure and resulting life table.

There are several sources of comparative data about other stocks or populations of belukhas dealing with one or more of the parameters listed above. We have not included a summary of those data because of the possible ambiguities with respect to definitions and differences in procedures used by other investigators. Primary sources of data that readers can compare with our findings include: Bel'kovich (1960), Brodie (1971), Sergeant (1973, in press), Heyland (1974), Finley (1976), Ognetev

(1981), Seaman and Burns (1981), Brodie et al. (1981), Finley et al. (1982), and Ray et al. (1984). Summary papers of interest are those by Braham (1982, 1984).

Our data indicate that gross annual production of calves per 1,000 belukhas of the composition sampled in northwest Alaska is about 106 (1,000 whales x 0.33 adult females x 0.32 crude birth rate).

Color Change

The change in coloration of belukhas from dark to white, as a function of increasing age and size, has long been known. Nelson's (1887) conclusion about the timing of these color changes was amazingly insightful, considering that he had no quantitative means of accurately determining age of individuals. He wrote (Nelson, op. cit., p. 290), "As already noted these animals are very dark-colored when young. They become lighter each year until the fourth or fifth season, when they are a pale milky bluish, and about the sixth or seventh year they are a uniform, clear milky white."

Various investigators have utilized slightly different categories for describing color phases of belukhas. Kleinenberg, et al. (1964, p. 32, Table 8) indicate the classification schemes used by 13 different researchers of which five used three color categories, six used four, one used five, and one used six. Hay and McClung (1976) refer to 11 color categories though they did not indicate any proportions or numbers within each. We used four categories that were closest to the system utilized by Arsen'ev (1936, in Kleinenberg, et al., loc. cit.). In fact, in the six studies reported in Kleinenberg et al. (loc. cit.) that utilized four color categories, the color phases were easily relatable to ours. Brodie (1982) reported that a captive male belukha from Bristol Bay, Alaska, maintained in the Vancouver Public Aquarium, obtained its white coloration at about age 6. He compared that to males from eastern Baffin Island that were found to become "noticeably" white at about 7 years. In our sample, males became "whitish" as young as age 5 and white as young as age 9. Considering the ambiguities of different characterizations of color phase, the captive whale, those we sampled, and those sampled by Brodie, indicate that the whitish and white phases are probably obtained at about the same age in whales from Alaska and eastern Baffin Island.

Sergeant (1973) compared the age at which whales from eastern Baffin Island, western Hudson Bay, and eastern Beaufort Sea become white. He found (p. 1072), " . . . that the white color is attained at a fairly constant age in different populations . . . ." He reported the minimum ages of white-colored animals taken in the vicinity of Churchill and Whale Cove, both in western Hudson Bay and in the Mackenzie Delta (animals from the latter area seasonally pass through waters adjacent to Alaska). Assuming two dentinal layers per year of age, minimum ages of white males and females from Churchill were 7 and 8 years respectively; 10 and 8 years respectively for Whale Cove; and 8 and 7 years respectively for whales from Mackenzie estuary. In the Mackenzie estuary, Sergeant (op. cit.) also reported grey-colored females as old as 15 years. Kleinenberg et al. (1964), similar to all other studies, found that each color phase includes a size range of animals that overlaps markedly, though the sizes of most animals in each color group do not.

White-colored belukhas are sexually mature adults. We found that at least in females, a high proportion of light grey animals (90%, N = 21) are also sexually mature. The proportion of adult belukhas in different populations have been indicated by various writers, on the basis of the proportion of white-colored whales. In our sample of 225 collected whales for which color was recorded, 53% were white and 17% were light grey. Of the light grey females, 19 of 21 (90%) were sexually mature.

The proportion of white and/or whitish-colored whales in samples reported by different investigators is presented in Table 16. Direct comparisons of color composition in samples, based on examination of whales landed and those classified during aerial surveys, may not be entirely appropriate. Landed whales can be more precisely categorized; whereas, there may be a tendency to combine (or an inability to differentiate) light grey and white-colored whales seen during aerial surveys. Our sample of examined belukhas (53% white and 17% grey) would probably be equivalent to 70% white and "whitish", as categorized during an aerial survey. Based on the probable age structure of belukhas sampled in northwest Alaska, the proportion of white and whitish-colored whales would be on the order of 65%.

Movements

Summer Movements in Eastern Chukchi Sea

Until recently, the perspective of summer belukha migrations in eastern Chukchi Sea was that gleaned from compilation of sightings made from shore or the edge of shorefast ice. Those general observations suggested two separate "waves" of migrants (cf. Foote and Williamson 1966, p. 1082); those passing northward through ice-covered waters mainly in March-May and those occurring in ice-free coastal waters and passing northward in a more leisurely manner in June-August.

Available evidence indicates that many or most of the early migrants near Alaska travel eastward after rounding Point Barrow (Braham and Krogman 1977; Fraker 1979; Seaman and Burns 1981; Ljungblad 1981). Perhaps most of these early migrants reach the eastern Beaufort Sea and Amundsen Gulf. Some enter ice-free coastal waters in mid-June through July and begin moving away from the coast in August, returning westward across the Beaufort Sea during August to October (Fraker 1979; Seaman and Burns 1981; Davis and Evans 1982).

Belukhas in the eastern Chukchi Sea also begin to enter ice-free coastal waters during June, first in the region of the northern Seward Peninsula and Kotzebue Sound. The northward movement of these whales is much less directed and more leisurely in that once they begin frequenting rivers, bays, and lagoons they remain in or near these habitats for days and perhaps weeks (as do many of the belukhas that reach eastern Beaufort Sea). Nonetheless, general direction of their movements is northward. In late July-August they leave the coastal zone, also as belukhas in eastern Beaufort Sea do, and by late August-September whales that summered in coastal waters of the eastern Chukchi and the eastern Beaufort seas are mostly associated with the ice front. It is possible, though not probable, that belukhas reaching the vicinity of Point Barrow, from the south, in

Table 16. Proportions of white and "whitish-"colored belukhas in different geographic regions as reported by various authors.

Region	Source	Proportion (%) white-colored animals	Sample size	Sampling method
Kara Sea	Medvedev 1970	61	99	Observation of passing whales from ice
Gulf of St. Lawrence	Vladykov 1944	61	219	Whales examined
White Sea	Provorov 1958	72	32	Whales examined
White and Kara seas	Ognetev 1981	70	385	Whales examined
White Sea	Klumov 1939	54 (white) 73 (white and light)	204	Whales examined
Western Hudson Bay	Doan and Douglas 1953	66	902	Whales examined
Northwest Alaska	Braham et al. 1984	62	507	Observation of passing whales from ice
Northwest Alaska	Braham et al. 1984	93	unknown	Aerial surveys
Northwest Alaska	Braham 1984	71	627	Aerial surveys
Northwest Alaska	This study	70	225	Whales examined

late July-early August move rapidly eastward through Beaufort Sea to the Mackenzie estuary. This probability is considered low in view of the somewhat synchronus departure of most belukhas from northern coastal waters at this time. We suggest that belukhas present in coastal waters of eastern Chukchi Sea during summer eventually reach the ice front generally north and northeast of Point Barrow where they mingle with whales migrating from eastern Beaufort Sea, as schematically shown in Figure 15. Radiotagging efforts in waters of northwest Alaska (a feasible undertaking) are required to verify the hypothesized movements. Kleinenberg et al. (1964) indicate that in Soviet waters, some belukhas are associated with the ice front in summer.

Autumn Migration in the Beaufort Sea

We have already reviewed the survey efforts and other studies that influenced our search for migrating belukhas in Beaufort Sea, west of the Canadian border. Several additional survey efforts are of significance in interpreting our results.

Davis and Evans (1982), reported results of extensive surveys undertaken in the Canadian Beaufort during July-September 1981. Results of these surveys were unavailable at the time of our effort in September 1982. Their survey design included five regions extending eastward from the Alaska-Canada border to and including eastern Amundsen Gulf. Systematic surveys were accomplished during four time periods; 18-25 July, 5-17 August, 19-29 August, and 7-14 September. Several important findings were made. They found that a rather large proportion of belukhas in the Canadian Beaufort did not enter the Mackenzie estuary as was previously thought. The number of belukhas in the Canadian Beaufort was very conservatively estimated to include at least 11,500 animals. Belukhas moved into deeper waters by the first of August and the westward autumn migration was offshore.

Harwood and Ford (1983) conducted more limited surveys during August-September 1982 in part of the region covered by Davis and Evans in 1981. In the 1982 surveys, those authors found that the westward movement of belukhas from the southeastern Canadian Beaufort had probably occurred prior to late August and certainly prior to surveys they conducted from 5-13 September 1982.

Dr. Steven Johnson (LGL Alaska, Ltd., Anchorage, Alaska, personal communication, 16 January 1982) conducted repetitive surveys of transects shown in Figure 16, on 1, 4, and 8 August and on 15, 18, and 22 September 1982. Their transects were 1,600 m wide and extended 20 nm from the near shore starting points. No belukhas were seen on any of those surveys.

Ljungblad et al. (1983) continued a program of very extensive aerial surveys for bowhead whales in the American part of the Beaufort Sea in August-October 1982. Their surveys did not extend appreciably north of 72°N and were mostly south of 71°N. Ice generally persisted in the survey area until mid-August, and then rapidly receded northward. In early August belukhas (numbers unspecified) were widely distributed in association with ice, mainly between 71°N and 72°N latitude (Ljungblad et al., loc. cit., p. 103). Of significance in relation to our surveys was that during extensive flights in September, they saw no belukhas. Belukhas were again sighted in

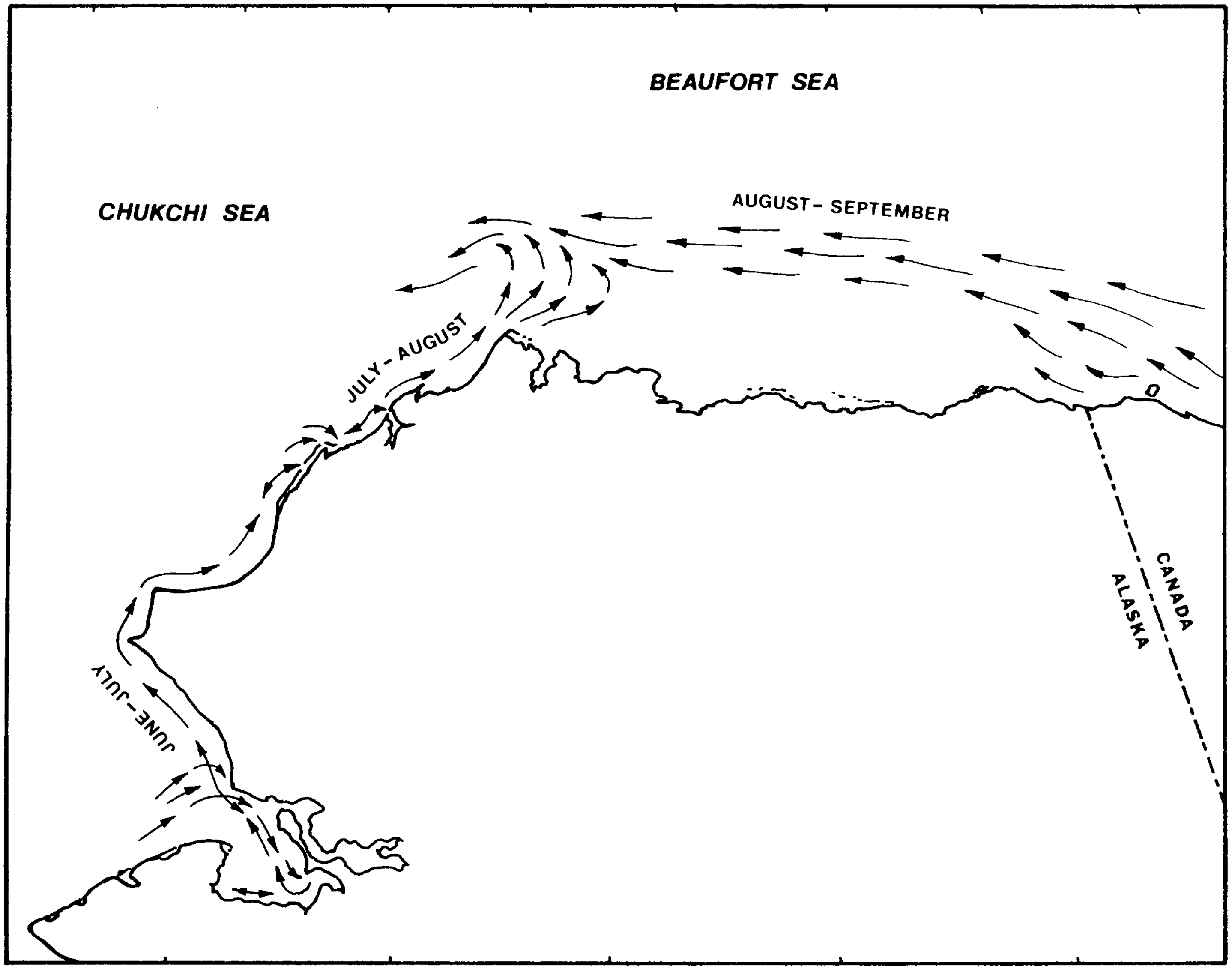

Figure 15. Schematic illustration of hypothesized movements of belukhas that occur in coastal waters of the Chukchi and Beaufort seas during summer.

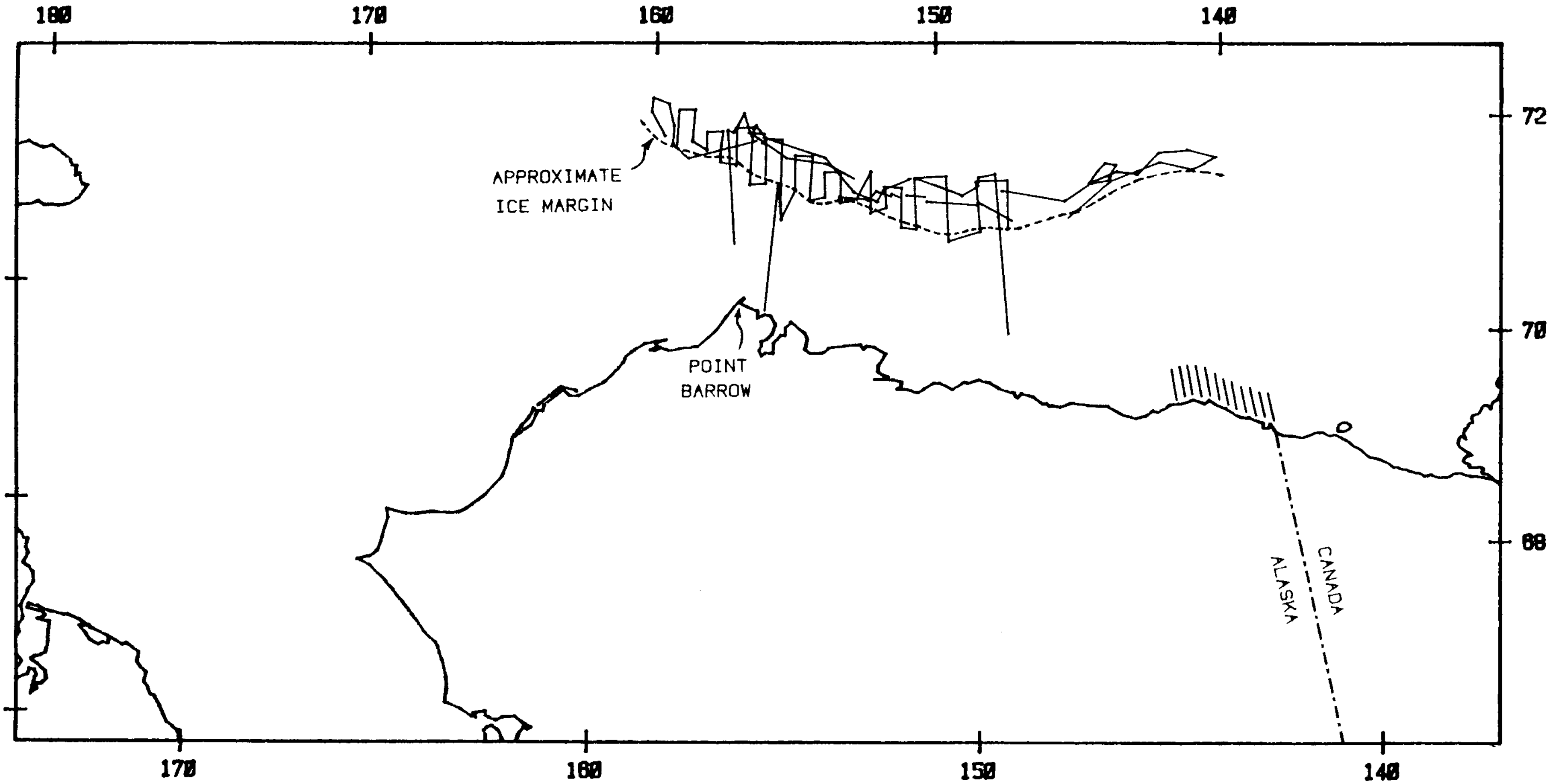

Figure 16. Aerial transect lines flown in September 1982 during this study and by S. Johnson (personal communication).

October during conditions of rapidly advancing and forming ice. A combined total of 485 belukhas were counted in August and October including 250 on 17 October, in the same general area northeast of Point Barrow where they consistently have been observed in September and October. Table 17, compiled from charts of survey transects flown by Ljungblad et al. (loc. cit.), indicates dates when they saw belukhas.

The most compelling evidence for a westward autumn migration route that is mainly offshore and largely determined by location of the prevailing ice front zone is shown in Figure 17. This figure depicts four things: general position of the ice margin during 17 to 21 September 1982; transect lines flown during this study (mostly near and north of the ice margin); transect lines flown by Ljungblad et al. in September 1982; and the locations of all sightings of belukhas during those two survey efforts.

Figure 18 depicts locations of all sightings of belukhas north of Alaska, based on sources available to us, for which we could determine geographic coordinates. Sources of data for this figure are presented in Table 18. It shows that during August belukhas are widely distributed throughout those areas of the western Beaufort that have been surveyed and occasionally along the Chukchi Sea coast as far as the vicinity of Wainwright. Ice conditions during August are highly variable, though in most years the pack has not yet melted and receded to the minimal annual coverage (Weeks and Weller 1984). Belukhas are present in the American part of Beaufort Sea during August, at the same time that maximum numbers were counted in the Canadian Beaufort. In our opinion, some of the whales that round Point Barrow do not make the long traverse to eastern Beaufort Sea. There appears to be a progressive movement away from shore in August. Current data are inadequate to describe this movement or to determine numbers of belukhas in western Beaufort Sea during August. The lack of reported sightings in August, west of Point Barrow, is probably an artifact resulting from almost no survey effort in the ice front during that month.

From Figure 18 it is evident that the westward migration is in full swing in September, that a concentration area exists north and northeast of Point Barrow, and that belukhas also occur in the northern Chukchi. The somewhat linear distributions of whale sightings indicate a strong association with the ice front (a linear feature), at least in the Beaufort Sea. Location of the margin and front zone in different years probably accounts for the seemingly great latitudinal distribution of sightings. Latitudinal distribution of sightings in September of different years was rather great and we have not made any correlations of whale distribution and bathymetry. The huge aggregation of belukhas found northwest of Point Barrow on 18 September 1974 by Ray and Wartzok (1980), swimming generally west-southwest, some 30 nm from pack ice, was assumed to have been a migrating assemblage.

In October, most sightings of belukhas were in the western Beaufort. Location of sightings indicates that a linear distribution related to location of the ice front still persists. Frequency and location of sightings suggest that peak migration out of the Beaufort occurs prior to October. However, it should be noted that combined survey efforts in this month have been much less than during September. Sightings in October 1975 by Ray and Wartzok (1980, Figure 26, p. 72) were mostly in central Chukchi

Table 17. Survey dates on which belukhas were sighted in the American sector of the Beaufort Sea in August-September 1982 (from Ljungblad et al. 1983).

August		September		October	
Survey date	Belukhas seen	Survey date	Belukhas seen	Survey date	Belukhas seen
1	no	1	no	2	yes
2	no	2	no	3	no
5	no	4	no	4	no
6	yes	7	no	5	yes
7	yes	8	no	6	no
8	yes	11	no	7	no
11	no	14	no	9	no
12	yes	15	no	10	no
14	yes	16	no	11	no
15	yes	18	no	12	yes
16	yes	21	no	13	no
17	yes	23	no	14	no
18	yes	24	no	15	no
20	no	25	no	16	yes
21	no	27	no	17	yes
22	no	28	no		
23	yes	29	no		
24	yes	30	no		
25	no				
28	no				

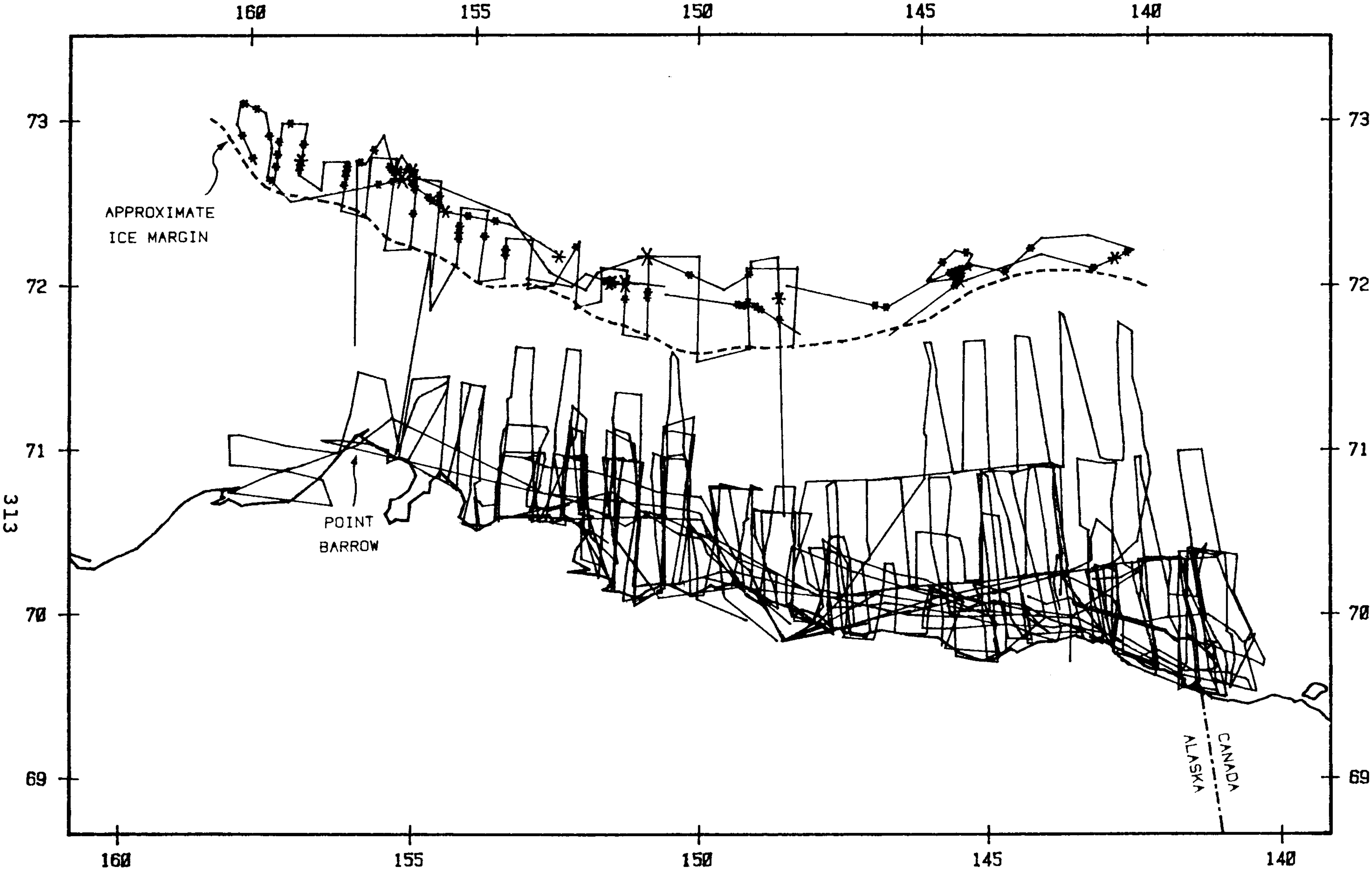

Figure 17. Survey transects flown in September 1982 during this study and by Ljungblad et al. (1983). Location of the ice margin and all belukhas sighted on transects are shown.

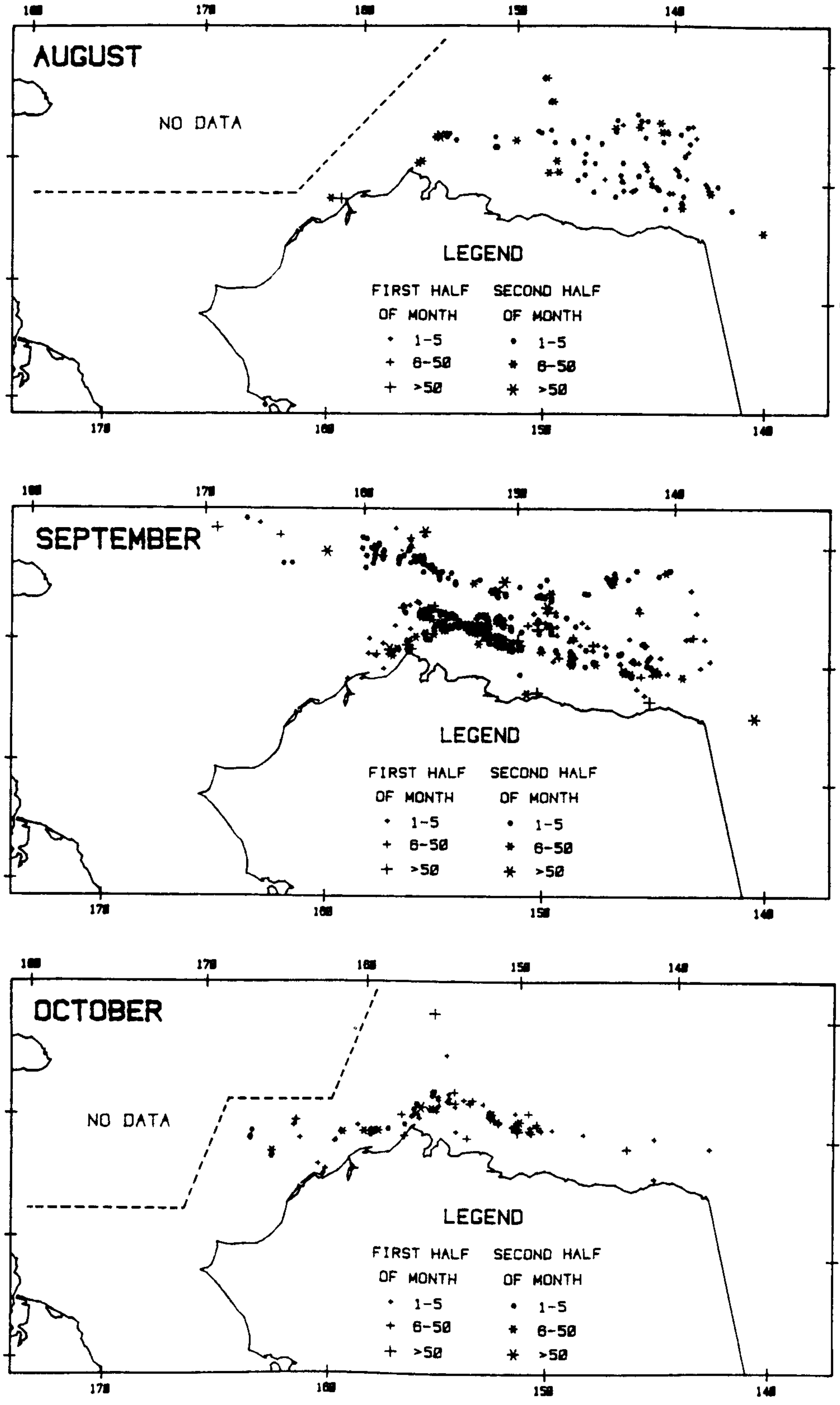

Figure 18. Composite of belukha sightings near northern Alaska in August to October, for which coordinates could be determined. Sources of data are in Table 18.

Table 18. Sources of data on belukha sightings shown in Figure 18. Virtually all sightings were made opportunistically, often during aerial surveys designed primarily for other species (especially bowhead whales and walrus). Only those data appropriate to month and region and for which geographic coordinates were provided, or could be reasonably determined, were utilized.

Source of data	Time of sightings		
	Aug.	Sept.	Oct.
Bitters, J., pers. comm., 1978	X		
Braham and Krogman 1977		X	
Burns, J., field notes, Sept. 1974		X	
Dohl, T., pers. comm., 1979		X	
Fiscus, C., pers. comm., 1974		X	
Fiscus et al. 1976		X	
Fraker et al. 1978		X	
Frost, field notes, 1978	X		
Harrison and Hall 1978	X		
Johnson 1979		X	
Johnson et al. 1981		X	
Johnson et al. 1982		X	
Ljungblad et al. 1980		X	X
Ljungblad 1981	X		
Ljungblad et al. 1982	X		X
Ljungblad et al. 1983	X	X	X
Murdock 1885		X	
Naval Arctic Res. Lab., files, 1978 and 1980	X		X
Nelson 1968	X		
Ray, C. G., pers. comm. in Braham and Krogman 1977		X	
Ray et al. 1984	X	X	
Univ. Rhode Island Lab. for Study of Info. Sci.[1]	X		

[1] Provided a computerized listing of belukha sightings recorded during various projects supported by the Alaska Outer Continental Shelf Environmental Assessment Program and subsequently submitted to the National Oceanic Data Center.

Sea, near and south of 70°N latitude; considerably south of sightings in September. These data are not included in this report as the geographical coordinates were not available to us.

For waters of northern Alaska and northwest Canada, available data indicate a weak association of belukhas with pack ice in July (numbers in coastal areas are greatest), becoming stronger in August when they depart coastal waters, and being very strong by September.

Migration in Soviet Waters

The limited information available about whale migrations and movements in waters of the Soviet far east indicates a "mirror image" pattern to that in Alaskan and western Canadian waters, at least during the first half of this century. Some belukhas remain in coastal waters of Bering Sea throughout the year, though most migrate north through Bering Strait during spring-early summer. Substantial numbers move northwest after passing Mys Dezhneva, summer in the western Chukchi and eastern East Siberian seas, and return to Bering Sea in autumn-early winter. Such a hypothesis is based on the following records.

Kleinenberg et al. (1964) report sightings of belukhas in May from the vicinity of Mys Navarin, the Gulf of Anadyr, and the region from Bukhta Provideniya to Ostrova Arakamchechen and around Chukhotka to Mys Serdtse-Kamen.

Large herds of belukhas occur in the Gulf of Anadyr during the second half of June, migrating along its western and northern shores, some entering Zaliv Kresta and large numbers entering Anadyrskiy Liman where they remain throughout the summer (Vinogradov 1949, in Kleinenberg et al. 1964; Tomilin 1957). The maximum number of belukhas in the Gulf of Anadyr occurs in July (Kleinenberg et al. 1964).

Nikulin (1947, in Kleinenberg et al. 1964) indicated that belukhas appear in the western Chukchi Sea in early summer, though Sverdrup (1930, in Kleinenberg et al. 1964) indicated that they occur in large numbers near Serdtse-Kamen, during April-May and are hunted at that time by the Chukchis. Klumov (1939) indicated that belukhas occur in large numbers near Wrangel Island, in summer. According to Arsen'ev (1939), along the north coast of the Chukchi Peninsula, large numbers of belukhas occur only as far west as Mys Shmidta. However, Tomilin (1957) includes the eastern part of the East Siberian Sea within the range of these whales. Gurevich (1980) states that, "They are common among the ice floes in the Long Strait near Vrangel Island and off the Chukchi coast from Cape Dezhnev westwards as far as Chaunskaya Guba." The latter location indicates a considerable penetration of the East Siberian Sea.

Kleinenberg et al. (1964) state that belukhas pass the settlement of Uelen, near Mys Dezhneva during spring and autumn; a situation similar to that on the Alaskan side of Bering Strait. Fedoseev (personal communication in Kleinenberg et al. 1964) reported seeing two large groups of belukhas. The first, seen on 4 October 1960, north of Wrangel Island, was a huge aggregation that extended over a distance of 15 km. The second group was seen on 17 October 1960, 80 miles from Wrangel Island. It was estimated to include 300-350 whales, swimming in the direction of Bering Strait.

Belikov et al. (1984) reported on opportunistic sightings of marine mammals made during repetitive ice reconnaissance flights from June to September in 1971 to 1979. Relatively few sightings of belukhas were reported. However, they did show that belukhas extended well into the East Siberian Sea as early as June. The majority of their sightings were in the general vicinity of Wrangel Island.

These various reports further support the comments of Kleinenberg et al. (1964) that in the western Chukchi Sea, during summer, belukhas occur, "not only near the coast but also north of Wrangel Island."

Natural Mortality

In his extensive review of information about belukhas, Tomilin (1957) summarized a number of instances of ice entrapment in widely scattered parts of their amphiboreal range. Several of those were noteworthy for the size of aggregations entrapped, as indicated by numbers removed by hunters. An instance in Kolyuchinskaya Guba, a bay on the coast of northwest Chukchi Sea, involved the capture of several hundred belukhas by local inhabitants. Tomilin (loc. cit.) also noted repetitive instances of entrapment in the same general location and predation by polar bears on trapped belukhas. He suggested that occasional entrapment is evidence for extensive penetration of "dense" (closely packed) ice by belukhas. Citing Geptner (1930), Tomilin (loc. cit.) indicated that in unbroken ice belukhas utilize seal holes for breathing and, where ice was forming, they used their backs to make and maintain openings.

Kleinenberg et al. (1964) included many of the information sources used by Tomilin (1957) and indicated that instances of ice entrapment have repeatedly been recorded. These authors used the Greenland Inuit term, savssat, apparently in reference to regular occurrences in waters adjacent to Greenland where a specialized hunt of entrapped belukhas sometimes occurs. Kleinenberg et al. (1964) noted that belukhas can survive entrapment without access to food for one-two months. Mitchell and Reeves (1981) list known records of ice entrapment of narwhals and belukhas in the eastern Arctic, extending as far back as 1750. Freeman (1968) presents a detailed account of an entrapment that occurred in Jones Sound, Northwest Territories, Canada.

Including the two instances of entrapment that occurred near Alaska in April 1984 (Lowry et al., in press), there are five confirmed records and numerous other reports involving belukhas of the Bering population. The five confirmed records are the entrapment of several hundred whales, apparently in autumn, that occurred in Kolyuchinskaya Guba (Tomilin 1957); one of 20+ whales in Eskimo Lakes, Mackenzie Bay in autumn-winter, 1966-67 (Hill 1967, 1968); one of an unknown number from which about 35 were taken by hunters near the northwest coast of the Seward Peninsula, in early March 1976 (Seaman et al. 1985); an unknown number trapped in ice of the central Chukchi Sea in late March (Jack W. Lentfer, formerly a polar bear specialist with the Alaska Department of Fish and Game, personal communication, 29 August 1984); and 2,000 to 3,000 entrapped in Proliv Senyavina (northwestern Bering Sea) in late December 1984.

Entrapment in elongated bays and large lakes during the period of autumn freezeup apparently results when extensive, rapidly forming ice blocks exit of the whales, as was reported for the Eskimo Lakes and Proliv Senyavina events. Hill's account of such an event was interesting in several respects. In August 1966, an estimated 50 belukhas were in the fourth or innermost of the Eskimo Lakes that bound the east shore of the Tuktoyaktuk Peninsula, some 150 miles inland from the Beaufort Sea. A similar number were seen on 20 September. Ice began forming in early October and only three open areas remained in the fourth Eskimo Lake on 1 November. Twenty belukhas were still present on 20 November, apparently utilizing one remaining hole. By 21 January 1967, only one whale remained. The natural hole at which the remaining whale was seen was frozen over when visited on 26 January. No hunting took place at this entrapment. It was presumed that these trapped whales starved. The maximum observed time of dives was 7 min and 25 sec, though a recording crew using hydroacoustic equipment noted that on 21 January, the single remaining whale was away from the hole for about 40 min. During their entrapment whales broke the overhanging ice around the hole with their backs, as has been reported previously by several authors. Records of ice entrapment in the eastern arctic are presented by Mitchell and Reeves (1981).

In April 1984 entrapment during the northward spring migration near Alaska occurred when early migrating whales that deeply penetrated the northern pack were caught by unusually low temperatures and severe freezing conditions. This followed almost a month of warm temperatures. Table 19 shows the average daily temperatures recorded at Nome and Cape Lisburne during March and April 1984. It can be seen that, in comparison to temperatures in March, those recorded in April were unusually cold. Though they are not precise indicators of temperatures that existed in Bering Strait-southern Chukchi Sea region, conditions recorded at Nome reflect the monthly trends and suggest the cause of entrapment in Bering Strait and near Kivalina.

With respect to predation by polar bears and killer whales, records available to us mainly add to the already existing body of information. Some additional insights about the combined impacts of entrapment and predation by bears are suggested by the incidences in April 1984.

Polar bears were exceptionally abundant in northern Bering Sea and eastern Chukchi Sea during winter-spring 1983-84. The largest recorded harvest ever made by coastal-based hunters in those areas were made during that period (292 polar bears; D. Taylor, U.S. Fish and Wildlife Service, Anchorage, AK, undated memorandum). Thus, any belukhas in the region, whether entrapped or free-ranging, were exposed to a potentially higher than normal probability of predation. Many bears did locate the savssat at entrapments found in April 1984. Additionally, during the course of field work in the Cape Lisburne area during April-May 1984, it was observed that polar bears routinely investigated areas where belukhas had rested under thin ice in newly refrozen leads. Such resting areas are obvious from the air as the whales leave elongate impressions in the thin ice that resemble closely scattered grains of rice. These distinctive impressions have variously been referred to as conical elevations (Kane 1926, in Mitchell and Reeves 1981, p. 675), cupolas (Davis and Finley 1979 Ms), or domes (McVay 1973).

Table 19. Average daily temperatures (°F) at Nome and Cape Lisburne, Alaska, during March-April 1984. Average temperatures are means of the daily highs and lows.

Nome				Cape Lisburne			
March	Temp.	April	Temp.	March	Temp.	April	Temp.
1	8	1	31	1	-27	1	2
2	0	2	24	2	-27	2	8
3	8	3	18	3	-28	3	4
4	-2	4	24	4	-25	4	-8
5	12	5	22	5	-20	5	-17
6	35	6	12	6	-13	6	-17
7	37	7	-4	7	-9	7	-18
8	26	8	-9	8	-6	8	-21
9	37	9	-4	9	-1	9	-19
10	37	10	-2	10	9	10	-17
11	31	11	-1	11	7	11	-13
12	25	12	0	12	16	12	-16
13	35	13	4	13	4	13	-8
14	26	14	5	14	6	14	8
15	15	15	7	15	-3	15	-2
16	13	16	2	16	-9	16	-13
17	32	17	-1	17	-10	17	-11
18	18	18	8	18	-12	18	-7
19	6	19	7	19	-15	19	-8
20	2	20	8	20	-17	20	-9
21	6	21	14	21	-15	21	-9
22	12	22	18	22	-21	22	-9
23	10	23	13	23	-15	23	-9
24	11	24	15	24	-16	24	-8
25	13	25	23	25	-17	25	-9
26	11	26	25	26	-22	26	6
27	11	27	32	27	-17	27	13
28	14	28	24	28	-15	28	6
29	27	29	26	29	-13	29	3
30	22	30	20	30	-10	30	2
31	25			31	-8		

Conditions that prevailed in spring 1984 were atypical. Savssat and predation on them by polar bears in the Bering and eastern Chukchi seas are probably uncommon in most years, as indicated by observations of other biologists that worked in the region over a number of years.

Mr. Jack W. Lentfer (personal communication, 29 August 1984) was engaged in polar bear tagging operations during spring, from 1967 to 1976, in the eastern Chukchi Sea region. This work involved many hundreds of hours of flying to track and capture bears. During his studies he found no instances of bear predation on belukhas and only one entrapment; in which a small number of savssat were present. Mr. James W. Brooks (formerly polar bear specialist for the U.S. Fish and Wildlife Service, personal communications, August 29 and September 6, 1984) was involved in a similar tagging effort during spring seasons, 1968-1972. His field work was all in the eastern Chukchi Sea, off Cape Lisburne. During those five seasons he recorded no instances of entrapment nor of successful predation on belukhas by bears. Mr. Steven Amstrup (currently polar bear specialist for the USFWS) has been tagging and tracking polar bears during spring, from 1981 to 1984. During three of those years he worked in the eastern Chukchi Sea and also reported no instances of belukha entrapment or predation on whales by bears.

Though these polar bear specialists normally started their field work at a time prior to arrival of belukhas in the Chukchi Sea, their field efforts normally included part of the period when migrating whales were present.

The situation in Bering and eastern Chukchi seas is in marked contrast to reports from experienced polar bear hunting guides that operated in western Chukchi Sea until 1972. Sport hunting for polar bears with the aid of small aircraft was common practice from about 1950-1971. General comments of interest were reported by various professional guides over a period of years.

These guides pursued large, trophy class polar bears primarily in the western Chukchi for three stated reasons: (1) bears near the Alaska coast, though numerous, tended to be smaller and included a larger proportion of subadults and sows with cubs; (2) pack ice was more fractured and mobile in the eastern part, with a broad active flaw zone (also see Burns 1970); and (3) on average, tracking and landing conditions for aircraft were more favorable in the western Chukchi because of thicker, more extensive ice. The polar bear guides, operating from villages along the eastern Chukchi coast began hunting in the east, though generally, while flying westward. Thus, they were very familiar with conditions in different parts of the Chukchi Sea.

Mr. Robert Curtis (pilot and polar bear guide, personal communication to Dr. F. H. Fay, 27 March 1967) reported finding a belukha in southwestern Chukchi Sea that had been killed and eaten by a polar bear. Mr. Nelson Walker (pilot, big game guide, 30+ year resident of Kotzebue, personal communications during numerous conversations with the senior author) summarized his observations of belukha entrapment and polar bear predation over the period 1952-1971. He recounted no instances of belukha entrapment in the central Chukchi region east of 168°W, and two instances of bear predation. In the western Chukchi the situation was much different. He recounted finding, on average, one or two instances of entrapment involving small numbers of savssat a year, with polar bears present at many of them. The most dead belukhas he reported (presumably killed by polar bears) was seven. Occasionally walruses, mostly single individuals, were also entrapped and successfully preyed upon by bears, according to Mr. Walker.

A recent instance of mass entrapment in Soviet coastal waters of northern Bering Sea received worldwide news media attention. It was reported that in late December 1984 several thousand trapped whales (up to 3,000) were found in Proliv Senyavina (Senyavin Strait) that separates Arakamchechen Island from the Chukchi Peninsula. According to newspaper accounts (i.e., Anchorage Daily News, Saturday, 23 February 1985; The New York Times, Tuesday, March 12, 1985) the Soviet icebreaker Moskva, overcoming great difficulties, made a channel through heavy ice, reaching the whales in late February 1985. The belukhas were reportedly reluctant to follow the ship to safety and were eventually coaxed by the sounds of classical music. Some savssat reportedly perished due to crowding in the small open holes.

These newspaper accounts are at some variance with what probably actually happened. According to S. P. Duniushkin, Marine Mammal Inspector, Okhotskrybvod, Magadan, U.S.S.R. (personal communications with the senior author in March and April 1985), several thousand belukhas were indeed trapped during late December, in Proliv Senyavina. Repeated attempts of the icebreaker to reach the whales were unsuccessful and some animals began to perish. In view of the grave situation and deteriorating condition of the trapped whales, some 300 to 400 animals were killed for local use by hunters from the nearby Native settlement of Yandrakinot. Eventual fate of the large number of entrapped whales is unknown at the time of this writing. Based on available information about time and location of the event, those whales would have had to survive entrapment until about late May, before ice conditions would have moderated enough to permit their escape.

It is evident that entrapment of belukhas of the Bering population occurs with some frequency. Entrapment in autumn-early winter, as a single factor, probably poses a greater threat of death to belukhas because of intensifying ice conditions and starvation of imprisoned animals over protracted periods of time. Entrapment during late winter-spring, during northward migration, would tend to be of shorter duration and whales would eventually be released by shifting ice before they starved. In either case, entrapment increases the likelihood of predation by polar bears and occasionally by man. Entrapment probably occurs with greater frequency in western rather than eastern Chukchi Sea due to penetration of more severe ice conditions by belukhas. The numbers of savssat involved in spring entrapments are, on average, probably small.

In our opinion, events affecting belukhas that occurred in Bering Strait and eastern Chukchi Sea during spring 1984 were unusual for two reasons; the uncommon abundance of polar bears and the unusually warm temperatures and extent of open water in March, followed by severe cold and extensive re-freezing of leads in April.

Predation by killer whales on belukhas is also of significance in the Bering and Chukchi seas. The extent of such predation is, as yet, not known, though it is probably common in some parts of the belukha's annual range. During the months of minimal ice extent, relatively few of the entire Bering Sea population of belukhas remain in the Bering Sea where killer whales are relatively abundant. Most belukhas are in the northern Chukchi, East Siberian, and Beaufort seas. The number of killer whales in the northern Chukchi is relatively low, based on the infrequency of sightings. There are no reported sightings from the central and eastern Beaufort, and their occurrence in the East Siberian Sea is unknown. Effective use of underwater broadcasting of killer whale sounds to keep belukhas out of major salmon streams in Bristol Bay, Alaska (e.g., Fish and Vania 1971) attests to the strong reaction of belukhas to the acoustical perception of killer whale presence.

Contaminant Levels

Addison and Brodie (1973) reported the occurrence of DDT residues found in samples from 14 adult belukhas taken from the Mackenzie Delta. Whales that summer in that region pass through waters adjacent to Alaska and are hunted by Alaskans. Those authors found that DDT and its metabolites were present at levels of 0.01 and 0.02 parts per million (ppm), fresh weight in muscle and liver tissue, respectively, and 2 to 4 ppm fresh weight in blubber. These levels were considered by those authors to be lower than in marine mammals from other regions such as the North Atlantic.

Addison and Brodie (1973) based their comments about sources of these contaminants on the premise that belukhas occurring in Mackenzie Delta do not migrate beyond the Beaufort and Chukchi seas. They concluded that residues of DDT and its metabolites were thus of local origin, obtained through the food web. However, based on the seasonal migrations of these belukhas it is equally probable that exposure occurs during winter when the belukhas are in the Bering Sea, a region dominated by inflow of North Pacific water.

Sergeant and Brodie (1975) stated that belukha fisheries in the eastern part of the Northwest Territories (Canada) that produced meat and muktuk for human consumption failed because of the discovery of mercury in meat. Mercury in belukha meat exceeded the 0.5 ppm wet weight level that was allowable for human consumption. Heavy metal burdens in belukhas of the Bering population are known only from four females taken in Mackenzie Estuary, the results of which were reported by Hunt (1979). In those four whales mercury in liver tissue ranged from 7.41 to 22.64 ppm ($\bar{x}$ = 13.3). Mean levels in meat and muktuk were 0.91 and 0.14 ppm respectively. Zinc also occurred at high levels, the mean of measurements being 24.1 ppm in liver, 23.8 in meat, and 21.6 in muktuk. Cadmium, copper, lead, and chromium were also reported as present.

Contemporary Harvests and Total Kills

Belukhas of the Bering population historically have been, and continue to be, hunted in coastal waters of three broad regions: far eastern Siberia and Chukhotka; western and northern Alaska and the eastern Beaufort Sea and Amundsen Gulf of Canada. In all three regions the historical aboriginal harvests appear to have been substantially larger than most annual harvests made at the present time (Tomilin 1957; Fraker et al. 1978; Seaman and

Burns 1981). The majority of belukhas taken in earlier times were hunted during open-water seasons by large numbers of men, usually employing kayaks (or similar small craft), harpoons, and spears in highly organized "drives" during which many belukhas were driven into shallows and killed (Pallas 1788, cited in Tomilin 1957; Nelson 1887; Kowta 1963; Meteyer 1966, quoted in Fraker et al. 1978; Foote and Williamson 1966; Ray 1966; Vanstone 1967; McGhee 1974; Fraker et al. 1978; Hunt 1979; Seaman and Burns 1981). During our work in villages of western and northern Alaska, we were frequently told of traditional sites where people formerly gathered to collectively hunt and process the catches.

Review of written records available to us, as well as discussions with Alaskan Natives and other informed individuals,indicates that the complex process of "modernization," has strongly affected belukha hunting. V. A. Arsen'ev, a well-known authority on marine mammals of the Soviet far east, worked in that region during the 1920's and 1930's. He recounted to the senior author, via personal discussions in 1967, that reduced hunting effort and landings in Chukhotka were, in part, due to consolidation of many of the smaller coastal settlements, increasing involvement of potential hunters in activities other than subsistence hunting (especially during summer months) and abandonment of the traditional hunting methods that involved large numbers of hunters. To a great extent, these changes have also occurred in Alaska (Seaman and Burns 1981; Seaman et al. 1985) and probably in northwest Canada. There is a general concensus that the contemporary magnitude of belukha kills, including increased losses associated with the use of rifles as opposed to harpoons and nets, is usually less than in former times for the Bering population of these whales (Arsen'ev, personal communication; Fraker et al. 1978; Seaman and Burns 1981).

Annual harvests of belukhas may fluctuate greatly. The "regular" seasonal harvests are affected by annual differences in abundance and availability of whales, especially in coastal waters during summer. Also, the periodic occurrence of savssat that accord opportunity for unusually large harvests to be secured, further contribute to great annual variations in harvest levels.

Accurate information on magnitude of contemporary kill levels, especially the component that includes numbers of belukhas wounded or killed and lost, is difficult to obtain and interpret. It is our intention to summarize what we consider to be the most reliable information and, from this, to derive an estimate of mortality due to hunting.

Soviet Harvests

Successful hunting for belukhas of the population under discussion, in what are now Soviet waters, formerly occurred over a broad expanse from Kamchatka to Chaunskaya Guba in the western part of the East Siberian Sea (Tomilin 1957). According to Tomilin (1957) and Arsen'ev (personal communciations) in recent times they have mainly been taken in the region of the northern Gulf of Anadyr.

Reported magnitude of landings varied by source. Tomilin (1957) indicates only that they are taken sporadically. Kleinenberg et al. (1964) reported that about 500 are taken in the Laptev, East Siberian, and Chukchi seas combined. It was not possible for us to determine what proportion of that reported level of take may have been from the whale population under discussion. These same authors also indicated a take of 100-300 belukhas in the Bering Sea.

Krupnik (1979, 1980) reported on characteristics of marine mammal harvests, including belukhas, made during the 1920's and 1930's by Asiatic Eskimos. Asiatic Eskimos live along the southern (Anadyr) and eastern (Bering Strait) shores of the Chukchi Peninsula. He indicated that during those years, Siberian Eskimos were 28% of the population of Chukhotka; they took an average of 25 to 30 belukhas a year in the mid-1930's; that catch was 50% to 70% of all whales taken by Native inhabitants of the Chukchi Peninsula and that hunting losses were high, on the order of 100% to 150% of the landed catch (50% to 60% of the whales struck were lost). Rozanov (1931) reported that formerly, belukhas were taken by shooting only near the settlement of Naukan. Nine belukhas were taken there in 1929 and 42 in 1930.

V. N. Gol'tsev, formerly a fisheries inspector in the Chukotka region during the 1960's (Soviet Ministry of Fisheries, Okhotskrybvod), informed the senior author that few people now normally hunt belukhas and the level of take is low; probably less than 40 whales per year on average, and mainly along the north coast of the Gulf of Anadyr (Gol'tsev, personal communication, August 1973). Yablokov (1979) indicated that former catches near the Chukchi Peninsula (Bering and Chukchi seas) sometimes reached 100 to 200 animals; that current catches are less than 100 in the Laptev, East Siberian, and Chukchi seas combined; and on the order of 20 to 50 in Bering Sea. Ivashin and Mineev (1981) reported the recent known harvests of belukhas in different parts of the U.S.S.R. In the Chukchi Sea, six were taken during the two-year period 1973-74. Reported harvests in the Bering Sea ranged from 15 to 32 in 1973-1980 with an annual average of 26 during 1976-1980. Harvests in 1981 to 1983, as reported by Mineev (1984), were 22, 12, and 18 respectively. Of these, only two were taken in the Chukchi Sea in 1983.

Most recently, A. Somov, Inspector for the Soviet Ministry of Fisheries, stationed in Magadan, informed the senior author that an annual landed catch of about 25 to 30 belukhas is made by workers from the settlement of Sireniki, at the southeastern corner of the Chukchi Peninsula in April and May (Somov, A. G., personal discussion with J.B., December 17, 1985) apparently utilizing the very important, persistent, polynya system referred to as Sirenikovsakaya Polynya by Bogoslovskaya and Votrogov (1981). Somov further indicated that although belukhas are occasionally hunted at other locations in the Bering and Chukchi seas, the average number taken per year is very low.

On the basis of all the information presented above, we conclude that a reasonable estimate of contemporary Soviet harvests from the Bering Sea population of belukhas is normally on the order of 60 whales per year. The large kill of savssat in Proliv Senyavina in 1985 will greatly increase reported harvest of 1985.

Western Canadian Harvests

Harvests of belukhas from the Bering population, made by Canadians, occur primarily in what is broadly referred to as the Mackenzie estuary of the eastern Beaufort Sea. In addition to kills in that estuary, an estimated 10 whales may be killed (not necessarily landed) in other parts of the western Canadian Arctic (Fraker 1980).

There are several sources of data about landings (retrieved harvest) in the Mackenzie estuary over several years. Those data we have used are presented in Table 20. The average annual landing in the Mackenzie estuary during the 11-year period from 1971 to 1981 was 129 belukhas. If it is assumed that six of the 10 belukhas killed per year, on average, in other parts of the western Canadian Arctic are landed, the average level of recent landings is about 135 belukhas per year.

Alaskan Harvests

The landed kill of belukhas in western and northern Alaska, for various years, is presented in Table 21. The most pertinent and reliable data are those for the years 1977 to 1984. During that eight-year period the annual average landed harvest was estimated to have been 220 animals.

The combined estimated annual landed harvest of belukhas from the Bering population, made in Soviet, Canadian, and American waters is 415.

Total Kills

It is extremely difficult to estimate the total annual kill of belukhas based on the landed catch. Losses depend on a great number of variables including the environmental circumstances under which whales are taken, methods of capture, location of hunting activity, attitudes and capabilities of the hunters, and behavior of whales. Loss rates range from zero when whales are taken with nets to very high when they are shot in narrow leads during their northward spring migration or in deep open waters during summer. Some authors have indicated the causes of hunting loss and/or suggestions for reducing it (Hunt 1976, 1977, 1979; Fraker 1980).

Though it may not be precise, a reasonable estimate of total kills, including whales landed and those struck and lost by rifle fire, is necessary in order to estimate the probable impact of harvesting on the population of whales as a whole. As was true for determinations of the landed harvest, the various sources of information are subject to different interpretations.

Estimates of the proportion of belukhas killed but not retrieved in the western Canadian Arctic vary considerably. Hunt (1976, 1979) estimated that 40% of the whales killed were not landed. Fraker (1980) estimated that loss at 33%, while Finley et al. (1983) indirectly indicated that it was about 57%, or an estimated 300 whales killed per year with average annual landings of 130.

We have chosen to use the estimate of 40%. On that basis, the average landing of 135 whales indicates a total kill of 225 in waters of northwestern Canada.

Table 20. Reported landings of belukha whales in the Mackenzie estuary, eastern Beaufort Sea.

Year	Number landed	Source of information	Year	Number landed	Source of information
1960	145	1	1971	82	2
1961	145	1	1972	120	2
1962	96	1	1973	177	2
1963	94	1	1974	122	3
1964	45	2	1975	142	3
1965	70	2	1976	154	3
1966	96	2	1977	140	3
1967	40	1	1978	121	3
1968	14	1	1979	120	4
1969	-	-	1980	90	4
1970	105+	2	1981	149	4

1 Sergeant and Brodie 1975. Data presented by these authors are for the western Canadian Arctic. Lacking clarification, we have assigned them specifically to the Mackenzie estuary.

2 Fraker et al. 1978.

3 Fraker 1980.

4 Fraker and Fraker 1982.

Table 21. Reported or estimated landings of belukhas in western and northern Alaska (Bering, Chukchi, and Beaufort seas) from 1963 to 1984.[1]

Year	Number landed	Source of information	Year	Number landed	Source of information
1963	225	2	1974	-	-
1964	225	2	1975	-	-
1965	225	2	1976	-	-
1966	225	2	1977	247	4
1967	225	2	1978	177	4
1968	150	3	1979	138	4
1969	170	3	1980	249	4
1970	200	3	1981	205	4
1971	250	3	1982	331	4
1972	180	3	1983	231	4
1973	150	3	1984	170	4

[1] When a range in the probable landed kill was indicated in the original data source, the mean of that range has been used in this table.

[2] Burns, J. J., Alaska Dept. of Fish and Game, unpublished.

[3] Seaman and Burns 1981.

[4] Data obtained during this study.

In eastern Canada, Orr and Richard (1985) reported on some aspects of the belukha hunts in Cumberland Sound in 1982 to 1984. Hunting was mainly unorganized in that boats mostly operated independently. Hunting efficiency, as reported by these authors, may have relevance to similarly conducted hunts in other regions. Orr and Richard (ibid.) made one statement that was difficult for us to interpret. They said (p. 3) that, "All the dead whales observed by DFP personnel, were buoyant and it is therefore unlikely that any were lost due to sinking." Their reference apparently was to a hunt on 21 July 1982 when 19 belukhas were landed. However, it was interspersed with more general comments about hunting methods. In our experience, whales that sink before being harpooned or speared, would not be seen unless they were subsequently grappled, or floated to the surface, usually a day or more after death. An assumption that no whales are lost due to sinking is questionable. Though Orr and Richard (op. cit.) reported the number of belukhas landed during each hunt they monitored, ancillary information about whales sunk, or that escaped after being wounded, was only mentioned in relation to five hunting forays made in August 1984. During those hunts (16, 18, 21, 23, and 25 August) an estimated 36 to 38 whales were struck by rifle fire. Of those struck, 11 were landed, 1 was known to have been killed and sunk, and 24 to 26 were wounded and escaped. Using values of 37 whales struck and 25 wounded but having escaped, 29.7% of the struck whales were landed, 2.7% were known to have been killed and sunk, and 67.6% were hit but escaped. Fate of belukhas in the latter category was, of course, unknown.
In Alaska, belukhas are mainly taken either in spring, as they migrate northward through the ice, or during the months of open water when they are mostly herded into shallows and killed. We have no additional information that alters our previous conclusions (Seaman and Burns 1981) of loss rates associated with these two types of hunting. The loss rate for hunts conducted at the land-fast ice edge is estimated at about 60% of the animals struck. That, associated with whale drives, is estimated at 20%. The average annual landed harvest of 220 in 1977 to 1984 is considered to have been comprised of 30% taken at the land-fast ice edge and 70% taken in shallow water. Thus, the average annual kill in western and northern Alaska is estimated to approximate about 360 belukhas per year. That estimate is high for years when landings include a significant number of whales caught in nets. In order not to underestimate losses, we have included such whales as being part of the catch taken by driving.

It appears that the Soviet harvest is mainly taken in April-May. We assume that conditions are similar to those in Alaska for hunts at the land-fast ice edge, where losses are estimated to be 60% of the whales killed. If so, an annual average harvest of 60 belukhas represents a kill of 150.

Based on the comments above, we conclude that the estimated total kill of belukhas from the Bering population, made in waters of the U.S.S.R., Canada, and the U.S.A. is on the order of 735 per year.

It has been obvious to all observers of belukha hunts conducted at the edge of land-fast ice that a considerable reduction of losses can be achieved; particularly by improving hunting methods of the less traditional, inexperienced, younger-aged hunters.

Size of the Bering Population

At present, there are no quantitatively verified estimates of total size of this population of belukhas. Burns (1984) indicated that, at a minimum, it probably included 25,000 to 30,000 animals. That minimum estimate was based primarily on numbers of whales that occur in coastal waters of western North America during months of open water and on information about distribution in other parts of the Bering-Chukchi region during those months.

During summer, in Soviet coastal waters of Bering Sea, belukhas have been reported to occur from south of Karaginskii Island to Mechigmen Gulf in western Bering Strait. The center of summer abundance in Soviet waters of Bering Sea appears to be in the region of the northern Gulf of Anadyr from Kresta Bay to Providenia Bay where they apparently stay or periodically occur throughout the summer (Kleinenberg et al. 1964).

As far as the Chukchi and East Siberian seas, several informants from Little Diomede Island (U.S.A.) informed the senior author that in former years when they traveled by skin boats to the settlements of Naukan and Uelen, near the northeast tip of the Chukchi Peninsula (up to 1946), belukhas were seen migrating northward and were occasionally taken in late July-early August. One of the apparent hunting sites was near the estuary between Uelen and Inchoun. According to Arsen'ev (1937, in Tomilin 1957) belukhas are reported to occur in coastal waters of the northern Chukchi Peninsula to a point as far west as Chaunskaya Guba in the East Siberian Sea. They have also been reported at Cape Schmidt in the East Siberian Sea (Arsen'ev 1939, in Kleinenberg et al. 1964). They are apparently numerous in the vicinity of Kolyuchinskaya Guba and Ostrov Vrangelya (Wrangel Island) (Kleinenberg et al. 1964).

Soviet investigators were the first to report that in summer these whales occur offshore as well as nearshore. Kleinenberg et al. (1964, p. 288) stated, "Observations from the air showed that the belukha is also found in summer at the edge of finely broken 4/10-5/10 ice and in polynyas, cracks, and leads in heavier pack ice of 9/10-10/10." The occurrence of belukhas in offshore waters during summer was also found to be the case in western North America (Davis and Evans 1982; this study).

Yablokov (1979) stated that there are no good census data from Soviet waters on which to base estimates of the size of various groups or populations. His approximate estimates of numbers include 1,000 to 2,000 in the East Siberian-Chukchi seas and 2,000 to 3,000 in Bering Sea. It is noteworthy that the 1985 entrapment in Proliv Senyavina, involved up to 3,000 belukhas.

In coastal waters of Alaska and northwest Canada, summer distribution of belukhas extends from Bristol Bay to Amundsen Gulf. The best available estimates of belukha abundance are for these waters and are as follows (see also Seaman et al. 1985).

In Bristol Bay, numbers of belukhas during summer have apparently remained about the same over many years. The estimates are of 1,000-1,500 animals (Brooks 1954b, 1955; Lensink 1961; Frost et al. 1984). At other locations in Alaska the estimates are 1,000-2,000 in the Yukon River Delta to Norton Sound (Seaman et al. 1985; this study) and 2,500-3,000 along the Chukchi Sea coast from Kotzebue Sound to Point Barrow (Seaman et al. 1985; this study). The estimate of 1,000-2,000 for the Yukon River Delta-Norton Sound region is conservative. In mid-June 1956, more than 2,000 belukhas were present in and near the middle mouth of the Yukon River (R. A. Hinman, Alaska Dept. Fish and Game, Juneau, personal communication, 23 Feb. 1985). No assessments have been made in the region between Bristol Bay and the Yukon River Delta, though belukhas are there during summer. Thus, the number of belukhas in coastal waters of western Alaska during summer is minimally estimated at 4,500-6,500 animals.

Several aerial surveys have been undertaken in the eastern Beaufort Sea and Amundsen Gulf. Sergeant and Hoek (1974), based on preliminary surveys, estimated that there were 4,000 belukhas present in the Mackenzie Delta region. Subsequent estimates in the Mackenzie estuary were based on more extensive surveys, the results of which were published mainly by Fraker (1977, 1980) and Fraker and Fraker (1982). The more recent of these works placed the number of belukhas in the Mackenzie estuary at about 7,000, not including neonates. Davis and Evans (1982) considerably expanded the survey area beyond the Mackenzie estuary and found that the minimum number of whales in the eastern Beaufort and Amundsen Gulf was 11,500. Their methods of arriving at the estimate were very conservative. Without doubt, future efforts in the eastern Beaufort Sea-Amundsen Gulf region will result in significantly higher numbers of belukhas being accounted for.

Considering these various estimates, the minimum number of belukhas in coastal waters of Alaska, together with those in the eastern Beaufort-Amundsen Gulf region, during summer is on the order of 16,000 to 18,000.

Burns' (1984) estimate of a minimum population on the order of 25,000 to 30,000 belukhas for the Bering Sea population as a whole is based on the assumptions of 3,000-4,000 belukhas occurring in offshore waters of the western Beaufort, northern Chukchi, and East Siberian seas; 6,000-8,000 in Soviet coastal waters, including those around Wrangel Island; and 16,000-18,000, as indicated above, for Alaska and Canada. It is highly probable that the Bering-Chukchi population of these whales is larger than 30,000, though at this point such a statement is pure speculation.

The number of whales that summer in waters of North America extending from Bristol Bay to Amundsen Gulf, and from which Alaskan and Canadian hunters kill an annual average of 585, is a minimum of 16,000 to 18,000. Thus, 585 whales are removed by hunting (including whales landed as well as those struck and lost) from groups of whales that produce, in aggregate, a minimum of 1,680 to 1,890 calves per year. Size of the Bering population, as a whole, is significantly larger than 16,000 to 18,000 animals.

Population Discreteness

The implicit assumption throughout this report is that belukhas in the Bering, Chukchi, Beaufort, and eastern part of the East Siberian seas and Amundsen Gulf are a single genetic population. This population winters in the ice-covered regions of the Bering Sea and, severity of winter ice conditions permitting, into the southern Chukchi Sea. During summer and early autumn, the seasonal range is greatly expanded, as indicated in several previous sections. The wide summer distribution includes nearshore waters, more distant waters in the Beaufort and western Chukchi seas, as well as the ice fringe and "front" north to (and perhaps into) the consolidated pack.

On an annual basis, there is great variability in numbers of whales and the duration of their occurrence in coastal areas, as indicated by our work in Norton Sound, Kotzebue Sound, and Kasegaluk Lagoon. This was also found to be the case in Bristol Bay (Brooks 1955), the Mackenzie estuary (Slaney 1975, Fraker 1980), and the Kara Sea (Tomilin 1957).

Recently, several authors have urged the recognition of separate summer aggregations of belukhas as constituting different stocks (Fraker 1980; Finley et al. 1982; Braham 1984). However, Yablokov (1979, p. 18) indicated that, "Very possibly, animals from Anadyr Bay (Bering Sea) belong (or are more closely connected) to the northern population." Such a view would be in agreement with reports of northward-migrating belukhas near Naukan and Uelen in July-August, seen in former times by Eskimos from Little Diomede Island. The most significant aspect of stock discreteness is whether or not the summer aggregations of whales that occur in coastal waters comprise different, reproductively isolated groups (populations). For the Bering population, that question will not be definitively answered until the annual movements and interactions among the different aggregations are known.

From our perspective, all of the available information supports the view that belukhas of the Bering, Chukchi, Beaufort, and eastern part of the East Siberian seas are of a single, interbreeding population.

Biological parameters we have examined show similarity in the whales from Bristol Bay to the Mackenzie Delta. It is clear that these whales winter in the Bering Sea. The majority of them pass through the narrow confines of Bering Strait during both the spring and autumn migrations. Extensive intermingling is suggested by the occasional sightings of huge aggregations such as those reported by Fedoseev (in Kleinenberg 1964) and Ray et al. (1984) and our observations in the region generally north of Point Barrow. Breeding probably occurs earlier in spring than was formerly thought, at a time when these belukhas are in the Bering Sea or just beginning the spring migration. There are no natural barriers to prevent intermingling during the breeding period or at other times of the year.

Belukhas are known to also form huge aggregations. Dorofeev and Klumov (1935a) reported the largest of which we are aware, no less than 10,000 animals in the Gulf of Sakhalin (Okhotsk Sea) during mid-June.

Our review of what is known about the seasonal movements, distribution, and biology of belukhas throughout their range suggests to us that different populations, in the traditional sense, are not necessarily represented by geographically separated summer aggregations. Different populations of belukhas are those for which the array of seasonal habitats, particularly those occupied in late winter-early spring, are separate. There can be both large and small, discrete populations. That appears to be the situation in Alaska with respect to the small (300-500 animals) Cook Inlet population and the much larger Bering population.

Physiography of the Bering-Chukchi region, as habitat for belukha whales and some other ice-associated marine mammals of the northern hemisphere, is unique. The region is very large. Extensive heavy ice conditions that preclude overwintering, mostly prevail north of the confines of Bering Strait. Favorable ice conditions occur, to varying degrees, south of the Strait. Species that winter in the seasonally ice-covered regions of Bering Sea have access to extensive summer ranges within the Bering Sea as well as the broader areas including the Chukchi, Beaufort, and part of the East Siberian seas. Species that exhibit seasonal movement patterns somewhat similar to those of belukhas in this region include spotted (*Phoca largha*), ribbon (*Phoca fasciata*), and bearded (*Erignathus barbatus*) seals, bowhead whales, and Pacific walruses. Pacific walruses exhibit a high degree of segregation during summer, with disjunct aggregations occurring at several locations along the Soviet and American coasts. Additionally, nearly all females and young summer in the Chukchi Sea and nearly all adult males in the Bering Sea (Fay et al. 1984).

Behavior

Because of the focus of our study, relatively little information about behavior of belukhas was obtained; thus, this section is mainly a discussion of information in reports and published literature.

Duration and Depth of Dives

As indicated by Ridgway et al. (1984), belukhas are not generally considered to be deep-diving animals, perhaps because of their abundance in relatively shallow coastal waters. Dhindsa et al. (1974) measured the respiratory characteristics of blood from belukhas maintained in captivity. They found a high blood oxygen capacity (25.8 vol.%) though they did not comment on the diving capabilities of belukhas. Ridgway et al. (op. cit.) measured blood characteristics of two active belukhas maintained in excellent physical condition. Blood oxygen capacities (Hb x 1.34) were similar to, but slightly higher than reported by Dhindsa et al. (op. cit.); being 28.0 and 27.2 vol.% for a juvenile male and an adult female, respectively. Mean hematocrits were 52.6% and 52.2% for the male and female.

Additionally, Ridgway et al. (1984) provided the most rigorous information about depth of dives, using the two animals for which blood characteristics were determined. The whales were trained to dive in the open ocean. During their experiments, the belukhas remained submerged as long as 15 min 50 s and the adult female dove as deep as 647 m.

Frost et al. (1985) monitored two radio-tagged belukhas in comparatively shallow areas of Bristol Bay, Alaska. A subadult male remained submerged for a maximum of 5 min 56 s and mean duration of its dives was 2.09 min. An adult female dove for a maximum of 2 min 8 s. Percent of time at the surface was found to be 3.8 and 34.7 for the male and female respectively.

Dorofeev and Klumov (1935a) reported that belukhas normally dive for 1 to 1.5 min and up to 3 min when alarmed. Kleinenberg et al. (1964) indicated that these whales can remain under water for 15 to 20 min. Hill (1967; 1968) reported maximum dive time of an entrapped belukha to have been 7 min

25 s though he also indicated that the last surviving whale at an entrapment was absent for up to 40 min. Hay and McClung (1976) reported the duration of dives (presumably all in shallow water) to average only 52 s.

Swimming Speed

Swimming speed of belukhas was reported by Dorofeev and Klumov (1935a) to be 3 to 5 knots (5.6 to 9.3 km/h) when undisturbed and up to 7 knots (13 km/h) when disturbed. Ray et al. (1984) reported that whales with young swam at the rate of 2.3 km/h and traveling groups (without young?) moved at 7 km/h. Kleinenberg et al. (1964) indicated that belukhas swim at 5-6 km/h with a maximum speed of 20 km/h. Ridgway et al. (1984) determined swimming speeds during commanded dives for an immature male and an adult female belukha. The male descended at an average rate of 8.2 km/h and ascended at 8.1 km/h; speeds for the female were 7.2 and 8.2 km/h respectively. Frost et al. (1985) reported a movement of 30 km in 6 h for a juvenile, radio-tagged male, an average of 5 km/h. They also reported regular daily movements by belukhas of 100 to 150 km.

Feeding

Feeding activity of belukhas while they are in estuaries and river mouths has been a point of considerable discussion. Sergeant (1973) suggested that the main advantage of the use of estuarine habitats during summer derives from the thermal advantages of warmer waters to neonates. He indicated that belukhas feed very little while in estuaries. In Alaskan waters, the occurrence of belukhas in rivers and estuaries is usually strongly associated with seasonal concentrations of fish, and the whales prey extensively on them. Bristol Bay is the best-studied location (Brooks 1954a-1957; Lensink 1961; Frost et al. 1983; Lowry et al. 1985). In that region, belukhas enter the estuaries and rivers as early as March and remain through July. They feed intensively on seaward-migrating smelt (*Osmerus mordax*) in March to May, on seaward-migrating sockeye salmon smolt in May-June, and on returning adult salmon, mainly sockeye, during June-July.

In the Yukon River and Norton Sound, belukhas arrive as soon as ice conditions permit, usually in late May or early June. Here, according to local residents, they also feed extensively on smelt, on the huge spawning concentrations of herring (*Clupea harengus pallasi*), and different species of salmon. Lowry et al. (1985) found that near Norton Bay, in June, belukhas had been feeding on herring, saffron cod (*Eleginus gracilis*), and various sculpins.

Aspects of belukha food habits, particularly in the Kotzebue Sound area, are discussed in great detail by Lowry et al. (1985). Of interest here is that the intensity of recent feeding by whales taken in Eschscholtz Bay during June was highly variable among years. Based on our sampling at that location, they were regularly feeding. In most years feeding apparently occurred in Kotzebue Sound, some hours prior to the whales' entering the confines of Eschscholtz Bay. Volumes of food remains in stomachs were relatively small and well digested. However, June 1982 was the exception in that belukhas were observed to be actively feeding within Eschscholtz

Bay and the volume of fresh food remains in stomachs, from which we collected subsamples, was consistently much greater than during previous years. Thus, it appears that the whales actively feed while in coastal waters of Kotzebue Sound and that whether or not they feed while in Eschscholtz Bay is a function of prey abundance (as it probably is at other nearshore locations).

The age at which young belukhas begin to feed independently, is not well known. Kleinenberg et al. (1964) reported the different opinions of various investigators and stated, " . . . we agree with the majority of authors that the lactation period lasts about half a year." The timing of our collections was such that we have no samples of first year animals between the birth period (when neonates are nursing) and about 1 year. A 12-month-old whale taken in Eschscholtz Bay had been feeding on saffron cod and remains of 26 such fishes were in its stomach (Lowry, personal communication).

Occurrence in Estuaries and Rivers

Nearshore movements in the lower (tidally influenced) reaches of rivers and confined estuaries are usually closely correlated with the ebb and flow of tides (see discussion of hunting in Eschscholtz Bay). Belukhas normally move into the confined estuaries and river mouths on incoming tides and return seaward during the ebb (Arsen'ev 1939; Vladykov 1944; Brooks 1954a; Lensink 1961; Kleinenberg et al. 1964; Frost et al. 1983; and numerous others).

These whales are known to ascend major rivers to a considerable distance upstream. Numerous occurrences were summarized by Kleinenberg et al. (1964). Yablokov (1979) stated that, at present, small schools of belukhas enter all large Siberian rivers. In the Yukon River of Alaska they were reported as far upstream as Nulato, 729 km by river from the sea (Nelson and True 1887). In mid-June 1982, five belukhas were reported near Tanana, 1,119 km from the mouth of the Yukon (B. Lentsch, personal communication) and a few days later a single whale was seen 18 miles above Rampart, at a location 1,257 km from the sea (P. Wakefield, personal communication). Other past occurrences of these whales in fresh water are indicated by Alaska place names including two different Beluga lakes, Beluga River, and Beluga Slough (Orth 1971).

Disturbance by Noise

Tolerance of non-lethal disturbance by cetaceans has proven very difficult to evaluate if only because of the difficulties of conducting controlled experiments on free-ranging whales. As Reeves et al. (1984) point out, under normal field conditions there are many problems involved in relating behavioral responses to acoustical stimuli.

There are most certainly great differences in potential for harmful effects between short-term, minor modification of behaviors such as group formation, position, swimming speed, dive time, or breathing rates, as compared to displacement from advantageous habitats, disruption of migration and movement routes, significant interruption of feeding opportunities, or other important vital functions.

As has been implied in this report as well as in all studies based on sampling of belukhas at traditional, nearshore hunting locations, the most intensive kind of repetitive disturbance is hunting. In spite of it, belukhas mostly continue to return to favored bays, estuaries, and rivers throughout their range. However, there have been changes in activity patterns, duration of use of favored areas, and tolerance to human-caused sounds.

Several recent reports deal with responses of belukhas to noise. Fraker (1977) observed that belukhas move away from approaching tug and barge traffic. In one instance, he found that a large group of belukhas being observed responded by rapidly swimming away from such vessels at a distance of 2.4 km. Scattering of these whales was still evident 3 h after the incident, but by 30 h they had resumed a normal distribution near their original location. As Mansfield (1983) pointed out, reaction of whales in the incident reported by Fraker (ibid.) was initiated at a distance far less than the estimated maximum perception range of sounds from the tugboat. Fraker (op. cit.) also found that belukhas reacted more to moving, as opposed to stationary, sound sources and that frequent tug and barge traffic impeded the movement of belukhas in that they did not move along their normal travel route until vessel activity temporarily ceased.

With respect to stationary sources of noise, McCarty (1981) reported that in Cook Inlet, Alaska belukhas, including females and calves, passed as close as 10 m to active oil production platforms. Further, belukhas seemed not to be affected by constant noise but showed a temporary avoidance reaction to sudden changes of noise levels.

Stewart et al. (1982, 1983) reported on results of their studies in the Bristol Bay region. They found that responses of belukhas to noise were strongly affected by both the activity of whales and the habitat in which noise occurred. Their work was in the Snake River and Nushagak Bay. The strongest reactions of belukhas were to sounds of outboard motors and, regardless of behavior before outboard motor noises began, whales immediately swam downriver. Similar flight responses were elicited by outboard noise in the bay though not to noises emanating from larger inboard-powered fishing and processing vessels. These authors also found that belukhas responded more to sudden noise disturbance than to constant noise. Feeding and traveling activity of whales was not greatly affected by play-back sounds of oil drilling activities and whales passed close to hydrophones while such sounds were being broadcast. Thomas and Kastelein (1983) found that captive belukhas quickly acclimated to sounds of oil drilling activities played at typical sound levels.

Tolerance to disturbance by human activities seems highly variable and it is difficult to make any generalizations, except that in Alaska, displacement of belukhas seems to occur to a greater degree in regions where the variety of man-caused intrusions includes active hunting. This suggests a degree of habituation, or lack thereof, associated with experience. Significant hunting only occurs in western and northern Alaska.

In Cook Inlet, belukhas seasonally occur close to the busy seaport of Anchorage and in the mouths of larger rivers where small boat traffic is heavy.

In the Bristol Bay region the whales likewise frequent rivers where fishing vessel traffic is especially heavy and parts of the bay where actual fishing effort is intense. Entanglement in salmon gillnets occurs and has already been discussed.

The situation north of Bristol Bay is apparently far more complex. Belukhas are hunted by coastal residents whenever the whales are available. In the Kuskokwim Bay region local residents consider the whales to be easily frightened by outboard-powered small boats, low-flying aircraft, and other loud noises. They indicate that whales still frequent Kuskokwim Bay but are far less tractable (in the sense that they can be herded) than during the days prior to the advent of high-powered outboard motors. That same opinion is shared by whalers of the Yukon Delta, Norton Sound, and Kotzebue Sound (Seaman and Burns 1981).

The experiences of whalers that hunt in and near Eschscholtz Bay have led them to conclude that disturbance of belukhas by small boat traffic and low-flying aircraft often keeps the whales from entering the bay. As a result, an agreement among the hunters and with local aircraft operators, in effect when whales are known to be present, restricts such traffic to times that coincide with low tide. The whalers are very aware that belukhas normally enter Eschscholtz Bay a few hours after the tide begins to rise. Sergeant and Brodie (1975) referred to excessive hunting or boat traffic near an Eskimo settlement in eastern Canada as a possible cause for a shift in whale distribution.

Eskimo lore also indicates differences in tolerance levels of belukhas in the pack ice. Whales passing through narrow leads or other small openings in the ice are said to be easily frightened by hunters. Those whales in large openings or wide leads reportedly often move at a more leisurely speed and frequently stop, mill about, or remain at the surface for longer periods of time. It would seem that the more confined openings increase both the risk of whales to predation by polar bears and the "alertness" of older, experienced whales in conditions that place them at high risk.

In western Alaska there is a generally held belief that the modernization of coastal communities, with all of the associated noises (generators, heavy equipment, airplanes, snow machines, outboard motors, etc.) and odors, is presently causing belukha whales and other marine mammals to pass communities at a greater distance from shore and to partially abandon traditionally favored sites now in close proximity to settlements. Sheshalik (= Sesualik and other dialectal variants of Inupiat), adjacent to the large community of Kotzebue is a location where belukhas, though still present, no longer remain in large numbers for long periods of time during summer. This geographic place name means a location where belukhas (sisuaq) congregate. Effects of such displacement are unknown. It seems probable that such avoidance responses are beneficial to the whales in that they are less exposed to hunting. As more information about belukhas has accumulated, it seems likely that such vital functions as successful birth and nurture of calves can occur beyond the coastal zone. Displacement from estuarine waters where whales are intensively hunted may not have an overall, adverse effect on the whale population if suitable habitat in other areas remains available.

Conversely, from a homocentric perspective, such displacement has a negative impact on subsistence users of belukhas and on opportunities for people to observe and study these whales.

ADDITIONAL RESEARCH NEEDS

Some conclusions we have drawn from this study are based either on limited data, or extensions of available information to geographic areas for which adequate data are not available. There are many information needs about belukhas in general and about the Bering Sea population in particular. Those we find to be most pressing are as follows:

1. At present, there is no information about the reproductive biology of belukhas during late winter-early spring. Therefore, duration and peak of the breeding period is not adequately known. Appropriate biological samples may be difficult to obtain because most belukhas are taken in late spring-early summer. However, it may be possible for investigators that work in waters adjacent to Greenland to sample entrapped whales that are taken by hunters during February to April.

2. The summer distribution of belukhas within and along the ice front zone of the Chukchi, Beaufort, and eastern East Siberian seas should be determined. A substantial portion of the Bering Sea population may occur in that habitat at the same time that whales occur in coastal waters in greatest numbers.

3. The number of belukhas that occur in Soviet coastal waters of the Bering, Chukchi, and East Siberian seas during summer, is unknown and should be studied. In a preliminary way, this could be accomplished through carefully designed aerial survey efforts.

4. The extent of segregation and perhaps habitat partitioning by belukhas, based on age, sex, and reproductive status is not known. These can be studied by sampling whales at different times during the prolonged spring migration or at entrapments that may occur in the same region at different times during winter and spring.

5. Relationships among different summer aggregations of belukhas in waters of northwestern North America and northeastern Asia are not known, though we suggest that they are all part of a single Bering Sea population. The extent of interchange during summer and of intermingling while whales are in Bering Sea during winter-early spring, can be studied with the aid of radiotelemetry techniques. Application of radio tags should be done as soon as possible.

6. Monitoring of annual harvests, at least on an intermittent basis, should be undertaken to determine magnitude and variation as well as extent of hunting loss, composition of harvested animals, and the biological parameters (particularly those relating to productivity) that can be determined by sampling harvested whales.

7. No systematic effort has yet been made to determine the regional distribution and abundance of belukhas in Bering Sea, during winter. It is probable that areas of high whale abundance do occur, perhaps

regularly. The need for information about stock identity and about whale distribution in relation to proposed offshore petroleum development, warrants initiation of efforts to determine winter-early spring distribution and relative abundance.

8. In the Chukchi Sea, incidences of ice entrapment during spring migration appear to be closely correlated with weather during March to mid-May. Assessment of entrapment as a source of direct mortality, and as a factor contributing to increased predation by polar bears should be attempted on an opportunistic basis.

9. Food habits of belukhas in waters beyond the coastal zone are not known and should be studied. It is recognized that such an undertaking would require an ability to respond to opportunistic situations involving belukhas killed by polar bears or at occasional entrapments.

10. Size of the Bering Sea population of belukhas is not known. It is recognized that several preliminary studies must be undertaken before a broad-based aerial census will be feasible. Such preliminary undertakings are indicated as items 2, 3, and 5 (above).

11. Annual variability and magnitude of the incidental catch of belukhas associated with the Bristol Bay salmon fishery should be determined. Preliminary studies indicate that such mortality may be substantial in some years.

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INVESTIGATIONS OF BELUKHA WHALES IN COASTAL WATERS OF WESTERN AND NORTHERN ALASKA

III. FOOD HABITS

by

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SUMMARY

The stomachs of 242 belukha whales from the Bering and Chukchi seas were examined. Of those, 141 contained food remains. Foods eaten during the spring migration in the Chukchi Sea included arctic cod, shrimps, and octopus. In coastal areas of the northern Bering and Chukchi seas summer foods were saffron cod, sculpins, herring, smelt, capelin, char, shrimps, squid, and octopus. Primary foods in Bristol Bay were salmon and smelt. No samples are available from autumn or winter. During those seasons it is probable that pollock are the main prey in the southeastern and southcentral Bering Sea, while saffron cod and arctic cod are major foods in more northern areas.

In Eschscholtz Bay young belukhas ate smaller saffron cod than did older animals, and males ate proportionately more sculpins than did females.

Belukha whales are large animals and where they are abundant they will consume substantial quantities of fishes. In the Kvichak River in 1983, belukha predation accounted for 5% of the red salmon smolt outmigration, 1% of the commercial catch of red salmon, and 9% of the commercial catch of other salmon species. Prey eaten by belukhas are similar to those eaten by several other marine mammals species, and harvested by commercial fisheries. Competition for food with other marine mammals and fisheries may influence population size and productivity of belukhas.

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We thank the many Eskimo hunters who made available to us the specimen material used in this study and provided much significant information on belukhas. Several personnel of the Alaska Department of Fish and Game (ADF&G), particularly Richard Tremaine and John Burns, assisted in field collections and laboratory analysis of specimens. John Burns was responsible for project management and provided editorial comments on the report. Project support was provided by the National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, ADF&G, and the Federal Aid in Wildlife Restoration Program.

INTRODUCTION

The belukha whale (*Delphinapterus leucas*) is a major component of the marine mammal fauna of Alaskan waters. It is the only ice-associated small cetacean commonly found in Alaska and as such occupies areas in which the mammal fauna is dominated by pinnipeds. Although the foods utilized by belukha whales in some parts of their range have been described in detail (e.g., Vladykov 1946; Kleinenberg et al. 1964), the only significant recent information on foods utilized in Alaskan waters is from studies in inner Bristol Bay (summarized in Lensink 1961). As part of a comprehensive investigation of the trophic relationships of marine mammals in the Bering, Chukchi, and Beaufort seas, we have obtained and examined samples of the stomach contents of belukha whales taken by Eskimo subsistence hunters. In addition, we have obtained some specimens from animals killed in fishing nets or dead from natural causes.

An understanding of the trophic relationships of this species is important for at least two reasons. First, major developments such as oil and gas exploration will soon occur in coastal and offshore waters of Alaska. Such development is presently underway in the Mackenzie River delta in Canada, an important part of the belukha whale's range. If potential effects of such development are to be fully assessed, an understanding of the food web of which belukhas are a part must be achieved. Second, management of marine mammals based on ecosystem concepts is mandated by the Marine Mammal Protection Act of 1972. Carrying capacity, defined as the maximum number of animals of a given species which the environment can support, is one such concept. Since major food resources are always shared by more than one consumer, carrying capacity in terms of food is not a single species parameter, but rather is related to the characteristics of all species which share the resource base. In order to understand the complex and dynamic nature of carrying capacity, the types of foods utilized by major consumers must be documented.

The results of our analysis of belukha whale stomach contents have been reported in part elsewhere (Lowry et al. 1981a, b; Seaman et al. 1982). In this report we present the results of all specimens examined from the initiation of this study in 1977 through the summer of 1982.

METHODS AND MATERIALS

Most belukha stomachs were obtained from whales taken in Eskimo subsistence harvests at various sites in the northern Bering and Chukchi seas from 1977 through 1981. One stomach was obtained from an animal that was accidentally caught in a fishing net and two were from animals found dead on or near shore. Sex was determined for each animal sampled by examination of the genital slit. Age determinations were based on counts of dentinal growth layers in thin longitudinal sections of mandibular teeth (Burns and Seaman 1985).

Stomachs were collected whole or slit longitudinally and the contents removed. In some instances when stomachs contained small amounts of a single type of prey, the contents were examined and quantified in the field. In all other stomachs the contents were preserved in a 10% buffered formalin solution for later analysis. Stomachs of animals taken in Eschscholtz Bay in 1982 were very full, and we collected only subsamples that ranged in volume from 10 to about 900 ml. Although formalin can degrade otoliths, we do not think that was an important factor in this study since we regularly recovered small otoliths with surface features intact.

In the laboratory, stomach contents were gently washed on a 1.0-mm mesh sieve. Components of the stomach contents were identified using appropriate keys and reference specimens and sorted to the lowest possible taxonomic level. The water displacement volume of each invertebrate taxon and of all fish material combined was determined. The number of fishes of each taxon consumed was estimated based on identification and counts of characteristic hard parts, particularly otoliths. For major prey species, a sample of otoliths that did not appear degraded was measured from each stomach (maximum length to 0.1 mm). The lower crest length of octopus beaks was measured (Clarke 1962) to the nearest 0.1 mm. These measurements were used to estimate lengths and weights of fishes and weights of octopus consumed using relationships determined from intact fishes and octopus collected in the Bering and Chukchi seas (Table 1).

We present our findings in three ways: (1) the percent of the total volume of stomach contents which was composed of a particular type of item (percent volume) was used for invertebrate taxa and all fish material in aggregate; (2) the percent of the total number of identified fishes represented by each taxon (percent number) for fish taxa; (3) the percent of all stomachs in a sample which contained each particular item (percent frequency) for all items.

RESULTS

Stomachs from a total of 242 whales were examined, of which 141 contained food remains. Three were from whales found dead in northeastern Bristol Bay, three were from whales taken at Elim in Norton Sound, and the remainder were from four locations along the Chukchi Sea coast (Figure 1). Samples were collected during the months of April-July.

A minimum of 18 species of invertebrates and 13 species of fishes were identified from the stomach contents (Table 2). The greatest variety of prey (minimum of 19 species) was found at Eschscholtz Bay, the area from which the largest number of stomachs was collected.

The volume of contents in stomachs we examined ranged from a few milliliters to over 5 liters. The great majority of stomachs contained less than 500 ml of food, usually consisting of bones and otoliths from fishes, beaks from cephalopods, carapaces from crustaceans, and inorganic material, particularly pebbles and sand.

The stomach of the belukha caught in a salmon net in Kvichak Bay in May 1980 contained remains of 70 rainbow smelt (490 ml), 2 flatfish (77 ml), and 10 shrimp (13 ml). On 29 June 1982 we found a subadult

Table 1. Regression equations used to estimate sizes of prey consumed by belukha whales (from Frost and Lowry 1981a and unpublished).

Prey Item	Otolith length range (mm)	Regression Equation
Eleginus gracilis (saffron cod)	≤ 8.5	fish length (cm) = 1.740 (otolith length (mm)) - 0.090
	≥ 8.5	fish length = 2.323 (otolith length) - 4.839
	--	fish weight (gms) = 0.0050 (fish length (cm))$^{3.095}$
Family Cottidae (sculpins)	all	fish length = 4.009 (otolith length) - 4.364
	--	fish weight = 0.0088 (fish length)$^{3.038}$
Oncorhynchus[1] *nerka* (red salmon)	all	fish length = 8.635 (otolith length) + 17.723
	--	fish weight = 0.00046 (fish length)$^{3.776}$
Octopus sp.	--	octopus weight (gms) = 0.0281 (lower crest length (mm))$^{3.389}$

[1] equations are preliminary based on measurements from 8 fishes

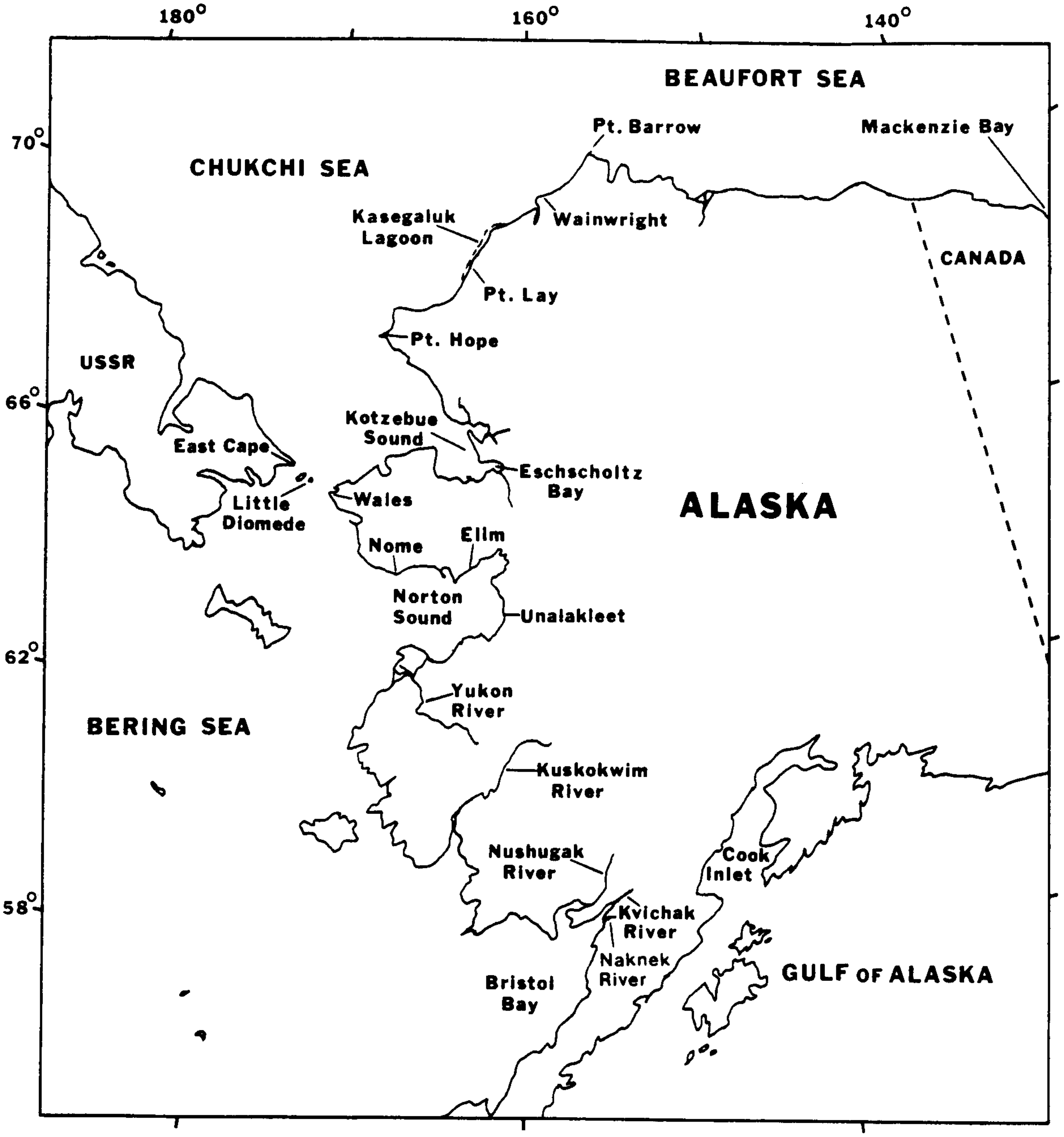

Figure 1. Map of Alaska showing major locations referred to in the text.

Table 2. Prey species identified from stomachs of belukha whales taken at 5 locations in western Alaska. Sample sizes indicated include only stomachs containing food remains.

TAXON	northeastern Bristol Bay May-July n=3	Elim June n=3	Eschscholtz Bay June n=113	Point Hope April-May n=18	Wainwright July n=3	Barrow May n=1
CEPHALOPODS						
Family Gonatidae (squid)				X	X	
Octopus sp.			X	X	X	
SNAILS						
Margarites sp.				X		
Polinices sp.			X		X	
CLAMS (unidentified)			X			
MYSIDS						
Mysis sp.			X			
Neomysis sp.			X			
AMPHIPODS						
Gammarus sp.			X			
SHRIMPS						
Argis sp.				X		
Crangon sp.				X		
Crangon septemspinosa	X		X			
Eualus sp.				X		
HERMIT CRABS						
Pagurus trigonochierus				X		
ISOPODS						
Saduria entomon			X		X	
Saduria sabini			X			
ECHIUROID WORMS						
Echiurus echiurus				X		
POLYCHAETE WORMS (unidentified)			X			
TUNICATES (unidentified)			X			
FISHES						
Boreogadus saida (arctic cod)			X	X		X
Catostomus catostomus (sucker)			X			
Clupea harengus (Pacific herring)		X				X
Coregonus sp. (whitefish)			X			
Eleginus gracilis (saffron cod)		X	X		X	
Family Cottidae (sculpins)	X	X	X			
Lycodes sp. (eelpout)			X			
Hypomesus olidus (pond smelt)	X					
Osmerus mordax (rainbow smelt)	X		X		X	
Family Pleuronectidae (flatfish)	X					
Pungitius pungitius (stickleback)						X
Oncorhynchus nerka (sockeye salmon)	X					
Salvelinus malma (arctic char)			X			
PEBBLES		X	X	X		

male belukha floating in the Snake River (Nushagak Bay) approximately 3 km upstream from the river mouth. The animal was freshly dead and was spewing remains of red salmon. In the stomach were remains of four salmon; based on sizes of otoliths, two of the fishes were 54.9 and 73.8 cm long and weighed approximately 1,715 and 5,240 g. On 1 July 1982 we located another subadult male belukha which had obviously been dead for several days. The carcass was above the high tide line about 10 km upstream from the mouth of the Snake River. In its stomach were a few fragments of a shrimp and otoliths from 68 rainbow smelt, 2 pond smelt, 7 sculpins, and 1 flatfish.

The stomach contents of three belukhas taken at Elim on 12 June 1977 were similar to one another and consisted of a combined total of 887 ml of partially digested fish and 381 ml of pebbles, mostly 2 cm or less in diameter. Fishes eaten by the three whales included at least 3,900 saffron cod, 55 sculpins, and 5 herring. Saffron cod eaten averaged 16.5 cm long (range 6.5-29.1 cm) and 40.0 g in weight (range 1.6-168.4 g); sculpins averaged 35.6 cm (range 22.9-51.0 cm) and 524.6 g (range 119.6-1,362.2 g).

We examined the stomach contents of 65 belukhas taken in Eschscholtz Bay in June 1978 (Table 3). Stomachs from three animals were empty; the remainder contained bones and otoliths of fishes, primarily saffron cod and sculpins, and small amounts of shrimp, isopods, snails, polychaetes, and octopus. Saffron cod eaten averaged 12.4 cm long (range 5.0-30.2 cm) and 17.7 g (range 0.7-188.9 g); sculpins averaged 22.5 cm (range 10.5-28.9 cm) and 131.7 g (range 11.2-242.5 g). In 1979 we examined the stomach contents of three whales taken between 16 and 23 June. Two were taken in Eschscholtz Bay and contained numerous saffron cod otoliths and traces of shrimp and snails. The third, taken near the village of Buckland (about 38 km up the Buckland River from Eschscholtz Bay), contained 5,810 ml of partially digested fish, most of which was the remains of 11 arctic char up to 50 cm long. Otoliths and bones representing 7 whitefish, 5 suckers, 50 sculpins, 22 smelt, and 1 arctic cod were also present. In June 1980 we examined the stomachs of 53 belukhas, 28 of which contained food remains. Food items identified were generally similar to previous years (Table 3). In comparison with 1978, whales taken in 1980 ate invertebrates, sculpins, and rocks less frequently and had eaten more rainbow smelt. In 1981 the stomachs of 11 whales taken on 15 June were examined. All of those stomachs were empty. In 1982, subsamples of stomach contents were collected from a sample of 20 whales. The animals had been actively feeding prior to being hunted and were observed feeding in the Bay again on the day after the hunt (Burns, field notes). Based on frequency of occurrence in the subsamples (Table 3) foods eaten were very similar to those found in previous years.

At Point Hope we examined the stomachs of 35 whales taken 22-27 May 1977 and 15 whales taken 25-26 April 1978. In 1977 30 stomachs were empty, and in 1978 six stomachs were empty. Stomachs of the whales taken in April 1978 contained mostly crangonid shrimp (Table 4). One stomach contained otoliths from 43 arctic cod. A total of 34 octopus beaks was found with a maximum of 15 in a single stomach. The animals examined in May 1977 contained almost exclusively octopus beaks and small pebbles.

Table 3. Stomach contents of belukha whales collected in Eschscholtz Bay.

Prey Item	13-18 June 1978, n=62			16-24 June 1980, n=28			22-23 June 1982 n=20
	Percent Volume	Percent Number	Percent Frequency	Percent Volume	Percent Number	Percent Frequency	Percent Frequency
Shrimp	4	--	76	3	--	50	90
Isopod	6	--	34	1	--	14	35
Octopus	<1	--	52	<1	--	14	5
Other Invertebrate	<1	--	41	<1	--	29	40
TOTAL INVERTEBRATE	11	--	90	5	--	82	95
Rocks and Pebbles	1	--	66	<1	--	4	5
TOTAL FISHES	87	--	94	95	--	96	100
Saffron Cod	--	88	94	--	90	86	100
Sculpins	--	11	42	--	2	25	10
Rainbow Smelt	--	<1	29	--	7	39	55
Pacific Herring	--	<1	3	--	1	7	5
Eelpout	--	<1	2	--	--	--	--
Mean Volume of Contents (ml)	47.2			81.1			410.7[1]
Total Number Identified Fishes	4,346			434			1,250

[1]mean volume of subsamples

Table 4. Stomach contents of belukha whales collected at Point Hope.

Prey Item	22-27 May 1977, n=5			25-26 April 1978, n=9		
	Percent Volume	Percent Number	Percent Frequency	Percent Volume	Percent Number	Percent Frequency
Shrimp	<1	--	20	99	--	67
Squid	0	--	0	<1	--	11
Octopus	75	--	100	<1	--	78
Other Invertebrate	<1	--	60	<1	--	11
TOTAL INVERTEBRATE	75	--	100	100	--	100
Rocks and Pebbles	25	--	40	<1	--	22
TOTAL FISHES	0	--	0	<1	--	11
Arctic Cod	--	0	0	--	100	11
Mean Volume of Contents (ml)	53.3				48.4	
Total Number Identified Fishes	0				43	

A total of 823 beaks was found with a maximum of 625 in a single stomach. Thirteen additional whales taken at Point Hope in 1979 and 1980 were examined. Stomachs of two of six taken on 6 and 8 May 1979 contained food in the stomach; one containing otoliths from three arctic cod; the other, one octopus beak, one saffron cod otolith, and two small unidentifiable fishes. Two of seven taken on 19 May 1980 contained traces of food; one had only beaks of two octopus, the other had beaks from seven octopus and fragments of a shrimp, the operculum from a snail, and a small pebble.

Three of 20 belukhas we examined at Wainwright contained food. One taken 22 July 1976 contained beaks from three octopus and four gonatid squids (probably Gonatopsis borealis). Two whales taken on 18 July 1979 contained 12 partially digested rainbow smelt, otoliths from two saffron cod, and trace amounts of snails and isopods.

The stomach of a belukha taken 17 May 1979 at Barrow contained one intact nine-spined stickleback (3.2 cm long), two intact herring (6-7 cm long), and otoliths from two arctic cod.

The large sample of belukha stomachs collected from Eschscholtz Bay in 1978 was examined for age- and sex-related differences in foods. The components of the stomach contents of young and older whales were very similar (Table 5). The range in size of saffron cod eaten was also similar (Figure 2). However, only 8.6% (9/104) of the saffron cod eaten by young animals were over 15 cm in length while 27.0% (115/426) of the saffron cod eaten by older animals were longer than 15 cm. This difference is highly significant ($\chi^2 = 10.749$, $P < 0.01$).

The composition of the stomach contents of male and female belukhas was slightly different (Table 6). Shrimp accounted for a greater proportion of the contents and occurred more frequently in females than in males; the opposite was true for isopods. The most obvious difference occurred in the consumption of sculpins which were eaten by 4 of 28 females and 21 of 29 males, a highly significant difference ($\chi^2 = 8.012$, $P < 0.01$).

DISCUSSION

Biases in Stomach Content Analysis

Over 100 kinds of organisms have been identified in the diet of belukha whales (Kleinenberg et al. 1964). We found several general types of prey in the belukha stomachs we examined, including benthic invertebrates (crustaceans, worms, molluscs, and tunicates), nektonic invertebrates (squids), pelagic and semidemersal fishes (arctic cod, saffron cod, herring, whitefish, smelt, char), and demersal fishes (sculpins, suckers, and eelpout). With the exception of octopus, many of the benthic invertebrates found in the belukha stomachs may have been released from the stomachs of fishes consumed and digested by the whales. Both saffron cod and sculpins commonly feed on benthic invertebrates (Andriyashev 1954). We examined the stomachs of 79 saffron cod caught in Kotzebue Sound in March 1978 and found that they had eaten mostly polychaetes, shrimps, amphipods, and mysids. Forty sculpins (Myoxocephalus spp.) caught in the northern Bering Sea and Norton Sound

Table 5. Stomach contents of belukha whales collected in Eschscholtz Bay, June 1978, separated by age categories.

	less than 6 years old, n=9			6 or more years old, n=47		
Prey Item	Percent Volume	Percent Number	Percent Frequency	Percent Volume	Percent Number	Percent Frequency
Shrimp	15	--	78	5	--	77
Isopod	7	--	22	7	--	38
Octopus	3	--	56	<1	--	47
Other Invertebrate	<1	--	44	<1	--	30
TOTAL INVERTEBRATE	25	--	100	12	--	89
Rocks and Pebbles	2	--	67	1	--	68
TOTAL FISHES	72	--	100	86	--	94
Saffron Cod	--	92	100	--	89	94
Sculpins	--	7	44	--	10	40
Rainbow Smelt	--	<1	33	--	<1	32
Pacific Herring	--	0	0	--	<1	4
Eelpout	--	0	0	--	<1	2

	less than 6 years old, n=9	6 or more years old, n=47
Mean Volume of Contents (ml)	9.9	44.3
Total Number Identified Fishes	571	3,562

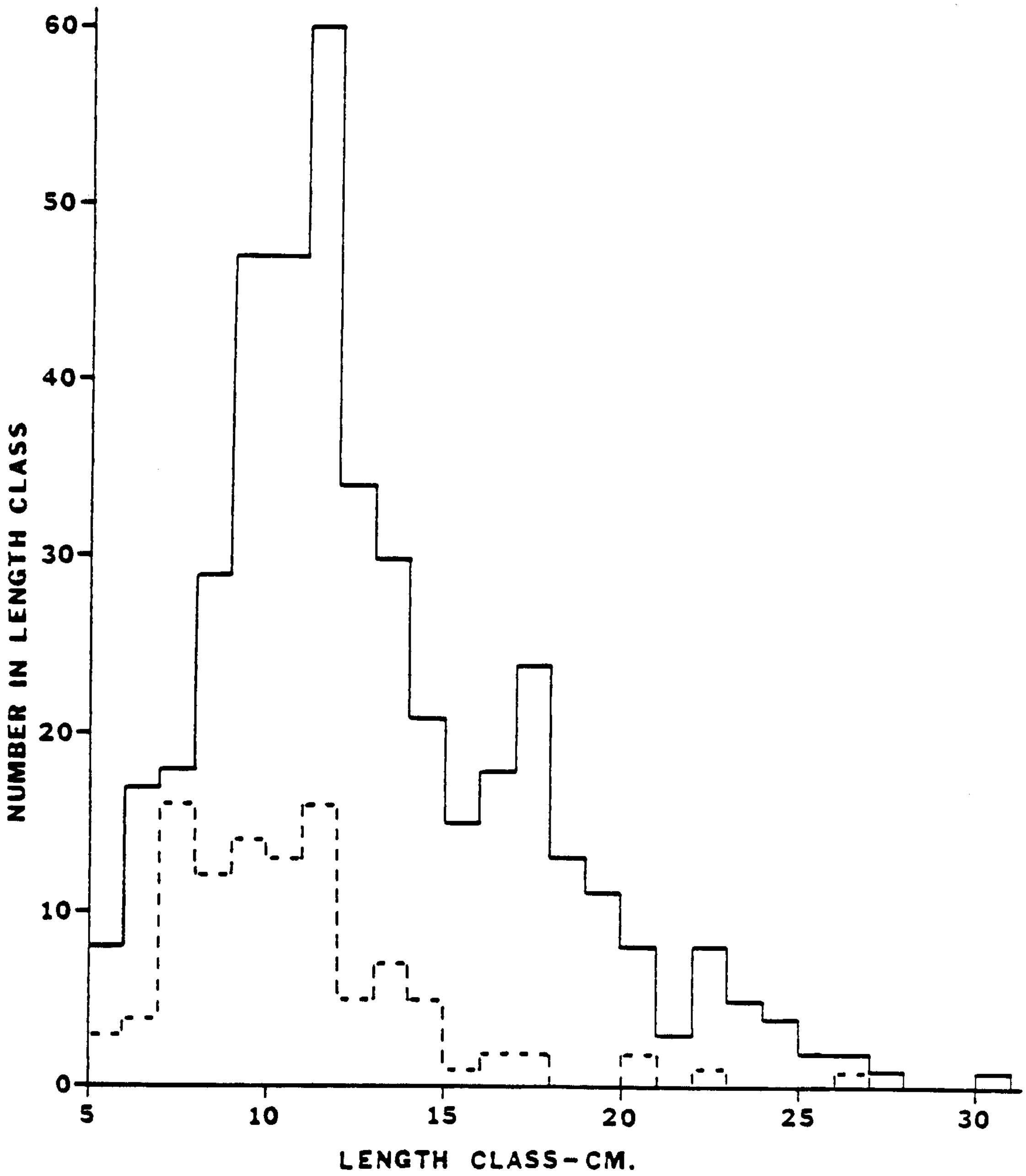

Figure 2. Length distribution of saffron cod eaten by belukha whales based on measurements of otoliths in stomachs. Dotted lines represent fishes eaten by whales five years old and younger; solid lines represent fishes eaten by older whales.

Table 6. Stomach contents of belukha whales collected in Eschscholtz Bay, June 1978, separated by sex.

	Females, n=28			Males, n=29		
Prey Item	Percent Volume	Percent Number	Percent Frequency	Percent Volume	Percent Number	Percent Frequency
Shrimp	11	--	82	2	--	72
Isopod	2	--	25	8	--	48
Octopus	<1	--	64	<1	--	34
Other Invertebrate	<1	--	21	<1	--	38
TOTAL INVERTEBRATE	14	--	93	10	--	86
Rocks and Pebbles	<1	--	64	1	--	69
TOTAL FISHES	85	--	89	88	--	97
Saffron Cod	--	98	89	--	82	97
Sculpins	--	<1	14	--	17	72
Rainbow Smelt	--	2	39	--	<1	24
Eelpout	--	<1	4	--	0	0

	Females	Males
Mean Volume of Contents (ml)	24.8	73.0
Total Number Identified Fishes	1,648	2,588

in October 1976 had eaten shrimps, amphipods, crabs, and fishes (Frost, unpublished). In belukhas taken in Eschscholtz Bay, snails, clams, amphipods, mysids, tunicates, and polychaetes were found only in stomachs which also contained fishes. Of 27 stomachs containing isopods 20 also contained sculpins. Kleinenberg et al. (1964) found a similar situation in the White Sea where certain benthic invertebrates were present only in belukha stomachs which contained flatfish. At Point Hope three of the whales examined in 1978 contained over 100 ml of shrimp and no fresh fish remains. We conclude that although many of the invertebrates we found were secondary prey, octopus, shrimps, and sometimes isopods are directly consumed by belukhas. Hay and McClung (1976) found a young belukha in Cumberland Sound with a stomach full of amphipods and seaweed.

Since most of the stomachs we examined contained little or no freshly ingested food, our measures of volume of food items in the stomachs are probably biased in several ways and may be of little value in determining the actual importance of the various prey. For fishes, we were able to determine the number of each species (or taxon) consumed during recent meals based on characteristic hard parts. This measure may be biased if parts of different fish species persist in the stomach for different lengths of time. However, we know of no data to indicate that such is the case, therefore we consider that our counts of fish parts reflect recent consumption. Miller (1978) noted that fur seals (Callorhinus ursinus) accumulate and later regurgitate squid beaks and Pitcher (1980) presents data which suggest that the same may occur in harbor seals (Phoca vitulina richardsi). Octopus flesh was not found in any of the belukhas we examined suggesting that they had been eaten some time before the whales were killed.

We found no evidence to suggest that stomach contents were regurgitated by belukhas during the course of their being pursued and killed. One pod of more than 200 whales was slowly driven for over two hours in Eschscholtz Bay. When a suitable location was reached, 45 of them were killed, of which 43 contained food in the same state of digestion. One belukha in the Buckland River was chased for several hours and when killed contained the largest volume of contents we encountered. However, our data from Eschscholtz Bay in 1981 suggest a limit on the persistence of food remains in the stomach. The whales were driven for about 3.2 hours before being killed and all 11 examined had empty stomachs. This indicates that either they had not fed prior to entering the Bay or all food remains were cleared from the stomachs during the drive.

Feeding During Spring Migration

Arctic cod, the most abundant semidemersal fish in northern ice-covered waters (Blacker 1968), was the fish species we found eaten in greatest numbers by belukhas taken in the spring. However, the presence of otoliths from 48 arctic cod in 19 belukha stomachs containing food indicates that arctic cod were not abundantly available or the whales chose not to feed intensively on them.

Shrimps were eaten in small but perhaps significant quantities by whales taken at Point Hope in April. Johnson et al. (1966) examined stomachs from two belukhas taken in May 1961 at Point Hope which contained arctic cod and shrimp of at least three species. We found shrimp in only trace amounts in two of nine belukhas taken at Point Hope in May. Shrimps, particularly the family Crangonidae, are widely distributed and quite abundant in arctic waters (Squires 1969; Lowry and Frost, unpublished).

Octopus beaks were more prevalent in belukha stomachs from Point Hope than elsewhere, occurring in 15 of the 18 stomachs examined. Although the beaks may persist in the stomachs for some time, the prevalence of beaks in the whales strongly indicates an abundance of octopus in the vicinity of Point Hope, although perhaps some distance to the south. The maximum number of beaks in a single whale was 625. Based on measurements of lower crest length, the mean weight of the octopus consumed by that belukha was 205 g; therefore, approximately 128 kg of octopus was consumed, enough to supply the food intake requirements of a belukha weighing 700 kg for four days. We conclude that octopus are a potentially significant food of belukhas during the spring migration.

The percentage of empty stomachs during the spring migration was high. Overall, at Point Hope 45 of 63 stomachs we examined were empty. At the same time of year nearly all stomachs of belukhas taken at Wainwright and Barrow are usually empty (R. Tremaine, personal communication). At Point Hope a much higher proportion of stomachs was empty in 1977 than in 1978. The difference is not significant ($\chi^2 = 2.016$ $P > 0.10$) but nonetheless suggests a difference in conditions which affect feeding. In 1977 most of the whales were taken during periods with unobstructed leads south of Point Hope which allowed belukhas to move steadily northward. Stomach contents of those whales were dominated by octopus beaks which may represent prey eaten several days earlier. In 1978 all the belukhas were taken in 12 hours immediately following the formation of a nearshore lead which had previously been kept closed by southerly winds. Numerous belukhas were seen in openings in the ice southeast of Point Hope. Whales taken immediately following the opening of the lead contained small amounts of recently eaten prey, largely crangonid shrimp. It appears that belukhas sometimes feed during their spring migration when their northward movement is prevented by ice.

Summer Feeding in Coastal Areas

Fishes were the dominant item in the stomachs of belukhas taken in coastal waters during summer. In the northern Bering and southern Chukchi seas, saffron cod were by far the most commonly eaten species, occurring in 104 of 113 belukhas taken at Eschscholtz Bay and in all three belukhas taken at Elim. Sculpins were eaten less commonly, occurring in 37 of the whales from Eschscholtz Bay and in two of the whales from Elim. The total quantity of sculpins and saffron cod represented by otoliths in belukha stomachs from Elim in 1977 and Eschscholtz Bay in 1978 was calculated (Table 7). The estimated amount consumed was about 28 times larger at Elim due to the greater number of otoliths in the stomachs and the larger individual size of fishes consumed. The differences in numbers of otoliths found in belukhas from the two areas may be the result of differences in location of feeding,

Table 7. Estimated quantities of fishes consumed by an average belukha whale taken near Elim (June 1977) and in Eschscholtz Bay (June 1978).

Location	Saffron Cod			Sculpins			Total
	Mean Number Consumed	Mean Weight (g)	Estimated Amount Consumed (kg)	Mean Number Consumed	Mean Weight (g)	Estimated Amount Consumed (kg)	Estimated Amount Consumed (kg)
Elim	1,300	40.0	52.0	18	524.6	9.4	61.4
Eschscholtz Bay	63	17.7	1.1	8	131.7	1.1	2.2

time when killed, and feeding conditions. The hunters from Elim said the belukhas were actively feeding when first sighted, as further indicated by the presence of several intact fish in the stomachs. The belukhas were moving westward away from Norton Bay. In most instances, belukhas taken in Eschscholtz Bay had probably eaten in Kotzebue Sound before entering the bay, though in 1982 they were feeding in the bay as indicated by the larger than usual quantities of food in their stomachs. In June belukhas enter Eschscholtz Bay on the rising tide and are normally intercepted and hunted within about one to two hours after entering. It is also noteworthy that because of their much larger size, sculpins are more important in the diet than is indicated by the relative numbers consumed (Table 7).

All our samples from Kotzebue Sound were obtained in June from Eschscholtz Bay. Curtis (1930) found that saffron cod was the most common item in belukhas taken in northern Kotzebue Sound near Sheshalik mostly in late June. Hunters from Kotzebue who have hunted many years near Sheshalik informed us that saffron cod were common in belukha stomachs and that shrimp and salmon were occasionally found. Belukha hunting at that locale usually ended before salmon arrived. Belukhas sometimes return to Eschscholtz Bay after the June-early July hunt and are occasionally seen in large numbers (Seaman, unpublished). They may feed on salmon in late July and August. Hunters in Eschscholtz Bay report that saffron cod, sculpins, and herring are common items in belukha stomachs. Herring normally appear in mid-June to July, generally after the hunts from which we obtained samples in 1978-82. Smelt appear in Eschscholtz Bay and the Buckland River in greatest numbers in May and early June.

The feeding of belukha whales inhabiting Bristol Bay in spring and summer was studied by Brooks (1954-1956) and summarized by Klinkhart (1966). Brooks (1954) and Lensink (1961) found a close relationship between prey abundance and belukha distribution and movements. Belukhas are present in Kvichak and Nushagak bays in large numbers in May through August. They are attracted to these rivers in early May by large concentrations of outmigrating smelt. As soon as ice cover on the rivers breaks up, belukhas frequently move upstream on flooding tides, apparently in pursuit of smelt. At the end of May whales shift from eating smelt to sockeye salmon fingerlings, which continue to be the predominant food items until about mid-June. In mid-June adult salmon become the primary prey. The frequency of occurrence of different species of salmon is directly correlated to their abundance; sockeye salmon predominating in stomachs in the first three weeks of July and other salmon species in late July and August (Brooks 1955). In addition to salmon and smelt, flounder, sole, sculpin, blenny, lamprey, two types of shrimp, and mussels were also reported in the stomachs examined. The three belukha stomachs we examined generally agree with the pattern described by Brooks.

Nelson (1887) reported on feeding of belukhas along the Yukon-Kuskokwim Delta. Near Saint Michael (southern Norton Sound), the first belukhas seen in spring arrived 5-10 June, coinciding with the arrival of spawning herring which they followed into bays and inlets. These observations are in agreement with those of Giddings (1967) who frequently saw belukhas near Cape Denbigh (northeastern Norton Sound) following schools of herring in June. Also, the people of Stebbins, Unalakleet, and Shaktoolik reported that they frequently see belukhas following schools of herring into Norton Bay. While surveying herring schools, Barton (personal communication) saw numerous belukhas associated with herring concentrations on 30 May 1978 near Golovnin Bay (northern Norton Sound), and somewhat later near Nome.

Nelson (1887) found that belukhas fed heavily on saffron cod in the mouths of many tidal creeks between Saint Michael and the Kuskokwim River. He found the mouths of these tidal creeks to abound in saffron cod between midsummer and freezeup. Whales actively fed on saffron cod throughout this period, ascending rivers after darkness and returning by daylight. We observed numerous belukhas in association with schools of saffron cod near Golovnin Bay in late September 1981. Informants from several villages in Norton Sound have reported salmon in belukha stomachs in July and early August. Fishermen from Elim who annually fish near the northern Yukon Delta frequently see belukhas near the mouths of this river while salmon are present. One fisherman reported taking belukhas with recently ingested chum salmon (*Oncorhynchus keta*) in their stomachs. It appears that salmon are important to belukhas when available, but that saffron cod are probably of greater importance because they are available and abundant over a longer period of time.

Large numbers of belukhas utilize the coastal and lagoon waters adjacent to Kasegaluk Lagoon (northern Chukchi Sea) from late June to August. No stomachs have been examined from whales in this region but observations of fish abundance, belukha behavior and movements, and past examination of stomach contents by hunters suggests some species which may be important food items. Fish frequently caught by subsistence fishermen in this area in June, July, and August include sculpins, arctic char, smelt, saffron cod, whitefish, and capelin (*Mallotus villosus*). In addition, salmon are caught in July and August. Certain regions of Kasegaluk Lagoon such as Utukok and Akoliakatat Passes are known for better fishing. Large concentrations of spotted seals (*Phoca largha*) are found in July and August in those areas.

The hunters of Point Lay believe that belukhas come to the Kasegaluk Lagoon area to feed. According to hunters, the stomachs from whales arriving in the area in late June or early July frequently contain shrimp, octopus or squid, and small fish. The first belukhas discovered and killed in the lagoon have usually eaten fish; at least sculpins, smelt, and char. The hunters reported that contents were highly digested and difficult to identify. Stomachs of whales taken from large localized concentrations in the passes of the lagoon were usually empty or contained digested fish remains.

On 10 July 1979 one of us (G. Seaman) observed several hundred belukhas for a period of six hours. The whales followed the coast within 50 m of shore, near Point Lay. They characteristically surfaced two to four times, then dove and remained submerged for 30 to 180 seconds. Occasionally a whale would remain near the observation site for five minutes making several dives and then continuing northward. On 9 and 10 July large schools of capelin were observed near the beach and occasionally washed up on shore. It appeared that belukhas were following and feeding on capelin. The residents of Point Lay said capelin occur off Kasegaluk Lagoon in very large numbers for a short period in mid-July of most years. Capelin are probably very important to belukhas during periods when they are present in the area, but they do not occur every year. A similar condition of occasional importance of capelin to belukhas was observed by Vladykov (1946) in the Saint Lawrence estuary, Doan and Douglas (1953) in Hudson Bay, and Kleinenberg et al. (1964) in Soviet waters.

After belukhas leave Kasegaluk Lagoon they often move northward along the coast and pass Wainwright. Our samples indicate that rainbow smelt may be a major food near there. Capelin also spawn on the beaches near Wainwright. We have received specimens collected on the beach in front of the village on 16 July 1978 (Lowry and Frost, unpublished).

Sex- and Age-related Differences in Foods

Our collections from Eschscholtz Bay give strong evidence of a difference in the selection of food by belukhas of different ages and sexes. Sexual dimorphism occurs in belukhas with females substantially smaller than males of the same age (Sergeant and Brodie 1969). Although the components of the food found in younger and older whales of both sexes were similar, older belukhas had eaten significantly larger saffron cod and males had eaten significantly more sculpins which were of a much larger size than saffron cod. This suggests that the smaller whales prefer smaller fish and the larger belukhas select for larger fish. Vladykov (1946) found the same to be true in the Gulf of Saint Lawrence where young belukhas and females ate small fish and shrimp, and adult males, in addition to the smaller prey, had eaten large cods (*Gadus* spp.) which were rarely eaten by small belukhas and females. Kleinenberg et al. (1964) showed a similar preference for prey by belukhas of different size and sex classes in waters of the Soviet Union.

Autumn and Winter Foods

Although no stomach samples are available from belukha whales in autumn and winter, their probable foods can be inferred from distribution and abundance of potential prey. Pollock (*Theragra chalcogramma*) is the most abundant species of finfish in the vicinity of the ice front (Pereyra et al. 1976) and is probably a major belukha food in this area. Based on the stomach contents of ringed seals (*Phoca hispida*), arctic and saffron cods are by far the most abundant forage fishes in the northern Bering Sea in autumn and winter (Lowry et al. 1980). Arctic cod are the most important single item in the winter diet of belukhas over much of their range, and thus the winter movements of belukhas are closely tied to the distribution of arctic cod (Lønø and Øynes 1961; Kleinenberg et al 1964; Tarasevich 1974). Saffron cod may also be an important autumn and winter food of belukhas in some portions of the Bering Sea. Residents of Gambell note that belukhas are frequently seen along the western and southern shores of Saint Lawrence Island where prevailing northeasterly winds keep the coast free of ice throughout most of the winter. The presence of belukhas in this area in winter is closely linked to abundance of saffron cod along the shores.

In addition to pollock and arctic cod, many other species of demersal, semidemersal, and pelagic fishes occur in the Bering Sea in autumn and winter and are certainly eaten at times by belukhas. Spawning smelt are abundant in some coastal areas in autumn. Shrimps and octopus may be eaten in quantities in some areas. However, based on observations of belukha foods in other areas and seasons, and the winter distribution and abundance of potential prey, we speculate that in the Bering Sea the bulk of their autumn and winter diet is composed of arctic and saffron cods in northern areas and pollock in southeastern and southcentral regions.

Trophic Interactions

Belukha whales are large and may be locally very abundant. Their foraging activities might therefore be expected to affect stocks of fishes on which they feed. Brooks (1955) estimated the number of adult salmon consumed by belukhas in Kvichak Bay as approximately 196,000 in 1954 and 99,000 in 1955. He also estimated that about three million red salmon smolt were eaten each season. This predation was considered significant in light of the depleted red salmon stocks. Frost et al. (1984) estimated that in 1983, belukhas in the Kvichak River consumed about six million red salmon smolt and 283,000 adult salmon (182,000 red salmon and 101,000 other species). This consumption amounted to about 5% of the average annual smolt outmigration, 1% of the commercial catch of adult red salmon, and 9% of the commercial catch of other salmon species.

The species of prey consumed by belukha whales are also major foods of other species of cetaceans and pinnipeds in the Bering and Chukchi seas (Johnson et al. 1966; Frost and Lowry 1981b; Lowry and Frost 1981). Gadid fishes (arctic and saffron cods and pollock), herring, capelin, and smelt are of particular importance in the diet of at least six species of pinnipeds and four species of cetaceans. Sculpins, shrimps, and octopus are of secondary importance in the diet of both seals and belukhas. Saffron cod and sculpins eaten by belukhas are generally larger than those eaten by seals (Lowry and Frost, unpublished), while arctic cod, capelin, smelt, and herring consumed by belukhas and seals are probably of similar size classes. Potential competition for food may be particularly great between belukhas and spotted seals since the distribution and food habits of these species overlap broadly throughout much of the year (Lowry and Frost 1981 and unpublished). The number of fish-eating pinnipeds in the Bering and Chukchi seas is difficult to estimate at present, but certainly exceeds two million. Given the broad dietary overlap with pinnipeds and the relatively much smaller population of belukha whales, limitation of the belukha population through competition for food appears to be a possibility. If so, the carrying capacity of the Bering-Chukchi system for belukha whales (as expressed by population size and productivity) may be influenced by foraging activities and population sizes of other species of marine mammals. In addition, commercial fisheries, particularly for herring and salmon in coastal areas of the Bering and Chukchi seas and for groundfish in the southeastern and central Bering Sea, remove great quantities of some marine mammal forage fishes (e.g., Pruter 1976; Lowry et al. 1979). The combined effects of predation and commercial fishing on fish stocks and the possible resultant effects on marine mammal populations remain unclear at present. However, a significant potential exists for interactions between belukha whales and commercial fisheries (Lowry et al. 1984).

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BEHAVIORAL RESPONSES OF GRAY WHALES TO INDUSTRIAL NOISE: FEEDING OBSERVATIONS AND PREDICTIVE MODELING

by

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ABSTRACT

An investigation was made of the potential effects of underwater noise from petroleum industry activities on feeding gray whales. The investigation consisted of two components, a field study and an acoustic model study. The field study was performed near Southeast Cape, St. Lawrence Island in August, 1985, using a 100 cu. in. air gun source and playback of drillship noise. Sound source levels and acoustic propagation losses were measured to permit estimation of sound exposure levels at whale sighting positions. The surface-dive patterns and blow rates of whales were determined by observation of focal groups. A computer-aided analysis of whale sighting data was performed to determine swimming patterns under pre-exposure, exposure, and post-exposure conditions. For the air gun source there was a 0.5 probability that the whales would stop feeding and move away from the area when the average pulse levels reached 173 dB (re 1 μPa). The 0.1 probability of feeding interruption was estimated to occur at 163 dB, but whale responses were highly variable. Most whales returned and resumed feeding after the air gun vessel had moved on. Playback of drillship noise did not produce clear evidence of disturbance or avoidance behavior for levels below 110 dB. Possible avoidance occurred for exposure levels approaching 119 dB. Until more playback data are available, 120 dB is recommended as the level for which a 0.5 probability of avoidance might be expected for continuous industrial noise sources near feeding areas. These behavioral response levels were used as criteria in the sound propagation modeling part of the study to obtain range estimates for the zone of influence for a specific source. For a large air gun array with a peak source level of 250 dB (re 1 μPa at 1 m) operating in the Chirikof Basin, an average pulse pressure level of 173 dB would be produced at a range of 2.6 km. For the Explorer II drillship (source level =

165 dB), a received level of 120 dB would be produced at a range of 300 m. Near Unimak Pass, for sources operating in uniform water depths of 30 m, the large array would produce an average pulse pressure of 173 dB at a range of 2.8 km, and the drillship would produce a received level of 120 dB at 500 m. For sources located offshore in deeper water with sound propagation upslope to whale locations nearer shore, the resulting ranges are 3 km and 700 m for the array and drillship, respectively.

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Mr. Don Croll, field observer

Ms. Jo Guerrero, field observer, data analysis

Ms. Linda Guinee, field observer, data entry

Mr. Guy Oliver, field observer, project representative to St. Lawrence Island

Ms. Victoria Rowntree, field observer.

The air gun was leased from Western Geophysical and was operated using an air compressor leased from Price Compressor, Inc. The equipment was mounted on board NANCY-H owned and operated by Latitude 60°N Enterprises, Inc., and chartered by BBN. The observation and playback source vessel was the BIG VALLEY owned and operated by Mr. Ralph Botkin. The ship handling skills of Mr. Botkin and Mr. Wolfgang Mikat of the NANCY-H were greatly appreciated - especially during the gale that terminated the observation period.

Within BBN Laboratories staff, the sound transmission analysis and model development of Dr. Preston Smith, Jr., were a major contribution to the zone-of-influence predictions. The expertise of Mr. Rafal Mlawski in the installation, maintenance, and operation of the acoustic equipment on board the BIG VALLEY was essential to the project. Mr. Creighton Gogos of BBN and Mr. Mac Warren of Marine Specialty were essential for the installation and operation of the air gun system on the NANCY-H. Mr. Paul Miles was the key expediter in getting all of the equipment ordered, shipped, and coordinated so that the field work could begin on time. Ms. Judy Russo's work in processing all of these words in a timely and patient manner is greatly appreciated.

The project and report responsibilities of the authors were:

Mr. Charles I. Malme - Project Manager and Principal Investigator for Acoustics, Acoustic data analysis

Consultants to BBN Laboratories

Dr. Bernd Würsig - Principal Investigator for Whale Behavior, Dive-surfacing and blow rate analysis

Mr. James E. Bird - Observation data analysis

Mr. Peter Tyack - Sighting data and track analysis

1. SUMMARY

This report presents the results of an investigation of the potential effects of underwater noise from petroleum industry activities on the behavior of feeding gray whales (Eschrichtius robustus). The objectives of the study were to determine the character and degree of response of feeding gray whales to playbacks of industrial noise or actual seismic sound sources and to develop predictive models of the potential zones of influence of various types of industrial noise sources for important gray whale habitats such as Chirikof Basin and Unimak Pass. The noise sources used were playback of drillship sound and a single 100 cu. in. air gun. The work was performed in the Bering Sea near Southeast Cape, St. Lawrence Island, during August 17-28, 1985.

Experimental Procedure

The acoustic environment of the test area was measured by determining the propagation loss and ambient noise levels. The output source levels of the playback source and the air gun were calibrated. These measurements permitted calculation of the test stimulus level at sighted whale positions. Ambient noise in the test area was generally low and controlled by wind-generated sea noise. Sound transmission was found to be more efficient than is usual for shallow water areas with a sand/silt bottom because of the probable presence of a sub-bottom rock layer.

Whale behavior data were obtained by close observation of focal whale groups, recording surfacing-dive and blow information. In addition, tracking of the focal groups was performed using a two-vessel triangulation procedure or a land-based theodolite when weather permitted. The experimental procedure involved location of feeding whales, observation of behavior during a control period with the support vessels present,

observation of behavior during an experiment period with the sound stimulus on, and observation of behavior during a post-experiment control period. Generally, several of these sequences were performed each day.

Surfacing-Dive and Blow Rate Analysis

The four basic characteristics used to describe the surfacing-dive behavior of gray whales were (1) respiration or blow interval, (2) length of surfacing, (3) length of dive, and (4) number of blows per surfacing. Blow rate was calculated from these data. For drillship sounds, blow intervals decreased and length of surfacing, length of dive, and number of blows per surfacing increased. Blow rate changed little. Recovery back to a pre-disturbance level occurred in about 30 min. after the stimulus was turned off. For air gun sounds, the characteristics changed in a reverse order. Blow intervals were increased, but length of surfacing, length of dive, and number of blows per surfacing all decreased. Blow rate did not change significantly except for high exposure levels when it increased - usually accompanied by cessation of feeding and movement away from the air gun vessel. Recovery to "normal" levels after exposure was less rapid than that for drillship sounds, requiring about one hour.

Whale Movement Analysis

Because of visibility conditions and the distance of feeding areas from shore, it was not feasible to use land-based theodolite tracking procedures except for one day. A two-vessel tracking procedure using a theodolite and binocular-compass provided sighting data which were analyzed using a computer-implemented triangulation program to determine whale distances from the sound source. The absolute position of the test geometry was determined using Loran C.

Limited data obtained for drillship playback sequences did not show any consistent pattern of feeding disturbance or avoidance of the sound source for levels up to 110 dB re 1 μPa; however, some whales were observed to leave the test area during an experiment when levels reached about 119 dB. The behavioral response of feeding gray whales to air gun sound was highly varied. At high exposure levels up to 176 dB (average pulse pressure level), some whales would continue feeding while others would stop feeding and move away from the sound source area. One whale was observed to leave a feeding area for an exposure level of about 150 dB. Most whales returned and resumed feeding after the air gun vessel had moved on.

Sound Transmission Modeling

The results of the sound propagation modeling were used for prediction of zones of influence for air gun array, air gun, and drillship sounds in the Chirikof Basin and Unimak Pass areas. The modeling procedure used both analytic and semi-empirical techniques assisted by measured data and data obtained from the literature. The whale migration corridor near Unimak Island is in shallow water near shore so it was necessary for the model to predict upslope sound propagation characteristics as well as characteristics for sound propagation in water of constant depth.

Conclusions

The data base obtained from the field study will not support the detailed statistical analysis required to obtain behavioral measures highly quantitized in terms of noise exposure level. However, it is possible to assign at least two general response levels to the stimuli used in the study.

For the drillship stimulus we recommend that 110 dB be considered as the lowest level which may possibly cause disturbance of feeding activity. This was the level that was observed to cause an onset of avoidance behavior for migrating gray whales. Until more data are available, we recommend that 120 dB be considered as the level which will probably cause avoidance of a potential feeding area near an industrial site by more than 50% of the local gray whale population. A level of 119 dB resulted in a 0.5 probability of avoidance for the average of all the playback stimuli tested with migrating gray whales.

Because of the wide range of responses of feeding gray whales to air gun noise, we recommend that an average pulse pressure level of 163 dB be considered the level at which the disturbance of feeding activity is possible. We also recommend that 173 dB be considered the level at which cessation of feeding activity and temporary movement away from the feeding area are probable for at least 50% of the whales exposed.

By using the sound level criteria given above together with the sound propagation model, it is possible to predict zones of influence for specific source types. For an air gun array with a peak beam pressure level of 250 dB, an average pulse pressure level of 173 dB will occur at a range of 2.6 km in the Chirikof Basin and at 2.8 km offshore of Unimak Island. For the EXPLORER II drillship, a level of 120 dB will occur at a range of 300 m in the Chirikof Basin, and at a range of 500 m offshore of Unimak Island.

Recommendations

Augmentation of the available data is necessary to have a better statistical basis for establishing sound exposure criteria for feeding gray whales.

An extended field study should be performed early in the season when the whale population is larger and weather conditions better. The St. Lawrence Island site would be desirable for this study because of the available high ground for a theodolite station. Potentially, this would eliminate the need for a second large support vessel and reduce the cost for the project.

2. BACKGROUND

The work described in this report was performed by BBN Laboratories Incorporated under NOAA Contract No. 85-ABC-00141. The study was funded by the Minerals Management Service through an interagency agreement with NOAA, as part of the Outer Continental Shelf Environmental Assessment Program. The contract officer's technical representative was Mr. Laurie Jarvela at NOAA, National Ocean Service, OMA, OAD, Anchorage.

The work was performed under Permit No. 511 issued by the National Marine Fisheries Service.

Previous work, under MMS sponsorship, concerning the behavioral response of migrating gray whales to petroleum industry noise has been described in BBN Report No. 5366 (Malme, Miles, Clark, Tyack, and Bird, 1983) and BBN Report No. 5586 (Malme, Miles, Clark, Tyack, and Bird, 1984). Many of the experimental procedures used in this study have evolved from this previous work. The two-vessel tracking procedure employed in this study was developed for a related study of feeding humpback whales and described in BBN Laboratories Report No. 5851 (Malme, Miles, Tyack, Clark, and Bird, 1985).

The acoustic modeling procedure used for the zone-of-influence estimation has been developed in conjunction with several ongoing projects concerning marine environmental acoustics. The reports for these projects, now in preparation, will provide information and technical discussions related to the material covered here. These reports are BBN Laboratories Report No. 6185 (Beaufort Sea) (Miles, Malme, Shepard, Richardson, and Bird, 1986) and BBN Laboratories Report No. 6125 (Pacific Ocean near Central California) (Malme, Smith, and Miles, 1986).

The region near Southeast Cape, St. Lawrence Island, selected for the test site, was also used in a previous study of feeding gray whale behavior by one of the authors (Würsig, Wells, and Croll, 1983, 1986). Thus, many of its advantages as a good observation area for gray whales were known. It also had the advantage of providing shelter from rough weather without requiring a long transit and resulting in lost field time.

The experimental procedure for the behavioral study, data analysis methods, and the results are described in Sec. 3. Section 4 describes the acoustic transmission modeling procedure and the results of the zone-of-influence estimates. Conclusions and recommendations are presented in Sec. 5. An error analysis for the whale position tracking procedures is provided in Appendix A.

3. STUDY OF BEHAVIORAL RESPONSE DURING FEEDING ACTIVITY

3.1 Field Environment and Observation Chronology

In this section we discuss the considerations that determined our selection of the test site. We also present a summary and chronology of observations, including viewing conditions, during the 17-26 August 1985 field season near Southeast Cape, St. Lawrence Island, Alaska.

3.1.1 Test site selection considerations

Gray whales migrate to the waters of the northern Bering and southern Chukchi Seas to feed during summer months (Pike 1962, Bogoslovskaya, Votrogov, and Semenova 1981, Oliver et al. 1983, Braham 1984, and Nerini 1984). The area of the northern Bering Sea has been characterized as a major feeding area (Oliver et al. 1983) with small aggregations of whales known to inhabit the southeastern Bering Sea along the Alaskan Peninsula (Gill and Hall 1983, Braham 1984), as well as other locations south of the Bering Sea (Hatler and Darling 1974, Patten and Samaras 1977, and Sumich 1984).

Based on a review of recent literature and discussions with researchers working on feeding gray whales in the northern Bering Sea (Würsig, Wells, and Croll 1983, 1986; Thomson 1984), we decided to conduct our studies in the nearshore waters off Southeast Cape, St. Lawrence Island, Alaska. The project was conducted in the latter half of August.

Nome, Alaska served as the project's staging area. In order to determine if gray whales were present and feeding in the proposed study area, an aerial survey was conducted on 16 August from 0920-1630 (Alaska Daylight Savings Time) using a twin engine Cessna 402 low-wing aircraft, with a pilot and three observers.

The survey concentrated on the area around St. Lawrence Island, especially near Southeast Cape, and King Island. Gray whales, apparently feeding as evidenced by mud plumes, were located in the area of Kialegak Point, Southeast Cape, in the same location where Würsig, Wells, and Croll (1983, 1986) conducted a study on the behavior of feeding gray whales in 1982.

3.1.2 Field observation summary

Project personnel, including seven whale behavior observers and two acousticians, left Nome on 17 August on board the BIG VALLEY, arriving at the study area on the morning of 18 August. The study area near St. Lawrence island is shown in Fig. 3.1. Data collection began on this date and ended on 26 August, during which time a total of 88.5 hr of observation was achieved. Table 3.1 summarizes our observations by date, hour of day, and location.

The number of whales present for study during the test period was expected to be considerably less than those available for the previous work with migrating gray whales (Malme et al. 1983, 1984). We therefore limited our playback test stimuli to one of the five industrial sounds used previously. Drillship sound was used because it had been observed to produce avoidance of migrating whales at a greater range than other test sounds. Other sounds were of drilling platform, production platform, semi-submersible rig, and helicopter. The test sound was produced by playing back a recorded sequence through the broadband underwater projector system used in the previous gray whale studies (Malme et al. 1983, 1984).

The second test signal employed in our study was the sound produced by a single 100 cu. in. air gun operated at 4500 psi,

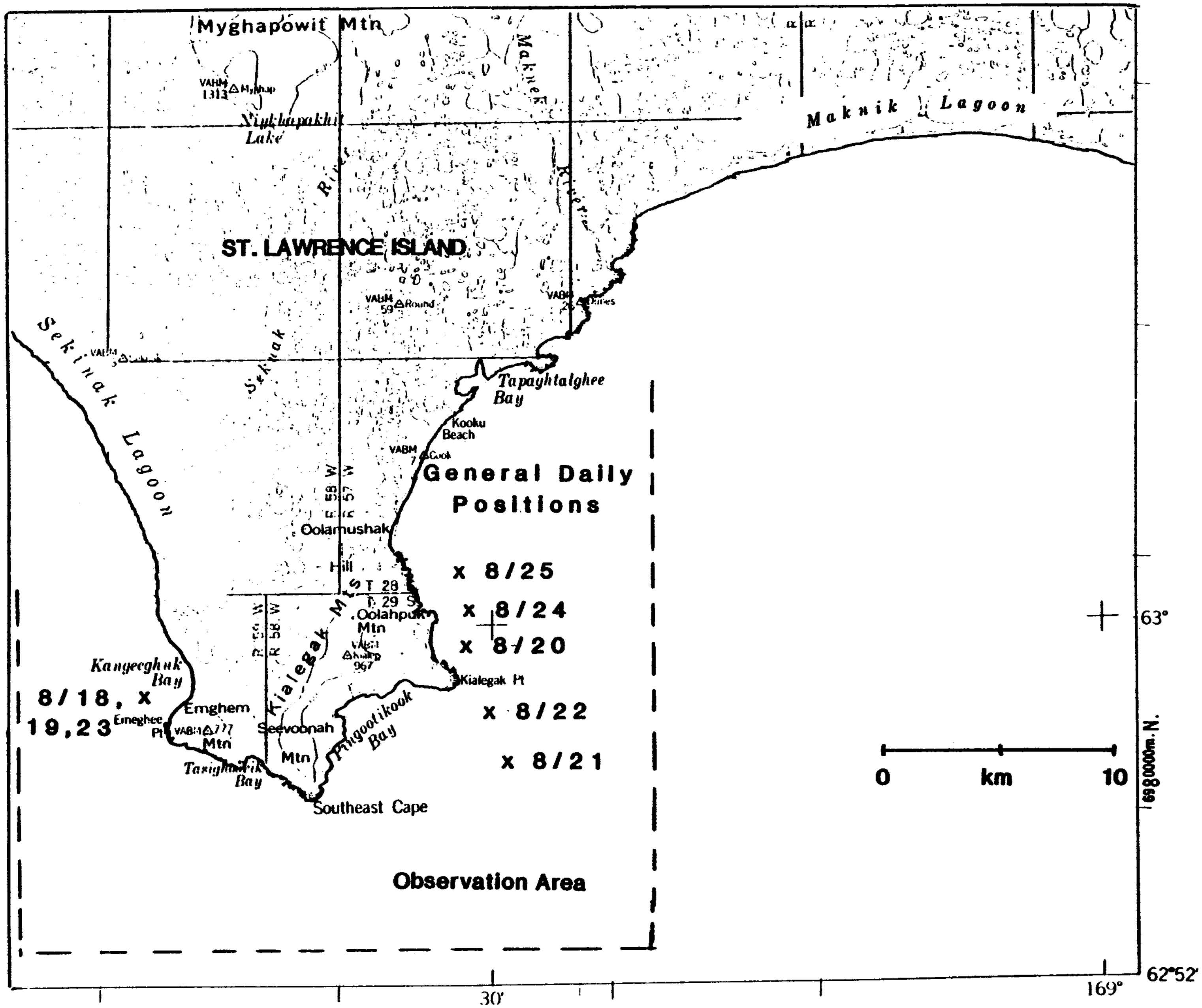


FIG. 3.1. STUDY AREA NEAR ST. LAWRENCE ISLAND.

TABLE 3.1. DATA SUMMARY FOR GRAY WHALE - STUDY 17-27 AUGUST 1985.

			No. of Whales				
Date	Time	Stimulus	Sighted	Sur/Resp Data	Tracking Data	Observation Location	General Observations
8/17	1400-2300 (1)	--	0	--	--	Nome to St. Lawrence	No gray whales seen on Nome-St. Lawrence Island transit.
8/18	0935-1016	C	6	6	--	Kialegak Point	Sea conditions prevented observers from determining whether whales were feeding or not.
	1306-2253	C	25	22	--	West of Southeast Cape	Most of the whales were between 100-400 m from "Big Valley". Observers were able to take data on one whale for 1.5 hr.
8/19	0709-0908	C	9	6	--	Kangeeghuk Bay	Observers took limited data on a mother/calf pair.
	1518-2108	C	26	16	--	Kangeeghuk Bay	Sea conditions and distance of whales from "Big Valley" prevented observers from determining whether whales were feeding or not.
	2108-2129	DS 1	1	1	--	Kangeeghuk Bay	The whale which observers were following was within 200 m of "Big Valley". It was last seen at 211128.

(1) All times given in Alaska Daylight Savings Time.

(2) These numbers represent number of simultaneous readings on whales. As explained in the table, we did not try to track individual whales during these two periods.

Stimulus abbreviations: C = Control Period; DS = Drillship Playback; AG = Air Gun Experiment.

TABLE 3.1. (Cont.) DATA SUMMARY FOR GRAY WHALE - STUDY 17-27 AUGUST 1985.

Date	Time	Stimulus	No. of Whales Sighted	No. of Whales Sur/Resp Data	No. of Whales Tracking Data	Observation Location	General Observations
8/19	2129-2239	C	14	5	--	Kangeeghuk Bay	Observers did not note another whale within 600 m of "Big Valley" until 2151. The five whales under observation during this control period were between 200-500 m from "Big Valley".
8/20	0730-0851	C	2	2	--	Kangeeghuk Bay	Observers took approximately 40 min. of data on one whale which may have been feeding for a limited time.
	1216-1713	C	2	1	--	Kialegak Point	From 1425 to 1552, four observers in the Zodiac searched for whales to the north but none were observed.
	1915-2330	C	5	1	--	Kialegak Point	Data was taken on a single whale for approximately 20 min. This was a small whale, possibly a first year calf.
8/21	0724-1142	C	9	5	2	NE of Kialegak Point	This was the first day that triangulation data was taken. Although mud and/or birds (2 indications of feeding) were not noted, one of the whales was moving slowly and staying in the same general area, a possible indication of feeding.
	1142-1212	DS 2	4	3	3	NE of Kialegak Point	One of the whales under observation was noted surfacing with mud present.

TABLE 3.1. (Cont.) DATA SUMMARY FOR GRAY WHALE - STUDY 17-27 AUGUST 1985.

Date	Time	Stimulus	No. of Whales Sighted	Sur/Resp Data	Tracking Data	Observation Location	General Observations
8/21	1212-1448	C	11	6	2	NE of Kialegak Point	The presence of mud was noted with four of the whales under observation. At one point, two whales were very close together (< 15 m) and a variety of behaviors were observed including underwater blows, a pectoral slap, and a vertical fluke. No indication of feeding was observed at this time, however when the whales separated the presence of mud was noted when both whales surfaced. One of the whales had been surfacing with mud visible before this interaction.
	1448-1542	DS 3	4	3	2	NE of Kialegak Point	Observers continued to take data on Whale W, which had been under continuous observation since 1258.
	1542-1650	C	5	5	--	NE of Kialegak Point	Observations continued on Whale W, which continued to feed.
	1800-1858	C	8	4	--	NE of Kialegak Point	No mud was noted with the four whales under observation; however, birds were noted with one whale. One of the focal whales passed under the bow of "Big Valley".
	1924-1950	C	5	5	2	NE of Kialegak Point	The Zodiac observers took surfacing/respiration data on five whales. Because of the close proximity of the whales to one another and their lack of individually distinctive features, it was not possible to track individual whales.

TABLE 3.1. (Cont.) DATA SUMMARY FOR GRAY WHALE - STUDY 17-27 AUGUST 1985.

Date	Time	Stimulus	No. of Whales Sighted	No. of Whales Sur/Resp Data	No. of Whales Tracking Data	Observation Location	General Observations
8/21	1950-2057	DS 4	26	1	22(2)	NE of Kialegak Point	Observers onboard the "Big Valley" noted a shift in movement of whales. Whales that had been to the west and inshore of "Big Valley" moved to the northeast.
	2057-2149	C	5	--	4(2)	NE of Kialegak Point	Very limited data taken. Most of the whales in the area had moved away. There were two whales 3-5 km to the northeast of "Big Valley" and a few to the north of the Zodiac and "Big Valley".
8/22	0730-1440	C	20	11	5	Kialegak Point	Surfacing/respiration data were taken on Whale E from 1141 to 1832. The presence of mud was noted during surfacings towards the end of observations, but not earlier presumably because overcast conditions in the late AM and early PM prevented its detection.
	1440-1600	AG 1	15	3	4	Kialegak Point	Observers continued to take data on Whale E. The Zodiac observers noted that the whales in the area (including Whale E) moved offshore and that apparent feeding stopped. This offshore movement appeared to continue until "Nancy H." was abeam of "Big Valley". During this period, "Big Valley" had to make two moves to stay in the same area as the whales and the Zodiac.

TABLE 3.1. (Cont.) DATA SUMMARY FOR GRAY WHALE - STUDY 17-27 AUGUST 1985.

Date	Time	*Stimulus	No. of Whales: Sighted	No. of Whales: Sur/Resp Data	No. of Whales: Tracking Data	Observation Location	General Observations
8/22	1600-1710	C	6	3	3	Kialegak Point	Observations on Whale E continued with mud noted for many surfacings. The control period ended when "Big Valley" was forced to start engines and move offshore because it was drifting into shallow water.
	1731-1758	AG 2	3	1	2	Kialegak Point	Observations on Whale E continued. Observers onboard the Zodiac noted that Whale E did not exhibit the same behavior (moving offshore) as seen during the first AG run.
	1758-1851	C	8	3	2	Kialegak Point	Observations on Whale E continued, with mud still being noted.
8/23	0730-1201	C	5	--	--	Kialegak Point	Weather conditions and poor visibility prevented taking surfacing/respiration data.
	1446-1851	C	3-4	1	--	Kangeeghuk Bay	Limited surfacing/respiration data taken.
	1851-2240	C	3	1	--	Kangeeghuk Bay	Limited surface/respiration data taken.
8/24	0735-1203	C	1	--	--	Pingootikook Bay	Very limited visibility
	1606-1715	C	6	1	6	Theodolite station N of Kialegak Point and nearshore waters	Whales were tracked from shore by theodolite while Zodiac observers monitored surfacing/respiration. Four of the six whales tracked were feeding, as evidenced by the presence of mud and birds.

TABLE 3.1. (Cont.) DATA SUMMARY FOR GRAY WHALE - STUDY 17-27 AUGUST 1985.

Date	Time	Stimulus	No. of Whales Sighted	No. of Whales Sur/Resp Data	No. of Whales Tracking Data	Observation Location	General Observations
8/24	1715-1758	AG 3	5	--	5	Theodolite station N of Kialegak Point	Theodolite tracking continued. The Zodiac observers stopped taking surface/respiration data at 1710 because of sea conditions and lack of individually identifiable whales.
	1758-1929	C	4	--	4	Theodolite station N of Kialegak Point	Theodolite tracking continues.
	1929-2026	AG 4	3	--	2	Theodolite station N of Kialegak Point	The "Nancy H " came within < 200 m of Whale B. Shore observers noted that this whale turned and moved to the southeast and offshore slightly. A fluke out was noted (the only time one was seen associated with Whale B). This whale continued to feed in same general area.
	2026-2050	C	1	--	1	Theodolite station N of Kialegak Point	Poor visibility prevented observation of mud at the surfacings of whales. Whale B had been followed almost continuously from 1609 to 2042.
8/25	0805-0857	C	4-5	--	--	N of Kialegak Point	Thick fog prevented taking surfacing/respiration data from "Big Valley".
	1020-1220	C	2	2	2	N of Kialegak Point	Surfacing/respiration data taken on one whale for over 1.5 hr and on the other whale for 1 hr. Triangulation data taken at the end of control period.

TABLE 3.1. (Cont.) DATA SUMMARY FOR GRAY WHALE - STUDY 17-27 AUGUST 1985.

			No. of Whales				
Date	Time	Stimulus	Sighted	Sur/Resp Data	Tracking Data	Observation Location	General Observations
8/25	1600-1706	AG 6	2	2	--	N of Kialegak Point	Thick fog prevented taking of triangulation data. Whale N continued feeding until ~1605 when it began traveling. It crossed within 100 m directly in front of the "Nancy H " at 1654; slowed down its traveling speed at 1704.
	1706-1901	C	1	1	1	N of Kialegak Point	Whale N returned to original location and resumed feeding.
8/26	0720-1031	C	2	2	--	Kialegak Point	Both whales feeding until 1021 when they began traveling, possibly in reaction to the presence of the Zodiac.
8/27							Because of worsening weather/sea conditions, observations were terminated at 1017 and we began preparations to leave St. Lawrence Island area.

the same type of air gun source used as in the previous studies. The tests were performed with the air gun vessel moving slowly to simulate the slowly changing level that a whale would experience when a seismic array passed by at some distance.

A chronological summary of the acoustic test periods and control periods used in the study is shown in Table 3.2.

Table 3.3 summarizes observation conditions during the field season. Viewing conditions were generally fair during the period; however, fog, ocean swell, and relatively high sea states hampered observations on several occasions. Very little surfacing and respiration data were collected on 20, 23, 24, and 26 August because of adverse weather and the project ended one day earlier than scheduled, on the morning of 27 August, because of a developing gale.

3.2 Experimental Procedure

This section contains a discussion of the whale behavioral observation techniques together with a summary of the procedures used to measure the acoustic environment and calculate sound stimulus exposure levels where whales were observed.

3.2.1 Overall

The experimental procedure was based on the techniques developed in previous studies of gray whale responses to acoustic stimuli. Both whale movement and respiration data were obtained to determine if behavioral changes occur in response to varying levels of industrial noise. Two research vessels were used. The BIG VALLEY, a 90 ft fishing/utility vessel, served as the primary observation and acoustic measurement vessel. The NANCY H, a 75 ft fishing/utility vessel, was the air gun handling vessel. A 16 ft Zodiac inflatable boat served as a secondary observation vessel when observations close to whales were required.

TABLE 3.2. TEST PERIOD SUMMARY, GRAY WHALE STUDY.

Date/Time		Stimulus	Control Duration	Stimulus Duration
8/18	0935-1016	C	41 m	
	1306-2253	C	9 h 47 m	
8/19	0709-0908	C	1 h 59 m	
	1518-2108	C	5 h 50 m	
	2108-2129	DS-1		21 m
	2129-2239	C	1 h 10 m	
8/20	0730-0851	C	1 h 21 m	
	1216-1713	C	4 h 57 m	
	1915-2330	C	4 h 15 m	
8/21	0724-1142	C	4 h 18 m	
	1142-1212	DS-2		30 m
	1212-1448	C	2 h 36 m	
	1448-1542	DS-3		54 m
	1542-1650	C	1 h 08 m	
	1800-1858	C	58 m	
	1924-1950	C	26 m	
	1950-2057	DS-4		1 h 07 m
	2057-2149	C	52 m	
8/22	0730-1440	C	7 h 10 m	
	1440-1600	AG-1		1 h 20 m
	1600-1710	C	1 h 10 m	
	1731-1758	AG-2		27 m
	1758-1851	C	53 m	
8/23	0730-1201	C	4 h 31 m	
	1446-1851	C	4 h 05 m	
	1851-2240	C	3 h 49 m	
8/24	0735-1203	C	4 h 28 m	
	1606-1715	C	1 h 09 m	
	1715-1758	AG-3		43 m
	1758-1929	C	1 h 31 m	
	1929-2026	AG-4		57 m
	2026-2050	C	24 m	

TABLE 3.2. (Cont.) TEST PERIOD SUMMARY, GRAY WHALE STUDY.

Date/Time		Stimulus	Control Duration	Stimulus Duration
8/25	0805-0857	C	52 m	
	1020-1220	C	2 h 00 m	
	1220-1323	AG-5		1 h 03 m
	1323-1600	C	2 h 37 m	
	1600-1706	AG-6		1 h 06 m
	1706-1901	C	1 h 55 m	
8/26	0720-1031	C	3 h 11 m	

Total Time: Control (C) 80 h 03 m, Drillship (DS) 2 h 52 m, Air Gun (AG) 5 h 36 m

TABLE 3.3. SUMMARY OF OBSERVATION CONDITIONS, 17-27 AUGUST, 1985, ST. LAWRENCE ISLAND, ALASKA.

17 August	Fair visibility early p.m. with BF* = 0, but 95% cloud cover causing glare. Wind increasing WSW 10-15 kts by late p.m. with BF = 1-2, visibility good with 100% cloud cover. Fair visibility with low light at end of observations.
18 August	Fair to good visibility in a.m. with winds increasing out of the ESE to 20 kts. BF 1-2 at start increasing to 4-5 with 100% cloud cover. Winds shift to WNW early p.m. then to NNE increasing to 40-45 kts by 1900. Cloud cover 50-100% during p.m. BF = 4-5 in p.m. with fair to poor visibility.
19 August	Fair to poor visibility early a.m. with wind N at 15-20 kts. Seas BF = 3-4 with 95-80% cloud cover. Winds up to 30 kts out of the NE by late a.m. with slight drizzle, BF = 6 with 100% cloud cover. Winds down to 15-20 kts out of the NE by mid-day. Visibility poor to fair rest of day with varying amounts of rain and winds out of the N,NE at 15-25 kts. 100% cloud cover.
20 August	Limited visibility with some fog/drizzle with wind increasing out of the SW to 8 kts by mid-day and some swell. 100% cloud cover with BF = 1. SW winds building to 15-20 kts by 1600 with BF up to 3-4 and rain. Winds decrease but by late p.m. shifted to NW up to 25 kts. Rain, poor visibility with 100% cloud cover.
21 August	Good visibility in a.m. with winds out of the NNW at 5-8 kts. Cloud cover 20% with fog to east. Early p.m. seas BF = 2-3 with wind NW at 10 kts shifting to SW at 10 kts and then back to NW at 7-9 kts at 1512. Visibility fair to good in p.m. with seas BF = 3 decreasing to BF = 1. Cloud cover 20-60% in p.m.

*Based on a 12 point Beaufort scale (Couper 1983).

TABLE 3.3. (Cont.) SUMMARY OF OBSERVATION CONDITIONS, 17-27 AUGUST, 1985, ST. LAWRENCE ISLAND, ALASKA.

22 August	Fair visibility in a.m. with low contrast, 95% cloud cover. Light E,NE wind early in a.m. increasing to N 3-5 kts by mid a.m. Good visibility by mid-day (low contrast/fog to NE and NW made viewing fair in those directions) continuing throughout rest of observations. BF = 0-1 entire day with 100-90% cloud cover. Limited time period in mid p.m. when glare affected visibility.
23 August	Fair to poor visibility most of a.m. with wind out of the W,SW at 8-12 kts. Strong 1 m swell by mid a.m. with steady rain. Early p.m. fair visibility with BF = 2. Winds shifted throughout rest of observations, usually staying between 5 to 8 kts. Visibility increased to good but by late p.m. mist/fog and rain made viewing poor. Cloud cover 100% all day.
24 August	Poor visibility much of a.m. with fog/low contrast. Wind out of the SE at 4-6 kts with large swell. By late a.m. BF = 3 with a 1 m swell. Viewing from shore was good out to 1-2 km with low light decreasing visibility by end of observations. Conditions on the water were good inshore but rough water/wind prevented effective offshore observations.
25 August	Poor visibility in early a.m. with mist/fog and low contrast. BF = 2 with wind out of the W at 5-7 kts. Increasing visibility out to 300 m by mid-day. During p.m. visibility stayed generally fair with wind out of the S, increasing to SW 10 kts by end of observations. Seas up to BF = 3-4 by mid p.m. Cloud cover 100% all day with drizzle during a.m. and early p.m.
26 August	Visibility conditions decreased throughout the day with seas reaching BF = 5-6 by mid p.m. and wind out of the S at 15+ kts. Cloud cover 100% all day with mist.
27 August	Visibility poor with seas BF = 4-5 and wind out of the S at 25 kts.

Daily observations usually began between 0730 and 0800 with two observers stationed on the flying bridge of the BIG VALLEY (height above water approximately 7 m) noting whale distribution in the general area. Observations ended at varying times between 1901 and 2330 (see Table 3.1). During some days it was necessary to actively search for gray whales over a large area. This usually required an approximate 4 hr transit between Kialegak Point and Kangeeghuk Bay, the two areas where most of our observations took place. At times, observers used the Zodiac to locate whale concentrations. Personnel on board the NANCY H, the air gun support vessel which arrived in the study area on 22 August, also assisted in locating whale groups.

During the first three days of the field season, observations were conducted from the BIG VALLEY. The following data were recorded:

Location of whales relative to BIG VALLEY

Surfacing, respiration (or blow), and dive times of whales (see Section 3.2.2 for definitions)

General heading of whales

Behavior, including presumed feeding (presence of mud, birds, and/or surfacing and diving in same general location), milling, active travel, and surface active behaviors (see Section 3.2.2. for definitions)

Individual identifying characteristics (e.g., scars and coloration pattern)

Loran position of BIG VALLEY and depth of water

The number of whales in the general area and observation conditions were recorded on an hourly basis or when a change occurred.

We refer to individual whales as "focal" whales when, during the two-boat experiments, both Zodiac and BIG VALLEY observers were tracking the whale (or whales), were noting all behaviors including surfacing, respiration, and dive times, and observed the whale (or whales) over a time period encompassing all or part of a control period and an experimental period. We borrow the term "focal" from Altmann (1974), however, the selection of focal whales was not random nor did we use set sampling periods (i.e., focal-animal sampling, Altmann 1974, p. 242).

Observation personnel consisted of 3-4 observers at any one time, with 2-3 observers surveying the area for whales, noting the surfacing, blow, and dive times of from 1-3 focal whales, and one person recording the data in real time. One of the whale observers was responsible for noting the water depth and the position of the BIG VALLEY. Visual observations were made with binoculars (various powers) and by unaided eye.

From 21-23 August and 25 August during which time the two-boat experiments were conducted, observers worked from both the BIG VALLEY and the Zodiac.

Four observers were stationed on the BIG VALLEY with the following responsibilities: theodolite (Topcon DT-20) operator, data recorder; whale observer/communications coordinator, and one person noting, at two minute intervals, Loran position and magnetic heading of the BIG VALLEY, radar range and bearing to the Zodiac and the NANCY H, and water depth. In practice, the theodolite operator and to a lesser extent the data recorder served as second and third observers. Personnel were rotated periodically. It was often difficult to determine if the whales were feeding because of observer height above water and distance to whales. Observers attempted to scan the entire area around the BIG VALLEY to assess whale distribution during control and experimental conditions, however this was not always feasible.

The Zodiac crew consisted of three individuals with the following responsibilities: boat operator/communications coordinator/observer, binocular compass (Fujinon model 7 x 50 MTRC)/ observer, and data recorder, who would assist in observations as time permitted. The Zodiac personnel attempted to note all surfacing, blow, and dive times of focal whales as well as their behavior, heading, and distance from boat. Observers also took depth readings (Lowrance X-15 depth sounder, 100 kHz) at periodic intervals near whales presumed to be feeding.

Previous studies have shown that gray whales can be individually identified by various morphological characteristics (Hatler and Darling 1974, Swartz and Jones 1978, 1980, and Darling 1984). Noting distinguishing features of whales proved useful and enabled observers on board the Zodiac to follow some individuals for relatively long periods of time; in one case for 7.2 hr (Whale E on 22 August). Two whales were seen in the same general area for periods longer than one day, thereby indicating at least short term site fidelity (Würsig, Wells, and Croll 1983, 1986). One whale observed on 22 August was noted again on 26 August and another whale observed on 21 August was again seen on 22 August.

We observed two mother/calf pairs (possibly the same) on 19 August, and a whale on 20 August was a small possible yearling. All other whales observed were judged to be adults (see Table 3.1 for number of whales sighted each day). Würsig, Wells, and Croll (1983, 1986) observed no calves during their work in the same area in July and September 1982.

During the course of the field season we observed a number of other marine mammal species, most notably spotted seals (Phoca largha) and up to ten minke whales (Balaenoptera acutorostrata), with five seen during a 1 hr period on 22 August near Kialegak Point. We did not observe any interactions between gray whales and these species. Seabirds were also prevalent during the study, with numerous black-legged kittiwakes (Rissa tridactyla), red-necked phalaropes (Phalaropus lobatus), and several immature Sabine's gulls (Xema sabini) associated with presumably feeding gray whales. These birds tended to follow gray whales, landing on the water's surface near surfacing whales, presumably taking advantage of food items brought to the surface. Both black-legged kittiwakes and red-necked phalaropes have been observed with feeding gray whales in the northern Bering and southern Chukchi Seas (Harrison 1979, Wilke and Fiscus 1961). However, Sabine's gulls have only been reported with one feeding gray whale sighted on 24 August 1980 in the Canadian Beaufort Sea (Rugh and Fraker 1981).

3.2.2 Behavior observation measures

Measurements of the surfacing, respiration, and dive cycles have proven useful in quantifying the behavior of large baleen whales (Harvey and Mate 1984, Würsig et al. 1984, Würsig, Wells, and Croll 1986) and have provided one means of assessing the effect of underwater noise from industrial and related activities on bowhead whales (Richardson et al. 1985; Richardson, Würsig, and Greene 1986) and humpback whales (Baker et al. 1983, Dean et al. 1985).

To assess the possible effects of air gun and drillship operations on the behavior of gray whales on the feeding grounds, we measured the following surfacing, respiration, and dive cycle variables (after Würsig et al. 1984, 1986) under control and experimental conditions: 1) Blow Interval - time between respirations while the whale is at the surface; 2) Length of Surfacing - time that the whale is at the surface discounting shallow submergences between respirations; 3) Length of Dive - time that the whale is below the surface between surfacings; 4) Number of Blows per Surfacing; and 5) Blow Rate - the number of blows per minute calculated from length of surfacing, length of dive, and number of blows per surfacing.

As outlined in Section 3.1.2, we also noted if whales were engaged in the following activities: 1) Feeding - the presence of mud, birds, and/or regular surfacing and diving in the same location; 2) Travelling - concerted movement in a particular direction; 3) Milling - movement at or near the surface accompanied by many direction changes; 4) Socializing - two or more whales within 1/2 body length (7-8 m) of each other and interacting in some way; and 5) Surface Active Behavior - breaching, pectoral slapping, etc. Because of small sample sizes, we were unable to compare statistically the frequency of these behaviors during control and experimental conditions. In Section 3.4.1, we mention these various behaviors in our narrative descriptions of the results of specific drillship and air gun experiments.

3.2.3 Measurement of whale positions and whale movement patterns

Most whale positions were ascertained by triangulating with a shipboard theodolite and binocular compasses, a technique developed by Malme et al. (1985) to study feeding humpback whales in Frederick Sound, Alaska. This procedure is shown in Fig. 3.2. On 24 August, when whale location and observation conditions were optimal, we were able to track feeding gray whales with a theodolite from a land-based station, 81.38 m high, approximately 2 km north of Kialegak Point (see Wursig 1978 and Tyack 1981 for a description of this technique). A total of six whale groups were tracked, with one whale followed for 4.7 hr. Observers using the Zodiac collected very limited surfacing and respiration data on two of these groups because of rough seas and problems with identifying individual whales.

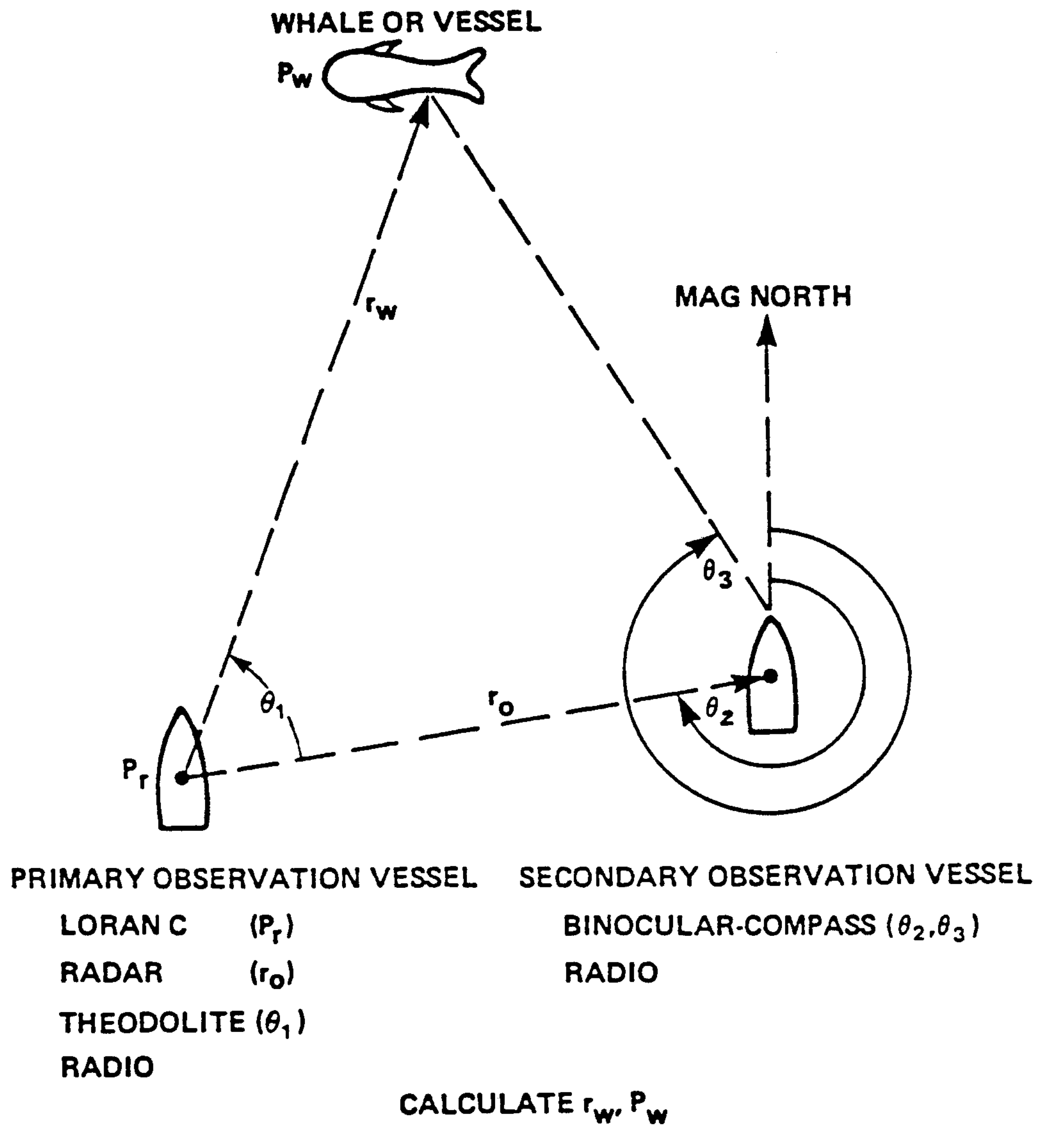


FIG. 3.2. WHALE TRACKING USING OBSERVATIONS FROM TWO VESSELS.

3.2.4 Acoustic environmental measurements

Navigation

A Northstar Model 6000, Loran-C on the BIG VALLEY was used to obtain absolute position references for the whale sighting data. A Furuno Model LC-80, Loran-C on the NANCY H provided position information for the air gun vessel. The radars on both vessels were used to coordinate the Loran track data and obtain position information on the whale observation vessel (Zodiac).

A recording fathometer was used for determining the water depth.

Oceanographic Measurements

The variation of water temperature and salinity with depth was measured with a Beckman Model RS5-3 conductivity, temperature, and salinity probe. This instrument provided a salinity measurement based on the temperature and conductivity data. Measurements were made at selected depths down to a position just off the bottom. The measured data were then used to calculate the sound velocity profile using Wilson's equation (discussed in Sec. 3.3.2).

Wave height was estimated visually.

Ambient Noise Measurements

A standard hydrophone system that combined an ITC Type 6050C hydrophone with a low-noise preamplifier and tape-recorder was used to obtain ambient noise data. The hydrophone sensitivity and electrical noise-floor characteristics are shown in Fig. 3.3. The acoustic noise measurement system block diagram is shown in Fig. 3.4. Overall frequency response of the measurement system was flat from 20 Hz to 15 kHz. All components of the system were

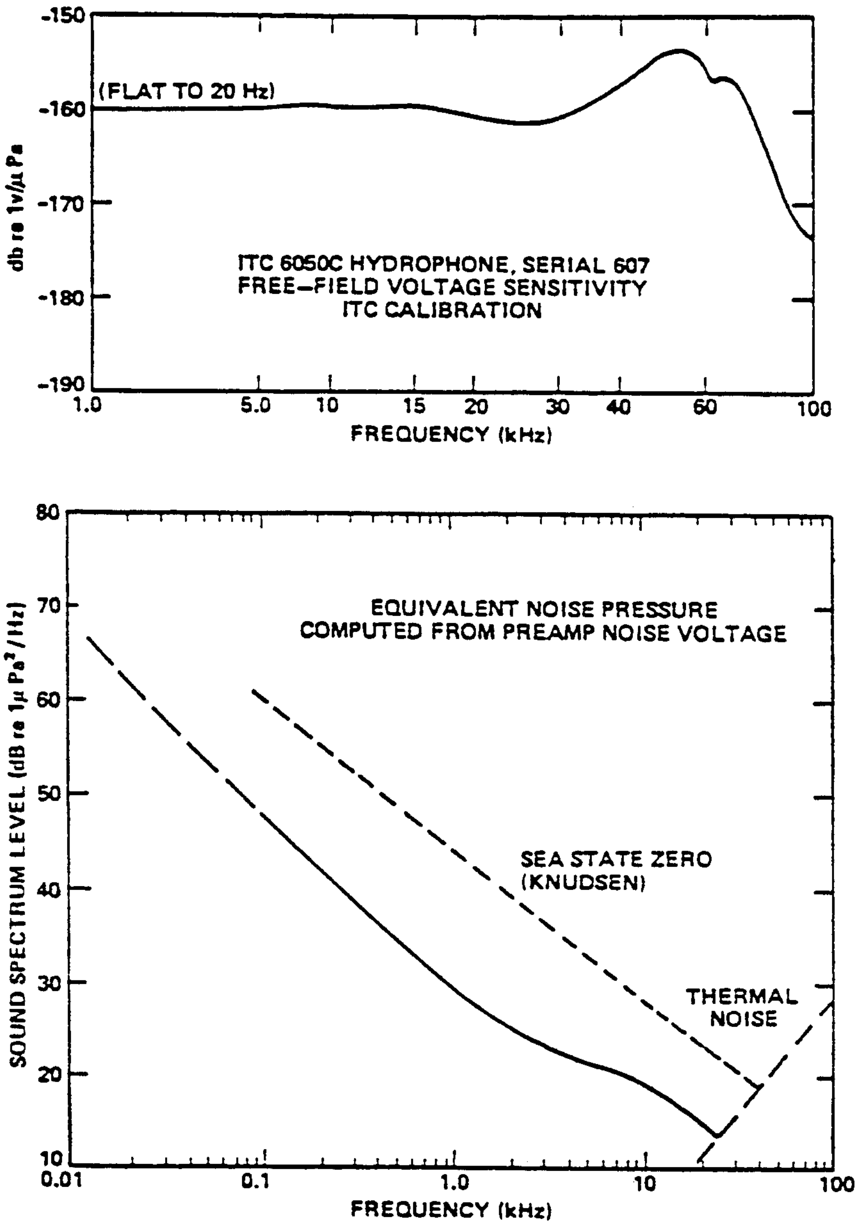


FIG. 3.3. MEASUREMENT HYDROPHONE CHARACTERISTICS.

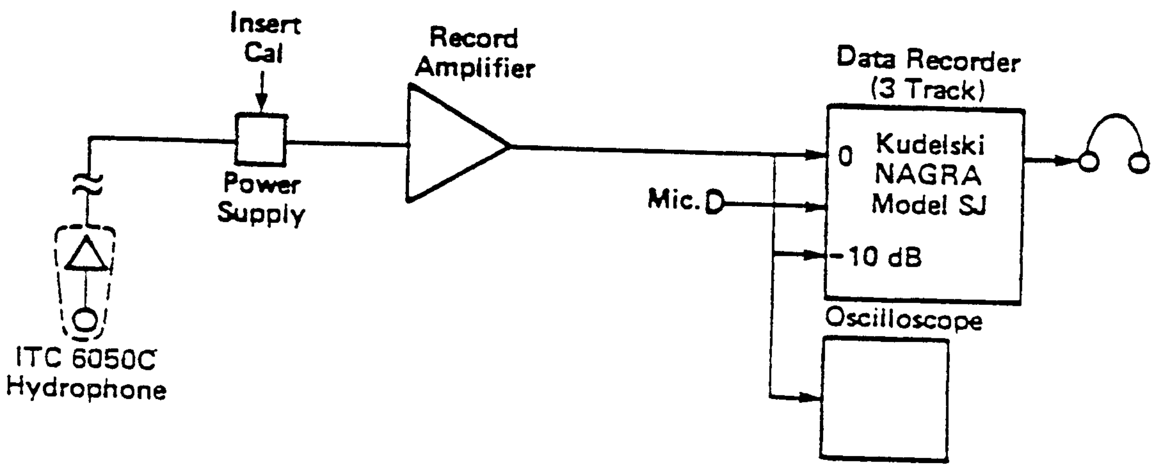


FIG. 3.4. ACOUSTIC MEASUREMENT SYSTEM

battery operated during ambient noise measurement. Cable fairings and a support float system were used to minimize strumming and surge noise effects on the ambient measurement hydrophone.

Transmission Loss Measurements

Transmission loss (TL) information was obtained by measurements using the air gun source. Data were obtained for several ranges extending from 0.15 km to 4 km. The source levels of both the air gun and projector system were established by measurement of the direct signal at close, measured ranges using a calibrated reference hydrophone. Transmission loss was then determined as the difference between the received sound energy level and the previously determined source energy level as the range from the source to the receiving hydrophone was increased.

3.2.5 Acoustic playback procedure

Projector System

The acoustic playback system was designed to provide sound levels and frequency response capable of realistically simulating the designated range of petroleum industry activities. In order to keep the system within the required operational constraints, a compromise was necessary to boost the low frequency response of the projector system. Two USN/USRD Type J-13 projectors were used to provide response down to 32 Hz. While some industrial noise sources have spectra extending below this frequency, playback sources for reproduction of ultra-low frequencies are very heavy and require special mechanical and electrical support equipment.

Because of the required broad frequency range needed to reproduce the industrial noise spectra, three sound projectors were used. In addition to the two low frequency projectors, a USN/USRD Type F-40 projector was used to provide high frequency sound above 2 kHz. Electrical equalization and cross-over networks were used to enable all of the projectors to be driven from a Crown 300-watt power amplifier. As a result of the use of two low frequency projectors and the electronic equalization network, the useful response of the system extended from 32 Hz to 20 kHz. The playback system and its response curve are shown in Fig. 3.5.

The three projectors were mounted vertically in a support frame to maintain correct acoustic alignment of the radiating surfaces and to facilitate handling. The spacing between acoustic centers was 26 cm. The assembly was lowered to a depth of 12 m with a boom on the BIG VALLEY. A vane was mounted on the projector assembly to keep the J-13 projectors pointed away from the current. This facilitated operation during high tidal current conditions by minimizing drag forces on the projector pistons which could cause signal distortion.

A reference monitor hydrophone (Celesco LC-10) was mounted at a distance of 1 m from the projector system to monitor the calibration of the projected sound levels.

During a playback sequence, a pre-recorded, 15-min. duration, industrial noise stimulus on a cassette tape was used to generate a test signal. Two cassette recorders coupled to a fader control (previously shown in Fig. 3.5) permitted uninterrupted continuous sound for as long as desired. Playback periods of 30 min to 1 hr were generally used.

Stimuli Projection and Monitoring

The drillship playback stimulus used in this study was the same recording used for the previous gray whale studies. Playback at a source level comparable to the original drillship output was not feasible because of projector power limitation. However, the playback levels used were high enough to insure a signal level of 111 to 117 dB re 1 μPa was obtained at a range of

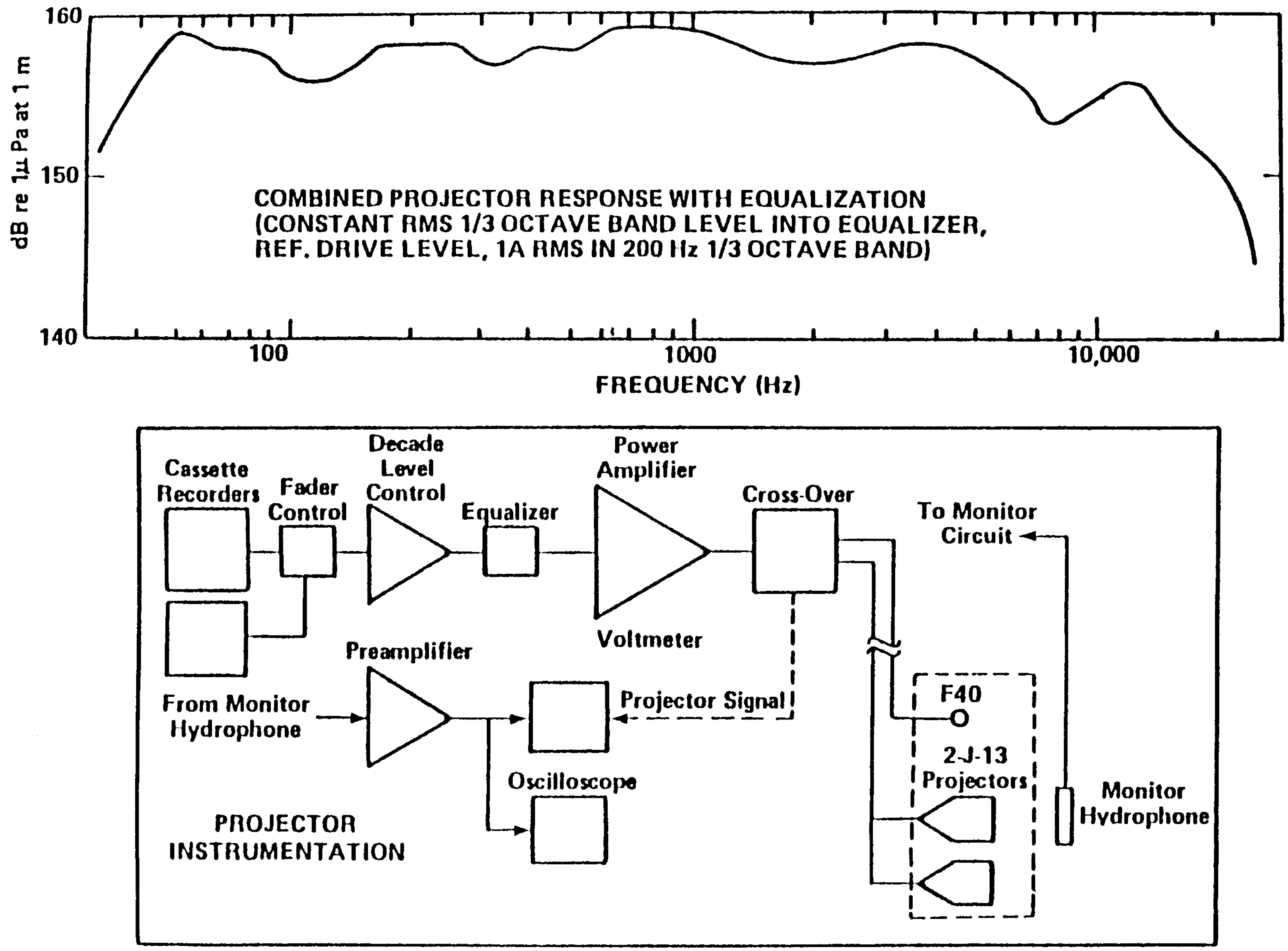


FIG. 3.5. PLAYBACK INSTRUMENTATION.

1 km. A level of 117 dB was observed to produce a 0.5 probability of avoidance for migrating whales (Malme et al, 1984). Because of the relatively low ambient noise level, an effective range of 6 to 8 km was obtained to the zone where the playback level became approximately equal to the ambient noise level. A comparison between the playback level and the original source level is shown in Table 3.4. The playback sound levels were subsequently scaled to the level reported for the actual source and range corrections were derived by using the measured transmission loss at the test site. This procedure is described in detail in Sec. 3.3.5.

Table 3.4 lists the maximum measured level for the stimulus as originally recorded. This sound level is based on the reported data for the actual tape dub used. The reference cited was used as the basis for establishing the original sound field level because of the difficulty in recovering and preserving a calibration chain through the dubbing and playback process. The original data were used to determine the dominant spectrum components of the original sound field and the frequency region of the principal output. Because of the low frequency limitation of the J-13 projectors below 32 Hz, it was not possible to reproduce the required levels for sources with very low dominant frequencies. In this case, the degree to which the frequency response above 32 Hz matched the original source was examined independently by comparison of this part of the playback spectrum with the comparable part of the reported original source spectrum.

The sound level output produced during playback is compared with the original sound source values in the last column of the table. The drillship stimulus level is below that of the actual source at all frequencies. The procedure for scaling level differences between playback and actual sources will be discussed

TABLE 3.4. PLAYBACK STIMULI INFORMATION.

Stimulus (Code)	Original Recording Dist. Meters	Dominant Frequencies Hz	Reported Level dB/µPa	Est. 100 m Level dB//µPa	Playback 100 m Level dB//µPa	Difference (PB-Orig) dB	Data Ref.
DRILLSHIP (DS)	185	278 (t)	123	126	122	-4	Greene 1982
(EXPLORER II)		50-315 (bb)	133	136	127	-9	(p. 322)

Key:

(t) tonal, (bb) broadband

in Sec. 3.3.5 using the measured TL and ambient noise data for the observation site.

3.3 Acoustic Measurements and Results

This section contains a description of the acoustic measurements made during the August 1985 field season and a summary of the results obtained. The analytical background for many of the procedures used was developed during previous studies with gray whales and humpback whales (Malme et al. 1983, 1984, 1985). Some of the discussion in these previous reports will be included here to facilitate understanding of the results and minimize the need to refer to the earlier reports.

The test procedure requires establishment of a controlled sound field in a region where feeding gray whales are present. To accomplish this, a calibrated source of sound must be used and knowledge of the attenuation rate of the sound with propagation distance must be obtained. This permits estimation of the signal levels at the observed positions of whales without requiring specific measurements at each position. The following discussion describes source calibration procedures, transmission loss measurements, ambient noise measurements, and procedures for estimation of noise exposure levels.

3.3.1 Acoustic source characteristics

The air gun and playback projector system were identical to those used in the August 1984 study, (Malme et al. 1985). A description of these sources was given previously in Sec. 3.2.5.

<u>Air Gun Source Characteristics</u>

The previous measurements of a single 100 cu. in. air gun (Malme et al. 1983, Sec. 5.1.2) showed that the average pulse pressure level was a useful measure of the received level of the transient signals from an air gun. This quantity is a measure of the effective energy of a noise pulse in terms of an average pressure level defined as (Urick 1983, Sec. 4.4)

$$E = \frac{1}{\rho c} \int_0^\infty p^2(t)dt = \frac{\bar{P}^2 T}{2\rho c} \text{ (Joules)} \quad (1)$$

where

ρc = the specific acoustic impedance of water

$p(t)$ = the original pulse pressure waveform

$\bar{P}$ = the average pulse pressure

T = the average pulse duration (the time required for $p^2(t)$ to decay to less than 13.5% of the initial value).

Generally it is more convenient to express acoustic pressure in logarithmic terms. Consequently, the average pulse pressure level is defined as

$$L_{\bar{P}} = 20 \, \text{Log}_{10}(\bar{P}/P_{ref}) \text{ dB} \quad (2)$$

where

P_{ref} = 1μPascal.

A Hewlett Packard Model 3562A signal analyzer was used to analyze air gun signals to obtain the average pulse pressure. This instrument performed signal capture, squaring and integrating functions to determine the total acoustic energy of the pulse. The time duration of the signals was determined by measurement of the integrated signal envelope on the analyzer display. Figure 3.6 illustrates a typical air gun signature and the analysis procedure.

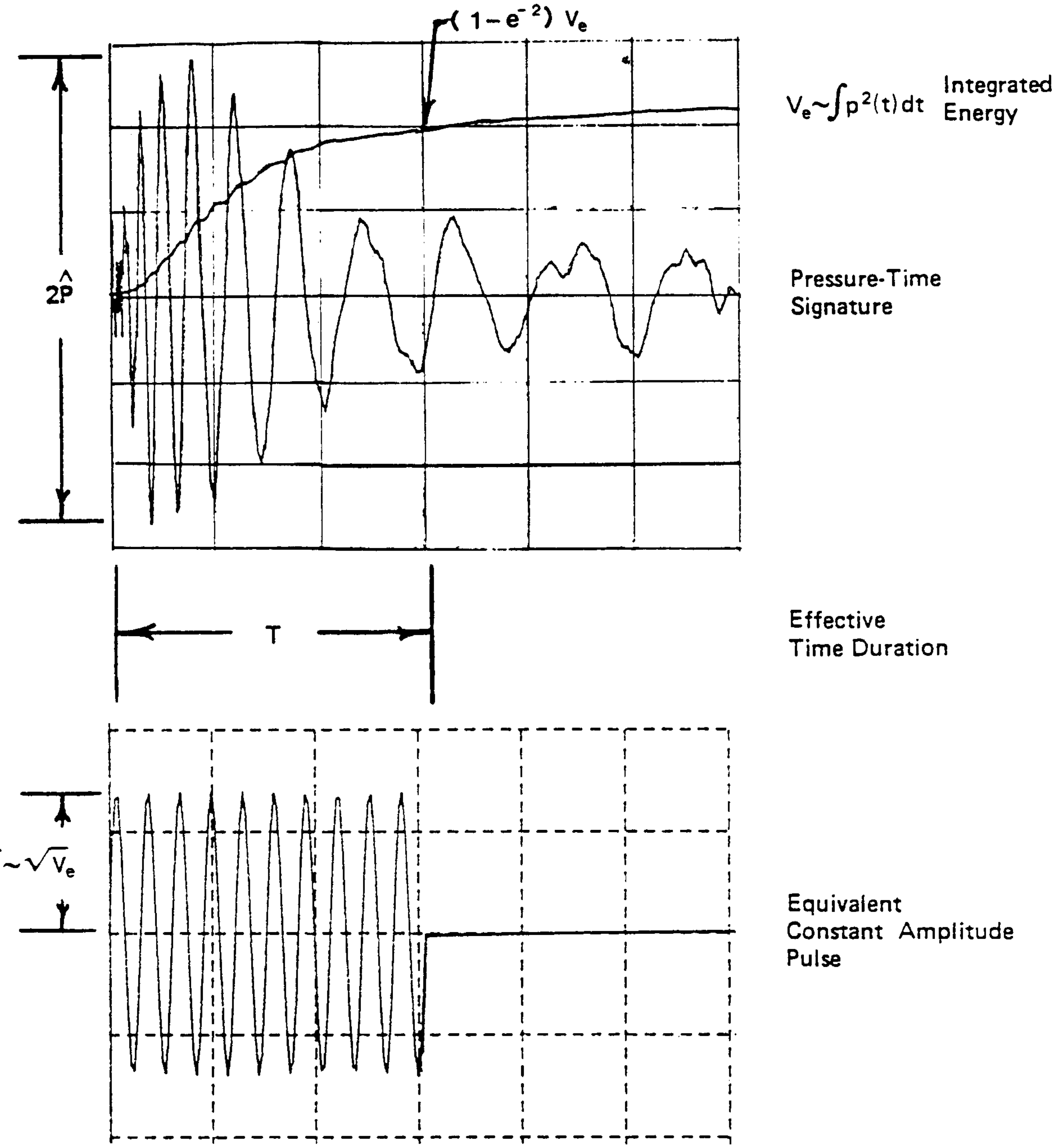


FIG. 3.6. ANALYZER RECORD SHOWING PULSE SIGNATURE AND INTEGRATED PULSE ENERGY.

Air Gun Signature Analysis

The Model 3562A analyzer was also used to analyze the energy spectrum of the air gun signatures at various ranges. The time waveforms of the pulses were also recorded to obtain peak pressure data and examine time duration as a function of range. For bottom conditions where multipath and high reverberation conditions occur, the time duration of a transient signal increases with increase in range. This was observed to occur at the California test site (Malme et al. 1983). However, at the St. Lawrence Island sites, the signal reverberation was much less, even though the bottom loss factors were appreciably smaller than those measured off California. For the relatively short transmission ranges used, the pulse time duration was observed to remain nearly constant, or even decrease with increasing range. A comparison of acoustic transmission parameters for the St. Lawrence Island test area is presented in Table 3.5.

The air gun was operated at ranges to the hydrophone of 4 km to 130 m at a firing rate of 6 pulses/min. The pressure signature observed at close range was found to agree quite well with the data obtained during the previous work with gray whales, also using a 100 cu. in. gun.

Playback System Response Measurement

As described previously in Sec. 3.2.5, the low frequency response of the playback system was improved by adding a second low-frequency projector. In addition, an equalization network was used to provide a smooth frequency response in the mid-band and high-frequency regions. The accuracy of the playback system was examined by recording the output of the source monitor hydrophone and comparing the spectrum of the reproduced signal with the relative spectrum of the original tape recording. An example of this comparison is shown in Fig. 3.7 for the drillship stimulus.

TABLE 3.5. AIR GUN PULSE PARAMETERS VS RANGE FOR REPRESENTATIVE TRANSMISSION DATA NEAR ST. LAWRENCE ISLAND.*

Range (km)	L_E (dB re 1μPa²sec)	T (sec.)	$L_{\bar{p}}$ (dB re 1μPa)	$L_{\hat{p}}$ (dB re 1μPa)	$L_{\hat{p}} - L_E$ (dB)	$L_{\hat{p}} - L_{\bar{p}}$ (dB)
.37	160.6	.02	180.6	183.2	22.6	2.6
.41	158.2	.031	176.2	-		
.65	155.8	.03	174.0	176.9	21.1	2.9
.93	152.5	.065	167.4	-		
1.3	148.6	.03	166.8	170.6	22.0	3.8
1.6	146.0	.03	164.2	167.6	21.6	3.4
2.2	143.6	.033	161.4	-		
2.6	139.5	.036	159.9	161.1	21.6	1.2
				Mean	21.8	2.8

Key: L_E = Total Pulse Energy Level

T = Effective Pulse Duration

$L_{\bar{p}}$ = Average Pulse Pressure Level

$L_{\hat{p}}$ = Peak Pulse Pressure Level

*Data for 8/25/1221-1254

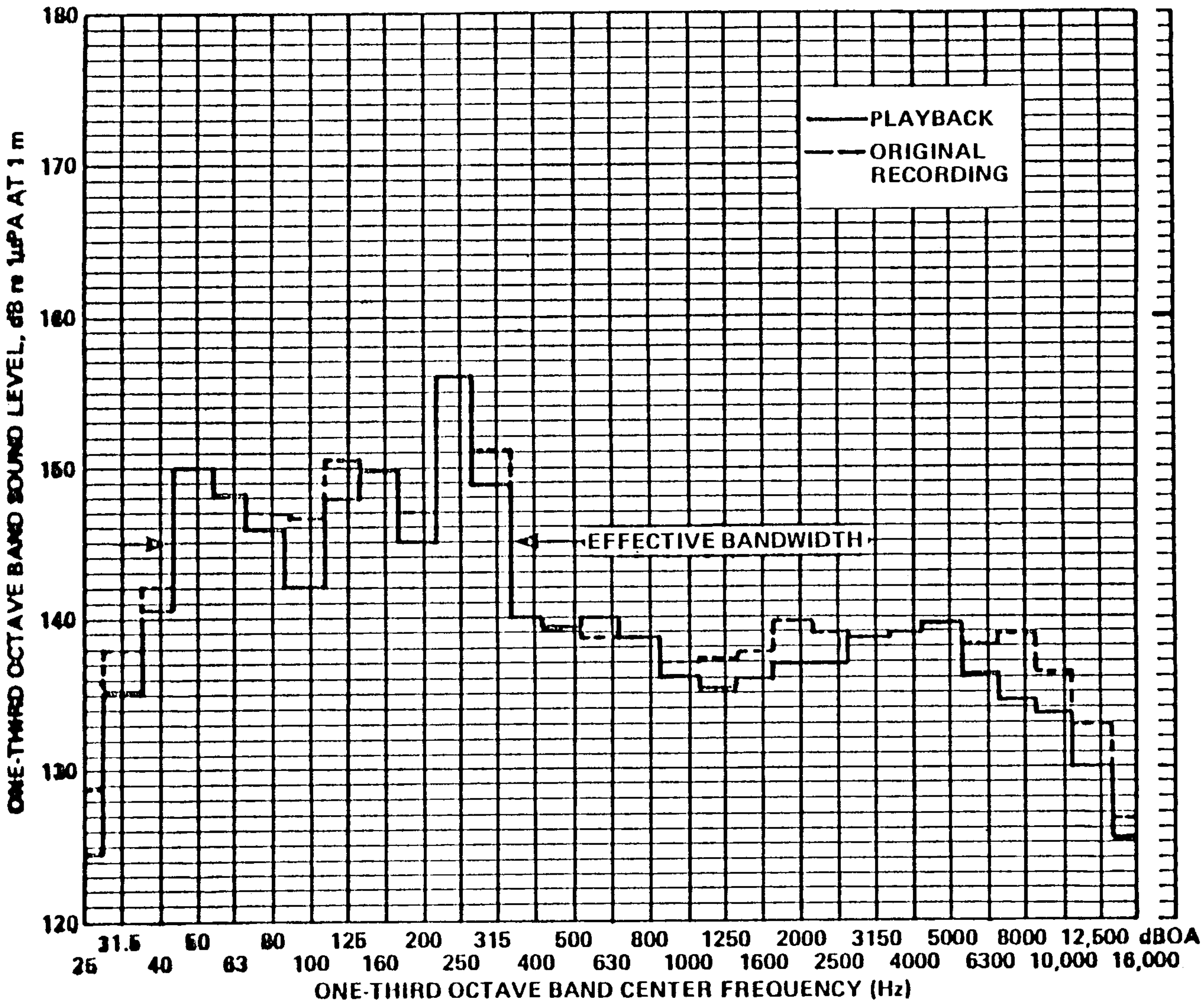


FIG. 3.7 DRILLSHIP ONE-THIRD OCTAVE SPECTRA.

3.3.2 Transmission Loss Measurements

Shallow Water Sound Propagation Characteristics

Acoustic transmission loss in shallow water is highly dependent on the acoustic properties of the bottom material since, in most areas, sound energy is transmitted mainly by paths that are multiply reflected from the bottom and surface. The average number of reflections (or "bounces") depends on the water depth, bottom slope, acoustic properties of the water column (sound velocity gradient), acoustic properties of the bottom, and any directional properties of the source and receiver. In most shallow water areas, the relationship between acoustic pressure and distance from the source (range) has been found to be modeled quite well by considering a spreading loss which is midway between that of unbounded deep water (spherical spreading or 20 log range) and that of ducted horizontal spreading (cylindrical spreading or 10 log range) (Urick 1983, Sec. 6.6). To the spreading loss must be added a loss due to molecular absorption in the water, a loss due to the scattering and absorption at the surface and bottom, and an energy increase due to the surface and bottom "image" sources. The resulting sound propagation model can be expressed in equation form as:

$$RSL = L_s + A_n - 5 \log H_{av} - 15 \log R - A_v R - A_r R / H_{av} - 41 \text{ (dB re } 1\mu\text{Pa)} \quad (3)$$

where

RSL = Received sound level at range R (dB re 1μPa)

L_s = Source level (dB re 1 μPa at 1 m)

R = Range in km

A_v = Molecular (volumetric) absorption (dB per km)

A_r = Reflection loss at surface and bottom (dB - meters per km)

A_n = Change in effective source level due to proximity of surface and/or bottom (dB) (local anomaly).

-41 = Conversion constant (5 log 2π-15 log m/km)

H_{av} = $(H_s + H_r)/2$ where H_s = depth at source (m) and H_r = depth at receiver (m).

For the previous gray whale studies off the California coast, a version of this sound propagation model was developed which incorporated an experimentally derived reflection loss coefficient. Transmission loss data were obtained using both the air gun and the projector sources. Regression analysis of the data provided a best fit value for the reflection loss in terms of an average "loss per bounce." Fortunately, the bottom characteristics in the test area were uniform and the sound velocity gradients were neutral so a single propagation loss equation was found to be applicable to all of the data.

This was not the case for the test area near St. Lawrence Island. Bottom reflection characteristics were found to be somewhat variable in this area. Moreover, appreciable sound velocity gradients were found to exist as a result of the lower salinity and higher temperature of the water near the surface. These gradients can cause variable sound shadowing or sound focusing effects which make transmission loss depth dependent as well as range dependent.

Water Temperature, Salinity, and Sound Velocity Profiles

Variations in the speed of sound with depth in the water column (gradients) can impose important variations on the transfer of acoustic energy from one point to another. Depending upon the average gradient of the sound velocity profile, acoustic energy can be refracted downward (negative gradient conditions - decreasing sound speed with depth), upward (positive gradient conditions - increasing sound speed with depth), or have little path curvature under neutral (mixed water column) conditions. Sound channeling occurs at the depths of local minima in the sound velocity profile, when acoustic energy becomes trapped (propagates without boundary reflections). An understanding of the variability of the sound velocity profile in various regions of the test area is particularly important, since the average profile will dictate the degree to which sound energy will interact with the ocean bottom and surface. Bottom and surface losses imposed on the incident acoustic energy can vary considerably with bottom material and roughness, and sea surface roughness.

Sound velocity in water varies directly with temperature, salinity, and pressure. One algorithm that defines this relationship was derived by Wilson and is used in many underwater sound texts such as Urick (1983). Wilson's equation states:

$$c = 1449.2 + 4.623T - 0.0546T^2 + 1.39(S-35), \text{ (m/sec)} \qquad (4)$$

where c is the speed of sound, T is the temperature (°C), and S is the salinity in parts per thousand. Wilson's equation also contains a term which depends on pressure. Because the depths of interest here are 25 m or less, the pressure term contribution is negligible and has been ignored in Eq. (4).

Temperature and conductivity were measured and salinity calculated at discrete depth increments to a maximum depth of 20 m. Sound velocity profiles were computed from the resulting temperature and salinity profiles with a hand-held calculator that was preprogrammed with Wilson's equation.

Figures 3.8 through 3.10 give typical sound velocity, temperature and salinity profiles in the test area. Most of the data are similar to measurements taken in the inlets of southeast Alaska where water with lower salinity, is often present in a surface layer. Near the surface, lower salinity and warmer temperature conditions produce opposing effects on the speed of sound. The sound velocity profiles shown in Fig. 3.8 result when the temperature is high enough near the surface to offset the effect of lower salinity. The profiles shown produce downward refraction which results in the loss of the direct sound path at a relatively short range between a source and receiver shallower than 15 m. Bottom reflected sound is dominant in determining acoustic transmission loss for shallow source-receiver geometry.

The lower salinity layer near the surface may be the result of the outflow from the Yukon River and other large streams which flow into the Bering Sea. Tidal mixing effects cause considerable variation in the observed temperature and salinity gradients in the area. Figure 3.9 shows a set of data taken in approximately the same area as that shown in Fig. 3.8, but one day later. Here the extreme gradients shown in Fig. 3.8 have been considerably reduced in magnitude. Temperature and salinity data were also taken in Kangeeghuk Bay (see Fig. 3.1), which is on the west side of Southeast Cape. Figure 3.10 shows the results for two sets of measurements taken five days apart. The water column can be seen to be very well mixed in this area with only the salinity data showing slight gradient effects. The reason for the dramatic differences in the temperature and salinity gradients between the east side and west side of Southeast Cape may be a result of turbulence in the tidal flow around the point. Kangeeghuk Bay is sheltered from the general tidal flow into the Chirikof Basin by the shoal area extending south from the cape.

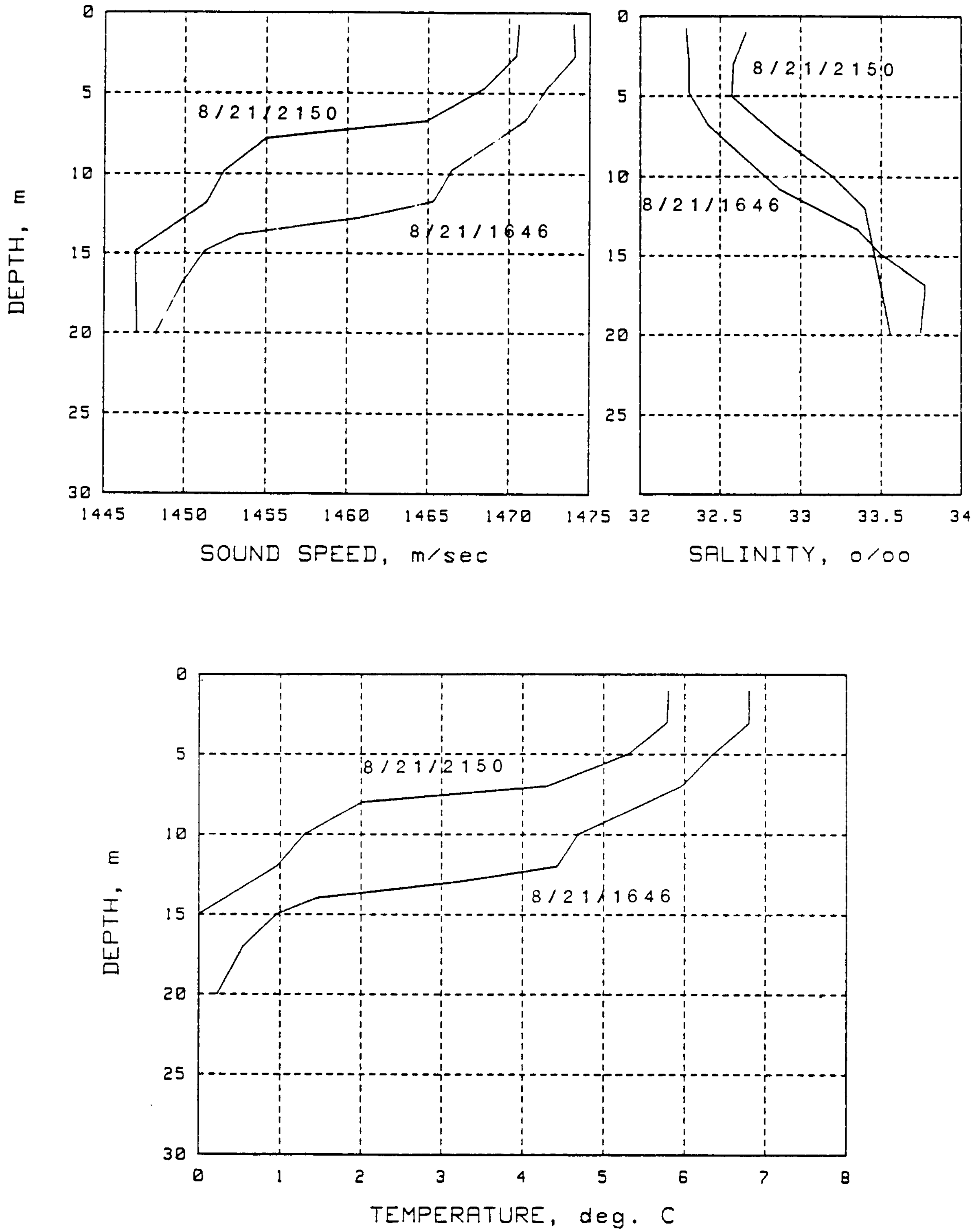
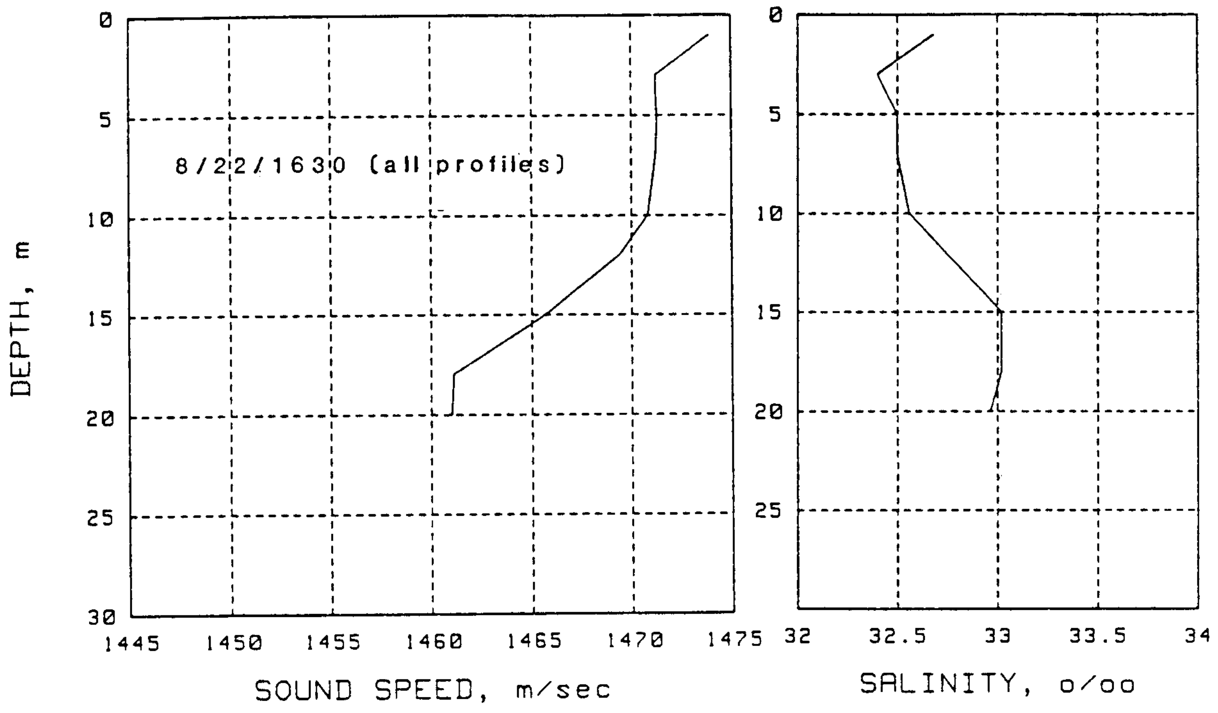


FIG. 3.8. SOUND SPEED, SALINITY, AND TEMPERATURE PROFILES FOR ST. LAWRENCE ISLAND AREA, 8/21/1646, 2150.



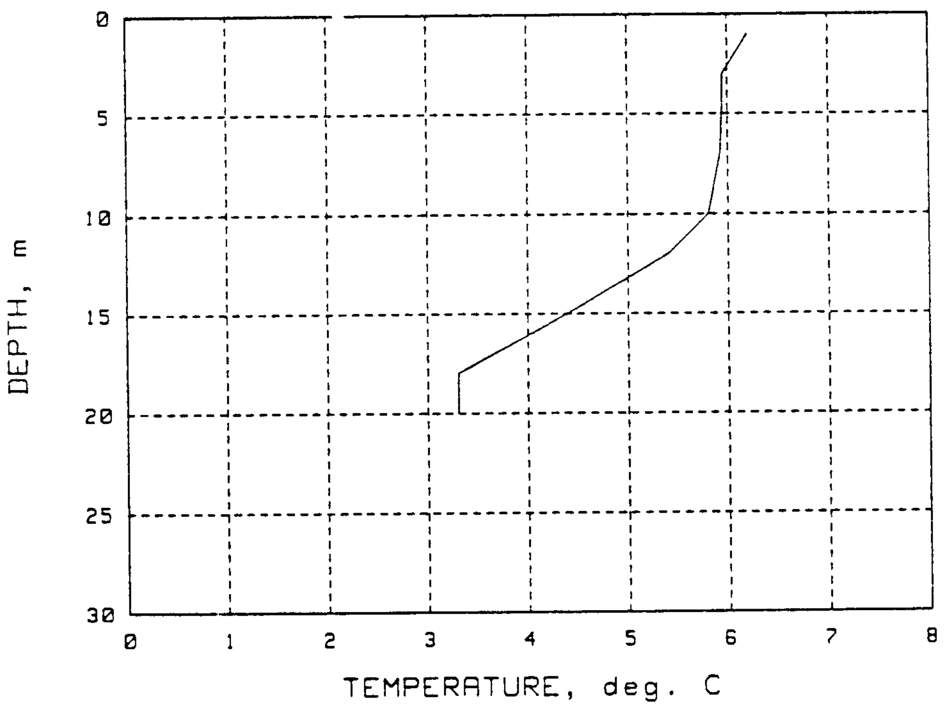


FIG. 3.9. SOUND SPEED, SALINITY, AND TEMPERATURE PROFILES FOR ST. LAWRENCE ISLAND AREA, 8/22/1630.

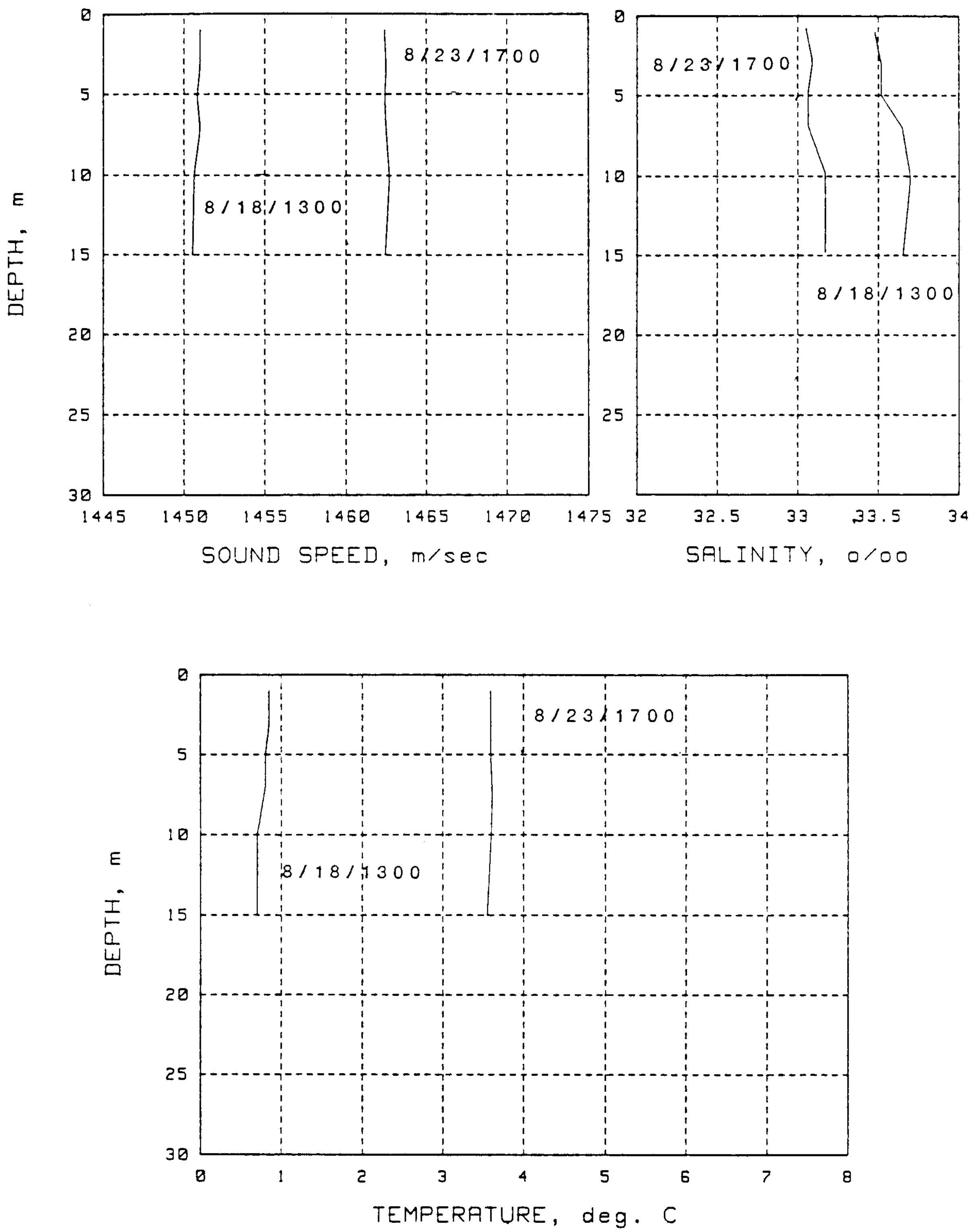


FIG. 3.10. SOUND SPEED, SALINITY, AND TEMPERATURE PROFILES FOR ST. LAWRENCE ISLAND AREA, 8/18/1300, 8/23/1700.

Sound Propagation Measurement Results

Transmission loss measurements were performed concurrently with the whale behavior tests. The air gun was operated at a depth of 10 m which was generally below or near the bottom of the surface layer of warmer, less saline water. Measurements of received level at several depths and ranges did not show the depth dependence expected to be produced by the observed strong downward refracting gradients such as those shown previously in Fig. 3.8. This was probably a result of the shallow water which ranged from 15 to 25 m in depth. Reflections and general scattering from the bottom and probable sub-bottom layers produced generally reverberant received signals.

Figures 3.11 and 3.12 show typical signal waveforms and pressure spectra for two different propagation ranges. The data shown in Fig. 3.11 are for short range propagation where the direct signal and probable sub-bottom reflections can be separated in the observed waveform. The spectrum can be seen to have an effective bandwidth extending from 30 Hz to 500 Hz. Figure 3.12A shows the effect of increased propagation range. Here, the waveform is generally higher frequency in character and has a shorter duration than that seen in Fig. 3.11A. The signal spectrum in Fig. 3.12B shows attenuation of both the low frequency and high frequency portions of the spectrum when compared to the short range spectrum shown in Fig. 3.11B. This demonstrates that sound propagation in shallow water has the effect of a bandpass filter. Low frequencies are attenuated because they often involve propagation through a portion of the bottom sediments with high energy absorption. High frequencies are attenuated as a result of volume absorption, boundary absorption, and boundary scattering. As a result there remains an optimum pass band, from about 100 to 350 Hz in this case, which suffers the lowest absorption losses (Smith 1986).

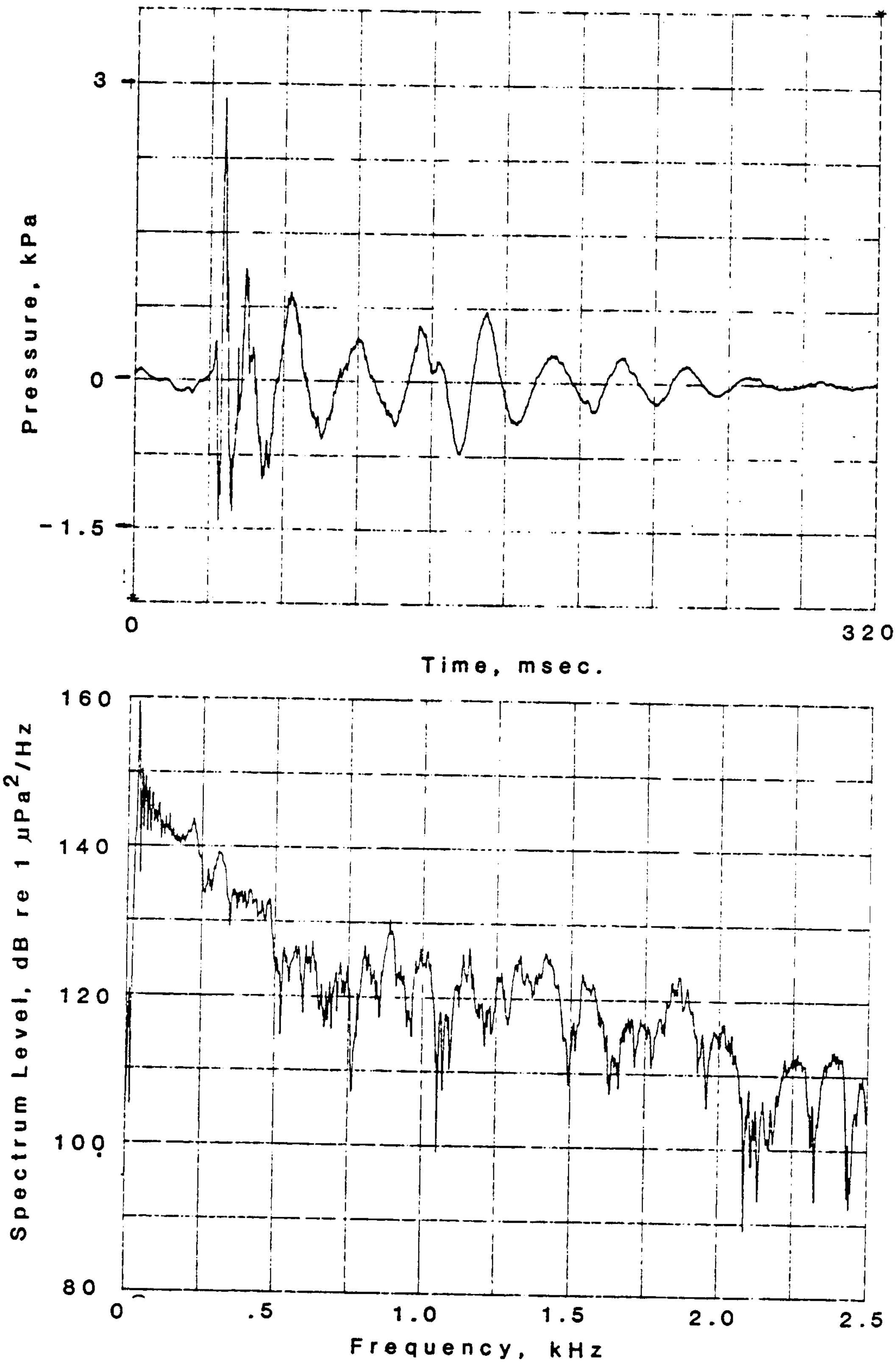


FIG. 3.11. AIR GUN SIGNATURE AND SPECTRUM, 100 in.^{3}, 4500 psi, RANGE 200 m, DEPTH 10 m.

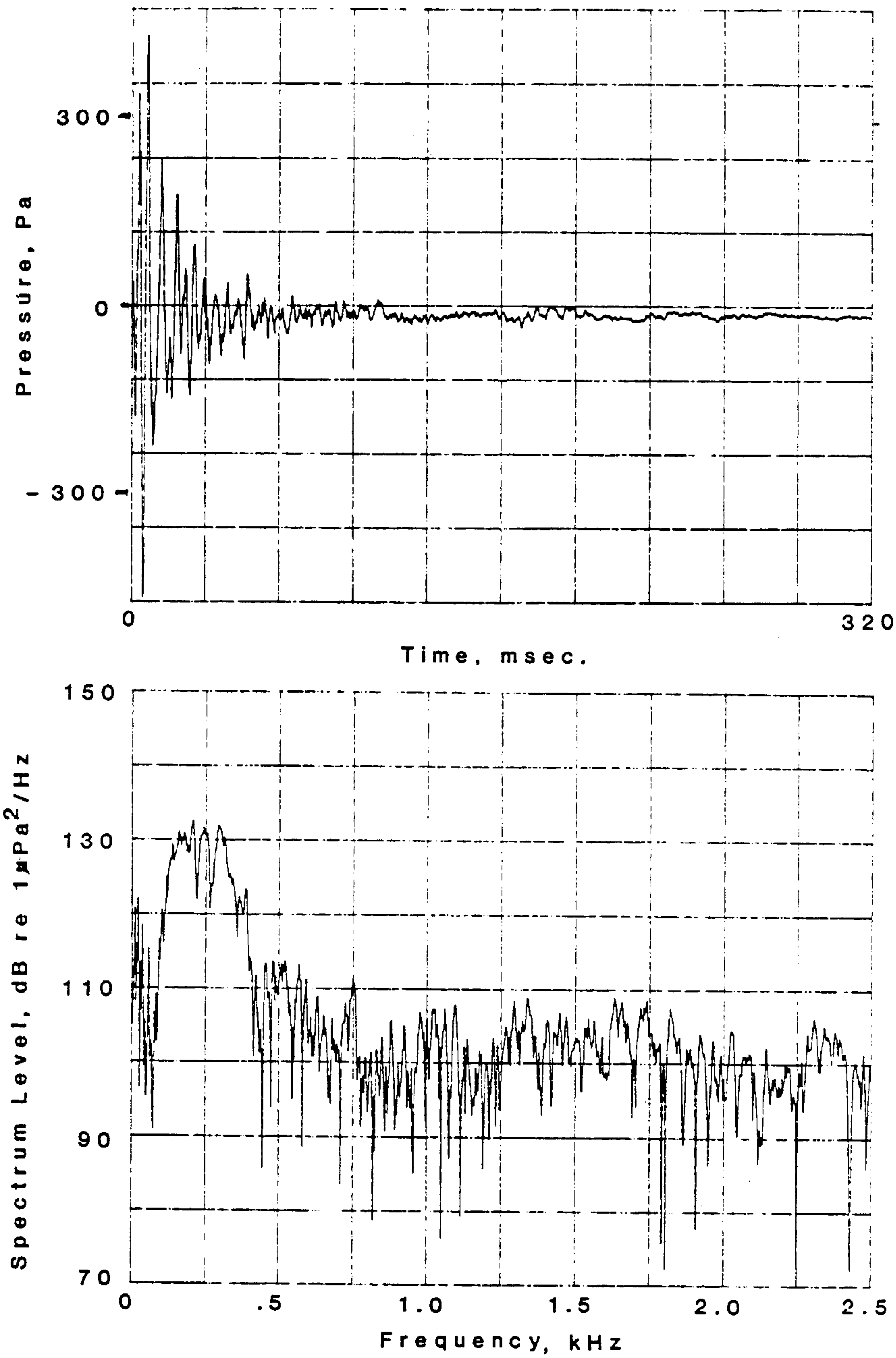


FIG. 3.12. AIR GUN SIGNATURE AND SPECTRUM, 100 in.^{3}, 4500 psi, RANGE 650 m, DEPTH 10 m.

The transmission loss measured in the St. Lawrence Island area was lower than that measured off the California coast during the migrating gray whale study (Malme et al. 1983, 1984). A comparison of the characteristics of the two areas for average pulse pressure propagation is shown in Fig. 3.13. A shallow sub-bottom layer of rock probably causes the considerably better sound propagation conditions observed off St. Lawrence Island since the bottom composition according to chart information is sand/silt for both areas. While no specific sub-bottom information has been obtained for the St. Lawrence test area, MacKensie (1973) reported underlying layers of granitic and basaltic rock at depths of 3 to 10 m for an area lying to the east of the island.

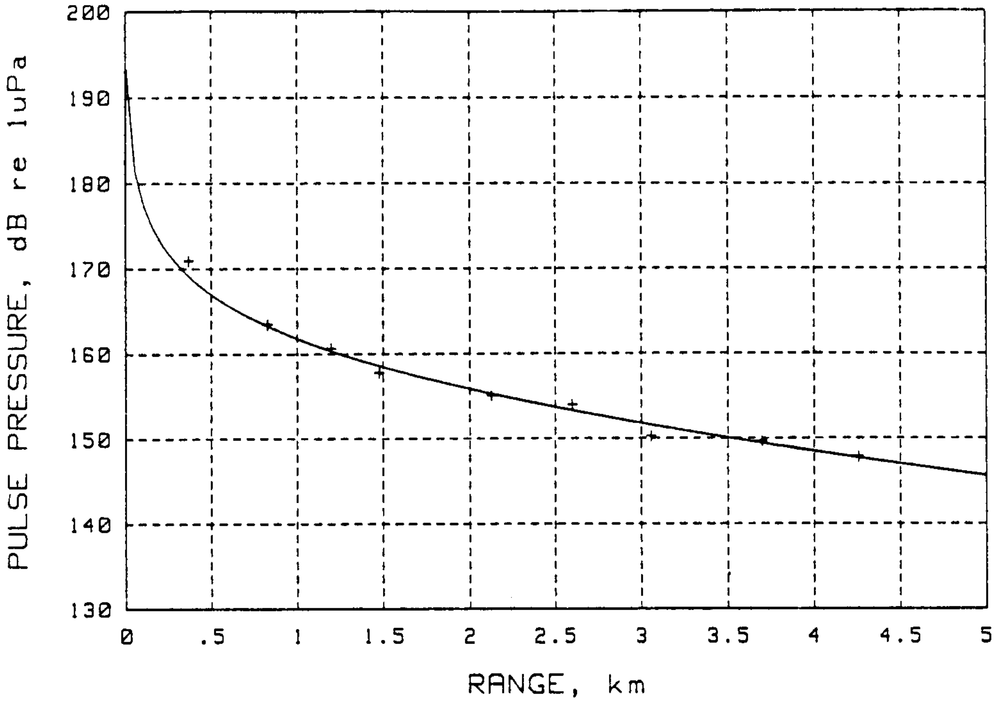
The average pulse pressure level incorporates measures of both pulse amplitude and time duration and is related to the total pulse energy level by the following relationship:

$$L_{\bar{p}} = L_e - 10 \log T \text{ (dB re 1 } \mu\text{Pa)} \quad (5)$$

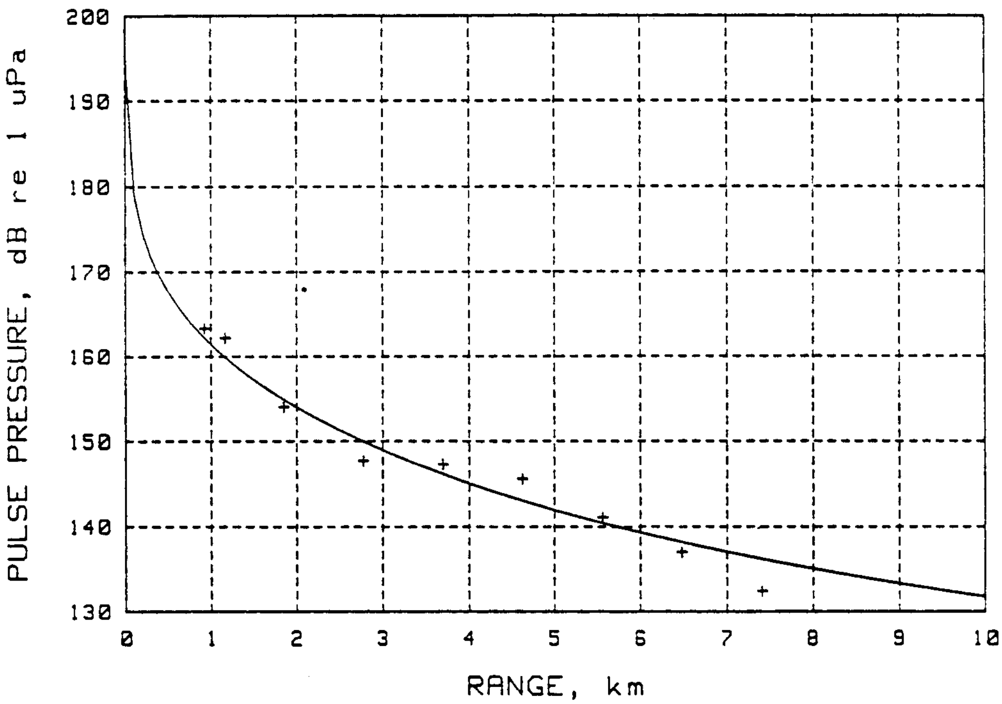
where the total pulse energy level,

$$L_e = 10 \log \bar{P}^2 T/2 - 10 \log \rho c \text{ (dB re 1 Joule)} \quad (6)$$

from Eq. (1). If L_e is referenced to 1 μPa^2-second, the correction term, 10 log ρc can be omitted. The pulse duration is influenced by bottom attenuation, surface roughness, and by multi-path propagation and, as a result, often changes with increasing range. A comparison of the air gun pulse duration characteristics of the California and St. Lawrence test sites is shown in Fig. 3.14A. The transmission loss characteristics as determined using the total pulse energy level from air gun tests

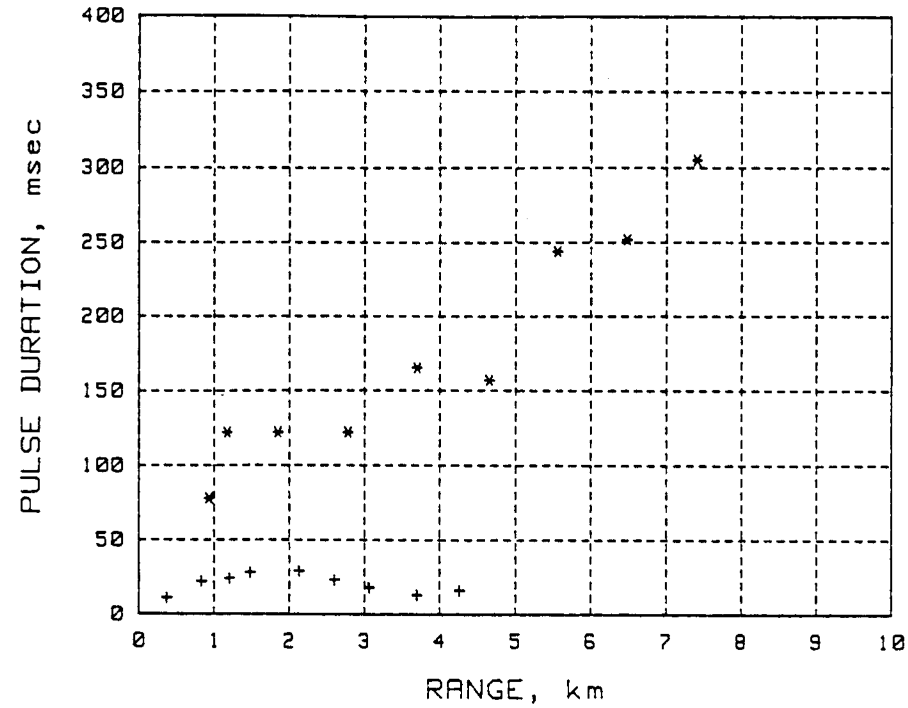


A. St. Lawrence Island Site, Depth 14 m, 0 Slope

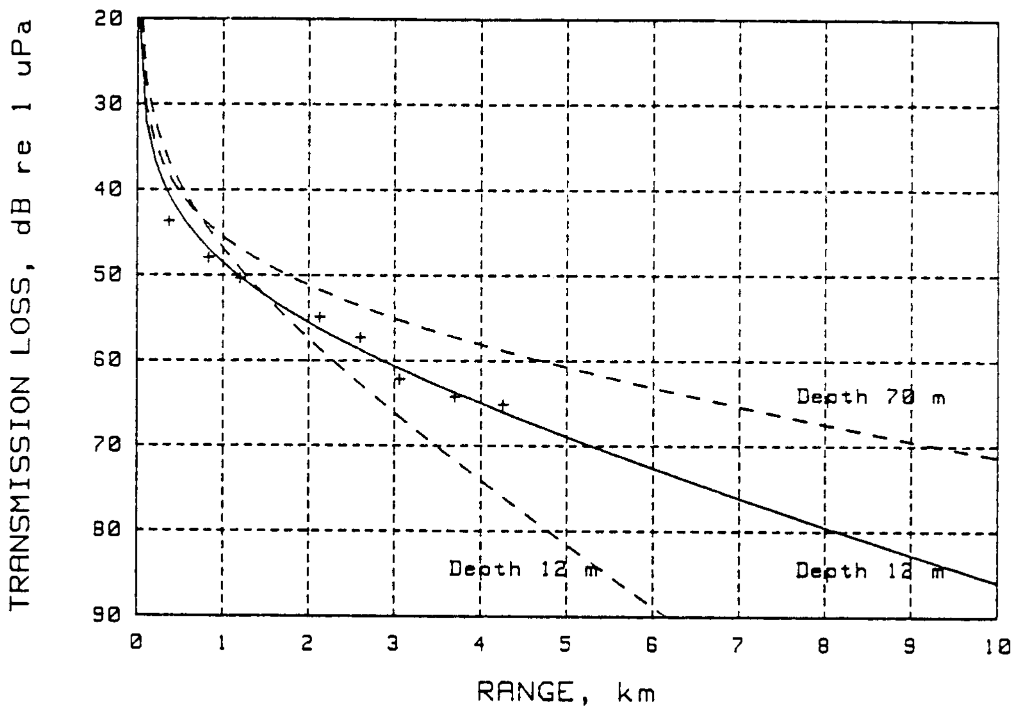


B. California Site, Avg. Depth 70 m, Slope .015

FIG. 3.13. COMPARISON OF AVERAGE PULSE PRESSURE DATA WITH PREDICTIONS OF EMPIRICAL PROPAGATION MODEL. (SOURCE - 100 CU. IN. AIR GUN AT 4,500 PSI.)



A. Pulse Duration, St. Lawrence Is. (+), California (*)



B. Transmission Loss, St. Lawrence Is. (+)——, California ----

FIG. 3.14. COMPARISON OF PULSE DURATION TIME SPREADING AND TRANSMISSION LOSS CHARACTERISTICS OF ST. LAWRENCE ISLAND AND CALIFORNIA TEST AREAS.

at the California and the St. Lawrence test sites are shown in Fig. 3.14B.

3.3.3 Ambient noise measurements

The ambient noise levels near St. Lawrence Island were determined by the local wind conditions and by the radiated noise from the vessels used in the study. No contributions from biological sources were measured. No definite gray whale vocalizations were heard during the ambient noise monitoring periods. The vessel noise was primarily caused by auxiliary generator operation since all maneuvering during test conditions was done at low speed.

The sea conditions during the acoustic study periods ranged from sea state 1/2 to sea state 2. During periods of higher sea states it was not possible to observe whales properly so testing was suspended. Figure 3.15 shows the one-third octave spectrum for representative ambient conditions. This spectrum is compared with data reported by Urick (1983) for other shallow water areas. The radiated noise source level for the BIG VALLEY is shown in Fig. 3.16. This noise spectrum is primarily caused by auxiliary generator operation and is also typical of that produced by the NANCY H generator. By referring to the transmission loss characteristic for the area, it is possible to estimate that the levels of the highest one-third octave bands will approximately equal ambient noise levels at a range of 3 to 4 km for the conditions existing for Fig. 3.15. The playback spectrum shown previously in Fig. 3.7 is louder than the radiated noise in all one-third octave bands. Thus, the generator operation during playback was not expected to influence the simulated drillship stimulus.

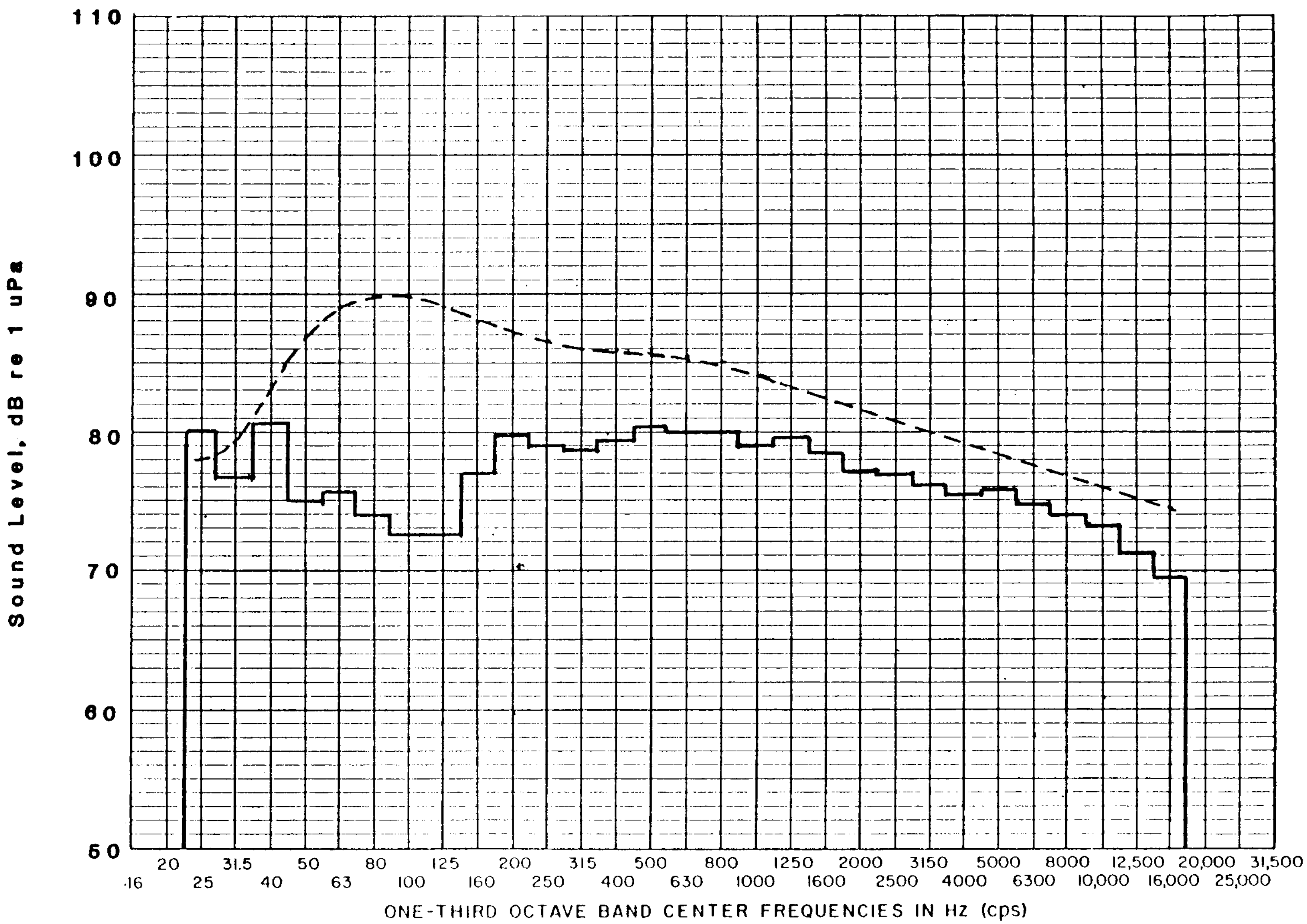


FIG. 3.15. AMBIENT NOISE SPECTRUM FOR ST. LAWRENCE ISLAND TEST AREA. WIND SPEED 10 KTS, DEPTH 12 m. DASHED CURVE FROM WENZ (1962) FOR SHALLOW WATER, 10 KT WIND, MODERATE SHIPPING TRAFFIC.

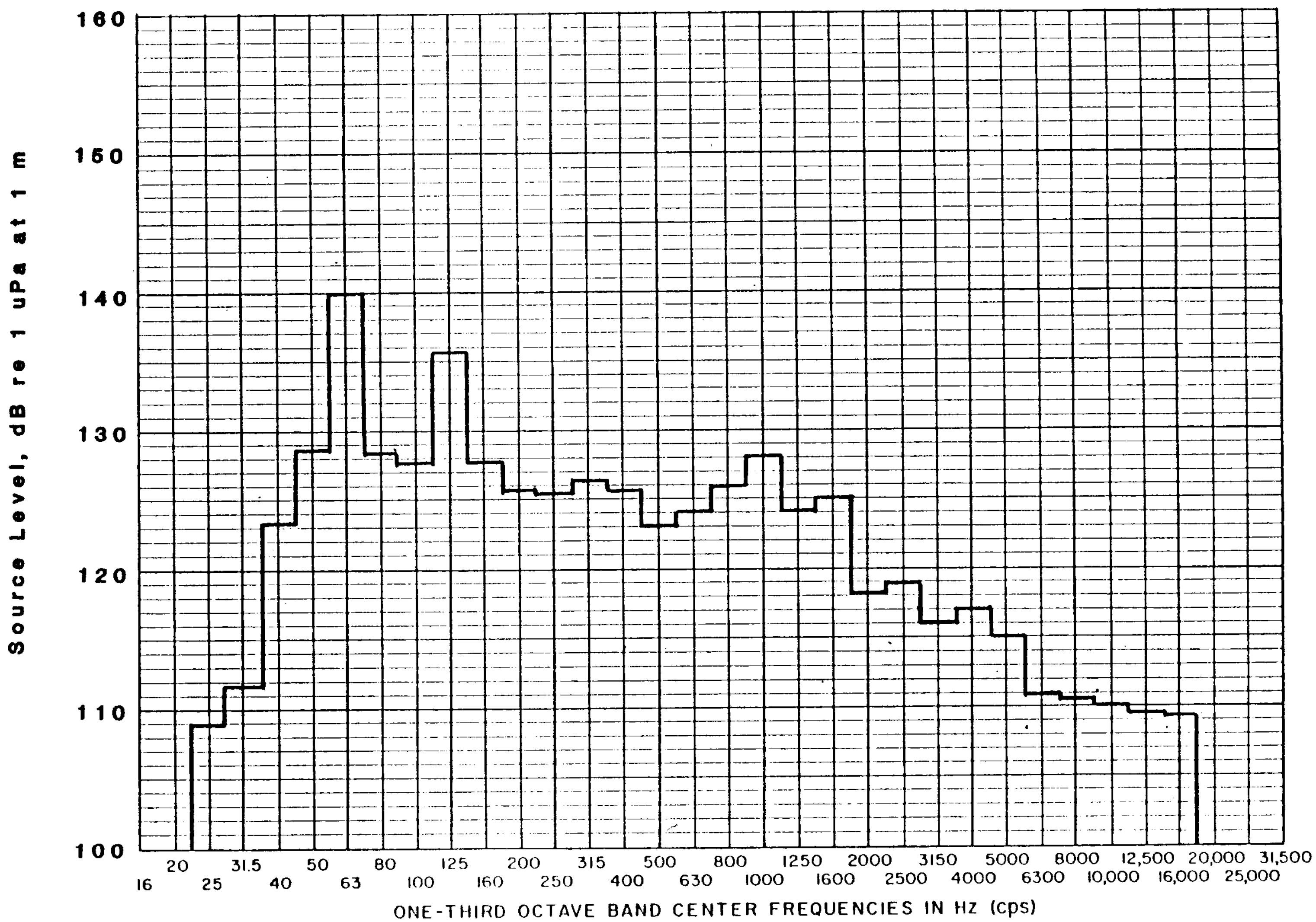


FIG. 3.16. RADIATED NOISE SOURCE LEVEL FOR AUXILIARY MACHINERY ON M.V. BIG VALLEY.

The control periods for the playback and air gun tests were performed with normal auxiliary machinery operating conditions on both the BIG VALLEY and the NANCY H. The air compressor for operating the air gun on the NANCY H was not running during control conditions to conserve fuel. This compressor was mounted on rubber tires and was not expected to contribute significantly to underwater radiated noise.

3.3.4 Acoustic exposure estimation

Since some variation in sound transmission was observed for the several test areas used, specific data from each test area were used in prediction of the sound exposure levels for whale sightings.

Air Gun Average Pulse Pressure

As described previously in Section 3.2.5, the data were analyzed using a computer-implemented least-squares technique which determines the best-fit values for two parameters in the received level equation presented previously as Eq. (3). The values of L_s' and A_r are determined by the computer using measured data. When the source level is calibrated, the effect of the local bottom and surface conditions on sound propagation can be determined as a local "anomaly" where:

$$L_s' = L_s + A_n \text{ (dB)} \quad (7)$$

Here, L_s is the pressure level measured at 1 m from the source and A_n is the local anomaly resulting from bottom and surface reflection effects.

The results of analysis of the transmission loss measurements are summarized in Table 3.6. The values of A_n and A_r

TABLE 3.6. SOUND TRANSMISSION PARAMETERS FOR ST. LAWRENCE ISLAND AIR GUN TESTS.

SOUND TRANSMISSION EQUATION

$$L_{\bar{p}} = L_s + A_n - 5 \log H_{av} - 15 \log R - A_r(R/H_{av}) - 41 \text{ (dB re } 1\mu\text{Pa)}$$

L_s = 213 dB re 1 μPa at 1 m

Date/Time	A_n* (dB)	A_r* dB-m/km	H_{av} (m)
8/22/1443-1600	-4	17	20
8/22/1731-1745	2	144	20
8/24/1722-1754	-3	20	10
8/24/2015-2024	0	30	12
8/25/1221-1254	7	54	14

*Determined from data using the method of least-squares.

shown in the table were used together with Eq. (3) to estimate the exposure levels at the whale sighting positions for the air gun experiments. An example of the received average pulse pressure level versus range characteristic was shown previously in Fig. 3.13A.

Playback Exposure Level and Signal-to-Noise Ratio

The results of the playback experiments with migrating gray whales (Malme et al. 1983, 1984) showed that two types of behavioral reactions occurred. An initial "detection" reaction occurred at ranges where the loudest portion of the playback spectrum approached the ambient noise level in the same frequency band (0 dB S/N). This reaction was generally observed as a change in swimming speed and often a slight change in heading. As a result of this change in swimming pattern, the whales would pass the region of the source at a greater distance than would be the case under control (no playback) conditions. A second type of behavioral reaction observed for some playback tests was a change in swimming direction occurring at a relatively close range to the source. In either case, the reaction resulted in varying degrees of "avoidance" of the region with loud sound levels. Accordingly, we have analyzed the playback data to provide information not only on the absolute level and spectrum of the reproduced signals but also on their relative levels in relation to local ambient noise conditions.

The sound transmission characteristics for the playback tests were estimated using the equations derived for the air gun tests in the areas where they were relevant. The exposure level versus range to the whales was then derived using the same techniques developed for the air gun data.

The "available S/N ratio" was estimated for each playback stimulus using the following procedure. The effective signal level for the playback signal was determined by calculating the RMS signal level for the "dominant" bandwidth. Referring back to Fig. 3.7, the dominant signal bandwidth was determined by observing the highest 1/3 octave band level in the signal as measured by the monitor hydrophone, and then including the total number of 1/3 octave bands which had levels within 10 dB of the maximum. The ambient noise spectra measured before and after the playback sequence were averaged and the RMS noise signal for the same dominant bandwidth was calculated. The available S/N ratio was obtained by subtracting the effective masking noise level (dB). Thus, in developing our estimated signal-to-noise (S/N) ratios for the playback stimuli, in the absence of specific hearing response measurements for gray whales, we have considered that the dominant masking of the playback signal is produced by ambient noise in the same frequency range.

Table 3.7 lists the results of analyzing the playback stimuli and the ambient noise levels at the time of projection according to the procedure discussed in the preceding section. The results are presented in terms of available S/N ratio, 1 m from the projector, and the estimated range for an effective S/N ratio of 0, 10, 20, and 30 dB. These ranges are presented both for the entire dominant bandwidth as well as for the highest 1/3 octave band in the respective stimulus. The last measure is appropriate for determining if observed response changes are the result of stimulus detection at low levels. This was not possible in the St. Lawrence Island tests because the detection response, if any occurred, would have been well beyond the range of observation.

The transmission loss relationship pertaining to the playback test areas is also listed in Table 3.7. This equation was used to obtain the range values given in the table.

TABLE 3.7. PLAYBACK SIGNAL/NOISE DATA AND ESTIMATED EFFECTIVE RANGE.

Date/Time	Stimulus Code	BW_{eff} Hz	L_S* dB**	L_N dB**	S/N dB	R_0 km	R_{10} km	R_{20} km	R_{30} km	B_M Hz	S/N dB	R_0 km	R_{10} km	R_{20} km	R_{30} km
8/21/1142	DS 2	50-315	162	86	76	8.4	4.8	2.2	0.7	250	80	10.2	6.3	3.2	1.2
8/21/1448	DS 3	50-315	156	86	70	6.3	3.2	1.2	0.32	250	74	7.7	14.2	1.8	0.53
8/21/1950	DS 4	50-315	159	86	73	7.3	3.8	1.6	0.45	250	77	8.8	5.2	2.3	0.79

*Referred to 1 m.

**Referred to 1 μPa.

Key: B_M = 1/3 octave band with highest S/N

R_0 = range at which S/N = 0 dB, etc.

Propagation Characteristic for Playback Tests

$$RSL = L_S - 5 \log H_{av} - 15 \log R - 30\ R/H_{av} - 41 \text{ (dB re 1}\mu\text{Pa)}$$

where

$H_{av} = (H_s + H_r)/2$, H_s = depth at source (m), H_r = depth at receiver (whale) (m)

R = range (km)

3.4 Behavioral Observations and Analysis

In this section we provide qualitative descriptions of gray whale movement patterns during control and experimental conditions as well as analyses of surface, respiration, and dive time variables and sighting data. These results are compared with other studies conducted on non-migrating baleen whales.

3.4.1 Gray whale movement patterns

The following behavioral descriptions are based on field notes, summaries written at the end of each observation day, estimated received sound levels (RSL) at whales observed under experimental conditions, and track plots of whale movement patterns. We have included only brief descriptions of overall whale movement patterns for Drillship experiments 1 and 4 (DS 1, DS 4) on 19 and 21 August, respectively. During DS 1, observations were made from only one vessel. Therefore no whale position or RSL data are available for this experiment. Low light conditions and inability to follow individual whales prevented detailed observations during DS 4.

The number of whales observed under experimental conditions was low throughout the field season. This was due mainly to the late starting date of the project, which resulted in a low number of whales present in the study area and adverse viewing conditions (see Section 3.1.2). The primary behavioral objective of this study was two-fold: to obtain surfacing, respiration, and dive data on individual whales during control and experimental conditions, as well as to track the movements of these same whales. Because many whale groups were so far offshore during much of the field season, it was not possible to use land-based theodolite tracking of individual whales in combination with small boat observations as was accomplished by Würsig, Wells, and Croll (1983, 1986). The use of this method would have increased the number of whale groups tracked, since land-based observers could have concentrated on 3 to 4 groups simultaneously, whereas the two-boat method most often employed required BIG VALLEY observers to focus only on the one to two groups under observation by Zodiac personnel in order to obtain whale movement data. During Air gun 1 and 2 (AG 1, AG 2) experiments on 22 August, for example, we have prolonged detailed observations, including both surfacing/respiration data and track plots, on one whale. What follows, then, with the two exceptions noted above, are descriptions of whale groups for which overall behavioral patterns are fairly complete. We have presented all times to the nearest minute.

Drillship Playback Experiments

DS 1,* 19 August, 2108-2129

Prior to the onset of DS 1, observers on board the BIG VALLEY took surfacing, respiration, and dive times on a number of whale groups within 600 m of the vessel, at times recording data on two whales simultaneously. Viewing conditions were fair to poor during this period; however, observers were able to take useful data. It could not be determined if the whales in the area were feeding.

In the first 3+ minutes after the onset of DS 1, only one whale was sighted in the vicinity of the BIG VALLEY. After 2111, no whales were observed within 600 m of the vessel until 2151, approximately 21 minutes after DS 1 had ended. Although observation conditions remained the same as they had been during the pre-DS 1 control period, it was our impression that the

*This was a preliminary experiment to check and adjust the projector system.

whales moved out of the immediate area of the BIG VALLEY after 2111, with whales returning to the area during the post-DS 1 control period. Individual identification of whales was not possible because of their distance from the observation vessel, so it is not known whether the whales in the vicinity of the BIG VALLEY before DS 1 were the same whales present after the experiment.

DS 2, 21 August, 1142-1212

Several whales were under observation prior to DS 2, most notably focal whale Q. Surfacing/respiration and movement data on one whale, Whale Q, were collected by Zodiac personnel from 1129-1203. There were no indications that Whale Q was feeding during this period.

During pre-DS 2 control period, observers noted that Whale Q increased its speed of movement at approximately 1134, moving away from the BIG VALLEY, which was motoring from north to south through the area. This time coincides with the closest recorded approach of the BIG VALLEY to Whale Q, 0.95 km. Other whales were under observation in the same general area and there is some indication that these whales, too, were moving away from the vessel between 1131-1134. Whale M exhibited similar behavior, moving away from the vessel at 1124-1125, a time coinciding with the closest recorded approach of the BIG VALLEY, 0.48 km. There is some indication, based on its movement pattern, that Whale M had been feeding prior to this time. Based on these limited observations, it is possible that the movement patterns observed during the pre-DS 2 control period were the result of BIG VALLEY's transecting through the area. Whale M was joined by two other whales at 1139, and the observed movement may also have been at least in part due to social activity. After this time, observations on Whale M were terminated because this whale could no longer be individually identified.

During DS 2 playback, Whale Q was exposed to peak RSL of 110 dB at 1150, with the BIG VALLEY 1.45 km distant. Subsequent levels decreased to 105 dB. No unusual behavior was noted.

DS 3, 21 August, 1448-1542

Focal whale W was first observed by Zodiac personnel at 1258 and was followed until 1617, a period encompassing both pre- and post-DS 3 controls. Movement data on this whale are only available for the pre-DS 3 control and DS 3 playback periods. Figures 3.17 and 3.18 present track plots of Whale W relative to the BIG VALLEY during the pre-DS 3 control and DS 3 playback, respectively.

From 1302-1313 during the pre-DS 3 control, Zodiac observers noted one of the few interactions between whales seen during the entire field season. This occurred before we started gathering triangulation data, so there is no figure for this. Whales W and Y joined, resulting in a number of underwater blows and two pectoral fin slaps. Prior to this time, Whale W had been feeding and after this interaction the whale resumed feeding, with mud observed on several occasions from 1322-1455. An examination of the track of Whale W on both figures shows that it stayed in the same general area throughout the time it was followed by both Zodiac and BIG VALLEY observers (1358-1536). At approximately 1403, the BIG VALLEY was 0.5 km distant from Whale W (see Figure 3.17). No unusual behavior was observed at that close distance. See Section 3.4.2 for a description of the surfacing/dive characteristics of Whale W related to experiment #2 of the day.

During the period from 1448, the start of DS 3, and 1455, RSL at Whale W peaked at 106 dB, with the BIG VALLEY 1.12 km distant. Subsequent levels decreased to approximately 103 dB near the end of the playback. These decreasing levels were the result of BIG VALLEY drifting northwest, away from Whale W,

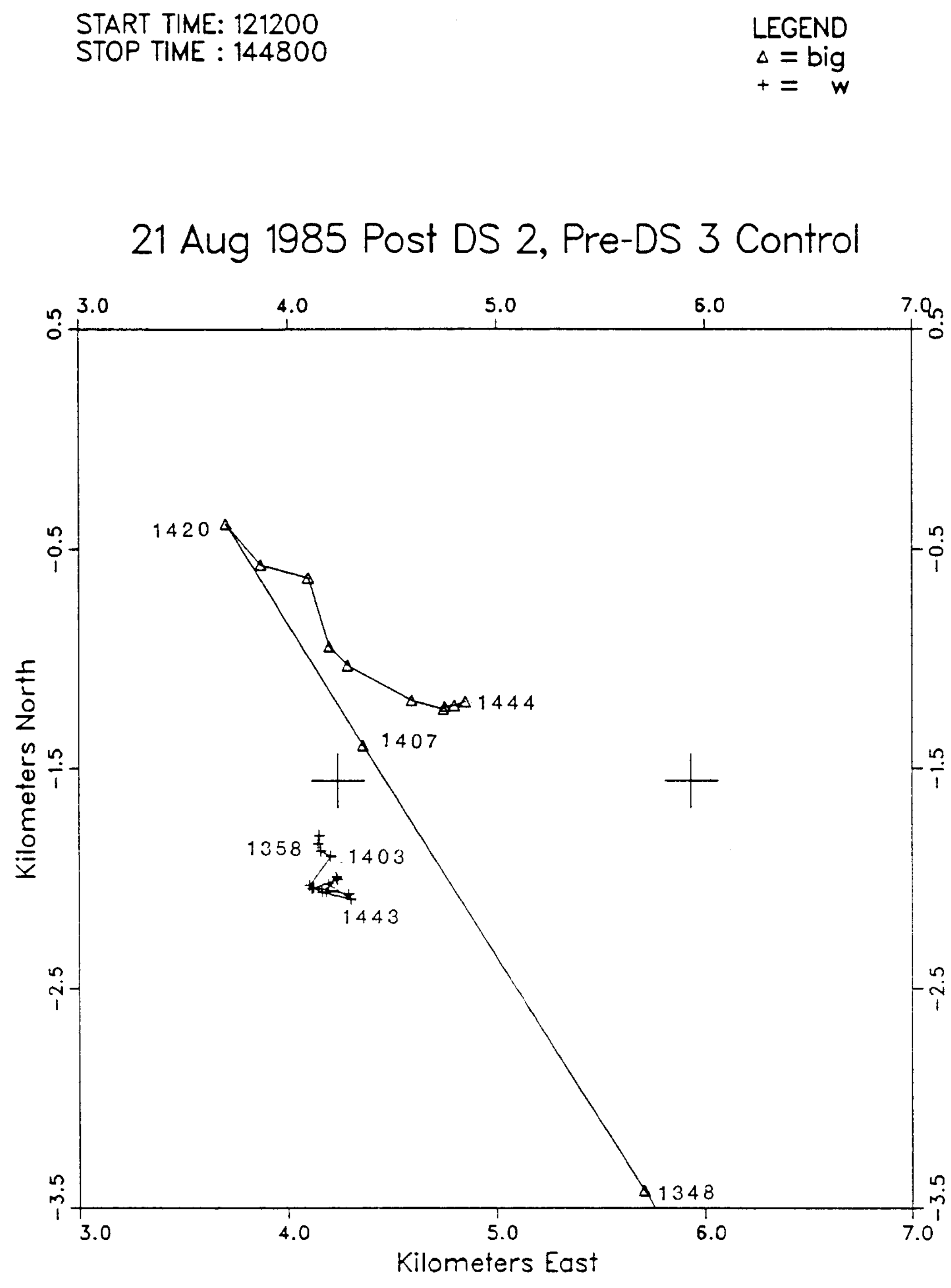


FIG. 3.17. TRACK PLOT OF WHALE W DURING PRE-DS 3 PLAYBACK CONTROL ON 21 AUGUST.

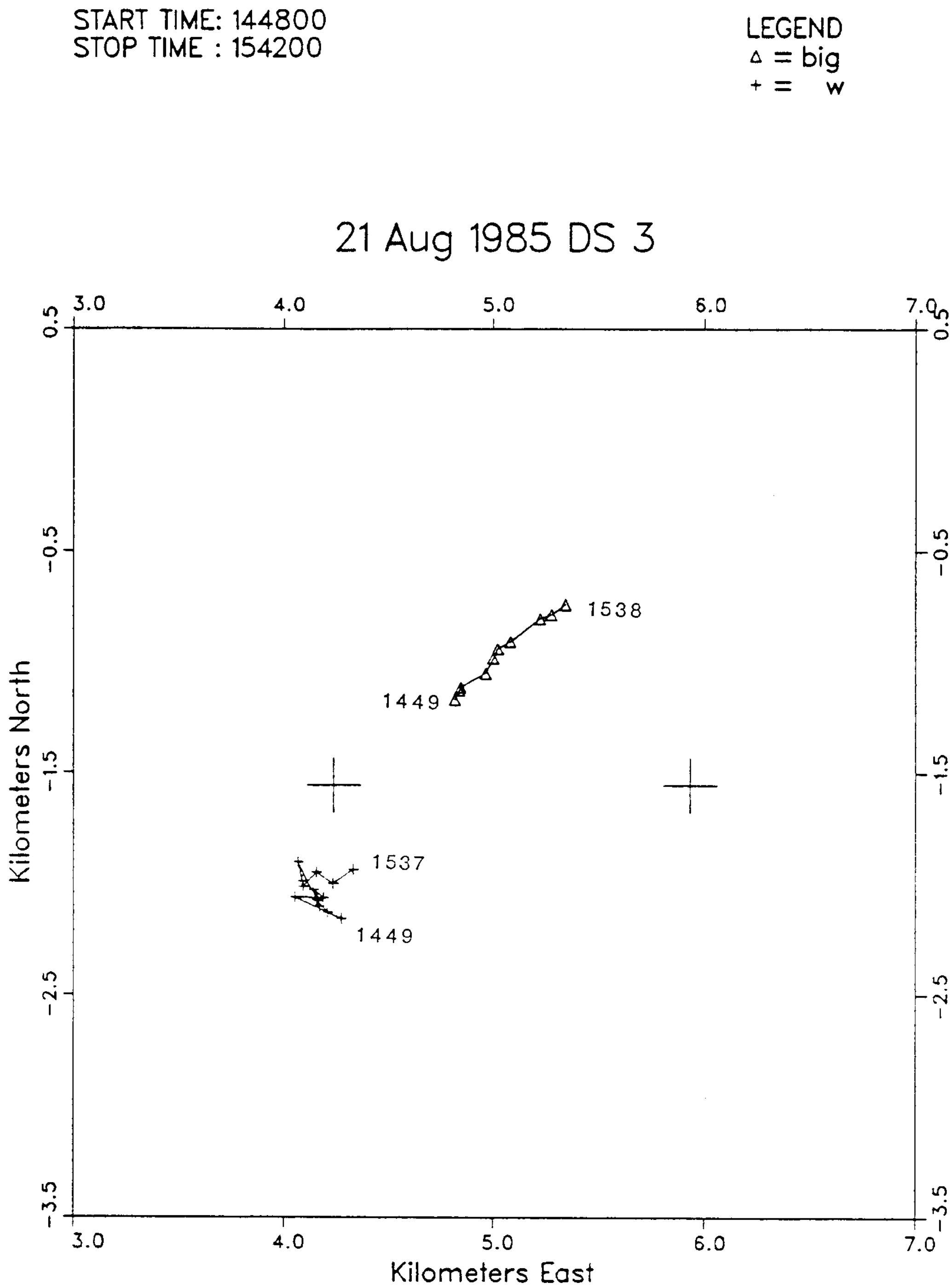


FIG. 3.18. TRACK PLOT OF WHALE W DURING DS 3 PLAYBACK ON 21 AUGUST.

during the playback (see Figure 3.18). Whale W was not observed to feed from 1456 until 1543, 1 minute after the end of DS 3. However, we believe that Whale W was feeding during this period because its pattern of changing direction and remaining in one area were typical of feeding behavior. Whale W continued to feed (as evidenced by mud plumes) until the end of observations at 1617.

DS 4, 21 August, 1950-2057

Difficulty in identifying and following individual whales and low light conditions hampered collection of data for DS 4. However, observers on BIG VALLEY qualitatively noted a shift in whale distribution within 10 minutes after the onset of the playback at 1950, with all whales under observation moving to the northeast. RSL at whales under observation during DS 4 varied from 108 to 119 dB. We took 27 position readings on approximately 15 whales. We were unable to determine if the whales were feeding.

Air gun Experiments

AG 1 and 2, 22 August, 1440-1600, 1731-1758

We combine the discussion of these two AG experiments because much of the data collected concerns a single focal whale followed for an extended period encompassing both experiments.

Whale E was followed by Zodiac personnel from 1141-1852, a total of 7.2 hr, the longest period that a whale was kept under continuous observation during the field season. Movement data were collected on this whale from 1327-1832. Figure 3.19 shows the movement of Whale E during pre-AG 1 control. Although mud was only observed associated with Whale E once during this control period, (observance of mud was hampered by poor visibility between approximately 1400-1632), the many direction

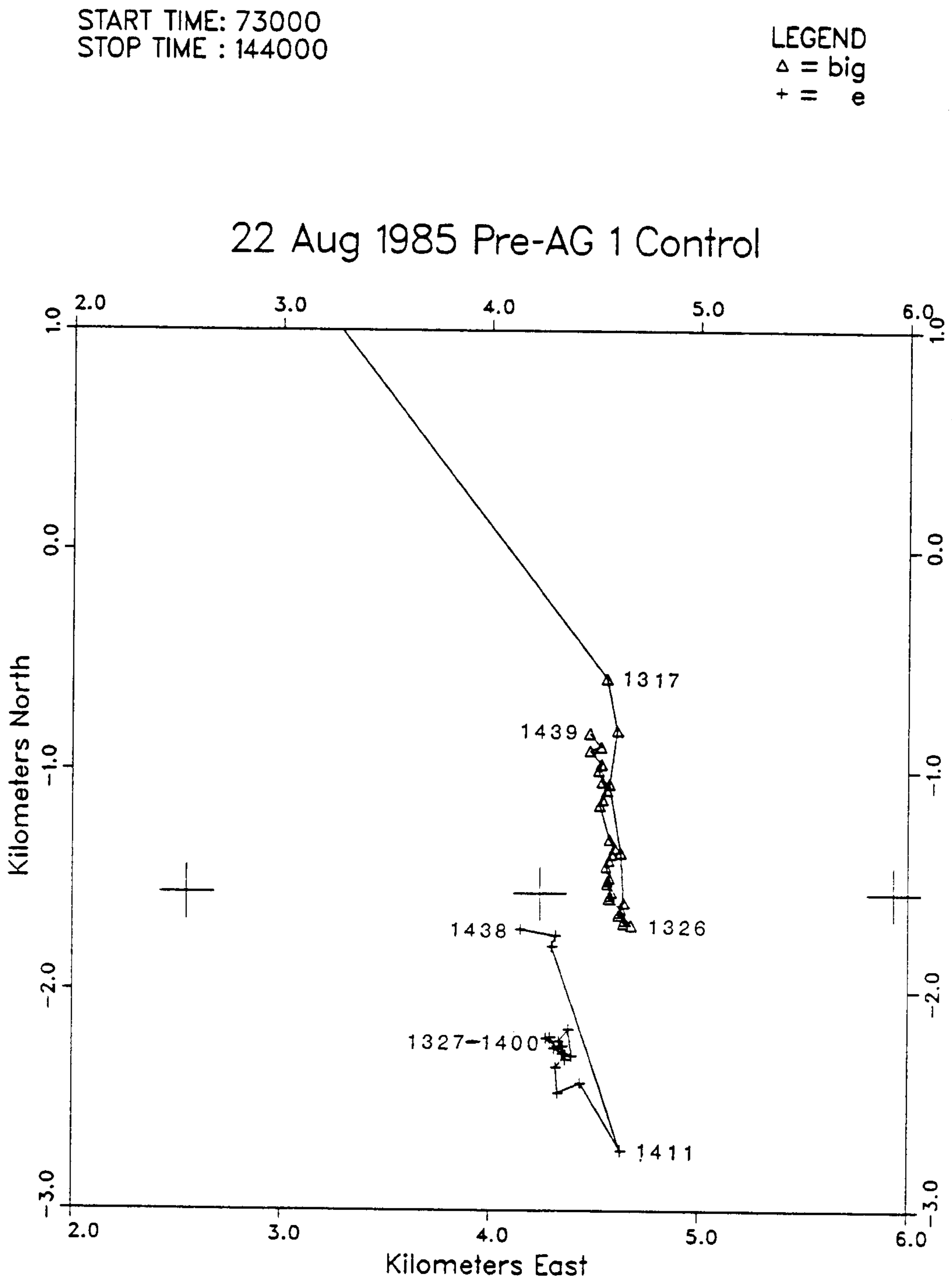


FIG. 3.19. TRACK PLOT OF WHALE E DURING PRE-AG 1 CONTROL ON 22 AUGUST.

changes and the fact that the whale stayed in the same general location during much of the time, led observers to conclude that this whale was feeding. We cannot explain the northward movement pattern between 1411-1438 as shown in Fig. 3.19. At 1446, 6 minutes after the onset of AG 1, personnel on the BIG VALLEY noted that the 5 to 7 whales under observation, including Whale E, were moving offshore. RSL at the whales was approximately 149 dB, with the NANCY H 3.9 km distant. The Zodiac personnel also noted the whales moving offshore at 1503, at which time the NANCY H was 3.63 km distant from Whale E and RSL was 150 dB. Throughout both control and experimental periods, Whale E was the only whale under continuous observation. Figures 3.20A and 3.20B show the movement pattern of Whale E in relation to the NANCY H, which was moving south towards the general area of the whale. At 1504, Whale E was joined by 1 or 2 whales, and the whales moved south, then southeast and offshore. RSL increased at Whale E throughout AG 1, with a peak level of 172 dB reached at 1559, with NANCY H 0.19 km distant. No indications of feeding by Whale E or by other whales in the area were noted during the experiment.

Examination of the track plot of Whale E in relation to the southward-moving NANCY H indicates that this whale was actively moving away from the vessel, possibly attempting to move offshore. However, the last three readings on Whale E during AG 1 indicate that it did not continue to move southeast, but stayed in the same area as the NANCY H approached its position. During this period (1549-1558), RSL at Whale E increased from 160 dB to 172 dB.

Our next reading of Whale E (see Figure 3.21) at 1606, almost 6 minutes after the end of AG 1, shows that between 1558 and this time, the whale moved back to the north and by 1633 was feeding, as evidenced by mud plumes. (Time 1633 coincides with

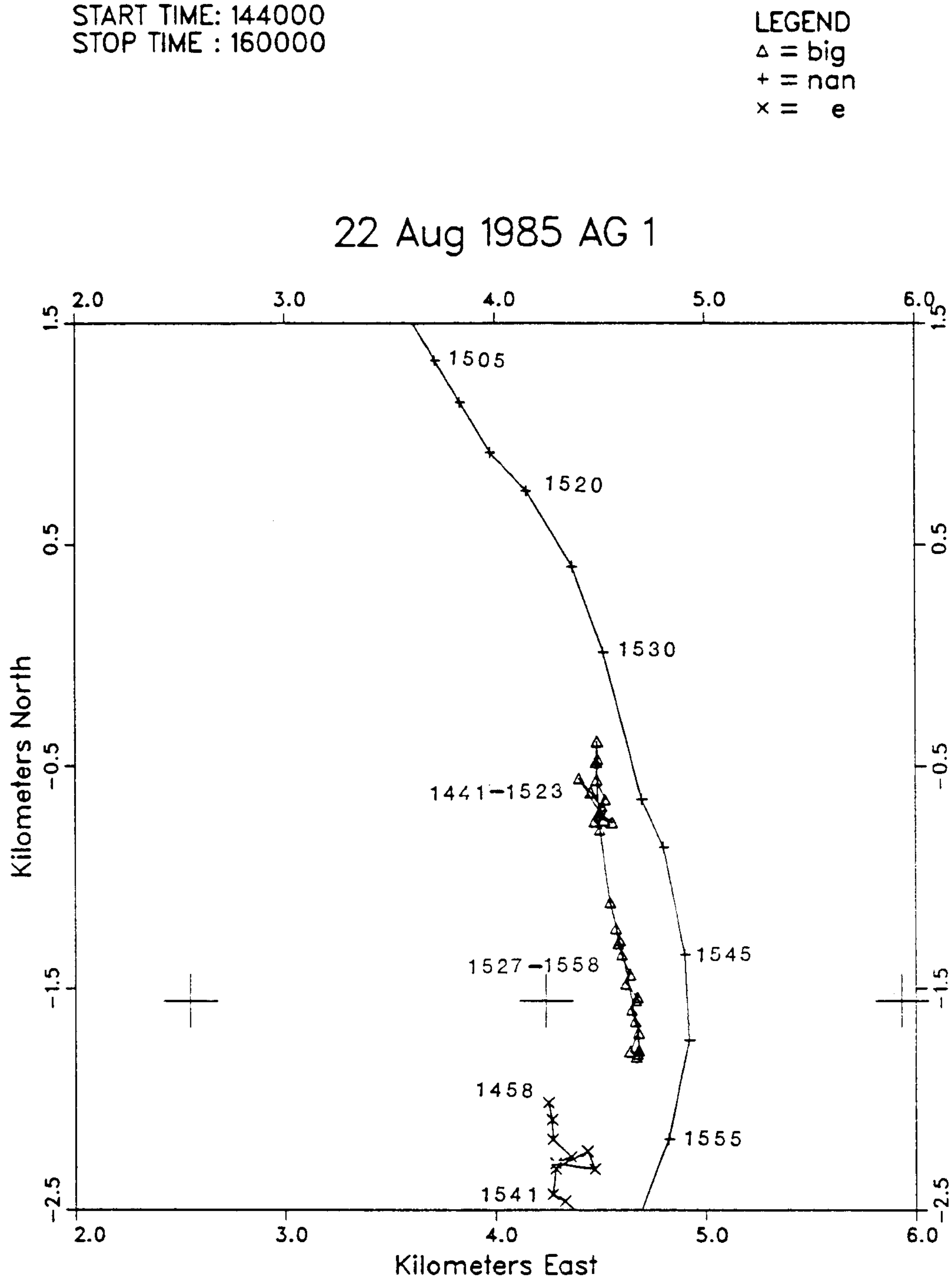


FIG. 3.20A. TRACK PLOT OF WHALE E DURING AG 1 ON 22 AUGUST. TWO FIGURES ARE PRESENTED TO SHOW THE SOUTHWARD PROGRESSION OF THE NANCY H.

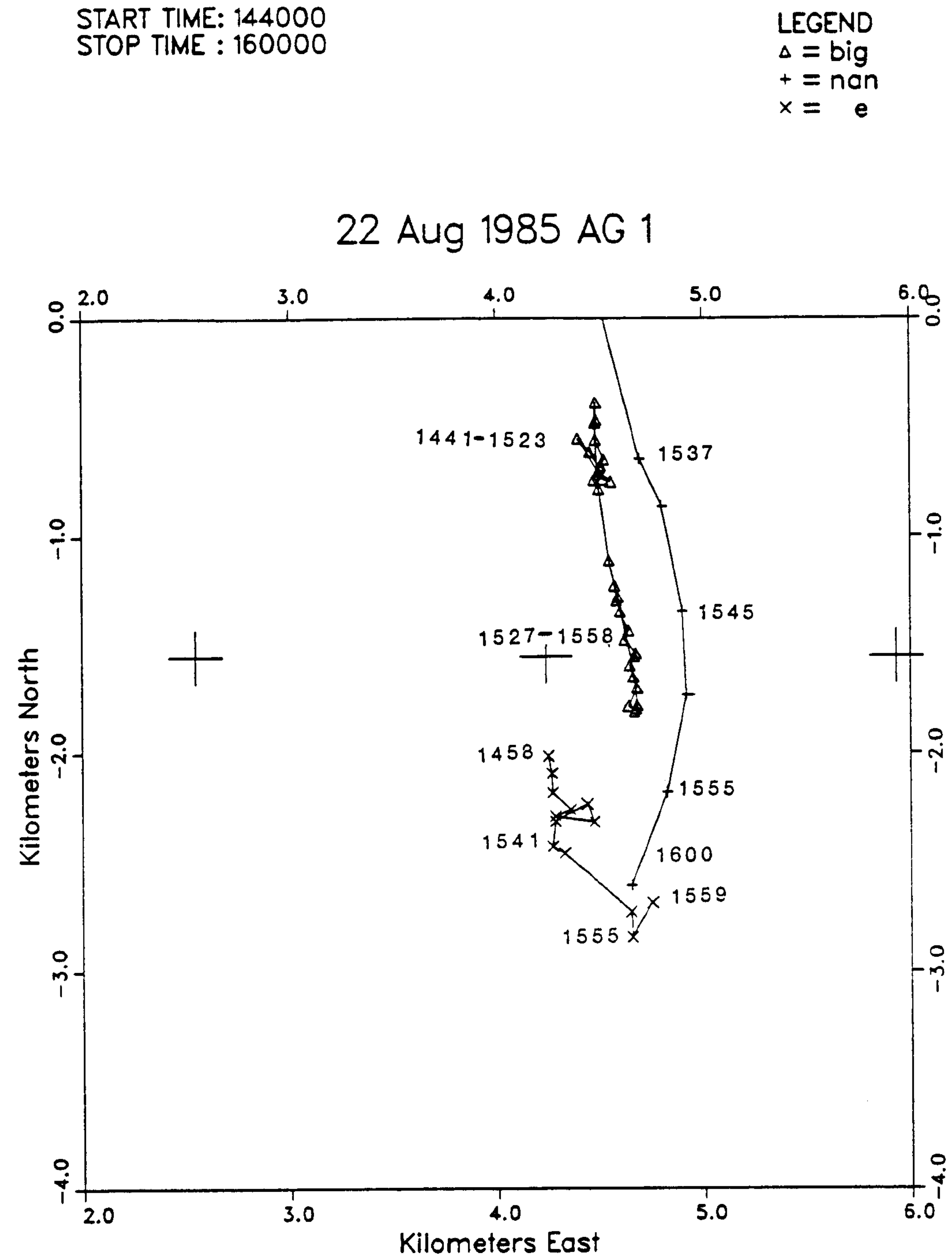


FIG. 3.20B. TRACK PLOT OF WHALE E DURING AG 1 ON 22 AUGUST. TWO FIGURES ARE PRESENTED TO SHOW THE SOUTHWARD PROGRESSION OF THE NANCY H.

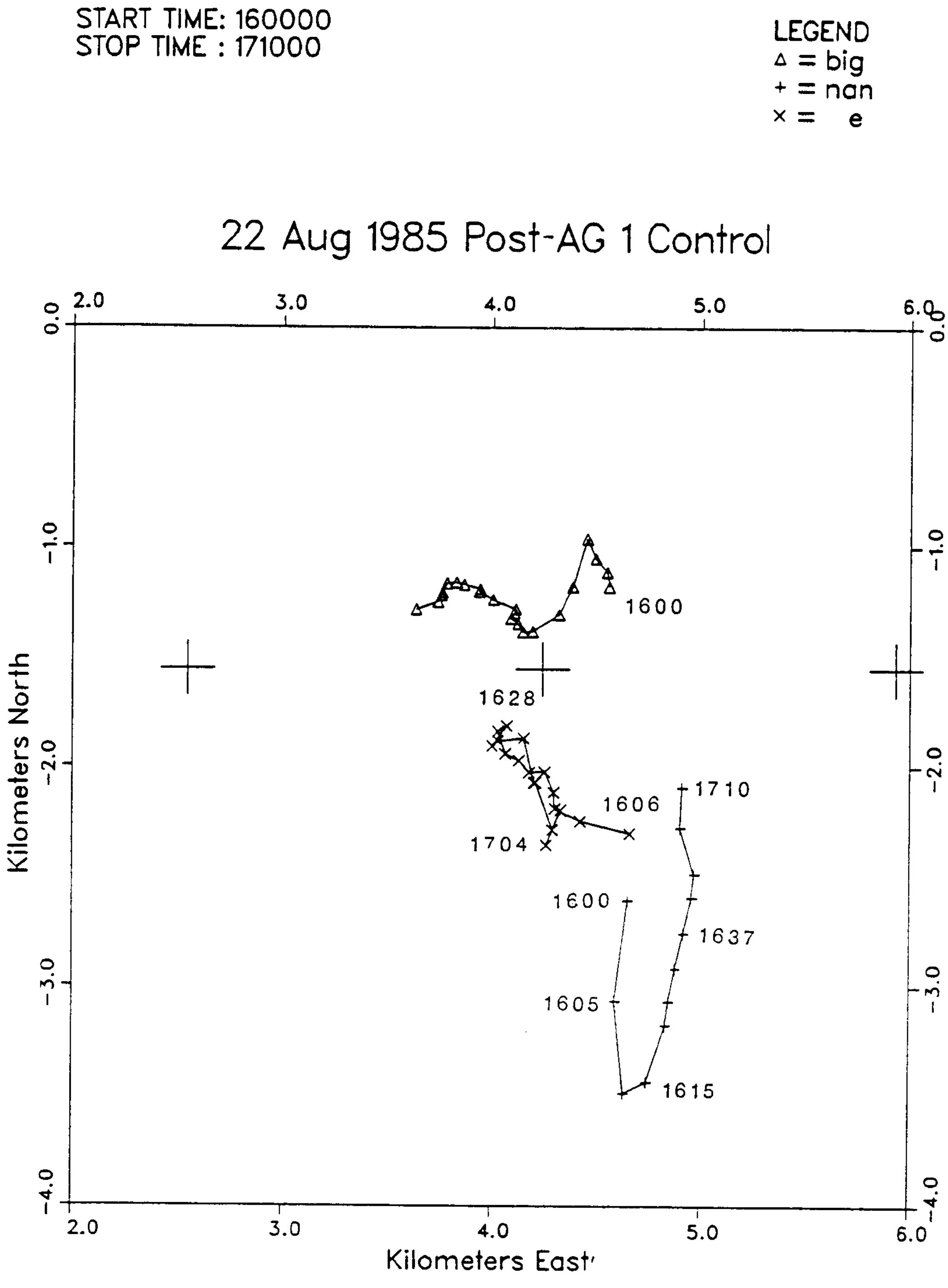


FIG. 3.21. TRACK PLOT OF WHALE E DURING POST-AG 1 CONTROL ON 22 AUGUST.

the first appearance of the sun all day, thereby making mud at the water's surface more easily visible to observers). At this time, the whale was approximately 0.5 km northeast of its pre-AG 1 control position. The whale stayed in this same general area, feeding, through the post-AG 1 control period. Zodiac personnel noted that after the end of AG 1, other whales were also moving inshore to the general area of Whale E. However, we do not have track information on these whales.

Prior to the onset of AG 2, Whale E was observed to be feeding in the same general area that it had returned to after the completion of AG 1. During AG 2, RSL reached a peak of 172 dB at 1742 with the NANCY H 0.47 km distant, moving to the northeast (see Figure 3.22). At 1739, roughly coinciding with peak RSL, observers on board the Zodiac as well as on BIG VALLEY noted Whale E "abruptly" change direction, turn approximately 135° from NW to ENE, and orient towards the NANCY H. Whale E moved toward the general location of the NANCY H until approximately 1746 when the whale turned to the southeast and continued south until at least 1754, at which time RSL at the whale was 163 dB. Mud was not seen associated with Whale E between the time of the abrupt change in direction and 1749; however, this whale was feeding both before and after these times. Figure 3.22 shows that the BIG VALLEY was within 0.5 km of Whale E during AG 2. This movement of the BIG VALLEY is the result of drift. It is unclear whether Whale E's movements during AG 2 were a response to the playback or were associated with feeding behavior.

Figure 3.23 shows that during the post AG 2 control period, Whale E moved SSE until approximately 1825 when it headed to the east. The whale continued to feed throughout this period. Unfortunately, the BIG VALLEY, which had been drifting into shallow water, was forced to start engines and move offshore at

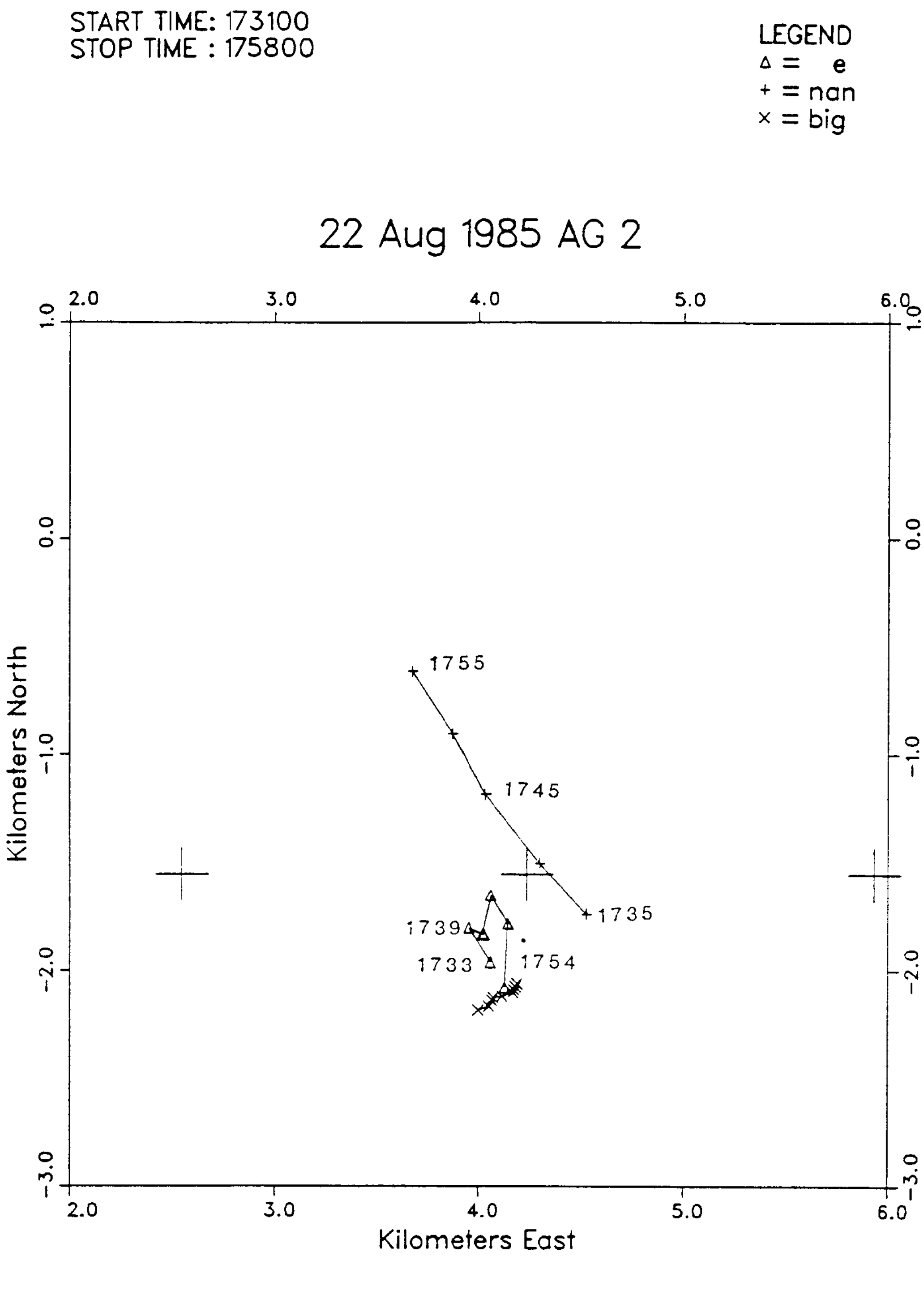


FIG. 3.22. TRACK PLOT OF WHALE E DURING AG 2 ON 22 AUGUST.

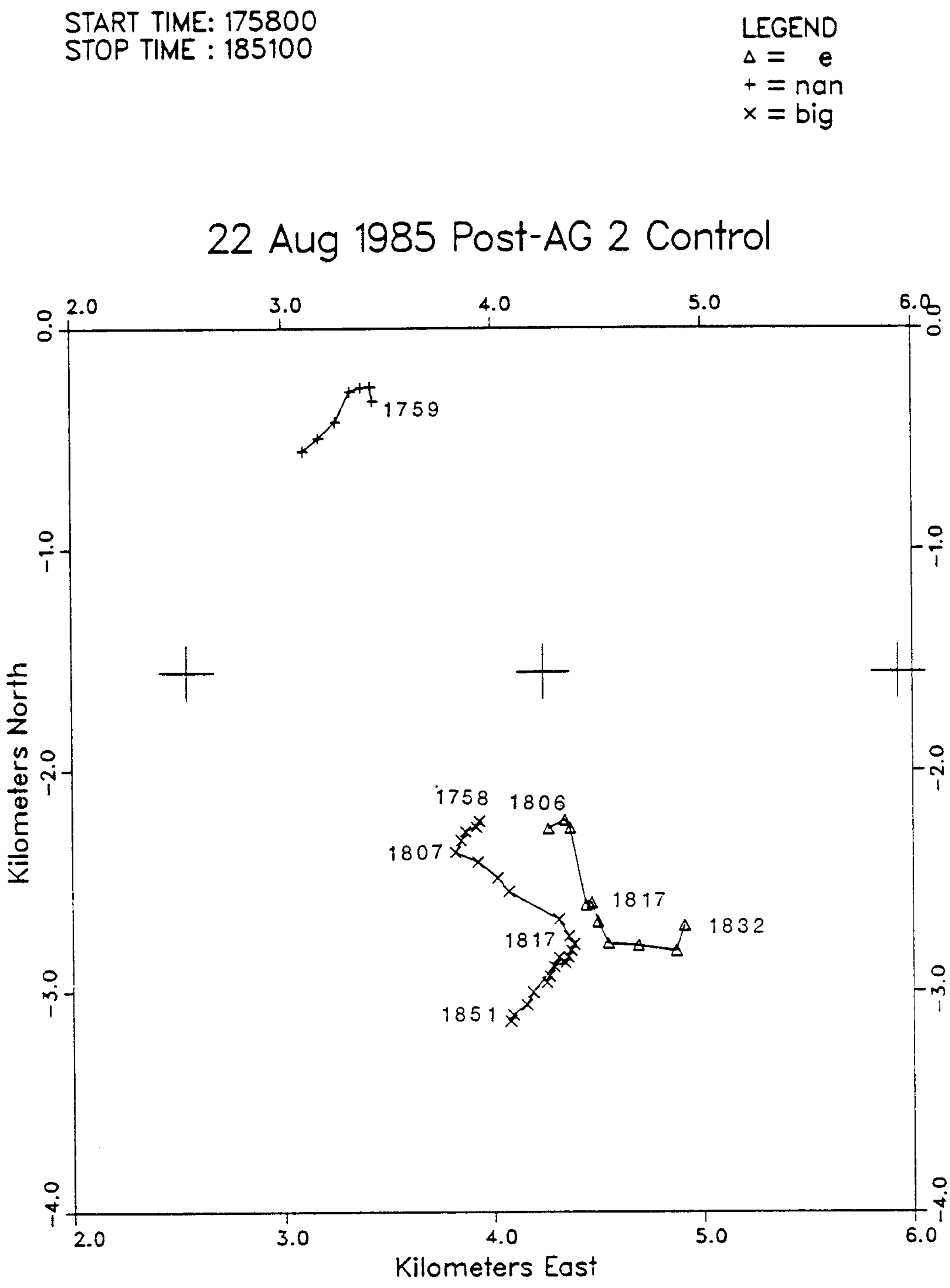


FIG. 3.23. TRACK PLOT OF WHALE E DURING POST-AG 2 CONTROL ON 22 AUGUST.

approximately 1807 during the post-AG 2 control. By approximately 1817, the BIG VALLEY was within 0.2 km of Whale E (Fig. 3.23). This close approach may have been responsible for the eastward movement of Whale E.

AG 3, 24 August, 1715-1758

As noted in Section 3.1.2, 24 August was the only day during the field season that viewing conditions and inshore whale locations allowed land-based transiting of whale group movement. We were able to track six whale groups; however, most of our data come from the two focal whales, A and B.

Whale A was first observed by shore-based personnel at 1606. The whale was feeding at this time and continued to feed throughout the pre-AG 3 control period. Whale A and Whale B, another feeding whale in the same general area, were noted moving toward each other at 1632, but they did not join. At 1649, Whale A and Whale E, which had been under observation since 1636 and also feeding, joined. Group A+E continued to feed together, generally moving northward.

Figure 3.24 shows the movement pattern of both Whales A and E during the pre-AG 3 control. At 1715, group A+E separated. Time 1715 coincides with the onset of AG 3, when RSL at the whales was approximately 154 dB, with the NANCY H 2.4 km to the SSW. Figure 3.25A shows the position of both the NANCY H and the BIG VALLEY at the start of AG 3. An examination of Figure 3.25B (extending 4 km N of the northern limit of 3.25A) shows that Whale A started to move to the northeast after separating from Whale E; however, it continued to feed until at least 1731, at which time RSL was 157 dB with the NANCY H 1.74 km distant. Whale E was only sighted and transited once after the group separated, at 1719. At this point, Whale E was still in close proximity to Whale A, indicating that it also was moving in a

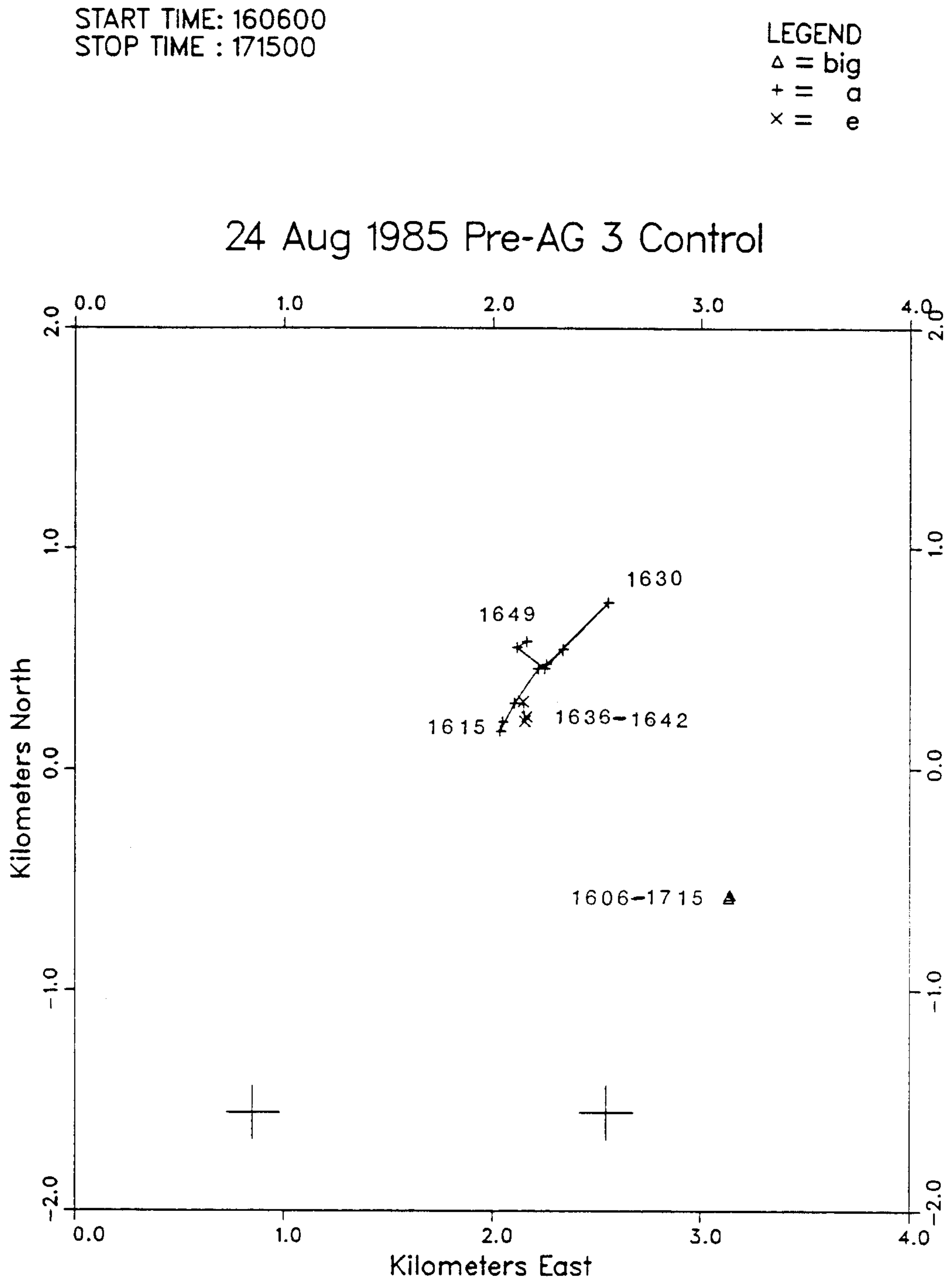
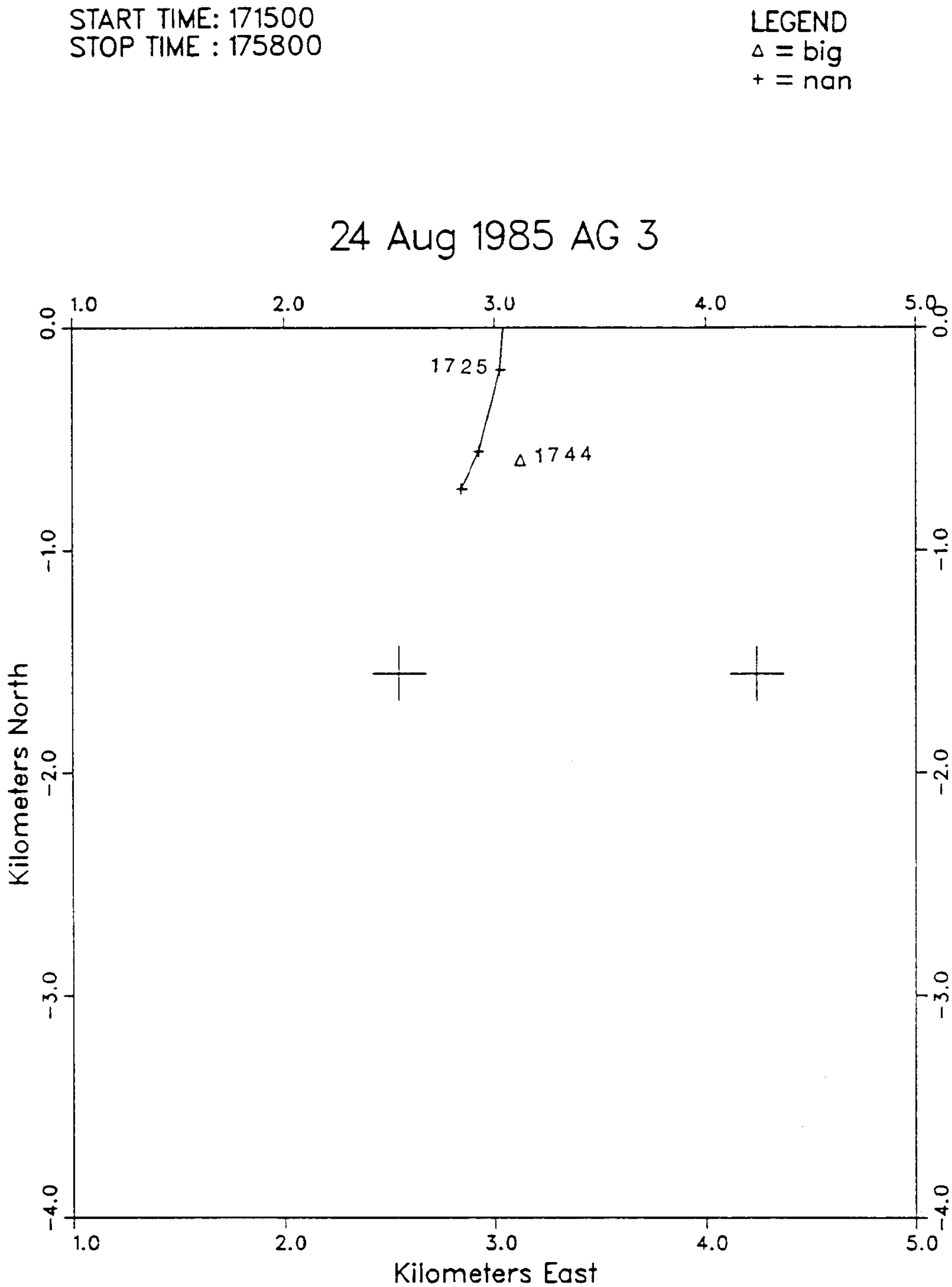


FIG. 3.24. TRACK PLOT OF WHALES A AND E DURING PRE-AG 3 CONTROL ON 24 AUGUST. THE MOVEMENT OF GROUP A+E IS NOT SHOWN AS NO POSITION DATA ARE AVAILABLE. HOWEVER, THE LAST LOCATION OF WHALE A AT 1649 IS THE POSITION WHERE THE JOINING OCCURRED.



FIGS. 3.25A. FIGURE 3.25A SHOWS THE POSITION OF THE M/V NANCY H. AND THE M/V BIG VALLEY AT THE START OF AG 3 ON 24 AUGUST.

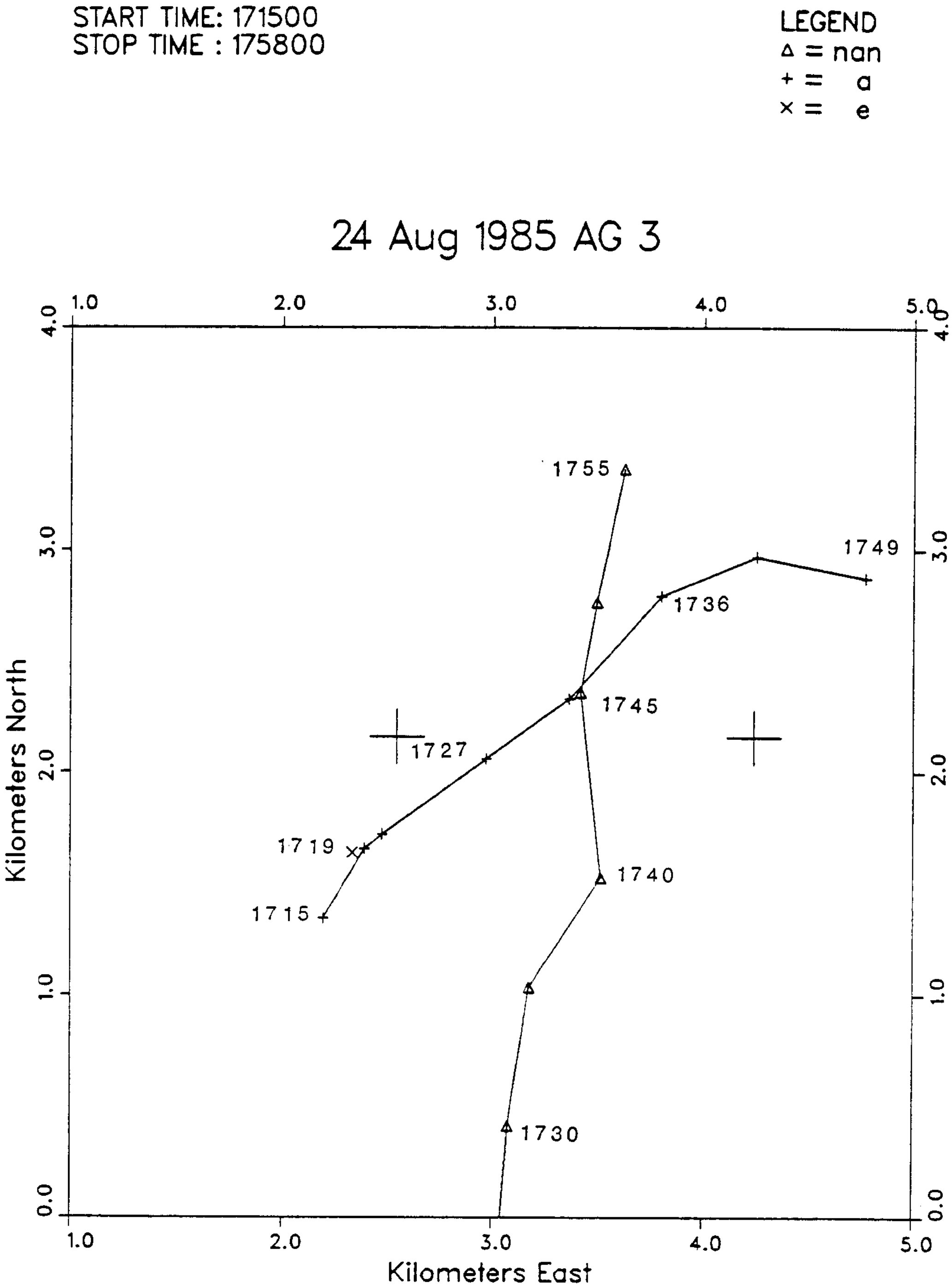


FIG. 3.25B. (CONTINUATION OF FIGURE 3.25) SHOWING THE NORTHWARD MOVEMENT OF M/V NANCY H. AND THE TRACK OF WHALE A DURING AG 3.

similar direction. Peak RSL of 160 dB was reached at 1740 at which time Whale A was moving almost directly west and offshore. It could not be determined if the whale was feeding after 1731; however, the steady offshore movement indicates that it was not.

During post-AG 3 control, Whale A continued to move offshore. Whale A's increasing distance from land-based observers, coupled with high sea state, prevented effective transiting of this whale's movement. As a result, only one further reading was successfully taken, at 1804. At this time the whale was approximately 0.6 km ENE of its 1749 position.

Whale B was first observed by land-based personnel at 1609 and was noted feeding at 1615. This whale continued to feed in the same general location throughout the pre-AG 3 control, AG 3, and post-AG 3 control periods. As noted previously, Whales A and B were observed moving towards each other at 1632. At 1658, Whale B was observed moving toward whale group A+E. In neither instance did Whale B join these other whales. Figures 3.26 through 3.28 show the movement pattern of Whale B during the three experimental periods.

At 1717, 2+ minutes after the onset of AG 3, RSL at Whale B was 158 dB, with the NANCY H 1.51 km to the SSW. RSL increased to a peak of 165 dB at 1734 with NANCY H 0.66 km distant. An examination of Fig. 3.27 shows that after this time the whale moved inshore slightly. This inshore movement may have been the result of increased RSL; however, the whale was observed to be feeding during this entire time and small changes in movement such as this are consistent with normal feeding behavior. By 1757, NANCY H was 2.72 km to the northeast of the whale and RSL was 153 dB.

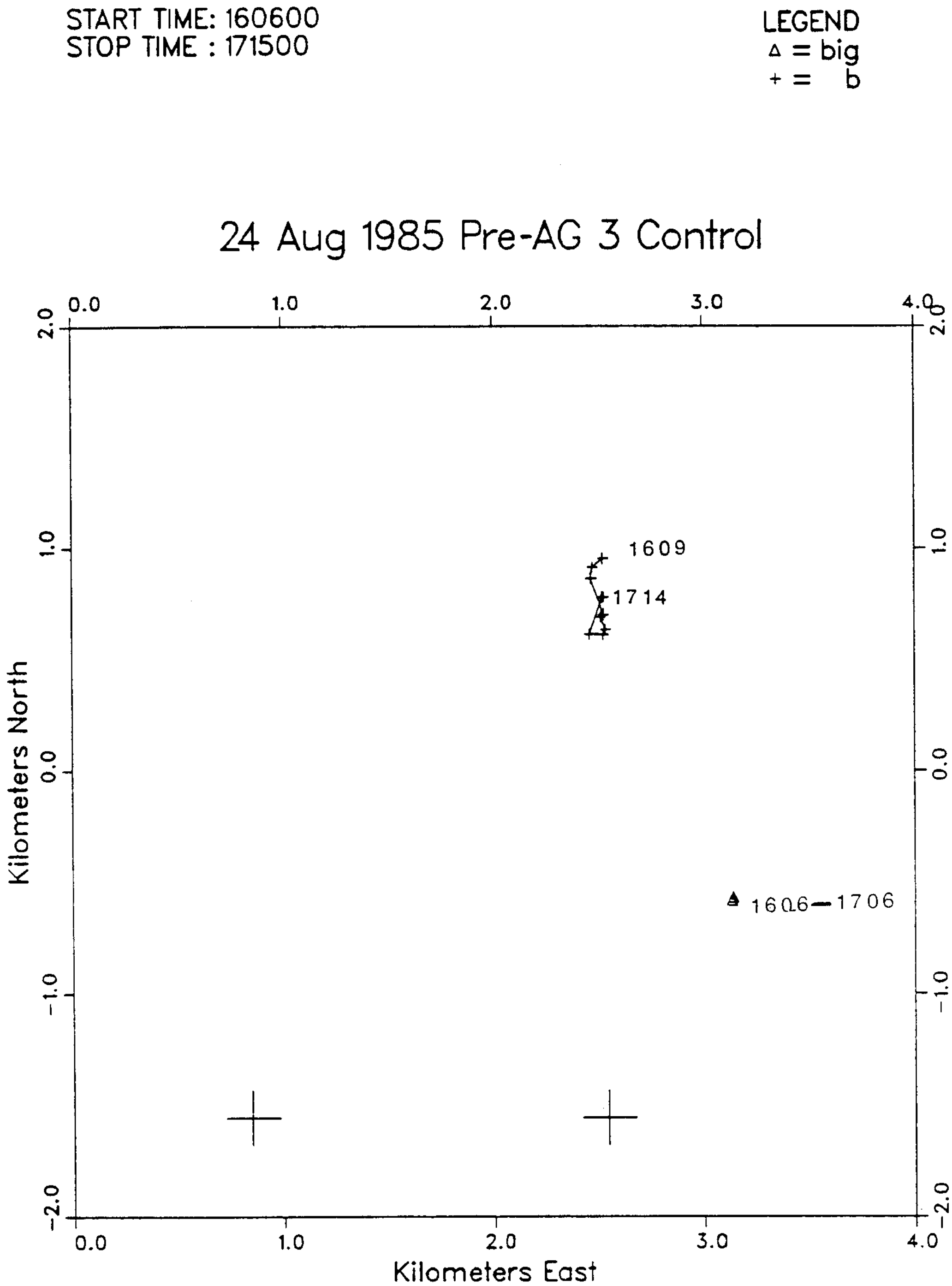


FIG. 3.26. TRACK PLOT OF WHALE B DURING PRE-AG 3 CONTROL ON 24 AUGUST.

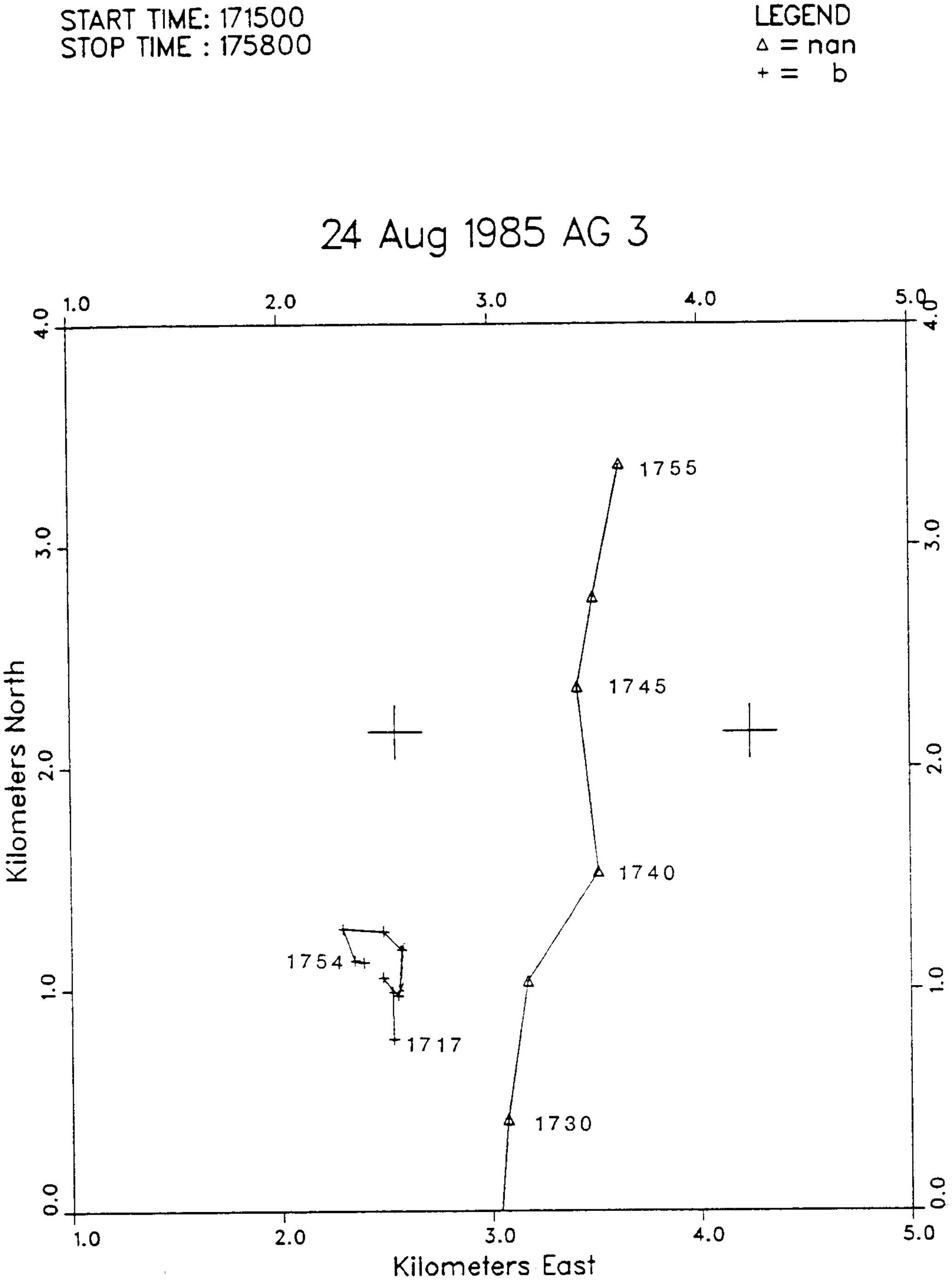


FIG. 3.27. TRACK PLOT OF WHALE B DURING AG 3 ON 24 AUGUST.

Figure 3.28 is a plot of Whale B's movement during the post-AG 3 control period. This whale was observed to be feeding the entire time in the same general location as it had been during the two previous experimental periods.

AG 4, 24 August, 1929-2026

As noted above, Whale B was observed to be feeding during the control period between AG 3 and AG 4 (see Fig. 3.28). Figure 3.29 shows the movement pattern of this whale relative to the NANCY H during AG 4. At the onset of AG 4, RSL at Whale B was 159 dB with the NANCY H 1.75 km to the north. Whale B continued to feed and between 1942-1954 was moving slowly to the north, toward the NANCY H, which was motoring southward. During this period, RSL was increasing and at 1957 it had reached 176 dB with the NANCY H 0.18 km directly offshore of Whale B. At this point, observers noted that the whale had turned and was moving rapidly to the south, diving with flukes out. This was the first time during the entire period of observation that Whale B displayed a full fluke out upon diving, and this action was unusual since the whale was in shallow water (depth < 9 m) in which fluke outs do not normally occur. The whale continued to move south, and at 2002 another full fluke out was noted. At this point, RSL had reached a peak of 177 dB with the NANCY H 0.17 km distant. Mud was observed with this dive, and Whale B was presumed to be feeding. The whale continued moving slowly to the south until approximately 2011, at which time it began to mill. By 2015, mud was again associated with Whale B, and the whale continued to feed throughout the remainder of AG 4, staying in the same general location. RSL at Whale B was decreasing during this period and by the end of the experiment was 159 dB, with the NANCY H 1.80 km to the southeast of the whale's location. Whale B continued to feed during the post-AG 4 control and was last observed at 2042. Figure 3.30 presents a track of Whale B's movement during this period.

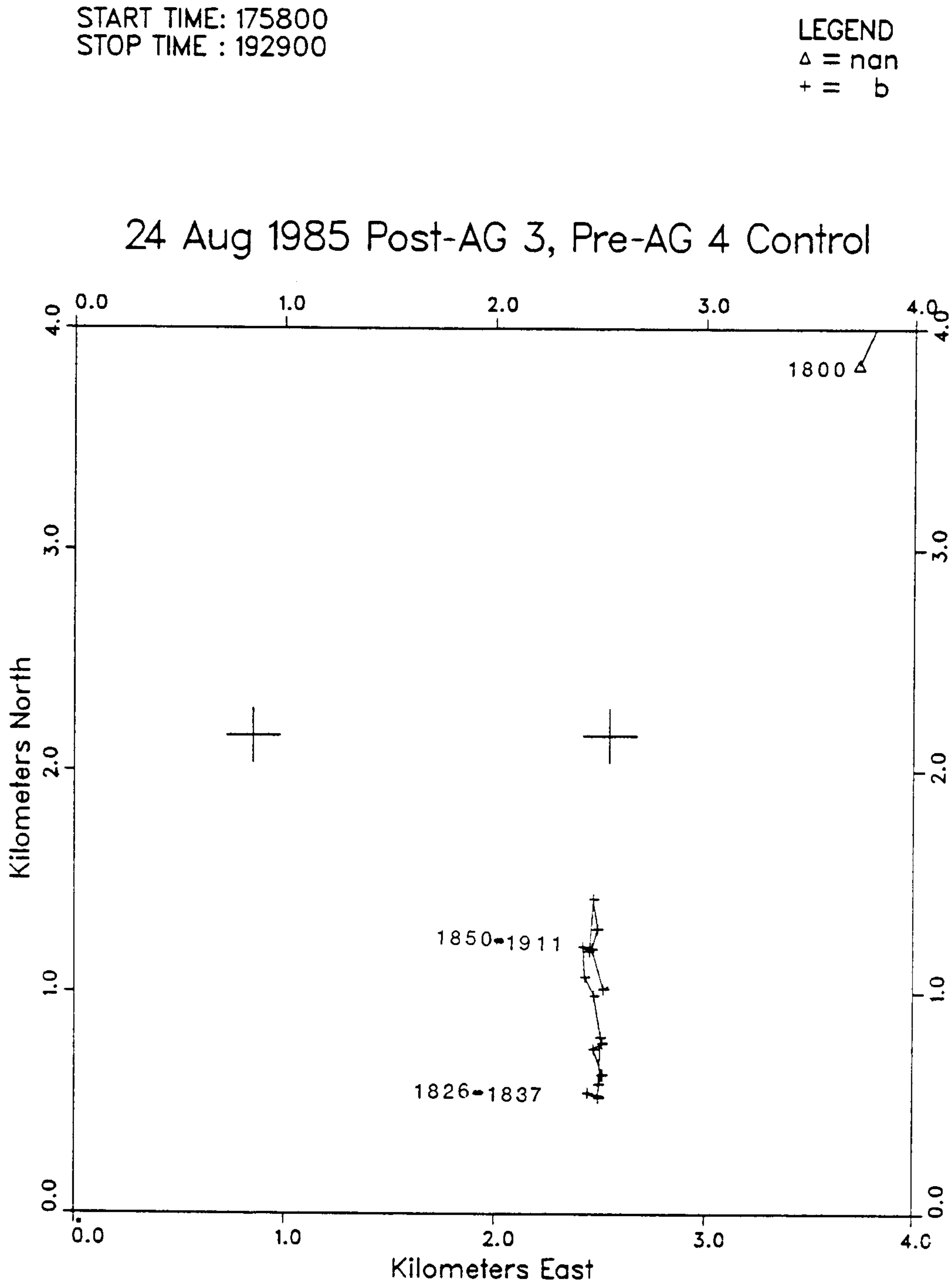


FIG. 3.28. TRACK PLOT OF WHALE B DURING POST-AG 3 CONTROL ON 24 AUGUST.

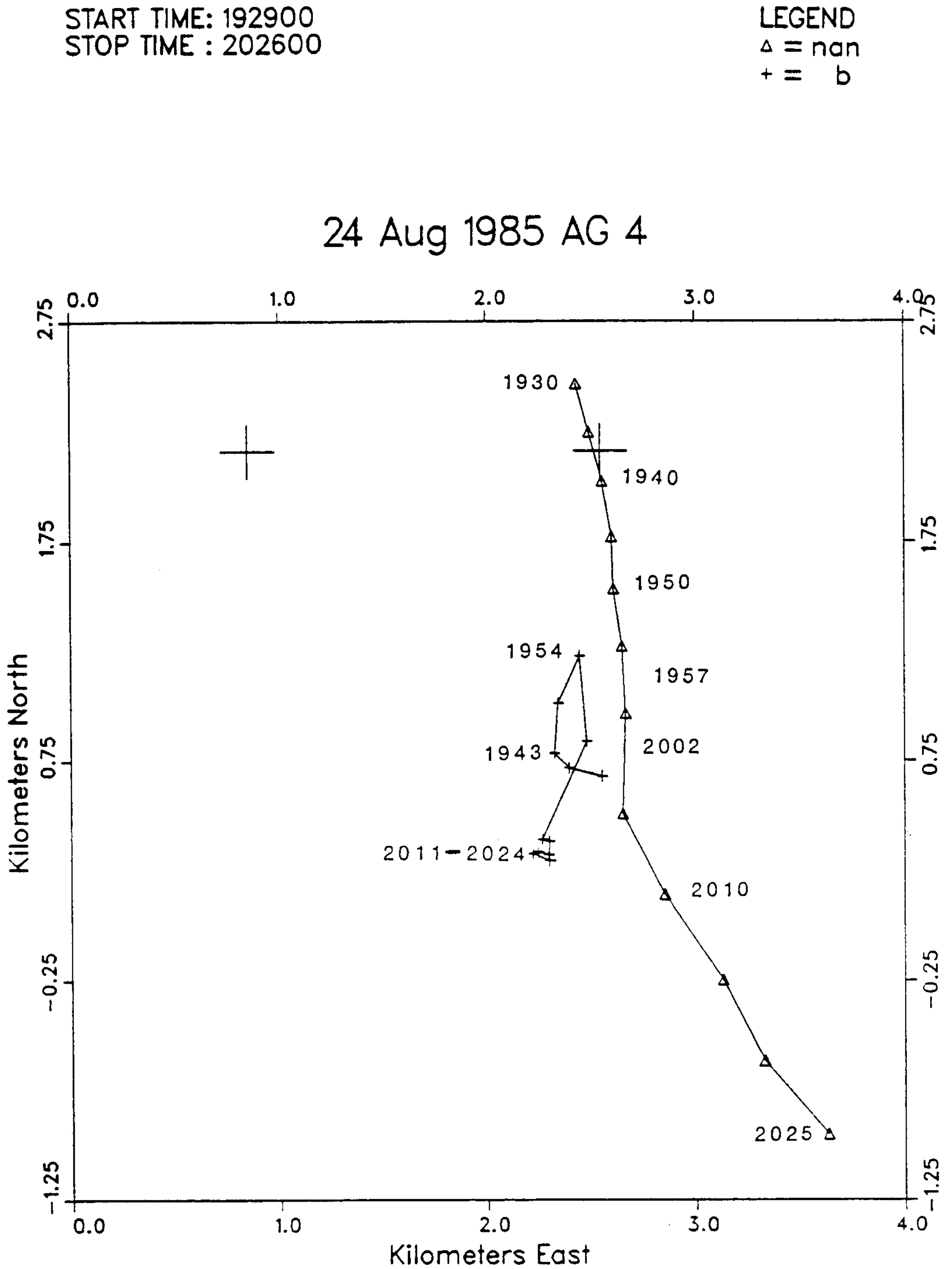


FIG. 3.29. TRACK PLOT OF WHALE B DURING AG 4 ON 24 AUGUST.

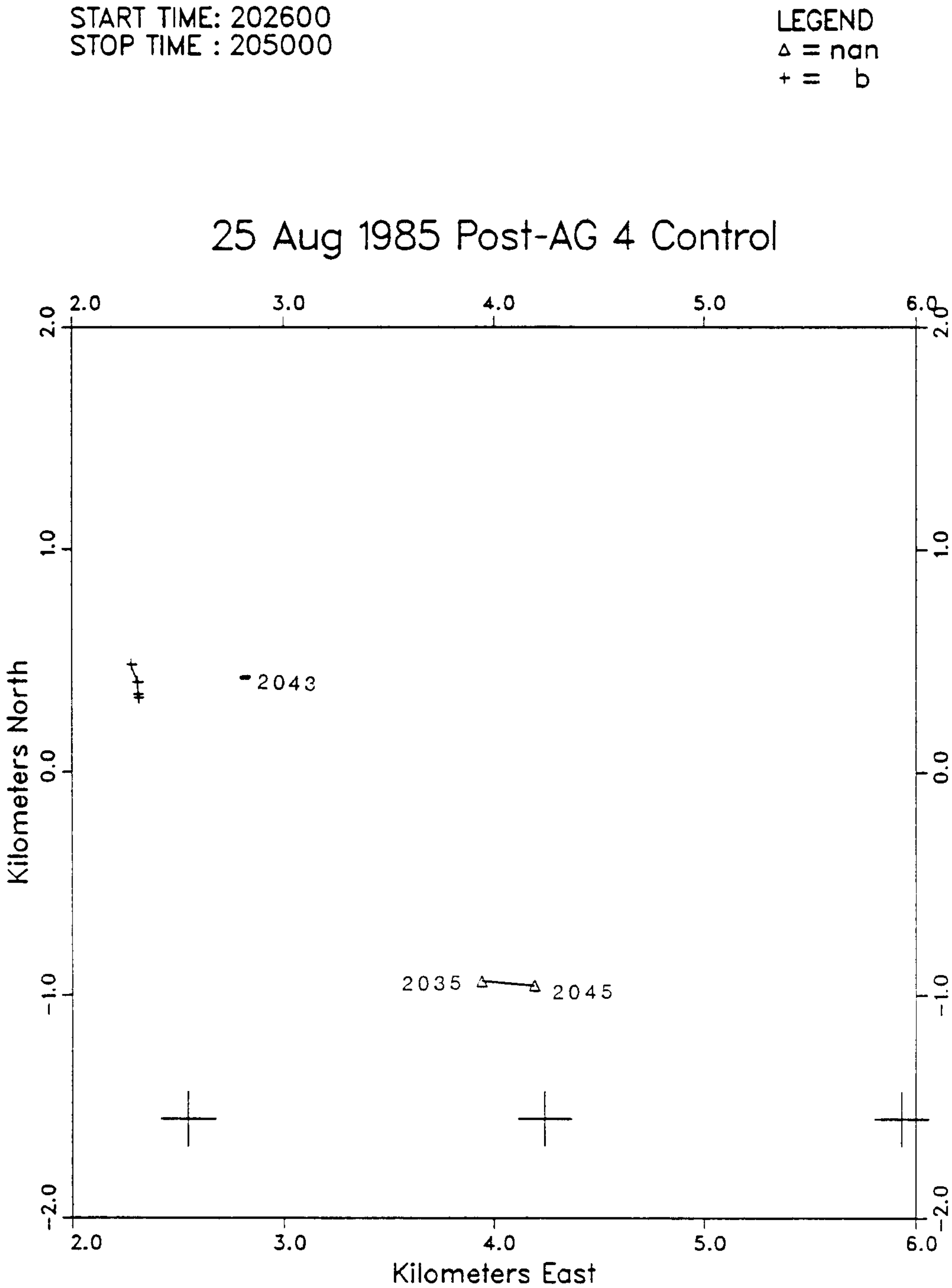


FIG. 3.30. TRACK PLOT OF WHALE B DURING POST-AG 4 CONTROL ON 24 AUGUST.

AG 5, 25 August, 1220-1323

Whale K was first observed by Zodiac personnel at 1042 and was followed until 1227. Unfortunately, poor visibility during much of this period restricted observers on board the BIG VALLEY from taking readings on this whale, with the first reading taken at 1207. Whale K was noted as feeding from 1042 to at least 1155, moving slowly to the north and west during much of this time. At 1129, Whale K and Whale L, another feeding whale under observation, joined for a brief period, then separated, staying in the same general area. At approximately 1158, Whale K began to move to the northeast, continuing on this heading until approximately 1212, when it headed to the southeast. Figure 3.31 shows Whale K's movement pattern between 1207 and the end of the pre-AG 5 control. As noted above, BIG VALLEY personnel were having difficulty in keeping the Zodiac and the whales under observation and were forced to motor closer, anchoring at 1205, approximately 0.4 km from Whale K. This NNW movement can be seen in Figure 3.31. At the time that Whale K started its northeast movement (1158), observers on the Zodiac noted that the whale moved out of the area in apparent response to the approaching BIG VALLEY.

At the onset of AG 5 at 1220, RSL at Whale K was 160 dB, with the NANCY H 2.4 km distant. Figure 3.32 shows Whale K's movement during the first 4 minutes of AG 5. At 1223, Whale K breached, with RSL at this point approximately 160 dB, with the NANCY H 2.3 km distant. At 1224, Zodiac personnel made the decision to select Whale L as the focal animal since it was assumed that Whale K was leaving the area. However, an examination of Figure 3.32 shows that Whale K had moved back towards the southeast by 1223. Given the movement of the BIG VALLEY into the area during the pre-AG 5 control period and the limited data on Whale K after the onset of AG 5, it is unclear whether Whale K responded to AG 5.

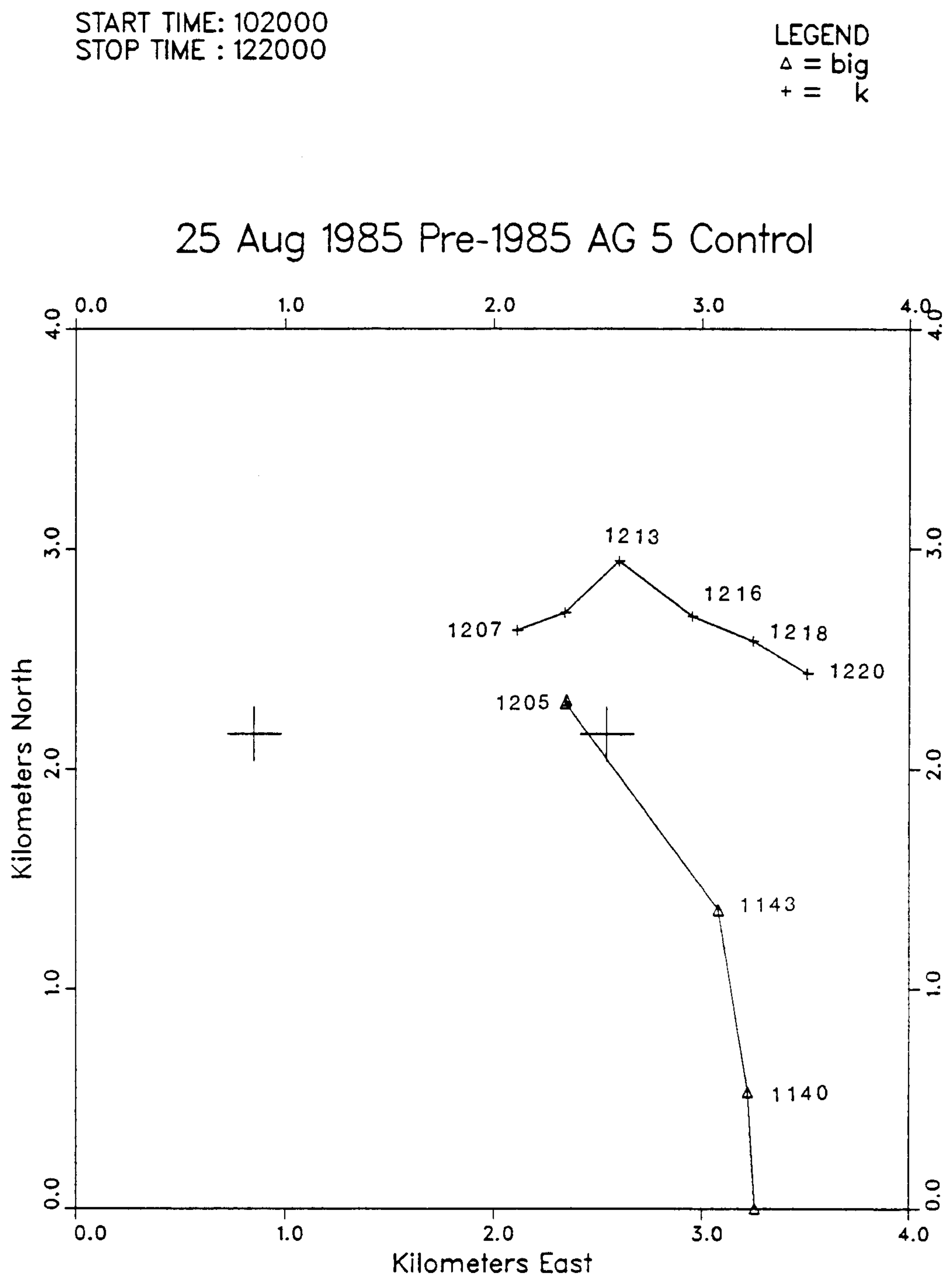


FIG. 3.31. TRACK PLOT OF WHALE K DURING PRE-AG 5 CONTROL ON 25 AUGUST AFTER THE M/V BIG VALLEY MOVED INTO THE AREA.

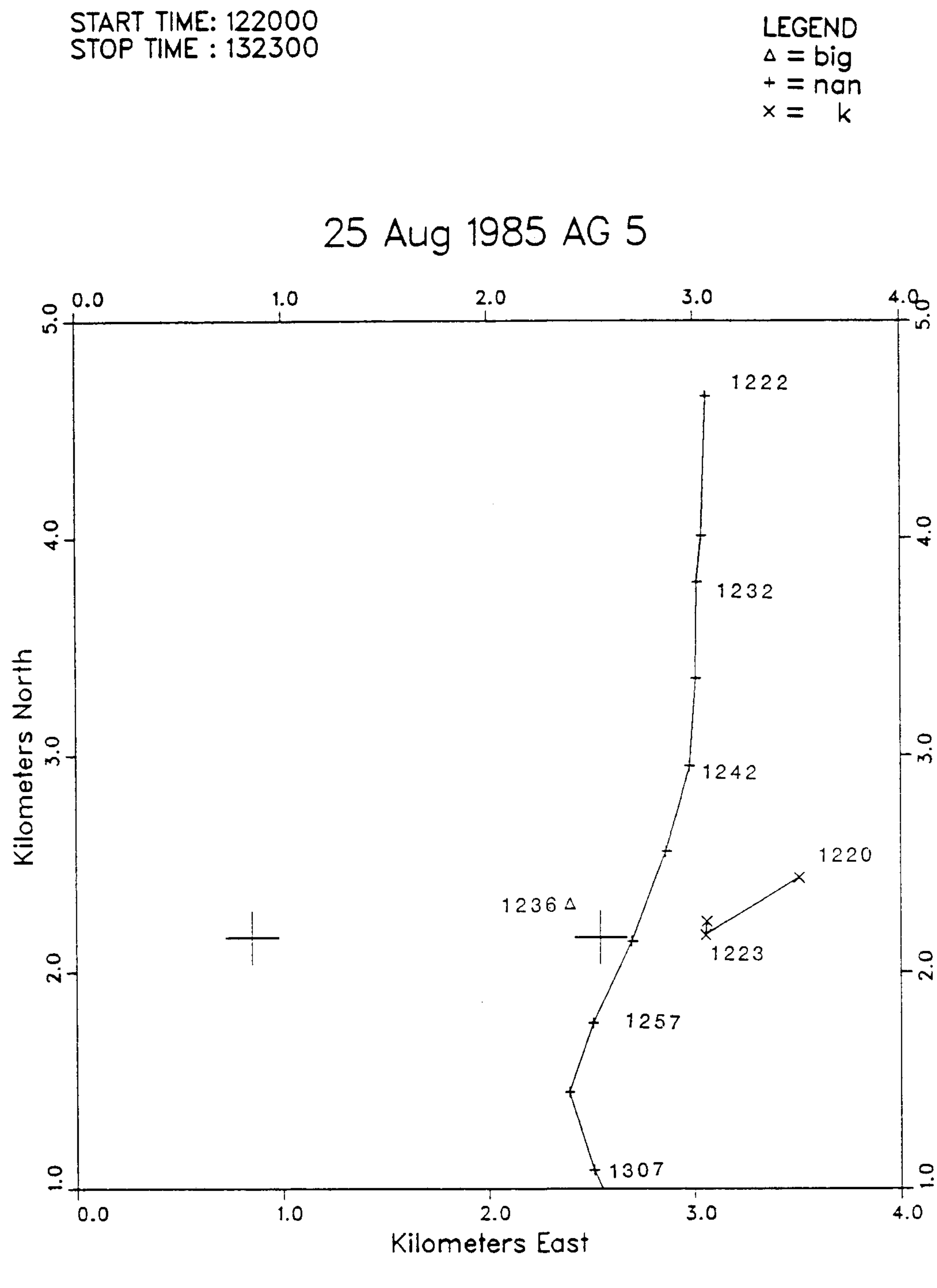


FIG. 3.32. TRACK PLOT OF WHALE K DURING AG 5 ON 25 AUGUST.

Whale L was first sighted at 1120 and, as noted previously, was in the same area as Whale K, joining this whale briefly at 1129. Whale L was feeding much of the time during the pre-AG 5 control period; however, we do not have reliable track information on this whale until 1236 (see Fig. 3.33), 16 minutes after the onset of AG 5. At this point, RSL at Whale L was 163 dB with the NANCY H 1.96 km distant and moving to the SSW. Whale L was moving to the south and feeding at 1250. RSL at this time was 167 dB, with the NANCY H 1.25 km distant. At 1258, Whale L moved toward and joined Whale N, a feeding whale first sighted at 1249. The two stayed together, slowly moving to the southwest until approximately 1336. During this time, Whale N was feeding, surfacing, blowing, and diving at regular intervals. Whale L was generally observed not to be feeding, spending a majority of time at or near the surface. At 1300, Whale L spyhopped, lifting its head vertically out of the water. Several more spyhops by this whale were noted over the next 9 minutes, during which time RSL peaked at 170 dB with the NANCY H 1.1 km directly offshore of group L+N. This group continued to move to the southeast (see Figure 3.33), with Whale N feeding the entire time.

At approximately 1336, 13 minutes after the end of AG 5, Whales L and N separated, with Whale L continuing to move to the southeast. Figure 3.34 shows the movement of Whales L and N during the post-AG 5 control period. We followed Whale L after the separation, and by 1352, Whale L had increased its speed, moving rapidly out of the area. The whale was last sighted at 1400, still moving southeast.

AG 6, 25 August, 1600-1706

In the course of following Whale L, observers noted another whale feeding in the same general area, and after leaving L started to follow this whale. By 1433, this whale was moving rapidly to the south and was last sighted at 1447. Whale N was

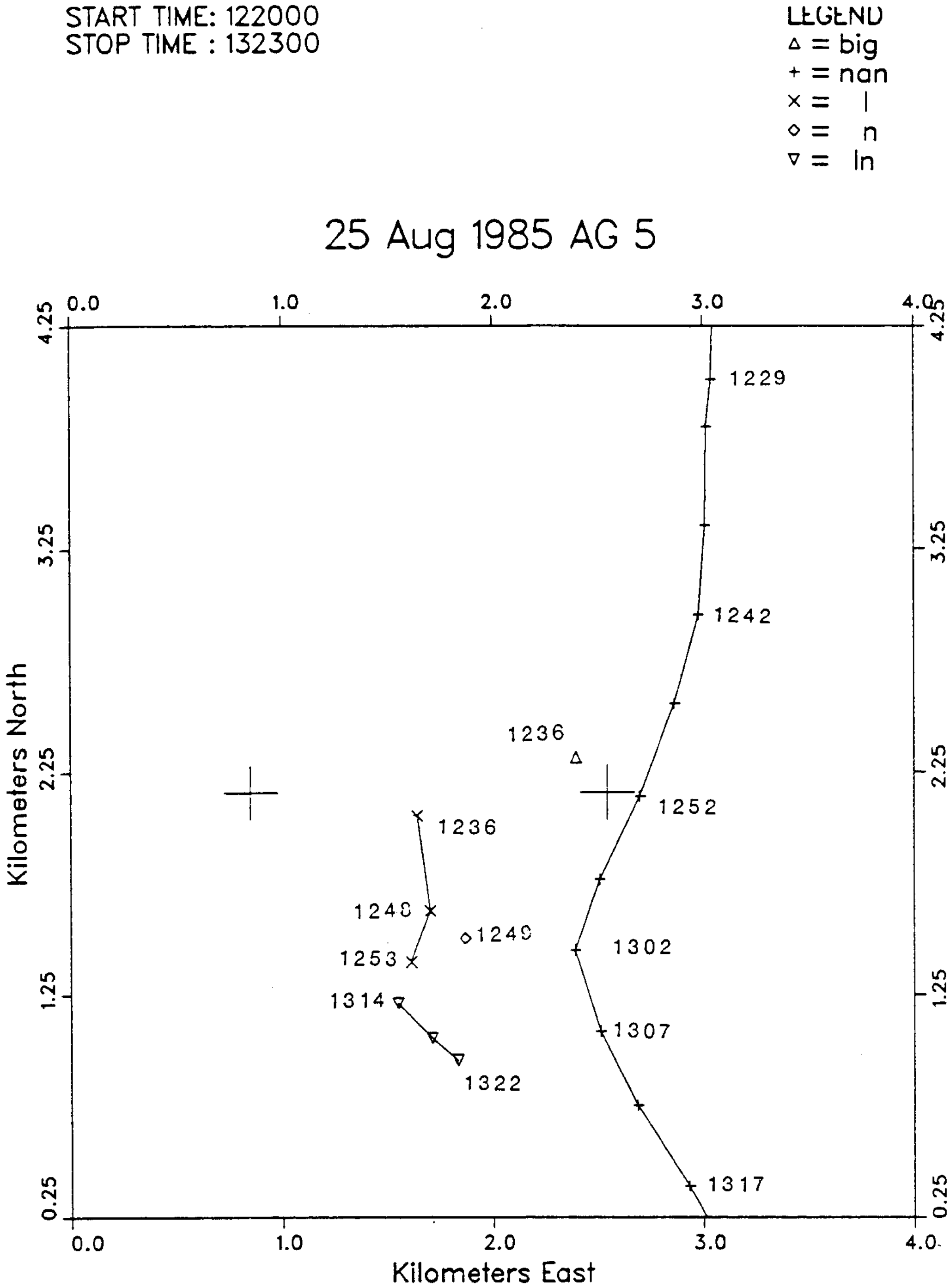


FIG. 3.33. TRACK PLOT OF WHALES L, N, AND GROUP L+N DURING AG 5 ON 25 AUGUST. WE DO NOT HAVE POSITION INFORMATION ON THESE WHALES BETWEEN 1253 AND 1314.

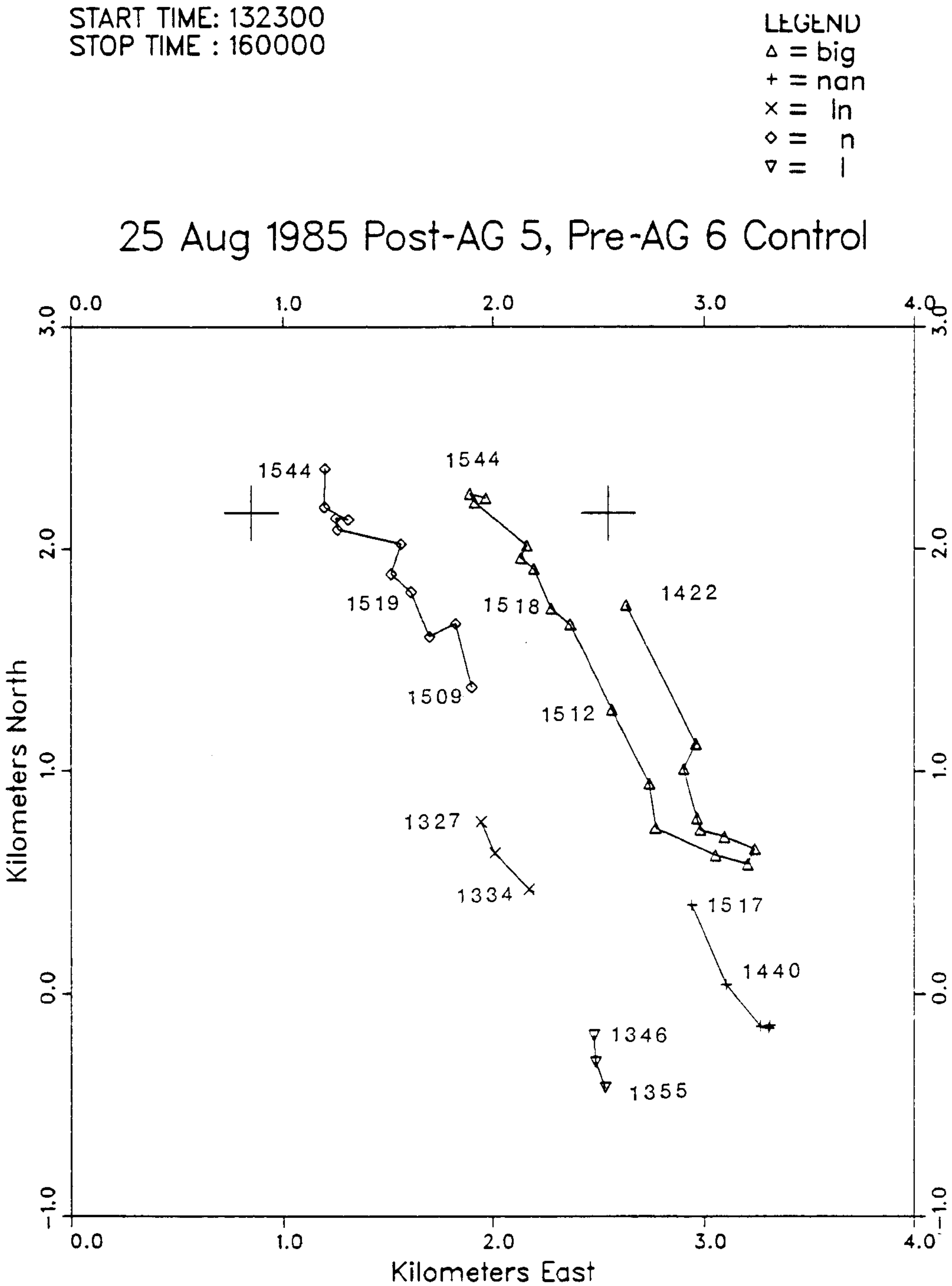


FIG. 3.34. TRACK PLOT OF GROUP L+N AND WHALE L DURING POST-AG 5 CONTROL AND WHALE N DURING PRE-AG 6 CONTROL ON 25 AUGUST.

resighted at 1500; it was feeding. Whale N was kept under continuous observation for the next 4 hours. Figure 3.34 shows the slow NNW movement of this whale. During the same period the BIG VALLEY was moving into position prior to AG 6, anchoring at 1544. Because of fog that moved into the area at 1502, the BIG VALLEY was forced to move fairly close to the Zodiac and Whale N. As can be seen in Fig. 3.34, the BIG VALLEY was at times approximately 0.5 km from Whale N. However, no unusual behavior was noted and the whale continued to feed throughout this period.

By 1545, 15 min. before the start of AG 6, viewing conditions had deteriorated further and observations of the Zodiac and Whale N from the BIG VALLEY were impossible. As a result, we do not have a plot of Whale N's movement during AG 6 and therefore RSL are not available. However, Zodiac personnel kept Whale N under close observation during AG 6. The following is a summary of the whale's behavior and movement during AG 6 with reference to Figure 3.35, the track plot of the NANCY H during the AG 6 experiment.

Whale N continued to feed until at least 1605, 5 minutes after the onset of AG 6. By this time, however, the whale had increased its speed, moving generally northward. After this time, Whale N was not observed to feed until 1807. Between 1635-1650 (see Figure 3.35), Whale N was paralleling the course of the NANCY H, at times coming to within 100 m of the vessel. At these ranges, Whale N must have received sound levels in excess of 188 dB. Observers on the Zodiac had the impression that the whale was attempting to move offshore during this period. At 1653, Whale N moved across (or possibly underneath) the bow of the NANCY H, coming very close to the vessel. Once on the offshore side of the NANCY H, Whale N moved rapidly to the northeast. Whale N continued to move offshore, alternating its rate of travel, until approximately 1715, 9 minutes after the end

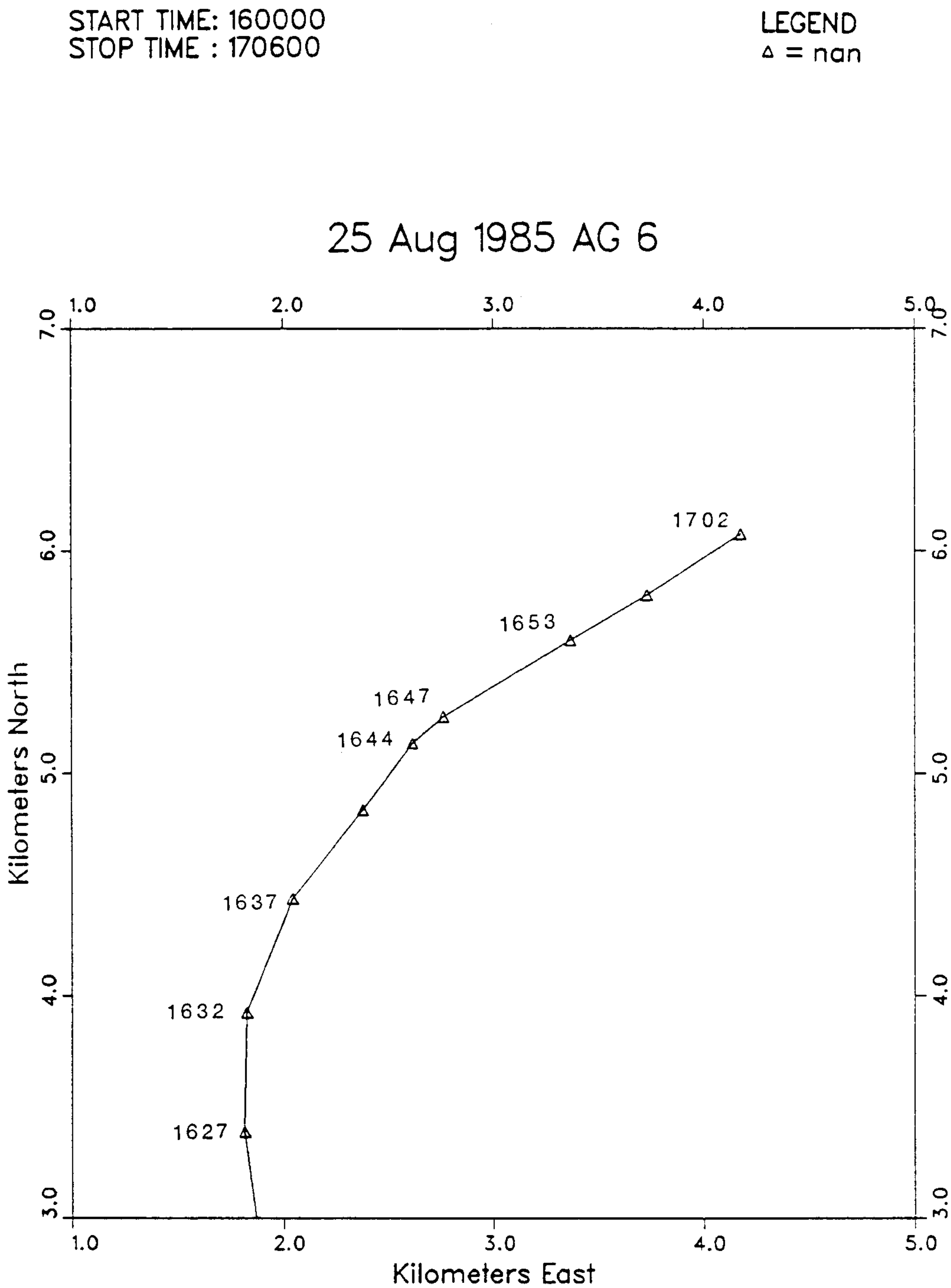


FIG. 3.35. TRACK PLOT OF M/V NANCY H. DURING AG 6 ON 25 AUGUST.

of AG 6. At this point the whale started to move back inshore. By 1727, observers on the BIG VALLEY were able to see both the Zodiac and the whale and were able to take position readings in coordination with Zodiac personnel. Figure 3.36 shows Whale N's movement from this time to the end of observations at 1902. At 1741, Whale N increased its speed, and between 1742-1746 it breached three times. The whale continued to move inshore, and at 1807 mud was seen associated with it, the first indication of feeding since 1615. At this point, Whale N moved slowly south, feeding the entire time. By the end of observations at 1902, the whale was in the same general area in which it had been feeding prior to AG 6. In fact, Whale N was within 200 m of where it was first sighted feeding at 1249 (see Figure 3.33).

Summary and Discussion of Movement Patterns

Drillship Playback

The two playbacks for which whale movement data are available, DS 2 and DS 3, suggest that the whales did not alter their movement patterns with RSL at 103 to 110 dB and the BIG VALLEY as close as 1.12 km. In one case (DS 3), a whale continued to feed in the same general area during both control and experimental periods. However, during the pre-control period for DS 2, whales appeared to respond to the presence of the BIG VALLEY, thus complicating interpretation of results. During DS 1 and DS 4, whales in the vicinity of the BIG VALLEY did move out of the general area; however, we were unable to obtain track data on individual whales and therefore RSL for specific focal animals are not available.

There have been very few controlled experiments involving drillship playbacks to non-migrating baleen whales. Richardson et al. (1985) and Richardson, Wells, and Würsig (1985) found some evidence for bowhead whale avoidance at distances of 4 to 5 km

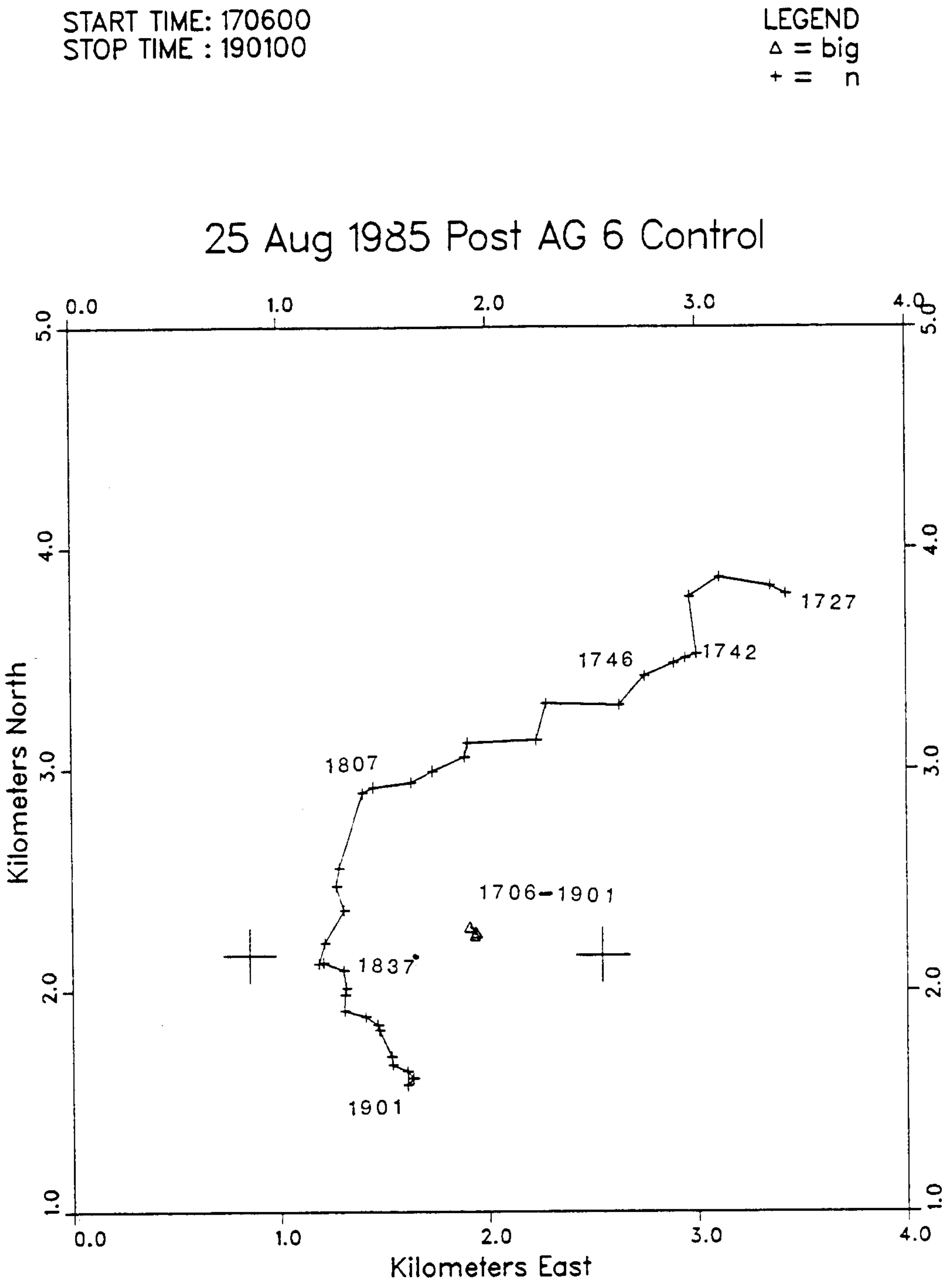


FIG. 3.36. TRACK PLOT OF WHALE N DURING POST-AG 6 CONTROL ON 25 AUGUST.

from the playback vessel with RSL at the closest whales ranging from approximately 100 dB to 112.5 dB. They note, however, that because of the limited number and short duration of the playbacks, more experiments are needed and that their results "...must be considered preliminary." (Richardson et al. 1985. p. 222.) Malme et al. (1985) conducted two drillship playback experiments on feeding humpback whales in Frederick Sound, Alaska. There were no consistent responses of whales at ranges to the sound source of >0.5 km with RSL >116 dB.

Air Gun

Alterations in whale movement patterns and/or feeding behavior were noted during each of the six air gun experiments. Table 3.8 summarizes the behavior of eight of the nine focal whales under observation during the experiments. As the pre-control behavior of Whale K on 24 August during AG 5 was possibly affected by the presence of the BIG VALLEY, this whale has not been included.

Responses were noted at RSL ranging from 149 dB to 176 dB at distances up to approximately 4 km. However, in one case, RSL reached a peak of 165 dB with the NANCY H 0.66 km distant with very little, if any, response observed. We did observe the cessation of feeding with apparent movement away from the experimental vessel during some part of air gun sound exposure on five occasions. However, in three of these cases the whales resumed feeding either during the experiment (one case) or during the post-control period (two cases). In the remaining two cases, one whale stopped feeding with apparent movement away from the experimental vessel (Whale A, AG 3) and continued to move out of the area during the post-control period; the other whale (Whale L) stopped feeding during AG 5; however, we do not have information on its pre-control movement pattern.

TABLE 3.8. SUMMARY OF FOCAL WHALE RESPONSE TO AIRGUN EXPERIMENTS, 22, 24-25 AUGUST 1985.

Date (Aug.)	AG# & Time	Focal Whale	Pre-Control Activity	AG Activity	Time of Response,	RSL (dB)	Source Distance (km)	Peak RSL and Source Distance	Post-Control Activity	Figure Reference
22	AG 1 1440-1600	E	Feeding	Movement away, stopped movement as AG approached, no feeding	1446,	~149,	~4.0	172, 0.19	Return to Pre-Control area, feeding	3.19-3.21
22	AG 2 1731-1758	E*	Feeding	Direction change, move towards and then away from N.H.[1] feeding before and after move	1739,	~172,	~0.47	172, 0.47	Feeding, movement possibly affected by B.V.[2]	3.22-3.33
24	AG 3 1715-1758	A	Feeding, joined Whale E	Group split at AG onset, A move north & east offshore, feeding to 1731	1731	157	1.74	160, 1.17	Continued offshore movement	3.24-3.25
24	AG 3 1715-1758	B*	Feeding	Feeding with inshore movement as N.H. moved past (possibly feeding related)	1740,	~162,	~0.9	165, 0.66	Feeding same general area	3.26-3.28
24	AG 4 1929-2026	B*	Feeding	Feeding, turn, speed increase, dive, fluke out, resume feeding	1957,	176	0.18	177, 0.17	Feeding same general area	3.29-3.30
25	AG 5 1220-1323	L*	Feeding, no track plot	Joined by Whale N, some feeding, spyhops, southeast movement	1300,	~169	~1.0	170, 1.02	Group split, L increase speed moving southeast out of area, no feeding	3.33-3.34
25	AG 5 1220-1323	N	Unknown	Joined Whale L, feeding	--	--	--	170, 1.02	Feeding, group split	-
25	AG 6 1600-1706	N	Feeding	Feeding to 1605, movement parallel to N.H. then offshore	1605	174	(est.)	>188, < 0.10	Offshore to 1715, then back to original location and feeding	3.36

*Response when N.H. broadside to whale.

[1] NANCY H

[2] BIG VALLEY

Most of the responses involved either an abrupt change in direction and/or an increase in speed with apparent movement away from the experimental vessel. On one occasion a whale spyhopped several times in apparent response to increasing RSL. We did note that in three and possibly four cases (marked with an asterisk in Table 3.8) whales showed a response to the operating air gun at a time coinciding with the NANCY H moving past the whale's position, at which point the whales were experiencing peak RSL. Malme et al. (1983) observed a similar response pattern in mother/calf gray whales to a moving seismic vessel.

Richardson, Würsig, and Greene (1986) conducted air gun experiments on non-migrating bowhead whales using a single 0.66-l Bolt air gun. During three experiments in 1981 and 1983 involving a moving source, they found no evidence of avoidance at distances from 3 to 5 km with RSL near the whales ≥ 118 to 133 dB. In 1984, two experiments were conducted using a stationary source. Results showed that at 0.2 to 1.2 km and 2 to 4.5 km with RSL described as "intense" (not measured because of sonobuoy overload) and 124 to 131 dB, respectively, whales moved away from the source vessel. Malme et al. (1985) conducted single air gun (100 cu. in.) experiments on feeding humpback whales in Frederick Sound, Alaska. They found no overall pattern of avoidance with RSL up to 172 dB. However, observers did note startle responses by whales at air gun onset on three occasions with RSL at 150 dB to 169 dB at ranges up to 3.2 km.

More data on focal whales under control and experimental conditions are needed before firm conclusions regarding the effects of drillship playbacks and air gun operations on feeding gray whales can be made. The present data set shows that feeding gray whales can respond in a variety of ways to a moving, single air gun and that these responses can occur at RSL ranging from 149 dB to 176 dB with whale distance up to 4 km from the source.

3.4.2 Surfacing-dive behavior

Four basic characteristics used to describe the surfacing-dive behavior of gray whales were (1) respiration or blow interval, (2) length of surfacing, (3) length of dive, and (4) number of blows per surfacing. A fifth characteristic, blow rate, was calculated from length of surfacing, length of dive, and number of blows per minute (Würsig et al. 1984, Würsig et al. 1986). The frequency distributions of the five characteristics are shown in Fig. 3.37. Blow interval and blow rate approximate a normal distribution, while the distributions of the other three characteristics are highly skewed. Consequently, blow interval and blow rate were analyzed with parametric testing procedures (by analysis of variance and Student-Newman-Keuls multiple comparisons tests), while length of surfacing, length of dive, and number of blows per surfacing were analyzed nonparametrically (by Kruskal-Wallis, Mann-Whitney-U, and nonparametric multiple comparisons; Zar 1974, Sokal and Rohlf 1981).

Whales were labelled as undisturbed during non-experimental days when large boats were not moving in the study area, and during the first pre-disturbance control periods of each experimental day. We did not label subsequent control periods of experimental days as "undisturbed" for the purposes of surfacing-dive behavior analysis, since the data indicate that such subsequent control periods may not have represented a true undisturbed situation, but instead whales were potentially affected by the previous experiment of that day.

There are clear correlations between several of the surfacing-dive characteristics (Fig. 3.38). Number of blows per surfacing increases with length of a surfacing, and whales surface for longer times between longer dives. These longer surfacings allow the whales to respire sufficiently between long

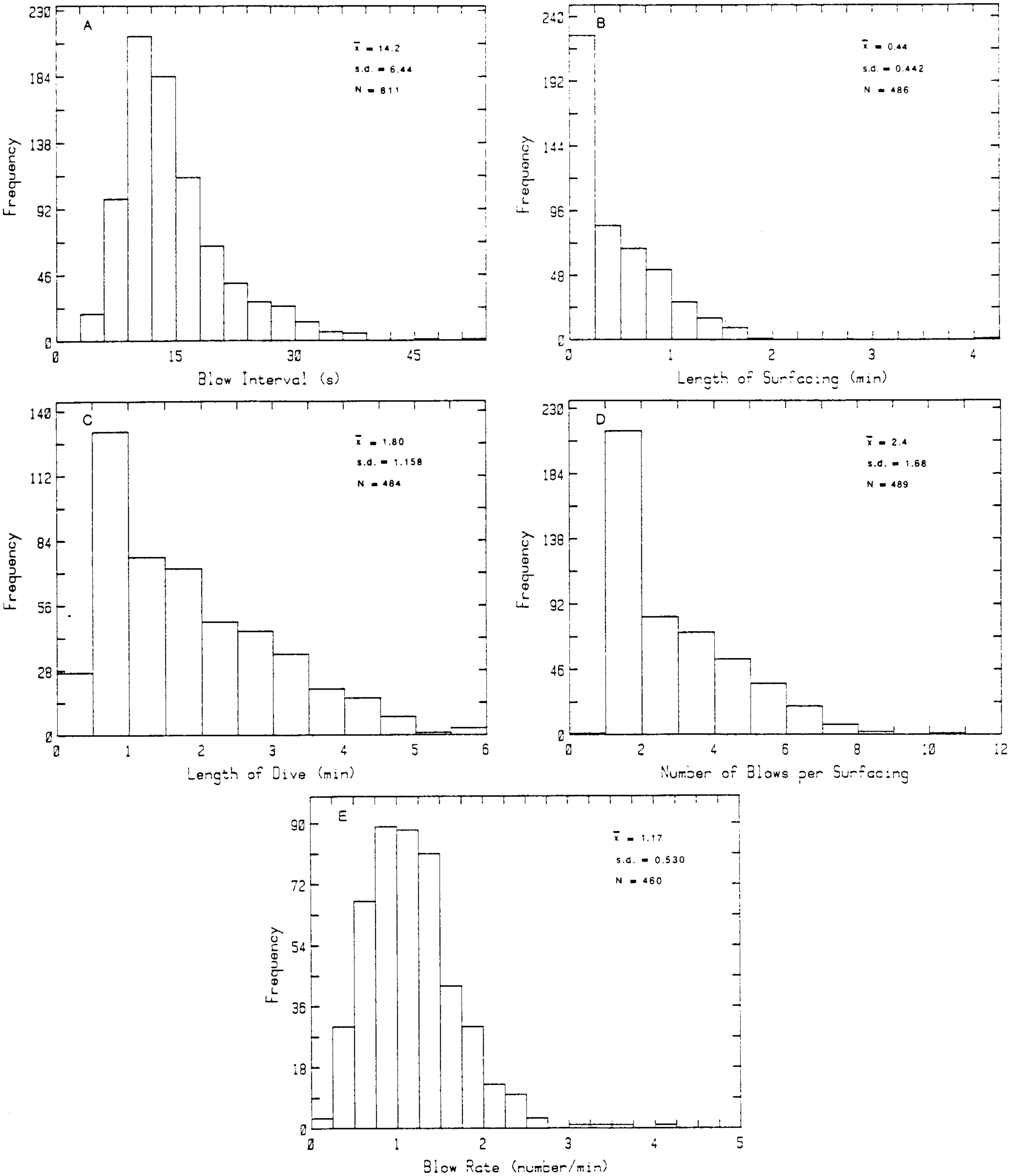


FIG. 3.37. FREQUENCY DISTRIBUTION OF SURFACING-DIVE DATA ON UNDISTURBED WHALES. SEE TEXT FOR DEFINITION OF UNDISTURBED.

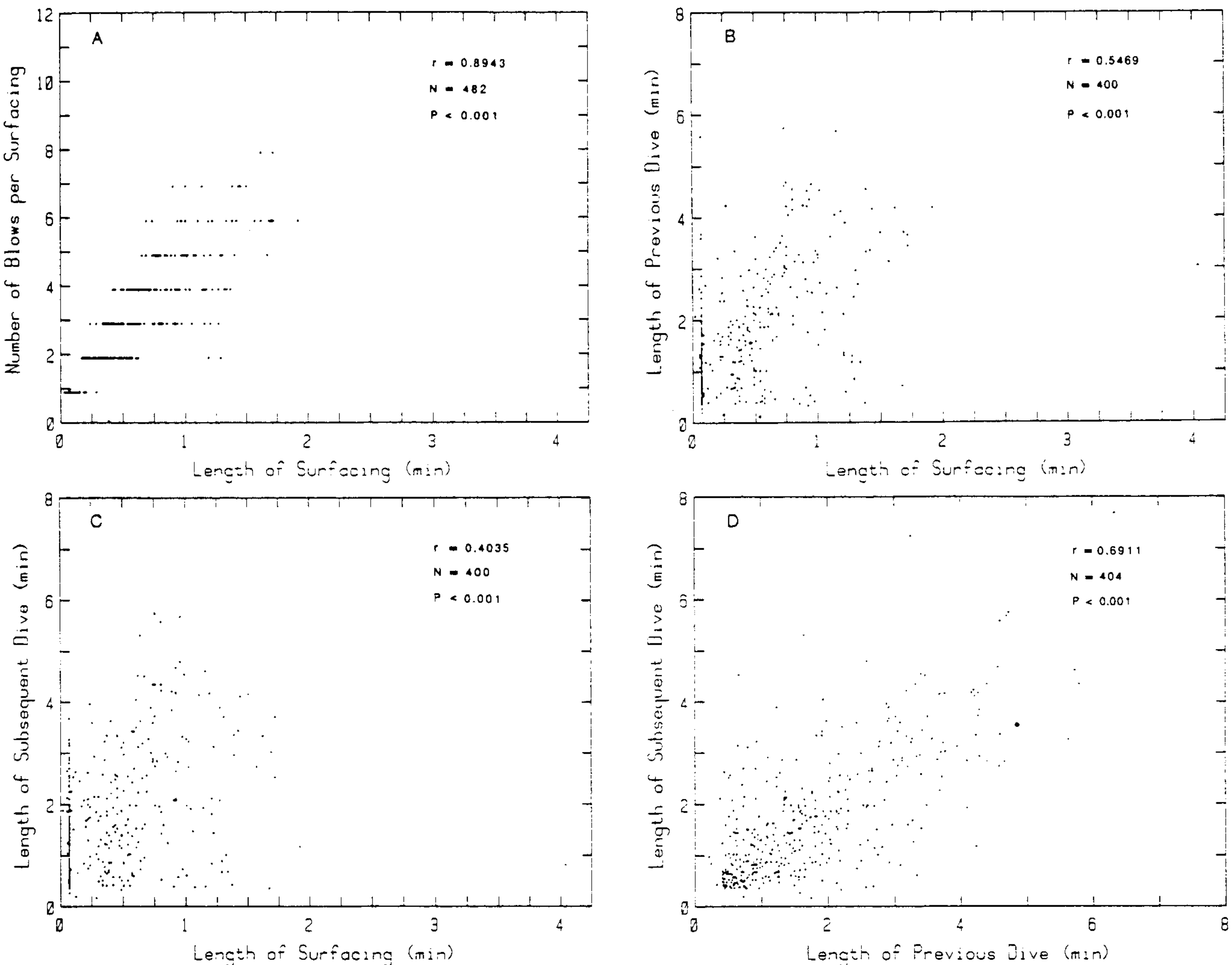


FIG. 3.38. CORRELATIONS BETWEEN SEVERAL SURFACING-DIVE VARIABLES, UNDISTURBED WHALES.

dives and, as a result of this interplay between characteristics, blow rate remains relatively constant between short and long dives. The correlation between dives before and after a certain surfacing (Fig. 3.38D) indicates that whales tend to dive for similar lengths of time in sequence. Frequency distributions and correlations between surfacing-dive characteristics for whales subjected to drillship and air gun experiments were similar to the undisturbed condition.

Although we divided our data into the broad behavioral categories of milling, travelling, socializing, and bottom feeding, we had too few surfacing-dive data in different behavioral categories for statistical analyses and meaningful interpretation. We therefore present no behavioral subdivisions in the present analysis, but will do so if further data are gathered in the area in the future.

3.4.3 Pooled experimental comparisons

There were significant differences in surfacing-dive characteristics between the condition of no known disturbance and the potential disturbances of drillship playbacks and air gun experiments (Table 3.9, Fig. 3.39). Blow interval decreased; and length of surfacing, length of dive, and number of blows per surfacing all increased during drillship playbacks. For air gun sounds, the response was opposite to that of drillship, with blow interval increasing and the other three primary characteristics decreasing. Interestingly, blow rate did not change from the presumed undisturbed situation, because blow intervals made up for shifts in lengths of surfacings and dives.

Figures 3.40 and 3.41 show these summary data in more detail. For drillship playback experiments, the surfacing-dive characteristics stay at a "disturbed" level within a one-half

TABLE 3.9. SUMMARY STATISTICS FOR UNDISTURBED WHALES AND WHALES DURING DRILLSHIP PLAYBACKS AND AIR GUN EXPERIMENTS.

Experimental Situation	Blow Interval(s)			No. of Blows/ Surfacing			Length of Surfacing (min)			Length of Dive (min)			Blow Rate (No./Min.)		
	$\bar{x}$	s.d.	n	$\bar{x}$	s.d.	n	$\bar{x}$	s.d.	n	$\bar{x}$	s.d.	n	$\bar{x}$	s.d.	n
Undisturbed	14.2	6.44	811	2.4	1.68	489	0.44	0.442	486	1.80	1.158	494	1.17	0.530	480
Drillship	12.5	5.18	115	3.0	2.76	46	0.52	0.314	45	2.32	1.414	45	1.20	0.790	41
Air gun	16.5	6.01	147	2.0	1.40	135	0.38	0.430	135	1.54	1.081	134	1.20	0.570	131

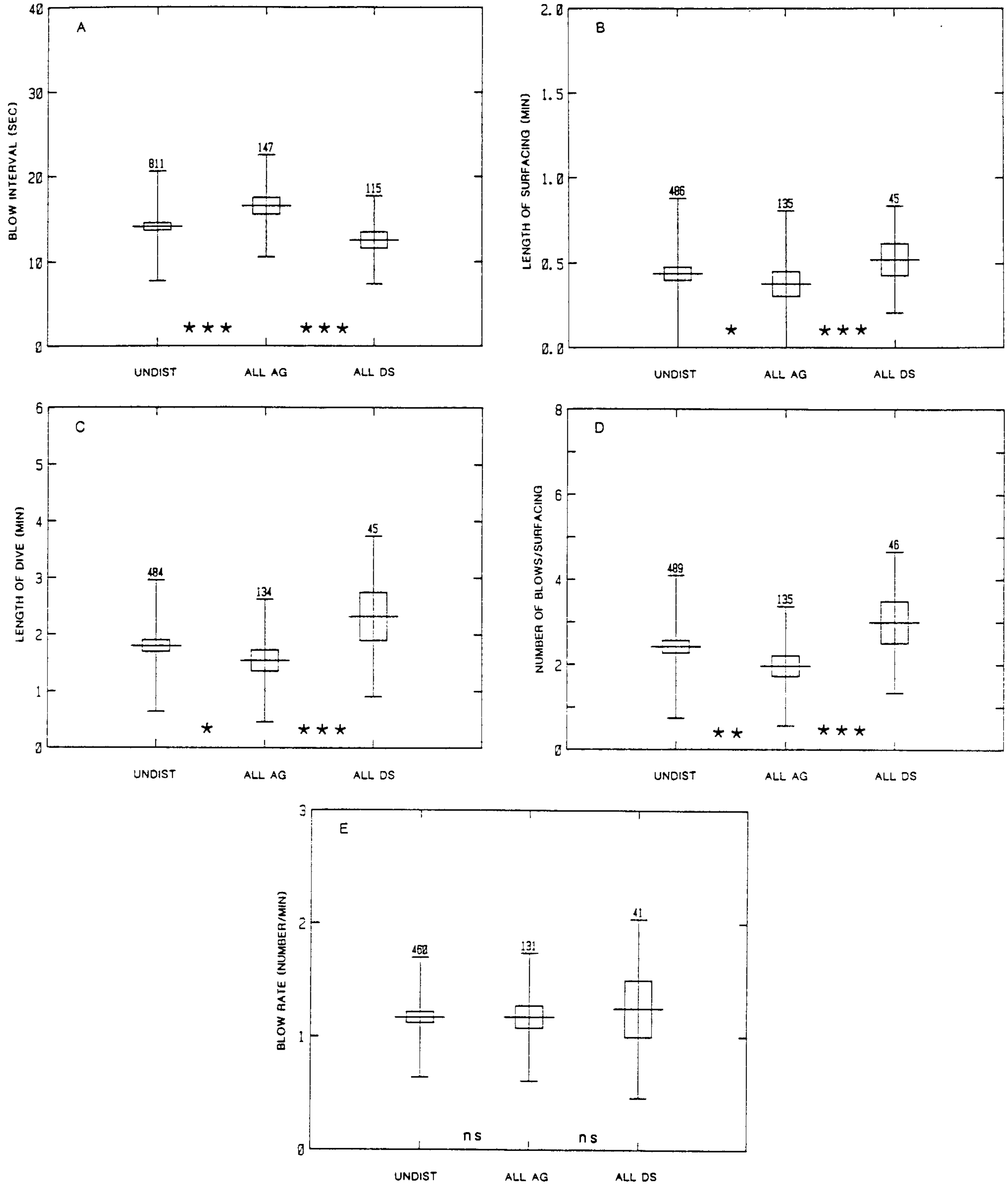


FIG. 3.39. SUMMARY STATISTICS FOR UNDISTURBED WHALES, AND WHALES DURING DRILLSHIP PLAYBACK (DS) AND AIR GUN EXPERIMENTS (AG). CENTER BARS DENOTE MEANS, BOXES DENOTE 95% CONFIDENCE INTERVALS, BARS DENOTE 1 S.D. ABOVE AND BELOW THE MEAN, AND NUMBERS DENOTE SAMPLE SIZE. ASTERISKS SHOW SIGNIFICANCE LEVELS OF PROBABILITY: * = 0.05, ** = 0.01, *** = 0.001. NS = NOT SIGNIFICANT.

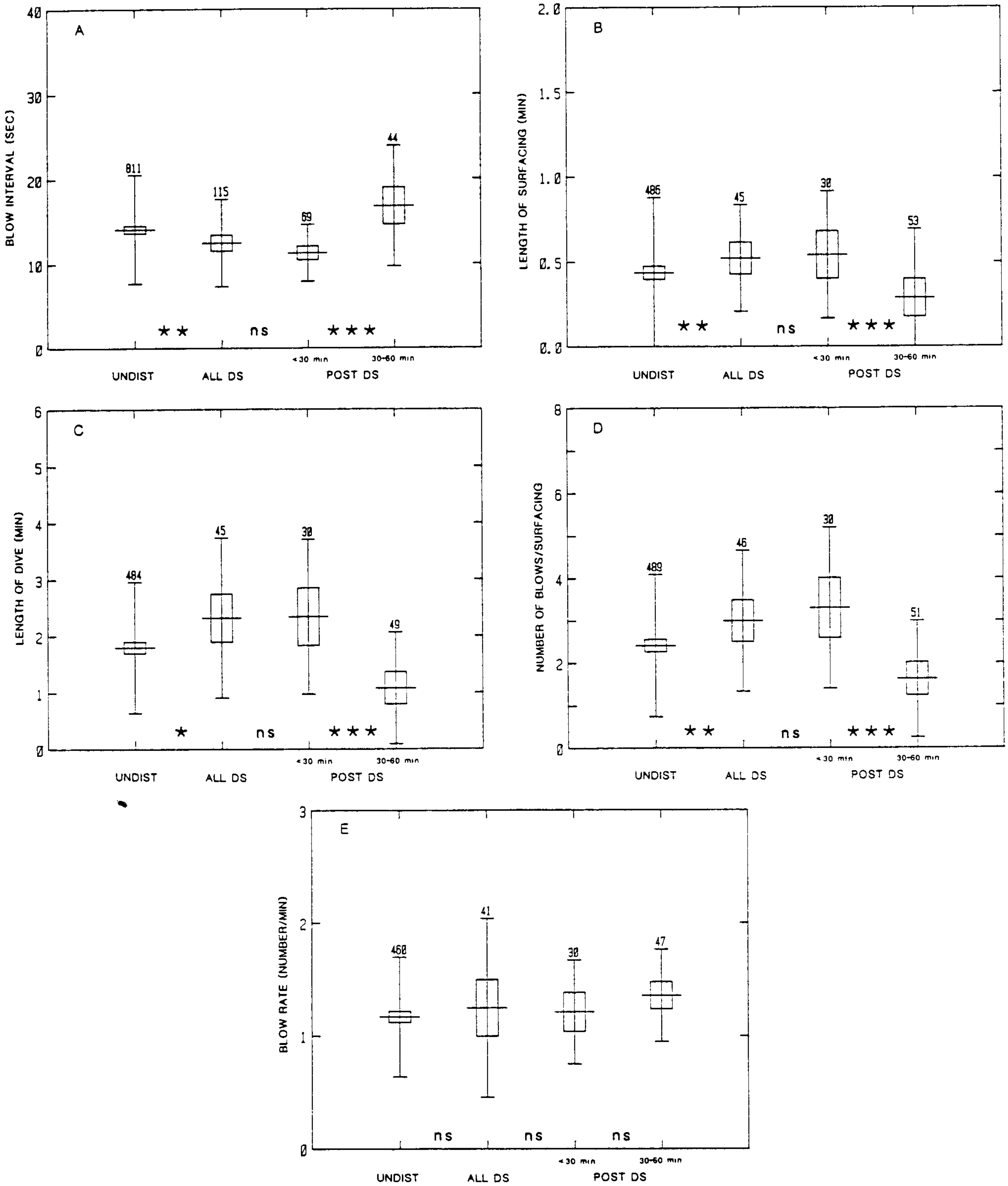


FIG. 3.40. SUMMARY STATISTICS FOR UNDISTURBED WHALES, AND WHALES DURING AND AFTER DRILLSHIP PLAYBACKS. DISPLAY AS IN FIG. 3.39.

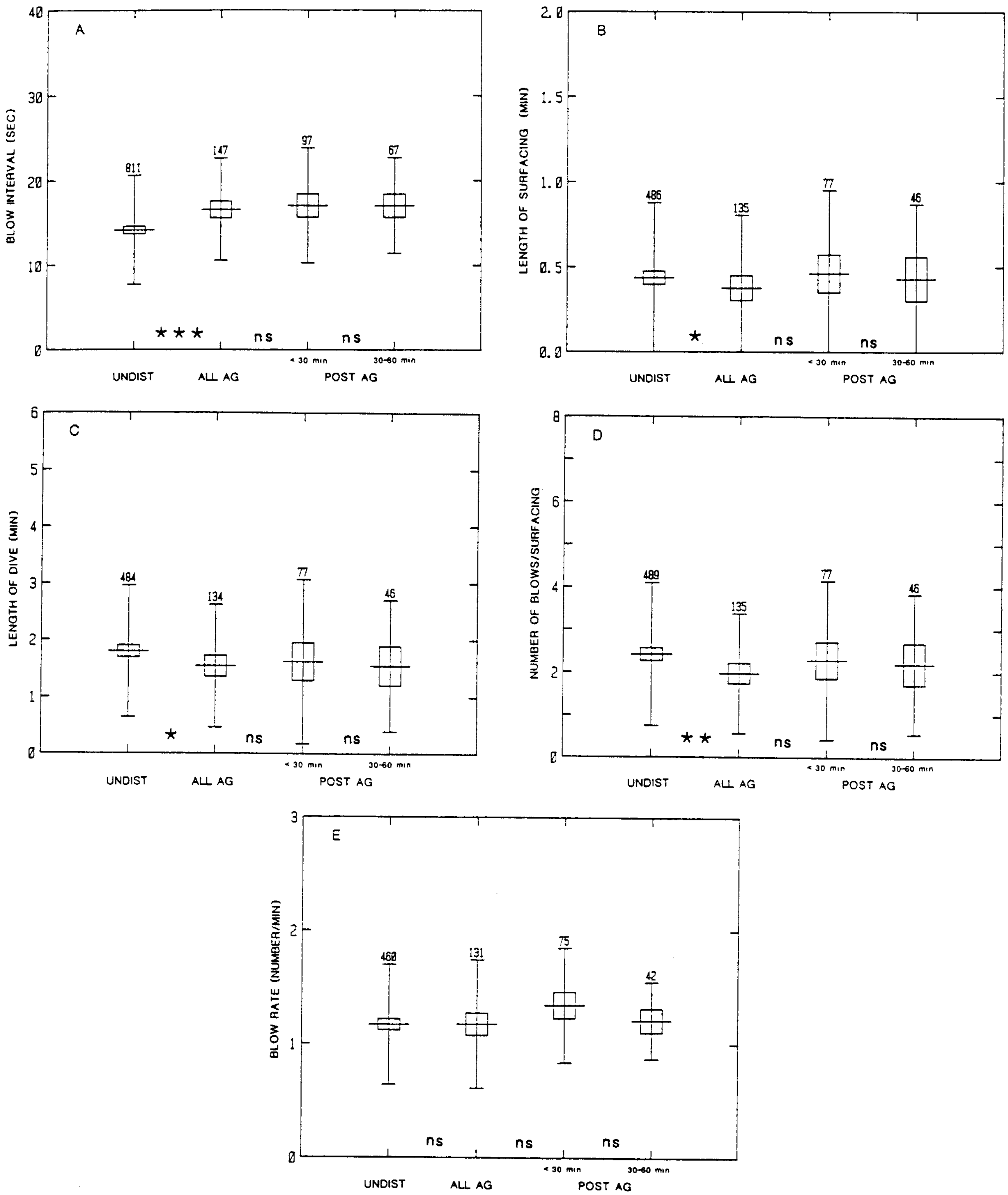


FIG. 3.41. SUMMARY STATISTICS FOR UNDISTURBED WHALES, AND WHALES DURING AND AFTER AIRGUN EXPERIMENTS. DISPLAY AS IN FIG. 3.39.

hour period after exposure of whales to drillship sounds. Whales shift their surfacing-dive characteristics close to the pre-disturbance level in the 30 to 60 minute period after exposure. They even appear to "overshoot" the presumed undisturbed level, with blow interval higher and the other three primary characteristics lower, than during the presumed undisturbed situation (Fig. 3.40). Responses of whales to air gun do not tend to go back to the presumably undisturbed condition within one hour of air gun sounds, especially for blow intervals and length of dives. These data indicate that air gun sounds have a longer-term effect on the normal behavior of primarily feeding gray whales than do drillship sounds (Fig. 3.41). A caution is necessary, however: drillship sounds were made by playbacks which may have some differences in sound characteristics from real drillships, and air gun sounds were supplied by only one air gun instead of the many often used during seismic mapping activities (see sound section for more detail).

3.4.4 Specific experimental comparisons

19 August 1985

Few numerical data exist for 19 August, and we can make no firm statements about surfacing-dive characteristics relative to stages of the drillship experiment (DS 1) of this date. During the almost four hours of control period before drillship sound playback, >15 whales were sighted within 2 km of the BIG VALLEY, and at least 2 to 3 whales were present within 600 M of the vessel at any one time. During the playback, only one whale was seen briefly at the beginning of playback, and then no whales were seen close to the vessel for >30 minutes. Four whales were seen 1.0 to 1.5 km from the vessel just after playback. As a result, we have almost no data during the drillship experiment and for the 30 min. post disturbance period (Fig. 3.42). During the 30 to 60 min. post disturbance period, blow interval

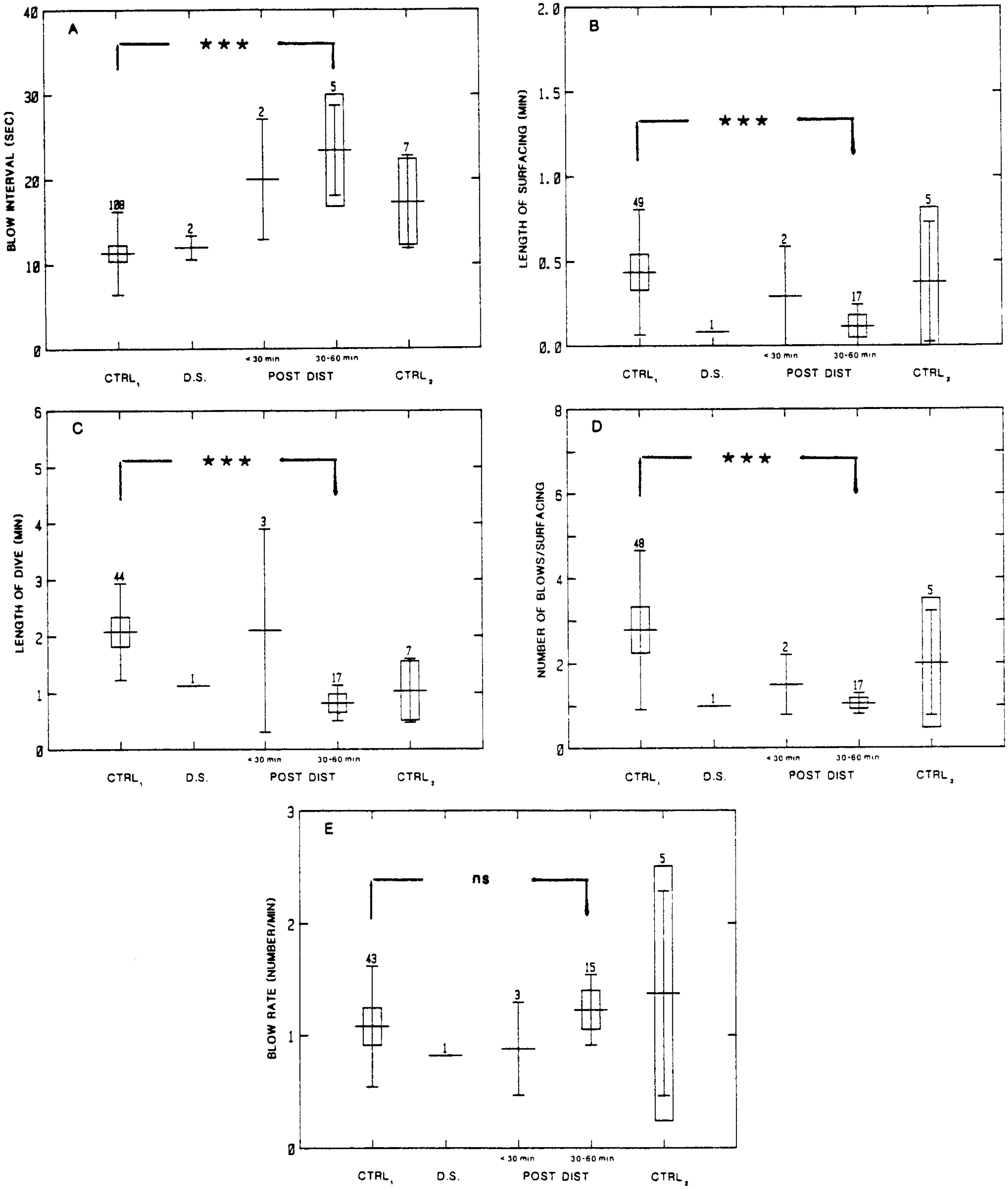


FIG. 3.42. AUGUST 19: DIFFERENT STAGES OF A DRILLSHIP EXPERIMENT COMPARED BY SURFACING-DIVE CHARACTERISTICS. DISPLAY AS IN FIG. 3.39.

increased over control, and length of surfacing, length of dive, and number of blows per surfacing all decreased (all at $p < 0.001$ level). Blow rate showed no clear trend. It is possible that the data for the 30 to 60 min. period represent an adjustment of surfacing-dive patterns after an unknown reaction during the actual noise playback. Unfortunately, we do not know what this reaction may have been, although we can guess from summary data of drillship exposure that blow interval decreased - and the other three primary characteristics increased from the pre-disturbance category.

21 August 1985

On this date, we performed three drillship playback experiments, but with few data on the third of this series of playbacks (Figure 3.43). There was a tendency for all blow intervals to decrease during playback, and not to go entirely back to pre-disturbance levels between playbacks. Responses to drillship are not as clear for the other surfacing-dive characteristics, however. During experiment 1 of the day (DS-2), length of surfacing, length of dive, and number of blows per surfacing tended to increase. They then stayed at high levels during post-disturbance times, however, and throughout the second experiment showed a steady decrease. It is likely that the second experiment (DS-3) was strongly affected by the first, and that whales did not show consistent changes in surfacing-dive characteristics because of this effect. During playback 1 of the day, the reaction of whales was not great, but was actually larger during the 0 to 30 minute post-disturbance times. It is possible that this corresponds to a delayed reaction by the whales, and the apparently disparate reactions of Exp. 1 and 2 of the day may be due to the cumulative effects of the first and second experiments as well as the continued presence of the vessel near the reacting whales.

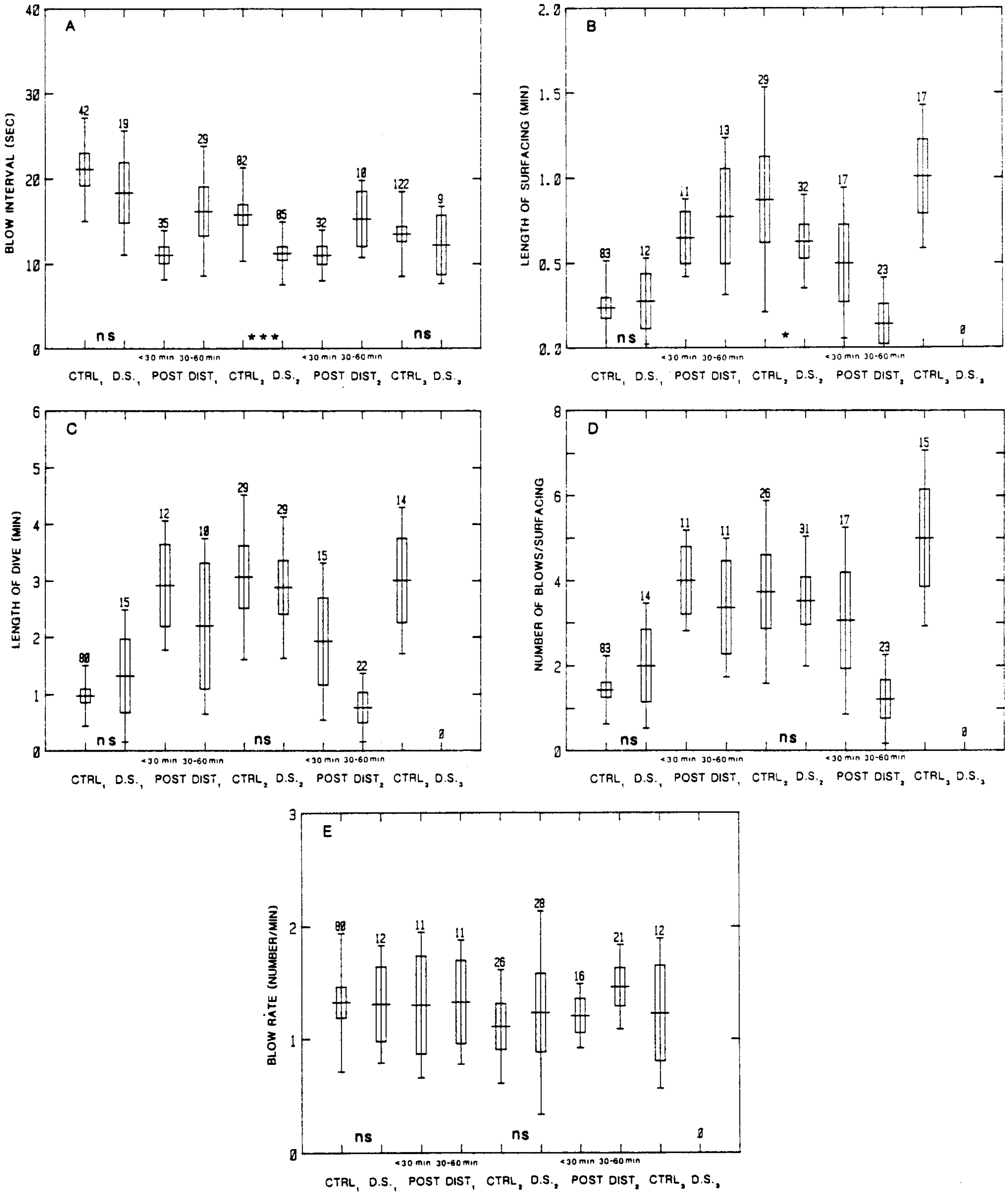


FIG. 3.43. AUGUST 21: DIFFERENT STAGES OF THREE DRILLSHIP EXPERIMENTS, PERFORMED SERIATIM THROUGHOUT THE DAY, COMPARED BY SURFACING-DIVE CHARACTERISTICS. DISPLAY AS IN FIG. 3.39.

22 August 1985

As stated earlier, the overall surfacing-dive reaction of whales during air gun sounds was opposite to the reaction whales showed during drillship sounds. This finding is illustrated well during the two experiments of 22 August. Blow interval showed a non-significant tendency to rise during the first air gun experiment (AG 1), but no rise during the second experiment (AG 2). Length of surfacing, length of dive, and number of blows per surfacing all decreased (at a $p < 0.001$ significance level) during the first experiment, and showed a generally non-significant trend to decrease during the second experiment. These decreases in length of surfacing, length of dive, and number of blows per surfacing tend to correlate with whales ceasing to feed during the air gun experiments, and travelling (see general behavior section). During the 30 to 60 minute post-disturbance for experiment 1, and the subsequent control period, values for these three surfacing-dive characteristics were exceptionally high (Figure 3.44b,c,d), and the second air gunperiod did not bring values down to the same level as seen during the first air gun period. Those high levels may represent an overcompensation to a pre-disturbance situation, as seen previously, but sample sizes are too low to make this conclusion firmly. After experiment 1, values during the 0 to 30 minute post-disturbance period remained similar to the air gun period, and then increased after that time. Values after experiment 2 increased during the 0 to 30 minute post-disturbance period and then decreased after that time. It appears that whales subjected to air gun sounds react for a longer period of time than do whales subjected to drillship sounds, and that a cumulative effect tends to lengthen this period after repeated exposure. Data are few for this set of experiments, however, and larger sample sizes and number of whales are needed for a proper assessment.

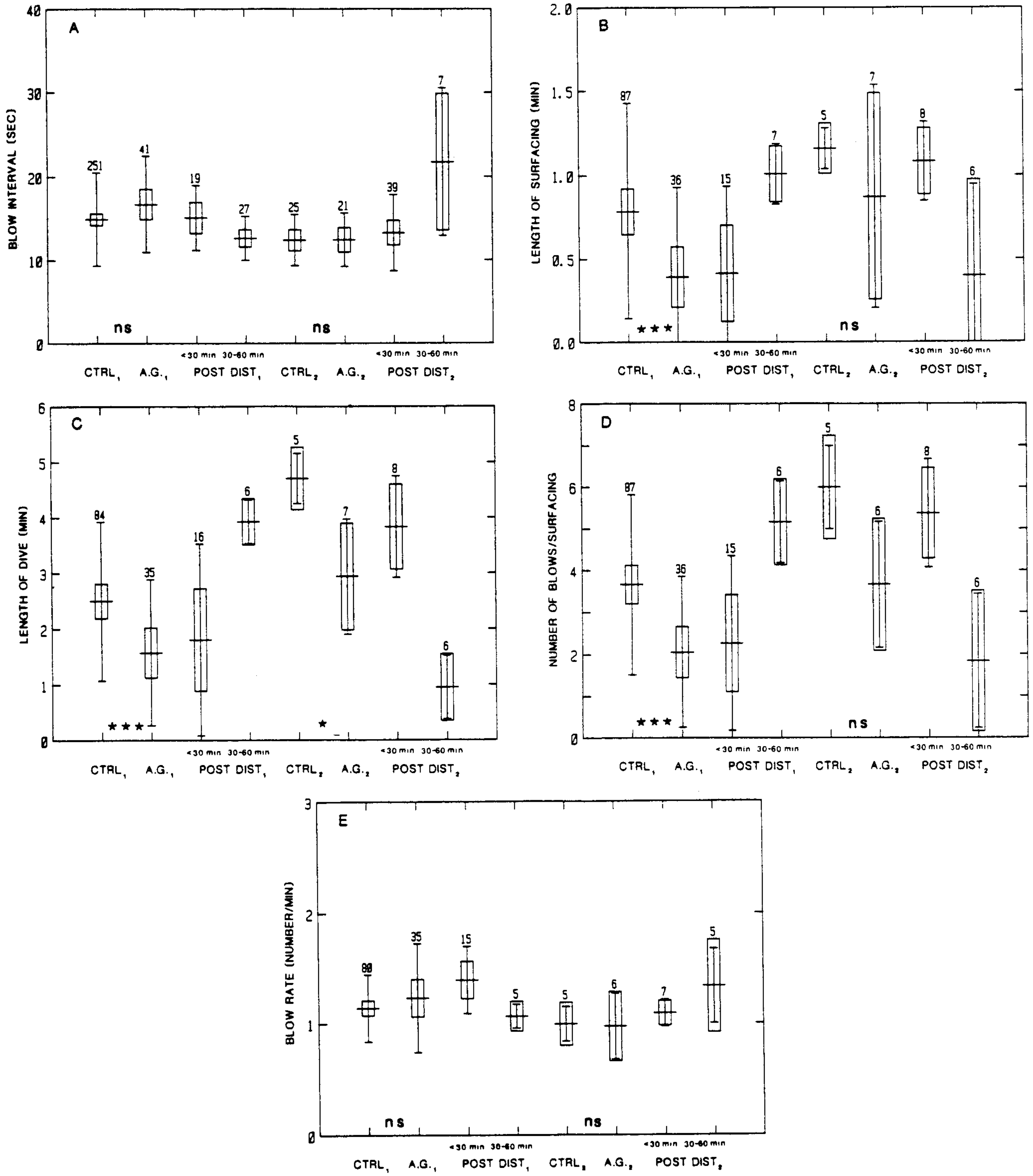


FIG. 3.44. AUGUST 22: DIFFERENT STAGES OF TWO AIR GUN EXPERIMENTS, PERFORMED SERIATIM, COMPARED BY SURFACING-DIVE CHARACTERISTICS. DISPLAY AS IN FIG. 3.39.

24 August 1985

No surfacing-dive data were gathered for experimental comparisons, but movement patterns relative to AG 3 and AG 4 experiments and general behaviors are discussed on pages 3-72 through 3-81.

25 August 1985

There was a non-significant trend for blow intervals to increase during disturbance of both air gun experiments on 25 August. Other characteristics changed non-consistently (Fig. 3.45). There was a weak but discernable trend for length of surfacing, length of dive, and number of blows per surfacing to increase during experiment 1 (AG-5), but decrease significantly during experiment 2 (AG-6). It is likely that the non-consistent reactions to air gun sounds of experiment 1 of the day are due at least in part to an apparent disturbance reaction noted before the onset of air gun sounds as whales moved away from the BIG VALLEY, and described on pages 3-83 through 3-91. As well, we observed that one whale, "N", apparently continued feeding throughout the air gun experiment, and this behavior was accompanied by continued high values of surfacing-dive characteristics (see Fig. 3.51). During the second experiment, on the other hand, this whale moved away from the vessel while the air gun was on, and this cessation of feeding while travelling resulted in decreases in length of surfacings, length of dives, and number of blows per surfacing. We conclude that whales were generally more disturbed during the second than during the first experiment of the day.

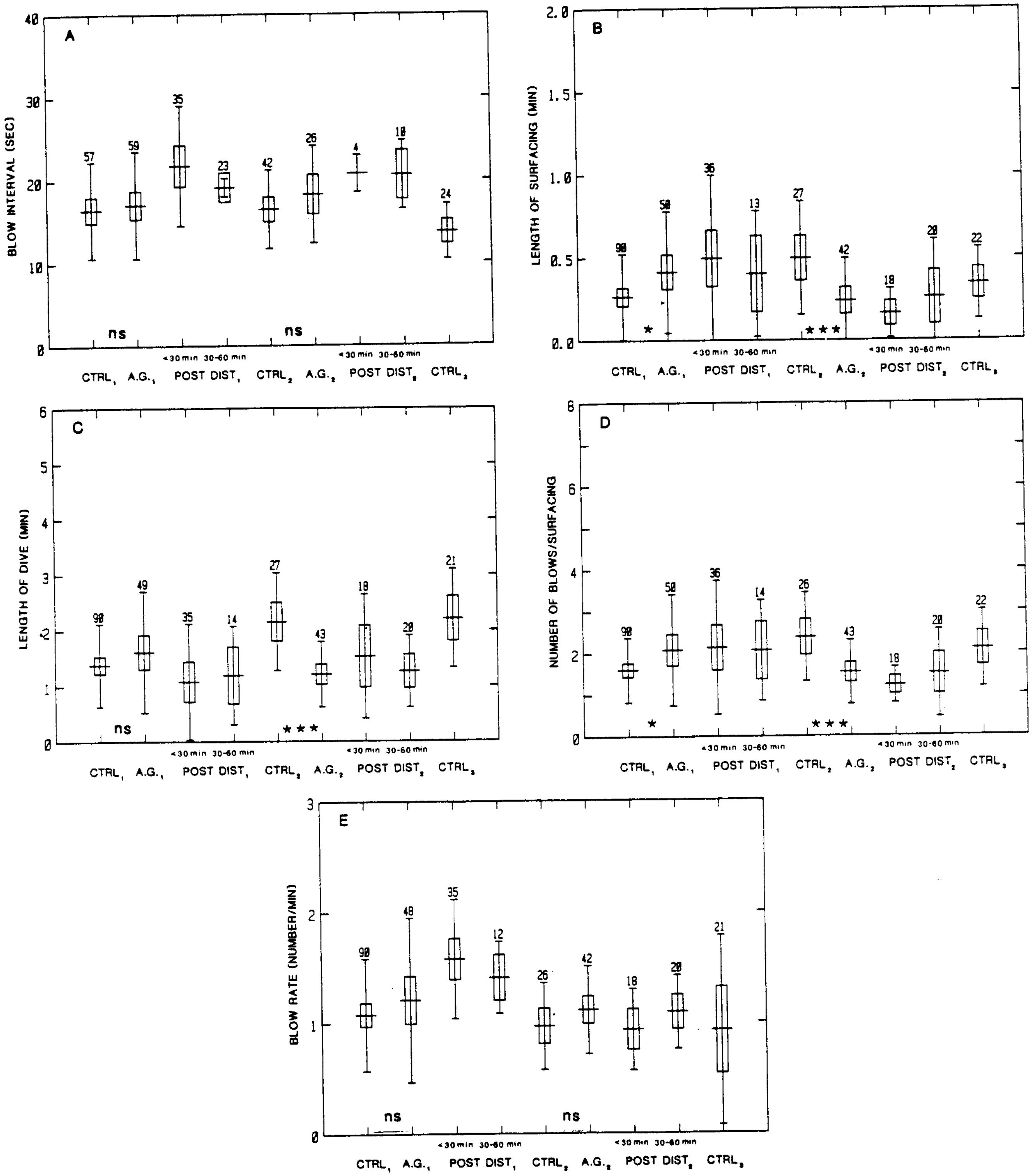


FIG. 3.45. AUGUST 25: DIFFERENT STAGES OF TWO AIR GUN EXPERIMENTS, PERFORMED SERIATIM, COMPARED BY SURFACING-DIVE CHARACTERISTICS. DISPLAY AS IN FIG. 3.39.

Specific Whales and Sound Levels

21 August 1985, Whale W

Whale W was observed before, during, and after drillship playback #2 of 21 August (DS-3) (see pages 3-60 through 3-62). The whale fed during most of that time, with some socializing for a 12-minute period during the control period before DS-3 playback. Surfacing-dive characteristics indicate a decrease in blow interval, length of surfacing, and length of dive (with a possible decrease for number of blows per surfacing as well) for the drillship versus control periods (Fig. 3.46). Recovery towards pre-disturbance level occurred within 60 minutes. Our observations indicated that Whale W did not cease feeding while it was subjected to the playback, and it stayed in the same area throughout our observations (pages 3-60 through 3-62). It is interesting that both length of surfacing and length of dive decreased during the playback. This indicates a more rapid cycling of the surfacing-dive repertory, and this may indicate a high "excitement" or "nervousness" level. Blow rate also showed a tendency to increase during drillship playback (albeit non-significant, possibly due to low sample size).

It is instructive to compare received levels of drillship sound, calculated for Whale W by taking distance of whale from the sound source and sound propagation characteristics of the area into account. We find that the decreases in blow interval, length of surfacing, and length of dive appear to be most pronounced during the lower than the higher exposure levels (Figure 3.47a,b,c). Higher sound levels occurred during the beginning of Whale W's exposure to the sound, and levels decreased as the whale slowly moved away. It is possible that the apparently greater response during the lower received levels is due to a cumulative effect of sound, and that Whale W reacted more strongly towards the end of drillship playback despite the

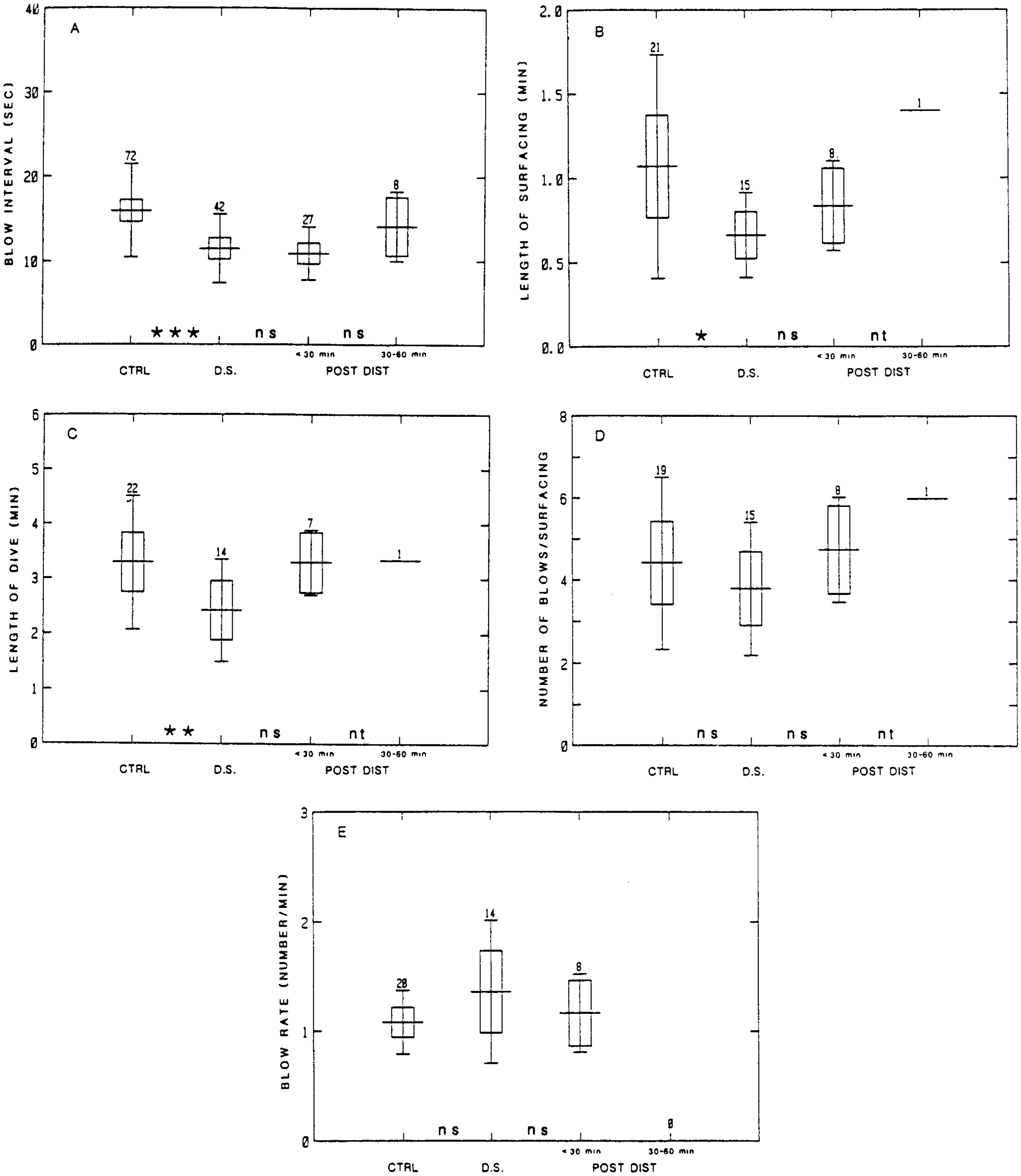


FIG. 3.46. AUGUST 21, WHALE "W" ONLY. DIFFERENT STAGES OF REACTION TO DRILLSHIP EXPERIMENT #2 OF THE DAY, COMPARED BY SURFACING-DIVE CHARACTERISTICS. DISPLAY AS IN FIG. 3.39; NT = NOT TESTED.

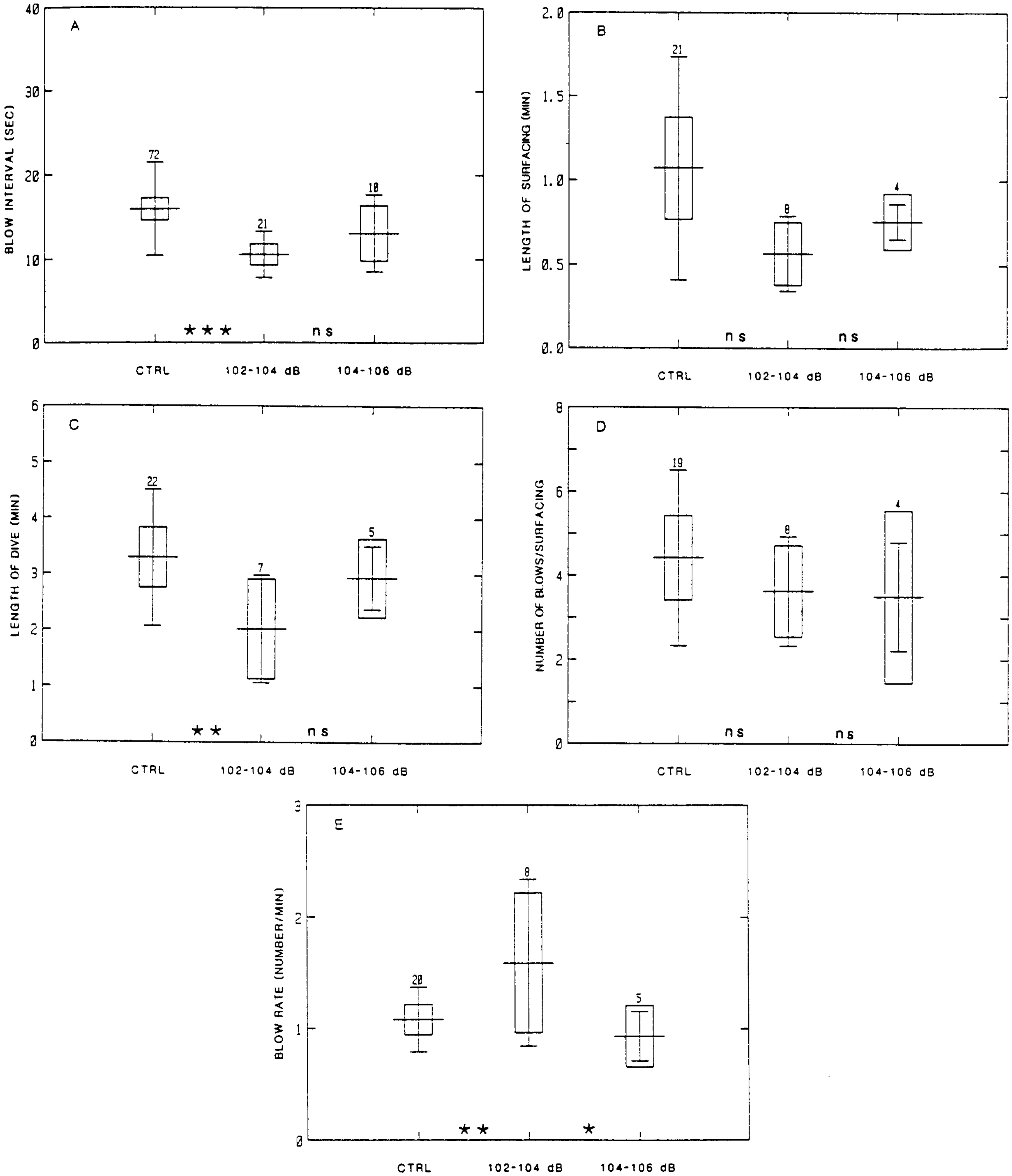


FIG. 3.47. AUGUST 21, WHALE W ONLY. CALCULATED RECEIVED LEVELS OF DRILLSHIP SOUND, DRILLSHIP EXPERIMENT #2 OF THE DAY, COMPARED BY SURFACING-DIVE CHARACTERISTICS. DISPLAY AS IN FIG. 3.39.

lower level of received sound due to this heightened sensitivity. The control period for this experiment was affected by the preceding experiment (see Fig. 3.43), and this must be taken into account when evaluating the apparent response of Whale W to drillship sound.

22 August 1985, Whale E

Surfacing-dive characteristics were collected on Whale E for approximately 7 hours, through both air gun experiments of the day. The results reflect general surfacing-dive characteristics for overall data of 22 August, since Whale E was responsible for much of the data gathered (compare Figs. 3.44 and 3.48). During air gun experiment 1 of the day (AG 1), Whale E remained in the area as the air gun vessel moved from about 3.8 km to as close as 0.2 km towards the end of the experiment. The surfacing-dive reaction of the whale was strong. Blow interval rose, and length of surfacing, length of dive, and number of blows per surfacing all decreased (Fig. 3.48). During the second experiment later in the day (AG-2), blow intervals did not change, and the other three characteristics showed a non-significant trend to decrease (non-significant possibly due to low sample sizes). Received sound levels ranged between 149 and 172 dB during the first experiment, and they varied between 163 and 172 dB during the second experiment. The average RSLs were thus higher for the second experiment. We have some evidence that Whale E continued to feed throughout the second experiment, and this apparent decrease in reaction between the first and second experiment may be due to partial habituation of Whale E to air gun sound by experiment #2. This conclusion should be treated with caution, however, because we gathered too few data on surfacing-dive characteristics for experiment #2 for firm conclusions.

We wondered whether there was a general difference in surfacing-dive characteristics, depending on the received level

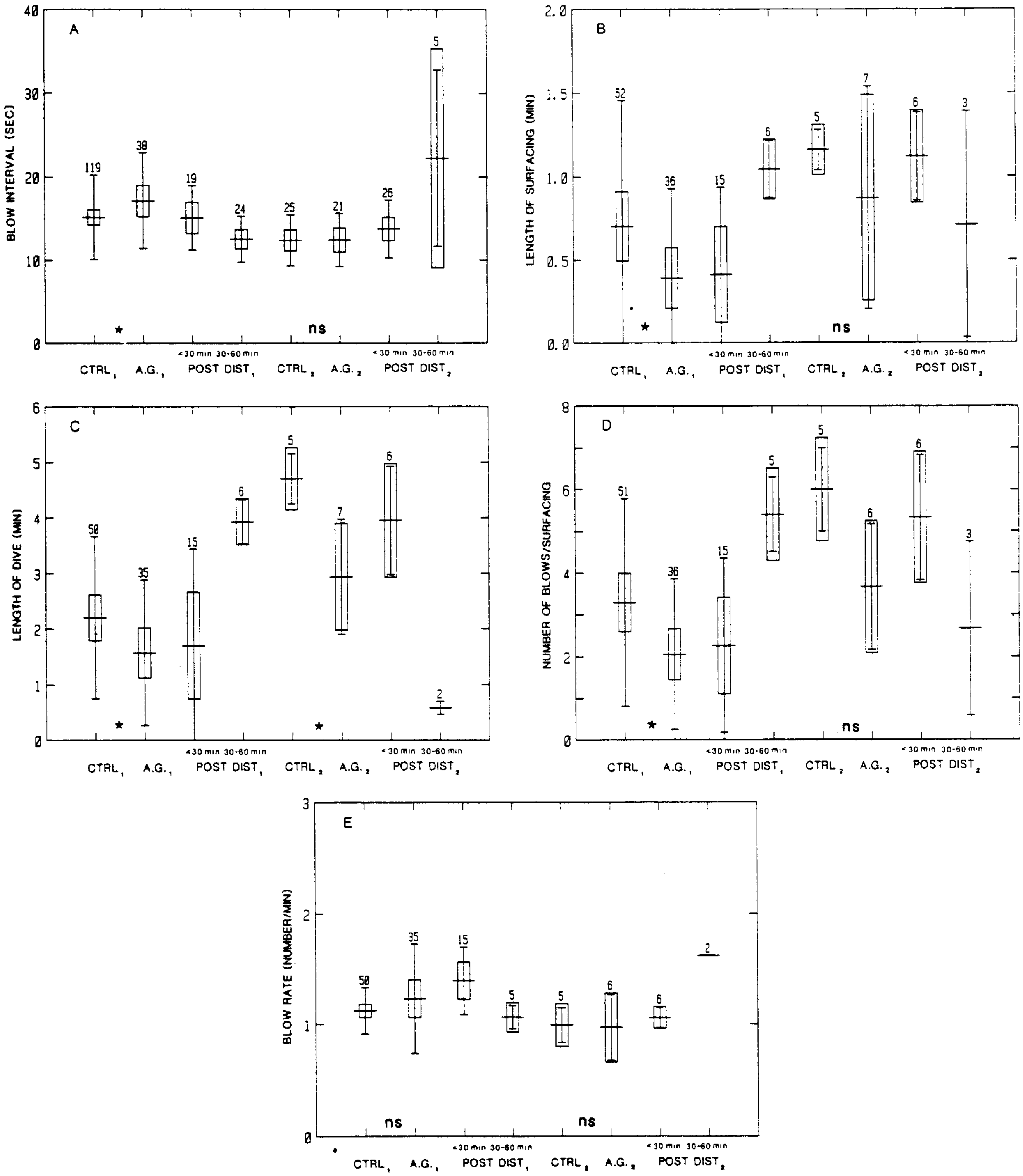


FIG. 3.48. AUGUST 22, WHALE E ONLY. DIFFERENT STAGES OF REACTION TO TWO AIR GUN EXPERIMENTS, COMPARED BY SURFACING-DIVE CHARACTERISTICS. DISPLAY AS IN FIG. 3.39.

of air gun sound. Whale E was the only whale for which enough data for comparison existed. We divided data into received levels of <155 dB (approximately 149 to 155 dB) and ≥155 dB (approximately 155 to 172 dB). In general, reactions to the higher sound levels appeared to be somewhat stronger than those to the lower levels, but once again data are non-significant and suggestive only, due to low sample sizes (Fig. 3.49).

25 August 1985, Whales L and N

The final focal whale comparisons for surfacing-dive characteristics related to air gun sounds were made for two whales for which behavior was well-documented. Whale L was observed during experiment #1 of the day (AG-5). Whale L apparently fed as it milled within 3.5 to 1.2 km of the air gun sounds (distance decreasing as the air gun vessel moved past the whale), for approximate received sound levels of 155 to 168 dB. It showed an increased mean blow interval and a decreased length of dive during and immediately after the air gun sounds. Blow rate also increased from the pre-disturbance level. Blow interval, length of dive, and blow rate did not go back to pre-disturbance levels within 60 minutes of the air gun sounds (Fig. 3.50).

Whale N was followed through both experiments of the day. During the first experiment, it stayed in the same area and continued to feed despite the presence of the air gun vessel as close as 1.23 km and an approximate received sound level of 168 dB. We have no pre-disturbance surfacing-dive data for this experiment, however. During the second experiment (AG-6), Whale N stopped feeding and moved across the bow of the air gun vessel, and then away from it. Whale N came back to its original pre-disturbance location within 116 minutes after the air gun was turned off, and there resumed feeding (see movement pattern analysis, pages 3-89 through 3-91). During its travel while exposed to the air gun sounds, Whale N showed an increased mean

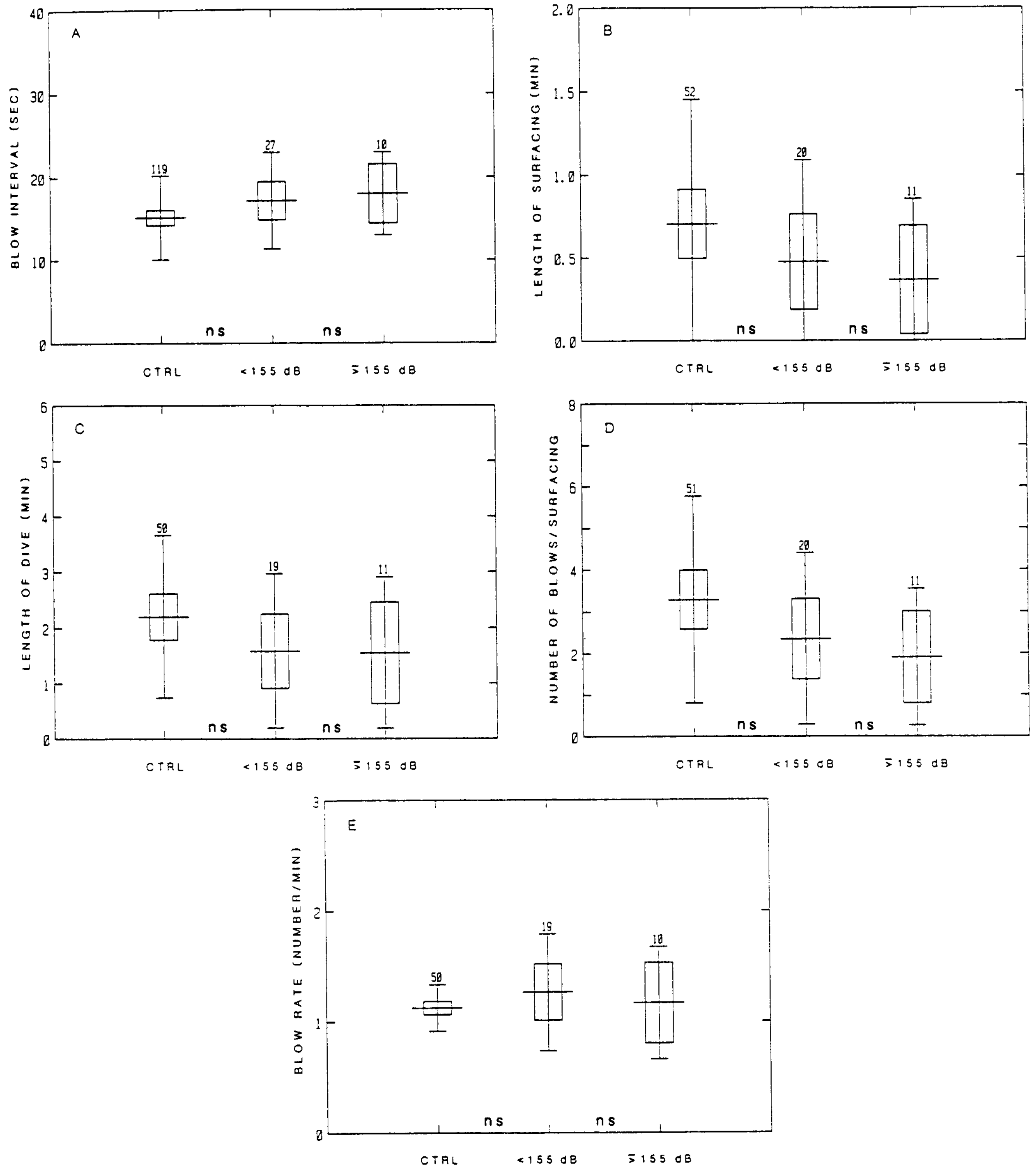


FIG. 3.49. AUGUST 22, WHALE E ONLY. CALCULATED RECEIVED LEVELS OF AIR GUN SOUND FROM TWO EXPERIMENTS, COMPARED BY SURFACING-DIVE CHARACTERISTICS. DISPLAY AS IN FIG. 3.39.

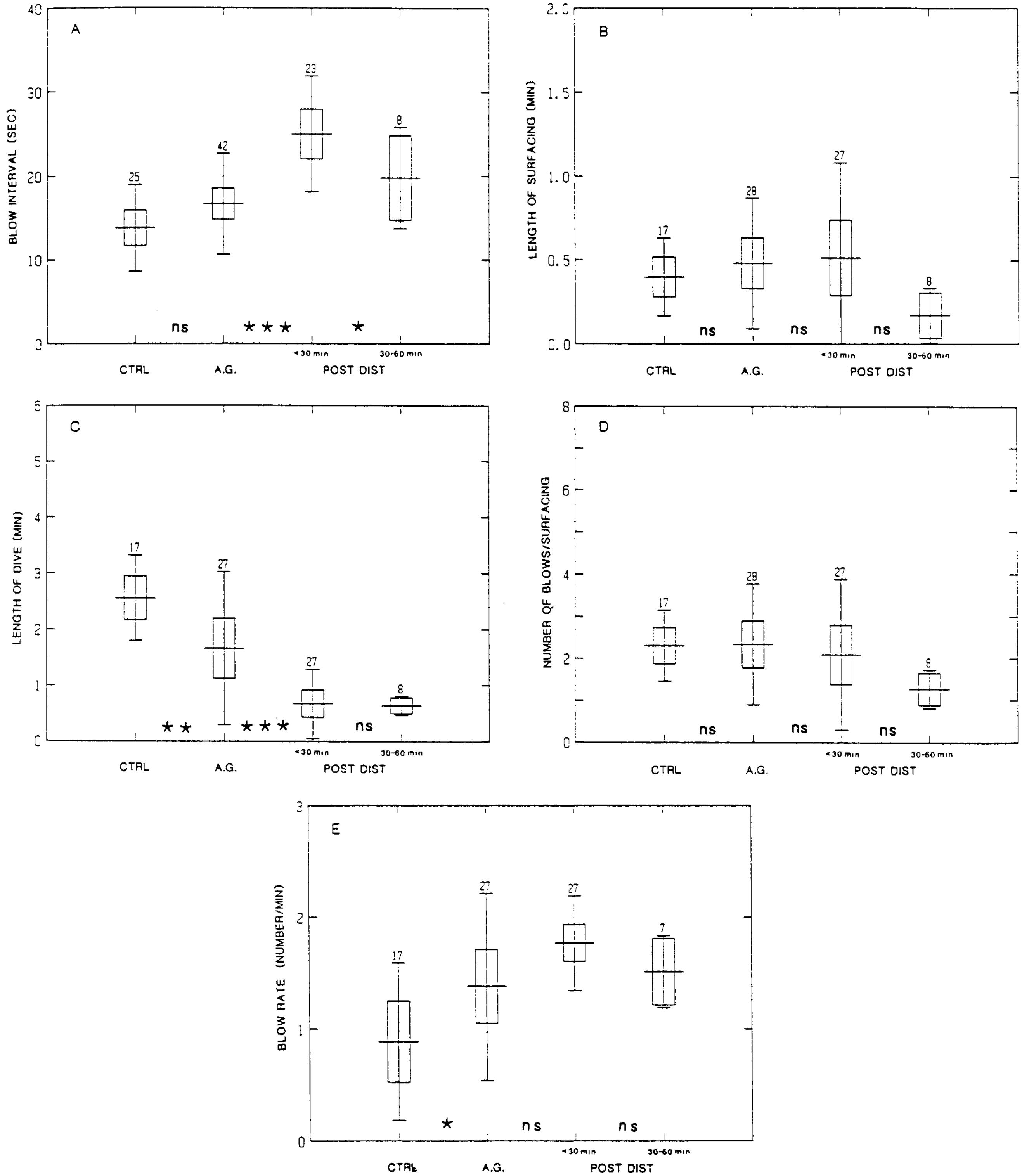


FIG. 3.50. AUGUST 25, WHALE L ONLY. DIFFERENT STAGES OF REACTION TO AIR GUN EXPERIMENT #1 OF THE DAY, COMPARED BY SURFACING-DIVE CHARACTERISTICS. DISPLAY AS IN FIG. 3.39.

blow-interval, and decreased length of surfacing, length of dive, and number of blows per surfacing. Blow rate also increased, possibly due to its energetic travel as Whale N moved away from the vessel (Fig. 3.51). Disturbance lasted throughout the 60 minute post-disturbance period, and surfacing-dive characteristics went back to pre-disturbance levels after that time. Unfortunately, we do not have enough calculated received sound levels for Whales L and N in order to compare surfacing-dive characteristics by different sound levels.

Summary

Although relatively few surfacing-dive data were collected for only several days, some interesting trends have emerged. In general, blow intervals decreased during drillship sounds, and length of surfacing, length of dive, and number of blows per surfacing increased. This trend indicates that whales are cycling through their basic surfacing-dive patterns more slowly while subjected to drillship sounds. They went back towards a pre-disturbance level relatively quickly, usually after about one-half hour post disturbance. Blow rate altered little. Air gun related behavior was different. Whales increased blow intervals and tended to decrease length of surfacing, length of dive, and number of blows per surfacing. In other words, they cycled through their repertory more rapidly, as they apparently alternated feeding with travel, or travelled away from the sound source. This trend was especially strong during several occasions when we noticed a definite cessation of feeding and movement away from the sound source. Recovery to "normal" levels was less rapid than for drillship sounds, but tended to occur about one hour after disturbance.

For both types of experimental situations, subsequent experiments of a day appeared to be affected by the earlier experiments. This took both the form of surfacing-dive data not

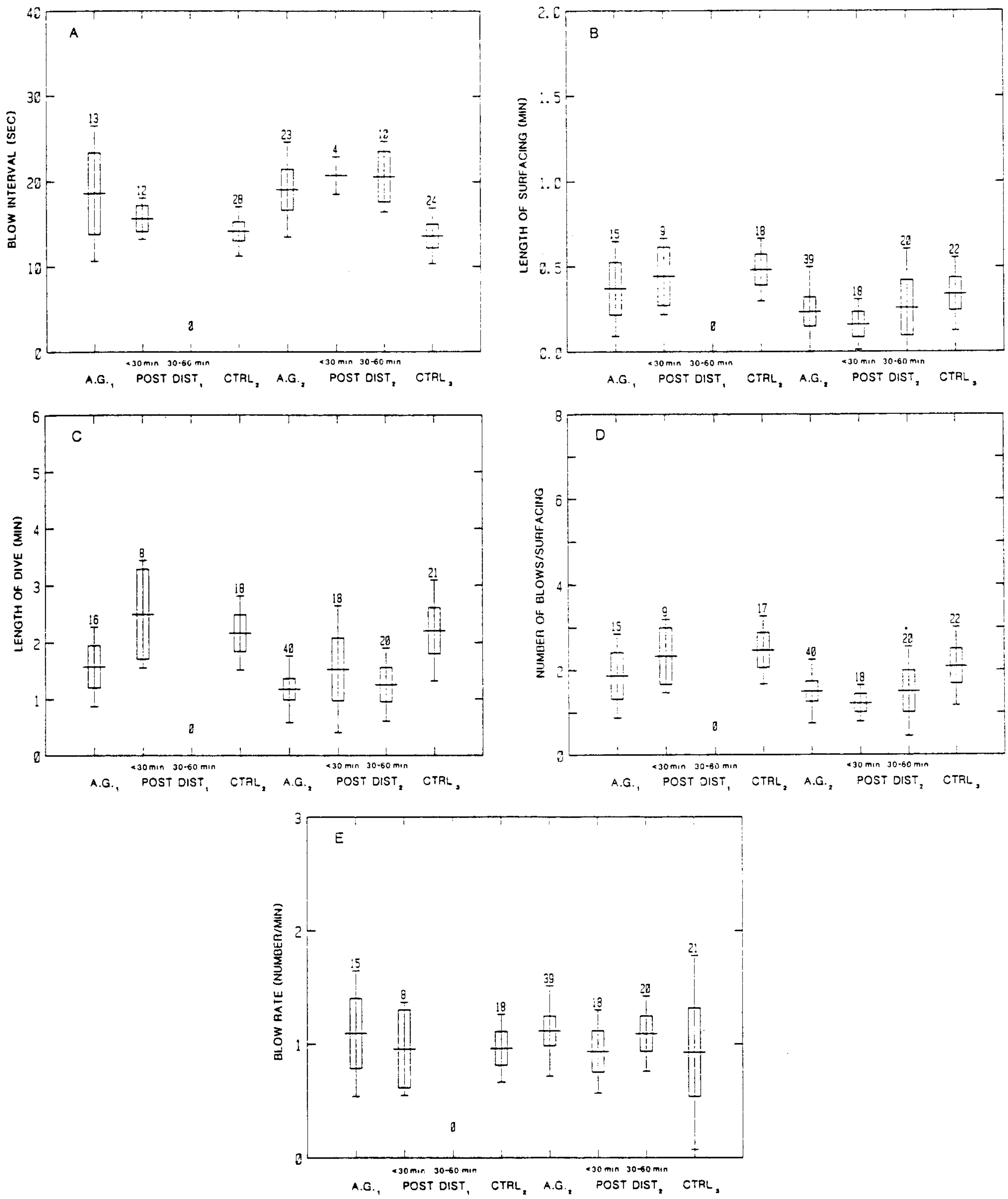


FIG. 3.51. AUGUST 25, WHALE N ONLY. DIFFERENT STAGES OF REACTION TO AIR GUN EXPERIMENTS #1 AND #2 OF THE DAY, COMPARED BY SURFACING-DIVE CHARACTERISTICS. DISPLAY AS IN FIG. 3.39.

always going back to a pre-disturbance level after the first experiment of the day, and whales at times reacting less strongly to a subsequent experiment. This is not a firm conclusion, however, because many other factors such as time of day, presence of one or two boats in the area, and general behavior of the whales may have served as confounding factors. Interestingly, number of blows per surfacing, length of surfacings, and length of dives were all lower during the present study than for presumed undisturbed gray whales studied in July and September 1982 in the same area (Würsig et al. 1986). We wonder whether our present results may have been affected by the presence of at least one large vessel near the whales at almost all times, unlike the situation in 1982, when observations were generally made from a small skiff > 1 km distant from the mothership. This possibility of a level of disturbance even during presumed "undisturbed" situations does not negate our results, however, since industrial disturbance is likely to be accompanied by the presence of larger vessels in real situations.

Disturbance reaction during air gun playback was extremely similar to the reaction found for surfacing-dive characteristics of bowhead whales (Balaena mysticetus) when subjected to air gun sounds (Richardson et al. 1985, Ljungblad et al. 1985a, Richardson et al. 1986). In bowheads, blow intervals increased and length of surfacing, length of dive, and number of blows per surfacing all decreased during air gun firing. The same basic behavioral shift from feeding or milling prior to air gun sounds to traveling away from the sound source were noted for bowheads during several experiments with full-scale seismic vessels (Ljungblad et al. 1985a).

3.5 Interpretation and Application of Results

3.5.1 Comparison with migrating activity

In this section we compare the results obtained by Malme et al. (1983, 1984) on the effects of industrial noise stimuli on the behavior of migrating gray whales to the results of the present study.

In general, the present study results are comparable in that measurable responses were observed at similar sound exposure levels. However, comparisons of gray whale behavioral reactions between these studies are difficult for three reasons. First, the whales under study were involved in very different behaviors, migrating in the earlier studies and feeding in the present study. Second, although blow rate and blow interval analysis was performed during the first set of studies, this analysis was done only on mother/calf pairs as opposed to analysis done on non-mother/calf pairs on the feeding ground. Third, the main focus of the migrating gray whale behavior studies was on the statistical analysis of migration track deflection scores and speed of movement as well as other movement-related behaviors. These measures were very sensitive because of the highly oriented movement of migrating gray whales. The present study focussed primarily (for statistical purposes) on the surfacing and respiration characteristics of gray whales. Since feeding gray whales turn so frequently and have such variable movement patterns, the track deflection analysis was not appropriate.

In spite of these differences in analytical methods, we can ask whether feeding or migrating gray whales show different behavioral reactions at similar exposure levels to industrial noise. We have chosen to present comparisons in narrative rather than tabular form because of the complexity of the study procedures.

Industrial Noise Sources

Malme et al. (1983) found that during playbacks of a variety of industrial noise stimuli to southbound migrants, each sound stimulus caused a statistically significant response and that each of these responses was different when compared to control conditions. Patterns of response appeared to vary predictably as a function of received sound level. Responses generally involved avoidance of the sound source, based on track deflection scores for whales exposed to playbacks of drilling platform, helicopter, and production platform sounds and a drop in speed for whales exposed to drilling platform, drillship, semisubmersible, and helicopter sounds. During drilling platform and helicopter sound playbacks, apparent avoidance of the source area out to about 250 m was noted with sound levels at this range approximately 111 to 118 dB.

During January 1984, similar industrial noise playbacks were conducted on southbound migrating gray whales (Malme et al. 1984). An analysis procedure was developed which permitted determination of the probability of avoidance of the region near the playback source. This measure showed that avoidance behavior began at sound exposure levels of around 110 dB for the overall signal and was greater than 80% for regions with signal levels higher than 130 dB. Some variation among the various playback stimuli was observed with the drillship producing the greatest avoidance and the production platform the lowest, for levels between 110 and 125 dB. However, for levels between 125 and 130 dB, the reactions to all playback stimuli were comparable.

During the present study, data on whales exposed to drillship sound playback suggest that gray whale movement was not affected by RSL at 103 to 110 dB and at distances to the sound source as close as 1.12 km. During two of the four drillship experiments, we did note a change in movement pattern with whales leaving the immediate area of the sound source; however, whale movement data are not available for these two experiments (see Section 3.4.1). During one of these latter two experiments, RSL at the whales moving out of the area was estimated at 108 to 119 dB at distances of approximately 1 km to 0.3 km, respectively. Results of drillship playbacks during the present study appear consistent with our earlier findings.

Seismic Sources

Malme et al. (1983) conducted experiments with seismic exploration sources on northward migrating mother/calf pairs during April and May 1983 using a stationary and towed single air gun and a 40 gun towed array. Overall, results showed that the most predictable responses of the whales to air gun activity occurred at received levels of > (greater than) 160 dB re 1 μPa when the air gun source was within 2 km of the animals.

Small sample sizes prevented definite quantification of response for average pulse pressure levels between 140 and 160 dB, but analysis showed that some behavioral changes did occur at these levels. In general, whales would slow down and turn away from the source. In several cases, groups were seen swimming into the surf zone and also positioning themselves in the sound shadow of a rock, island, or outcropping. There were significant differences, independent of range or level of exposure, in milling indices, speed indices for groups prior to exposure and those same groups during exposure to the air gun noise. There were also significant differences in milling indices and speed indices for groups during exposure and after exposure to air gun noise.

Of the ten groups of northward migrating mother/calf pairs that were exposed to RSL > 160 dB during the air gun array runs, of April-May 1983, four were being overtaken from behind by the boat during the entire observation period; five were overtaken from behind and were passed by the boat, and one was approached and passed. None of the four that were being chased turned south, milled, or moved inshore. All five of the groups that were overtaken from behind and were passed turned south and/or moved inshore within five min. after the vessel passed its closest point of approach (CPA), then continued to mill and behave in a disoriented and confused manner. The one group that was approached head on and eventually passed turned south, away from the boat, when it was within one minute of its CPA. Again, this group milled and moved in close to shore. These responses are probably related to the high level of directivity in the horizontal plane of the air gun array. As the array passed a group broadside, the group would experience a sudden increase in sound level on the order of 20 dB. As noted in Section 3.4.1 in the present study, responses were observed in three and possibly four cases where the whale was passed by the air gun vessel. In all four cases, RSL was greater than 160 dB.

During the southbound January 1984 migration, seismic experiments were conducted using both a stationary single air gun and a towed single air gun. During stationary air gun experiments, whales avoided the sound source area by moving further offshore or inshore of the air gun vessel. This avoidance response was first detected at 2 km north of the vessel and persisted until the whales were at least 2 km south of the vessel. No identifiable avoidance response was observed during moving air gun experiments. However, these experiments were of short duration and sample sizes were low.

The probability of avoidance analysis for the stationary air gun source showed that the threshold of avoidance behavior occurred for average pulse pressure levels of approximately 164 dB. This was somewhat higher than the level of 160 dB which was observed to produce changes in the migration behavior of mother/calf pairs during the April and May 1983 field experiments.

During the present study, we did not conduct stationary single air gun experiments. We did, however, observe a variety of responses to the moving single air gun experiments as outlined in Section 3.4.1. Responses were observed at average pulse pressure levels at the whales of between 149 and 176 dB at distances up to 4 km, with four of the six responses, where RSL was known, occurring at levels > 160 dB. These sound levels and distances are comparable to results obtained during our earlier studies on migrating gray whales.

It is difficult to compare experimental results concerning migrating gray whales with those of feeding gray whales. Different behavioral responses were measured in feeding and migrating gray whales. The pattern of gray whale responses may scale not only with RSL, but also rate of change of RSL or movement of the sound source. Both of these parameters varied with moving vs. stationary air gun sources. A priori one may expect the response of gray whales to noise stimuli to be a function of behavioral state as has been pointed out by Brodie (1981) and Richardson et al. (1985). However, the results of our studies on the behavioral responses of migrating and feeding gray whales to drillship sound playback and air gun operations indicate measurable responses at similar exposure levels.

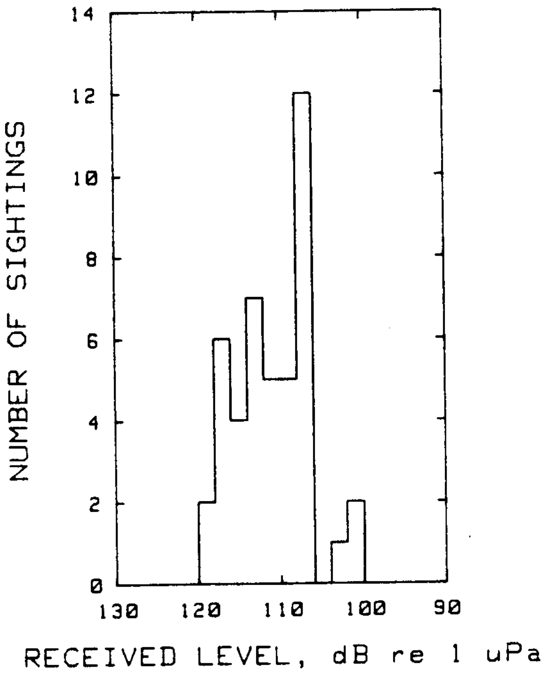
3.5.2 Application of results

In the previous studies of migrating gray whales, the large number of whales sighted and tracked during the field observation periods provided a good data base for statistical analysis. As a result, it was possible to quantify the response of the whales in terms of exposure level for a given stimulus. A measure of the degree to which whales would tend to avoid the region near the source was developed and termed "probability of avoidance."

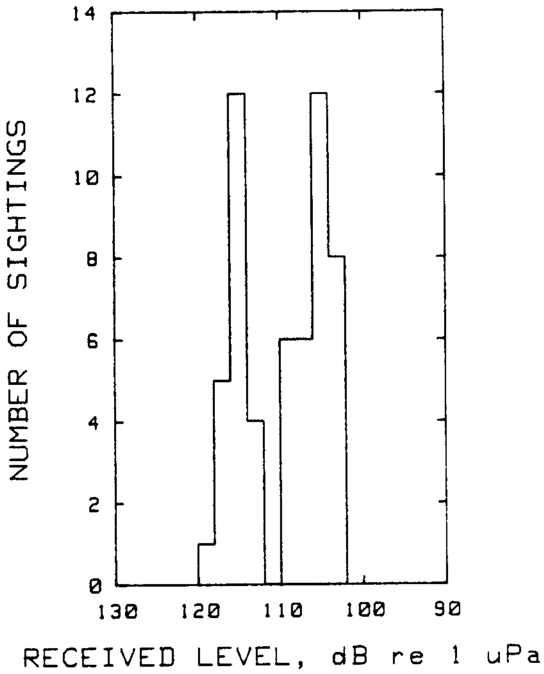
This procedure is difficult to apply in experiments where the source is moving as well as the whales since the distance from the source to the whales, which determines the exposure level, is not controlled by whale swimming response alone. Moreover, the number of whale position sightings obtained is considerably reduced when it is necessary to move the experiment to find new subjects.

In order to determine whether or not the probability of avoidance procedure could be applied to the observations obtained near St. Lawrence Island, histograms and cumulative sighting distributions were developed showing the number of sightings as a function of received level for the combined drillship playback periods and the combined air gun periods. Similar distributions were developed for the corresponding control (no sound stimulus) periods. The control period data were plotted using a virtual received level, i.e., the level that would have existed with the source operating.

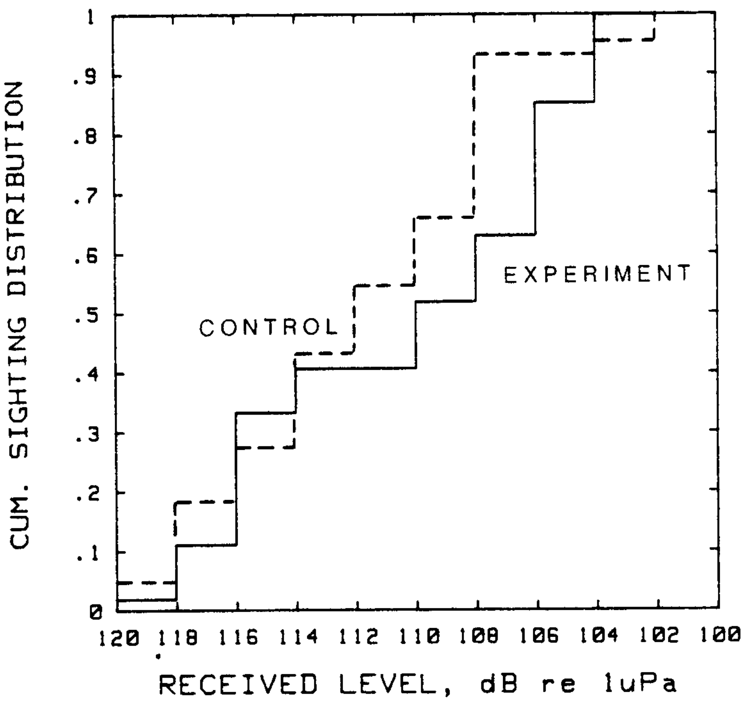
The resulting histograms and distributions for the drillship playback data are shown in Fig. 3.52. If the whales consistently avoided the high sound level region near the source, a comparison of the cumulative distributions for the control and experimental periods would show the number of sightings at high sound levels during the experimental periods to be lower than the number of sightings at the same range (virtual sound level) during the control periods. Examination of the data in Fig. 3.52 shows that this did not occur. While the cumulative density at the 120 - 116 dB level is slightly lower for the stimulus condition, no definite shift in the sightings away from the source region during the experimental periods can be seen. In fact, Fig. 3.53 for the air gun stimulus shows a higher sighting density near the source during the stimulus periods than during the control periods. We do not believe that this proves that whales are attracted by the air gun sound. Rather, it suggests that the distance from the source to a whale under observation was strongly influenced by the initial geometry at the start of an



A. All Control Periods Summed



B. All Experiment Periods Summed



SIGHTING DISTRIBUTIONS, Experiment vs. Control

FIG. 3.52. DRILLSHIP STIMULUS, WHALE SIGHTING DATA.

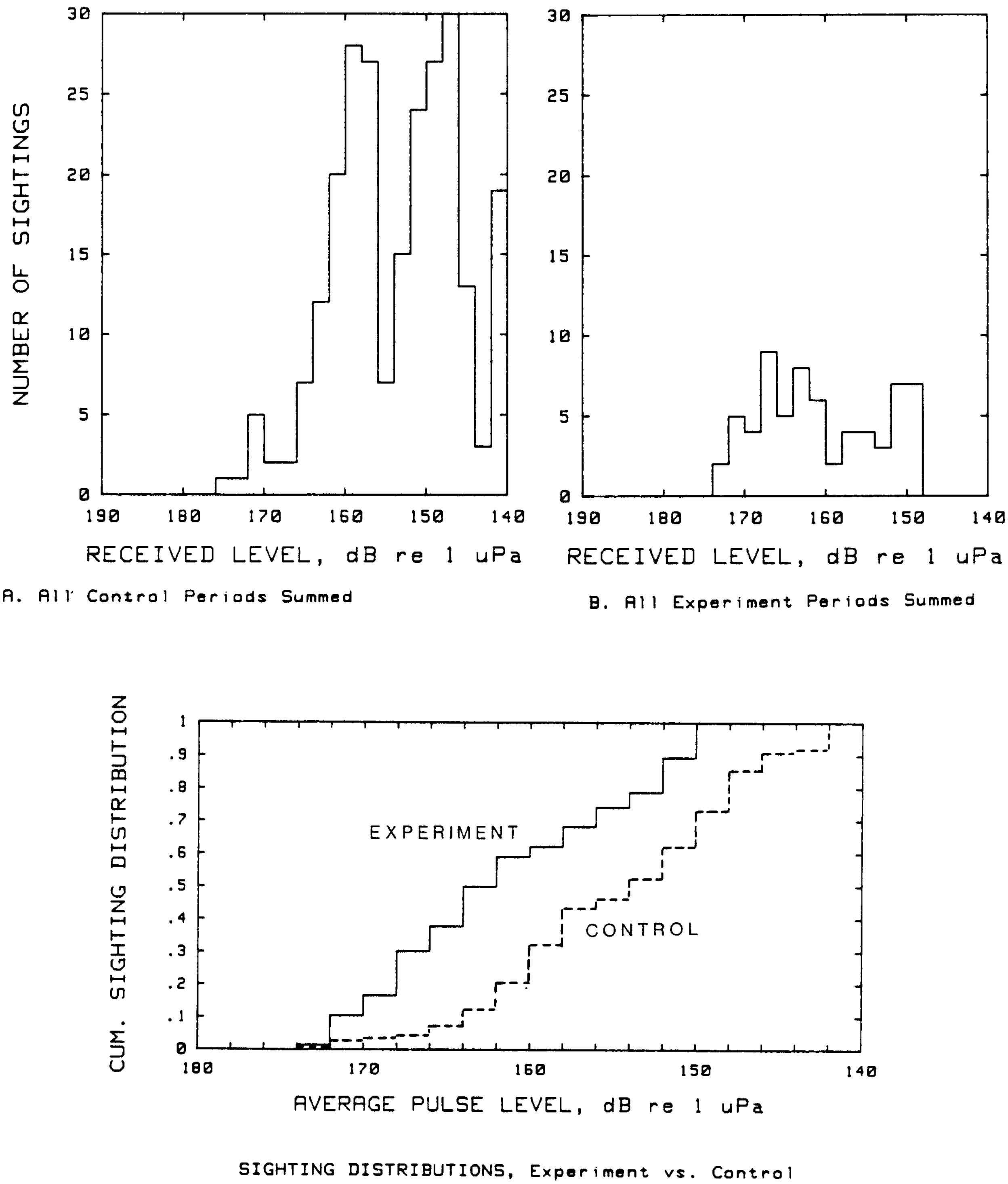


FIG. 3.53. AIR GUN STIMULUS, WHALE SIGHTING DATA.

experiment and by the track of the source vessel during the stimulus presentation period and probably influenced less by any avoidance behavior by the whale. Consequently, the probability of avoidance analysis technique cannot be used for moving source experiments unless the vessel movement procedures are identical for both control and experimental periods. In the St. Lawrence tests, the air gun vessel was repositioned during control periods to set up the approach geometry for the next experimental period. This was done in order to maximize the number of samples obtained from a dispersed whale population. As a result, the source vessel-whale distances were generally greater during control periods than during the experimental periods when the vessel was being actively maneuvered toward the whales.

In order to derive a general guideline for estimating the probable behavioral response of summering and feeding gray whales to air gun noise, it is necessary to examine the summary of individual whale responses presented previously in Table 3.8. On the basis of the information presented in this table, the summary cumulative distribution function shown in Fig. 3.54 was developed. The number of whales included in this function is less than those shown for the combined air gun tests in Fig. 3.53 because Fig. 3.54 only includes whales for which detailed track and observation records are available. Moreover, it includes only those whales for which a definite interruption of feeding activity was observed. If a whale resumed feeding after the air gun vessel had moved away or stopped firing, the corresponding original response exposure level is marked "F".

The resulting cumulative distribution can be seen to be somewhat skewed, having an interpolated median value of 173 dB and a calculated mean value of 169.6 dB. If the data values shown are considered to be representative samples of the true acoustic response statistics which might be obtained with more extensive testing, it is useful to calculate the confidence

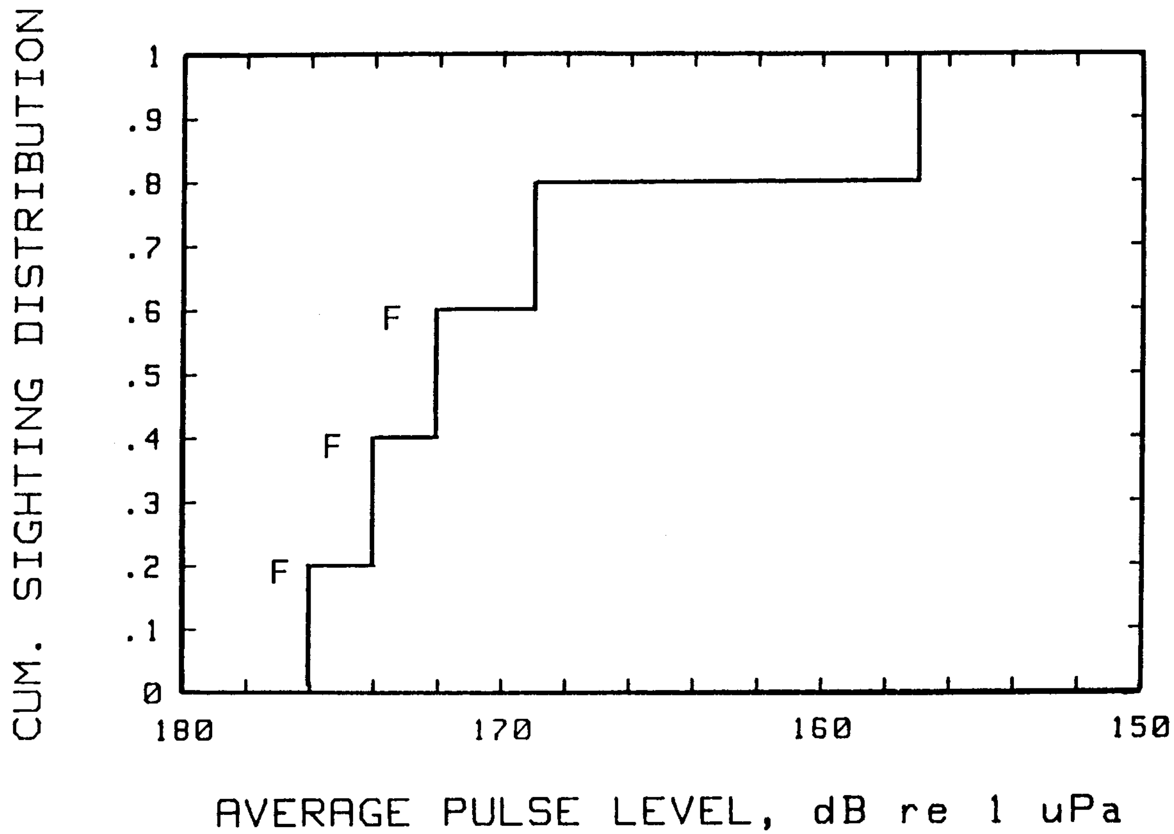


FIG. 3.54. CUMULATIVE DISTRIBUTION FOR OBSERVED FEEDING DISTURBANCE (DATA FROM TABLE 3.8, F - WHALE RETURNED AND RESUMED FEEDING).

limits of the acoustic response measures determined by the present data. We need to estimate how well the data represent the range of expected feeding gray whale responses to air gun noise disturbance.

A distribution-free confidence interval test for the median was developed by Thompson (1936). This test provides a means of calculating the confidence level of a median estimate based on a number of samples from a parent population having an unknown distribution form. The results of applying this test to the data shown in Fig. 3.54 give a confidence estimate of 68% that the true median (.5) response level lies between 170 and 175 dB and a 94% confidence estimate that it lies within the interval of 163 dB to 177 dB.

For skewed distributions, the median is a better estimator for the expected value than is the mean, Zar (1974), p. 24. Thus, an average peak pressure level of 173 dB will be considered as the level of air gun noise at which 50% of feeding gray whales will probably interrupt feeding activity. Based on the data shown in Fig. 3.54 and on the confidence limit calculation, 163 dB will be considered as the air gun noise level which will probably cause 10% of feeding gray whales to interrupt feeding activity.

Comparing these values with the probability of avoidance values obtained for migrating gray whales, we find that a 0.1 probability of avoidance occurred for an air gun noise level of 164 dB and a 0.5 probability of avoidance occurred for a level of 170 dB. The acoustic sensitivity of gray whales to air gun noise when feeding is thus apparently not greatly different from their sensitivity while migrating.

Drillship Playback

The sighting data presented in Fig. 3.52 for the combined drillship playback experiments showed that a number of whales were exposed to levels that produced avoidance behavior for migrating gray whales (110 to 120 dB). No definite pattern of avoidance of the source area was observed. However, until more testing is performed at higher exposure levels, we believe that the application of the probability of avoidance results for migration activity would provide a conservative response estimate for feeding activity. For the purpose of estimating zones of influence, we will consider that exposure of feeding gray whales to noise levels of 110 dB or more (from a continuous stationary source, such as from a drillship), would result in possible avoidance of the region near the source, and exposure to levels of 120 dB or more would probably cause avoidance of the area by more than one-half of the gray whales. These values will be used in the zone of influence analysis discussed in Sec. 4.5.4.

4. ESTIMATES OF THE EFFECTIVE RANGE OF INDUSTRIAL NOISE SOURCES IN BERING SEA GRAY WHALE FEEDING AREAS

By combining what has been learned about gray whale behavioral response to industrial noise with acoustic modeling techniques, it is possible to estimate the "zone of influence" of a noise source if its acoustic source level is known. The results of this procedure are described in this section for studies of the Chirikof Basin area and the region near Unimak Pass. The locations of these areas and the location of the 1985 field study near St. Lawrence Island are shown in Fig. 4.1.

The response of gray whales to industrial noise can be quantified in terms of an absolute measured or estimated noise exposure level or in terms of a relative signal-to-noise ratio (S/N). In this case, the "signal" is the industrial noise and the noise is the normal background ambient noise - generally due to wave splash (wind) noise and distant ship traffic. In this study and in the previous study of migrating gray whales, the behavioral responses have been quantified in terms of the absolute noise exposure level since it was not possible to obtain behavioral response data under several different ambient noise conditions to obtain an independent measure of response to S/N variations for a constant signal level. Studies of the behavioral response of bowhead whales have generally reported results in terms of the signal-to-noise ratio (see Richardson, et al. 1985, for example). The results of this model study, therefore, incorporate estimates of ambient noise levels in the areas studied so that zones of influence can be estimated using either received exposure levels or signal-to-noise ratios.

The following discussion includes a description of the physical parameters relevant to underwater sound propagation in the areas of concern, estimates of the ambient noise

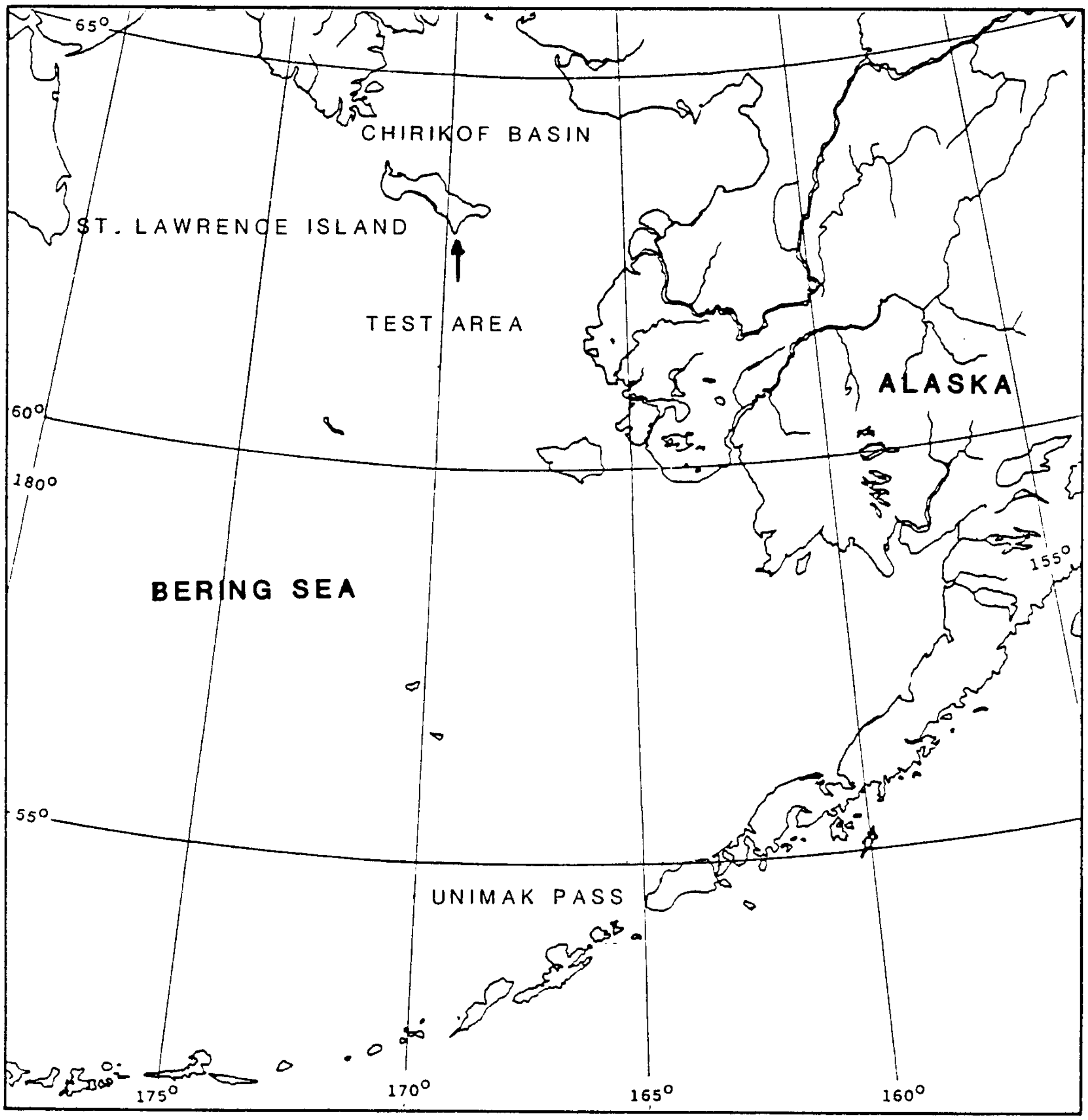


FIG. 4.1. STUDY SITE LOCATIONS.

characteristics, discussion of the sound propagation modeling procedure, comparison of model predictions with reported data, and presentation of received level predictions to permit the estimation of zones of influence for representative petroleum industry noise sources.

4.1 Acoustic Parameters of the Areas Studied

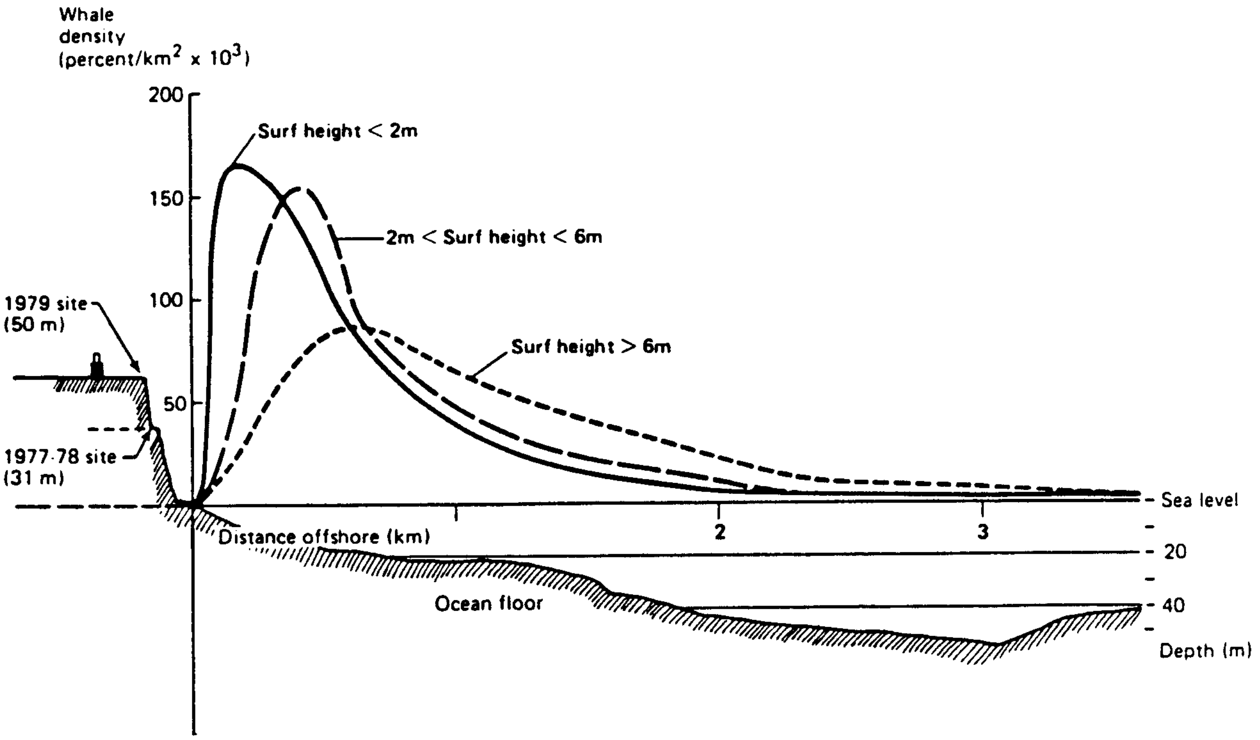
The study was concerned with two areas in the Bering Sea which have high concentrations of gray whales during portions of the summer feeding season. Unimak Pass is used by all of the migrating gray whales that regularly feed in the Bering and Chukchi Seas. They pass through close to the shore of Unimak Island on their northbound migration in April through June with the highest density occurring around 1 May (Braham 1984). The southbound migration occurs in November and December with a peak around 1 December (Rugh 1984). During the northbound migration, the whales feed as they move north along the coast of Unimak Island and continue up along the Alaska Peninsula. Some whales remain in this area during the entire summer.

The Chirikof Basin north of St. Lawrence Island has been observed to have high concentrations of feeding gray whales for a number of years (Ljungblad 1985b). They reach this area around late May and remain through mid-October. This area is uniformly shallow (40 m) and is representative of other areas in the Bering Sea where gray whales have been observed to feed.

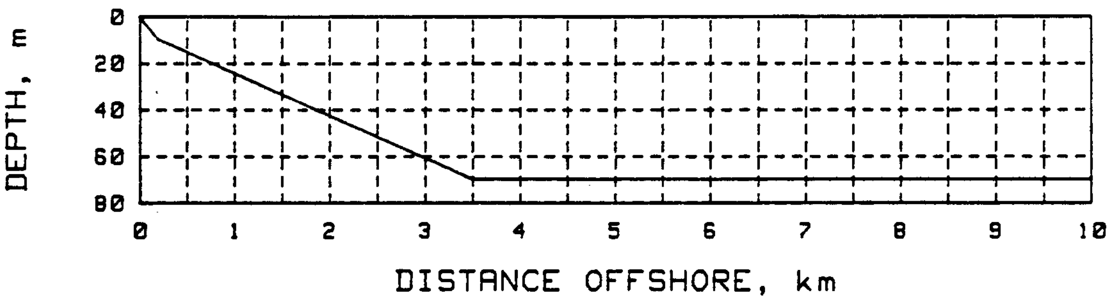
The Bering Sea has two major provinces of approximately equal area. Oceanic depths lie to the northwest of Unimak Pass and an extensive shallow continental shelf to the northeast. The areas of interest for this study are located along the continental shelf which extends under Bristol Bay and on up to St. Lawrence island and beyond to the Bering Strait. Bottom sediments on this shelf consist primarily of fine sand, silt, and clay.

In the shallow shelf areas of the Bering Sea, the sound velocity profile (SVP) shows little vertical structure under winter ice cover conditions. In the spring as the ice edge recedes, the surface layer begins to warm up and a higher velocity layer forms near the surface. This effect is in contention with a surface layer of slower sound speed fresh water from rivers and estuaries. Generally, the temperature effect is dominant and a deep surface layer of warmer, higher sound speed water forms which may extend over as much as 1/2 of the water column (Mackensie 1973). This upper layer causes strong downward refraction of sound rays,which results in higher propagation losses, because of the increased number of bottom contacts, than would occur under isospeed or upward refracting conditions.

Since the whale migration corridor near Unimak Island is generally near shore (Rugh 1984), it is necessary to consider not only the bottom composition but also its slope in modeling the sound propagation near the island. Near Unimak Island the sand is of volcanic origin. The sediment thickness ranges from 5 to 10 meters with a volcanic rock sub-bottom (Mackenzie 1973, Rugh 1984). The whale migration occurs in water depths of 15 to 20 m where the bottom slope ranges from .008 to .03. The distribution of whales observed near Cape Sarichef for the southbound migration is shown in Fig. 4.2A. The bottom profile near the cape is irregular so an approximation was necessary for use with the acoustic model. The approximate slope profile is shown in Fig. 4.2B.



A. Depth profile offshore of Cape Sarichef related to whale density during fall migration (from Rugh 1984)



B. Approximate depth profile used in model

FIG. 4.2. WHALE MIGRATION DENSITY AND DEPTH PROFILE NEAR UNIMAK ISLAND.

4.2 Ambient Noise Estimates

For the purposes of this study it was necessary to estimate the ambient noise spectrum statistics for the regions used in the propagation modeling. The ambient noise spectra were estimated in 1/3-octave bands since this type of proportional bandwidth analysis is representative of mammalian hearing processes. The spectra representing the 5th, 50th, and 95th percentile average ambient levels* for the summer months were developed by examining wind speed and wave height data in the NOAA Climatic Atlas for the Bering Sea (Brower, Diaz, and Prechtel 1977).

Figure 4.3 shows the estimated ambient noise spectra for the Chirikof Basin and Unimak Pass areas. These spectra were developed by using the wind speed and wave height statistical data from the atlas together with published ambient noise data (Urick 1983). The spectrum levels for the Unimak Pass area are somewhat higher than those of the Chirikof Basin because of the proximity of deeper water and a slightly higher influence of ship traffic noise at low frequencies. The region considered in this case is off the north side of the island and extending northward into Bristol Bay. Generally both areas considered here are sheltered from the influence of shipping noise by the effect of shallow water producing high sound attenuation at low frequencies and by the absence of nearby lanes of heavy ship traffic.

4.3 Shallow Water Sound Propagation Models

No analytic or computer-based transmission loss model exists that is capable of handling all of the significant environmental parameters that influence shallow water sound propagation. The major modeling difficulties occur at low frequencies for sites

*The 5th percentile spectrum represents the rms levels which are not exceeded 5% of the time, for example.

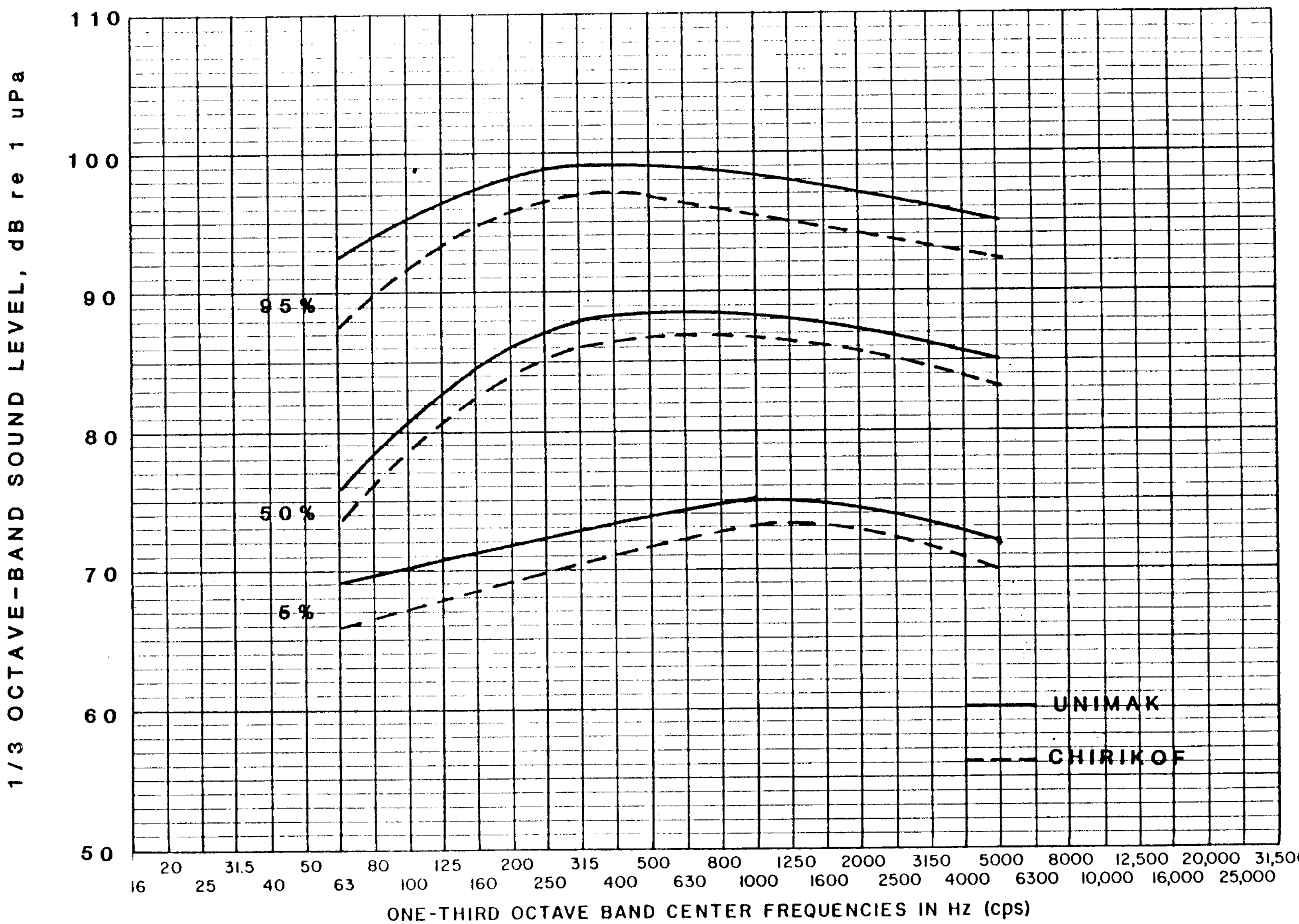


FIG. 4.3. ESTIMATED AMBIENT NOISE SPECTRA FOR CHIRIKOF BASIN AND UNIMAK PASS AREAS.

with a sloping bottom and strong sound velocity gradients. As a result, for this study and other similar acoustic model studies,* we have developed semi-empirical models which use sound transmission data obtained from in-situ measurements to provide a general sound propagation characteristic for a specific area. These semi-empirical models have been developed assuming both the 10 Log R and 15 Log R spreading loss characteristics. In addition, a computer-based analytic model has also been found to be useful within the restriction that it is appropriate only for conditions of neutral or small sound speed gradients. All of these models have been applied in analyzing the transmission loss data to obtain the most general interpretation of the results. The following discussion covers the development and application of both the analytic and empirical models.

4.3.1 Analytic sound propagation model

The shallow-water environment is very complex from the acoustical viewpoint. A complete specification would involve descriptions of:

- the sound speed profile in the water
- bottom topography
- bottom stratigraphy as function of location.
- surface conditions (roughness, ice).

Elaborate computer programs would then be required to use this information in a prediction of transmission.

Fortunately, since such detailed information is rarely available, it has been found possible to make reasonable predictions from simple formulas in the typical case where the sound

*See Malme, Smith, and Miles 1986; and Miles, et al. 1986.

speed is nearly independent of depth and the bottom slopes gradually, with nearly constant slope. These formulas have been developed and tested by Dr. D.E. Weston of the British Admiralty Research Establishment (Weston 1976).

In the simplified formulas, there are five parameters:

1. dominant frequency
2. water depth at the source
3. bottom slope along track

4,5. two parameters to describe the reflection loss of the bottom.

In these formulas, the term for the reflection loss (RL) in decibels for reflection of a plane sound wave incident at a grazing angle ϕ is taken to be:

$$\text{RL (dB)} = 4.34\ b \sin\phi, \text{ if } \phi < \phi_{cr}, \text{ or}$$
$$\text{RL} = \text{large}, \text{ if } \phi > \phi_{cr}. \quad (8)$$

The two parameters to be estimated are b and the critical angle ϕ_{cr}.

Because of bottom stratigraphy, the bottom reflection loss parameters are found to vary with frequency (Smith 1986). The explanation is simple. A typical bottom in shallow water consists of a layer of sand or silt overlying rock. If the layer is thin, the sound 'senses' the rock; if the layer is thick, the sound is effectively isolated from the rock. Calculations indicate that the transition occurs when the surface layer thickness equals about one-half wavelength of sound.

Typical values of the bottom loss parameters are:

sand/silt: $b = 2$, $\sin\phi_{cr} = 0.4$
hard rock: $b = 0.4$, $\sin\phi_{cr} = 0.7$.

Soft rock, such as limestone or chalk, can be very absorptive because of transmission of energy in the shear wave. The values of the parameters are also very sensitive to the value of the shear wave speed (Smith 1986).

Weston's formulas for transmission loss divide the track into four regions, each of which has a characteristic range dependence. The regions are, in order of increasing range:

a. spherical spreading, where bottom-reflected rays are steeper than the critical angle;

b. a transitional, cylindrical spreading region;

c. a "mode stripping" region, wherein energy striking the bottom at steeper angles is attenuated more rapidly than that at shallower angles;

d. the "lowest-mode" region, wherein only the fundamental mode carries significant energy.

Only in the last region is transmission dependent on frequency, so long as the sand layer is either thin ($d < \lambda/2$) or thick ($d > \lambda/2$) at all frequencies of interest. (See discussion of bottom reflection loss, above.)

In addition to water depth and bottom composition, the slope of the bottom is also important in determining transmission loss in shallow water. For sound transmission from a shallow region to deeper water, the increasing depth permits the sound energy to spread out over a larger volume than would have been available if the depth had remained constant. This results in a reduction in sound level. On the other hand, the increase in depth results in fewer bottom and surface reflections and thus less energy loss per kilometer. For most bottom types, the reduction in reflection loss has the strongest influence so the net effect of a positive bottom slope (increasing depth with increasing range) is lower transmission loss. This effect is most pronounced when neutral or upward refracting sound speed gradients exist. For these conditions sound transmission becomes ducted and is no longer influenced by bottom reflection loss.

For sound transmission into a decreasing depth region (negative bottom slope), the decrease in available volume for the sound energy would normally cause the sound level to be higher than it would be at the same range in a constant depth region. However, the number of surface and bottom reflections increases as the depth decreases. This causes the sound level to drop. This effect again usually predominates and the transmission loss becomes higher as sound propagates upslope. As the depth decreases, a depth is reached where there is a transition from multimode to single mode propagation. This usually results in a shift from a 15 Log R to a 10 Log R spreading loss characteristic. The attenuation per kilometer is determined primarily by the bottom material and may be quite high for soft bottom sediments. As water depth continues to diminish, there will be a point when effective propagation to long distances for frequencies of interest is not efficient (transmission loss becomes very high).

The Weston formulas noted previously apply to both positive and negative uniform bottom slopes as well as to the constant depth case.

A BASIC computer program was designed by P.W. Smith, Jr. at BBN which incorporates these formulas, yielding a value of transmission loss (dB re 1m) when given a value of range. This model, which we have called the Weston/Smith model, does not incorporate refraction effects produced by sound speed gradients and is appropriate for conditions where gradients are small or neutral. Nevertheless, it has been found to provide good predictions in shallow water conditions and thus was used as a comparison to the measured data at several sites.

4.3.2 Empirical sound propagation models

<u>Multi-Mode Model (15 Log R)</u>

This empirical model is based on the shallow water acoustic ray theory for an isospeed sound channel. The transmission characteristic for this case where many propagating modes are present has been given as (Smith 1971):

$$T = (2\pi/bHR^3)^{1/2}\, e^{-a_v R} , \qquad (9)$$

where b is a bottom loss factor defined previously in Eq. (8), H is the bottom depth, R is the range from the source, and a_v is the volumetric absorption. This is the characteristic that applies in the region c (mode stripping) portion of the computer model discussed previously. To develop the empirical model, we allow for an approximately uniformly sloping bottom by substituting:

$$H_{av} = (H_s + H_r)/2 = H \quad (m) \qquad (10)$$

where H_{av} is the average depth. An additional range-dependent loss factor is added to account for surface and bottom scattering and for losses produced by refraction not accounted for in the original analytic expression. The resulting modified transmission characteristic is:

$$T = (2\pi/bH_{av}R^3)^{1/2}\ e^{-a_aR/H_{av}}\ e^{-a_vR} \qquad (11)$$

where a_a is an anomalous attenuation factor which can be considered as a "loss-per-bounce," with the number of ray bounces being determined by the ratio of the range to the average depth. For convenience, Eq. (11) is converted to the logarithmic form of transmission loss (TL), where TL = -10 Log T or

$$TL = 5 \log (bH_{av}) + 15 \log R + A_aR/H_{av} + A_vR - 4 \text{ (dB)} \qquad (12)$$

Equation (12) is similar in form to a semi-empirical formula developed earlier by Marsh and Schulkin (1962) for intermediate range shallow water transmission loss prediction. In applying this relationship, the attenuation factor A_a is determined by analyzing a set of measured received level data which have been obtained in the area of interest. A calibrated sound source is used to obtain these data. To implement this analysis, Eq. (12) is used in the received level equation

$$L_r = L_s - TL$$

where L_s is the source level (dB re 1 μPa at 1 m) or:

$$L_r = L_s' - 5 \log H_{av} - 15 \log R - A_aR/H_{av} - A_vR + 4 \text{ (dB re 1 μPa)} \qquad (6)$$

where:

$L_s' = L_s + A_n - 45$, dB re 1 μPa at 1 km

L_s = Source Level, dB re 1 μPa at 1 m

R = range, km

A_v = volumetric absorption, dB/km (may be neglected for ranges less than 10 km and frequencies less than 1 kHz)

A_a = bottom and surface absorption and scattering losses, dB/bounce.

This equation is used in a computer-implemented, two-parameter, least-squares analysis using the measured values of L_r versus range. The results of this analysis produce estimated values of effective source level L_s' and A_a. Since the actual source level is known, this permits estimation of the effective change in source level resulting from surface- and bottom-reflected energy. This change will be called the local anomaly, A_n. For low sea states where surface losses are negligible, $A_n \approx -5 \log b$. Since the usual values of the local anomaly, A_n are small, the mean error of the regression curve fit must also be small to obtain a good estimate of the loss factor, b. Conversely, if a good calibration of the local anomaly for a given area is available, this permits estimation of the source level of an uncalibrated source.

Cylindrical Spreading Model (10 Log R)

The analysis procedure using Eq. (12) and Eq. (13) is not appropriate at low frequencies in water depths where only a few modes are propagating and ray acoustic theory does not apply. It also is not appropriate at higher frequencies when ducted or upward refracted, surface-reflected (RSR) sound propagation paths dominate.

For these conditions, Eqs. (12) and (13) have been modified to incorporate a cylindrical spreading loss and a continuous boundary attenuation loss

$$TL = 10 \log H_{av} + 10 \log R + A_s R + A_v R \text{ (dB)} \tag{14}$$

or

$$L_r = L_s' - 10 \log H_{av} - 10 \log R - A_s R - A_v R \text{ (dB re 1 } \mu\text{Pa)} \quad (15)$$

where:

$L_s' = L_s + A_n - 30$ dB re 1 Pa at 1 km

A_s = boundary attenuation loss, dB/km.

Equation (14) is also similar to the cylindrical spreading TL equation developed earlier by Marsh and Schulkin (1962). Equations (14) and (15) are not suitable for areas where there is a large variation in bottom depth along the propagation path (> 20%).

4.4 Results of Predictive Modeling and Comparison with Reported Data

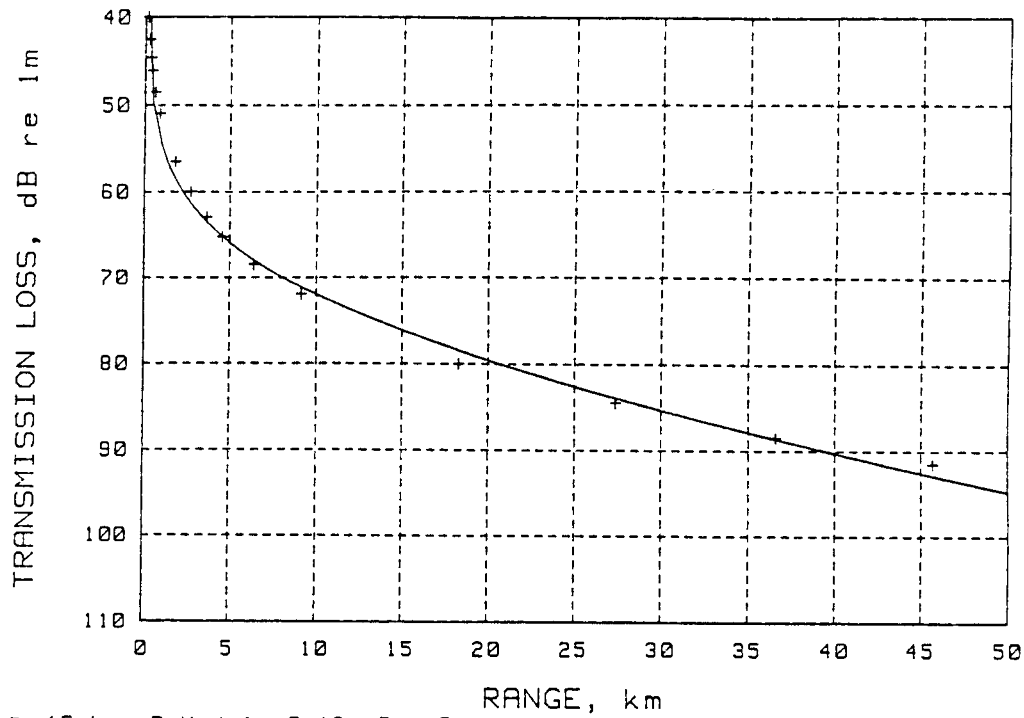
The semi-empirical sound propagation model described previously has the capability of closely matching a set of measured data and providing a means of extrapolating sound transmission characteristics beyond the measured range of the data. However, for sloping bottoms where the depth becomes too shallow to support multimode propagation, this model has no provision for changing over to single mode calculation procedure. We have, therefore, developed a procedure for matching the Weston/Smith analytic model to a measured set of data. This model is capable of making a transition in computation procedure when required by changes in the depth along the propagation path. Thus, extrapolation estimates using this model are expected to be more accurate in applications where significant changes in depth occur along the sound propagation path.

4.4.1 Chirikof Basin

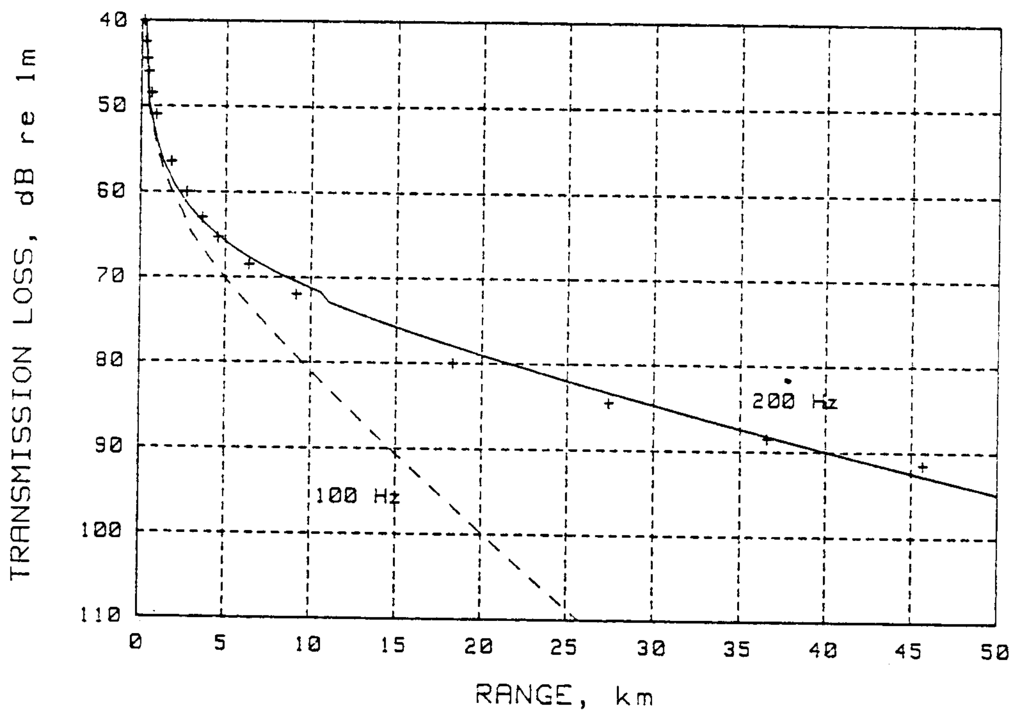
The air gun sound propagation data obtained near St. Lawrence Island were obtained in depths of 10 to 20 m, whereas the average depth of the Chirikof Basin is 40 m. It was necessary therefore to obtain sound transmission data for the Chirikof Basin or similar areas to compare with the measurements near St. Lawrence Island and verify the model predictions for the Chirikof Basin. Fortunately, Mackensie (1961, 1973) has reported measurements that can be used to compare with the model predictions.

Figure 4.4A shows the results of matching a Semi-empirical Model curve with data reported by Mackensie for measurements at 200 Hz. The values of the reflection loss coefficient A_r obtained are comparable to values obtained for the test areas near St. Lawrence Island that were well offshore (see Table 3.6). The values for A_r obtained in this area of the Bering Sea are considerably lower than the value of A_r = 85 obtained for the transmission loss measurements at the California test site.

The Mackensie transmission loss measurements were made using a source depth of 4.5 m and receiver depths of 5 m and 30 m. The transmission loss to the deep receiver was about 2 to 5 dB more than that obtained to the shallow receiver for most of the measurement ranges. This may have been caused by modal propagation conditions wherein sound levels are not uniform throughout the water column. These conditions are also believed to be responsible for the negative local anomaly values (A_n) obtained from the curve-fitting analysis program. In shallow water, positive values of A_n usually occur because of the added energy of bottom and surface reverberation. When strong modal effects exist, the sound level at the receiver is influenced not only



A. 15 Log R Model, A=12, An=-5



B. Weston/Smith Model, b=0.8, Sin Φcrit=0.5, An=-5

FIG. 4.4. MODEL PREDICTIONS COMPARED WITH REPORTED DATA FOR TRANSMISSION LOSS IN THE CHIRIKOF BASIN (MACKENSIE 1961 ++).

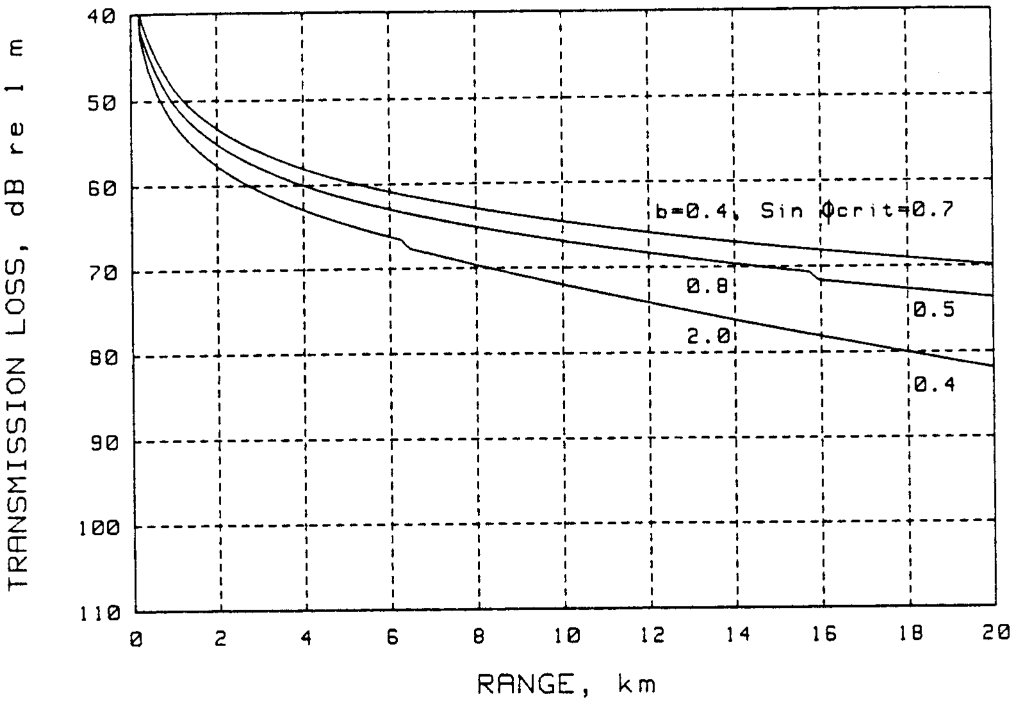
by the range to the source but also by its location in the modal standing wave pattern. We have chosen to model the propagation from a surface source to a deep receiver since that is believed to represent the usual geometry for an industrial noise source and feeding whales.

The curve shown in Fig. 4.4B was obtained using the Weston/ Smith Model to match the Mackensie data. The bottom parameter values used to obtain the curve shown are intermediate between those for silt/sand and those for soft rock. The sound energy may be reflecting off both the bottom and sub-bottom layers. At lower frequencies, the energy is reflected primarily from the sub-bottom rock layer resulting in lower transmission losses than would occur for a silt/sand bottom alone.

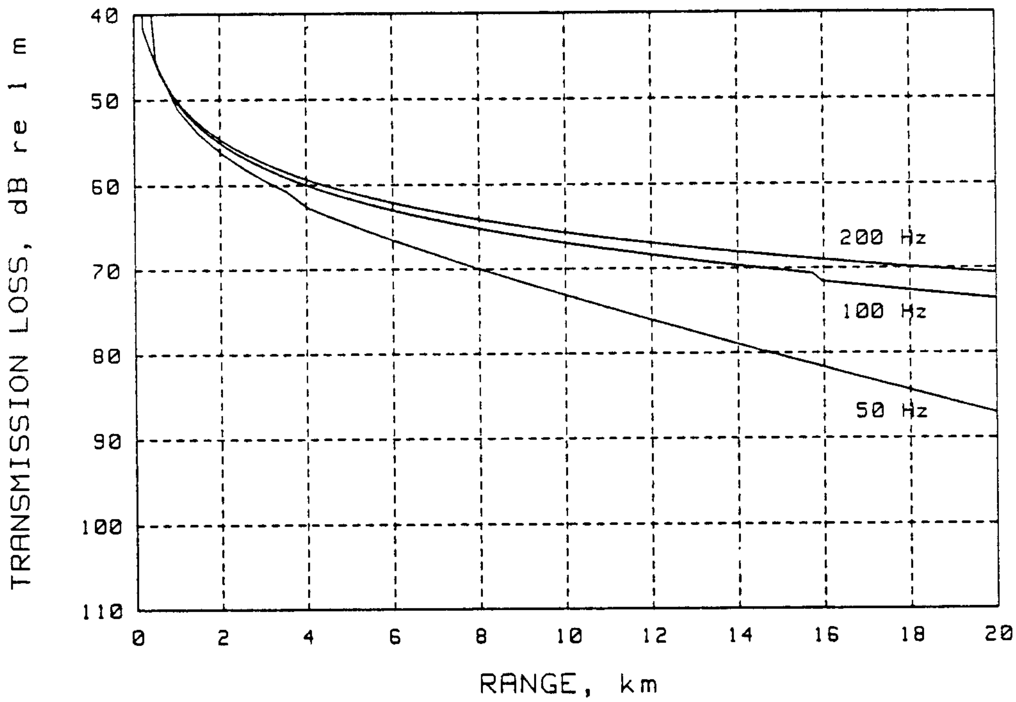
4.4.2 Unimak Pass

Since the whales travel quite close to shore, it is likely that any industrial activity will be located offshore from their position or potentially at a comparable distance offshore. Thus, the model predictions will include consideration of upslope propagation as well as propagation along a constant depth path.

Figure 4.5A shows the predicted transmission loss characteristics for constant depth conditions near Unimak Island. Characteristics for several types of bottom material are shown since no measured transmission loss data were found for this area. The upper curve is the characteristic for a soft rock bottom and the lower curve is for a sand/silt bottom. The intermediate curve is for the bottom parameters used for the Chirikof Basin transmission loss model. Since the bottom composition in the Unimak Island area is also sand and gravel with an underlying rock layer, we will use the same intermediate bottom parameters for the modeling work in this area. However, a



A. Effect of Bottom Parameters, 100 Hz, Depth 70 m



B. Frequency Dependence, b=0.8, Sin ϕcrit=0.5, Depth 70 m

FIG. 4.5. TRANSMISSION LOSS CHARACTERISTICS NEAR UNIMAK ISLAND, WESTON/SMITH MODEL.

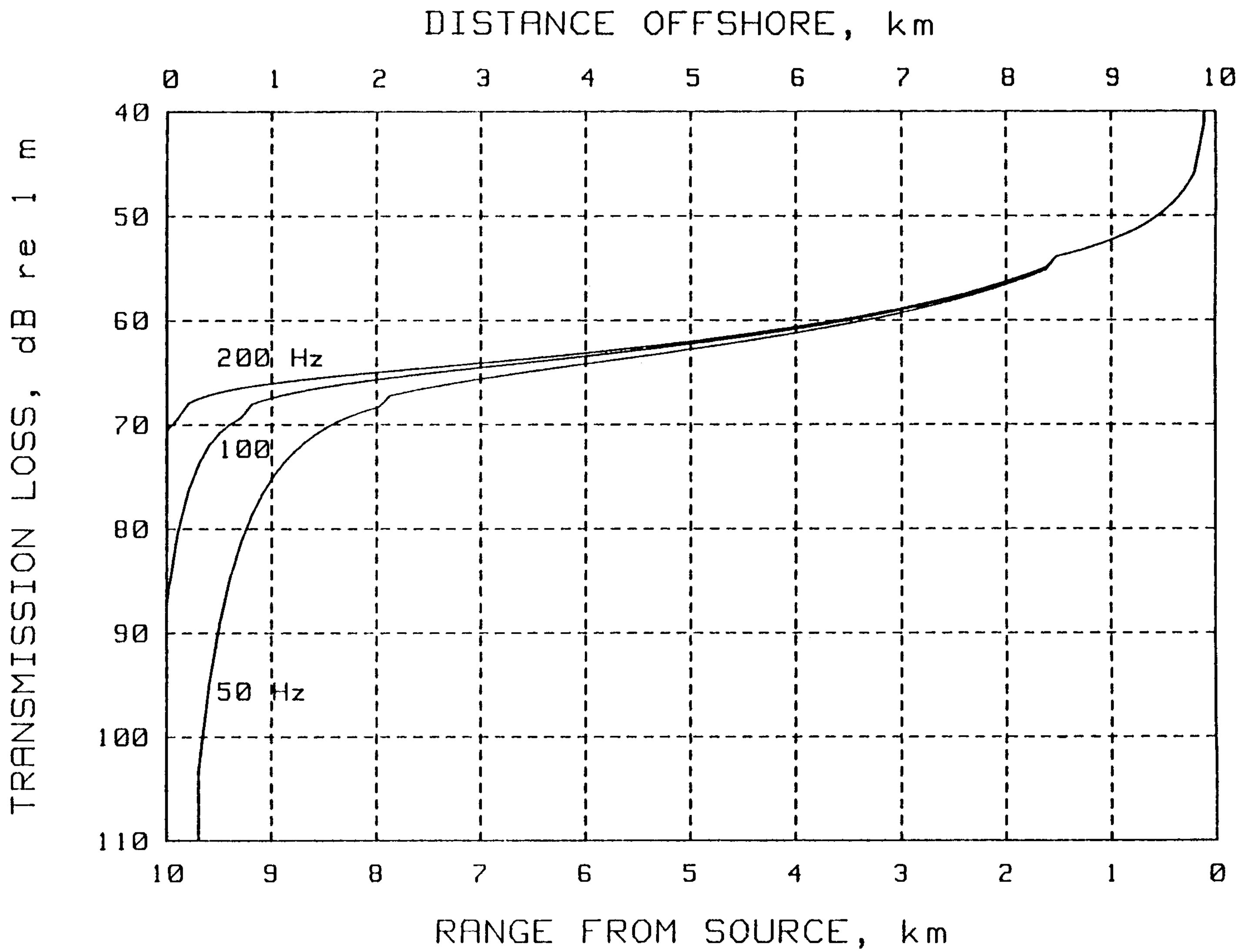
local anomaly of 0 dB will be used instead of -5 dB since no measured transmission loss data are available for this area to provide specific information on A_n. This will have the effect of reducing the estimated transmission loss for a given range and water depth compared to that for the Chirikof Basin.

Figure 4.5B shows the frequency dependence of the transmission loss for constant depth. The 70 m depth used in the figure corresponds to a relatively flat region starting about 3 to 4 km offshore to the north of Unimak Island. Frequencies below 100 Hz can be seen to be attenuated more rapidly than higher frequencies because of the shallow water.

The transmission loss characteristics for a source located offshore to the north of Cape Sarichef are shown in Fig. 4.6. The characteristics are shown for propagation upslope toward shore from a source located 10 km offshore. This geometry is relevant to offshore seismic survey activities and to offshore platform or drillship locations. Note that the effect of a sloping bottom is to produce a rapid attenuation of low frequency sound as shallow water is reached. This is beneficial in reducing the sound exposure levels in the migration zone.

4.5 Predicted Zones of Influence of Petroleum Industry Sound Sources

Three types of sources were considered in developing the predictions of zones of influence. These were large air gun array, small air gun array or single gun, and drillship. While there are a large number of source types that could be included, we selected these as representative of the output source levels, frequency range, and source directivity factors that must be considered in using the prediction model. The resulting curves can thus be used with other sources by changing the source level value.



Bottom Slope = .018, b=0.8, Sin ϕcrit=0.5, Depth at Source 190 m

FIG. 4.6. TRANSMISSION LOSS CHARACTERISTICS FOR UPSLOPE PROPAGATION TOWARD UNIMAK ISLAND, WESTON/SMITH MODEL.

4.5.1 Received level calculation procedure

The received sound level for a given source and propagation path is predicted by the following relationship:

$$L_r = \left(L_s(f) + D(f,\theta,r)\right) - TL(f,r) \text{ (dB re 1 } \mu\text{Pa)} \tag{16}$$

where the source level, L_s, is a function of frequency; the directivity factor, D, is a function of frequency and the sound radiation angle, θ. The source directivity is sometimes also a function of range when, for shallow sources or large arrays, the negative surface reflection causes an additional interference loss which is range-dependent (Malme et al. 1984). The transmission loss, TL, is a function of frequency and range.

4.5.2 Source level determination

The source level for large seismic arrays is usually given as the peak pressure value at one meter on the axis of the main beam. It is usually measured in deep water at a sufficient distance from the array so that the pulses from all of the individual sources are in coincidence (far field). The measured pressure is then corrected to an equivalent of one meter using a spherical spreading loss of 20 log r. The peak pressure measured to the side of a large array is less than the main beam peak pressure because the individual sources are not in coincidence. For an array geometry consisting of two or more parallel linear subarrays, the peak pressure measured horizontally is maximum along the broadside axis because the pulses from all of the sources in a subarray are in coincidence. A directivity correction for radiation along this direction can be estimated by dividing the main beam peak pressure by the number of subarrays (assuming that all subarrays have the same number of sources), or in logarithmic terms:

$$D = 20 \log 1/N_s \text{ (dB)} \quad (17)$$

where N_s is the number of subarrays. For arrays that do not have a simple linear geometry, a more detailed examination of the axes of maximum pulse coincidence must be made to determine the ratio of the total horizontal pulse pressure to the main beam pulse pressure (Malme, Smith, and Miles 1986).

For large air gun arrays, the transmission loss characteristic has been observed to have a 25 log range dependence instead of the usual 15 log range dependence generally observed in shallow water (Malme et al. 1983). The additional 10 log r factor is believed to result from the close proximity of the array to the surface and is observed primarily near broadside aspect and not at endfire. This effect is included as a directivity factor in the modeling procedure so that the same TL characteristics can be used for both single air guns and arrays. The following combined directivity relationship results for large arrays:

$$D_a = 20 \log 1/N_s - 10 \log r \text{ (dB)} . \quad (18)$$

For small arrays where the effective dimension of the array with respect to the sound propagation direction is less than 1/2 wavelength at the dominant output frequency and the depth is greater than 1/4 wavelength, the additional 10 log r factor should not be used.

The source level of drillships and other large distributed sources is determined by measurements of the radiated sound level at a number of successive distances from the source which are large compared to the overall dimension of the source. The measurements are then analyzed using an appropriate propagation model, such as Eqn. (3), to estimate what the effective sound level would be at 1 m from an equivalent point source. A calibration of the transmission path should be made using a calibrated sound source to determine the local transmission anomaly caused by site-specific bottom and surface reflection properties. This allows correction of the measured source level to an equivalent deep water value.

Large Air Gun Array Example

Peak-to-peak pressure on axis, 60 Bar-meters

Acoustic Source Level (Peak), 250 dB re 1 μPa at 1 m

Broadside directivity, D, -6 dB (two linear subarrays)

Ratio of peak to average pulse pressure levels, 4 dB (assumes range independent pulse durations based on St. Lawrence Island data)

Average pulse pressure level, 240 dB re 1 μPa ($L_p = L_s + D - 4$)

Dominant frequency range, 50 to 200 Hz

Single Air Gun or Small Array Example

Peak-to-peak pressure, 3 Bar-meters

Acoustic source level (peak), 224 dB re 1 μPa

Horizontal directivity, D, 0 dB (omnidirectional)

Ratio of peak to average pulse pressure levels, 4 dB

Average pulse pressure level, 220 dB re 1 μPa

Dominant frequency range, 50 to 200 Hz

Drillship Example (Explorer II)*

Acoustic source level (rms), 165 dB re 1 μPa at 1 m

Dominant frequency range, 80 - 1600 Hz (loudest tonals at 72 and 239 Hz)

4.5.3 Received level estimates for source examples

The transmission loss characteristics developed for the Chirikof Basin and Unimak Pass areas were combined with the source level examples in accordance with Eq. (16) to obtain predictions of received level versus range from the source.

Chirikof Basin

Figures 4.7 through 4.9 show the results of this procedure for the Chirikof Basin. Figure 4.7, for a large air gun array, incorporates the additional 10 log r attenuation due to the vertical directionality of the source. These figures can be used to predict the received levels for sources other than those of the examples by adjusting the predicted value of L_r by the amount of the source level difference. Figures 4.7 and 4.8 should be used for large air gun arrays and single air guns (or small arrays), respectively. Figure 4.9 should be used for sources having a higher frequency acoustic output with dominant components in the range of 200 to 300 Hz.

Unimak Pass

The received level characteristics for the example sources in the Unimak Pass area are shown in Figs. 4.10 through 4.12.

*Measurements reported by Greeneridge Sciences in 1985 show that the radiated noise spectrum of the drillship Explorer II has changed from that measured previously in 1981 (Greene 1982). The 1981 radiated noise recordings are the source for the playback stimuli used in the gray whale behavioral response study.

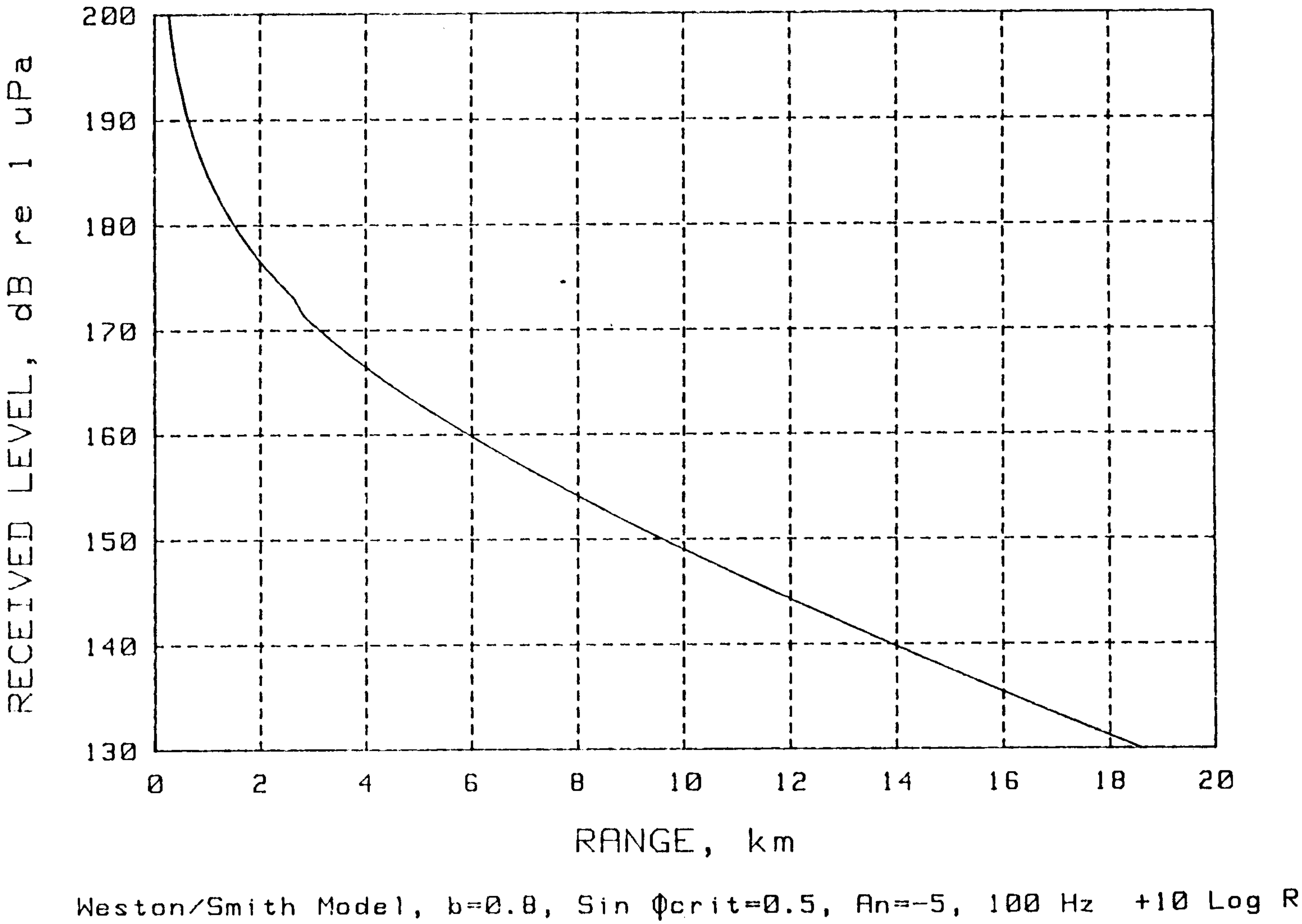
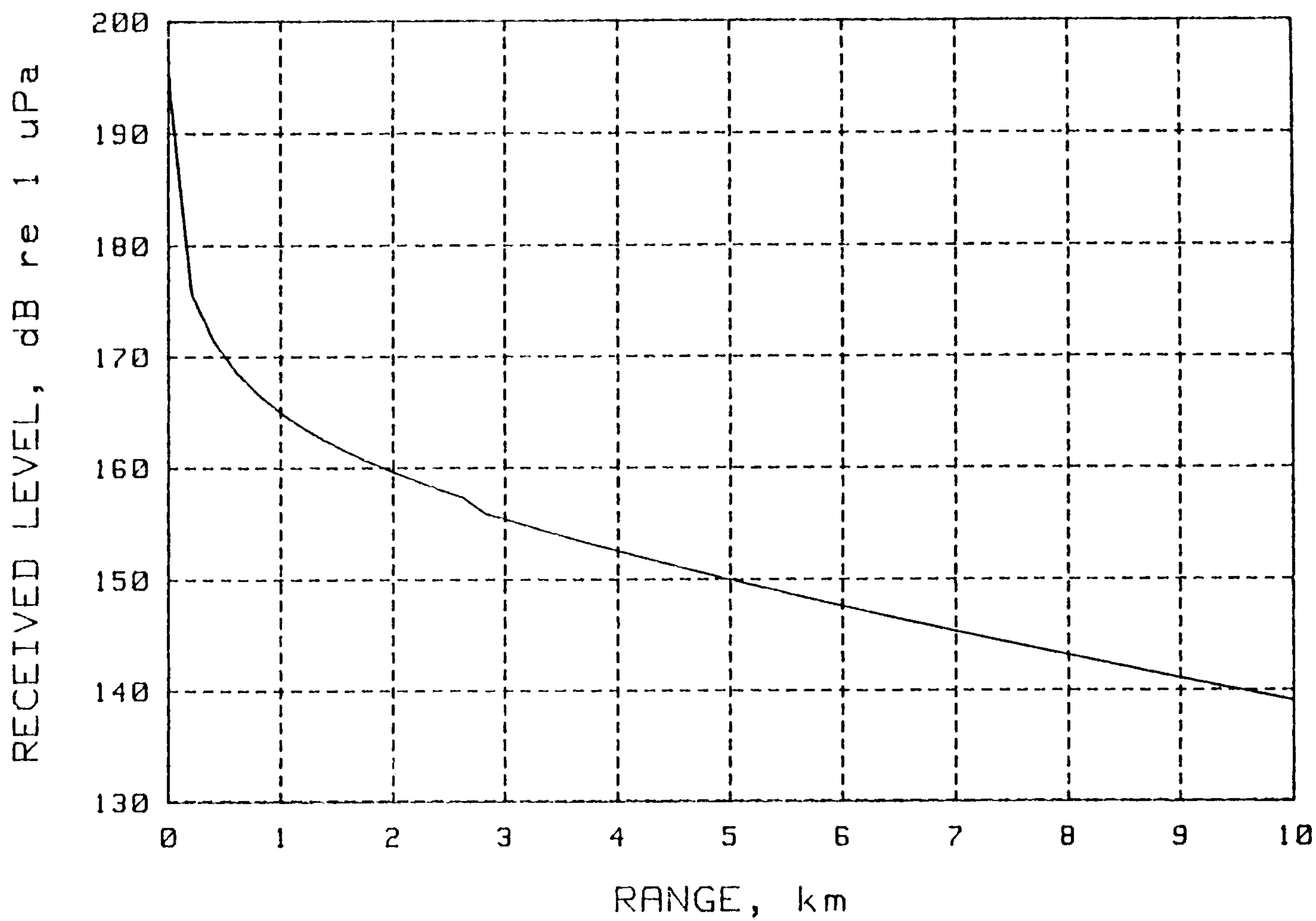
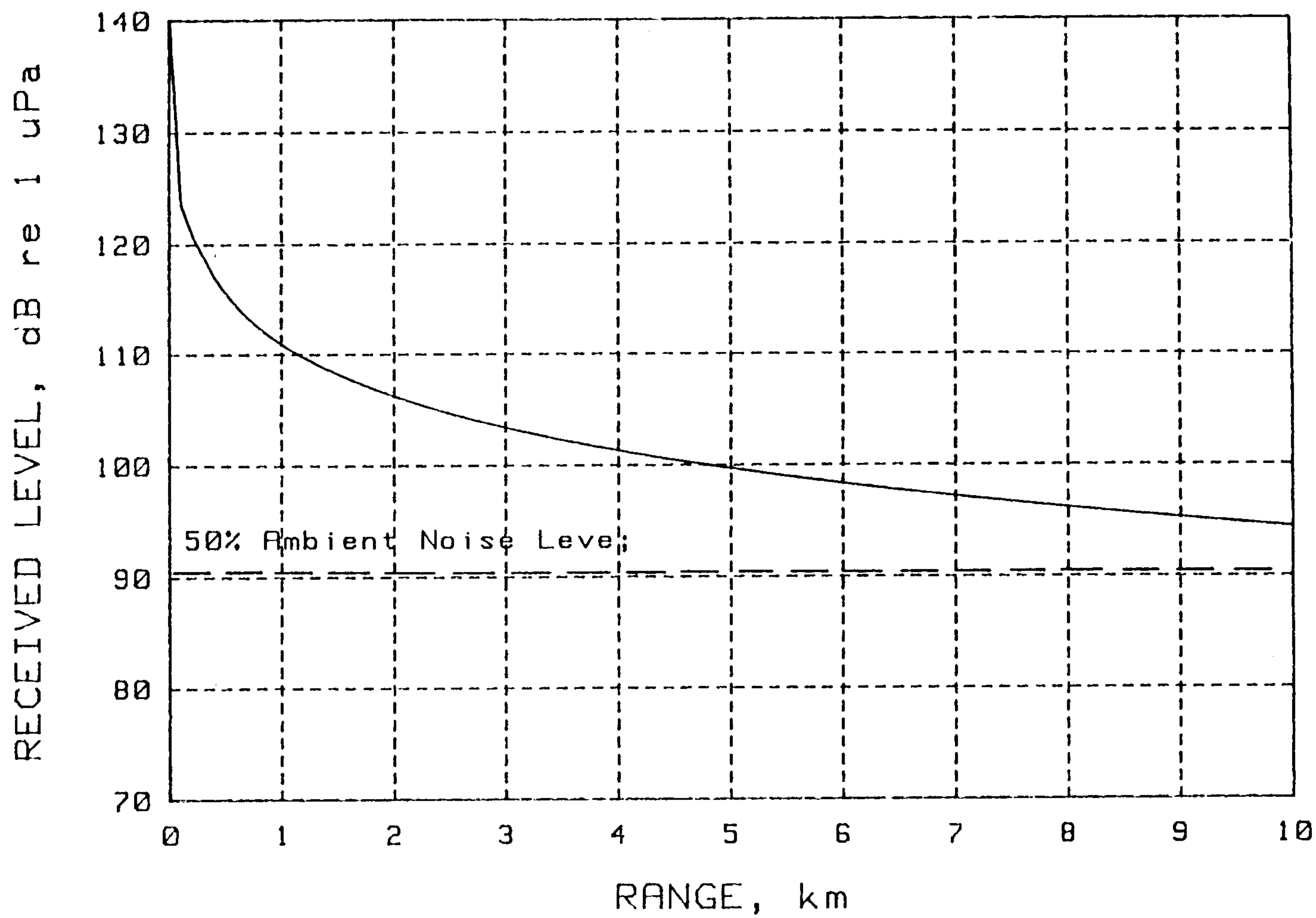


FIG. 4.7. AVERAGE PULSE PRESSURE LEVEL VS. RANGE IN CHIRIKOF BASIN LARGE AIR GUN ARRAY, L_s = 240 dB re 1 μPa at 1 m.



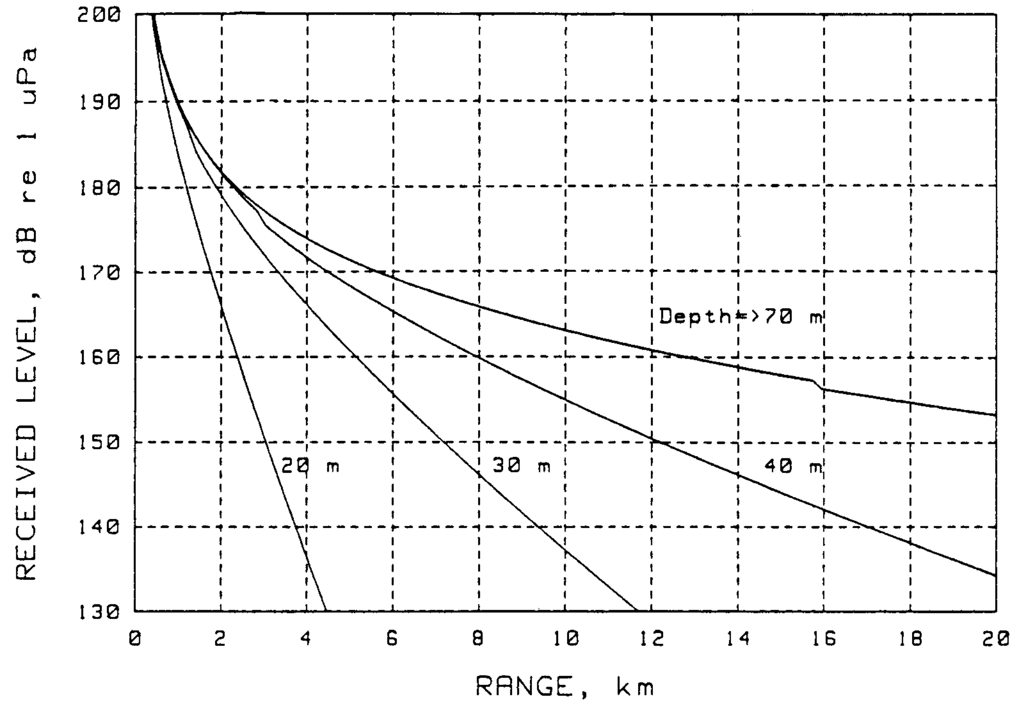
Weston/Smith Model, b=0.8, Sin Φcrit=0.5, An=-5, 100 Hz

FIG. 4.8. AVERAGE PULSE PRESSURE LEVEL VS. RANGE IN CHIRIKOF BASIN AIR GUN OR SMALL ARRAY, L_s = 220 dB re 1 μPa at 1 m.

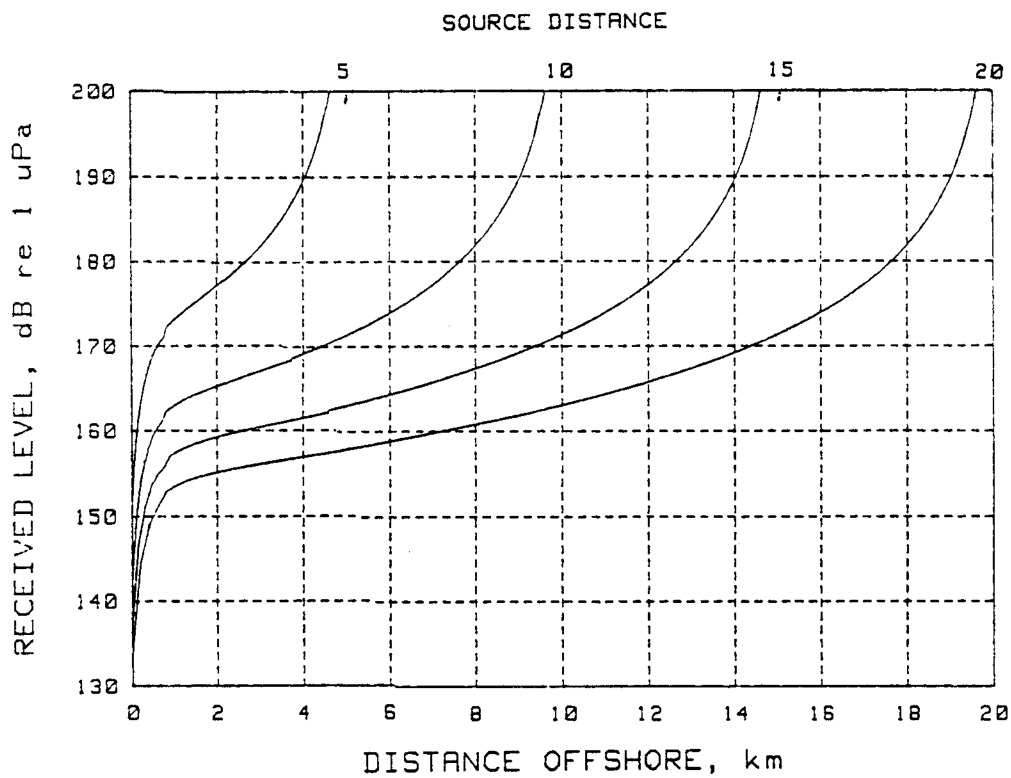


Weston/Smith Model, b=0.8, Sin Φcrit=0.5, An=-5, 250 Hz

FIG. 4.9. RECEIVED LEVEL VS. RANGE IN CHIRIKOF BASIN DRILLSHIP (EXPLORER II) L_s = 165 dB re 1 µPa at 1 m.

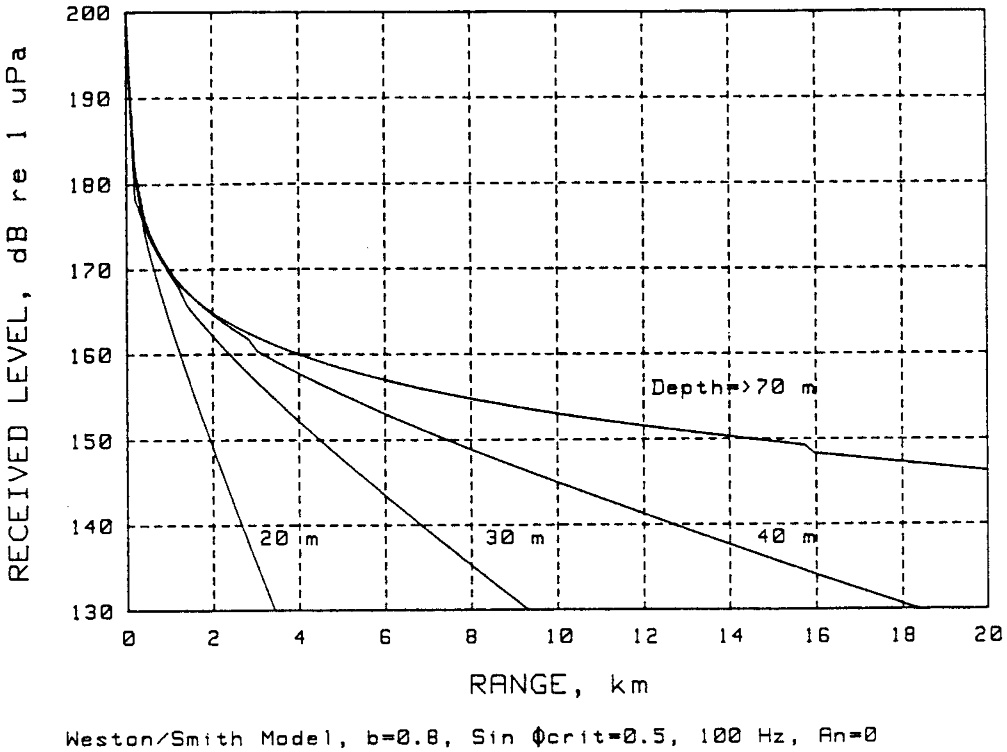


A Weston/Smith Model, b=0.8, Sin Φcrit=0.5, 100 Hz, An=0, +10 Log R



B Weston/Smith Model, b=0.8, Sin Φcrit=0.5, 100 Hz, An=0, +10 Log R

FIG. 4.10. AVERAGE PULSE PRESSURE VS RANGE, UNIMAK LARGE AIR GUN ARRAY, L_S = 240 dB re 1 μPa AT 1 m. A. CONSTANT DEPTH; B. UPSLOPE.



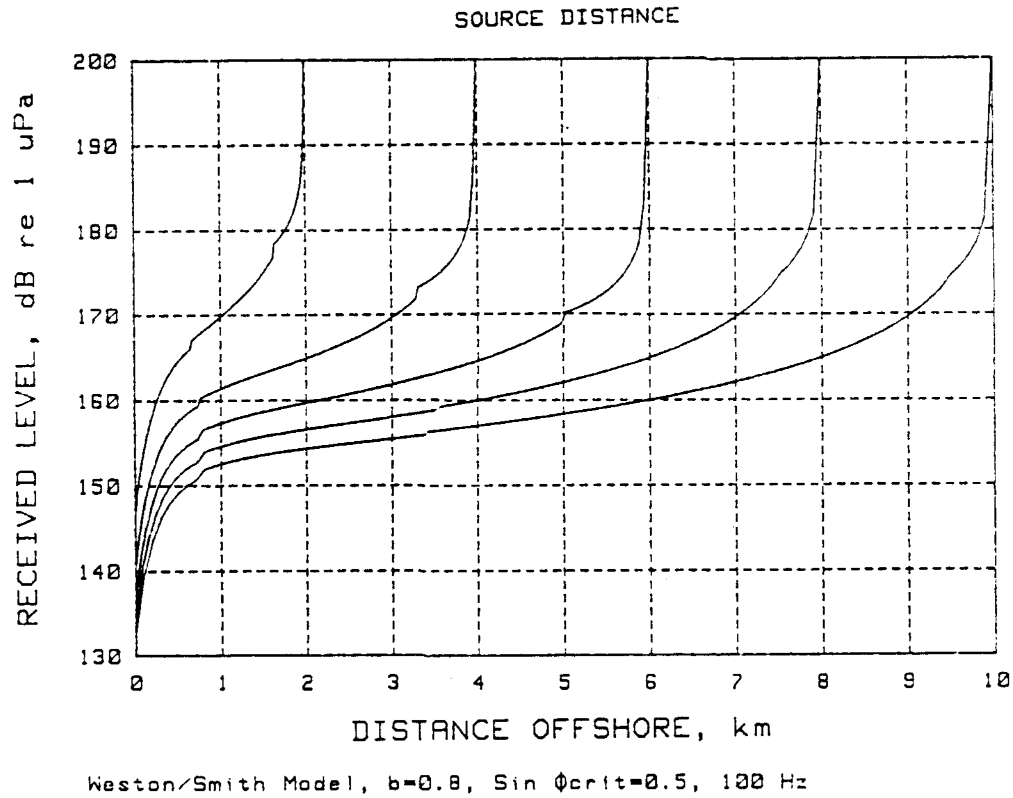
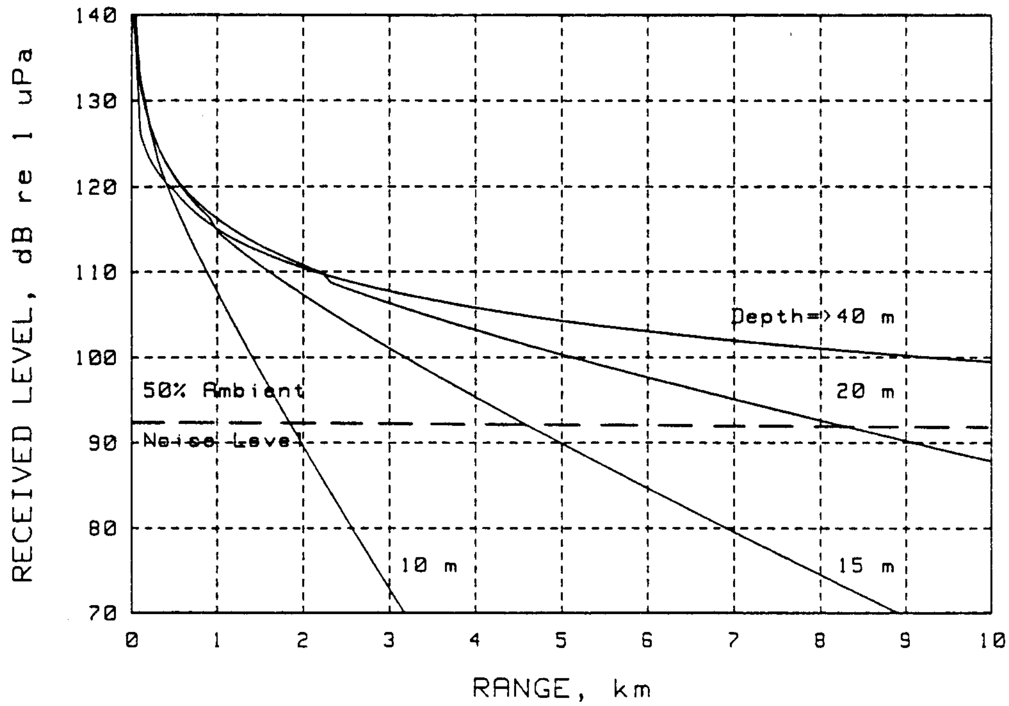
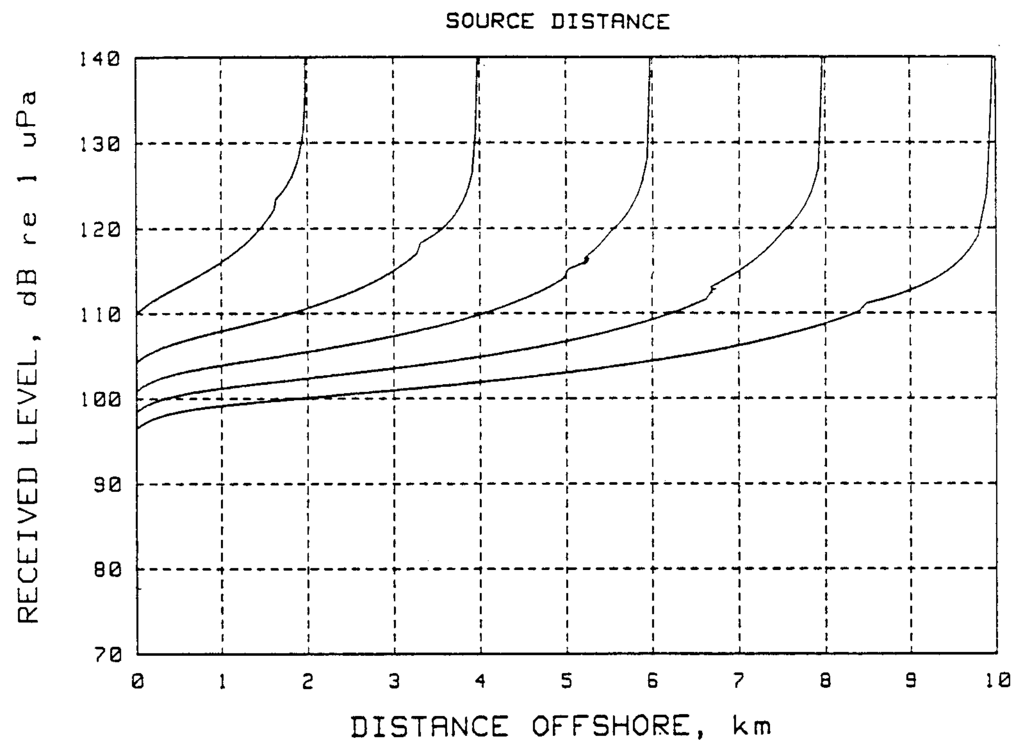


FIG. 4.11. AVERAGE PULSE PRESSURE VS RANGE, UNIMAK AIR GUN OR SMALL ARRAY, L_S = 220 dB re 1 μPa AT 1 m. A. CONSTANT DEPTH; B. UPSLOPE.



Weston/Smith Model, b=0.8, Sin Φcrit=0.5, 250 Hz, An=0



Weston/Smith Model, b=0.8, Sin Φcrit=0.5, 250 Hz

FIG. 4.12. RECEIVED LEVEL VS RANGE, UNIMAK DRILLSHIP (EXPLORER II), L_S = 165 dB re 1 μPa at 1 m. A. CONSTANT DEPTH; B. UPSLOPE.

Here, predicted levels are shown for propagation at constant depth (parallel to the shoreline of Unimak Island) as well as for propagation from an offshore source toward the shore. The characteristics for upslope propagation are given for the offshore source distances indicated at the top of the curves. Interpolation between the curves may be done for intermediate source positions. These curves may be used for both fixed and moving offshore sources. For moving sources, the received level indicated for a given offshore source distance and receiver location would be the level occurring at the closest point of approach. Thus, for example, referring to Fig. 4.10B, whales in the migration corridor .5 km offshore would experience average pulse levels of 170 dB for passage of the example seismic array about 5 km offshore. For the single air gun, a level of 170 dB .5 km offshore would be created by passage of the source vessel at an estimated 1.5 km offshore as shown by interpolation in Fig. 4.11B. When the source and receiver are about the same distance offshore, the constant depth characteristics shown can be used. For example, if the seismic array were operating in the migration corridor where the depth is 20 m, the 170 dB received level would occur at a range of about 1.7 km as shown in Fig. 4.10A.

4.5.4 Zone of Influence estimates

The information developed in the received level curves may be used to predict zones of influence for the example sources. To do this, it is necessary to use criteria which determine the received level at which a sound is likely to produce a given behavior in gray whales. As discussed previously in Sec. 3.4, the general criteria which seems appropriate for summering and feeding activity are:

Air gun and air gun arrays (moving sources)

Criterion	$L_{\bar{p}}$
0.1 probability of feeding disturbance	163 dB re 1 μPa
0.5 probability of feeding disturbance	173 dB re 1 μPa
(Including temporary avoidance of source region)	

Continuous sources such as drillships (fixed location)

Criterion	L_r
0.1 probability of avoidance	110 dB re 1 μPa
0.5 probability of avoidance	120 dB re 1 μPa

The above criteria have been used to develop Table 4.1 which shows the zones of influence for the example sources.

Observations of the behavioral response of bowhead whales to industrial noise in the Beaufort Sea has resulted in the development of response criteria based on the S/N of the industrial sound to the local ambient noise level (Richardson et al. 1985). It was found that a 20 dB industrial/ambient noise ratio produced occasional avoidance of the source region and that a 30 dB ratio resulted in probable avoidance. The results of applying this type of criteria to gray whales in the two Bering Sea study regions are also shown in Table 4.1. Note that for the 50th percentile ambient noise spectra used in the table, the zone of influence ranges for the drillship as determined by both noise exposure level criteria and the S/N ratio criteria are similar. The ranges for the 20 dB and 30 dB S/N of the array and single gun have not been listed since there have been no observations of behavioral response to air gun transient signals below 130 dB.

TABLE 4.1. ZONES OF INFLUENCE FOR REPRESENTATIVE PETROLEUM INDUSTRY NOISE SOURCES.

	Chirikof Basin (water depth, 40 m)			Unimak (water depth, 30 m)			Unimak (Toward Shore) (receiver 0.5 km offshore)		
Source Type	Array[1]	Single[2] Gun	Drillship[3]	Array	Single Gun	Drillship	Array	Single Gun	Drillship
Received Level	km	km	km	km	km	km	km	km	km
173 dB	2.6	.32		2.8	.63		3	0.55	
163 dB	5.0	1.3		4.5	1.8		7	1.5	
120 dB			0.3			0.5			0.7
110 dB			1.1			2.1			2.5
S/N (50%)[4]									
30 dB			0.3			0.4			0.6
20 dB			1.1			1.7			2

Notes: [1]Array main beam peak source level 250 dB re 1 μPa at 1 m Horizontal effective source level 240 dB average pulse pressure.

[2]Single air gun or small array, peak source level, 224 dB, 220 dB average pulse pressure.

[3]Drillship source level, 165 dB.

[4]Ratio of drillship noise to 50th percentile ambient noise in effective drillship bandwidth.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Analysis of the surfacing-dive data showed that blow intervals decreased during drillship sounds, and length of surfacing, length of dive, and number of blows per surfacing increased. Pre-disturbance rates were re-established within about 1/2 hour after the stimulus was turned off. Blow rate changed little. The response to air gun sound was different. Blow intervals increased but length of surfacing, length of dive, and the number of blows per surfacing all decreased. This trend was strongest on occasions when cessation of feeding and movement away from the source vessel were observed. Recovery to pre-stimulus conditions occurred in about one hour after disturbance. Detailed statistical analysis to quantify dive cycle and respiration data in terms of acoustic exposure level was not possible because of limited sample size.

The two-vessel tracking procedure provided whale position information which was useful for determining the whale source distance necessary for noise exposure estimation. The error of this procedure is estimated to be within 10% for ranges less than 1 km. This procedure was used to obtain the movement patterns of focal whales during control and experimental conditions.

Limited playback experiments using a drillship stimulus showed no consistent evidence of feeding disturbance or avoidance of the source for exposure levels up to 110 dB. Some whales were observed to leave the test area for exposure levels up to 119 dB. However, observations during control periods showed that whales appeared to respond to the presence of the sound source vessel itself, thus complicating interpretation of results. Until more data are obtained, we recommend that the level of 110 dB be considered as the level which will possibly cause disturbance of feeding activity by a continuous industrial noise. This was the level of drillship noise observed to produce a 0.1 probability avoidance for migrating gray whales. A level of 117 dB was observed to cause a 0.5 probability of avoidance for drillship noise and 119 dB caused a 0.5 probability of avoidance for the average of all of the noise stimuli tested. As a reference value, we recommend that 120 dB be considered the level of a continuous industrial noise which will probably disturb at least 1/2 of the feeding gray whales.

Experiments using a 100 cu. in. air gun at exposure levels up to 176 dB (average pulse pressure) showed that gray whale behavioral response while feeding is varied. At high exposure levels some were observed to stop feeding and move away from the source area, while others continued feeding. Because of the moving source geometry used to simulate air gun array operations, it was not possible to perform the probability of avoidance type of analysis as was done for previous studies of migrating gray whales. Instead, detailed observations of focal animals were used to determine a range of air gun pulse pressure levels that would generally cause disturbance of feeding activity. Based on a limited number of samples, average pulse pressure levels of 173 dB and above were observed to result in cessation of feeding activity and movement away from the source area for at least 50% of the whales exposed. Movement back to the original area and resumption of feeding occurred in most of the observed reactions after the source had moved away. Average pulse pressure levels of 163 dB were determined to cause disturbance of feeding activity with some avoidance reaction for 10% of the whales exposed.

The results of the sound propagation model study were used for prediction of zones of influence for representative oil industry sources in Chirikof Basin and near Unimak Pass. The transmission loss predictions were aided by data obtained near St. Lawrence Island for the behavior study and by data reported in the literature. Sound propagation in the Bering Sea is better than would normally be expected for a shallow sea because of the presence of a sub-bottom rock layer. As a result, the zones of influence of industrial noise sources extend further than would be the case for propagation at similar depths off the California coast.

5.2 Recommendations

The data obtained during the short field period in 1985 near St. Lawrence Island were limited by weather conditions and by relatively few whales in the study area. Augmentation of the available data would be highly desirable to be able to have a better statistical base for establishing maximum sound exposure criteria for gray whales engaged in feeding activity.

An extended field study should be performed at St. Lawrence Island earlier in the season when the whale population is higher and the weather is better. This would permit establishment of a theodolite station on the island so that only one large support vessel would be required. It would also allow for more extended control periods so that the degree of interaction between successive test periods would be minimized.

The procedure for conducting moving air gun tests should be revised so that the control periods involve the source vessel moving in the same manner as during the active air gun period. This will significantly increase the required time for each complete test sequence, however. If a second large vessel is not required as an observation platform, this would help eliminate a potential confounding factor.

Playback sequences need to be much longer than those used with migrating whales to minimize the start-up transient effects. It would be highly desirable for the source vessel to spend several days at a site near active feeding areas. This would simulate the actual source more realistically as well as allow for the whales to adjust to the presence of the vessel during an initial long control period.

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APPENDIX

COMPARISON OF TRIANGULATION, THEODOLITE, AND RADAR LOCATION DATA OF SHIPS TO THE SHIPS' LORAN READINGS

Peter Tyack

APPENDIX: COMPARISON OF TRIANGULATION, THEODOLITE, AND RADAR LOCATION DATA OF SHIPS TO THE SHIPS' LORAN READINGS

Triangulation vs LORAN

On 22 and 25 August 1985, the location of the NANCY H was determined by observers on the BIG VALLEY and the Zodiac using the same triangulation method used to locate whales on these days. By comparing these readings to LORAN readings from the NANCY H, we can analyze potential errors of the technique. In the table below, the column marked "error" indicates the difference between the triangulation reading of the NANCY H from the BIG VALLEY and the LORAN reading from the NANCY H. Ranges and errors are in kilometers.

Time of Localization			
Triangulation	LORAN	Range	Error
1207	1207	2.887	1.454
1236	1252	0.347	0.184
1436	1440	0.706	0.100
1516	1517	1.382	0.057
1515	1515	1.397	0.550
1550	1549	0.314	0.081
1600	1557	1.103	0.074
1650	1649	1.748	0.407
1730	1730	0.398	0.080
1750	1752	1.595	0.381

Table 1 shows the same data sorted by range along with a linear regression of error as a function of range. The correlation of error and range is 0.85 indicating a robust ($p < 0.01$ that $r = 0$ from this sample) increase in error with increasing range. Figure 1 plots the actual vs estimated error and residuals from Table 1. Figure 2 shows a scatter plot of the data along with the regression line. The error actually appears to be relatively constant at approximately 100 m out to a range of just over 1 km and then to increase rapidly. The 100 m error at short ranges is probably due to the limits of precision of the LORAN which should not increase with range. More data is required to calibrate the triangulation technique, but this data indicates it is accurate to 100 m at ranges of up to 1 km, but that it may not be useful at greater ranges.

TABLE 1. LINEAR REGRESSION OF ERROR VS RANGE FOR TRIANGULATION TECHNIQUE.

Linear Regression - Range vs Error

Index	Actual Range	Actual Error	Estimated Error	Residuals
1	0.31	0.08	-0.06	-0.14
2	0.35	0.18	-0.05	-0.23
3	0.40	0.08	-0.02	-0.10
4	0.71	0.10	0.12	0.02
5	1.10	0.07	0.30	0.22
6	1.38	0.06	0.43	0.37
7	1.40	0.55	0.43	-0.12
8	1.59	0.38	0.52	0.14
9	1.75	0.41	0.59	0.19
10	2.89	1.45	1.11	-0.34

Estimated Regression equation is:

error (y) =	variable	×	coefficient	error
x(0)	constant		-0.20	0.14
x(1)	range		0.46	0.10

Correlation coef (r) = 0.852 coefficient of determination r^2 = 0.725 standard error of estimate (see) = 0.24

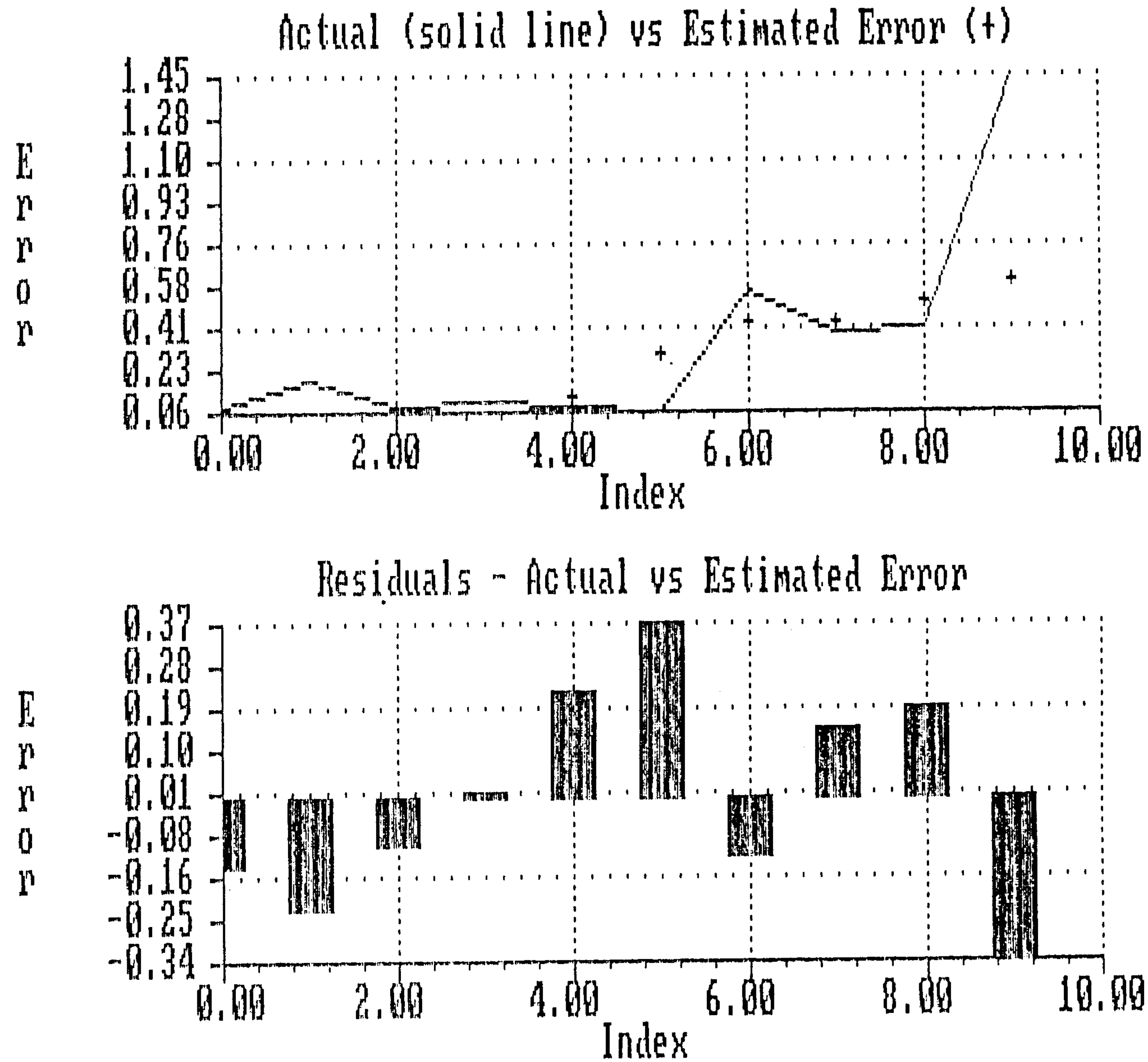

FIG. A.1. PLOT OF ACTUAL VS. ESTIMATED ERRORS FROM REGRESSION ANALYSIS OF TRIANGULATION DATA.

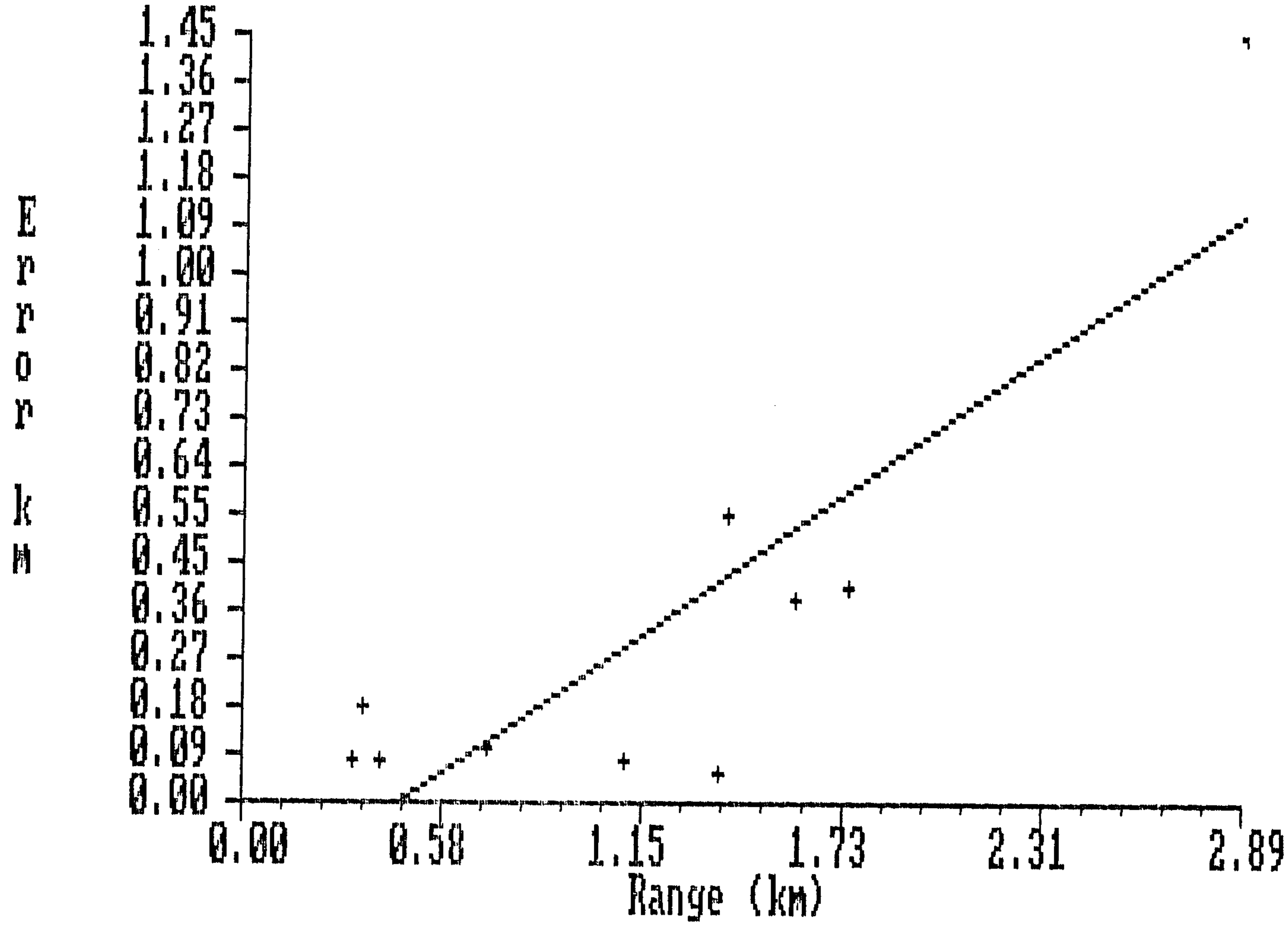

FIG. A.2. SCATTER PLOT OF RANGE VS. ERROR FOR TRIANGULATION TECHNIQUE.

Theodolite vs LORAN

On 24 August 1985, observers at the theodolite station fixed the location of either of the two vessels 13 times within two minutes of a LORAN fix of the vessel. The location of the theodolite station was not determined in the field and it initially was estimated by triangulating azimuths of landmarks on a chart. Comparison of LORAN readings with vessel fixes revealed a range-independent offset of 490 m W and 1059 m N. This was within the range of precision of our determination of the station location, and the location was corrected by this offset. The following table shows the differences of theodolite and LORAN fixes of the boats after offset correction.

Time Transit	LORAN	LORAN Range	Error
1603	1606	3.185	0.295
1609	1610	6.675	0.672
1637	1637	7.378	0.920
1718	1717	2.935	0.380
1725	1725	3.035	0.312
1734	1735	3.339	0.165
1740	1740	3.830	0.373
1807	1805	5.578	0.581
1847	1845	6.294	0.639
1847	1848	3.185	0.294
1931	1930	3.462	0.232
1944	1945	3.146	0.148
2010	2010	2.854	0.258

Table 2 shows the same data sorted by range along with a linear regression of error as a function of range. The correlation of error and range is 0.94 indicating a robust ($p < 0.01$ that $r = 0$ from this sample) increase in error with increasing range. Figure 3 plots the actual vs estimated error and residuals from Table 1. Figure 4 shows a scatter plot of the data along with the regression line. The errors of the transit technique were on the order of 200 to 300 m out to ranges of 4 km. These errors did not appear to be strongly range-dependent and may be, in part, due to limits in the precision of the LORAN used to calibrate the transit. Errors tended to increase with greater range up to an error of almost 1 km at a range of 7.4 km.

TABLE 2. LINEAR REGRESSION OF ERROR VS RANGE FOR THEODOLITE TECHNIQUE.

Index	Actual Range	Actual Error	Estimated Error	Residuals
1	2.85	0.26	0.22	-0.03
2	2.93	0.38	0.24	-0.14
3	3.03	0.31	0.25	-0.06
4	3.15	0.15	0.26	0.12
5	3.18	0.29	0.27	-0.03
6	3.18	0.29	0.27	-0.03
7	3.34	0.16	0.29	0.12
8	3.46	0.23	0.30	0.07
9	3.83	0.37	0.35	-0.02
10	5.58	0.58	0.58	0.00
11	6.29	0.64	0.68	0.04
12	6.67	0.67	0.73	0.06
13	7.38	0.92	0.82	-0.10

Estimated regression equation is:

error (y) =	variable	× coefficient	error
x(0)	constant	-0.15	0.07
x(1)	range	0.13	0.01

Correlation coefficient (r) = 0.938 coefficient of determination r^2 = 0.880 standard error of estimate (see) = 0.08.

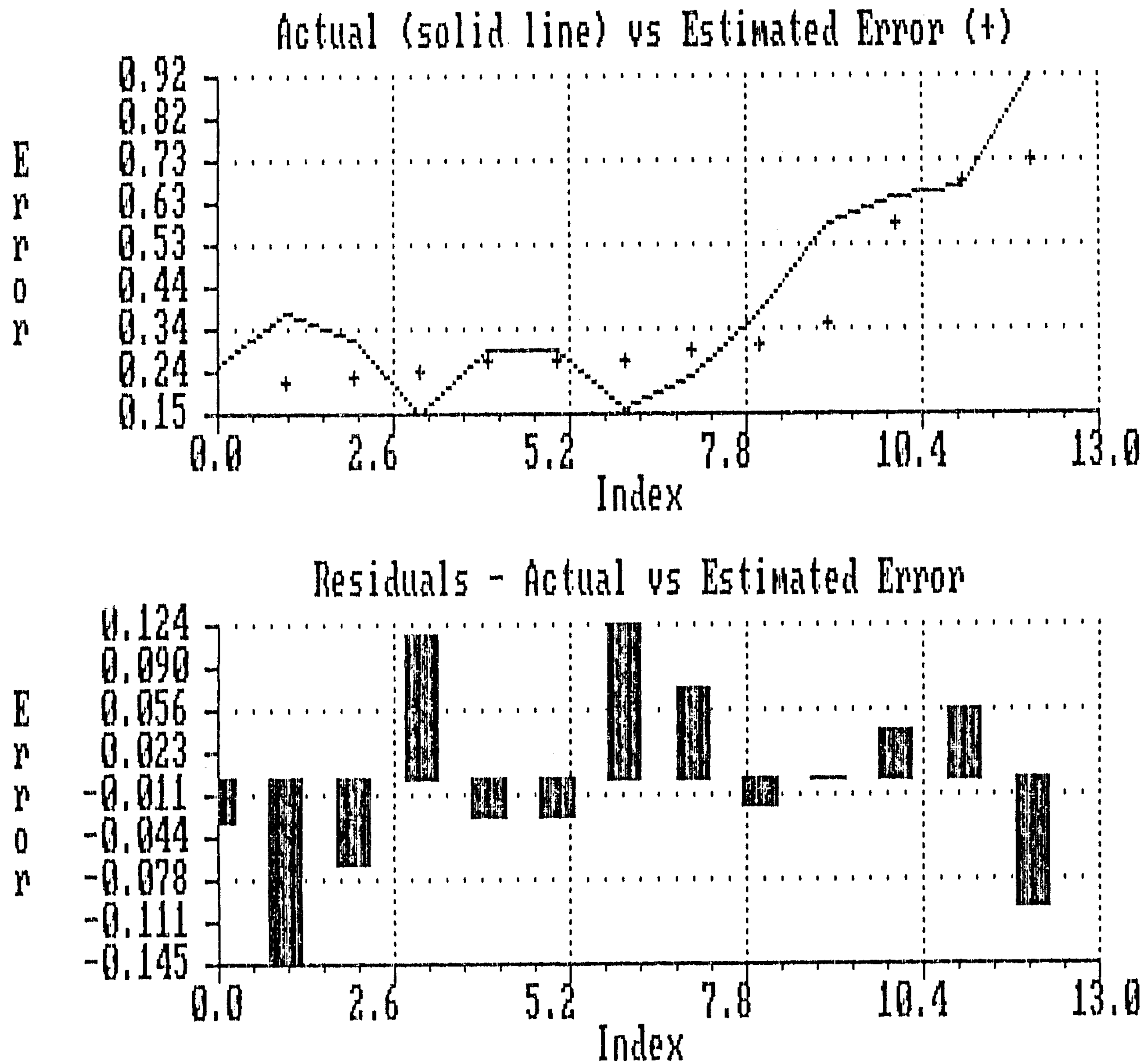

FIG. A.3. PLOT OF ACTUAL VS. ESTIMATED ERRORS FROM REGRESSION ANALYSIS OF THEODOLITE DATA.

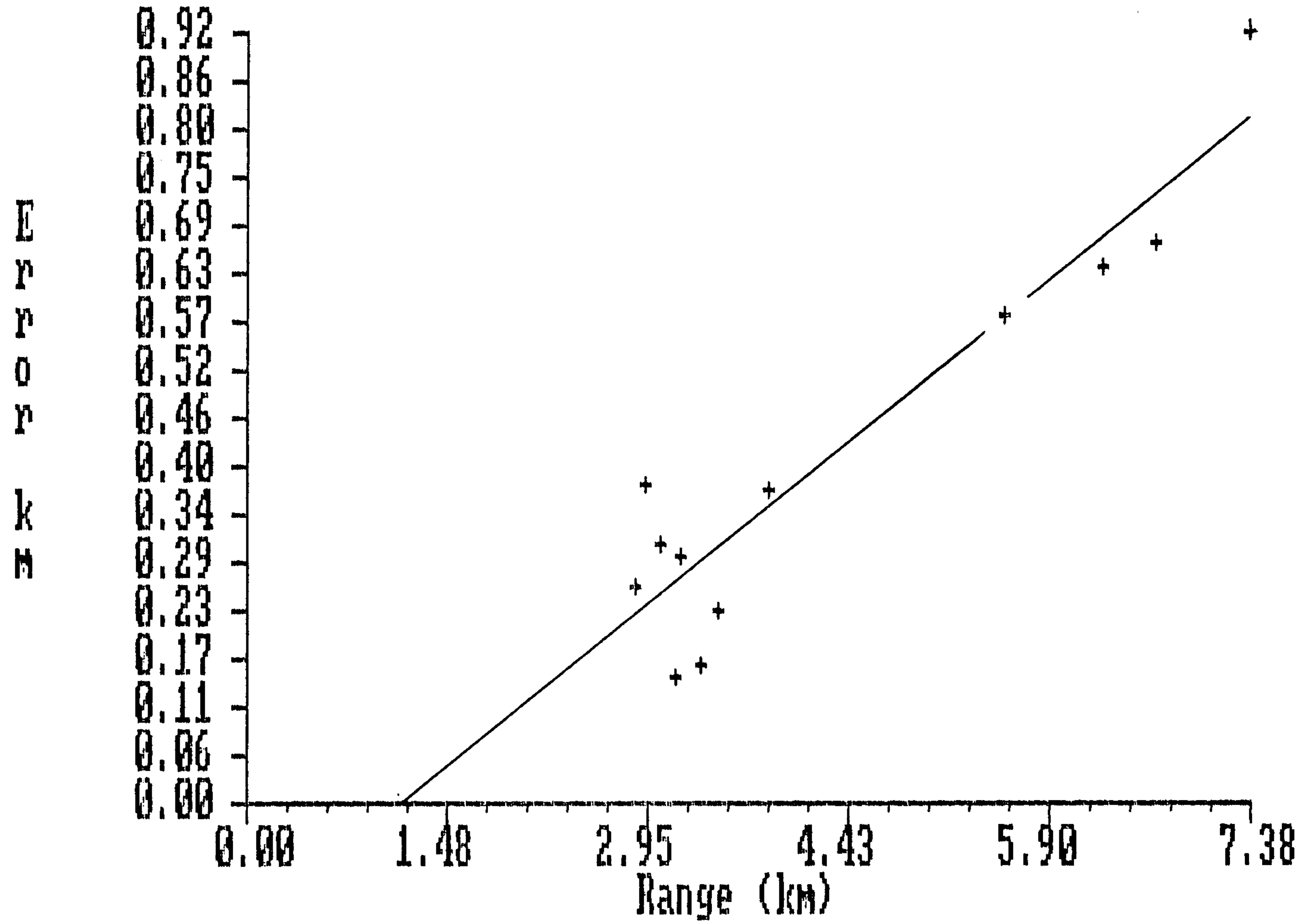

FIG. A.4. SCATTERPLOT OF ERROR VS. RANGE FOR THEODOLITE TECHNIQUE.

Radar vs LORAN

On 25 August, a careful radar range between the Nancy H and the BIG VALLEY was made within five minutes of LORAN readings from both vessels. This allows us to double check both methods for consistency. The origin of the coordinate system is centered on the theodolite station of 24 August.

1600 Radar range of 0.75 nm from NANCY H to BIG VALLEY

		km N/S	km E/W
1603	LORAN reading of BIG VALLEY	1.445	3.308
1605	LORAN reading of NANCY H	-2.168	-2.435
		-0.723	0.873

LORAN Distance 1.1335

Radar Distance = 0.75 nm × 1.852 km/nm = 1.389

These two readings are off by 256 m, which is probably within the limits of precision of the radar readings. This indicates that the two LORANs gave consistent readings at ranges of over 1 km.

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