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Final Reports of Principal Investigators

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Anchorage, Alaska

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Outer Continental Shelf Environmental Assessment Program

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CONTENTS

AERIAL SURVEYS OF ENDANGERED CETACEANS AND OTHER MARINE MAMMALS IN THE NORTHWESTERN GULF OF ALASKA AND SOUTHEASTERN BERING SEA

by

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ABSTRACT

Aerial surveys were conducted in the northwestern Gulf of Alaska and southeastern Bering Sea to determine the abundance, distribution, and habitat use patterns of endangered cetaceans and other marine mammals. Seven, 7- to 20-day surveys were flown between April and December 1985 from a DeHavilland Twin Otter aircraft along almost 44,000 nmi (mean = 5,437 ± 1,972 SD) of randomly selected trackline stratified by water depth. Four species of cetaceans listed by the Federal Government as endangered were observed: gray (377 groups, 589 individuals), humpback (98, 185), finback (74, 149), and sperm (7, 23) whales. Sightings were also made of seven nonendangered species of cetaceans: minke (8, 8), Cuvier's beaked (1, 2), Baird's beaked (2, 9), belukha (6, 8), and killer (25, 67) whales, and Dall (50, 157) and harbor (1, 1) porpoises.

Most of the gray whales were observed during the April-May (12%) and November-December (87%) survey periods, which coincide with the spring and fall migrations through the study area. The spring migration route along the south side of the Alaska Peninsula was coastal from Seal Cape to Unimak Pass, although some animals were observed traveling along the continental shelf edge. Spring surveys were not conducted east of Seal Cape or along the north side of the peninsula. The fall migration route followed along the north side of the Alaska Peninsula from Ugashik Bay to Unimak Pass and coincided with the progressively narrowing 0- to 40-m depth contour band. The fall route along the south side of the peninsula remained coastal until Seal Cape where it moved offshore toward the southwest end of Kodiak Island. Some whales were observed following the continental shelf edge toward Kodiak Island. Fifteen gray whales, including thirteen observed during a 1986 sea otter survey, were recorded summering in the study area, primarily north of the Alaska Peninsula (13 of 15 whales) in or near bays and large estuaries.

Most (90%) humpback whales were observed from June through August and the rest during October and November. All humpbacks were observed in the Shumagin Planning Area, where 66% of the survey effort occurred. Approximately 69% of the humpback whales were observed on the continental shelf, 1% on the slope, and 30% in waters greater than 2,000 m deep. Humpbacks were repeatedly observed on Sanak Bank, Shumagin Bank, and an unnamed bank at longitude 158°W. These banks are near sharp relief where biological productivity was probably high and their repeated use by humpbacks suggests site fidelity. Humpback whale abundance was estimated at 333 ± 217 from the line transect procedure.

Finback whales were only observed during July and August, all in the Shumagin Planning Area. Approximately 90% of the finbacks were observed on the continental shelf and 10% on the slope. None were observed in waters greater than 2,000 m deep. Use of shelf and slope waters was not significantly different ($p > 0.05$), but 90% were observed near high relief areas between 45 m (25 fathoms) and 137 m (75 fathoms) deep. Finback whales were repeatedly observed near Lighthouse Rocks (157°25'W), suggesting site fidelity. Finback whale abundance was estimated at 184 ± 90 animals from the line transect procedure.

Sperm whales were only observed in the Shumagin Planning Area in waters 3,500-4,000 m deep, but too few were observed to derive an abundance estimate. Killer whale abundances were estimated for the St. George Basin (639 ± 476) and Shumagin (244 ± 136) planning areas only, since too few were encountered in the North Aleutian Basin.

Estimates for humpback, finback, and killer whales were not corrected for missed animals. Abundance was not estimated for the remaining nonendangered species because too few were observed, or, as in the case of the Dall porpoise, they could not be accurately observed at the altitude flown.

These results show that the project area is an important feeding ground for relatively large numbers of humpback and finback whales and lower numbers of gray and sperm whales. Moreover, the project area is a critical link in the gray whale migration route between seasonal ranges. The project area also supports a variety of other marine mammals both seasonally and annually.

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INTRODUCTION

Seven species of endangered whales seasonally inhabit the northwestern Gulf of Alaska and southeastern Bering Sea (Rice and Wolman 1982; Morris *et al.* 1983). Humpback (*Megaptera novaeangliae*), finback (*Balaenoptera physalus*), and right (*Balaena glacialis*) whales feed in both waters during the summer and early fall, while blue (*Balaenoptera musculus*), sei (*Balaenoptera borealis*), and sperm (*Physeter macrocephalus*) whales are more restricted to the North Pacific or the deeper western Bering Sea (Berzin and Rovnin 1966; Rice 1974). Gray whales (*Eschrichtius robustus*) pass through the Gulf of Alaska and eastern Bering Sea twice each year on their annual migration between breeding lagoons in Mexico and feeding grounds in the northern Bering and Chukchi seas (Braham 1984*b*). A few gray whales summer along the Alaska Peninsula (Gill and Hall 1983). Many of these species occur in the North Pacific and Bering Sea throughout the year (Brueggeman *et al.* 1984). Bowhead whales (*Balaena mysticetus*) winter in the Bering Sea but their range is beyond the study area, northwest of Bristol Bay (Brueggeman 1982).

Stocks of these whales were severely reduced by commercial whaling in the North Pacific Ocean and Bering Sea. Protection of the North Pacific right whale stock from commercial whaling began in 1937 and protection of the gray whale began in 1946, after both had been severely reduced by high-seas whaling in the 19th century (Townsend 1935). Only a few hundred right whales survive today (Rice 1974; Rice and Wolman 1982), while the gray whale population has apparently recovered to pre-exploitation levels (Gambell 1976; Reilly 1981; Rice and Wolman 1982).

The large-scale exploitation of these species began with the introduction of modern whaling methods after the turn of the century. Between 1912 and 1939, over 5,000 blue, finback, humpback, and sperm whales were taken from the northwestern Gulf of Alaska and southeastern Bering Sea by Alaska shore-based whaling stations (Brueggeman *et al.* 1984; Leatherwood *et al.* 1985; Reeves *et al.* 1985). After a brief respite during World War II, Soviet and Japanese pelagic whaling fleets further harvested blue and humpback whales from these waters until their protection in 1967 and finback and sei whales until their protection in 1976. Population levels of North Pacific rorquals presently range from approximately 8% (1,200) of the estimated original numbers of humpback whales to 32-44% (14,620-18,630) of estimated original finback whales (Braham 1984*a*). The sperm whale, though listed as an endangered species, is commercially harvested by Japan in the North Pacific, where approximately 400 whales are annually taken from an estimated 472,100 animals composing the entire North Pacific stock (Ohsumi 1980; Braham 1984*a*; IWC 1986).

Nonendangered whales endemic to the northwestern Gulf of Alaska and southeastern Bering Sea include the minke whale (*Balaenoptera acutorostrata*), Stejneger's beaked whale (*Mesoplodon stejnegeri*), Cuvier's beaked whale (*Ziphius cavirostris*), Baird's beaked whale (*Berardius bairdii*), killer whale (*Orcinus orca*), harbor porpoise (*Phocoena phocoena*), and Dall porpoise (*Phocoenoides dalli*). Population sizes for these species are unknown except for the Dall porpoise which is currently estimated at between 136,671 and 253,865 animals in the Gulf of

Alaska (Bouchet 1981). These cetaceans have not been specifically harvested by commercial whalers in the eastern North Pacific.

Other marine mammals common in these waters are the northern fur seal (*Callorhinus ursinus*), northern sea lion (*Eumetopias jubatus*), harbor seal (*Phoca vitulina*), and sea otter (*Enhydra lutris*). The coast of the Alaska Peninsula and Aleutian Islands is the major breeding area for the latter three species, whereas the Pribilof Islands are the main breeding ground for the northern fur seal (Fiscus 1978; Kenyon 1982; Loughlin *et al.* 1984).

Information on marine mammal abundance, distribution, and habitat use patterns in the northwestern Gulf of Alaska and southeastern Bering Sea is incomplete. Most available information is derived from limited systematic surveys, opportunistic sightings, and historic whaling records. Aerial surveys and some vessel surveys have been conducted by the National Marine Mammal Laboratory (NMML) and other investigators (Braham *et al.* 1977; Rice and Wolman 1982; Leatherwood *et al.* 1983; Braham 1984*b*; Rugh 1984; Stewart *et al.* 1987) supported through the NOAA/MMS Outer Continental Shelf Environmental Assessment Program (OCSEAP). While these efforts have contributed substantially to a better understanding of the biology of these species, the results remain inconclusive because of the large area surveyed, difficult logistics, and the small number and sporadic distribution of many endangered cetacean and other marine mammal populations.

In 1985, we surveyed endangered cetaceans and other marine mammals in the northwestern Gulf of Alaska and southeastern Bering Sea in order to characterize their use of these areas. Our surveys were part of an OCSEAP study to determine the effect of proposed petroleum exploration and development on marine mammal populations in the Shumagin, North Aleutian Basin, and St. George Basin planning areas, as stipulated by the Marine Mammal Protection Act and the Endangered Species Act. Aerial surveys were conducted during six 20-day periods between June and December, and an additional 7-day survey was conducted during April-May by Donald K. Ljungblad and his staff from the Naval Ocean Systems Center, San Diego. Exact survey dates are included in Table 1. The primary objectives of the study were to:

1) Characterize large cetacean abundance and habitat use in the Shumagin Planning Area twice each season (during the seven survey periods) from spring through early winter.

2) Define fall migration patterns of gray whales and their use of feeding areas in the St. George Basin and North Aleutian Basin planning areas.

3) Characterize large cetacean abundance and seasonal habitat use in the St. George Basin and North Aleutian Basin planning areas during June-July, November, and December surveys and make semiannual comparisons using available data from other sources.

4) Document sightings and behavior of other marine mammals encountered during the surveys.

Table 1.–Aerial survey periods, 1985.

Survey number	Survey period	Actual survey date[a]
1[b]	April - May	28 April - 4 May
2	June - July	24 June - 11 July
3	July - August	23 July - 5 August
4	August	21 - 31 August
5	October	13 - 31 October
6	November	11 - 24 November
7	December	2 - 19 December

[a] Dates shown are first and last days of actual survey.
[b] Survey conducted by D. K. Ljungblad and staff at NOSC, San Diego.

STUDY AREA

The study area included the waters offshore of the Alaska Peninsula in the Bering Sea and the northwestern Gulf of Alaska (Figure 1). The southeastern Bering Sea is a sandy-bottomed shelf region less than 200 m deep. It is separated from the deep (2,500 m) Bering Sea basin by the shelf break that runs northwestward from Unimak Pass. In contrast, the continental shelf on the south side of the peninsula is rock-bottomed and has extensive reefs and island complexes. The shelf extends approximately 75 km from the coast before dropping precipitously into the 8,000-m-deep Aleutian Trench. Surveys were conducted as far as 325 km offshore of the Alaska Peninsula.

The oceanographic characteristics of Alaska Peninsula waters are primarily influenced by two major currents: the Alaska Coastal Current (ACC) and the Alaska Stream. The narrow ACC, driven by snowmelt and runoff, travels southwestward along the south side of the Alaska Peninsula. It then enters the Bering Sea through Unimak Pass (Royer 1981; Schumacher and Moen 1983) before flowing northeastward into Bristol Bay. According to Schumacher and Reed (1986), the islands and submarine canyons along the south side of the peninsula bifurcate the ACC and create mixing zones between the shelf and current waters. The much stronger Alaska

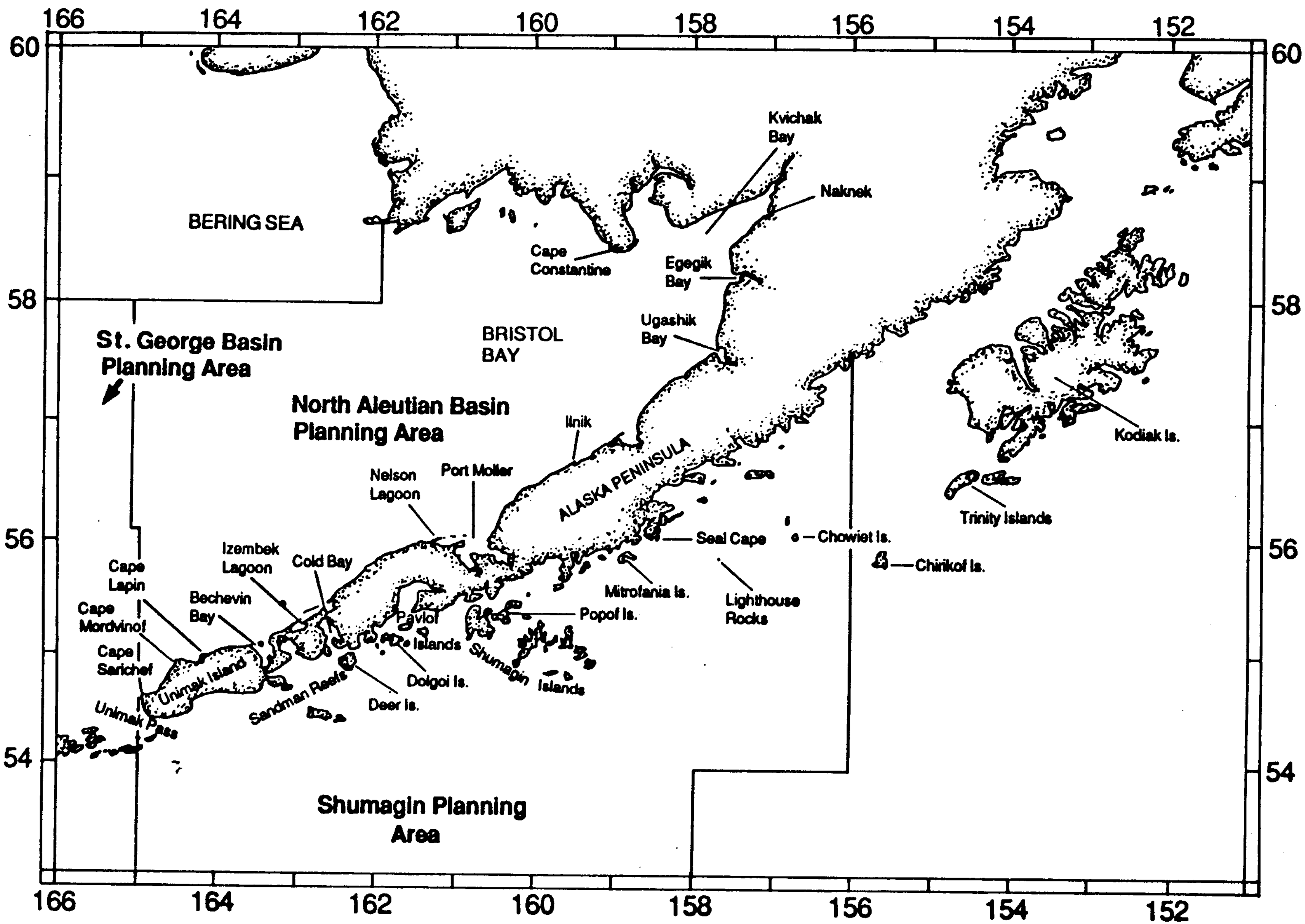

Figure 1.–Study area with place names mentioned in the text.

Stream flows southwestward along the edge of the continental shelf south of the peninsula. Part of this current diverges and travels through various Aleutian Island passes and mixes with Bering Sea waters (Favorite 1974). Both currents are influenced by the persistent and heavy winds typical of the Alaska Peninsula and the Aleutians. Monthly mean wind speeds, ranging between 24 and 29 km/hr, are highest and most persistent during winter when cyclonic storms are frequent. In turn, these currents and winds greatly influence the biological oceanography in the study area.

The northwestern Gulf of Alaska climate is maritime with little influence from continental air masses. Daily and seasonal temperature extremes are confined to fairly narrow limits and readings below -18°C (0°F) are very rare. Conversely, the Bering Sea is partially covered with sea ice from approximately October through June. Although the southern limit of the pack ice is north of the study area, shorefast ice reaches its southern limit approximately halfway down the Alaska Peninsula (Port Moller). During particularly cold years, fast ice may reach Unimak Island (Schneider and Faro 1975). Shorefast ice is present in the study area from approximately January through March.

METHODS

Survey Design and Procedures

The study area was stratified into three levels of survey effort: (1) planning area, (2) sampling block, and (3) water depth zone (Figure 2). The planning areas, which are federally delineated oil and gas lease sites, included the Shumagin unit (south of the Alaska Peninsula) and the North Aleutian Basin and St. George Basin areas (north of the Alaska Peninsula and eastern Aleutian Islands). Within these planning areas, 65 survey blocks, each 110 km long by 74 km wide, were uniformly distributed. There were 29 survey blocks in the Shumagin Planning Area, 20 in the North Aleutian Basin, and 16 in the St. George Basin. The blocks intersected three water depth categories: shallow, transition, and deep water. The shallow water zone, 0-200 m deep, corresponded to the outer continental shelf. The transition zone, 200-2,000 m deep, corresponded to the outer continental slope. The water depth beyond 2,000 m but within approximately 325 km of the coast represented the deep water zone. Survey blocks within each planning area were divided among the three zones so as to stratify the study area into habitats defined by water depth and geographic location.

For each survey period, blocks to be flown were randomly selected (without replacement) from all blocks in the planning area. Surveys were conducted in the Shumagin Planning Area during each period. On the other hand, the North Aleutian Basin and St. George Basin were surveyed only during the June-July, November, and December periods; a limited survey (173 nmi) was also conducted in the North Aleutian Basin during the August survey period. This schedule, developed by OCSEAP, was designed to correspond with the historic use of these areas by endangered whales. This includes spring through fall use in the Shumagin area and spring-early summer and late fall-early winter use in the North Aleutian Basin and St. George Basin areas.

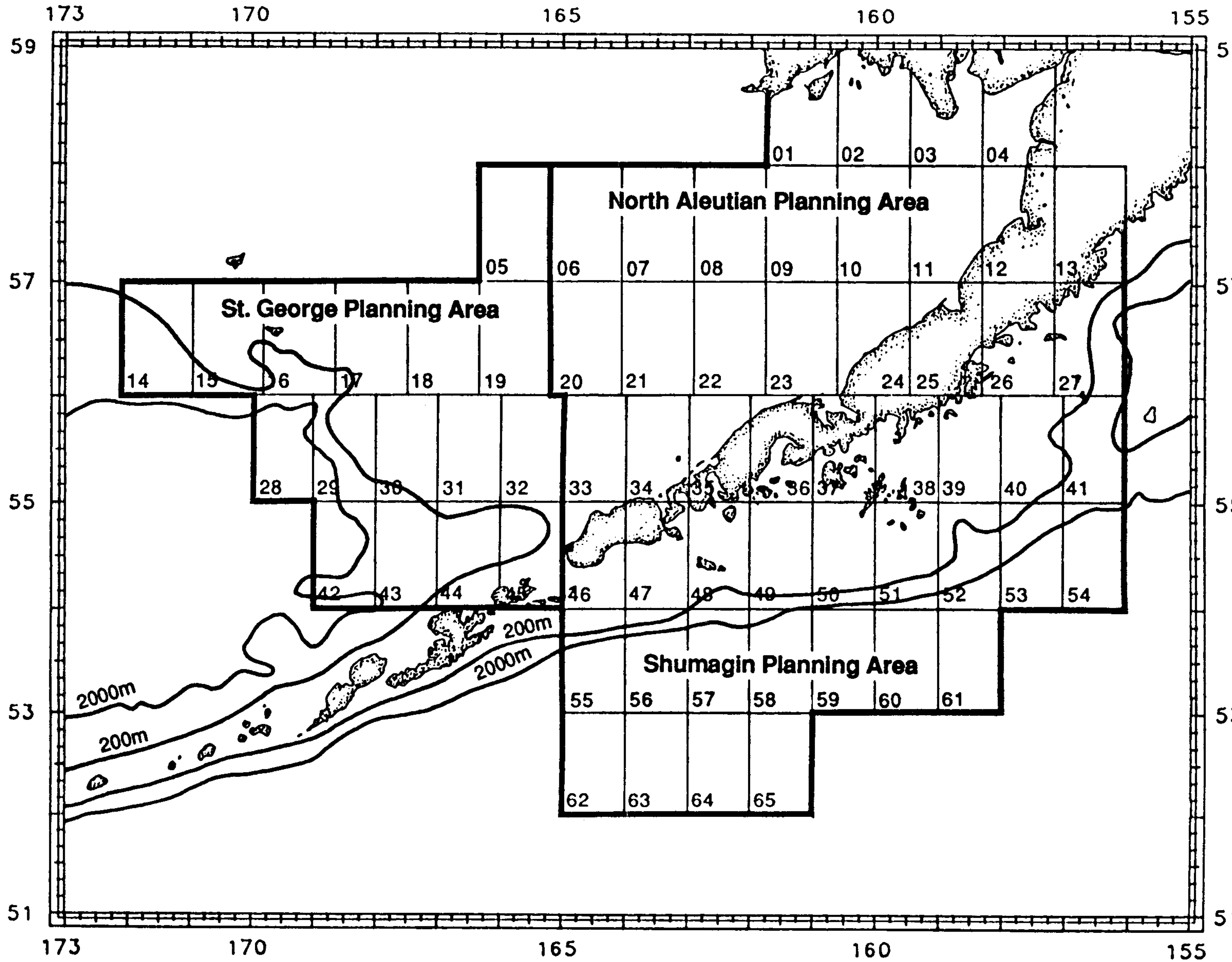

Figure 2.–Survey design.

Survey effort was recorded by planning area and water depth zone. The effort achieved for all surveys combined was a total of 540 hours of flight time, 60% of which was spent in the Shumagin Planning Area, 24% in the North Aleutian Basin, and 16% in the St. George Basin. Within these planning areas, approximately 76% of the effort was accomplished in the shallow water zone, 7% in the transition zone, and 17% in the deep water zone.

Aerial surveys were conducted along the transect lines uniformly distributed in each survey block (Figure 2). Each block contained ten transect lines, 110 km (60 nmi) long and spaced 7.4 km (4 nmi) apart, that were oriented in a north-south direction. These systematic transect lines were consecutively surveyed except for periods of unsuitable weather conditions. Transect lines were also surveyed when flying from Cold Bay (base of operations) to a sampling block, and these were termed random surveys. A third type of transect, termed a deadhead, was surveyed when flying between connecting systematic lines, when verifying a marine mammal sighting, or during non- or limited-effort transit flights. The latter type of survey provided information on species composition and distribution, but the data were not used to estimate population parameters since the effort was not constant. Surveys were occasionally conducted when sea state exceeded a Beaufort 4 or when ceiling height was below 90 m (300 ft), but these efforts were recorded as deadheads.

Surveys were conducted from a DeHavilland Twin Otter aircraft equipped with an auxiliary fuel tank to extend the potential flight duration to 10 hours. Surveys were flown at 230 m (750 ft), except when ceiling height forced the flight to a lower altitude. Air speed was maintained at 100 knots during all systematic and random transect flights. Air speeds greater or less than 100 knots occurred only during deadhead surveys or non-effort transit flights. Two observers, positioned on each side of the aircraft behind the pilot and copilot, relayed observations to a data recorder situated in the aft section of the aircraft. Observers viewed the survey area through bubble windows specially equipped on the aircraft to provide downward and forward visibility. A third observer rotated with the primary observers every 2 hours to reduce fatigue. The third or off-duty observer generally rested but also backed-up the others through a flat rear window during periods of frequent marine mammal encounters.

A Hewlett-Packard 85 computer, interfaced with the aircraft's Global Navigation System (GNS) and radar altimeter, provided the data recorder with an instantaneous readout of time, altitude, latitude, and longitude. The recorder combined these data with sighting and environmental information given by the observers. Sighting information included number of animals, group size, species, clinometer angle, behavior, direction of travel, number of calves, and whether the sighting was a duplicate. Duplicates were recorded when confirming a sighting. A group was defined as all animals within 3-4 body lengths of each other. Environmental information included sea state according to the Beaufort Wind Scale, with sea state descriptors (Black and Adams 1983), visibility, and glare. Visibility and glare descriptions are provided in Appendix C. Environmental conditions were evaluated by the observers at the beginning and end of each transect line or whenever conditions changed.

The April-May surveys were conducted by Donald K. Ljungblad and his staff at the Naval Ocean Systems Center (NOSC). Survey techniques were similar except north-south survey tracks were selected randomly within the area between Unimak Pass and the Shumagin Islands. Surveys were conducted from the same Twin Otter generally at an altitude of 230 m (750 ft) but which varied between 215 and 335 m (700 and 1,100 ft) depending on weather conditions. Data recording procedures and orientation of the observers in the aircraft were identical to those followed during the June-December surveys. Further information on the NOSC survey techniques can be found in Ljungblad *et al.* (1986).

Analytical Procedures

Marine mammal density and abundance were estimated from the line-transect procedure (Burnham *et al.* 1980). This procedure uses the perpendicular distances of animals from a survey trackline to determine a probability density function. The value of the function at the trackline (f(0)) is multiplied by the number of whales observed per distance of trackline to obtain the observed density. This procedure is the standard technique for estimating cetacean density and abundance. It must satisfy the following assumptions:

1) The area of interest is sampled randomly or the population is distributed randomly within the area.

2) All animals on the transect centerline are seen.

3) All measurements are made without error.

4) The animals do not move in response to the aircraft prior to being detected from it.

5) Sightings are independent events.

6) The size of a group of animals does not affect its probability of being observed.

Steps were instituted during this study to minimize the violation of these assumptions. The first assumption was satisfied by randomly sampling survey blocks, since marine mammals are usually not randomly distributed.

The degree to which the second assumption was fulfilled is unclear; however, the following procedures and aircraft modifications were implemented to reduce this source of error: (1) bubble windows, constructed on each side of a high-winged aircraft, provided forward and downward visibility to the observers; (2) observers were constantly instructed to examine the trackline below and forward of the aircraft; and (3) pilots were instructed to alert observers to marine mammals detected on the trackline. Some whales that were below the surface were not detected by the observers. Species-specific information on respiration patterns is required to determine the proportion of missed or submerged whales. However, as various investigators have reported, respiration patterns are highly variable relative to behavior, sex, and age classes of animals. Because of this variability, it is not possible to calculate a meaningful correction factor. Hay (1982), however, reported that the proportion of animals missed can exceed the observed number by 50%.

The third assumption, that measurements are error-free, relies upon accuracy in the two measurements needed to calculate a perpendicular distance: (1) altitude and (2) angle to animals. The altitude (in feet) was measured by a radar altimeter that was calibrated at the start of the surveys and directly linked to a portable computer for real-time measurements. The altitude was simultaneously recorded with the angle measurement of a sighting. Angles were obtained from clinometers and recorded to the nearest degree. While the altimeter values were accurate, the accuracy of the clinometer values decreased with increasing distance from the trackline. However, the influence of this error was reduced by truncating the tail of the sightability curve to calculate the f(0). The truncation process eliminates the furthest outlying sightings. These contribute little to the estimates of f(0) and density but often create problems for parametric and non-parametric estimation procedures. The outliers frequently cause difficulties such as a lack of fit for estimation models and necessitate adding terms in the Fourier series approach. A model with one or two terms is always preferred to one with four to six terms. Consequently, most estimation methods benefit from truncation of the data to eliminate outliers (Burnham *et al.* 1980).

The fourth assumption was almost certainly fulfilled since the speed of the airplane is great relative to the speed of the whales. The aircraft was moving at over 20 times the speed of the whales, and thus was fast enough to overcome the effects of any reaction of the whales to the aircraft.

The fifth assumption, that sightings are independent events, was generally met. Sightings were usually spaced at sufficient distances to reduce the likelihood that one sighting initiated the sighting of additional groups of whales. When multiple groups were tightly clustered, however, the independence of observations is uncertain. Failure to fulfill this assumption would affect only the sampling variance of the density estimate, rather than the density estimate itself (Burnham *et al.* 1980).

Lastly, the sixth assumption, that group size does not affect the probability of detection, was generally fulfilled. Because group sizes were typically small, the potential disparity in the probability of detecting different group sizes was substantially reduced. Larger groups have a higher probability of being observed than smaller groups. The result is an overestimation of mean group size and an underestimation of the mean number of groups per unit of area. Because group size was quite consistent within each species, observers were experienced at sighting whales, and individual animals were readily detected at 230 m (750 ft) altitude, group size did not substantially influence the probability of detecting a whale. Consequently, the line-transect procedure was suitable for estimating cetacean density and abundance for this study.

The probability density function of the perpendicular distances, f(x), was estimated from calculated distances and evaluated at zero (f(0)). (See Appendix A for a list of the basic notation used in the following calculations.) The following expression was used to calculate density:

$$D_i = \frac{n_i f(0)}{2L_i} \qquad \text{(Equation 1)}$$

where n_i is the number of groups of animals and L_i is the length of trackline searched in sampling block i. Only systematic and random trackline surveys were used to estimate density. The non-parametric Fourier-series estimator was used to calculate f(0). This method is recommended by Burnham *et al.* (1980) because it is a robust estimator of f(0) which is especially suitable to apply to marine mammal data. Program TRANSECT (Laake *et al.* 1979) was used to execute the calculations. The f(0) was determined for a set of perpendicular distances truncated at the tail of the sightability curve. K. Burnham (pers. commun.) recommended this procedure to reduce the variability of f(0) since the larger perpendicular distance values that compose the tail of the curve are less accurate and may represent a different sighting process.

Because survey effort was variable in each randomly selected sampling block, the following expression was used to calculate a weighted density of groups:

$$D_{wi} = \frac{\sum_{i=1}^{b} (L_i D_i)}{\sum_{i=1}^{b} L_i} \qquad \text{(Equation 2)}$$

where b is the number of sampling blocks surveyed. The weighted density was calculated for all sampling blocks surveyed in each of the three water depth zones. The total number of groups (G) in a planning area was calculated by summing the estimated abundance in each zone according to the following expression:

$$N_G = \sum_{i=1}^{3} (A_i D_{wi}) \qquad \text{(Equation 3)}$$

where A_i is the area of a planning area composed of one to three possible zones.

Because the group rather than the individual is the basic observation for marine mammals, the abundance estimate (N_G) is converted to an estimated number of individuals (N_I) by the following expression:

$$N_I = N_G \bar{K} \qquad \text{(Equation 4)}$$

where $\bar{K}$ is the average group size for a particular species of marine mammal.

An estimate of the sampling variance for density as derived by D. Chapman for this study is:

$$V\,(D_{wi}) = \left[\frac{\sum_{i=1}^{b} L_i (D_i)^2 - \dfrac{\left(\sum_{i=1}^{b} L_i\, D_i\right)^2}{\sum_{i=1}^{b} L_i}}{\left(\sum_{i=1}^{b} L_i\right)^2} \right] \left(\frac{B-b}{B-1}\right) \qquad \text{(Equation 5)}$$

where B is the total number of sampling blocks in a zone of a planning unit. The $\frac{B-b}{B-1}$ expression is a finite population correction factor.

The variance of the total number of individuals is then computed by the following expression:

$$V(N_I) = \sum_{i=1}^{3} \left[A_i^2\, V(D_{wi})\right] f(0)^2\, \bar{K}^2 \; + \sum_{i=1}^{3} \left[A_i\, D_{wi}\right]^2 V\left[f(0)\right]^2 \bar{K}^2 \; + \sum_{i=1}^{3} \left[A_i\, D_{wi}\right]^2 \left[f(0)\right]^2 V(\bar{K}) \qquad \text{(Equation 6)}$$

where V f(0) was calculated from Burnham *et al.* (1980) and the V($\bar{K}$) from the following equation:

$$V(\overline{K}) = \frac{\sum_{i=1}^{G} K_i^2 - \frac{\left(\sum_{i=1}^{G} K_i\right)^2}{G}}{G(G-1)} \qquad \text{(Equation 7)}$$

where G is the number of groups of size K. The same sighting function (f(0)), and also the same mean group size ($\overline{K}$), are used for all sampling units within the three zones.

Approximately 95% confidence intervals were calculated for the estimate of abundances from the following formula:

$$N_I \pm 2\sqrt{V(N_I)} \qquad \text{(Equation 8)}$$

The number of whales missed during the surveys was not factored into the estimated density and abundance values. Missed animals include those at the surface but not seen by observers and those that were submerged. Corrections of aerial survey estimates for missed marine mammals based on dive-time data have not been derived because correction factors may be strongly influenced by behavior, group size, season, time of day, and many other biological and environmental factors. Pending availability of such correction factors, it is conservatively assumed that 50% of whales go undetected (H. H. Whitehead in Hay 1982).

RESULTS AND DISCUSSION

Species Composition and Effort

Sixteen species of marine mammals, including 1,274 cetaceans, 3,719 pinnipeds, and 4,463 sea otters were observed along 38,050 nmi of trackline surveyed in the Shumagin, North Aleutian Basin, and St. George Basin planning areas between April and December 1985 (Table 2). Approximately 63% of the marine mammals were encountered in the Shumagin area, 36% in the North Aleutian Basin, and 1% in the St. George Basin. Survey effort was correspondingly highest (66%) in the Shumagin area, lowest in the St. George Basin (13%), and intermediate in the North Aleutian Basin (21%).

Four of the eleven species of cetaceans that we observed are listed by the federal government as endangered throughout their range. The survey recorded 589 gray whales, 185 humpback whales, 149 finback whales, and 23 sperm whales, which together accounted for almost 80% of the total number of cetaceans sighted. Of the seven nonendangered species, the

Table 2.—Species composition and number of marine mammals observed in the three planning areas, April–December 1985.

Species	Shumagin (25,059 nmi)[a]		North Aleutian Basin (8,061 nmi)		St. George Basin (4,930 nmi)		Total (38,050 nmi)	
	No.	Group	No.	Group	No.	Group	No.	Group
Cetacea								
Mysticeti								
Minke whale *(Balaenoptera acutorostrata)*	3 (1)[b]	3 (1)[b]	3	3	1	1	7 (1)	7 (1)
Finback whale *(Balaenoptera physalus)*	93 (56)	49 (25)	0	0	0	0	93 (56)	49 (25)
Humpback whale *(Megaptera novaeangliae)*	129 (56)	75 (23)	0	0	0	0	129 (56)	75 (23)
Gray whale *(Eschrichtius robustus)*	75 (116)	33 (40)	334 (64)	221 (43)	0	0	409 (180)	254 (83)
Unidentified baleen	33	24	14	9	1	1	48	34
Odontoceti								
Cuvier's beaked whale *(Ziphius cavirostris)*	2	1	0	0	0	0	2	1
Baird's beaked whale *(Berardius bairdii)*	5 (4)	1 (1)	0	0	0	0	5 (4)	1 (1)
Unidentified beaked whale	3 (1)	1 (1)	0	0	0	0	3 (1)	1 (1)
Sperm whale *(Physeter macrocephalus)*	23	7	0	0	0	0	23	7
Belukha whale *(Delphinapterus leucas)*	0	0	5 (3)	5 (1)	0	0	5 (3)	5 (1)
Killer whale *(Orcinus orca)*	32 (6)	11 (3)	1 (1)	1 (1)	27	9	60 (7)	21 (4)
Harbor porpoise *(Phocoena phocoena)*	1	1	0	0	0	0	1	1
Dall porpoise *(Phocoenoides dalli)*	71 (32)	25 (7)	21	7	33	11	125 (32)	43 (7)
Unidentified porpoise	8	5	6	6	10	7	24	16
Subtotal	478 (271)	234 (101)	384 (68)	252 (45)	72	29	934 (340)	515 (146)
Pinnipedia								
Otariidae								
Northern sea lion *(Eumetopias jubatus)*	2,997	171	341	19	4	2	3,342	192
Northern fur seal *(Callorhinus ursinus)*	4	3	4	1	10	6	18	10
Phocidae								
Harbor seal *(Phoca vitulina)*	282	54	53	3	0	0	335	57
Odobenidae								
Pacific walrus *(Odobenus rosmarus)*	0	0	24	18	0	0	24	18
Subtotal	3,283	228	422	41	14	8	3,719	277
Carnivora								
Mustelidae								
Sea otter *(Enhydra lutris)*	1,880	383	2,568	358	15	1	4,463	742
Total	5,639 (271)	844 (99)	3,374 (68)	651 (44)	101	38 (1)	9,113 (340)	1,532 (146)

[a] Total distance surveyed.

[b] Additional number or groups or animals observed on deadhead survey tracklines.

most abundant were the Dall porpoise (157) and killer whale (67). Fewer than 15 animals each were encountered of Cuvier's beaked whales, Baird's beaked whales, belukha whales, minke whales, and harbor porpoises. There were 76 unidentified cetaceans.

The richness of cetacean species was highest in the Shumagin Planning Area and lowest in the St. George Basin Planning Area (Table 2). Ten of the eleven species were observed in the Shumagin area, whereas five and three species were observed in the North Aleutian and St. George basins, respectively. All of the endangered whale species except the gray whale were recorded solely in the Shumagin area. Gray whales also occurred in the North Aleutian Basin. The Dall porpoise, killer whale, and minke whale were the only species found in all three planning areas. Belukha whale observations were confined to Bristol Bay in the North Aleutian Basin.

Four species of pinnipeds and 4,500 sea otters were also observed in the planning areas (Table 2). The northern sea lion was the most common pinniped, followed by the harbor seal, Pacific walrus, and northern fur seal. Large numbers of these species reproduce in rookeries distributed throughout the planning areas. Observations of pinnipeds and sea otters were incidental to those of cetaceans.

Survey effort in the planning areas totaled 38,050 nmi of systematic and random surveys and 5,634 nmi of deadhead surveys (Figure 3). Deadhead surveys were only used to describe marine mammal distribution, and they accounted for 338 (27%) cetacean observations. Systematic and random survey effort, the basis for the analysis, averaged 5,437 nmi (±1,972 SD) per survey period. Effort was highest during the June-July and July-August periods and lowest during the April-May period. The Shumagin Planning Area was surveyed during all seven periods and the effort averaged 3,580 nmi (±2,329 SD) (Figure 4). Effort averaged 2,016 nmi (±1,269 SD) for the four survey periods in the North Aleutian Basin, and 1,644 nmi (±767 SD) for the three survey periods in the St. George Basin. The total survey effort we achieved represents the highest intensity of coverage in these planning areas and it exceeds previous survey efforts (Leatherwood *et al.* 1983; Stewart *et al.* 1987) by at least a factor of three.

Viewing conditions during surveys primarily featured good to excellent visibility and Beaufort sea states of 0 to 3 (Figure 5). Good to excellent visibility conditions occurred during 86% of the total survey effort in the Shumagin Planning Area, 77% in the North Aleutian Basin, and 75% in the St. George Basin. The same visibility conditions were experienced in 76-92% of the effort in each of the seven survey periods (Table 3). Sea state, estimated according to the Beaufort Wind Scale, was between 0 and 3 during 78% of the total survey effort in the St. George Basin, 71% in the Shumagin area, and 57% in the North Aleutian Basin. Sea states were highest during the fall survey periods (particularly November) when Beaufort 4 and 5 conditions occurred during 43-63% of the total effort. During the spring and summer periods, sea states of these magnitudes prevailed during only 10% and 26% of the total survey effort. Consequently, survey conditions were best during periods one through four (April-August), worst during period six (November), and intermediate during periods five and seven (October, December).

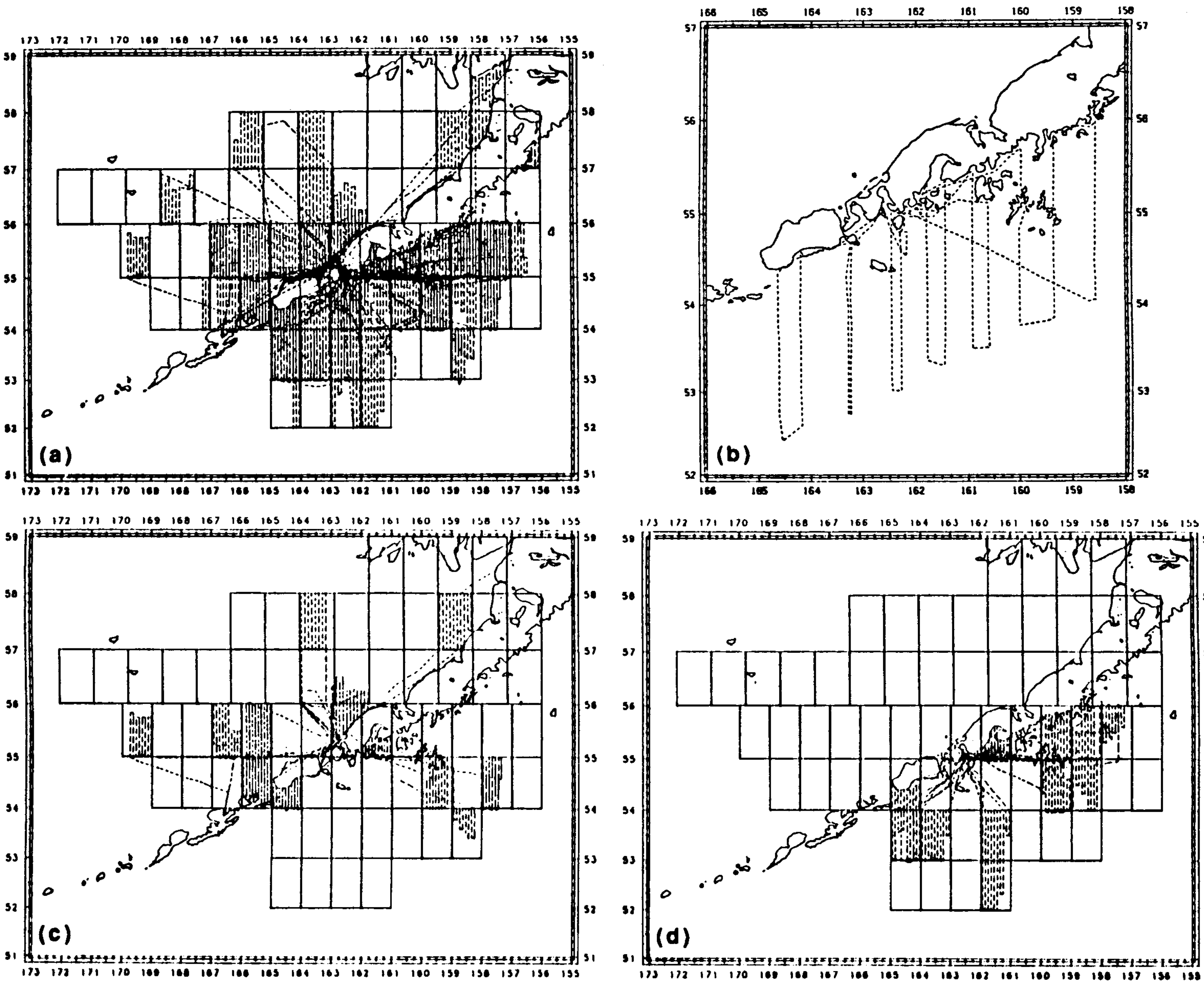

Figure 3.–Survey effort for April through December 1985 (a, total survey effort; b, April-May; c, June-July; d, July-August).

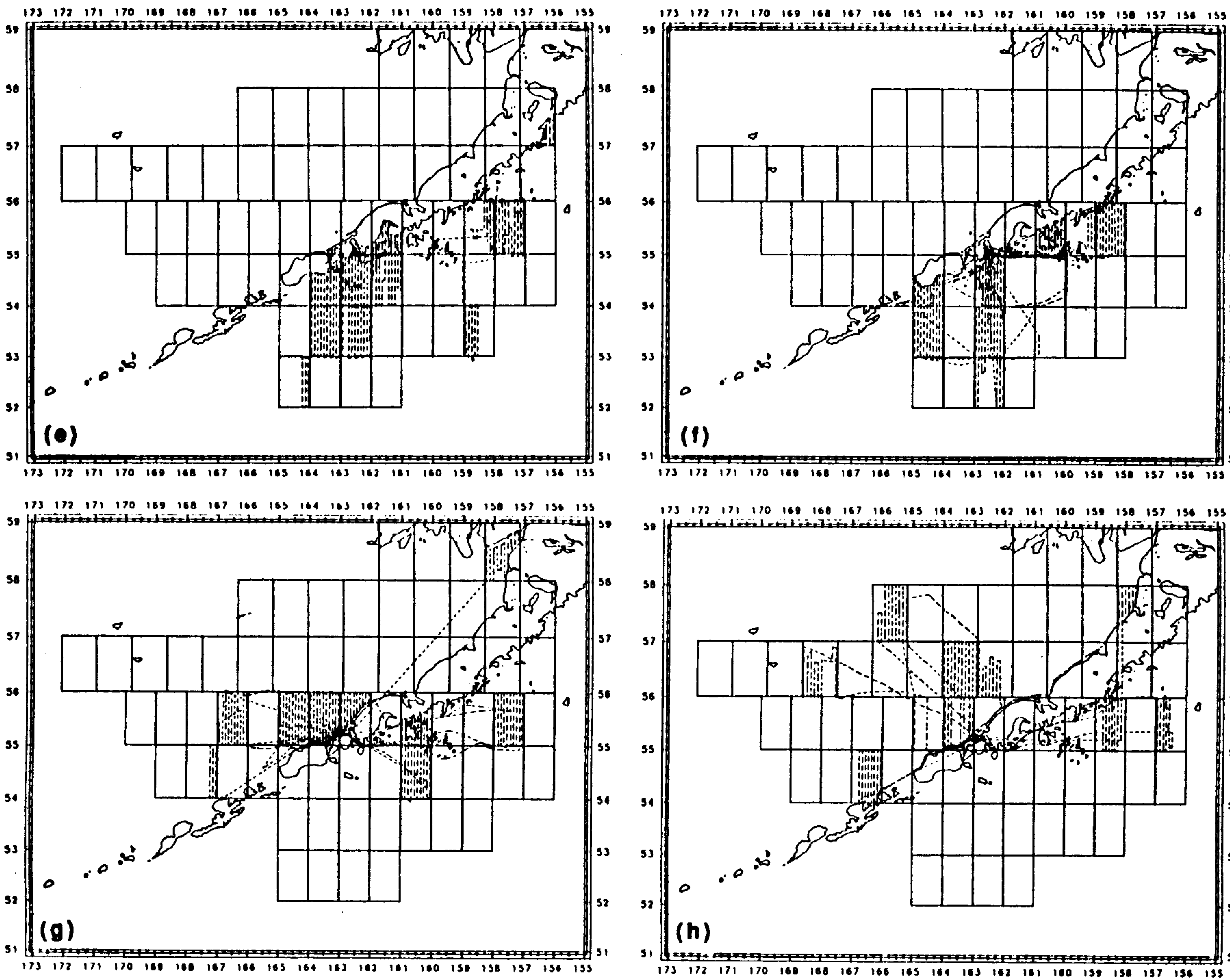

Figure 3 (continued).–Survey effort for April through December 1985 (e, August; f, October; g, November; h, December).

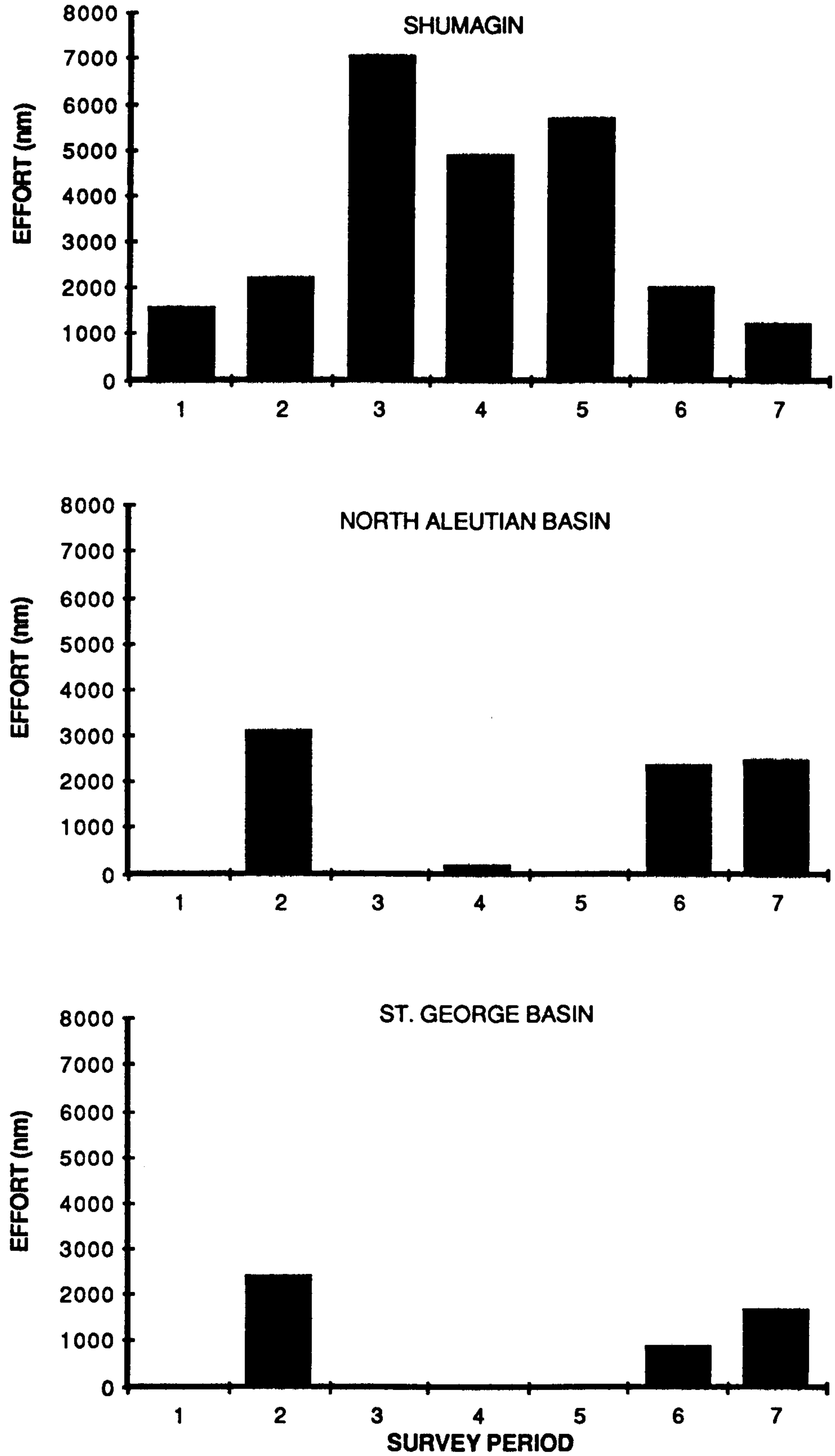

Figure 4.–Survey effort in the Shumagin, North Aleutian Basin, and St. George Basin planning areas, 1985.

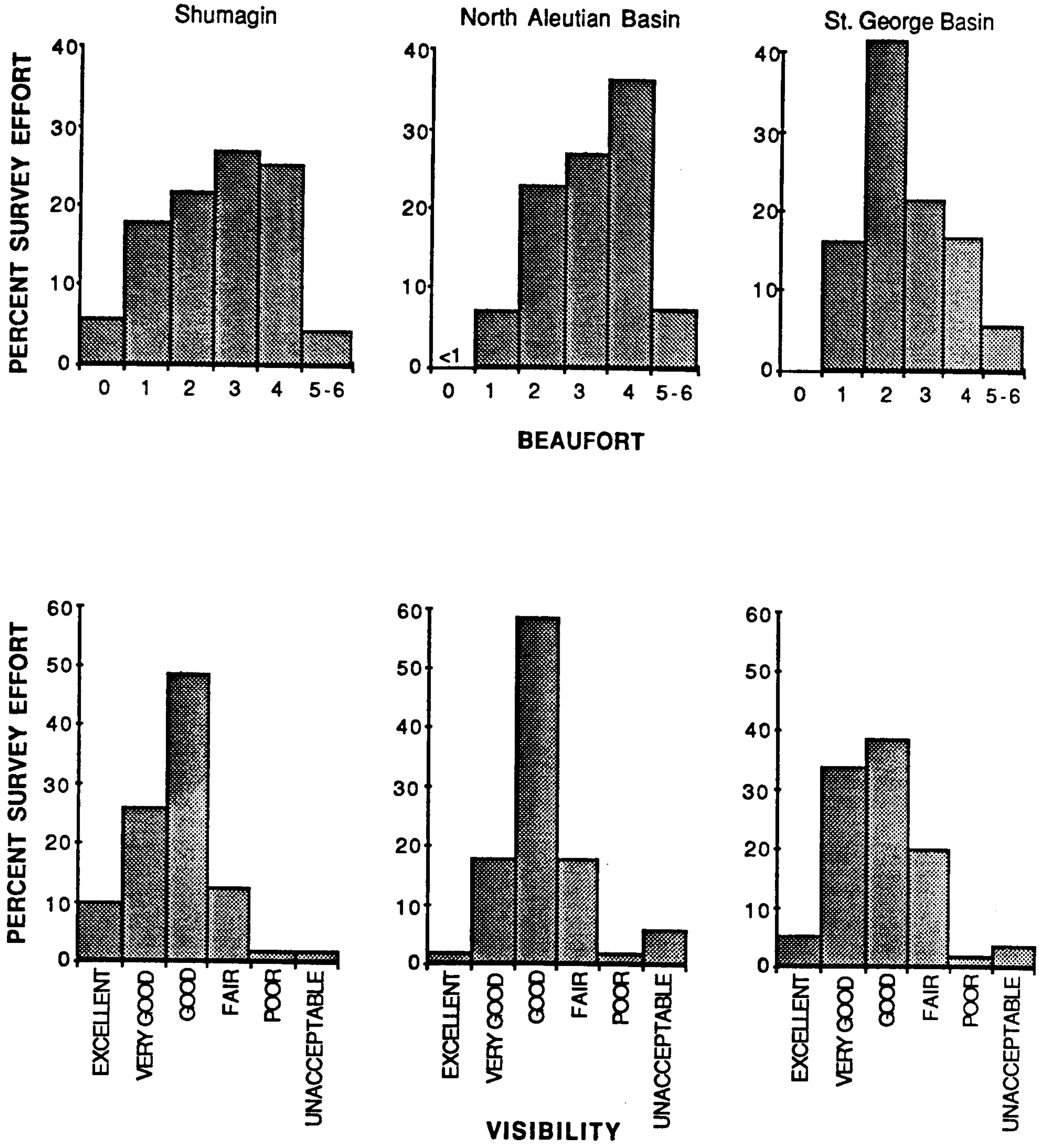

Figure 5.–Percentage of effort by Beaufort sea state and visibility in the Shumagin, North Aleutian Basin, and St. George Basin planning areas, 1985.

Table 3.—Survey conditions in the study area, April–December 1985.

Survey period[a]	Planning area[b]	Survey distance[c]	Visibility (percent)						Beaufort wind scale (percent)						
			UN	PO	FA	GO	VG	EX	0	1	2	3	4	5	6
1	Shumagin	1,576	0	0	19	18	21	42	17	25	21	11	9	17	0
2	Shumagin	2,205	1	1	7	53	36	2	3	28	27	29	13	0	0
	St. George	2,389	5	1	21	31	42	0	0	20	59	21	0	0	0
	North Aleutian	3,082	10	T[d]	19	52	18	1	0	12	25	34	26	3	0
	Subtotal	7,676	6	1	16	45	31	1	1	19	36	29	14	1	0
3	Shumagin	7,092	1	1	8	37	44	10	9	21	32	28	10	0	0
4	Shumagin	4,887	T	T	6	54	27	13	4	21	23	35	18	0	0
	North Aleutian	173	0	0	0	0	97	3	0	34	62	4	0	0	0
	Subtotal	5,060	T	T	6	53	29	13	4	22	24	34	17	0	0
5	Shumagin	5,860	1	1	24	48	18	9	1	13	15	23	35	12	1
6	Shumagin	2,201	0	T	12	84	5	0	0	T	4	14	79	3	0
	St. George	858	0	0	11	73	16	0	0	0	19	23	55	3	0
	North Aleutian	2,353	T	0	16	75	9	T	1	4	15	26	50	4	0
	Subtotal	5,412	T	T	14	78	8	T	T	2	11	20	63	3	0
7	Shumagin	1,238	T	1	9	74	16	T	0	T	18	48	33	1	0
	St. George	1,683	4	T	25	32	28	11	0	17	27	21	22	10	4
	North Aleutian	2,453	5	T	17	57	20	T	0	3	24	22	38	8	6
	Subtotal	5,374	4	1	17	53	21	4	0	6	24	27	32	7	4
Total	Shumagin	25,059	1	1	12	49	27	10	5	17	22	27	25	4	T
	St. George	4,930	4	1	20	38	33	4	0	16	41	21	17	4	1
	North Aleutian	8,061	6	T	17	59	17	1	T	7	23	27	36	5	2

[a] Survey period 1=April–May, 2=June–July, 3=July–August, 4=August, 5=October, 6=November, and 7=December.

[b] St. George Basin was surveyed during periods 2, 6, and 7. North Aleutian Basin was surveyed during periods 2, 4, 6, and 7.

[c] Distance (nmi) was calculated for only systematic and random surveys.

[d] T signifies <1 percent.

Gray Whale

The coastal habits of the eastern Pacific gray whale stock have made it the most studied mysticete. Gray whales were exploited to near extinction by commercial whalers in the mid-1800s and again in the 1900s (Reilly 1981). Since receiving protection in 1946, the stock has recovered to an estimated 17,000 animals (Rugh 1984), which is at or near the pre-exploitation level (Rice 1974; Rice and Wolman 1982). A limited number of gray whales are harvested annually by Soviet aboriginal whalers (IWC 1986).

The gray whale's annual cycle includes an 18,000 nmi migration between breeding lagoons along Baja California and feeding grounds in the Bering, Beaufort, and Chukchi seas. Nearly half of this annual cycle is spent in transit between the seasonal ranges (Mate and Harvey 1984). The migration route is coastal (Scammon 1874) even in Alaska, where shorter, open-water routes are available (Pike 1962; Rice and Wolman 1971; Braham 1984*b*). Braham (1984*b*) has provided a comprehensive account of the gray whale migration in Alaska from a series of projects conducted by the National Marine Mammal Laboratory since 1975. While these projects and others (Gill and Hall 1983) have documented the spring migration along the north side of the Alaska Peninsula, the migration along the south side of the peninsula and the fall migration on both sides are incompletely understood.

Not all gray whales return each year to traditional feeding grounds in the high latitudes. Small numbers summer in areas between the seasonal ranges (Pike 1962; Rice and Wolman 1971; Hatler and Darling 1974; Patten and Samaras 1977; Sprague *et al.* 1978; Sullivan *et al.* 1983; Darling 1984; Sumich 1984), which include the lagoons and bays along the north shore of the Alaska Peninsula (Gill and Hall 1983). The percentage of the total population that feeds in these peripheral areas, as well as the location of important feeding areas in Alaska waters, is not fully known.

Our study confirms and clarifies the movement patterns of gray whales along the Alaska Peninsula during the spring and fall migrations. Furthermore, it defines additional summer feeding areas and confirms that gray whales use the peninsula's nearshore waters during the summer months.

Results

Number and distribution

A total of 337 groups of 589 gray whales were observed during four surveys in 1985 (Table 4). Eighty-seven percent of the groups were observed during November and December when 28% of the survey effort was conducted. These periods coincided with the gray whale fall migration in Alaska (Braham 1984*b*; Rugh 1984). Twelve percent of the sightings occurred during an April-May survey which corresponded to the spring migration. Only 4% of the 1985 survey effort was conducted at this time. Less than 1% (two whales) were observed during the summer. Another 15 groups were observed during sea otter surveys we conducted in 1986. Because seven of these sightings occurred during periods when gray whales were not observed

Table 4.—Effort (nmi) and number of gray whales observed in the study area, 1985 and 1986.

Period	Shumagin			North Aleutian Basin			St. George Basin			Total		
	Effort	No.	Group	Effort	No.	Group	Effort	No.	Group	Effort	No.	Group
1985												
April–May	1,576	21 (100)	9 (30)	—[a]	—	—	—	—	—	1,576	21 (100)	9 (30)
June–July	2,205	0	0	3,082	2	2	2,389	0	0	7,676	2	2
July–August	7,092	0	0	—	—	—	—	—	—	7,092	0	0
August	4,887	0	0	173	—	—	—	—	—	5,060	0	0
October	5,860	0	0	—	—	—	—	—	—	5,860	0	0
November	2,201	1	1	2,353	39 (12)	21 (10)	858	0	0	5,412	40 (12)	22 (10)
December	1,238	53 (16)	23 (10)	2,453	293 (52)	198 (33)	1,683	0	0	5,374	346 (68)	221 (43)
Subtotal	25,059	75 (116)	33 (40)	8,061	334 (64)	221 (43)	4,930	0	0	38,050	409 (180)	254 (83)
1986[b]												
1–15 Mar.		4	1		1	1		—	—		5	2
28 June–12 July		1 (1)	1 (1)		4 (5)	4 (3)		0	0		5 (6)	5 (4)
18 Aug.–1 Sept.		0	0		2	2		—	—		2	2
2–16 Oct.		0	0		0	0		—	—		0	0
Subtotal		5 (1)	2 (1)		7 (5)	7 (3)		0	0		12 (6)	9 (4)
Total		80 (117)	35 (41)		341 (69)	228 (46)		0	0		421 (186)	263 (87)

[a] Dash (—) signifies area not surveyed.

[b] Effort not available for 1986.

in 1985 (July and August), they have been added to this report to supplement the distributional information. Approximately 78% of all the gray whales were observed north of the peninsula and 22% south of it. No gray whales were observed in the St. George Planning Area.

Spring distribution.–A total of 39 groups of 121 gray whales were observed during the April-May survey period. Surveys were conducted only in the Shumagin Planning Area, where 1,576 nmi were surveyed in a 7-day period. An additional two groups of five whales were incidentally recorded in March 1986 during sea otter surveys. One animal was observed along the north shore of Unimak Island on 11 March, the earliest recorded sighting of a gray whale in the Bering Sea (Braham 1984*b*). The other four gray whales were observed in the Shumagin Islands on 14 March. Both 1986 groups were traveling toward their usual summer feeding grounds in the Bering Sea.

During the spring survey, gray whales were observed from Seal Cape to Unimak Pass (Figure 6). Ninety-two percent were found near (within 4 nmi) the mainland or nearshore islands. These results confirm that most gray whales travel in the nearshore waters south of the Alaska Peninsula. The remaining two groups were sighted considerably away from the mainland, one in the southern Shumagin Islands and the other in deep water 110 nmi (200 km) south of Unimak Island.

Fall distribution.–A total of 296 groups of 466 gray whales were observed during the November and December survey periods. Both periods coincide with the fall migration through Unimak Pass which peaks in late November-early December (Rugh 1984). The earliest sighting was 13 November. A total of 10,756 nmi of survey effort was achieved over all three planning areas. However, 2,541 nmi of this effort was achieved in the St. George Basin Planning Area, where no gray whales were observed. Only occasionally have gray whales been observed in the St. George Basin (Braham 1984*b*), and these were closer to the Pribilof Islands.

The distribution of whales north of the peninsula was coastal (Figure 6), with 69% within 2 nmi (3.7 km) of shore and 95% within 5 nmi (8.3 km) (Figure 7). The distribution from shore was not consistent as gray whales traveled toward Unimak Pass (Figure 8). From Ugashik Bay to Izembek Lagoon only 13% of 74 groups were within 1 nmi (1.85 km) of shore. Between Izembek Lagoon and Cape Mordvinof the percentage within 1 nmi increased to 36% (of 94 groups) and between Cape Mordvinof and Cape Sarichef it jumped to 67% (of 24 groups). All of these sightings, except one, were within the 40-m depth contour. One group of five whales was observed 17 nmi (31 km) north of Unimak Island.

The distribution of whales south of the peninsula was coastal between Deer Island and Seal Cape (Figure 6), although some whales were 12 nmi (22 km) off the mainland as they traveled between large islands. This suggests that migrating gray whales had a strong coastal affinity for islands as well as the mainland. However, the gray whales tended to become less coastal and more pelagic as they approached Kodiak Island from the Shumagin Islands. East of Seal Cape, ten groups of gray whales were observed 60 nmi (110 km) offshore between Chowiet Island and Lighthouse Rocks, traveling toward Kodiak Island. A group of seven was

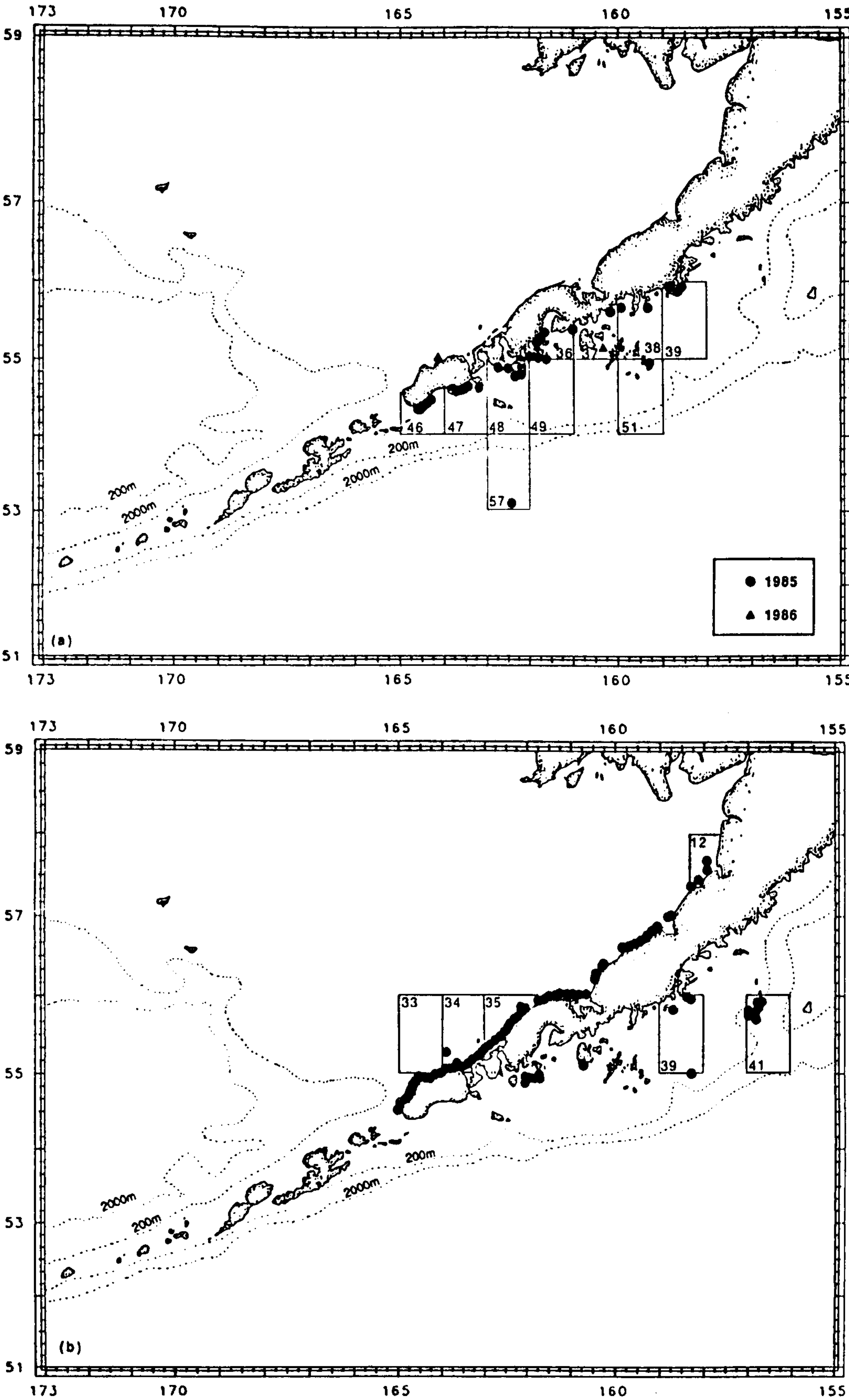

Figure 6.-Locations of gray whales observed in the study area in spring (a) and fall (b).

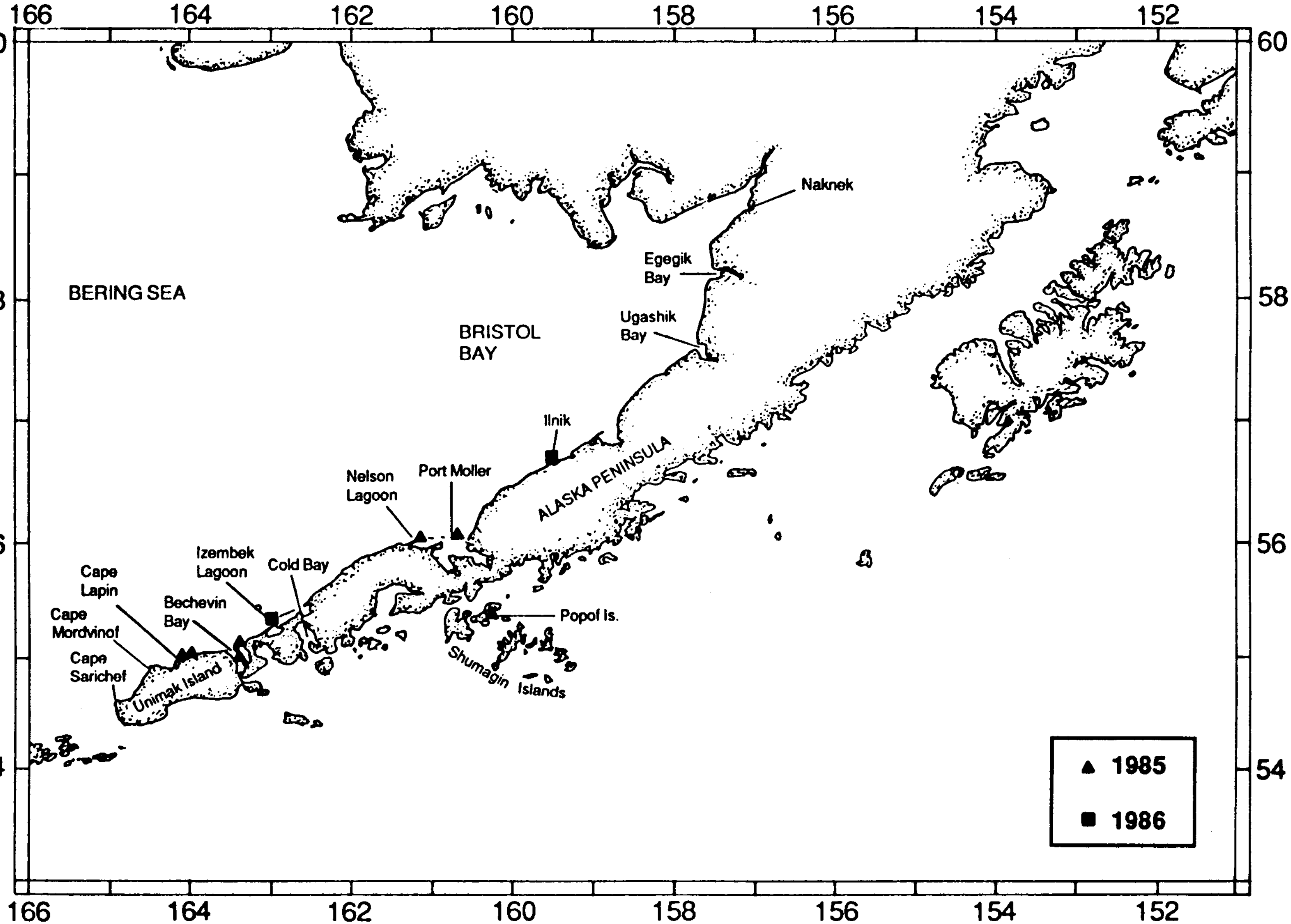

Figure 6. (continued)–Locations of gray whales observed in the study area during summer.

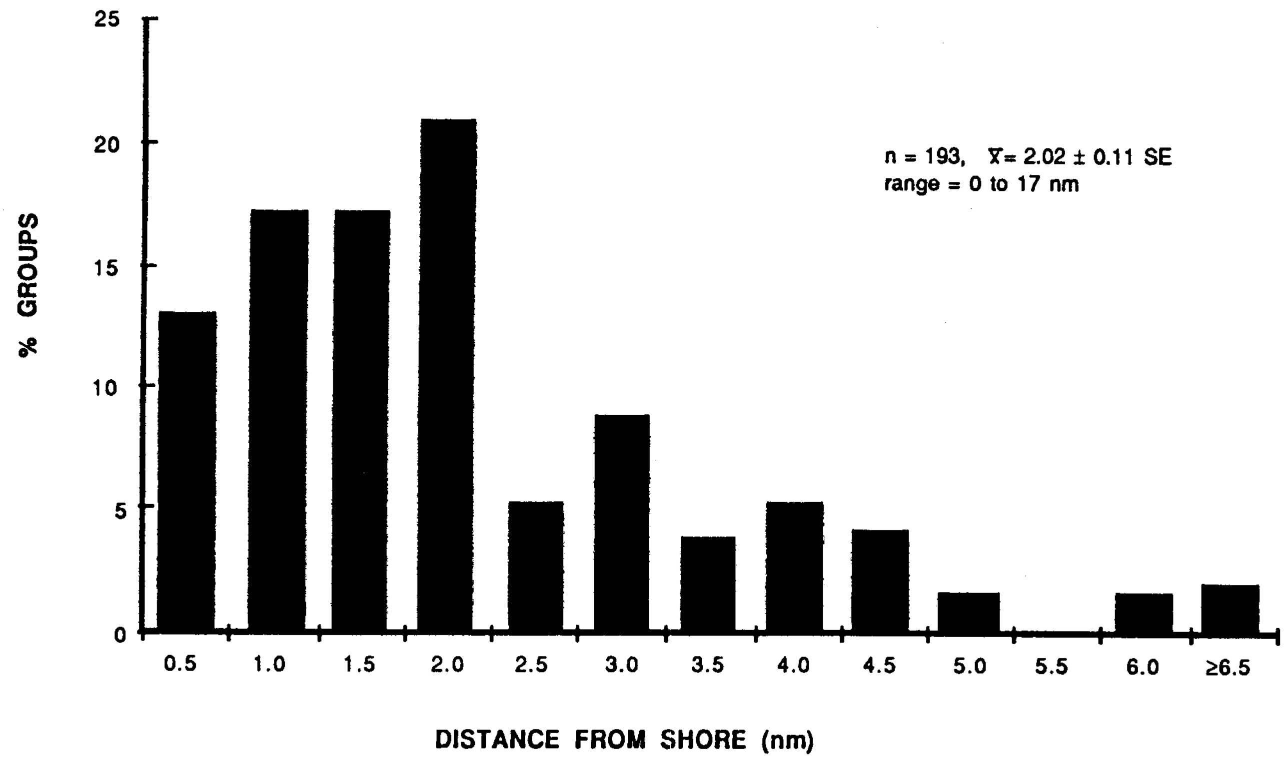

Figure 7.–Gray whale distance from shore along the north side of the Alaska Peninsula, fall 1985.

observed 60 nmi (110 km) south of Seal Cape traveling along the continental shelf edge, also toward Kodiak Island.

Summer Distribution.–Only two single gray whales were observed during the three summer survey periods in 1985 even though 17,439 nmi of effort were achieved in the Shumagin and North Aleutian planning areas during this period (Table 5, Figure 6). Surveys directed at sea otters in 1986 were more intense in the nearshore areas and yielded 11 groups of 13 whales. Eleven of the total thirteen groups observed in both years were found along the north shore of the Alaska Peninsula between Unimak Island and Ilnik. Ten of these groups were sighted in or near the confluence of estuaries (Figure 6). Gray whales were repeatedly observed in Bechevin Bay. In the Shumagin Planning Area a single whale was observed near Popof Island on 7 July 1986 and again on 9 July. No gray whales were observed in the St. George Basin Planning Area even though 2,389 nmi of trackline were flown.

Group size

Gray whale mean group sizes were significantly different ($p < 0.05$) between the spring and fall (Figure 9). Mean group sizes were greater during the spring (3.10 ± 0.46 SE) than during the fall (1.60 ± 0.06 SE). Small groups (1-2 animals) composed only 59% of the spring migrators compared to 84% for fall whales. These results do not concur with Herzing and

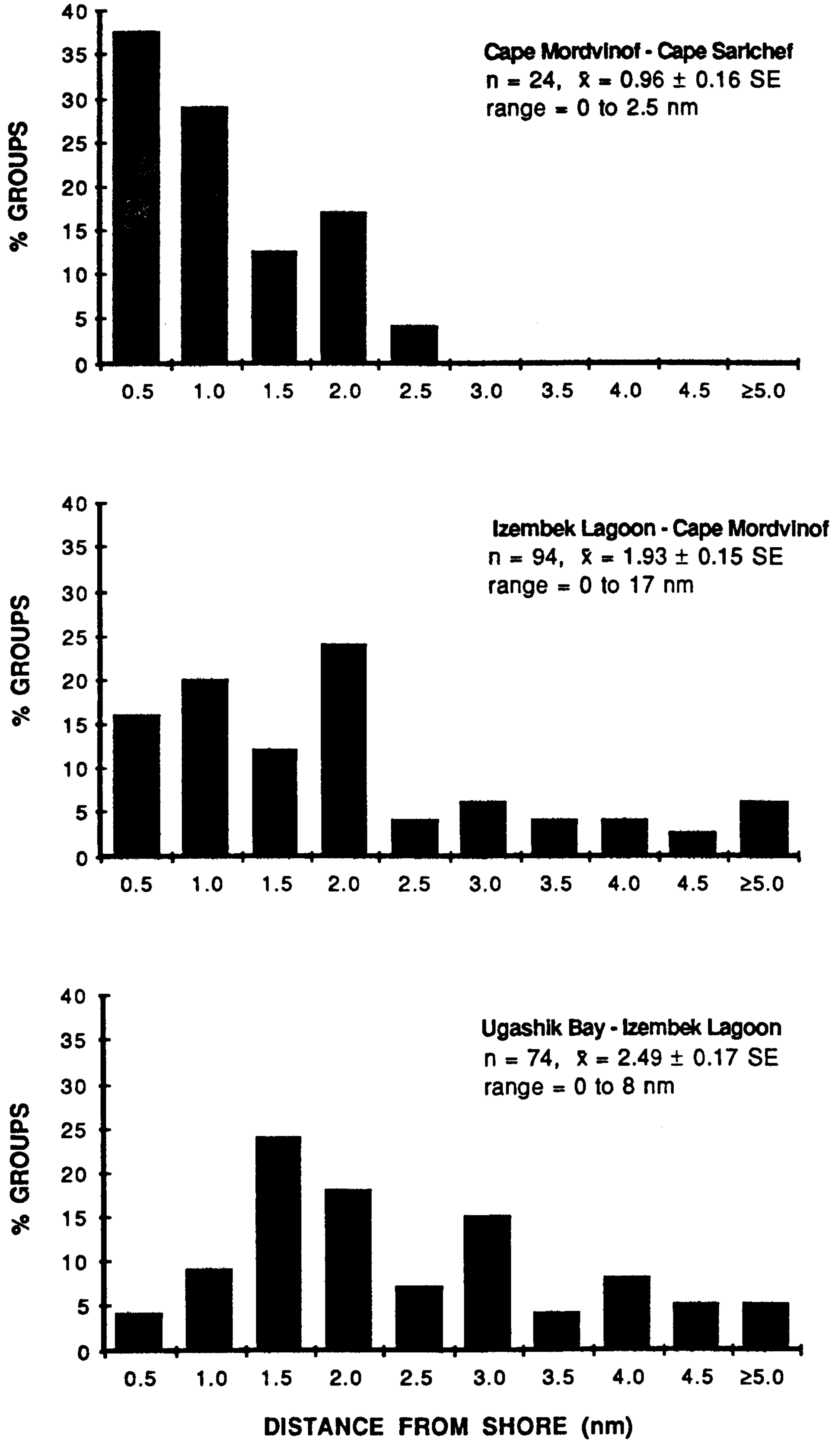

Figure 8.–Gray whale distribution from shore along segments off the north side of the Alaska Peninsula, fall 1985.

Table 5.–Summer gray whale sightings along the Alaska Peninsula during 1985 and 1986 aerial surveys.

Location	Date	Number	Groups
South side of Alaska Peninsula			
Popof Island	7 July 1986	1	1
Popof Island	9 July 1986	1	1
North side of Alaska Peninsula			
Unimak Island	29 June 1986	1	1
Unimak Island	21 August 1986	1	1
Bechevin Bay	29 June 1986	4	2
Bechevin Bay	21 August 1986	1	1
Izembek Lagoon	29 June 1985	1	1
Nelson Lagoon	8 July 1986	3	3
Port Moller	8 July 1986	1	1
Ilnik	6 July 1985	1	1
Total		15	13

Mate's (1984) findings from a 2-year study on the Oregon coast. In both years of their study, they found that small groups compose approximately 75% of the first-phase northward migrations and 50% of the southbound migrations. However, Herzing and Mate observed that significantly more small groups were recorded during the latter half of the first-phase northbound migration than during the earlier half. Furthermore, they, as well as Rice and Wolman (1971), noted that large groups during the southward migration were observed more frequently in the middle of the migration period. Therefore, discrepancies between our respective data may be a result of the timing of our surveys. All of the summer sightings were either singles or pairs, with an average group size of 1.15 (±0.10 SE) animals.

Orientation and behavior

There was a significant (Rayleigh's test) tendency for traveling whales to be oriented in a direction consistent with their migration route during both the spring and fall survey periods (Figure 10). Gray whales traveling along the south side of the Peninsula during the April-May survey period were oriented generally to the southwest, or toward Unimak Pass. Even the single whale observed far offshore, although traveling northwest, was directly oriented toward

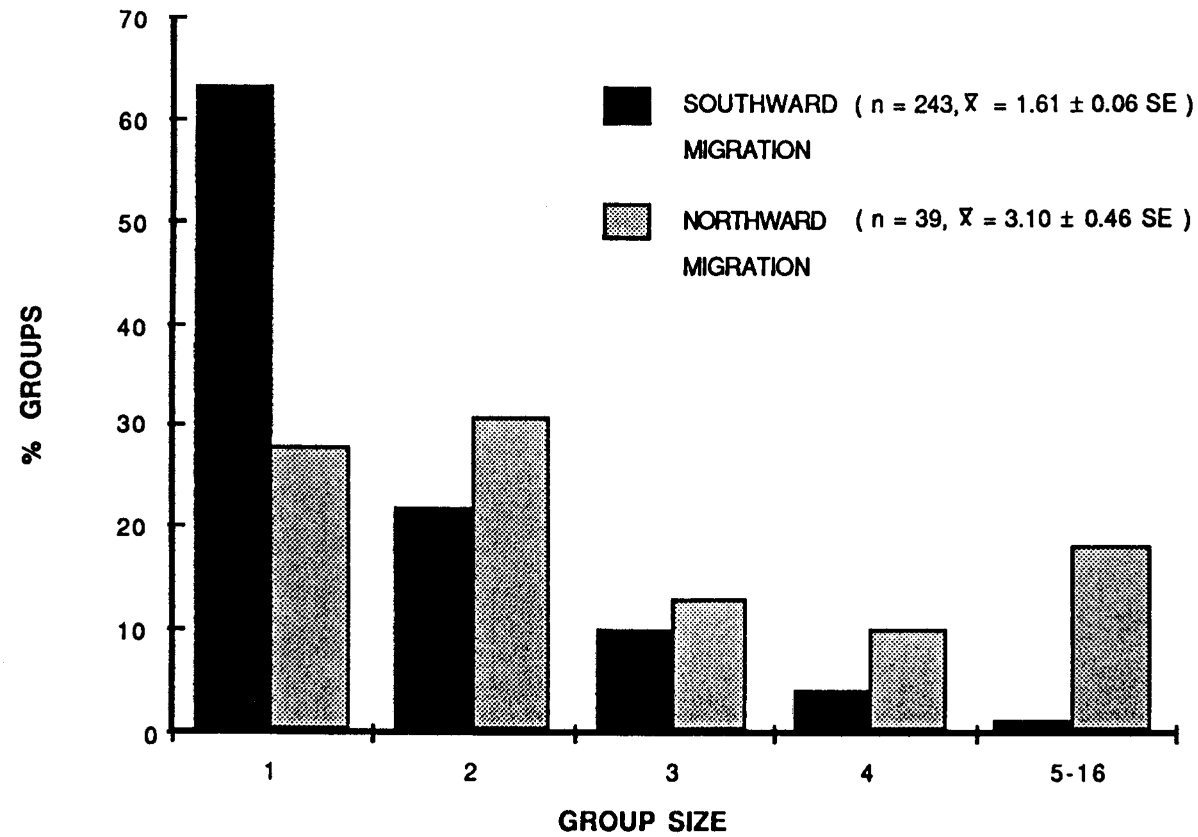

Figure 9.–Group sizes of gray whales migrating along the Alaska Peninsula, 1985.

Unimak Pass. Whales observed during the fall surveys were oriented west or southwest on the north side of the Alaska peninsula and generally northeast on the south side. There was not a significant directional tendency for whales observed during the summer, implying they were summer residents and not migrating.

Gray whale behavior observed during the spring and fall was consistent with migration activities: 81% of the spring whales and 97% of the fall whales were traveling (Figure 11). The remaining whales for each season were either milling or breaching; none were observed feeding. In contrast, 42% of the summer whales were observed feeding, as shown by trailing mud plumes, 8% were milling, and 50% were traveling. These behavioral observations, coupled with the time of year they were observed and a lack of directional tendency, support observations by Gill and Hall (1983) and Braham (1984*b*) that a small contingent of whales remain along the north shore of the Alaska Peninsula each summer rather than follow the main herd north. In addition, a few whales summer south of the peninsula.

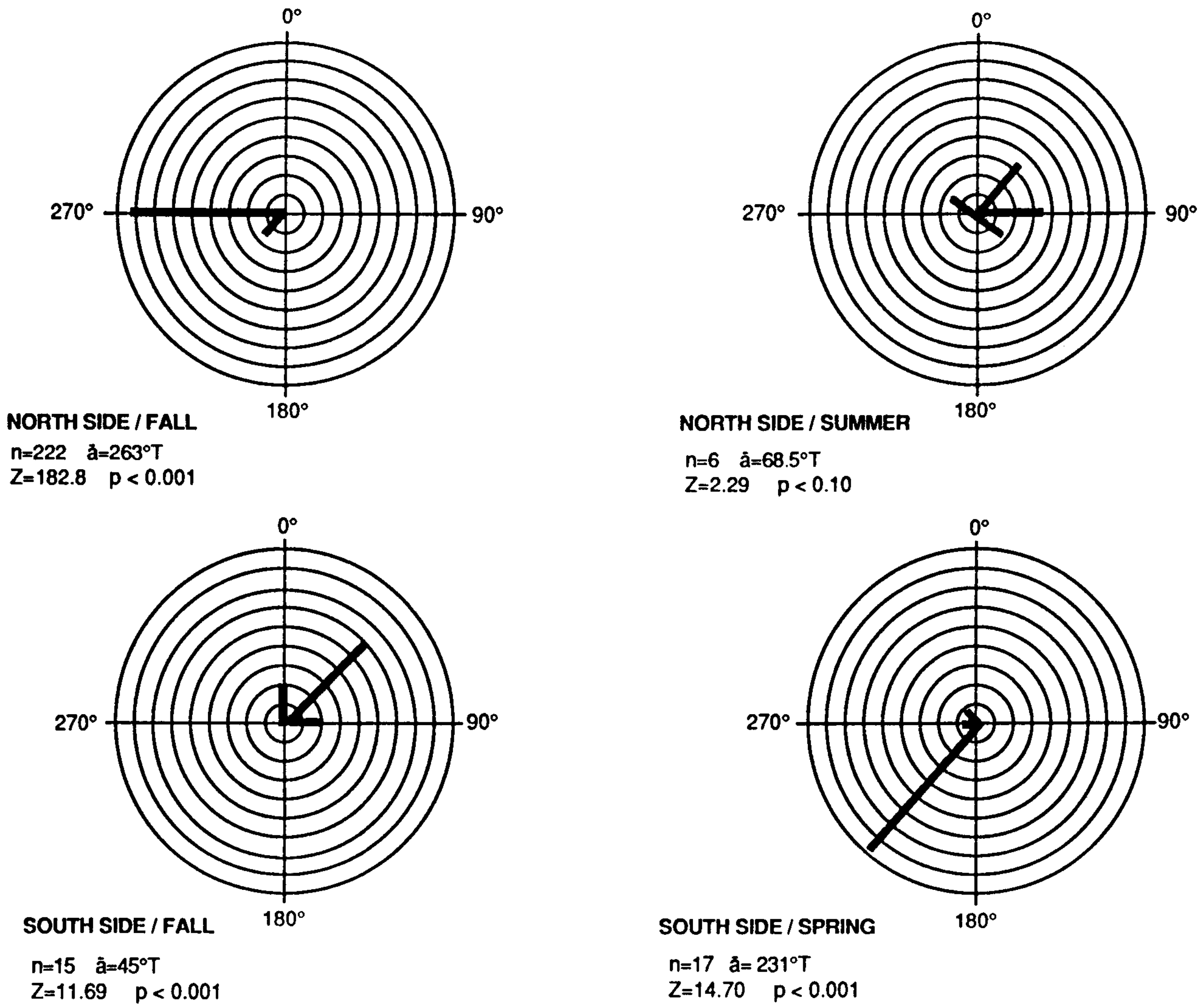

Figure 10.–Directional analysis of traveling gray whales, 1985 and 1986. Each concentric circle equals 10%.

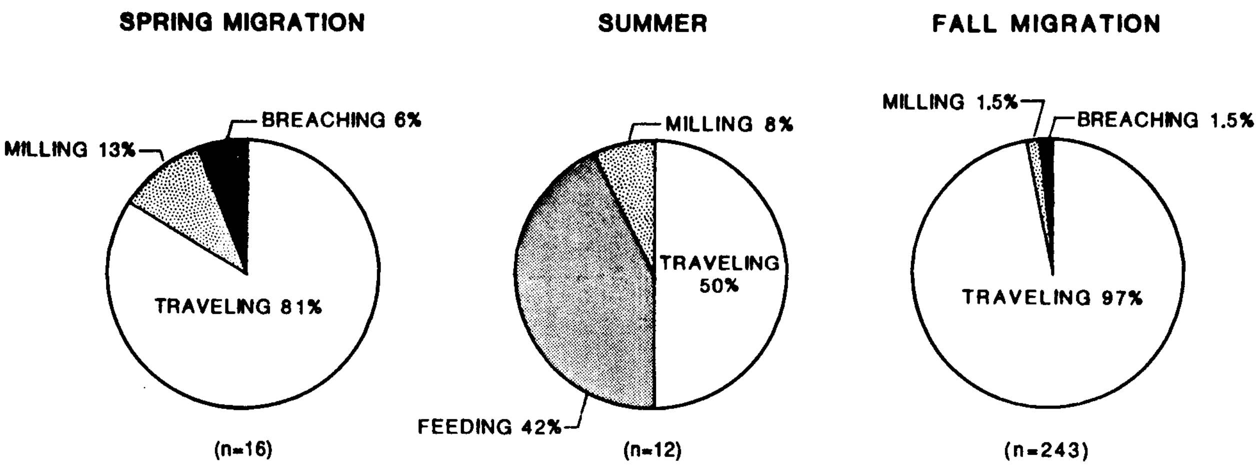

Figure 11.–Observed gray whale behavior in the study area, 1985 and 1986.

Discussion

Spring migration

Our spring surveys (28 April-4 May) occurred during a period previously identified as the peak of the northbound migration (late April-early May) but prior to the arrival of cow-calf pairs (Hessing 1981). Since no calves were observed during our surveys, our descriptions concern the first wave of the bimodal (Herzing and Mate 1984) spring migration.

The spring migration along the south side of the Alaska Peninsula is coastal, at least between Seal Cape and Unimak Pass. Ninety-two percent of the northbound groups were within 4 nmi (7.4 km) of the peninsula coast or nearshore islands. Some of the whales apparently traveled the outer perimeter of large nearshore islands such as Deer and Dolgoi, even though it increased their travel distance. A group observed in the southern Shumagin Islands and another in pelagic waters 110 nmi (200 km) south of Cold Bay confirm that not all whales journey close to the coast. No whales were observed in offshore waters northeast of the Shumagin Islands because we did not survey east of Seal Cape, where whales traveling between Kodiak Island and the peninsula might be expected (Braham 1984*b*; Leatherwood *et al.* 1983). Therefore, the precise spring route between either Kodiak Island (or Shelikof Strait) and the peninsula remains unknown, but may be similar to the following description of the fall route.

Fall migration

Our fall gray whale observations largely confirm speculations by Braham (1984*b*) that the southbound migration along the north side of the Alaska Peninsula occurs farther offshore than the spring northbound migration. We observed 87% of 192 southbound groups beyond 0.5 nmi (0.9 km) from shore and 32% beyond 2 nmi (3.7 km). In contrast, Braham (1984*b*) reports that only 6 of 511 (1%) northbound whales traveling the north side of the Alaska Peninsula were observed beyond 0.6 nmi (1 km) from shore. However, 95% of our observations were still within 5 nmi (9 km) of shore and therefore the fall migration must be considered coastal.

The difference in the distance gray whales travel from the shore between the spring and fall seasons, at least north of the Alaska Peninsula, may reflect differing migration patterns across Bristol Bay. In the spring, northbound whales cross Bristol Bay from Egegik River west to Cape Constantine via lower Kvichak Bay (Gill and Hall 1983; Braham 1984*b*). Braham (1984*b*) suggests that the whales cross here to avoid shallow water and the extreme tidal fluctuations near the Naknek, Kvichak, and Nushagak rivers. Our 1985 fall surveys suggest that the route across Bristol Bay taken by southbound whales occurs farther southwest, because of the lack of whales sighted between Ugashik Bay and Kvichak Bay and because whales observed near Ugashik were among the furthest offshore. The reason for the difference may be that the Kvichak River and its tributaries discharge nearly twice as much sediment in fall as in spring (Bigelow *et al.* 1985) and thus create unfavorable conditions for migrating whales.

The whales moved closer inshore as they traveled down the peninsula. They closely followed the 0- to 40-m contour interval, even when it narrowed dramatically along Unimak

Island. Only 1 of 262 groups occurred outside of this band. Rugh (1984) also observed this shoreward trend on a November 1978 survey along the north side of Unimak Island. Rugh reported that only 5% of the whales he observed northeast of Cape Mordvinof were within 0.8 nmi (1.4 km) of the shore but 82% of the whales between Cape Mordvinof and Cape Sarichef were within this distance. Consequently, the coastal affinity of gray whales may be more a preference for shallow (<40 m) water than for simply being near land. This is perhaps most evident in the migration route between northern feeding grounds and northern Bristol Bay, where both the 0- to 40-m contour interval and the distribution of migrating whales is widest (Braham 1984*b*).

Previous researchers have reported that the fall migration along the south side of Unimak Island was highly coastal (<2 nmi) (Rugh 1984). Our data suggest that once east of Unimak Island, whales move as far as 12 nmi (22 km) offshore as they pass through the Sandman Reefs and the Pavlov and Shumagin islands. East of the Shumagin Islands, whales were observed along the coast as far as Seal Cape and then were found offshore 60 nmi to the east near Lighthouse Rocks and Chowiet Island. These whales (10 groups) were traveling both toward Chirikof Island and the Trinity Islands. By "island-hopping" between Seal Cape and Kodiak Island, these whales would be able to maximize their travel in shallower waters. Alternately, a few whales may follow the Shumagin Islands out to the shelf edge and then travel the edge to Kodiak Island, as shown by a sighting near the edge. Apparently, it is not unusual for some gray whales to travel alternate routes. Darling (1984) observed gray whales migrating along the east side of Vancouver Island when most travel the west. Thus, based upon our results and others (Forsell and Gould 1981; Rugh 1984), we propose in Figure 12 a route for the fall migration of gray whales along the Alaska Peninsula.

No gray whales were observed in the St. George Basin Planning Area between Unimak Pass and the Pribilof Islands (Figure 6), even though a substantial survey effort was accomplished between the two areas during November and December. Thus, we cannot substantiate a fall migration from the Pribilof Islands to Unimak Pass even though gray whales have been observed near the Pribilof Islands in the past (Braham 1984*b*).

Summer

Previous researchers have noted that most gray whales observed feeding during migration were located near the mouths of rivers or estuaries (Nerini 1984) where, presumably, organically richer substrates exist. Ten of eleven whale groups observed during the summers of 1985 and 1986 along the north shore of the Alaska Peninsula were either within or near the confluence of an estuary. We observed gray whales on the north shore of Unimak Island, within Bechevin Bay, and near the confluences of Izembek Lagoon, Nelson Lagoon, Port Moller, and Ilnik. Gill and Hall (1983) described the importance of Nelson Lagoon to summering whales and observed gray whales at all major estuaries from Nelson Lagoon to Egegik, including Port Moller and Ilnik. Braham (1984*b*) reported summer sightings from Izembek Lagoon to Egegik and Leatherwood *et al.* (1983) recorded three sightings of gray whales apparently feeding near Nelson Lagoon on 24 September 1982. We found no previous reports of gray whales using the north shore of Unimak Island or Bechevin Bay during summer. Our results confirm that

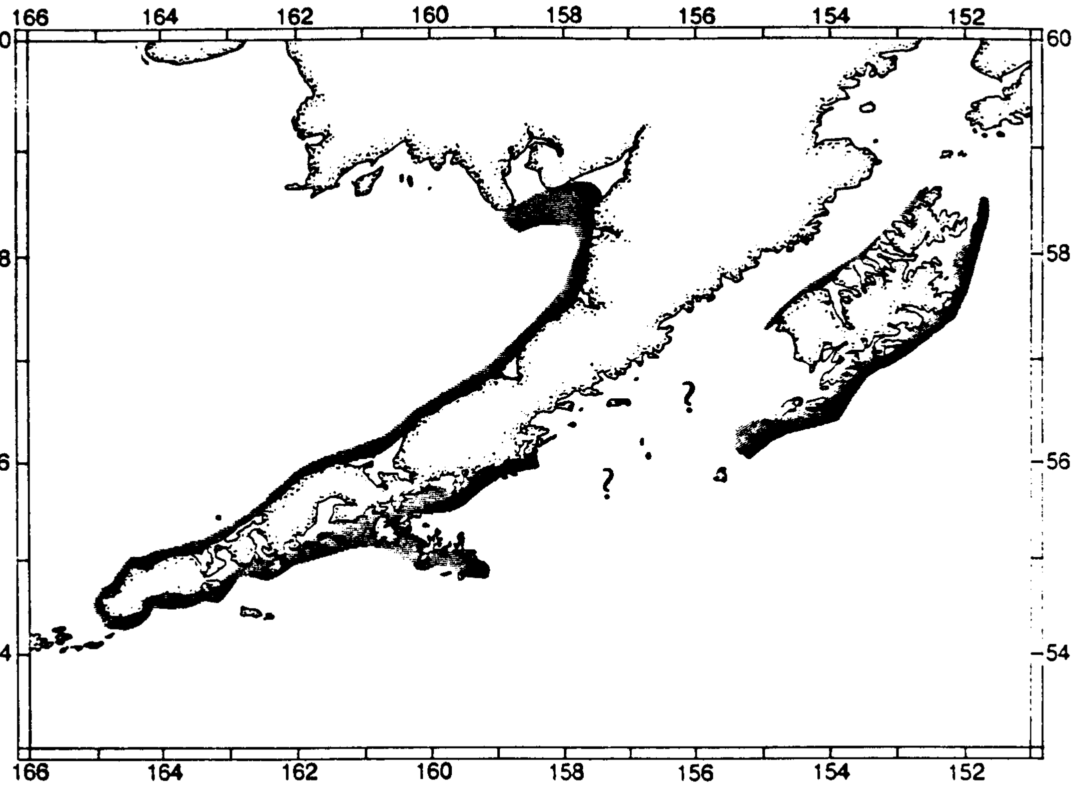

Figure 12a.–Proposed spring migration route of gray whales along the Alaska Peninsula based upon data from Braham (1984), Leatherwood *et al.* (1983), and this study.

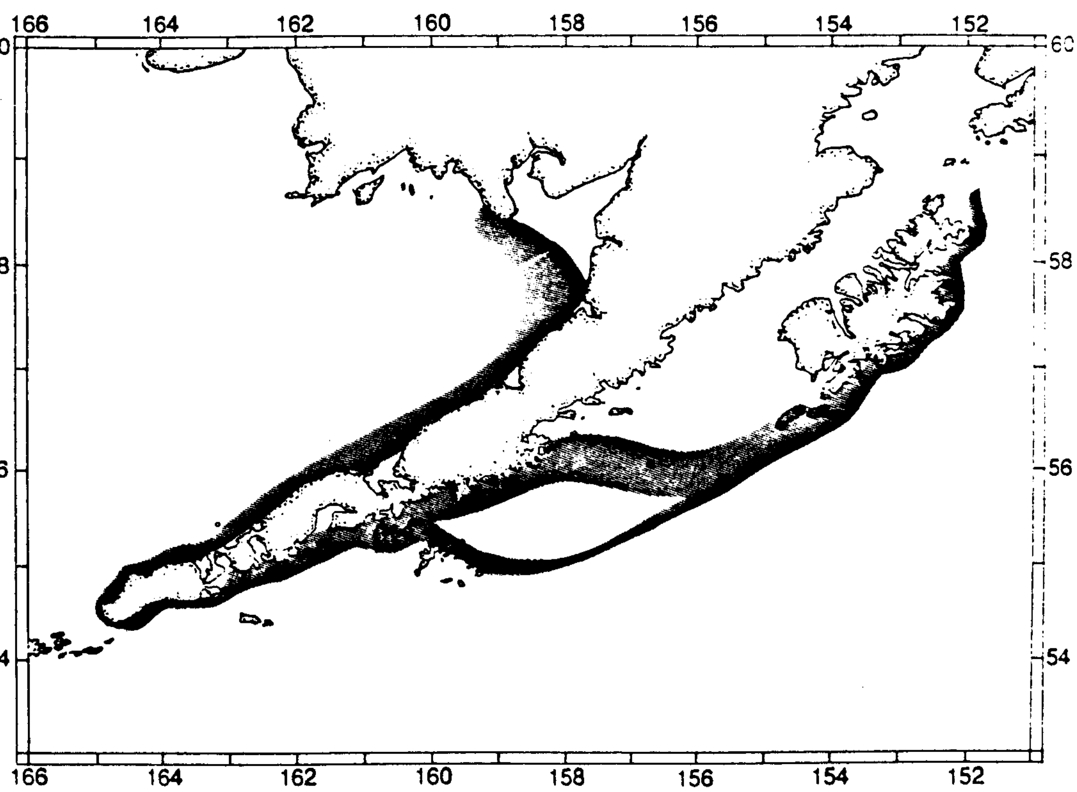

Figure 12b.–Proposed fall migration route of gray whales along the Alaska Peninsula based upon data from Forsell and Gould (1981), Rugh (1984), and this study.

almost every estuary on the north side of the Alaska Peninsula is important to summering gray whales.

There are few summer sightings from the south side of the Alaska Peninsula. The substrate on the shelf is largely rocky reef. Also, the bays are rather deep and do not contain extensive shallow beds like the north side. The only reliable summer gray whale record we could find is a Platforms of Opportunity Program sighting of a group of two whales observed just south of Chowiet Island on 31 August 1984. Our sightings at Popof Island combined with this sighting indicate a few gray whales summer south of the peninsula.

Humpback Whale

The North Pacific humpback whale population was heavily exploited by commercial whalers until it received protection beginning in 1966 (Rice 1978*a*). The animal's slow swimming speed and coastal affinity made the humpback whale particularly vulnerable to exploitation by shore stations off Baja California, central California, British Columbia, and Alaska (Tonnessen and Johnsen 1982). Between 1912 and 1939, 3,083 humpback whales were harvested in Alaska by the Akutan and Port Hobron whaling stations (Reeves *et al.* 1985). Similarly high catches were reported for the other shore stations. By the early 1960s, the only area remaining in the North Pacific where large numbers of humpbacks congregated in the summer was near the eastern Aleutians and south of the Alaska Peninsula between 150° and 170°W longitude (Berzin and Rovnin 1966). Japanese and Soviet pelagic whaling operations killed over 4,000 humpbacks in these areas between 1962 and 1965 (Rice 1978*a*). Present population estimates of the remaining North Pacific stock vary from 1,200 to over 2,100 whales (Darling 1983) for a species originally estimated to number 15,000 animals (Rice and Wolman 1982).

The North Pacific humpback whale population consists of three breeding stocks that summer in Alaska waters (Herman and Antinoja 1977) (Figure 13). The eastern stock migrates off the coasts of Canada and the United States from its breeding grounds in the bays and near the islands of Baja California and mainland Mexico. Animals from this stock summer in Alaska waters and off of California in the Farallon Islands. The central stock migrates from its breeding grounds in Hawaii to Alaska. Some interchange between Hawaiian and Mexican winter grounds has been revealed by recent photo identification studies (Darling and McSweeney 1985) and this suggests that the eastern and central stock may be one stock. The western or Asian stock is believed to migrate from breeding grounds near the Ryukyu, Bonin, and Mariana islands, south of Japan, to northern feeding areas in the Sea of Okhtosk, Kamchatka Peninsula, Aleutian Islands, and Bering Sea (Kellogg 1929; Tomilin 1957; Berzin and Rovnin 1966).

Tagging and photo identification studies suggest that the summer feeding areas of these stocks may overlap in the waters surrounding the Alaska Peninsula and eastern Aleutian Islands. Eight whales tagged with discovery markers in waters off Japan were recovered in the eastern Aleutian Islands and near the Alaska Peninsula (Ivashin and Rovnin 1967; Ohsumi and Masaki 1975). Fluke pictures of whales wintering in Hawaii have been matched with whales

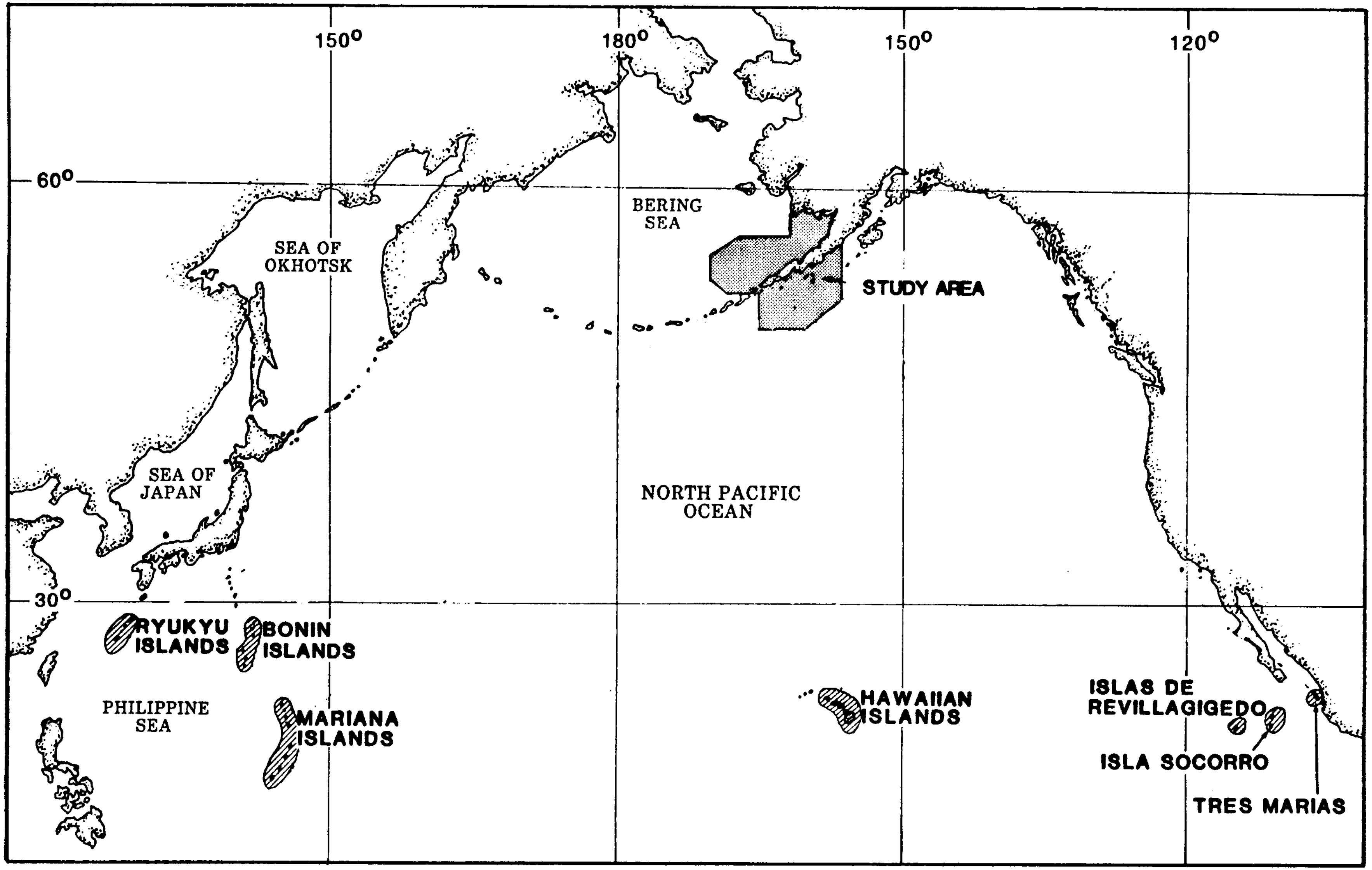

Figure 13.–Known winter breeding grounds of humpback whales and their relation to the study area.

summering in southeast Alaska, Prince William Sound, and the western Gulf of Alaska near Kodiak Island (Baker *et al.* 1986). In addition, whales wintering in Mexico have been matched with whales summering in southeast Alaska and Prince William Sound (Baker *et al.* 1986). While the information suggests the potential unique ecological importance of the waters bordering the Alaska Peninsula, confirmation of these associations has not been achieved because little effort has been directed at determining humpback whale use of these areas.

Rice and Wolman (1982) conducted 3,403 nmi of vessel survey east of the study area in the Gulf of Alaska between Cape Fairweather (138°W) and Chirikof Island (156°W), and reported observations of 191 humpback whales. Leatherwood *et al.* (1983) conducted 28,743 nmi of aerial survey in Shelikof Strait, and the St. George Basin and North Aleutian Basin planning areas and reported 15 humpback sightings. Incidental sightings have been irregularly reported by other investigators (POP), but because there have been few sightings, no comprehensive information exists on humpback whale occurrences in the the Shumagin, St. George Basin, and North Aleutian Basin planning areas since the cessation of humpback whaling in 1966.

In this section, we document information on the abundance, distribution and habitat use patterns of humpback whales in these areas. This information will serve as a basis for future studies to determine interactions between different breeding stocks and to monitor the impacts of petroleum activities.

Results

Number and distribution

During the seven survey periods between April and December 1985, 98 groups representing 185 humpback whales were observed in the Shumagin Planning Area (Table 6). Humpbacks were not observed in the other two planning areas. Humpbacks were encountered during every survey period except April and December. Almost 90% of the whales were observed during the three June through August surveys, when approximately 57% of the total effort was accomplished. Fewer than 15 animals were observed in October or November. Humpbacks are reported to inhabit Alaska waters from approximately May to November, with peak numbers in June through August (Baker *et al.* 1985; Stewart *et al.* 1987). A small proportion of whales appears to overwinter in Alaska waters (Baker *et al.* 1985).

Humpback whales were widely distributed in the Shumagin Planning Area between 157° and 164°W (Figure 14). Chi-square analysis indicated that the whales were not uniformly distributed across the longitudes ($p < 0.05$) (Table 7). Approximately 67% of the groups were observed between 157° and 160°W, where 35% of the effort was achieved (Figure 15). Particularly large numbers ($p < 0.10$) of humpbacks were encountered between 158° and 160°W. Whales were encountered in this area during four of five June-to-November survey periods. Humpbacks were not observed in the extreme eastern or western portion of the Shumagin Area.

Humpbacks were encountered in all three water depth zones (Table 6). Approximately 67% were observed in the shallow zone, 1% in the transition zone, and 30% in the deep water

Table 6.—Survey effort (nmi) and number of humpback whales observed in the Shumagin planning area, April–December 1985.

Survey period	Shallow zone[a]			Transition zone[a]			Deep zone[a]			Total		
	Effort	Number	Group	Effort	Number	Group	Effort	Number	Group	Effort	Number	Group
April–May	773	0	0	186	0	0	617	0	0	1,576	0	0
June–July	1,316	46(19)	18(10)	292	1	1	597	0	0	2,205	47(19)	19(10)
July–August	4,621	18 (2)	12 (1)	582	0	0	1,889	0	0	7,092	18 (2)	12 (1)
August	3,132	20 (6)	16 (2)	416	0	0	1,339	28(22)	13 (7)	4,887	48(28)	29 (9)
October	3,977	0	0	431	0	0	1,452	9	9	5,860	9	9
November	1,991	7 (7)	6 (3)	153	0	0	57	0	0	2,201	7 (7)	6 (3)
December	1,105	0	0	133	0	0	0	0	0	1,238	0	0
Total	16,915	91(34)	52(16)	2,193	1	1	5,951	37(22)	13(7)	25,059	129(56)	75(23)

[a] Zones were defined as <200 m for shallow, 200–2,000 m for transition, and >2,000 m for deep. Numbers in parentheses equal additional individuals and groups counted on deadhead surveys.

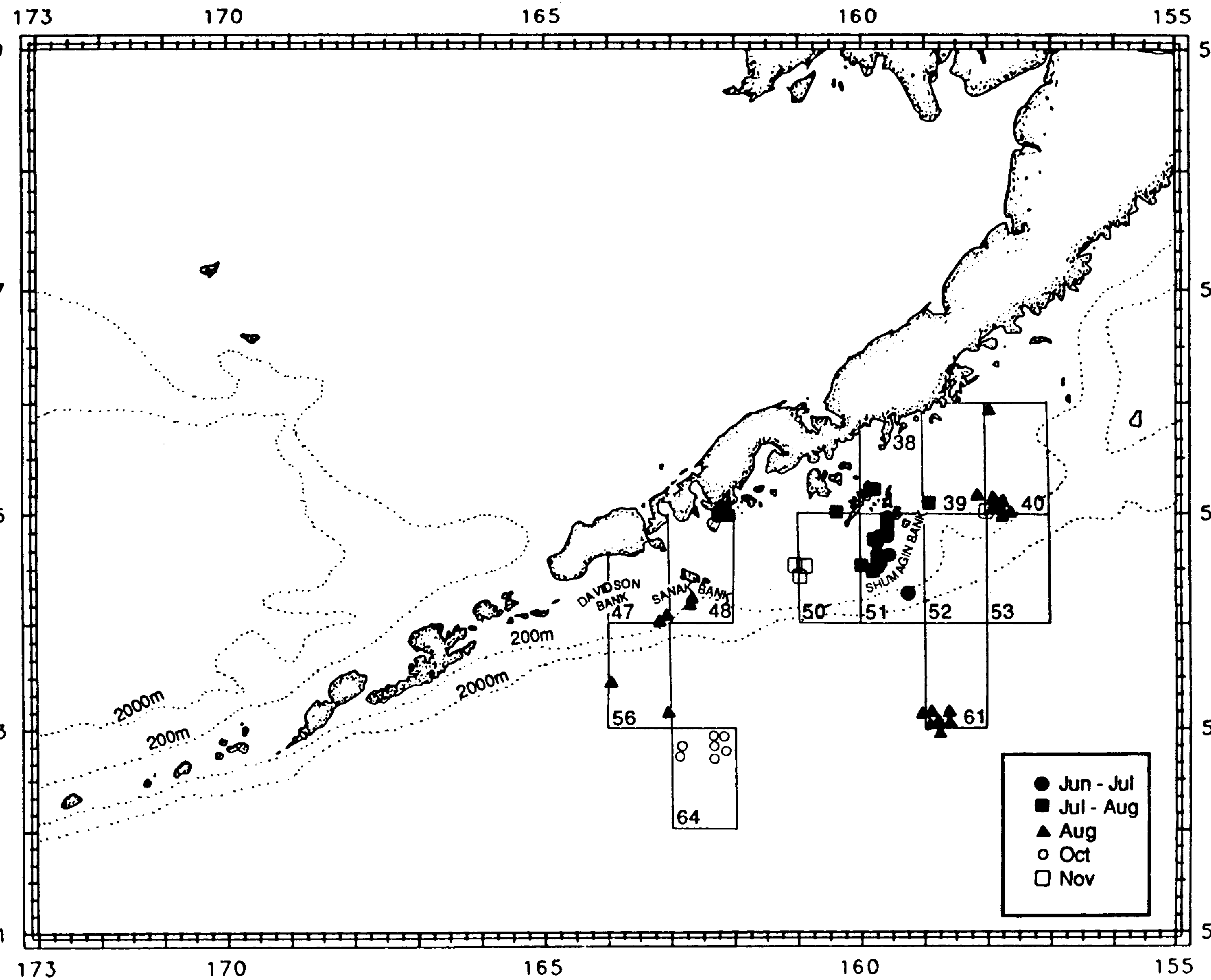

Figure 14.-Locations of humpback whales observed in the Shumagin Planning Area, 1985.

Table 7.–Relative occurrence of humpback whales by longitude degree in the Shumagin Planning Area.

Longitude	Percentage effort	Percentage occurrence	Preference[a]
164°–165°(W)	10.5	0.0	–
163°–164°	9.5	4.1	–
162°–163°	18.4	19.4	0
161°–162°	16.5	1.0	–
160°–161°	10.5	8.2	0
159°–160°	10.3	35.7	+
158°–159°	13.6	20.4	+
157°–158°	8.9	11.2	0
156°–157°	1.7	0.0	0
Total	99.9	100.0	
Total effort and number of groups	23,431 nmi[b]	98	

[a] – indicates significant avoidance, + indicates significant preference, and 0 indicates no selection ($p < 0.10$).

[b] Effort included distances surveyed during Beaufort 0-4 and fair to excellent visibility conditions.

zone. Effort was highest in the shallow zone, lowest in the transition zone, and intermediate in the deep zone. Whales were observed in the shallow zone during four of the five June-to-November survey periods (Figure 16). They were much less frequently encountered in the other two zones except during August and October. Chi-square analysis indicated that use of the three zones by the whales was significantly different ($p < 0.05$; $x^2 = 32.74$) among the surveys (Table 8). Whale observations were higher than expected in the combined shallow-transition zones during the early to mid-summer periods, and higher than expected in the deep water zone during the late summer and early to mid-fall periods.

Group size

Group size averaged 1.72 (±0.14 SE) animals for the five survey periods (Figure 17). Approximately 96% of the groups included between one and three animals, but single animals were most common (63%). The largest group size included eight animals and was recorded during the June-July survey. Average group size among the survey periods was significantly different ($p < 0.05$), and it ranged between 1.00 and 2.47 animals. Tukey's multiple range test identified that the June-July average group size differed significantly ($p < 0.05$) from all other periods. Approximately 36% of the groups for this survey were singles, 11% pairs, 42% triads,

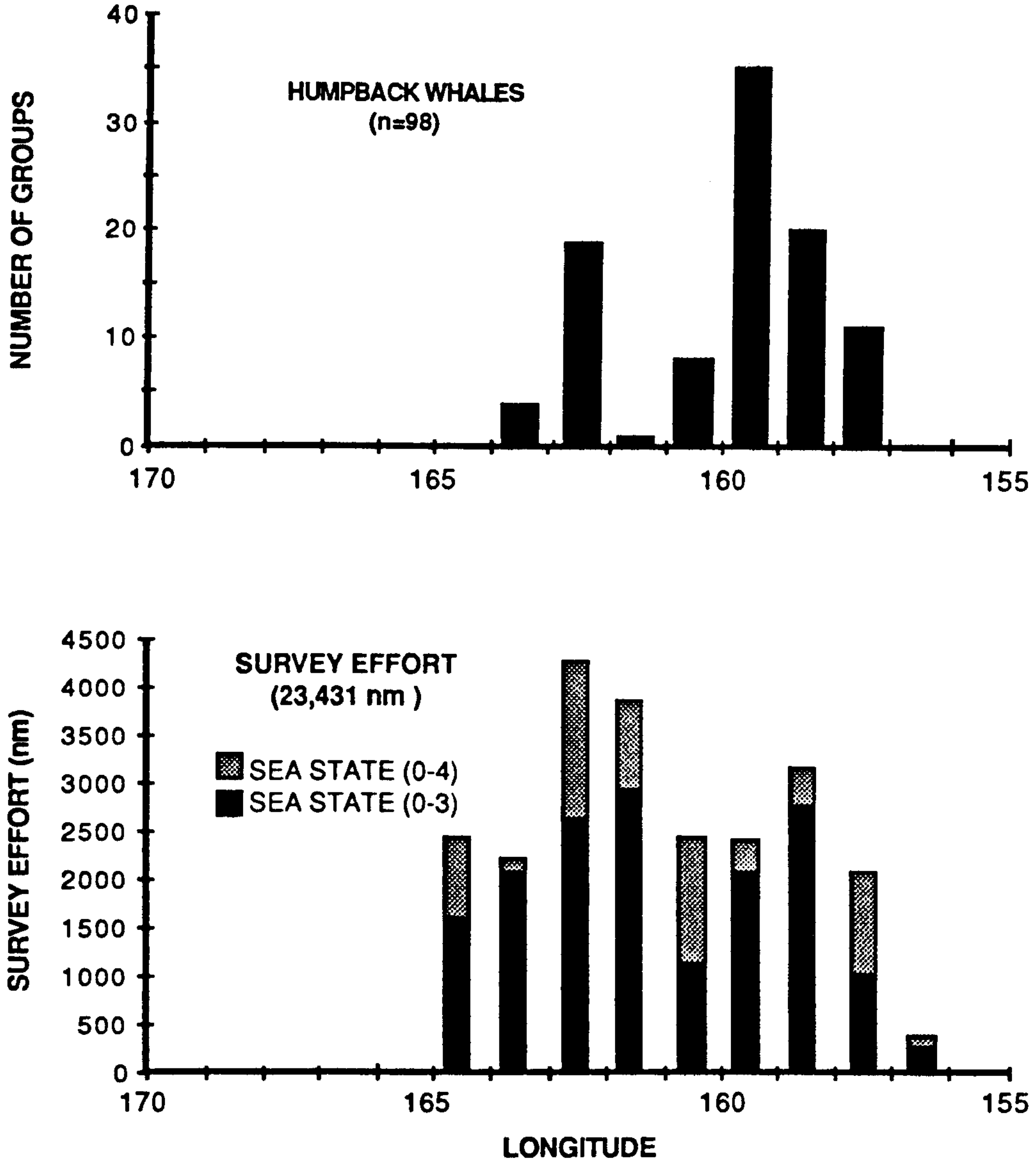

Figure 15.–Survey effort and number of humpback whales observed by longitude degree.

and the remainder were in groups of between four and eight animals. On the other hand, single animals were most common (>62%) in each of the other periods. While group sizes were usually small, 64% of the groups were in clusters ranging from 2 to 20 groups in a 3- to 4-nmi radius.

Orientation and behavior

The lack of a major movement pattern suggests that the majority of humpbacks observed in the Shumagin area were summering there. There was no consistent directional orientation ($p < 0.05$) in 53 humpbacks evaluated in the Shumagin area (Figure 18). This was found for humpbacks in each of the survey periods, except for humpbacks encountered in the deep water

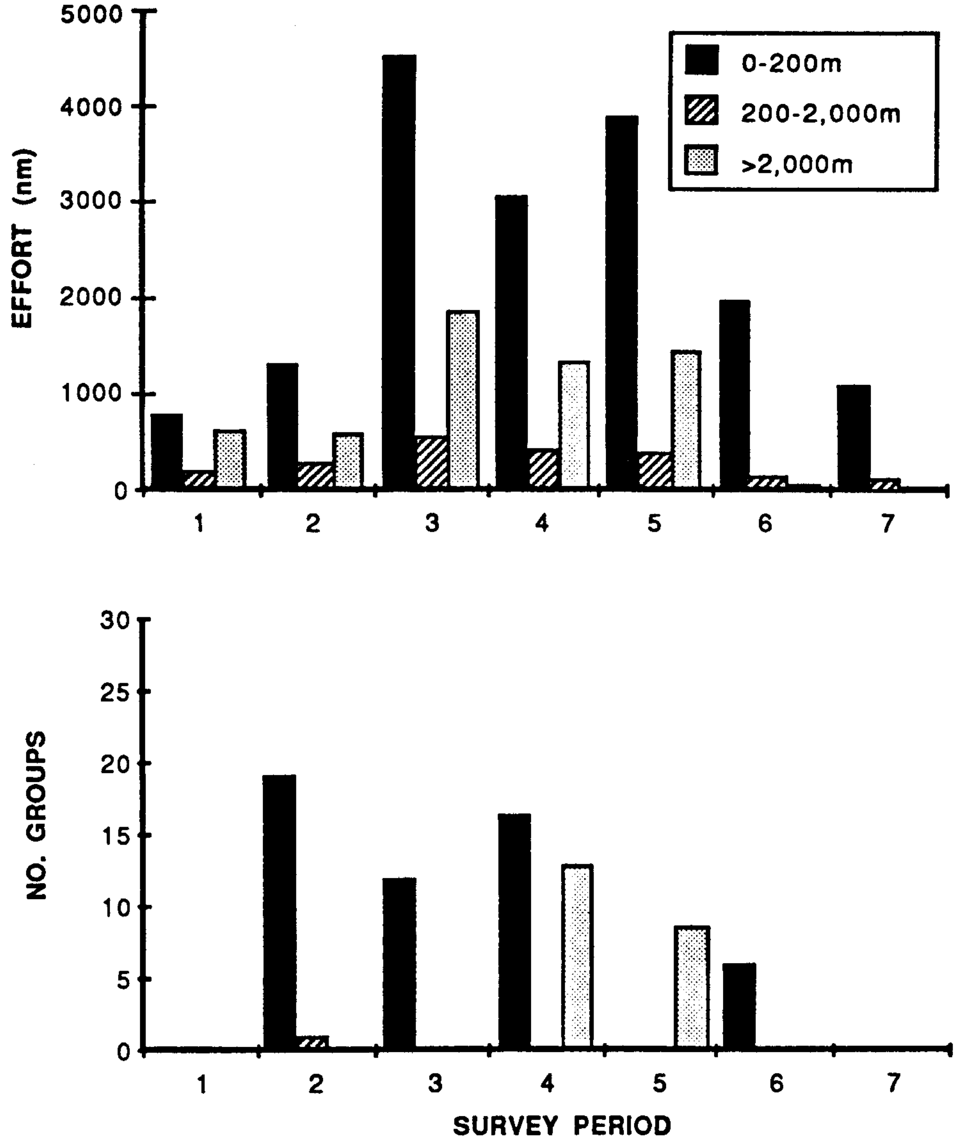

Figure 16.–Number of humpback whales observed in each water depth zone relative to survey effort.

zone. Of the 12 groups evaluated in this zone during the August (9) and October (3) periods, 83% were oriented in south (9) and southwest (1) directions. These southward-moving whales accounted for 32% of the 22 groups reported in August and all of the groups in October. Conversely, 93% of the 41 groups encountered in the shallow and transition zones were oriented in the west, north, and east cardinal directions.

The behavior of individual humpback whales was classified into one of five categories recorded incidental to the surveys (Figure 19). The predominant behavior of humpbacks was traveling, which was defined as a group of animals moving in essentially the same direction. The other categories of milling, feeding, breaching, and resting were infrequently observed for

Table 8.—Observed and expected number of humpback whale groups in each water depth zone.[a]

	June–August			August			October–November			Total	
Zone	Effort (nmi)	Observed	Expected	Effort (nmi)	Observed	Expected	Effort (nmi)	Observed	Expected	Effort (nmi)	Observed
Shallow-transition	6,810	31	22.7	3,549	16	21.1	6,553	6	12.2	16,912	53
Deep	2,486	0	8.3	1,339	13	7.9	1,509	9	2.8	5,334	22
Total	9,296	31	31	4,888	29	29	8,062	15	15	22,246	75
Chi-square			11.33			4.53			16.88		32.74

[a] Analysis was based on whales seen on systematic and random surveys. The shallow and transition water zones were combined as were also the June–July with the July–August and the October with the November to fulfill Cochran's (1954) assumption that no more than 20 percent of the expected frequencies should be less than five for the Chi-square analysis.

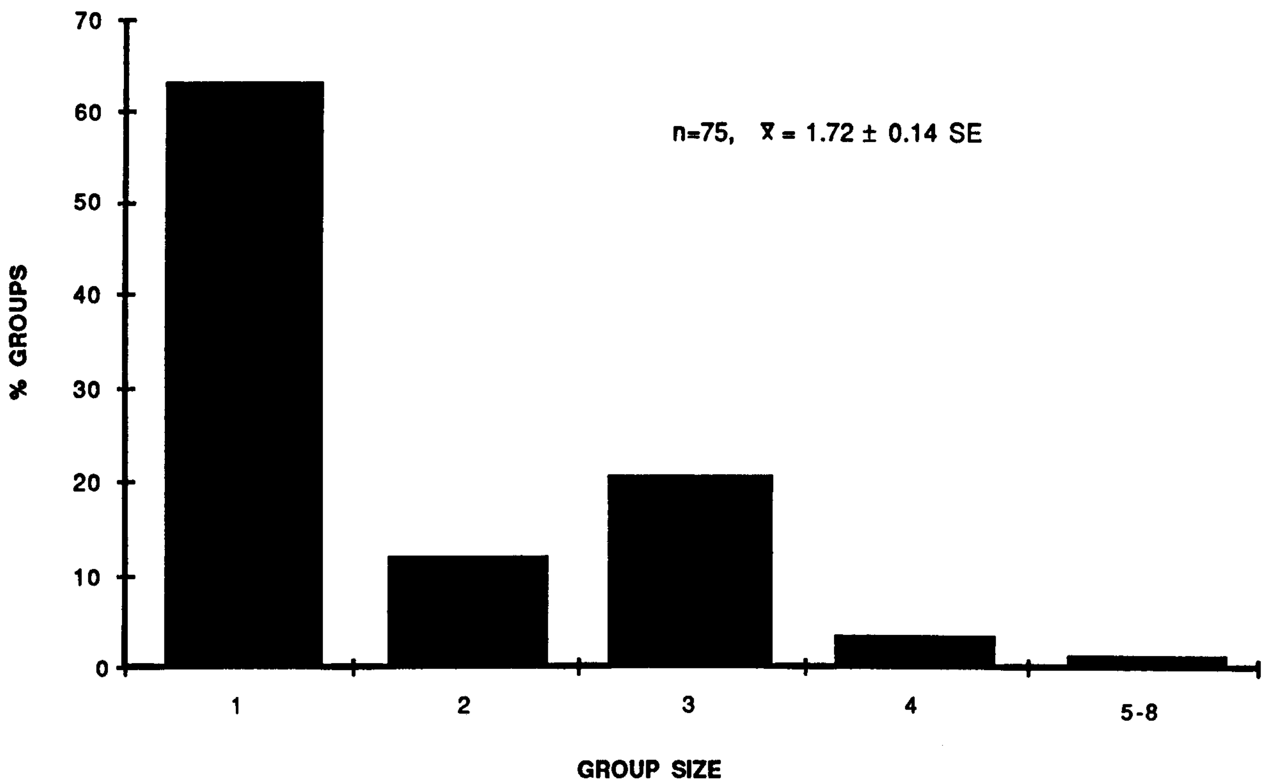

Figure 17.–Group size of humpback whales.

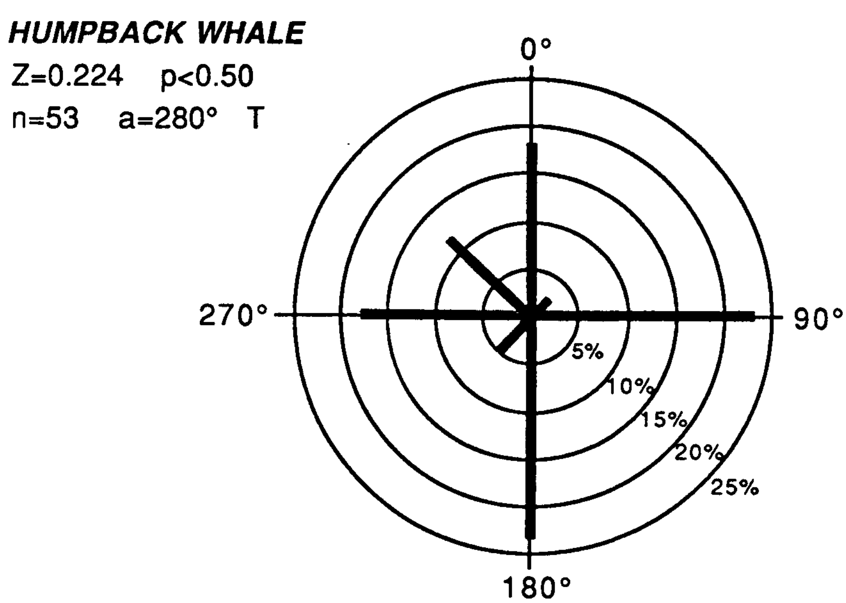

Figure 18.–Directional orientation of humpback whales.

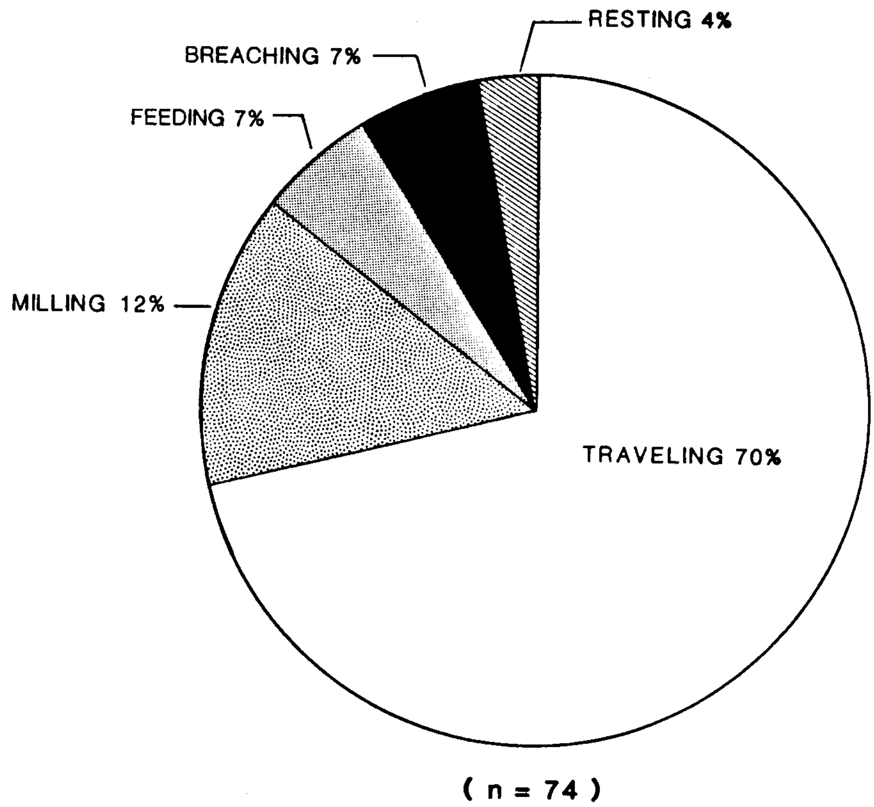

Figure 19.–Humpback whale behavior observed in Shumagin Planning Area, 1985.

humpbacks. Each of these categories made up less than 15% of the 74 groups of humpbacks included in the behavioral analysis. However, the ability of an observer to accurately evaluate behavior of whales from airplanes was limited by both the high survey altitude and the air speed.

Density and abundance

Humpback whale density and abundance estimates are provided in Table 9. Estimates were derived from systematic and random survey data for the three periods from June through August. These periods were chosen because almost 90% of the total 185 humpbacks were counted during these months, which corresponded to the reported peak period of humpback use in Alaska waters (Baker *et al.* 1985). The survey data were further screened to include only whales observed during good to excellent conditions and sea states between 0 and 2 Beaufort wind scale. Chi-square analysis indicated that observed numbers of whales were considerably fewer than the expected numbers during fair to poor visibility conditions and 3-5 Beaufort sea states ($p < 0.05$). Numbers of whales in the acceptable visibility and sea state categories were too few to analyze by individual viewing category, so the data were pooled into one category. Forty-three groups of humpbacks, observed along 7,581 nmi of trackline, were used for the density and abundance estimates.

Table 9.—Summary of statistics used in humpback whale density (n/nmi^2) and abundance estimates for Shumagin planning area.

Zone	Area (nmi^2)	Trackline length (nmi)	Number of groups	f(0)[a]	Density	Abundance	f(0)[b]	Density	Abundance
Shallow	21,855	5,117	22	1.405 (17.5)[c]	.006	131	1.327 (7.8)[c]	.006	123
Transition	6,501	626	1	—	.002	14	—	.002	14
Deep	24,960	1,838	11	—	.008	208	—	.008	196
Total number ± 95% confidence level						353 ± 255			333 ± 217

[a] f(0) was derived from 34 perpendicular distances of humpback whale groups.

[b] f(0) was derived from 59 perpendicular distances pooled for humpback (34) and finback (25) whale groups (CV).

[c] Coefficient of variation ( ).

The f(0) was calculated two ways. In one method, the perpendicular distances obtained for humpback whales were used alone; in the other, these distances were combined with those of finback whales. The latter method was used to increase sample size, and it required that several assumptions be met. First, finback and humpback whales must have equal probabilities of detection. This could be an incorrect assumption if there are differences in blow characteristics, body size, and group size. The two species, however, have prominent blows, large body sizes (15 vs. 20 m), and generally small group sizes. Average group sizes for humpbacks (1.98) and finbacks (1.90) were not significantly different ($p < 0.05$). Average group size was calculated for whales encountered under the favorable conditions cited above, except that groups encountered in a Beaufort 3 sea state with good or better visibility conditions were included. The group sizes of these animals were not significantly different ($p < 0.05$) from those seen under Beaufort 0-2 conditions, but were different from those associated with a Beaufort 4. While there are other biases, we felt the sightability of the two species was sufficiently similar to justify combining them to provide a second estimate of f(0). In addition, the f(0) values were not significantly different ($p < 0.05$) between these two species. Hay (1982) developed a combined humpback-finback whale f(0) to estimate their abundance in the North Atlantic Ocean, since he felt the two species usually had the same sighting cue.

The Fourier series fit of the perpendicular distances for humpback and combined humpback-finback sightings is given in Figure 20. The calculated perpendicular distances were used to estimate f(0) and to derive the Fourier series fit. The tails of the curves were truncated as recommended by Burnham (pers. commun.) to improve the fit by eliminating the highest distance estimates. These are generally the most difficult and least accurate to obtain from a survey platform. The truncation process reduced the perpendicular distance sample sizes from 43 to 34 groups (21%) for humpbacks and from 69 to 59 groups (15%) for combined humpback-finback distances. The f(0) values were similar and the associated coefficients of variation were small and ranged between 7.8 and 17.5%.

To construct the total density and abundance estimates, these values were determined for each zone and summed for the Shumagin Planning Area. The estimated f(0) and mean group size were assumed to be constant among zones since sample were too small to partition by zone. The resulting abundance estimates ranged from 333 ± 217 to 353 ± 255 humpback whales. These are minimum estimates, since they do not account for submerged animals.

Discussion

Our results show that humpback whale use of the Alaska Peninsula and eastern Aleutian Island waters has declined considerably since commercial exploitation commenced. While there are no pre-exploitation estimates, commercial whalers harvested over 7,000 humpbacks in these waters between 1912 and 1965 (Rice 1977; Reeves *et al.* 1985; Stewart *et al.* 1987). Commercial catches averaged over 1,000 whales each year in 1962 and 1963 (Rice 1978*a*). This value compares to only 185 whales we observed during approximately 38,050 nmi of aerial survey effort. Correspondingly, Stewart *et al.* (1987) reported that no humpbacks were observed during 3,690 nmi of aerial surveys on or near the whaling grounds hunted from the Akutan whaling station, where 1,510 whales were harvested between 1912 and 1939. Rice and

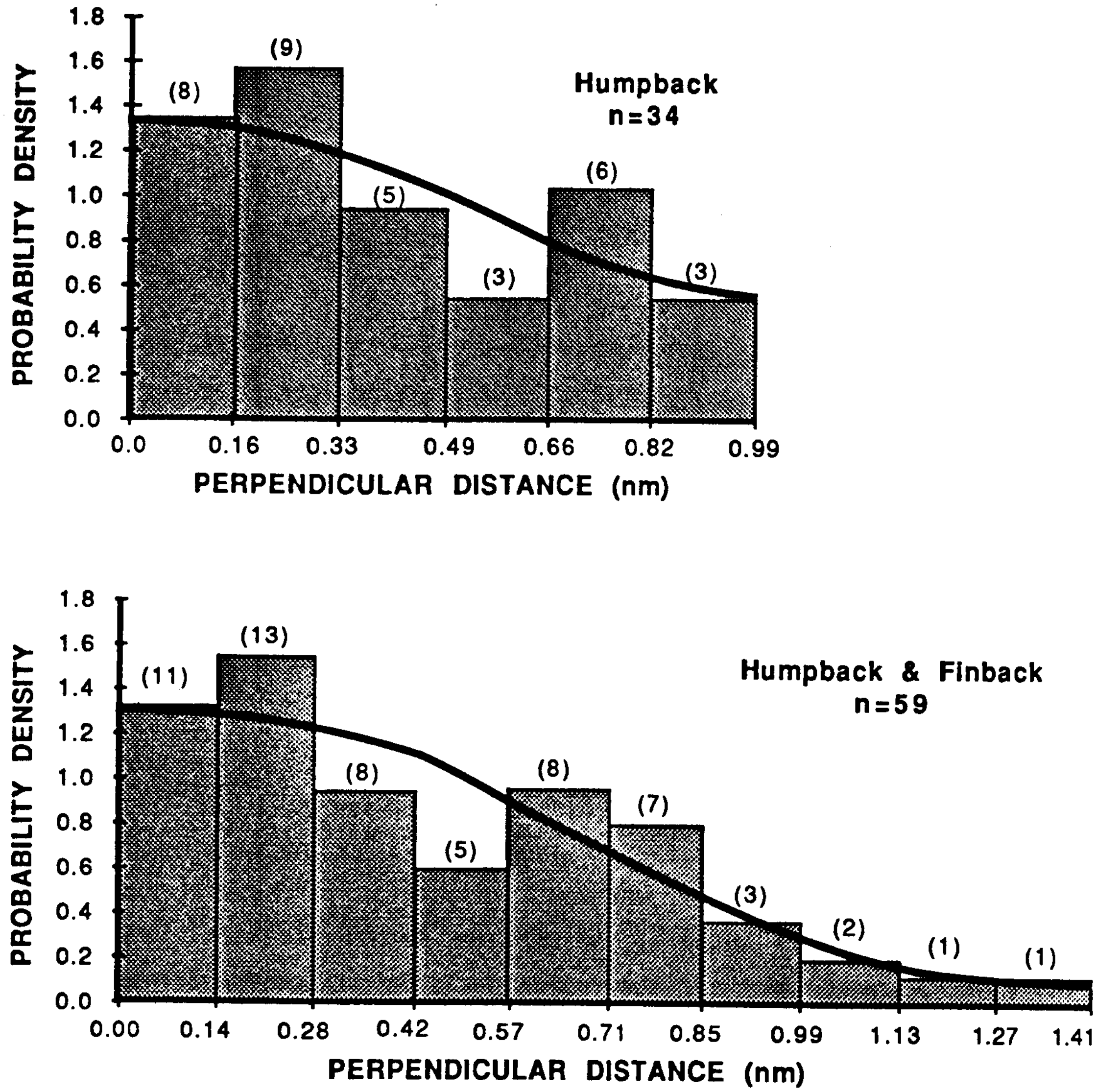

Figure 20.-Probability density function f(0) fit of the Fourier series to a histogram of sighting frequency and perpendicular distance for 34 sightings of humpback whales and 59 sightings of combined humpback and finback whales recorded on aerial transect surveys, 1985.

Wolman (1982) reported relatively few whales in the Kodiak area, where Port Hobron whalers took 1,573 humpbacks between 1926 and 1937. These findings suggest that humpback whale use of the area between Kodiak Island and Akutan Island, including the Alaska Peninsula, is substantially depressed from historic levels. Harvest records suggest that the waters north of the Alaska Peninsula did not support large numbers of humpback whales, which corresponds to our results and those of Leatherwood *et al.* (1983).

In our surveys, humpback whales occupied the Alaska Peninsula and eastern Aleutian Island waters from early July to mid-November, with the peak numbers occurring during July and August; surveys were not conducted during September. Similarly, whalers at the Akutan station harvested humpbacks from May through October (Brueggeman unpubl. data) and highest catches were from June through August (Stewart *et al.* 1987). This pattern of occupancy is also similar to southeast Alaska where Baker *et al.* (1985) reported that humpbacks arrived in June and numbers peaked in August and September. Whales occupying Prince William Sound arrived during late May-early June and stayed until October-November, when most began to move out of the Sound (Hall 1979). Consequently, our results show that the temporal pattern of use by humpbacks has not substantially changed from the initial period of humpback exploitation and the pattern is similar to other areas in southeast Alaska. Baker *et al.* (1985), however, reported that humpbacks were observed in southeast Alaska during December, when no humpbacks were observed in the study area.

The spatial distribution of humpbacks in the Alaska Peninsula and eastern Aleutian Island waters shows that the whales primarily are concentrated in the shallow shelf waters near islands and the shelf break. Townsend (1935) and Nishiwaki (1966) reported that humpback observation and catches by the Japanese in the North Pacific primarily occurred in these types of areas. Approximately 70% of the 98 groups of humpback whales that we observed were near island complexes or within 10 nmi of the shelf break in narrowly defined areas or banks (Table 10). These banks included Sanak Bank, Shumagin Bank, and an unnamed bank along 158°W longitude. Whales were repeatedly observed at Shumagin Bank (June-July, July-August) and the unnamed bank (August, November). No humpbacks were seen, however, on Davidson Bank, where large numbers of whales were harvested by Akutan whalers. Humpback whales in the Atlantic Ocean have been reported by Sutcliff and Brodie (1977) and Brodie *et al.* (1978) to feed most frequently along the edges of banks where prey concentrations are highest. A change in bathymetric relief on the shelf is often accompanied by a concentration of near-surface zooplankton, particularly when changes are abrupt (Sutcliff and Brodie 1977). The remaining 13 groups of whales that we observed on the shelf were distributed near clusters of islands where currents probably enhanced the productivity of prey. Consequently, these results show that humpbacks occurred in relatively narrow geographic areas associated primarily with oceanic banks and secondarily with island complexes.

The results also show that humpback whales have not reestablished use of Davidson Bank to the historic levels suggested by the Akutan whaling station harvest records. Approximately 4,371 nmi were surveyed in sampling blocks on and near this bank but no humpbacks were observed (Table 11). Moreover, the bank was surveyed during the four periods from June through October and the effort averaged 1,093 nmi per survey period. Given the extent of this survey effort, it is unlikely that the relative absence of humpbacks was simply a temporary variation in normal summer feeding patterns. Baker *et al.* (1986) reported that humpbacks in southeast Alaska showed strong fidelity to feeding sites. Individually identified whales, recognized from photos of flukes, repeatedly used the same feeding sites over several years. Furthermore, these feeding herds demonstrated strong geographic segregation. Consequently, our results coupled with surveys by Stewart *et al.* (1987) suggest that the intensive harvesting of whales on Davidson Bank may have depleted that feeding herd. Bockstoce (1978) and Rice (1978*a*) reported that harvests in southeast Alaska by the Tyee shore-based whaling station declined rapidly after one or two good seasons, suggesting that feeding herds specific to that area were depleted.

Table 10.–Number of humpback groups observed on or near areas of major relief changes or associated with island complexes.

Location	Number of groups	Range of distances of groups from major relief change (nmi)[a]	Closest major contour interval (fathoms)	Distance between depths delineating major contour interval (nmi)
Sanak Bank	4	1-6	50-100	2
Shumagin Bank	26	0-5	50-100	8
Unnamed bank	12	1-10	50-100	11
Near shelf edge	8	6-10	100-500	7
Islands complexes	18	–	–	–
Total	68			

[a] Minimum and maximum distances of groups of whales from 50-fathom or 100-fathom (near-edge) contour line.

Table 11.–Survey effort (nmi) on or near Davidson Bank in the Shumagin Planning Area, April-December 1985.

Sampling block	Survey period				
	June	July	August	October	Total
46	280	335	–	339	954
47	36	271	498	142	947
55	–	641	–	647	1,288
56	–	540	600	42	1,182
Total	316	1,787	1,098	1,170	4,371

In addition to whales encountered on or near the shelf, 29 groups were observed in deep water during the August and October surveys. Significantly, the direction of 10 of the 12 groups classified by orientation was primarily southward. While migrational movements to wintering areas seem unlikely during August, the high proportion (100%) of whales observed in October in deep water coupled with the southward orientation suggests these whales were migrating to the southern breeding grounds. The orientation included both a southwest direction toward the Asian breeding grounds and southern direction toward the Hawaiian breeding grounds.

Group sizes of humpback whales that we observed appeared to be smaller than reported in other surveys of humpbacks on the North Pacific feeding and breeding grounds. Rice and Wolman (1982) found that 37% of 83 groups of humpbacks surveyed in the Gulf of Alaska (east of Chirikof Island) were singles, 41% pairs, 11% triads, and 11% were in groups of 4 to 10 animals. Nemoto (1964) reported that 50% of 92 groups of humpbacks on the summer feeding grounds in the north Pacific were singles, 43% pairs, 3% triads, and 4% were in groups of four and five animals. We observed much higher proportions of singles (63%), lower proportions of pairs (12%), higher proportions of triads (21%) and similarly low numbers of groups exceeding three animals. The observed differences are difficult to explain, but may be due to counting biases associated with the different survey platforms. Our aerial counts may have overestimated singles and underestimated pairs when compared to vessel counts reported by the other investigators. The results of the three data bases do support the conclusion that humpbacks occupy the summer feeding ground primarily in groups of one to two animals and seldom in groups exceeding five animals. Humpbacks on the winter breeding grounds in Hawaii occur in larger groups (32% were made up of at least three animals) since females are seen serially and simultaneously with multiple males, and males are seen serially with multiple females (Baker and Herman 1984; Herman and Antinoja 1977).

Humpback whale abundance in the Alaska Peninsula waters was estimated at 353 ± 255 and 333 ± 217 animals. These estimates were derived from identical databases, but the f(0) was calculated for humpback sightings alone to obtain the former estimate and for combined humpback and finback whale sightings to obtain the latter estimate. Although both estimates had relatively small coefficients of variation (CV) (36% vs. 33%), we believe the lower estimate is the best since the f(0) was based on the higher number of sightings and the CV was lower. Both estimates were derived from sighting data screened for visibility and sea state, and calculated by water depth zones. This screening reduced the sample size by 55% but correspondingly reduced the variability of the data. Consequently, the estimates were based on the data set with the fewest sources of bias. The estimates were reasonable since we observed 185 humpbacks, including 76 animals during one survey.

The size of the North Pacific humpback whale population is estimated at 1,200 whales (Rice and Wolman 1982), but the relative abundance of whales on the summer feeding grounds is incompletely understood. Estimates have been made for most of the historic summering areas in Alaska, except for the Alaska Peninsula and Aleutian Islands waters west of Chirikof Island and the Bering Sea (Table 12). Baker *et al.* (1985) estimated that 310 (270-372) humpbacks summered in southeast Alaska. Their estimate was based on a mark-recapture technique applied to photographic data on individually distinguished whales for 1981-1982. Rice and Wolman (1982) estimated 306 whales in the Gulf of Alaska east of Chirikof Island and an additional 58 whales in aggregation areas associated with the Gulf. The former estimate was derived from 25 groups of whales counted in 1980 along 3,106 nmi of strip transect line. The aggregation area estimate represented maximum counts of whales. Rice (pers. commun.)

Table 12.–Humpback whale estimates for the summer feeding areas in Alaska. The estimates represent minimum numbers except for southeast Alaska which is a total (surface and subsurface) estimate.

Area	Estimate (95% CI)	Method	Investigator
Southeast Alaska	310 (270-372)	Mark-recapture analysis of photographic data	Baker et al. (1985)
Gulf of Alaska	306[a]	Strip transect analysis from survey	Rice and Wolman (1982)
Prince William Sound	12[a]	Maximum count from vessel survey	Rice and Wolman (1982)
Yakutat Bay	13[a]	Maximum count from vessel survey	Rice and Wolman (1982)
Cape St. Elias-Middleton Island	13[a]	Maximum count from vessel survey	Rice and Wolman (1982)
Barren Islands	20[a]	Maximum count from vessel survey	Rice and Wolman (1982)
Alaska Peninsula	353 (±255)[b] 333 (±217)[b]	Line transect analysis from aerial surveys	Current study
Total	1,007 (750-1,286)[c]		

[a] Estimate based on density determined by strip transect procedure. Total number was determined by straight expansion of area surveyed to total study area. Sample size was too small to calculate confidence interval.

[b] The first estimate of 353 animals was calculated from f(0) derived from humpback whale sightings. The second estimate of 333 animals was calculated from f(0) derived from combined humpback and finback whale sightings.

[c] Numbers were based on the 333 humpback estimate for Shumagin because it had the lowest coefficient of variation.

believed that their estimate of 364 whales included the 40-60 humpbacks Baker *et al.* (1985) estimated for Prince William Sound. These estimates combined with our estimate of 333 (116-550) whales in the Alaska Peninsula waters provide a minimum abundance estimate of approximately 1,007 humpback whales (750-1,286) summering in Alaska waters.

This estimate for humpbacks summering in Alaska is approximate since there are several inherent biases. The estimates for the Alaska Peninsula and Gulf of Alaska do not account for submerged or missed whales. The Gulf of Alaska estimate does not include a variance component. Furthermore, the estimates may include duplicate counts of whales moving among the Alaska Peninsula, Gulf of Alaska, and southeast Alaska. The influence of this latter bias on the counts may be small, since Rice and Wolman (1982) and Baker *et al.* (1985) reported that humpbacks appear to form discrete feeding herds that have strong site fidelity and generally do not travel to other known feeding areas. Furthermore, all of the estimates except for Baker *et al.* (1985) were derived from summer counts (June-August) rather than counts taken in spring or fall, when animals are very mobile. While it is difficult to determine the effect of these biases on the estimate, the 1,007 animals is the best minimum estimate currently available for the Alaska region.

The North Pacific population estimate of 1,200 animals falls within the 750-1,286 range we calculated for humpbacks summering in Alaska. Since the range does not account for submerged or missed whales or whales summering outside Alaska waters, the current size of the North Pacific humpback whale population may exceed 1,200 animals.

Finback Whale

The size of the North Pacific finback whale population is estimated at between 14,620 and 18,630 animals, about 32-44% of the pre-exploitation population of between 42,000 and 45,000 animals (Rice and Wolman 1982; Braham 1984*a*). Finbacks were not commercially harvested until the advent of modern whaling because they were too fast for traditional whaling vessels of the early 1900s. Whaling for finbacks intensified in the mid-1900s after humpbacks became depleted (Rice 1974). Between 1958 and 1970, the eastern North Pacific stock of finback whales alone decreased 55% from approximately 20,000 to 9,000 animals (Rice 1974). Commercial whaling continued in the North Pacific until 1976 when the finback whale stock was protected by the International Whaling Commission.

North Pacific finback whales winter in subtropical to temperate waters and migrate in the spring to subarctic and arctic waters from the Gulf of Alaska to the Chukchi Sea (Nemoto 1959; Rice 1974). The Asian stock of finback whales migrates north along the Kurile Islands and southern Kamchatka to the Commander Islands where some move east to the Aleutian Islands and others pass north along the Asiatic coast, possibly to the Chukchi Sea (Berzin and Rovnin 1966). The eastern stock migrates off the Pacific Coast to the Gulf of Alaska and eastern Aleutian Island (Berzin and Rovnin 1966). Some of these animals migrate farther north into the Bering Sea and the Chukchi Sea. Tagging studies show that the two stocks intermingle along the Aleutian Islands. A finback whale tagged in 1955 north of Unalaska Island in the Bering Sea was killed in 1956 in the region of Kamchatka (Omura and Kawakami 1956).

The distribution of finback whales in the Gulf of Alaska and waters bordering the Alaska Peninsula is poorly understood. Between 1911 and 1937, commercial whalers harvested a large number of finbacks in these waters from shore-based operations, and during the 1950s and

1960s from Russian and Japanese factory whaling operations (Tonnessen and Johnsen 1982). Berzin and Rovnin (1966) reported that finbacks observed during a Russian scientific-exploration cruise from 1958 through 1964 and harvested from various whaling expeditions were widespread in the northern part of the Gulf of Alaska and east between the Trinity and Shumagin islands. Furthermore, they encountered few finback whales in Bristol Bay, but larger numbers on the Bering Sea side of the Aleutian Islands. Consequently, the Gulf of Alaska and Alaska Peninsula waters were important feeding grounds for the North Pacific finback whale population.

Recent surveys by Rice and Wolman (1982), Consiglieri and Braham (1982), and Leatherwood *et al.* (1983) found small numbers of finback whales widespread in these traditional summering areas. Their effort was, however, relatively low and the findings were incomplete. Their effort was particularly low in the waters bordering the Alaska Peninsula west of Chirikof Island to Unimak Pass and Bristol Bay. Consequently, finback whale distribution and abundance in this area is poorly understood.

In this section we document the distribution and abundance of finback whales in the Alaska Peninsula waters based on an intensive aerial survey. The information we report confirms and substantially expands the results from previous studies.

Results

Number and distribution

In the Shumagin Planning Area, 74 groups representing 149 finback whales were observed during the seven survey periods between April and December 1985 (Table 13). Finback whales were only observed during the July-August and August survey periods when 48% of the total effort was accomplished. Approximately equal numbers of whales were recorded during the two periods, but survey effort was 1.5 times higher in the July-August period. An aggregation of 19 large but unidentified whales observed during the November survey was suspected to be finbacks. No finbacks were observed in the other two planning areas.

Finback whales were not uniformly distributed ($p < 0.05$) in the Shumagin Planning Area (Figure 21). Seventy-three of the 74 total groups of finback whales were observed between 157° and 160°W longitude, where 34% of the total effort was accomplished (Figure 22). Particularly high numbers of finbacks were encountered in a 70-nmi band from 157° to 159°W ($p < 0.05$) (Table 14). Whales were repeatedly observed in this area during the July-August and August survey periods.

Finback whales were observed in two of the three water depth zones (Table 13). Approximately 90% of the finbacks were observed in the shallow zone, 10% in the transition zone, and none in the deep zone. A high proportion (>82%) of these whales was repeatedly observed during the two survey periods in the shallow water zone, where approximately 65% of the effort was accomplished (Figure 23). Chi-square analysis indicated that use of the shallow and transition zones, however, was not significantly different ($p > 0.05$, $X^2 = 1.36$) (Table 15). No finbacks were observed in the deep water zone.

Table 13.—Survey effort (nmi) and number of finback whales observed in the Shumagin planning area, April–December 1985.

Survey period	Shallow zone[a]			Transition zone[a]			Deep zone[a]			Total		
	Effort	No.	Group	Effort	No.	Group	Effort	No.	Group	Effort	No.	Group
April–May	773	0	0	186	0	0	617	0	0	1,576	0	0
June–July	1,316	0	0	292	0	0	597	0	0	2,205	0	0
July–August	4,621	34 (24)	16 (11)	582	5 (8)	2 (3)	1,889	0	0	7,092	39 (32)	18 (14)
August	3,132	52 (24)	30 (11)	416	2	1	1,339	0	0	4,887	54 (24)	31 (11)
October	3,977	0	0	431	0	0	1,452	0	0	5,860	0	0
November	1,991	0	0	153	0	0	57	0	0	2,201	0	0
December	1,105	0	0	133	0	0	0	0	0	1,238	0	0
Total	16,915	86 (48)	46 (22)	2,193	7 (8)	3 (3)	5,951	0	0	25,059	93 (56)	49 (25)

[a] Zones were defined as <200 m for shallow, 200/2,000 m for transition, and >2,000 m for deep. Number in parentheses equals additional individuals and groups counted on deadhead surveys.

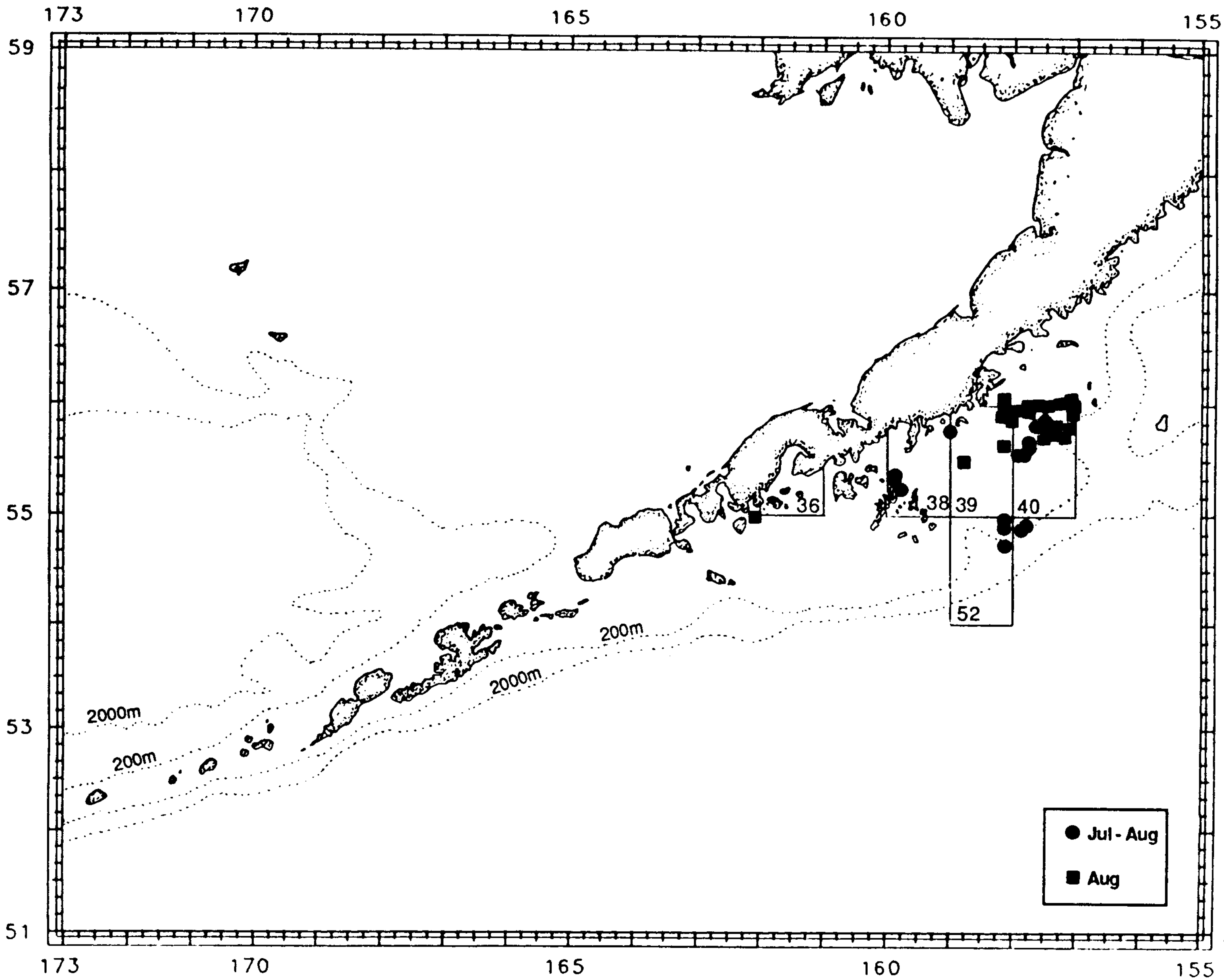

Figure 21.–Locations of finback whales observed in the Shumagin Planning Area, 1985.

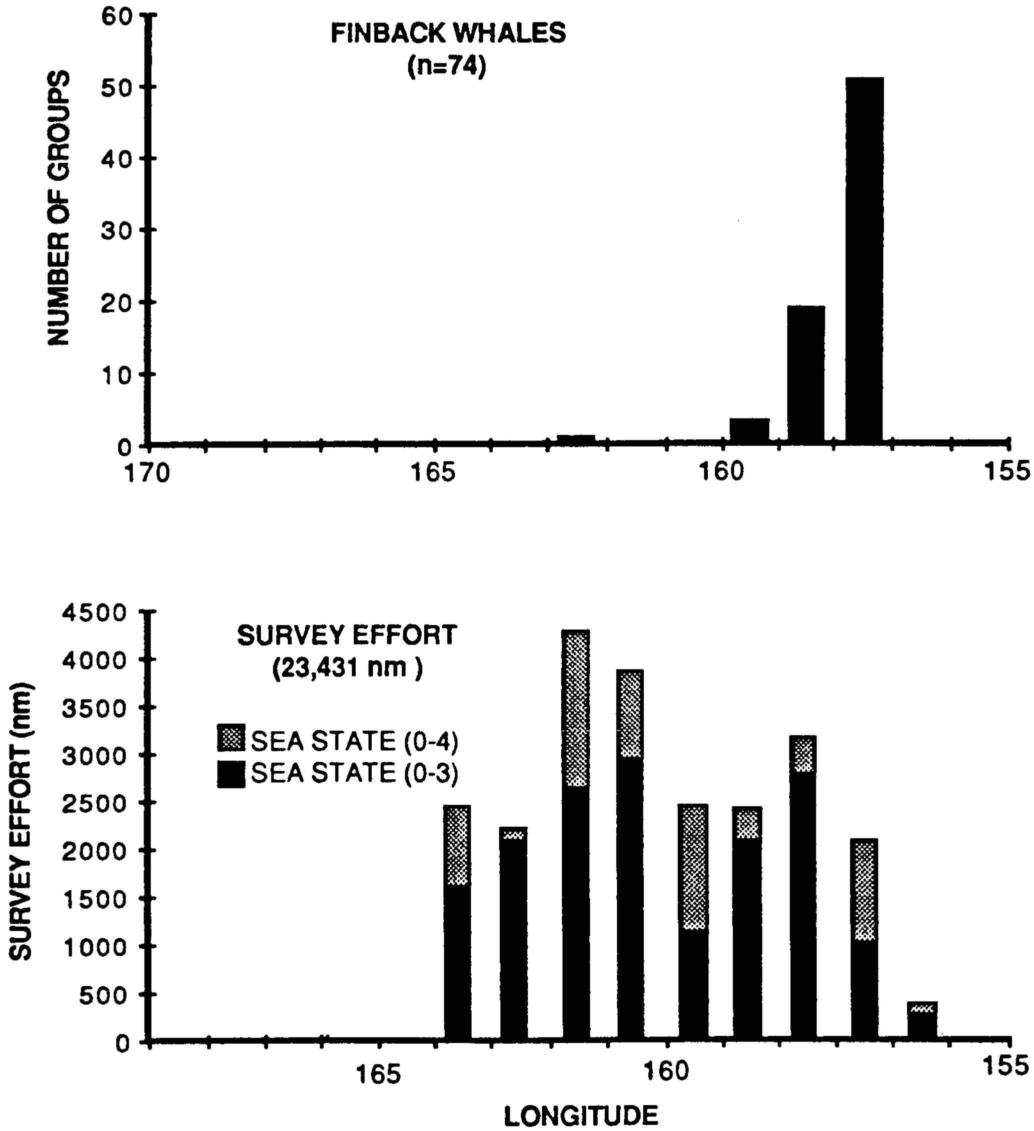

Figure 22.–Survey effort and number of finback whales observed by longitude degree.

Group size

Group size averaged 1.88 (±0.15 SE) animals for the two survey periods (Figure 24). Approximately 80% of the groups were composed of one or two animals, but single animals were the most common (45%). Fewer than 10% of the observations were in each of the remaining group size categories, which ranged from three to five animals. Average group size was not significantly different ($p < 0.05$) between the two survey periods. While group sizes were usually small, 86% of the 74 groups were in clusters ranging from 2 to 10 groups in a 3- to 5-nmi radius.

Table 14.–Relative occurrence of finback whales by longitude degree in the Shumagin Planning Area.

Longitude	Percentage effort	Percentage occurrence	Preference[a]
164°–165°(W)	10.5	0.0	–
163°–164°	9.5	1.4	–
162°–163°	18.4	0.0	–
161°–162°	16.5	0.0	–
160°–161°	10.5	4.1	–
159°–160°	10.3	25.7	+
158°–159°	13.6	68.9	+
157°–158°	8.9	0.0	–
156°–157°	1.7	0.0	0
Total	99.9	100.1	
Total effort and number of groups	23,431 nmi[b]	74	

[a] – indicates significant avoidance, + indicates significant preference, and 0 indicates no selection ($p < 0.10$).

[b] Effort included distances surveyed during Beaufort 0-4 and fair to excellent visibility conditions.

Orientation and behavior

There was no consistent directional orientation ($p < 0.05$) of finbacks in the Shumagin area to suggest a major movement pattern (Figure 25). Finbacks were observed moving in a variety of directions during the two survey periods. While the whales were primarily observed traveling (98%), feeding activity may not have been detected by the aerial survey team (Figure 26). Finback whales feed by passing horizontally through the water and occasionally turning on their sides (Watkins and Schevill 1979), behavior which is difficult to distinguish from traveling.

Density and abundance

Finback whale density and abundance estimates and associated statistics are provided in Table 16. Estimates were derived for systematic and random surveys for the combined July-August and August periods. Finbacks were only encountered during these two periods, which correspond to the major period of use on these summer feeding grounds (Stewart *et al.* 1987). The survey data were screened to include only whales observed during good to excellent visibility conditions and sea states between 0 and 2 Beaufort wind scale. Chi-square analysis indicated that observed numbers of whales were considerably fewer than expected numbers for

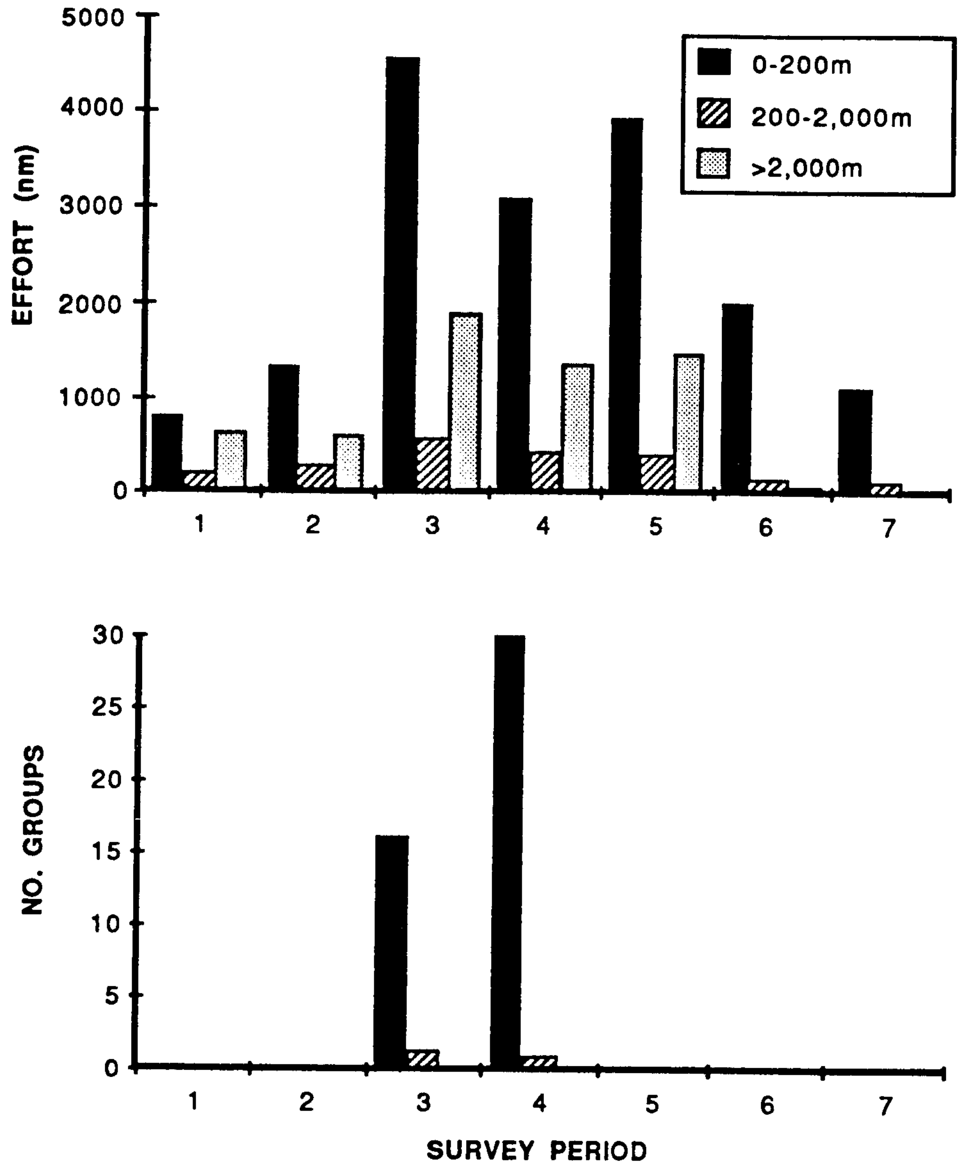

Figure 23.–Number of finback whales observed in each water depth zone relative to survey effort.

the other environmental conditions ($p < 0.05$). As with the humpback whales, the numbers of whales in the acceptable visibility and sea state categories were too few to analyze them by separate viewing categories, so the data were pooled into one category. Consequently, density and abundance estimates were derived from 25 groups of finback whales observed along 4,840 nmi of trackline.

The f(0) was calculated for perpendicular distances obtained for the finback whales and also for perpendicular distances obtained for finback and humpback whales combined. The justification for combining the distances of the two species is given in the preceding section on humpback whales. The Fourier series fits of the finback whale and the combined finback and

Table 15.–Observed and expected numbers of finback whale groups in each water depth zone.[a]

Zone	July-August Observed	Expected
Shallow	46	43.4
Transition	3	5.6
Total	49	49

[a] Analysis was based on whales seen on systematic and random surveys. Expected values were weighted by effort. The July-August and August surveys were combined to fulfill Cochran's (1954) assumption that no more than 20% of the expected frequencies should be less than five for the Chi-square analysis. Chi-square value equaled 1.36.

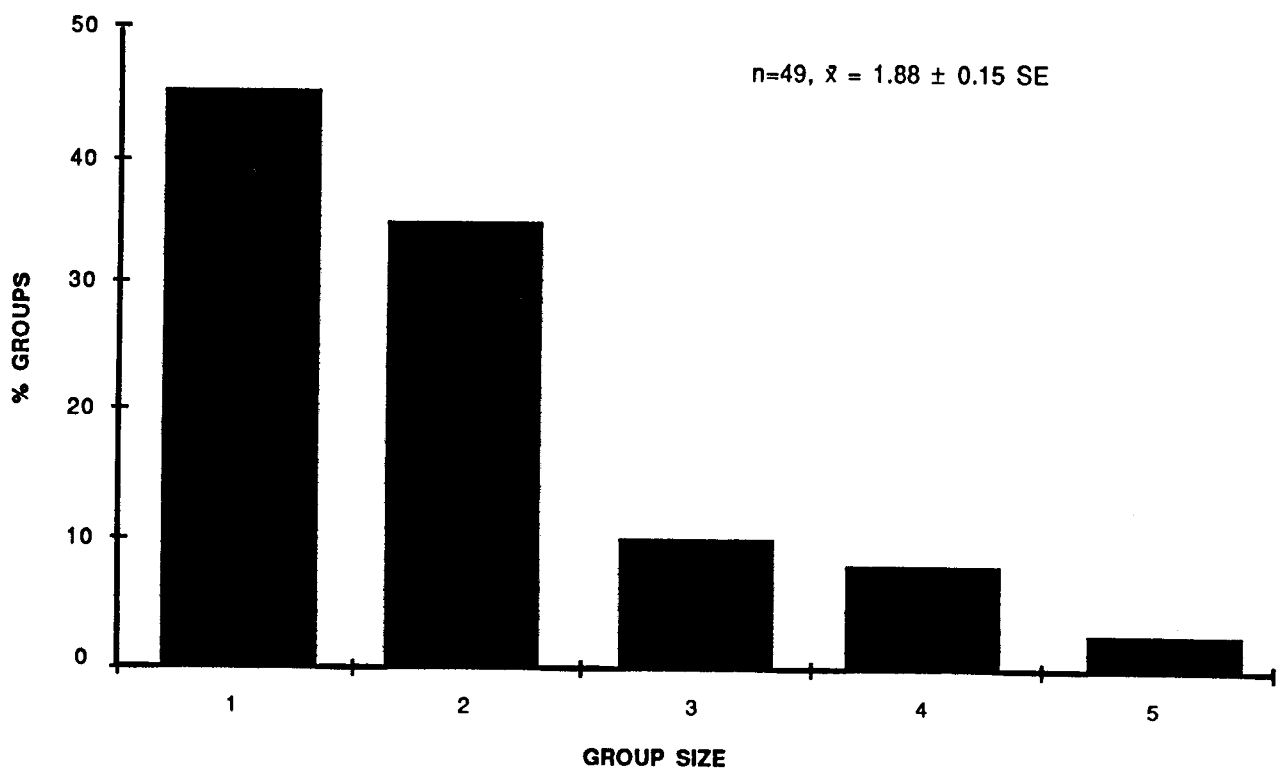

Figure 24.–Group size of finback whales.

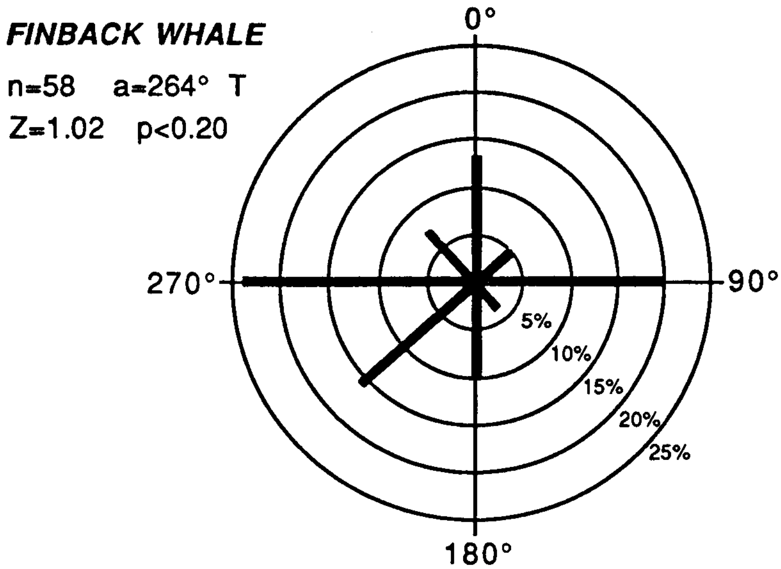

Figure 25.–Directional orientation of finback whales.

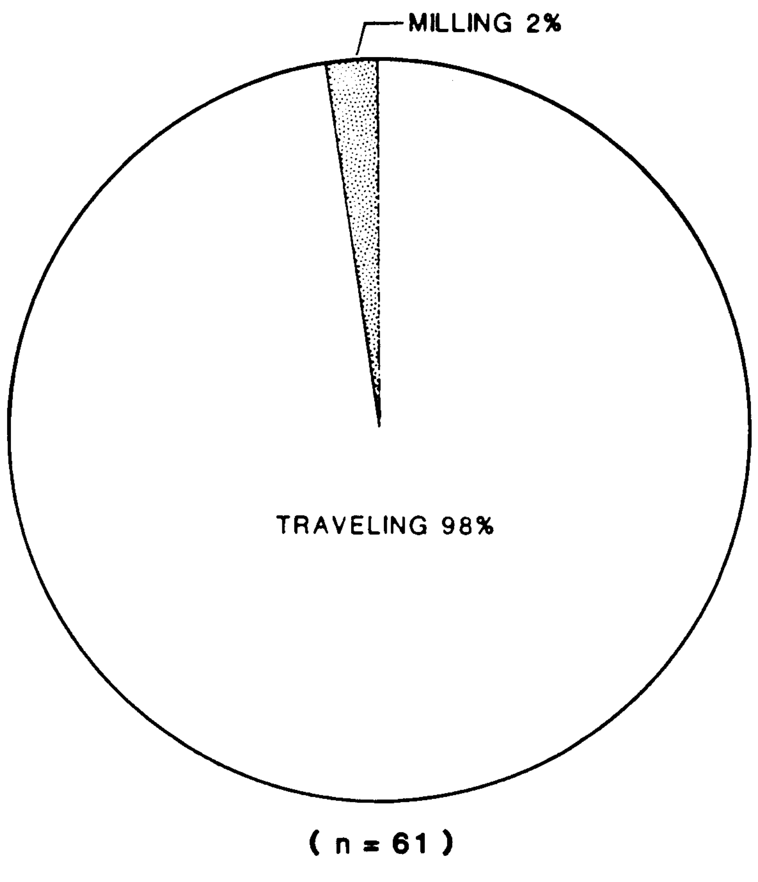

Figure 26.–Finback whale behavior observed in the Shumagin Planning Area, 1985.

Table 16.—Summary of statistics used in finback whale density (n/nmi^2) and abundance estimates for Shumagin planning area.

Zone	Area (nmi^2)	Trackline length (nmi)	Number of groups	f(0)[a]	Density	Abundance	f(0)[b]	Density	Abundance
Shallow	21,855	4,446	23	1.197 (15.6)[c]	0.006	129	1.327 (7.8)	0.006	143
Transition	6,501	394	2	—	0.006	37	—	0.006	41
Deep	24,960	1,585	0	—	0	0	—	0	0
Total number ± 95% confidence interval						166 ± 93			184 ± 90

[a] f(0) was derived from 25 perpendicular distances of finback whale groups.
[b] f(0) was derived from 59 perpendicular distances pooled for finback (25) and humpback (34) whale groups.
[c] Coefficient of variation ( ).

humpback whale perpendicular distances are given in Figure 27. The tails of the curves were truncated as recommended by K. Burnham (pers. commun.) to reduce variability. The truncation process reduced the perpendicular distance sample size for finback whales from 26 to 25 groups. The f(0) was 1.197 and the coefficient of variation was 15.6%. These values were similar to those developed for the combined finback and humpback whale sightings described previously.

To construct the total density and abundance estimates, these values were determined for each depth zone and summed for the Shumagin Planning Area. Since no finback whales were observed in the other two planning areas, these estimates were zero. The estimated f(0) and mean group size were assumed to be constant among the zones since the number of groups was too small to partition into zones. The resulting abundance estimates ranged from 166 ± 93 to 184 ± 90 finback whales. These are minimum estimates, since they do not account for submerged or missed animals.

Discussion

Our results show that finback whale use of the Alaska Peninsula and eastern Aleutian Islands has declined considerably since commercial exploitation commenced. Japanese commercial whalers alone harvested over 4,000 in or near these waters between 1945 and 1962 (Nishiwaki 1966). Catches in these areas ranged from 1,300-2,500 whales each year from 1954 to 1966 by all whalers (Tonnessen and Johnsen 1982). The 149 finbacks that we observed during approximately 43,700 nmi of aerial survey effort fall considerably below the average catch of finbacks 20 years ago. Others have also reported low numbers of finback whales in cetacean surveys. Stewart *et al.* (1987) observed only 11 finback whales during 3,690 nmi of aerial surveys on or near the former whaling grounds of the Akutan whaling station, where over 2,498 finbacks were harvested between 1912 and 1939. Rice and Wolman (1982) encountered 33 finback whales during 3,403 nmi of vessel survey effort in the Gulf of Alaska east of Chirikof Island, where the Port Hobron whaling station harvested over 464 finbacks between 1926 and 1937 (Reeves *et al.* 1985). These results show that while finback whales currently summer in the Gulf of Alaska and Alaska Peninsula waters, their use of the region is substantially below historic levels.

Finback whales were encountered in the Alaska Peninsula waters during the July-August and August surveys only, despite intensive survey effort during the other periods. Berzin and Rovnin (1966) reported that finback whales first arrived in the region of the eastern Aleutian Islands and Gulf of Alaska in April or May and departed in November. Hall (1979) observed finback whales in Prince William Sound from April to June and believed that they were primarily transients. Stewart *et al.* (1987) determined from the catch records of the Akutan whaling station that finback whales were taken in the Bering Sea and North Pacific near Akutan and Unalaska Islands from April through September, with peak catches occurring between July and early September. Consequently, the temporal distribution that we observed corresponds to the peak period of finback whale use in the Alaska Peninsula and adjoining waters. The absence of sightings during the other survey periods may be simply due to fewer numbers of whales. Our findings, however, do indicate that the temporal pattern of use by finback whales has not substantially changed from the historic one.

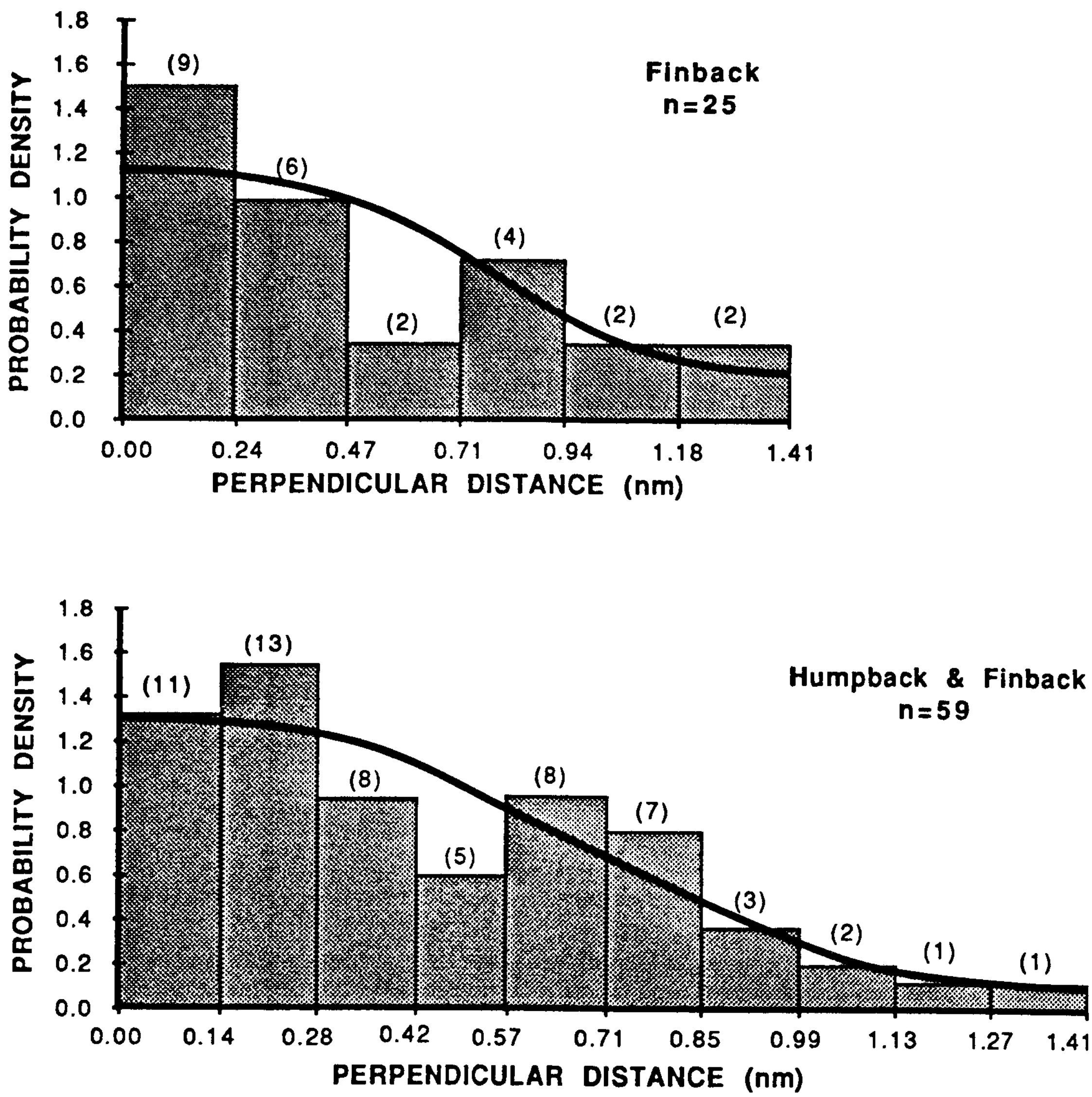

Figure 27.–Probability density function f(0) fit of the Fourier series to a histogram of sighting frequency and perpendicular distance for 25 sightings of finback whales and 59 sightings of finback and humpback whales combined recorded on aerial transect surveys, 1985.

The spatial distribution of finback whales in Alaska Peninsula waters was primarily on the continental shelf near areas of high bathymetric relief. Approximately 97% of the 74 groups of finback whales were distributed on or near (≤10 nmi) the 50-fathom (91-m) contour line (between 25 and 70 fathoms, or 46 and 128 m) and concentrated along the 158°W longitude line. This area, particularly southwest of the Semidi Islands where the largest aggregations of finback whales occurred, features sharp relief characterized by a deep canyon that bisects the shelf. Whales were repeatedly observed in this area during the two survey periods. Finback whales taken in the Gulf of Alaska by commercial whalers were also near areas of high relief where gyres, upwelling, and oceanic fronts provided high biological productivity (Uda 1954;

Berzin and Rovnin 1966; Shurunov 1970; Nasu 1974). Consiglieri and Braham (1982) similarly recorded that finback whales reported in the POP database primarily occurred in areas of upwelling along the continental slope and shelf in the western Gulf of Alaska to Unimak Pass. Several finback whales we observed were associated with island complexes, generally near areas of high relief except for the two finbacks by Deer Island.

The distribution of finbacks was very narrow, despite the broad spatial coverage achieved in the survey effort. These results suggest that finback whales, as we report for humpback whales, have not reinhabited some historically used areas since being depleted by commercial whalers. While large numbers of finbacks were historically taken by whalers off Davidson Bank (Reeves *et al.* 1985), no finback whales were recorded in this area during our surveys. Stewart *et al.* (1987) also found no finback whales associated with this bank following their aerial surveys. The narrowly defined areas where we did report finbacks may have been areas that whalers missed or hunted considerably less, possibly because of territorial boundary restrictions on access by foreign vessels (Rice, pers. commun.). Whales using these areas may display site fidelity similar to humpback whales (Baker *et al.* 1985).

The group sizes of the finback whales that we observed were generally similar to those reported by other investigators for the summer feeding grounds in Alaska. Rice and Wolman (1982) found that 47% of 15 groups of finback whales encountered in the Gulf of Alaska were singles, 20% pairs, and 33% were groups of three to five animals. Consiglieri and Braham (1982) similarly reported that 40% of 65 groups of finback whales recorded in the POP database for Alaska were singles, 25% pairs, and 35% composed groups of three or more whales. Single animals (45%) were most commonly observed during our surveys also, and groups exceeding three animals were relatively uncommon. We saw more pairs (35%) than reported by the other investigators but the difference was not substantial and may have been due to observer biases. In general, however, our results confirm that finback whales inhabit the summer feeding grounds in small groups. Small groups of finbacks (mean = 2.61) were also predominant on the North Atlantic summering grounds (Hay 1982).

Finback whale abundance in the Alaska Peninsula waters was estimated at 184 ± 45 and 166 ± 93 animals. We believe the higher estimate is the best, since the f(0) was based on the larger sample size derived from the combined finback and humpback sightings and the coefficient of variation was lowest (7.8% vs. 15.6%). To reduce biases, the estimation process followed the same data screening procedure as described in the previous section on humpback whales. The estimates are reasonable since we observed 149 finbacks, including 78 during a single survey period. The estimates were not corrected for whales missed by the observers, so they are minimum numbers.

The size of the North Pacific finback whale population is estimated at 14,620-18,630 animals (Braham 1984*a*) but the number on the Alaska summer feeding grounds is unknown. Rice and Wolman (1982) estimated 159 finback whales in the Gulf of Alaska, east of Chirikof Island. Their estimate was derived from seven groups of whales recorded along 3,106 nmi of strip transect line. A confidence interval was not calculated because of the small sample size. Since there are no other estimates for these waters, we combined it with our estimate of 184

(94-274) whales in the Alaska Peninsula waters to provide a minimum abundance of 343 (253-433) finbacks summering in these Alaska waters. This estimate falls considerably short of the North Pacific population estimate of 17,000. Since finback whales summer in the Bering Sea (Brueggeman *et al.* 1984) and elsewhere in the northern waters (Berzin and Rovnin 1966), the total finback whale population would not be expected to summer in the Gulf of Alaska and Alaska Peninsula waters. There are no comparable estimates for the proportion of whales summering outside these waters.

Killer Whale

Killer whales are one of the most cosmopolitan of all the toothed cetaceans. They inhabit all oceans and major seas (Martinez and Klinghammer 1970; Dahlheim 1981) including the tropics (Dahlheim *et al.* 1982), but they are most common in the higher latitudes. There are no world or North Pacific estimates for the killer whale population.

Killer whales are distributed in the arctic and subarctic regions of Alaska. They occur seasonally and are possibly resident in the Gulf of Alaska and Bering Sea (Braham and Dahlheim 1982; Leatherwood *et al.* 1982; Brueggeman *et al.* 1984; Lowry *et al.* 1987), and some move into the Chukchi Sea when ice recedes (Scammon 1874; Cook 1926; Braham and Dahlheim 1982; Leatherwood *et al.* 1983). The most notable concentrations occur in the eastern Aleutian Islands (Murie 1959) and along the shelf edge northwest of Unimak Pass (Leatherwood *et al.* 1983). Approximately 100 whales have been estimated in each of southeast Alaska, Prince William Sound, and Shelikof Strait during the summer salmon migrations (Hall 1981; Leatherwood *et al.* 1983*a*). Except for a few incidental sightings, very little information exists on killer whale use of the waters bordering the Alaska Peninsula.

In this section we provide information on the abundance, distribution, and habitat use patterns of killer whales in the planning areas.

Results

Number and distribution

Twenty-five groups of 67 killer whales were observed in the three planning areas between April and December (Table 17). Whales were observed during five of the seven survey periods. Counts were generally below ten animals for each period except in July-August and December when 20 and 27 whales (including those seen on deadhead) were recorded, respectively. Survey effort was highest for July-August but lowest for December. No whales were encountered during April or October, although approximately 7,500 nmi of trackline were surveyed.

Killer whales were widely distributed in the study area (Figure 28). They were observed in all three planning areas but the number of observations was variable. The highest number

Table 17.—Survey effort (nmi) and number of killer whales observed in the three planning areas, April–December 1985.

	Shumagin			North Aleutian Basin			St. George Basin			Total		
Survey Period	Effort	No.	Group	Effort	No.	Group	Effort	No.	Group	Effort	No.	Group
April–May	1,576	0	0	0	—[a]	—	0	—	—	1,576	0	0
June–July	2,205	12 (1)	5 (1)	3,082	0	0	2,389	0	0	7,676	12 (1)	5 (1)
July–August	7,092	15 (5)	5 (2)	0	—	—	0	—	—	7,092	15 (5)	5 (2)
August	4,887	5	1	173	0	0	0	—	—	5,060	5	1
October	5,860	0	0	0	—	—	0	0	0	5,860	0	0
November	2,201	0	0	2,353	1	1 (1)	858	0	0	5,412	1 (1)	1 (1)
December	1,238	0	0	2,453	0	0	1,683	27	9	5,374	27	9
Total	25,059	32 (6)	11 (3)	8,061	1 (1)	1 (1)	4,930	27	9	38,050	60 (7)	21 (4)

[a] Dash (—) signifies area was not surveyed.

[b] Number in parentheses indicates animals seen on deadhead transects.

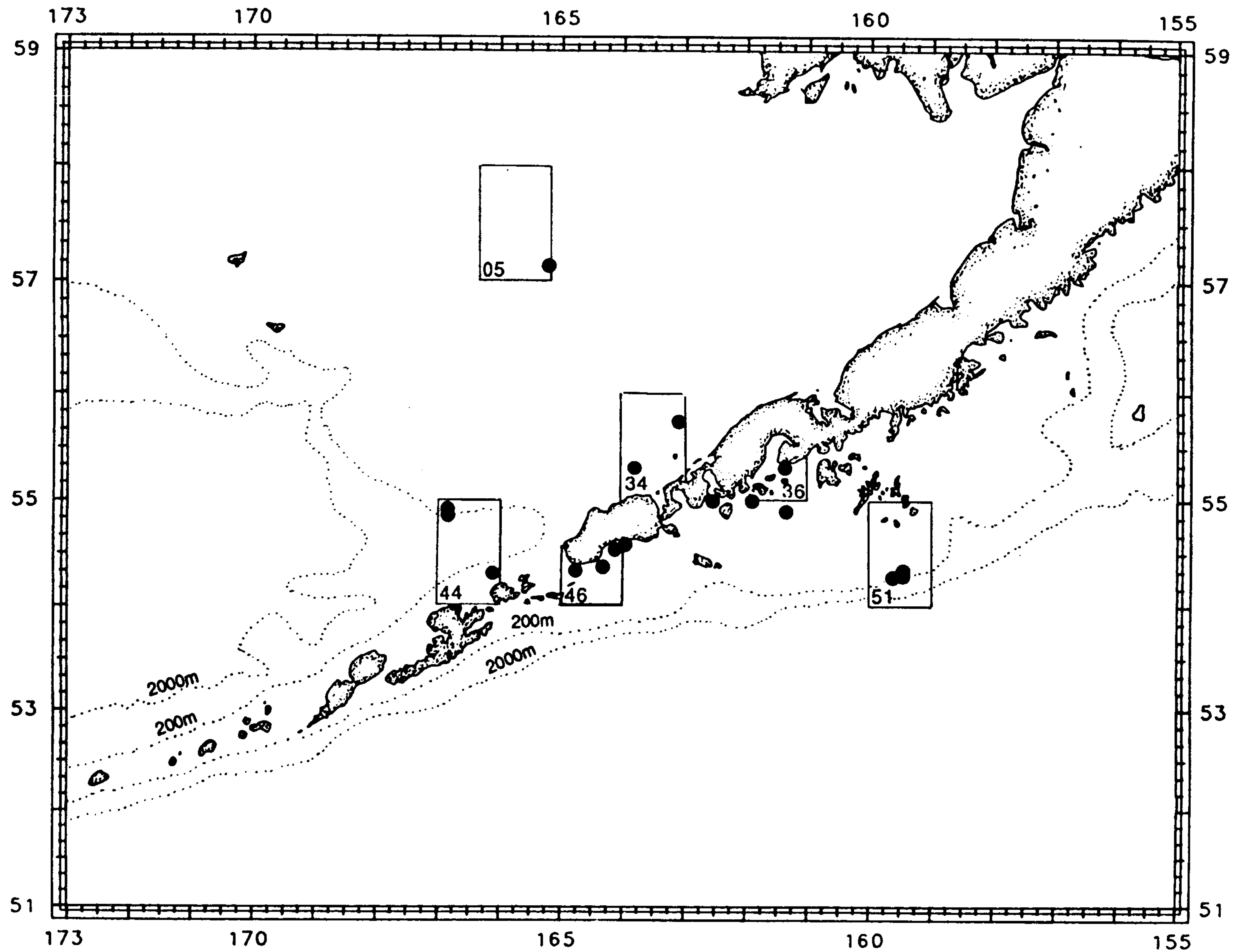

Figure 28.-Locations of killer whales observed in the study area, 1985.

of killer whales was encountered in the Shumagin area, where survey effort was highest. Slightly fewer whales were observed in the St. George Basin but effort was 80% lower than in the Shumagin. Only two whales were recorded in the North Aleutian Basin, which was surveyed during four periods. Conversely, killer whales were recorded during two of three St. George Basin survey periods and during three of seven Shumagin area survey periods. Consequently, killer whale use of the planning areas was variable but highest in the Shumagin and St. George Basin planning areas.

Killer whales were associated with the shallow and transition water zones. Approximately 56% of the 21 groups were in shelf waters. These whales were primarily in the nearshore waters. Braham and Dahlheim (1982) reported that killer whales frequented the nearshore waters in the Gulf of Alaska. Moreover, Consiglieri and Braham (1982) found that killer whale sightings extracted from the Platforms of Opportunity Program (POP) for the Gulf of Alaska were almost exclusively on the continental shelf in water depths less than 200 m. The remaining 44% of the whales we observed during the surveys were on the slope near the edge of the continental shelf. No whales were observed in the deep water zone.

Group size

Group sizes of killer whales averaged 3.053 (±0.510 SE) and ranged from one to nine animals (Figure 29). Forty-three percent of the total groups were singles, 10% pairs, and 47% three or more animals. On five occasions, we observed two or more groups traveling together. Since killer whale pods are sets of closely related individuals which travel together in loosely formed groups, the clusters of groups we observed were probably members of the same pod (Ford and Fisher 1983).

Groups of the same pod may be separated by as much as 4 nmi (7.3 km) (Martinez and Klinghammer 1970). By combining groups traveling together, the pod sizes averaged 4.79 (±1.25 SE) and ranged from 1 to 18 animals for our study area.

Orientation and behavior

There was no consistent directional orientation of killer whales to suggest a major movement pattern in the study area (Figure 30). The behavioral activity of the whales, however, was almost entirely observed as traveling. The movements may have been local rather than regional. One group of six killer whales was observed attacking a single northern sea lion. The whales encircled the sea lion and slapped it with their tails. We watched the attack for approximately 30 minutes but left before the confrontation ended.

Density and abundance

Killer whale density and abundance estimates and associated statistics are provided in Table 18. Estimates were derived from systematic and random survey data for the Shumagin and St. George Basin planning areas. Estimates were not calculated for the North Aleutian Basin Planning Area because too few whales were observed in 1985. Only whales observed

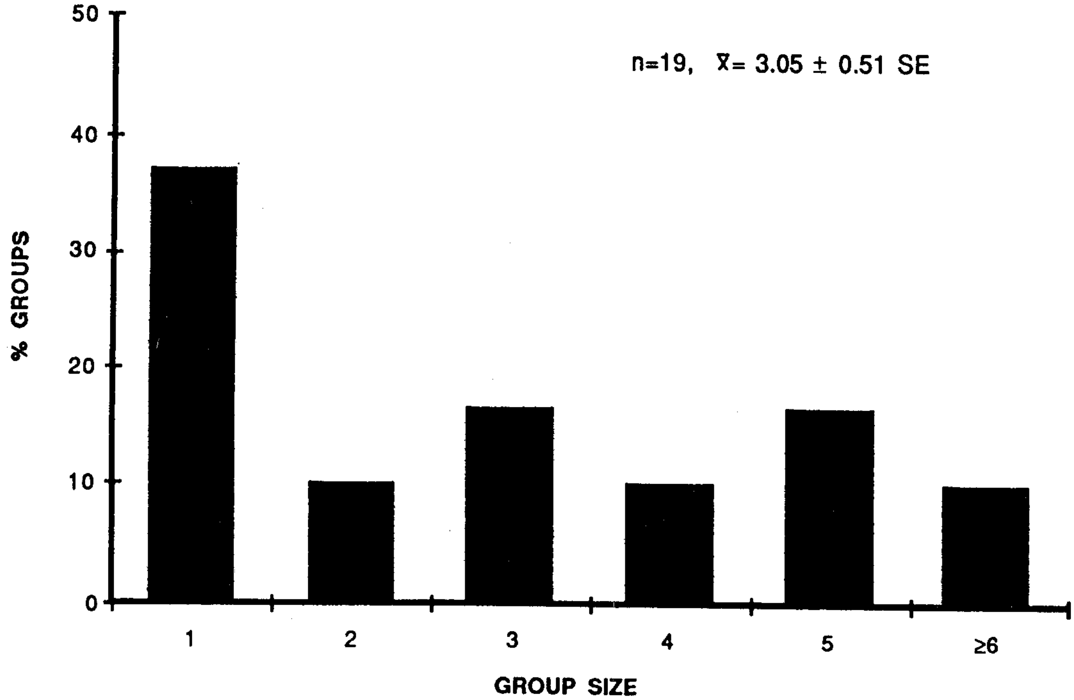

Figure 29.–Group sizes of killer whales observed in the Shumagin, North Aleutian Basin, and St. George Basin planning areas, 1985.

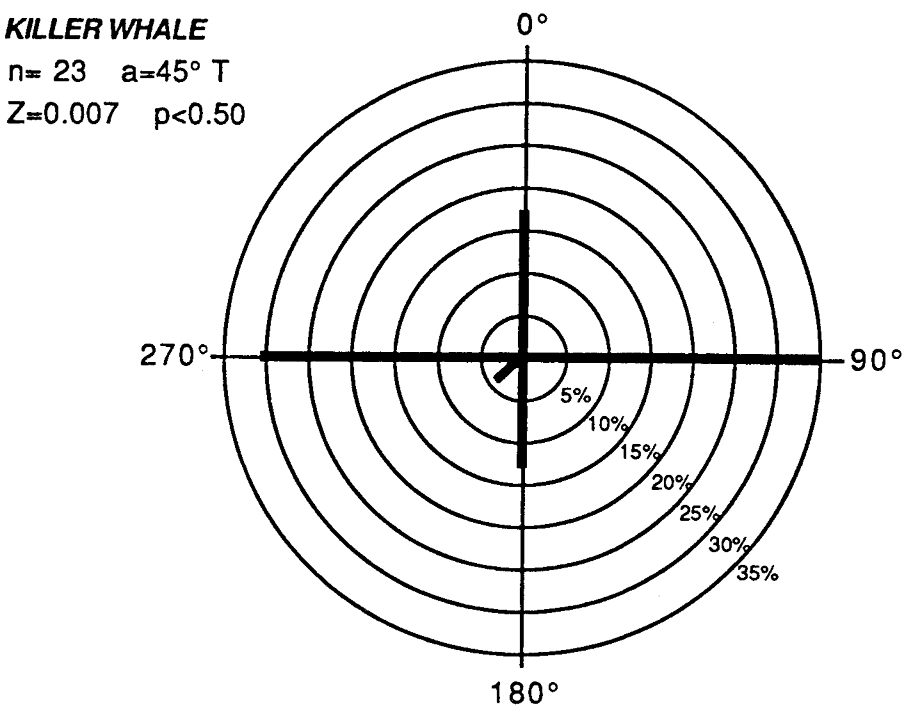

Figure 30.–Directional analysis of traveling killer whales in the Shumagin, North Aleutian Basin, and St. George Basin planning areas, 1985.

Table 18.—Summary of statistics used in killer whale density (n/nmi^2) and abundance estimates for the Shumagin and St. George Basin planning areas.[a]

Planning areas	Strata	Area (nmi^2)	Trackline length (nmi)	Number of Groups	f(0)[b]	Density	Abundance[c]
Shumagin	Shallow	21,885	7,459	8	3.306		119
	Transition	6,501	783	3			125
	Deep	24,960	2,374	0			0
Subtotal number ± 95% confidence interval							244 ± 136
St. George	All	35,441	2,246	8	3.306		639 ± 476
Total number ± 95% confidence interval							883 ± 612

[a] St. George Basin estimate was pooled for all three zones because sample size was small. No estimate was derived for the North Aleutian Basin because numbers of observations were insufficient.

[b] f(0) was derived from 29 perpendicular distances.

[c] Alternative strip transect estimates were 243 ± 120 animals for the Shumagin and 634 ± 442 animals for the St. George Basin Planning Areas.

during good to excellent visibility conditions and sea states between 0 and 2 Beaufort wind scale were included in the analysis. These groups were pooled into one environmental condition category for analysis because there were too few whales recorded to stratify the results by each viewing condition. Eleven total groups in the Shumagin and eight groups in the St. George Basin planning areas were used for the density and abundance estimates.

Density and abundance estimates were derived from the line and strip transect procedures. The f(0) for the line transect procedure was estimated from 29 perpendicular distances of killer whales. Twelve of the 29 distances were extracted from aerial surveys conducted by Brueggeman *et al.* (1984) in the central Bering Sea. These survey procedures were similar to this study and both were conducted from aerial platforms flown at approximately identical altitudes. In addition, the average group sizes were not significantly different ($p < 0.05$). The pooled sighting data were fit to a Fourier series curve to estimate f(0) (Figure 31). The tail of the curve was not truncated because doing so produced a horizontal line. The horizontal line indicated that the probability of detecting a whale was 1.0 within a 0.61-nmi band or 0.305-nmi width per side (Figure 32). This relationship fulfilled the primary assumption for the strip transect procedure. The density, abundance, and associated variance were calculated from the strip transect procedure according to Method I described by Estes and Gilbert (1978). We applied a finite population correction factor to their formula (1) for calculating the variance of the density. This eliminated the need for the area correction factor in their formula (2) for calculating the variance of the abundance. The calculation procedure we followed is given in Appendix B.

Density and abundance estimates for the Shumagin Planning Area were determined for each depth zone and summed. The estimated f(0) and mean group size were assumed to be constant among zones. Density and abundance estimates for the St. George Basin Planning Area were not determined by depth zone but for the entire planning area. The resulting estimates for the Shumagin Planning Area ranged from 243 (±120 SD) using the strip transect method to 244 (±136 SD) using the line transect method. The strip estimates were much higher for the St. George Basin, ranging from 634 (±442 SD) to 639 (±476 SD). These are minimum estimates and do not account for submerged or missed animals.

Discussion

Since little is known about killer whales in the North Pacific and Bering Sea, it is difficult to compare our findings with others to reach conclusions. However, some general conclusions can be made about our results, though it must be recognized that the sample size is relatively small. Killer whales inhabited the planning areas from at least summer through early winter. Braham and Dahlheim (1982) suggested that portions of the killer whales inhabiting the Gulf of Alaska are year-round residents, while some move through the area to other locations. The whales we observed were widely distributed but generally associated with the nearshore water or edge of the continental shelf. These inshore waters likely contain shoaling fishes that Sleptsov (1961) found were common killer whale prey along the north side of the eastern Aleutian Islands and Alaska Peninsula. Sea otters, seals, and sea lions are also prevalent in these areas which, as we observed and others have reported, are prey to killer

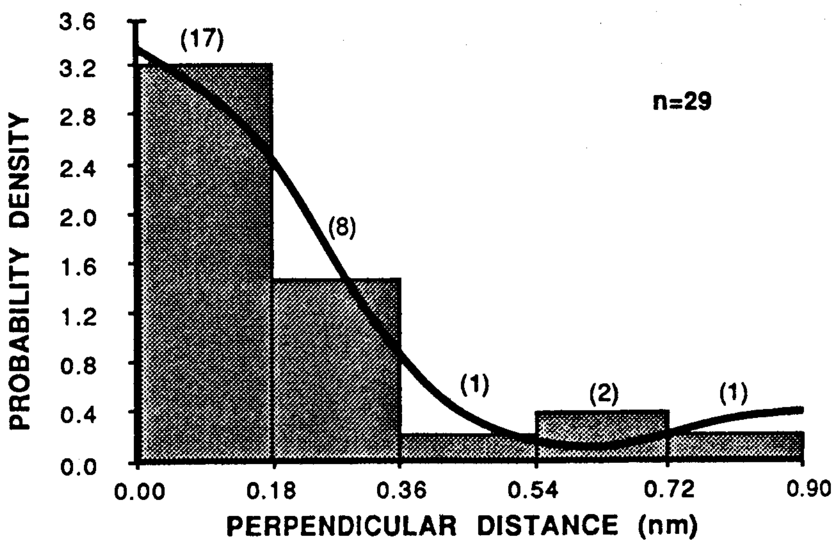

Figure 31.–Probability density function f(0) fit of the Fourier series to a histogram of sighting frequency and perpendicular distance for 29 sightings of killer whales recorded on aerial transect surveys, 1985.

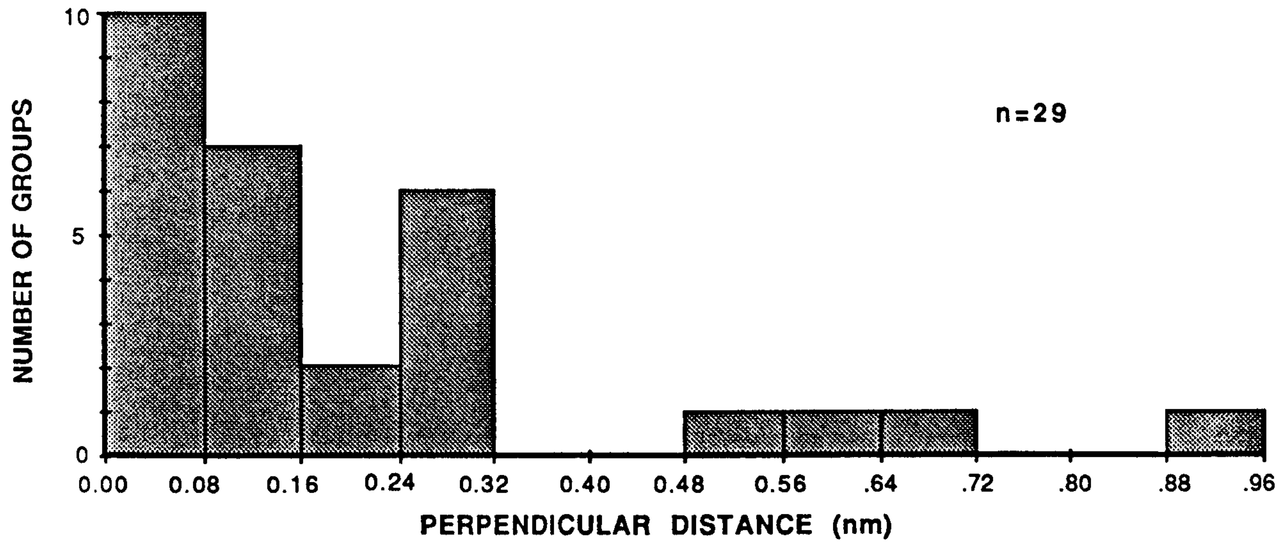

Figure 32.–Frequency histogram of perpendicular distances of killer whale sightings for determining strip width from aerial transect surveys, 1985.

whales (Scheffer and Slipp 1948; Tomilin 1957; Rice 1968; Lowry *et al.* 1987). The mean number of killer whales we estimated in the planning areas was 883 with a range of 271-1,495 animals. Our strip transect estimate fell within this range. The estimate is not unreasonable, considering the size of the planning areas and the high abundance of prey, relative to the previously stated estimates available for much smaller areas such as Prince William Sound and Shelikof Strait.

Sperm, Beaked, Belukha, and Minke Whales

Five species of medium-to-large whales were observed in the project area: (1) sperm, (2) Baird's beaked, (3) Cuvier's beaked, (4) belukha, and (5) minke whales (Figure 33). The number of observations recorded for each of these species was too small for detailed analysis. A brief description of our results, however, is provided below.

Sperm Whale

The sperm whale is the most abundant of the great whales. Their population has been estimated at 274,000 in the eastern North Pacific (Braham 1984*a*), although producing a reliable method for estimating sperm whale numbers has proven difficult (Ohsumi 1980). North Pacific sperm whales are classified as endangered, yet approximately 400 are harvested annually by Japanese whalers under special permit (IWC 1986). This number is down considerably from the 1960s and 1970s when annual harvests ranged from 7,000 to 16,000 (Ohsumi 1980). Nearly 269,000 sperm whales were killed in the North Pacific from 1910 to 1976 (Ohsumi 1980). Approximately 1,000 sperm whales were taken by Alaska shore-based whaling stations operating from 1912 to 1939 (Reeves *et al.* 1985).

Sperm whales are characteristically found in pelagic waters near continental shelf edges (Berzin and Rovnin 1966; Leatherwood and Reeves 1982). They feed largely on squid, although deepwater bottom fish are common in their diet (Caldwell *et al.* 1966; Rice 1978*b*), especially in the eastern North Pacific (Okutani and Nemoto 1964). Males apparently dive deeper, presumably for squid, than the much smaller females (Lockyer 1976). Large bulls have been tracked to depths of 2,500 m (1,367 fathoms) (Leatherwood and Reeves 1982). Mature males are also found at higher latitudes than immature males and females (Pike and MacAskie 1969; Leatherwood and Reeves 1982) during the summer. The northern limit of females and immature males in the North Pacific is approximately 50°N (Berzin and Rovnin 1966; Pike and MacAskie 1969); therefore, only mature males regularly inhabit Alaskan waters. Over 90% of the sperm whales harvested at the Akutan and Port Hobron whaling stations in Alaska were males (Brueggeman, unpubl. data).

In 1985, seven groups of 23 sperm whales were observed in the Shumagin Planning Area (Table 2). One group of five was observed in July and the other six groups in August. The latter were traveling together in groups of one to seven whales. All 23 whales were observed beyond the continental slope in waters approximately 3,500-4,000 m (1,914-2,187 fathoms) deep (Figure 33). Previous studies in the Gulf of Alaska (Consiglieri and Braham 1982; Rice and Wolman 1982) also found most sperm whales near, but beyond, the shelf edge. Berzin and Rovnin (1966) indicated that concentrations of sperm whales are found where there is a large, rapid change in depth, such as occurs near a continental slope or seamount. All our sightings appeared to be groups of large animals that were probably males, which is consistent with reports that only males inhabit Alaskan waters.

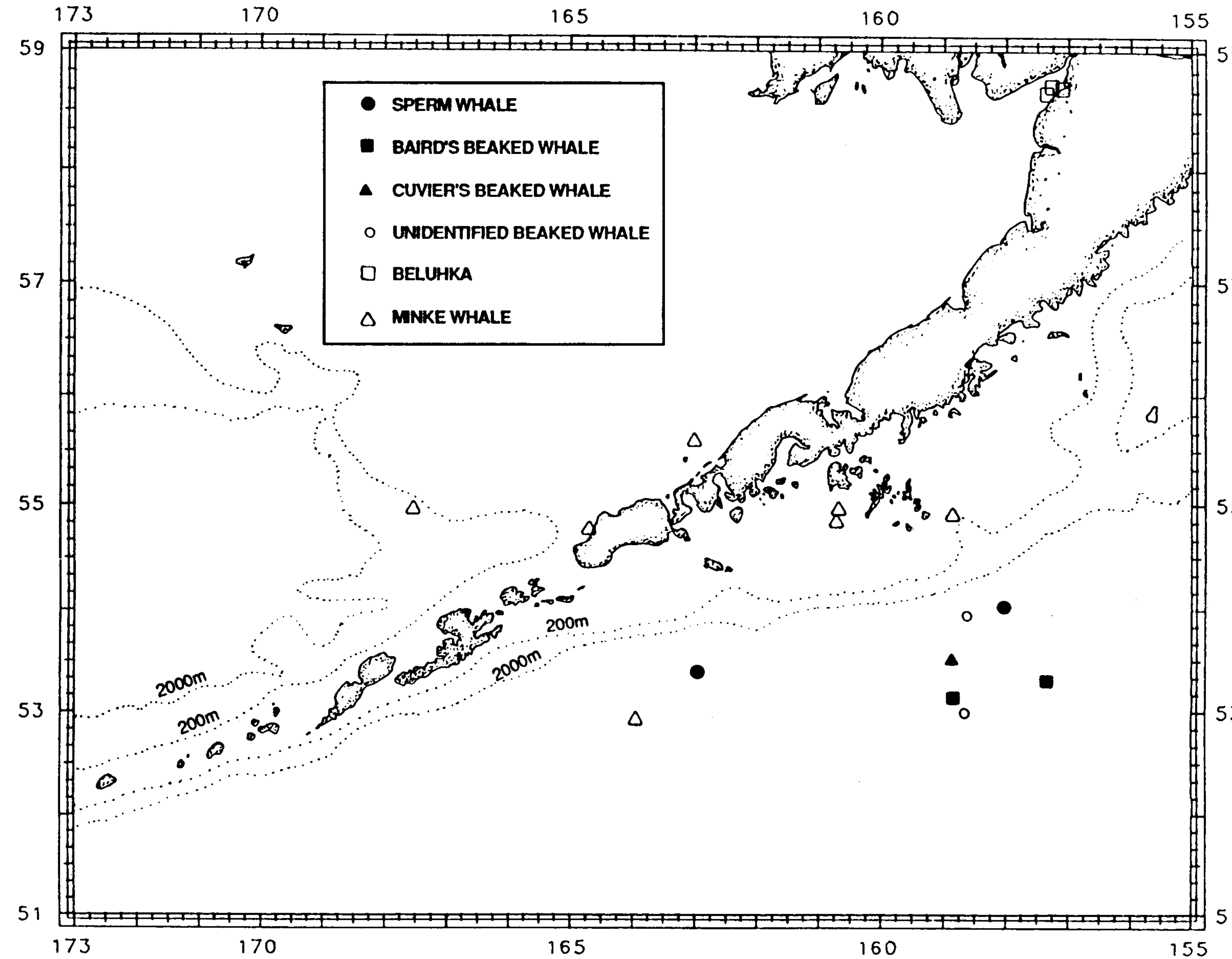

Figure 33.–Locations of the other medium-large whales observed in the study area, 1985.

Beaked Whales

Three species of beaked whales have been identified, usually from strandings, in Alaska waters (Leatherwood *et al.* 1982; 1983). The largest of these is the Baird's beaked whale, which reaches lengths of 12.8 m (42 ft) (Mitchell 1975). Baird's beaked whales have been commercially hunted only on an opportunistic basis in the eastern North Pacific (Leatherwood and Reeves 1982). They have, however, been exploited by small shore-based Japanese fisheries since World War II (Ohsumi 1975; Balcomb and Goebel 1977). Japanese whalers took 37 Baird's beaked whales in 1983 (IWC 1985). Cuvier's beaked whales are smaller, reaching maximum lengths of about 7 m (23 ft) and Stejneger's beaked whales reach 5.3 m (17.4 ft). Virtually nothing is known of the life histories of these two species. Baird's and Stejneger's beaked whales are confined to the North Pacific, including the Bering Sea (Leatherwood *et al.* 1982), while Cuvier's beaked whales are found in most oceans of the world (Moore 1963). Beaked whales are primarily found in pelagic water near shelf edges where they feed on squid and deepwater fish (Mitchell 1975).

Two species of beaked whales were observed in 1985 (Table 2). A group of two Cuvier's beaked whales and two groups of four and five Baird's beaked whales, respectively, were observed in pelagic waters of the Shumagin Planning Area during June and August. There were also two sightings of unidentified beaked whales. All five beaked whale observations were in waters between 4,800 and 5,500 m deep (Figure 33). Rice and Wolman (1982) observed a group of six Cuvier's beaked whales in about 5,400 m (2,952 fathoms) of water southeast of Kodiak Island. However, another Cuvier's beaked whale sighting by Rice and Wolman (1982) and one Baird's beaked whale sighting by Leatherwood *et al.* (1983) in the Gulf of Alaska and southeastern Bering Sea were in shallower waters of 1,110 m and 659 m, respectively.

Belukha Whale

Belukha or white whales are well-adapted for living in arctic waters with their all-white coloration, lack of a dorsal fin, and thick dermis and blubber layer (Leatherwood and Reeves 1982). Belukha whales are circumpolar with the North American arctic population estimated at 30,000 (Sergeant and Brodie 1975). In Alaska there are estimated to be between 150 and 300 belukhas in Cook Inlet and between 1,000 and 1,500 in Bristol Bay (Sergeant and Brodie 1975). These whales feed on a wide variety of fish and invertebrates, usually in waters less than 90 m (50 fathoms) deep (Doan and Douglas 1953). In Alaska, belukhas travel up rivers each summer to feed on returning salmon. This is most evident in the Kvichak River where belukhas have been considered a serious threat to commercial salmon fisheries (Fish and Vania 1971; Frost *et al.* 1984). Belukha whales were once harvested on a large scale, especially in the USSR where annual catches were 3,000-4,000 animals (Mitchell 1975). The annual world catch in recent years has been estimated at between 1,500 and 2,000 (IWC 1985; 1986). Most whales were taken by Denmark, followed by Canadian, Alaskan, and Siberian natives. The annual Alaskan harvest has ranged between approximately 170 and 354 from 1980 to 1984 (IWC 1986).

Five single belukhas were observed in November in Kvichak Bay near the mouth of the Kvichak River (Table 2, Figure 33). Another group of three whales was observed approximately

2 nmi up the Naknek River on the same date. Whales in Kvichak Bay were difficult to see because of muddy water conditions and scattered pancake ice. Belukhas are normally common in this area and reach high numbers there during annual salmon migrations (Fish and Vania 1971; Frost *et al.* 1984).

Minke Whale

Minke whales, the smallest of the baleen whales, are found worldwide. Today they are the mainstay of the whaling industry, since the stocks of larger whales are depleted. The annual take in Antarctica is around 6,000 animals and another 2,000-3,000 are taken in the rest of the world (IWC 1986). Korean and Japanese shore stations take nearly 800 each year from the North Pacific (IWC 1986). Scheffer (1976) estimated the species' world population at 340,000.

Minke whales are commonly found in Alaska during the summer. They are a coastal species usually occurring within the 200-m (109-fathom) depth contour (Tomilin 1957; Morris *et al.* 1983). Minke whales feed mainly on euphausids and schooling fish (Nemoto 1959; 1970). They are difficult to observe because of their small size (8-10 m) and low, inconspicuous blow (Leatherwood *et al.* 1982).

Minke whales were observed in all three planning areas (Table 2). Eight single animals were observed from July to late October. Six sightings were in shallow water (<200 m) and two in deep water (>1,000 m) (Figure 33). All whales observed were traveling. Nine additional singles were observed during sea otter surveys in 1986. Six were observed in the North Aleutian Basin Planning Area and three in the Shumagin Planning Area during June, July, August, and October. Aerial surveys in 1986 were flown 137 m (450 ft) lower in altitude than the 1985 surveys, which may have facilitated detecting minke whales.

Although all of the minke sightings were singles, three animals were observed within a 2-km radius of each other near the mouth of Cold Bay. Rice and Wolman (1982), Leatherwood *et al.* (1983), and Brueggeman *et al.* (1984) also observed a high occurrence of single minke whales in the North Pacific and Bering Sea. All 37 minke whales observed by Rice and Wolman (1982) in the Gulf of Alaska, 8 by Brueggeman *et al.* (1984) in the Bering Sea, and 39 of 46 (mean = 1.18) by Leatherwood *et al.* (1983) were singles. Furthermore, two cow-with-calf pairs were observed by Leatherwood *et al.* (1983). No calves were observed during our surveys.

Consiglieri and Braham (1982) reported that minke whales were virtually absent from the Gulf of Alaska by fall (October-December). Only three sightings recorded from the Platforms of Opportunity Program since 1958 were made during this period (Consiglieri and Braham 1982). Conversely, 7 of the total 17 (41%) sightings in this study during 1985 and 1986 were between 8 and 30 October. Leatherwood *et al.* (1983) and Brueggeman *et al.* (1984) observed minke whales during the fall, and even the winter, in the Bering Sea and Shelikof Strait. Consequently, minke whales are probably present in the Gulf of Alaska and Alaska Peninsula waters year-round in small numbers.

Dall Porpoise and Harbor Porpoise

Two species of small whales or porpoises were observed in the study area: Dall and harbor porpoises. The small size of these animals precluded an accurate census from the survey altitude we flew. The observations were, therefore, incidental to the endangered whale survey. A brief description of the survey results is provided below for each species.

Dall Porpoise

Dall porpoises are a ubiquitous delphinid endemic to the North Pacific. The population is estimated at over 1 million animals with as many as 250,000 in the Gulf of Alaska alone (Bouchet 1981). Dall porpoises are common both over the continental shelf and offshore but are found inshore more often during the summer (Hall 1979). They are taken both commercially and incidentally by Japanese fisheries. The 1983 commercial take was 12,766 porpoises and the incidental take, mostly by Japanese high-seas salmon drift net fisheries, was 3,082 (IWC 1985). The actual annual incidental takes, however, may reach 20,000 animals (NMML 1981).

Dall porpoises feed on schooling fish such as capelin, hake, arctic cod, and herring (Scheffer 1949, 1953; Sleptsov 1961), but squid may be their principal food (Tomilin 1957; Pike and MacAskie 1969). Groups of Dall porpoises usually range from 2 to 10 animals, with a mode of about 4, although groups of over 200 have been reported (Morris *et al.* 1983).

In 1985, we sighted 50 groups of 157 Dall porpoises (Table 19) distributed throughout all three planning areas (Figure 34). The highest observed density (number per 1,000 nmi) of Dall porpoises occurred in the St. George Basin Planning Area with 2.232 groups observed per 1,000 nmi surveyed. Densities in the other two planning areas were similar to each other: 0.998 groups per 1,000 nmi for the Shumagin and 0.869 groups per 1,000 nmi for the North Aleutian Basin. Densities by depth zone were examined in the Shumagin Planning Area. In the shallow water depth zone (<200 m) groups of Dall porpoises were encountered at a rate of 0.946 per 1,000 nmi. The densities in the transition (200-2,000 m) and deep (>2,000 m) water zones were much higher: 3.650 groups per 1,000 nmi and 3.193 groups per 1,000 nmi, respectively. This supports previous observations by other researchers (Morris *et al.* 1983; Leatherwood *et al.* 1983) that Dall porpoises are most abundant in deep pelagic waters and along continental shelf edges. We were not able to examine depth zone by season because of too few fall sightings in the Shumagin Planning Area.

Dall porpoises were observed during all survey periods except April-May and November (Table 19). Sixty-two percent (31) of the groups were observed during the summer survey periods, 10% in October (5), and 28% in December (14). An additional 26 groups of 44 individuals were sighted during the 1986 sea otter surveys, with all but one observed in the North Aleutian Planning Area. Ninety-six percent of these groups were observed between 29 June and 21 August. No Dall porpoises were observed in March during the sea otter survey and only a single animal was observed during October. Because all of the 1986 surveys were conducted in shallow water, the lack of spring and fall sightings perhaps suggests a seasonal inshore-offshore migration such as Leatherwood and Fielding (1974) have described in southern

Table 19.—Survey effort (nmi) and number of Dall porpoises observed in the three planning areas.[a]

	Shumagin			North Aleutian Basin			St. George Basin			Total		
Period	Effort	No.	Group	Effort	No.	Group	Effort	No.	Group	Effort	No.	Group
April–May	1,576	0	0	0	—[b]	—	0	—	—	1,576	0	0
June–July	2,205	5	3	3,082	0	0	2,389	15	5	7,676	20	8
July–August	7,092	12	4	0	—	—	0	—	—	7,092	12	4
August	4,887	37 (32)	12 (7)	173	0	0	0	—	—	5,060	37 (32)	12 (7)
October	5,860	9	5	0	—	—	0	—	—	5,860	9	5
November	2,201	0	0	2,353	0	0	858	0	0	5,412	0	0
December	1,238	8	1	2,453	21	7	1,683	18	6	5,374	47	14
Total	25,059	71 (32)	25 (7)	8,061	21	7	4,930	33	11	38,050	125 (32)	43 (7)

[a] Number in parentheses is additional animals counted on deadhead surveys.

[b] Dash (—) signifies area was not surveyed.

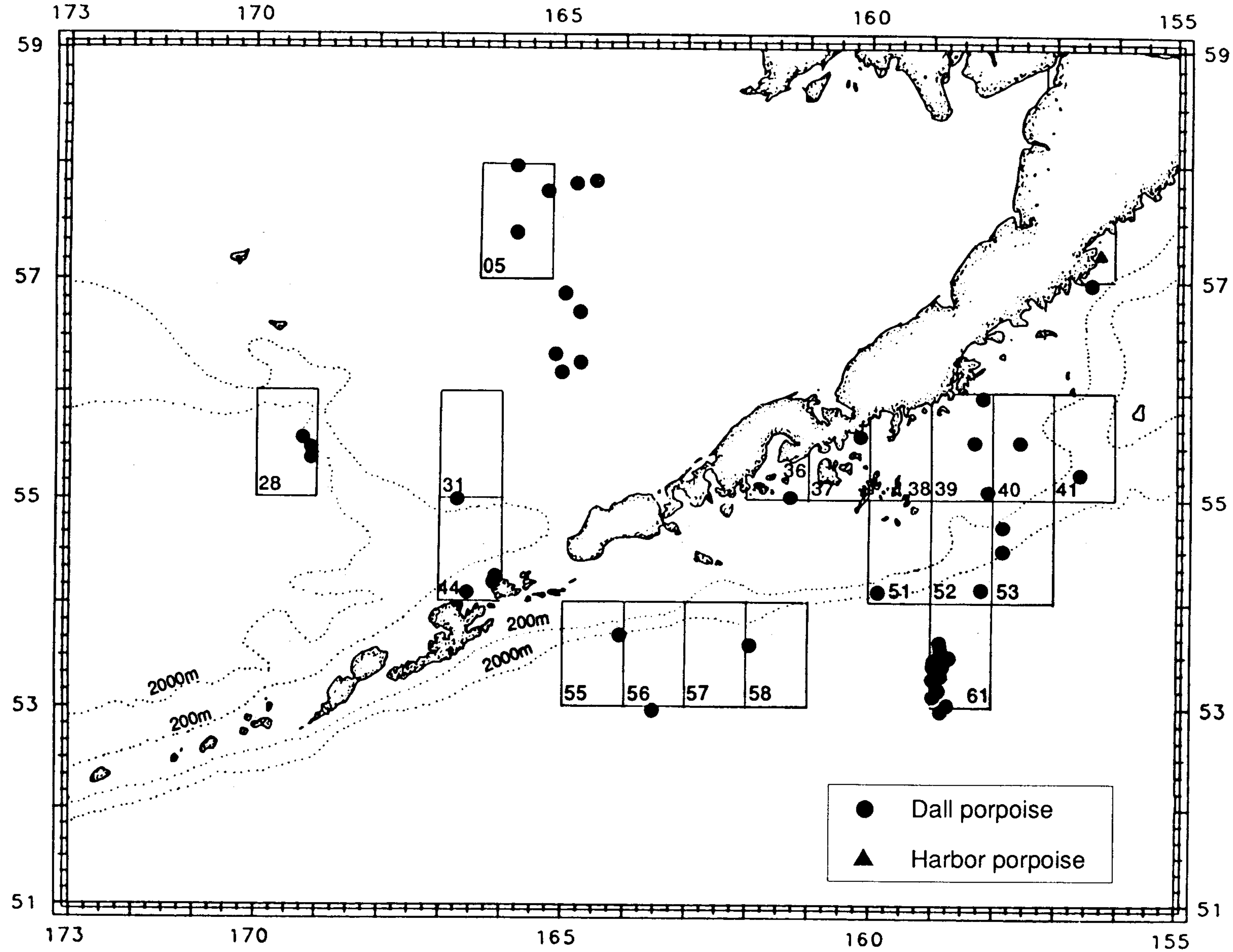

Figure 34.-Locations of Dall and harbor porpoises observed in the study area, 1985.

California. Others (Fiscus and Niggol 1965; Hall 1979) have also suggested a winter movement offshore.

Harbor Porpoise

Harbor porpoises are shy, inconspicuous delphinids which inhabit the coastal waters of the North Pacific and Bering Sea. They are generally found in waters less than 20 m (11 fathoms) deep (Leatherwood and Reeves 1978) and feed on a wide variety of schooling fish, including salmon (Tomilin 1957; Smith and Gaskin 1974). No population estimates exist for the North Pacific or the Bering Sea, except for Prince William Sound where Hall (1979) estimated a summer population of 946.

During 1985, we observed only one harbor porpoise (Figure 34). We attribute our lack of sightings to the difficulty of detecting these animals from the 230 m (750 ft) altitude flown during the endangered cetacean surveys. We saw a marked increase in the number of harbor porpoise sightings during the 1986 sea otter surveys, which were flown at 90 m (300 ft). Fifty-three groups composed of 94 individuals were observed during those surveys. Harbor porpoises were commonly sighted during all 1986 survey periods (March-October) and 70% were observed in the North Aleutian Planning Area. We also received reports of influxes of harbor porpoises at Nelson Lagoon during the sockeye salmon runs (M. Mack, pers. commun.). A more comprehensive analysis of the Dall and harbor porpoise data will appear in a later report which will combine the 1985 and 1986 survey results.

Unidentified Whales

Thirty-four groups of 48 unidentified baleen whales were recorded in the three planning areas (Table 2). The distribution of these animals is given in Figure 35. An additional 16 groups of 24 unidentified porpoises and 2 groups of 4 unidentified beaked whales were recorded during the surveys (Table 2).

Whales Expected But Not Observed in Study Area

Blue Whale

Blue, sei, and right whales historically inhabited the waters off the Alaska Peninsula and eastern Aleutian Islands, but none were observed during our surveys. The pre-exploitation size of the North Pacific blue whale population has been estimated at between 4,500 and 5,000 animals (Ohsumi and Wada 1972; Tillman 1975; Gambell 1976; Braham 1984*a*). Prior to receiving protection in 1967, the population was severely depleted by commercial whalers, using the modern whaling methods of the 1900s; blue whales were too swift and powerful for nineteenth century whalers to chase with their open boats and kill with their hand-thrown harpoons (Rice 1974; Tonnessen and Johnsen 1983). The current population size is estimated at 1,400-1,900 animals (Tillman 1975; Gambell 1976; Braham 1984*a*), and the data indicate that the North Pacific population has increased since receiving protection (Ohsumi and Wada 1972).

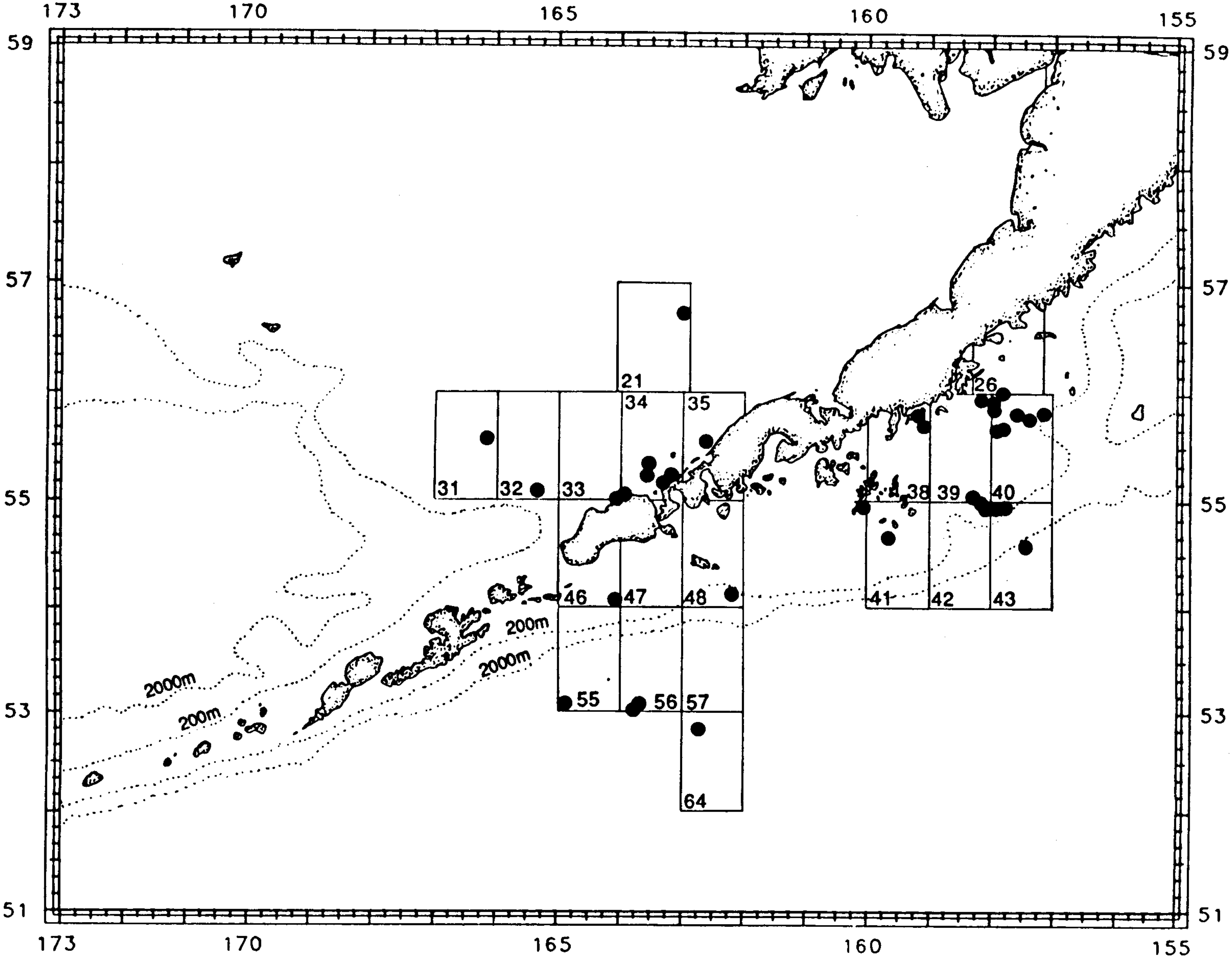

Figure 35.–Locations of unidentified baleen whales observed in the study area, 1985.

The commercial catch records from the shore-based stations operating off Akutan Island and Sitkalidak Island (Port Hobron, near Kodiak Island) show that substantial numbers of blue whales were harvested between 1917 and 1939 (Brueggeman *et al.* 1985). A total of 835 blue whales were harvested off Akutan and 218 blue whales were harvested off Sitkalidak Island. No whales were taken in the Bering Sea from the Akutan station, which supports the contention that few blue whales occur north of the Aleutians and Alaska Peninsula (Nishiwaki 1966). The majority of the blue whales harvested were located within the boundaries of the area we surveyed.

The absence of sightings from our surveys suggests that the number of blue whales using the Alaska Peninsula and eastern Aleutian Island waters is small, and the population has not recovered from commercial exploitation.

Sei Whale

The pre-exploitation sei whale population for the North Pacific was estimated at 45,000 whales (Ohsumi and Fukuda 1975; Braham 1984*a*). The sei whale was not heavily harvested in the North Pacific until around 1963 when the finback and blue whale stocks were severely depleted. Sei whale catches by Japanese and Soviet fleets in the North Pacific and Bering Sea increased from 260 animals in 1962 to over 4,500 animals in 1968 and 1969 after which catches declined rapidly until the species received protection in 1976 (Mizroch *et al.*, 1984). The current sei whale population size in the North Pacific is estimated between 22,000 and 37,000 animals (Braham 1984*a*).

The summer feeding grounds of the sei whale include the boundaries of the project area (Nishiwaki 1966). Rice (1974) reported that sei whales rarely occur north of the Aleutian Islands. Catch locations of almost 900 sei whales harvested east of 180° by the Japanese between 1952 and 1962 show that the animals were widely distributed along the south side of the Alaska Peninsula and Aleutian Islands (Nishiwaki 1966). Recent surveys of this area by Rice and Wolman (1982) yielded no sei whale sightings, while Leatherwood *et al.* (1983) found one sei whale in the southwestern Bering Sea.

The absence of sei whale sightings during our surveys and those of other investigators, suggests that few sei whales summer in the project area. Sei whales, however, may have been unnoticed during the surveys since they travel in small groups (Tomilin 1957) which are difficult to detect from an airplane, and they are not readily distinguished from finback whales. While these factors may account for some missed sei whales, the results support the conclusion that sei whales are not abundant in the project area.

Right Whale

During the 19th century, commercial whalers almost completely exterminated the North Pacific right whale population (Rice 1974). An estimated 15,451 right whales were taken in the North Pacific between 1935 and 1969 (DuPasquier 1986). The intensity of the hunt was so great that between 1846 and 1851 an estimated 300-400 ships were taking right whales on the

Kodiak Grounds (Gilmore 1978). An indication of how close the whalers came to exterminating the population is that only 24 right whales are know to have been killed in Alaska and British Columbia between 1905, when modern whaling methods were introduced on the West Coast, and 1935, when the species was protected (Rice 1974). Although scattered sightings of right whales have been recorded since 1937 (Nasu 1960, 1963; Omura *et al.* 1969; Pike and MacAskie 1969; Brueggeman *et al.* 1984; Scarff 1986), the North Pacific population has never recovered from exploitation and is presently estimated to number 100-200 animals (Tillman 1975; Gambell 1976; Wada 1979).

The project area occurs within the historic summer range of right whales in the eastern North Pacific Ocean (Townsend 1935). Right whales summered primarily north of 50°N but were particularly abundant in the "Kodiak Grounds" which encompassed the Gulf of Alaska from Vancouver Island to the eastern Aleutians (Scammon 1874; Townsend 1935; Berzin and Rovnin 1966; Rice 1974). Some whales also frequented the Bering Sea, primarily in the southeastern corner from Alaska to St. Matthew and Nunivak islands (Townsend 1935; Berzin and Rovnin 1966; Berzin and Doroshenko 1982).

Right whales have been harvested or sighted in the region of the study area since the period of heavy exploitation in the 1800s. Shore-based whaling stations at Akutan Island and Port Hobron harvested 20 right whales between 1917 and 1935 (Brueggeman *et al.* 1986). Nine additional right whales were harvested by the Japanese by special permit during 1961, 1962, and 1963 off Kodiak Island and north of the eastern Aleutian Islands (Omura *et al.* 1969). Seventeen more right whales were observed during Japanese sighting cruises north of 50°N and east of 180°W between 1965 and 1979 (Scarff, 1986). There have been no confirmed sighting of right whales in the region of the study area since the 1970s, although Brueggeman *et al.* (1984) observed two right whales in the Bering Sea northwest of St. Matthew Island in 1983.

The absence of sightings, combined with the intensive effort of our surveys, confirms that right whales have not recovered from commercial exploitation.

SUMMARY AND CONCLUSIONS

Four of seven endangered cetaceans which historically occurred in the northwestern Gulf of Alaska and southeastern Bering Sea were encountered during seven aerial surveys conducted from April through December in these waters during 1985 (Table 20). Humpbacks were present from June to November, finbacks June to August, and sperm whales during July and August. Humpback and finback whales were observed feeding in the study area and sperm whales were presumed to also be feeding. Gray whales were observed migrating through the study area in April and May, and November and December. Small numbers were also observed feeding in the study area during June through August. We estimated that 333 ± 217 humpbacks and 184 ± 90 finbacks summered in the study area. These estimates are conservative since they were not corrected for missed animals. There were too few sperm whales observed and gray whales were too transitory to develop abundance estimates. Although we did not observe blue, sei, or right

Table 20.–Survey periods cetaceans were observed in the study area, 1985.

Species/status	Apr-May	Jun-Jul	Jul-Aug	Aug	Oct	Nov	Dec
Endangered species							
Humpback whale		X	X	X	X	X	
Finback whale			X	X			
Gray whale[a]	X	X				X	X
Sperm whale			X	X			
Other cetaceans							
Minke whale		X	X		X		
Cuvier's beaked whale		X		X			
Baird's beaked whale				X			
Belukha whale						X	
Killer whale	X	X	X			X	X
Harbor porpoise			X				
Dall porpoise	X	X	X	X			X

[a] Gray whales were also observed during the months of March, June, July, and August during 1986 sea otter surveys.

whales, these species historically summered in the project area but were exploited to such low levels that the likelihood of encountering them was small.

Seven species of whales that are not listed as threatened or endangered by the Federal Government were also observed in the study area. Killer whales and Dall porpoises were observed essentially throughout the entire survey period which suggested that these species are probably year-round residents. We estimated that 883 ± 612 killer whales occurred in the study area. No estimate was developed for Dall porpoises since the survey altitude was too high for accurately detecting this species. Other cetaceans observed included minke, beaked (Cuvier's, Baird's), and belukha whales and harbor porpoises, but too few of these species were observed to estimate abundances.

The species of cetaceans observed in the project area were unequally distributed among the three planning areas. Humpback, finback, and sperm whales were recorded only in the Shumagin Planning Area. Gray whales occurred in the Shumagin and North Aleutian Basin during the migration periods. Gray whales also summered in both planning areas, although 13 of the 15 animals were in the North Aleutian Basin.

These observed distributions are generally more restrictive than has been historically reported. Berzin and Rovnin (1966) and Nishiwaki (1966) reported that relatively large numbers of finback and humpback whales were harvested or sighted in areas of the Bering Sea corresponding to the St. George and North Aleutian Basin planning areas, as well as the Shumagin region of the North Pacific, by Japanese and Russian whaling fleets between 1958 and 1964. More recently, Leatherwood *et al.* (1983) observed small numbers of humpbacks in the St. George Basin and finbacks in both the St. George and the North Aleutian basins. Braham (1984*b*) reported that gray whales seen near the Pribilof and St. Matthew islands may demonstrate that not all whales strictly follow the coastline past Unimak Pass but may move offshore through the St. George Basin. These observations identify a wider distribution than we report for humpback, finback, and gray whales. However, our finding that sperm whales do not summer north of the Alaska Peninsula or the eastern Aleutians coincides with the historic distribution of sperm whales (Berzin and Rovnin 1966). While our results generally confirm findings of other investigators, they also indicate that finback and humpback whales have not reinhabited the summer feeding grounds to historic levels.

Of the seven nonendangered species of whales, minke and killer whales and Dall porpoises were generally widespread in all three planning areas. Gross densities (number per nmi) not adjusted for visibility or sea state suggest that the St. George Basin supports the highest densities of these three species. The North Aleutian Basin had the lowest densities of killer whales and Dall porpoises, whereas the Shumagin Planning Area had the lowest density of minke whales. Of the remaining four species, all but the belukha whale were recorded in the Shumagin Planning Area. Belukhas were found only in the North Aleutian Basin. The observed distributions of these species generally agree with findings of other investigators (Leatherwood *et al.* 1983); however, a summary of beaked whale stranding and sighting records by Leatherwood *et al.* (1983) showed Baird's and Cuvier's beaked whales occurring in both Bering Sea planning areas. Furthermore they reported relatively large numbers of harbor porpoises in these two planning areas. Consequently, our findings combined with those of other investigators show that beaked and minke whales probably occur in all planning areas in small numbers. Dall porpoises, harbor porpoises, and killer whales are similarly widespread but occur in much larger numbers. Belukhas are primarily found in eastern Bristol Bay.

The distribution of whales in the planning areas generally corresponded to their feeding habits. The endangered species of whales were primarily distributed on the outer continental shelf. Gray, humpback, and finback whales predominantly occurred on or near the shelf waters while sperm whales occurred in deep water outside the shelf. Grays migrated in the nearshore waters less than 40 m deep, while those summering in the study area were generally occurred in bays, lagoons, or nearshore waters. This coastal affinity has been reported in other investigations of gray whales, which typically feed on benthic organisms in shallow waters (<60 m).

While some overlap occurred between distributions of humpback and finback whales, the two species generally used separate feeding areas and geographic ranges. Humpback and finback whales were generally associated with areas of sharp relief near the 50-fathom (91-m) contour on the shelf. Humpbacks were closely associated with oceanic banks while finbacks were more associated with the sharp relief of submarine canyons. (Both of these high relief areas create upwelling which typically supports high production of the zooplankton and fish that humpback and finback whales prey upon.) Furthermore, humpback distribution tended to be greater to the west of the Shumagin Islands, whereas finback distribution was greater to the east.

Sperm whales occurred outside the shelf area in waters exceeding 3,000 fathoms (5,487 m). Sperm whales feed on squid, which are commonly associated with deeper water. Consequently, these four species appeared to partition their use of habitats in the project area.

The nonendangered species distributed themselves somewhat differently among the three water depth zones. The beaked whales occurred exclusively in the deep water zone outside the shelf, where they feed on pelagic schooling fishes. Conversely, killer whales were observed primarily on the shelf, where they feed on pinnipeds and fishes typically associated with nearshore areas. Dall porpoises were encountered in all three zones, a finding which suggests that this species is a more generalistic feeder than the other species. Braham *et al.* (1983) and Leatherwood *et al.* (1983) identified a similarly wide distribution of this species but reported that Dall porpoises were most abundant in deep pelagic water and in areas along the outer continental shelf break. Minke whales were also widely distributed in the three zones. Other investigators report that minke whales inhabit both shallow shelf waters and deep waters (Fiscus *et al.* 1976; Leatherwood *et al.* 1983) but tend to be more prevalent on the shelf waters (Braham *et al.* 1982). Lastly, both harbor porpoises and belukha whales occurred on the shelf in nearshore areas. Belukhas were associated with mouths of rivers in eastern Bristol Bay, where they feed on fish, while the single harbor porpoise observed during our surveys was close to shore. A subsequent sea otter survey conducted in 1986 recorded 53 total groups of harbor porpoises in the shallow shelf waters. Leatherwood *et al.* (1983) similarly reported high occurrences of harbor porpoises on the shelf waters. These results show that cetaceans occurred across all three water depth zones, but the areas on or near the shelf supported the highest diversity of whales.

In conclusion, the results show that a variety of cetaceans inhabit the study area both seasonally and annually. The four endangered species use the area seasonally for feeding and during migration periods. The North Aleutian Basin serves primarily as a migration corridor for gray whales while the Shumagin Planning Area is an important feeding area for humpback, finback, and to a lesser degree, sperm whales. There were no observations of these species in the St. George Basin, although finback whales historically migrated through this basin. The nearshore areas of the North Aleutian Basin and Shumagin planning areas provided important habitat to migrating gray whales. Furthermore, these nearshore areas and bays were important feeding habitat for small numbers of gray whales, particularly in the North Aleutian Basin. Conversely, the high relief areas associated with the oceanic banks and submarine canyons near the outer continental shelf on the Shumagin Planning Area were important habitat to humpback and finback whales. These two species also fed around the island complexes in the planning areas. Sperm whales were outside the shelf in deep waters south of the Alaska Peninsula. Gray whales were probably the most abundant species, although they were primarily transitory. Of the endangered whales feeding in the study area, humpbacks represented the highest number, followed by finbacks and then sperm whales.

The seven nonendangered species inhabit the study area seasonally and some probably annually. Our results combined with others indicate that killer whales, minke whales, Dall porpoises, and harbor porpoises annually occupy the study area. Minke whales and Dall porpoises were probably the most widespread species in the three planning areas, while killer whales and harbor porpoises were more restricted to the shallow shelf waters. Too few belukhas and beaked whales were observed to derive conclusions; however, large concentrations of belukhas are known to summer in eastern Bristol Bay and probably small numbers of beaked whales summer throughout the deeper waters in all three planning areas.

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APPENDIX A

Statistical abbreviations.

$\bar{a}$	Sampling mean of measurements on a circular scale
A_i	Area of planning area i
B	Number of sampling blocks available for survey
b	Number of sampling blocks surveyed
D_i	Density estimator of animal groups in sampling block i
D_{wi}	Weighted density estimator of animal groups in sampling block i
f(0)	Probability density function at zero distance from the trackline
f(x)	Probability density function of perpendicular distances
G	Number of animal groups
$\bar{k}$	Average group size
K_i	Number of animals in group i
L_i	Length of trackline searched in sampling block i
n_i	Number of animal groups in sampling block i
N_G	Estimated number of animal groups in study area
N_I	Estimated number of individual animals in study area
$V(D_{wi})$	Sampling variance of weighted density
$V(N_I)$	Sampling variance of estimated number of individuals in study area
V [f(0)]	Sampling variance of the probability density function of zero distance from the trackline
z	Test statistic for circular data

APPENDIX B

Strip transect procedure followed for calculating killer whale density, abundance, and associated variance.

Estimated density: $D_i = \dfrac{\Sigma\, n_i}{\Sigma\, x_i}$

where:

n_i = number of groups in box i of zone i

x_i = area of strip in box i of zone i

Estimated number of groups: $N_G = \sum_{i=1}^{3} D_i\, A_i$

where: A_i = area of zone i

Estimated number of individuals: $N_I = N_G\, \bar{k}$

where: $\bar{k}$ = mean group size

Estimated variance for density of groups:

$$V(D_i) = \left[\left[\sum_{i=1}^{b} (n_i/x_i) - D_i \Sigma n_i\right] / (b-1)\Sigma x_i\right] * \frac{B-b}{B-1}$$

where:

b = number of boxes surveyed in zone i

B = number of boxes in zone i

Estimated variance for number of individuals:

$$V(N_I) = \sum_{i=1}^{3} [A_i^2 V(D_i)] \bar{k}^2 + \sum_{i=1}^{3} [(A_i D_i)^2 V(\bar{k})]$$

$$- \sum_{i=1}^{3} [A_i^2 V(D_i)] V(\bar{k})$$

95 percent confidence interval $N_I \pm 2 \sqrt{V(N_I)}$

APPENDIX C

Visibility and glare criteria.

Table C-1. Criteria used to determine relative visibility.

Visibility	Highest Allowed Beaufort Sea State	Descriptors
Excellent	1	Calm and clear
Very Good	2	Surface ripple, some glare.
Good	4	Light chop, glare, fog
Fair	5	Chop, glare, shadows, fog but all animals on line visible
Poor	5	Same as Fair only some animals on line obscured
Unacceptable	--	Survey tract obscured

Table C-2. Criteria used to classify glare.

Glare Number	Percent area obscured by sun reflection, fog, or moisture on window surface
1	1 - 10 percent
2	11 - 25 percent
3	26 - 50 percent
4	51 - 75 percent
5	76 - 100 percent

APPENDIX D

Record of whales encountered in southeastern Bering Sea and northwestern Gulf of Alaska during April-December 1985.

Month/Day/Year	Number	Species[a]	Latitude	Longitude
7/02/85	1	BA	5500N	16735W
7/02/85	1	BA	5446N	16435W
7/02/85	1	BA	5446N	16435W
7/03/85	1	BA	5535N	16258W
7/23/85	1	BA	5259N	16351W
10/30/85	1	BA	5459N	16045W
10/30/85	1	BA	5458N	16044W
10/30/85	1	BA	5458N	15855W
6/28/85	5	BB	5418N	15727W
8/26/85	4	BB	5308N	15855W
7/24/85	3	BP	5459N	15809W
7/24/85	1	BP	5456N	15809W
7/24/85	2	BP	5444N	15809W
7/24/85	3	BP	5444N	15809W
7/24/85	2	BP	5444N	15808W
7/24/85	3	BP	5444N	15808W
7/24/85	3	BP	5444N	15809W
7/26/85	1	BP	5511N	15945W
7/26/85	1	BP	5517N	15949W
7/26/85	1	BP	5517N	15951W
8/ 2/85	3	BP	5546N	15858W
8/ 2/85	2	BP	5535N	15757W
8/ 2/85	4	BP	5534N	15757W
8/ 2/85	2	BP	5534N	15757W
8/ 2/85	3	BP	5534N	15751W
8/ 2/85	3	BP	5534N	15754W
8/ 2/85	2	BP	5533N	15754W
8/ 2/85	2	BP	5539N	15745W
8/ 2/85	1	BP	5536N	15747W
8/ 2/85	2	BP	5550N	15739W
8/ 2/85	4	BP	5551N	15733W
8/ 2/85	1	BP	5550N	15733W
8/ 2/85	3	BP	5549N	15733W
8/ 2/85	2	BP	5548N	15731W
8/ 2/85	2	BP	5548N	15731W
8/ 2/85	3	BP	5548N	15731W
8/ 2/85	4	BP	5548N	15731W
8/ 2/85	3	BP	5551N	15730W
8/ 2/85	2	BP	5551N	15730W
8/ 2/85	1	BP	5552N	15730W
8/ 4/85	1	BP	5455N	15752W
8/ 4/85	1	BP	5456N	15744W
8/21/85	2	BP	5548N	15703W

[a]Species Codes:

BA=Minke whale
BB=Baird's Beaked whale
BP=Fin whale
DL=Belukha whale
ER=Gray whale
MN=Humpback whale
OO=Killer whale
PC=Sperm whale
PD=Dall's porpoise
PP=Harbor porpoise
ZC=Cuvier's Beaked whale

Month/Day/Year	Number	Species	Latitude	Longitude
8/21/85	2	BP	5558N	15703W
8/21/85	6	BP	5600N	15703W
8/21/85	2	BP	5603N	15704W
8/21/85	1	BP	5604N	15706W
8/21/85	4	BP	5547N	15709W
8/21/85	1	BP	5544N	15715W
8/21/85	2	BP	5547N	15715W
8/21/85	2	BP	5547N	15715W
8/21/85	1	BP	5548N	15715W
8/21/85	2	BP	5602N	15716W
8/21/85	2	BP	5549N	15721W
8/21/85	1	BP	5548N	15715W
8/21/85	2	BP	5547N	15716W
8/21/85	1	BP	5547N	15721W
8/21/85	1	BP	5547N	15721W
8/27/85	2	BP	5556N	15757W
8/27/85	1	BP	5600N	15745W
8/27/85	1	BP	5600N	15745W
8/27/85	2	BP	5558N	15745W
8/27/85	2	BP	5557N	15745W
8/27/85	1	BP	5547N	15739W
8/27/85	2	BP	5548N	15739W
8/27/85	4	BP	5559N	15739W
8/27/85	2	BP	5600N	15739W
8/27/85	2	BP	5600N	15739W
8/27/85	1	BP	5600N	15739W
8/27/85	1	BP	5600N	15733W
8/27/85	1	BP	5544N	15733W
8/27/85	2	BP	5546N	15736W
8/28/85	2	BP	5459N	16209W
8/28/85	1	BP	5551N	15803W
8/28/85	2	BP	5551N	15803W
8/28/85	1	BP	5551N	15803W
8/28/85	1	BP	5603N	15809W
8/28/85	1	BP	5601N	15809W
8/28/85	1	BP	5558N	15809W
8/28/85	1	BP	5558N	15809W
8/28/85	4	BP	5557N	15809W
8/28/85	2	BP	5553N	15809W
8/28/85	5	BP	5538N	15809W
8/30/85	1	BP	5528N	15844W
11/12/85	1	DL	5839N	15719W
11/12/85	1	DL	5839N	15719W
11/12/85	1	DL	5840N	15719W
11/12/85	1	DL	5840N	15719W
11/12/85	1	DL	5840N	15719W
11/12/85	3	DL	5843N	15700W
4/28/85	2	ER	5440N	16326W
4/28/85	1	ER	5437N	16340W
4/28/85	4	ER	5423N	16434W
4/28/85	8	ER	5425N	16433W
4/28/85	7	ER	5425N	16432W
4/28/85	2	ER	5426N	16427W
4/28/85	1	ER	5427N	16424W
4/28/85	16	ER	5428N	16421W

Month/Day/Year	Number	Species	Latitude	Longitude
4/28/85	2	ER	5430N	16419W
4/28/85	1	ER	5438N	16343W
4/28/85	5	ER	5438N	16341W
4/28/85	4	ER	5438N	16339W
4/28/85	4	ER	5438N	16333W
4/28/85	1	ER	5439N	16330W
4/28/85	3	ER	5440N	16309W
4/28/85	4	ER	5457N	16244W
5/ 1/85	1	ER	5453N	16212W
5/ 1/85	1	ER	5451N	16213W
5/ 1/85	5	ER	5449N	16216W
5/ 1/85	1	ER	5448N	16217W
5/ 1/85	1	ER	5308N	16227W
5/ 1/85	3	ER	5454N	16227W
5/ 1/85	2	ER	5500N	16213W
5/ 1/85	7	ER	5503N	16201W
5/ 1/85	2	ER	5506N	16156W
5/ 1/85	3	ER	5513N	16151W
5/ 1/85	2	ER	5515N	16150W
5/ 1/85	3	ER	5517N	16148W
5/ 1/85	7	ER	5502N	16146W
5/ 3/85	2	ER	5525N	16059W
5/ 3/85	1	ER	5502N	16140W
5/ 3/85	2	ER	5503N	16200W
5/ 4/85	2	ER	5538N	16009W
5/ 4/85	1	ER	5540N	15958W
5/ 4/85	2	ER	5458N	15918W
5/ 4/85	3	ER	5543N	15922W
5/ 4/85	2	ER	5556N	15853W
5/ 4/85	2	ER	5555N	15839W
5/ 4/85	1	ER	5558N	15834W
6/29/85	1	ER	5516N	16258W
7/06/85	1	ER	5634N	15946W
11/13/85	1	ER	5509N	16315W
11/14/85	1	ER	5504N	16353W
11/14/85	4	ER	5550N	16215W
11/16/85	1	ER	5503N	16344W
11/16/85	1	ER	5505N	16343W
11/16/85	1	ER	5504N	16348W
11/16/85	1	ER	5504N	16350W
11/16/85	1	ER	5504N	16348W
11/16/85	2	ER	5504N	16349W
11/16/85	1	ER	5505N	16352W
11/16/85	1	ER	5501N	16400W
11/16/85	1	ER	5522N	16300W
11/16/85	1	ER	5520N	16258W
11/16/85	1	ER	5552N	16154W
11/16/85	1	ER	5511N	16045W
11/21/85	2	ER	5502N	16352W
11/21/85	1	ER	5501N	16401W
11/21/85	7	ER	5501N	16410W
11/21/85	1	ER	5501N	16407W
11/21/85	1	ER	5502N	16355W
11/23/85	1	ER	5513N	16307W

Month/Day/Year	Number	Species	Latitude	Longitude
11/24/85	4	ER	5505N	16349W
11/24/85	3	ER	5506N	16350W
11/24/85	1	ER	5506N	16350W
11/24/85	3	ER	5515N	16332W
11/24/85	1	ER	5515N	16325W
11/24/85	1	ER	5515N	16316W
11/24/85	1	ER	5515N	16311W
11/24/85	2	ER	5516N	16302W
11/24/85	1	ER	5517N	16303W
11/24/85	2	ER	5517N	16302W
11/24/85	1	ER	5517N	16302W
11/24/85	1	ER	5517N	16301W
11/24/85	1	ER	5518N	16301W
12/02/85	1	ER	5518N	16303W
12/02/85	1	ER	5520N	16302W
12/02/85	1	ER	5520N	16301W
12/02/85	3	ER	5518N	16303W
12/02/85	3	ER	5519N	16303W
12/05/85	3	ER	5500N	16201W
12/05/85	1	ER	5456N	16159W
12/05/85	2	ER	5455N	16159W
12/05/85	2	ER	5459N	16153W
12/05/85	3	ER	5459N	16150W
12/05/85	1	ER	5459N	16150W
12/05/85	1	ER	5500N	16143W
12/05/85	2	ER	5502N	16143W
12/05/85	1	ER	5559N	15823W
12/05/85	4	ER	5557N	15815W
12/05/85	3	ER	5500N	15815W
12/05/85	1	ER	5551N	15845W
12/05/85	1	ER	5551N	15845W
12/05/85	1	ER	5546N	15912W
12/06/85	4	ER	5511N	16307W
12/06/85	1	ER	5513N	16311W
12/06/85	1	ER	5514N	16313W
12/06/85	2	ER	5502N	16357W
12/06/85	3	ER	5520N	16351W
12/06/85	2	ER	5507N	16351W
12/06/85	1	ER	5505N	16351W
12/06/85	1	ER	5504N	16351W
12/06/85	2	ER	5504N	16351W
12/06/85	6	ER	5506N	16348W
12/06/85	2	ER	5501N	16358W
12/06/85	1	ER	5501N	16358W
12/06/85	1	ER	5501N	16358W
12/06/85	1	ER	5503N	16345W
12/06/85	1	ER	5504N	16345W
12/06/85	3	ER	5504N	16345W
12/06/85	1	ER	5505N	16345W
12/06/85	1	ER	5505N	16345W
12/06/85	2	ER	5504N	16342W
12/06/85	2	ER	5504N	16342W

Month/Day/Year	Number	Species	Latitude	Longitude
12/06/85	3	ER	5504N	16340W
12/06/85	2	ER	5515N	16309W
12/06/85	4	ER	5514N	16309W
12/06/85	1	ER	5514N	16309W
12/06/85	3	ER	5512N	16312W
12/06/85	2	ER	5512N	16312W
12/06/85	1	ER	5512N	16312W
12/06/85	3	ER	5512N	16311W
12/13/85	1	ER	5508N	16319W
12/13/85	2	ER	5509N	16322W
12/13/85	1	ER	5508N	16323W
12/13/85	1	ER	5505N	16333W
12/13/85	1	ER	5505N	16335W
12/13/85	1	ER	5504N	16338W
12/13/85	3	ER	5505N	16339W
12/13/85	2	ER	5504N	16339W
12/13/85	1	ER	5505N	16342W
12/13/85	1	ER	5505N	16344W
12/13/85	1	ER	5505N	16347W
12/13/85	1	ER	5505N	16349W
12/13/85	4	ER	5504N	16352W
12/13/85	2	ER	5504N	16352W
12/13/85	1	ER	5503N	16356W
12/13/85	2	ER	5502N	16359W
12/13/85	1	ER	5502N	16359W
12/13/85	4	ER	5501N	16401W
12/13/85	1	ER	5501N	16401W
12/13/85	1	ER	5501N	16402W
12/13/85	1	ER	5500N	16403W
12/13/85	1	ER	5500N	16404W
12/13/85	2	ER	5459N	16405W
12/13/85	2	ER	5459N	16405W
12/13/85	2	ER	5459N	16411W
12/13/85	2	ER	5458N	16411W
12/13/85	1	ER	5458N	16412W
12/13/85	1	ER	5457N	16413W
12/13/85	1	ER	5457N	16415W
12/13/85	1	ER	5457N	16416W
12/13/85	1	ER	5456N	16417W
12/13/85	1	ER	5456N	16419W
12/13/85	2	ER	5456N	16422W
12/13/85	2	ER	5456N	16424W
12/13/85	2	ER	5456N	16424W
12/13/85	1	ER	5456N	16425W
12/13/85	1	ER	5456N	16426W
12/13/85	3	ER	5452N	16437W
12/13/85	2	ER	5450N	16436W
12/13/85	1	ER	5450N	16435W
12/13/85	1	ER	5450N	16435W
12/13/85	1	ER	5452N	16434W
12/13/85	3	ER	5448N	16439W
12/13/85	1	ER	5447N	16440W
12/13/85	2	ER	5447N	16440W

Month/Day/Year	Number	Species	Latitude	Longitude
12/13/85	1	ER	5446N	16441W
12/13/85	1	ER	5446N	16441W
12/13/85	3	ER	5446N	16441W
12/13/85	2	ER	5444N	16442W
12/13/85	4	ER	5443N	16443W
12/13/85	2	ER	5442N	16443W
12/13/85	1	ER	5442N	16443W
12/13/85	3	ER	5442N	16443W
12/13/85	1	ER	5441N	16444W
12/13/85	2	ER	5441N	16444W
12/13/85	3	ER	5441N	16444W
12/13/85	2	ER	5441N	16444W
12/13/85	1	ER	5440N	16444W
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12/13/85	2	ER	5439N	16447W
12/13/85	1	ER	5439N	16450W
12/13/85	2	ER	5439N	16451W
12/13/85	2	ER	5438N	16453W
12/13/85	1	ER	5438N	16453W
12/13/85	2	ER	5437N	16455W
12/13/85	3	ER	5436N	16456W
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12/13/85	2	ER	5436N	16458W
12/13/85	5	ER	5436N	16458W
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12/14/85	1	ER	5511N	16312W
12/14/85	2	ER	5510N	16312W
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12/14/85	1	ER	5506N	16327W
12/14/85	1	ER	5506N	16327W
12/14/85	1	ER	5505N	16327W
12/14/85	1	ER	5552N	16206W
12/14/85	1	ER	5548N	16208W
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12/14/85	2	ER	5519N	16301W
12/14/85	1	ER	5517N	16305W
12/14/85	1	ER	5513N	16313W
12/14/85	3	ER	5513N	16313W
12/14/85	1	ER	5510N	16318W
12/15/85	2	ER	5527N	16237W

Month/Day/Year	Number	Species	Latitude	Longitude
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12/15/85	1	ER	5532N	16232W
12/15/85	1	ER	5533N	16231W
12/15/85	1	ER	5533N	16231W
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12/15/85	1	ER	5534N	16229W
12/15/85	1	ER	5535N	16228W
12/15/85	1	ER	5535N	16228W
12/15/85	1	ER	5538N	16224W
12/15/85	2	ER	5539N	16222W
12/15/85	1	ER	5540N	16221W
12/15/85	1	ER	5540N	16220W
12/15/85	2	ER	5542N	16218W
12/15/85	1	ER	5544N	16215W
12/15/85	2	ER	5545N	16213W
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12/15/85	1	ER	5548N	16206W
12/15/85	1	ER	5549N	16203W
12/15/85	1	ER	5549N	16202W
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12/15/85	1	ER	5557N	16136W
12/15/85	1	ER	5557N	16135W
12/15/85	1	ER	5557N	16135W
12/15/85	1	ER	5558N	16131W
12/15/85	1	ER	5558N	16130W
12/15/85	1	ER	5559N	16125W
12/15/85	1	ER	5559N	16118W
12/15/85	1	ER	5600N	16117W
12/15/85	1	ER	5602N	16107W
12/15/85	1	ER	5602N	16105W
12/15/85	1	ER	5602N	16102W
12/15/85	2	ER	5603N	16056W
12/15/85	1	ER	5603N	16053W
12/15/85	2	ER	5603N	16050W
12/15/85	1	ER	5603N	16036W
12/15/85	3	ER	5618N	16021W
12/15/85	1	ER	5620N	16019W
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12/15/85	1	ER	5644N	15922W
12/15/85	1	ER	5644N	15921W
12/15/85	1	ER	5645N	15918W
12/15/85	1	ER	5646N	15917W

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12/15/85	1	ER	5718N	15815W
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12/16/85	1	ER	5509N	16317W
12/16/85	2	ER	5505N	16330W
12/16/85	2	ER	5505N	16330W
12/16/85	1	ER	5505N	16331W
12/16/85	1	ER	5505N	16343W
12/16/85	1	ER	5505N	16343W
12/16/85	1	ER	5505N	16347W
12/16/85	1	ER	5504N	16350W
12/16/85	1	ER	5504N	16351W
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12/16/85	2	ER	5459N	16403W
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12/17/85	1	ER	5557N	15822W
12/17/85	4	ER	5550N	15657W

Month/Day/Year	Number	Species	Latitude	Longitude
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12/19/85	1	ER	5502N	16358W
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7/04/85	1	MN	5456N	15933W
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7/04/85	2	MN	5454N	15933W
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7/25/85	2	MN	5504N	16206W
7/26/85	2	MN	5509N	15945W
7/28/85	1	MN	5459N	16024W
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7/29/85	1	MN	5459N	16209W
7/29/85	3	MN	5434N	15945W

Month/Day/Year	Number	Species	Latitude	Longitude
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7/29/85	1	MN	5434N	15945W
7/29/85	1	MN	5445N	15945W
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8/23/85	1	MN	5330N	16357W
8/25/85	4	MN	5508N	16208W
8/25/85	1	MN	5400N	16309W
8/25/85	2	MN	5312N	16303W
8/25/85	1	MN	5404N	16303W
8/26/85	3	MN	5309N	15857W
8/26/85	1	MN	5308N	15857W
8/26/85	1	MN	5259N	15851W
8/26/85	3	MN	5309N	15851W
8/26/85	7	MN	5254N	15843W
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8/26/85	2	MN	5254N	15843W
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8/26/85	1	MN	5300N	15839W
8/26/85	4	MN	5300N	15839W
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8/26/85	2	MN	5301N	15839W
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8/27/85	1	MN	5501N	15745W
8/27/85	2	MN	5501N	15739W
8/27/85	1	MN	5504N	15741W
8/28/85	1	MN	5459N	16209W
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8/28/85	1	MN	5508N	15809W
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10/24/85	1	MN	5255N	16215W
10/24/85	1	MN	5244N	16215W
10/26/85	1	MN	5249N	16245W
10/26/85	1	MN	5243N	16245W
11/10/85	1	MN	5505N	15745W
11/11/85	1	MN	5426N	16057W

Month/Day/Year	Number	Species	Latitude	Longitude
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11/11/85	1	MN	5426N	16057W
11/11/85	1	MN	5425N	16057W
11/11/85	2	MN	5424N	16057W
11/11/85	4	MN	5423N	16100W
11/11/85	1	MN	5424N	16059W
11/11/85	2	MN	5425N	16059W
7/03/85	1	OO	5500N	16157W
7/03/85	2	OO	5500N	16157W
7/03/85	1	OO	5500N	16157W
7/04/85	1	OO	5419N	15927W
7/04/85	4	OO	5421N	15927W
7/04/85	4	OO	5419N	15939W
7/23/85	2	OO	5459N	16233W
7/25/85	5	OO	5419N	16445W
7/25/85	1	OO	5421N	16421W
7/25/85	3	OO	5430N	16409W
7/25/85	3	OO	5430N	16410W
7/25/85	1	OO	5517N	16121W
8/ 4/85	5	OO	5448N	16123W
8/25/85	5	OO	5508N	16109W
11/13/85	1	OO	5539N	16303W
11/14/85	1	OO	5522N	16345W
12/13/85	1	OO	5448N	16645W
12/13/85	3	OO	5448N	16645W
12/13/85	1	OO	5448N	16645W
12/13/85	3	OO	5449N	16645W
12/13/85	6	OO	5419N	16609W
12/13/85	9	OO	5419N	16609W
12/13/85	1	OO	5419N	16609W
12/13/85	2	OO	5419N	16609W
12/14/85	1	OO	5710N	16515W
7/24/85	5	PC	5409N	15809W
8/25/85	5	PC	5333N	16303W
8/25/85	2	PC	5333N	16303W
8/25/85	2	PC	5333N	16303W
8/25/85	1	PC	5333N	16303W
8/25/85	7	PC	5333N	16303W
8/25/85	1	PC	5333N	16303W
6/28/85	2	PD	5430N	15751W
6/28/85	2	PD	5444N	15751W
7/01/85	6	PD	5406N	16632W
7/02/85	4	PD	5532N	16909W
7/02/85	2	PD	5525N	16903W
7/02/85	2	PD	5522N	16903W
7/02/85	1	PD	5500N	16742W
7/04/85	1	PD	5406N	15951W
7/24/85	5	PD	5410N	15809W
7/27/85	2	PD	5335N	16157W
7/28/85	1	PD	5501N	16117W
8/ 2/85	4	PD	5532N	15733W
8/26/85	1	PD	5328N	15857W
8/26/85	1	PD	5325N	15857W

Month/Day/Year	Number	Species	Latitude	Longitude
8/26/85	2	PD	5317N	15857W
8/26/85	7	PD	5307N	15857W
8/26/85	7	PD	5259N	15851W
8/26/85	8	PD	5309N	15854W
8/26/85	1	PD	5320N	15850W
8/26/85	4	PD	5325N	15851W
8/26/85	4	PD	5325N	15851W
8/26/85	5	PD	5332N	15851W
8/26/85	6	PD	5332N	15851W
8/26/85	1	PD	5336N	15851W
8/26/85	2	PD	5339N	15851W
8/26/85	2	PD	5341N	15851W
8/26/85	8	PD	5330N	15845W
8/26/85	1	PD	5302N	15845W
8/27/85	4	PD	5658N	15626W
8/28/85	2	PD	5557N	15809W
10/19/85	2	PD	5339N	16403W
10/19/85	1	PD	5258N	16332W
10/29/85	3	PD	5536N	16009W
10/30/85	1	PD	5532N	15815W
10/30/85	2	PD	5505N	15803W
12/13/85	3	PD	5414N	16605W
12/13/85	2	PD	5411N	16607W
12/13/85	5	PD	5459N	16639W
12/14/85	4	PD	5642N	16445W
12/14/85	3	PD	5651N	16502W
12/14/85	2	PD	5743N	16515W
12/14/85	2	PD	5748N	16449W
12/14/85	1	PD	5749N	16429W
12/16/85	2	PD	5614N	16503W
12/16/85	6	PD	5625N	16507W
12/16/85	5	PD	5759N	16543W
12/16/85	1	PD	5728N	16543W
12/16/85	3	PD	5618N	16443W
12/17/85	8	PD	5515N	15633W
8/27/85	1	PP	5713N	15617W
8/26/85	2	ZC	5329N	15857W

SHIPBOARD SURVEYS OF ENDANGERED CETACEANS IN THE NORTHWESTERN GULF OF ALASKA

by

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Final Report
Outer Continental Shelf Environmental Assessment Program
Research Unit 673

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ABSTRACT

Shipboard surveys were conducted during June-July 1987 along 2,034 nmi of trackline south of the Alaska Peninsula to determine the abundance and distribution of endangered whales and other marine mammals. There were 150 observations of humpback whales, 122 of finback whales, 351 of Dall porpoises, 101 of killer whales, 12 of minke whales, 3 of harbor porpoises, and 170 of pinnipeds and sea otters. Humpbacks were primarily associated with the 50-fathom isobath, particularly near banks. Finbacks were associated with the 50- and 100-fathom isobaths, particularly near the Shelikof Strait submarine canyon and some banks. Humpbacks and finbacks were observed on one occasion feeding together, but their distribution generally did not overlap. The other species were widespread in the study area except for killer whales, which were observed together east of Kodiak Island. Abundance was estimated for humpbacks at 1,247 (±392 SE) and finbacks at 1,257 (±563 SE). Sample sizes were too small to estimate abundance for the other species. These results are similar to those developed for this area in 1985.

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INTRODUCTION

Seven species of endangered whales seasonally inhabit the northwestern Gulf of Alaska (Rice and Wolman 1982; Morris *et al.* 1983). Humpback, finback, and possibly right whales feed in the outer continental shelf and slope waters during the summer and early fall, while the distribution of blue, sei, and sperm whales is more pelagic (Berzin and Rovnin 1966; Rice 1974). Gray whales pass through the Gulf of Alaska twice each year on their annual migration between breeding lagoons in Mexico and feeding grounds in the northern Bering and Chukchi seas (Braham 1984*a*). Small numbers of gray whales also feed in the nearshore areas of the Gulf of Alaska (Brueggeman *et al.* 1987) and along the north side of the Alaska Peninsula (Gill and Hall 1983).

The numbers of these whales in the Gulf of Alaska were severely reduced by commercial whaling. Although the North Pacific right whale was protected in 1937 the population has yet to recover: current estimates are that only a few hundred remain (Rice 1974; Rice and Wolman 1982). The population was so reduced by commercial whaling that only 20 right whales were harvested by shore-based whalers in the Gulf of Alaska between 1900 and 1937 (Brueggeman *et al.* 1986). Over 2,339 blue, humpback, finback, and sperm whales were taken between 1926 and 1937 by the Port Hobron shore-based whaling station, located on Sitkalidak Island (Brueggeman *et al.* 1985; Reeves *et al.* 1985). Virtually all of these whales were captured southeast of Kodiak Island over Albatross Bank. In addition, 5,325 animals of these four species were taken between 1912 and 1939 by the Akutan Island shore-based whaling station (Brueggeman *et al.* 1985; Reeves *et al.* 1985). Most of these whales were captured south of Unimak Pass, in the area including Davidson Bank. Soviet and Japanese pelagic whaling fleets further harvested blue and humpback whales from these waters until their protection in 1967 and finback and sei whales until their protection in 1976 (Rice and Wolman 1982). Population levels of North Pacific rorquals presently range from approximately 8-14% (1,200-2,100) of the estimated original humpback whale population to 32-44% (14,620-18,630) of the original finback population (Braham 1984*b*; Darling and Morowitz 1986). The gray whale is the only endangered whale species that has apparently recovered to pre-exploitation levels.

Most of the existing information on endangered whale abundance, distribution, and habitat use patterns in the northwestern Gulf of Alaska has been derived from limited systematic surveys, opportunistic sightings, and historic whaling records. Aerial and vessel surveys have been conducted by the National Marine Mammal Laboratory (NMML) and other investigators (Braham *et al.* 1977; Rice and Wolman 1982; Leatherwood *et al.* 1983; Braham 1984*a*; Rugh 1984; Stewart *et al.* 1987) supported through the NOAA/MMS Outer Continental Shelf Environmental Assessment Program (OCSEAP). While these efforts have contributed substantially to better understanding the biology of these species, the results remain inconclusive because of the large area surveyed, the complexity of survey logistics, and the small number and sporadic distribution of many of the endangered cetaceans.

In 1985, extensive aerial surveys were conducted by Brueggeman *et al.* (1987) to characterize the use of the northwestern Gulf of Alaska and southeastern Bering Sea by endangered cetaceans and other marine mammals. That OCSEAP study resulted in over 25,000 nmi of survey effort, and the first estimates of humpback and finback whale abundances in this region. The present study is a follow-up to the 1985 surveys and was conducted between 18 June and 14 July 1987, aboard the NOAA ship *Miller Freeman*. The primary objectives of the study were to:

1) Characterize the abundance, distribution, and habitat use patterns of endangered whales summering in the Shumagin and Kodiak lease planning areas and the lower portion of the Cook Inlet Planning Area.

2) Compare the above findings with the 1985 aerial survey results to examine annual patterns of distribution and abundance.

3) Document sightings of other marine mammals encountered during the survey.

STUDY AREA

The study area is located south of the Alaska Peninsula on the outer continental shelf, and includes Davidson Bank, Sanak Bank, Shumagin Bank, Albatross Bank, Shelikof Strait, portions of Portlock Bank, and the inland waters of Kodiak Island (Figure 1). The continental shelf in the northwestern Gulf of Alaska is generally rock-bottomed with extensive reefs, island complexes, and submarine canyons. The shelf extends approximately 40 nmi from the mainland coast before dropping precipitously to almost 4,000 fathoms deep in the Aleutian Trench. Surveys were primarily conducted on the shelf.

The oceanography off the Alaska Peninsula is influenced primarily by the nearshore Alaska Coastal Current (ACC), and to a lesser degree by the Alaska Stream. The narrow ACC current, driven by snowmelt and runoff, travels southwestward along the south side of the Alaska Peninsula before entering the Bering Sea through Unimak Pass (Royer 1981; Schumacher and Moen 1983). The ACC is bifurcated by islands and submarine canyons at various locations; this separation, in turn, creates zones where shelf and current waters mix (Schumacher and Reed 1986). The much stronger Alaska Stream flows southwestward along the continental shelf edge. The persistent and heavy winds characteristic of the area influence these currents and, in turn, the biological oceanography in the study area. Average monthly wind speeds range between 13 and 16 knots, and are highest and most persistent during the winter.

The climate of the northwestern Gulf of Alaska is maritime and is seldom influenced by continental air masses. Both daily and seasonal air temperature extremes are confined to fairly narrow limits, and readings below 0°F are very rare.

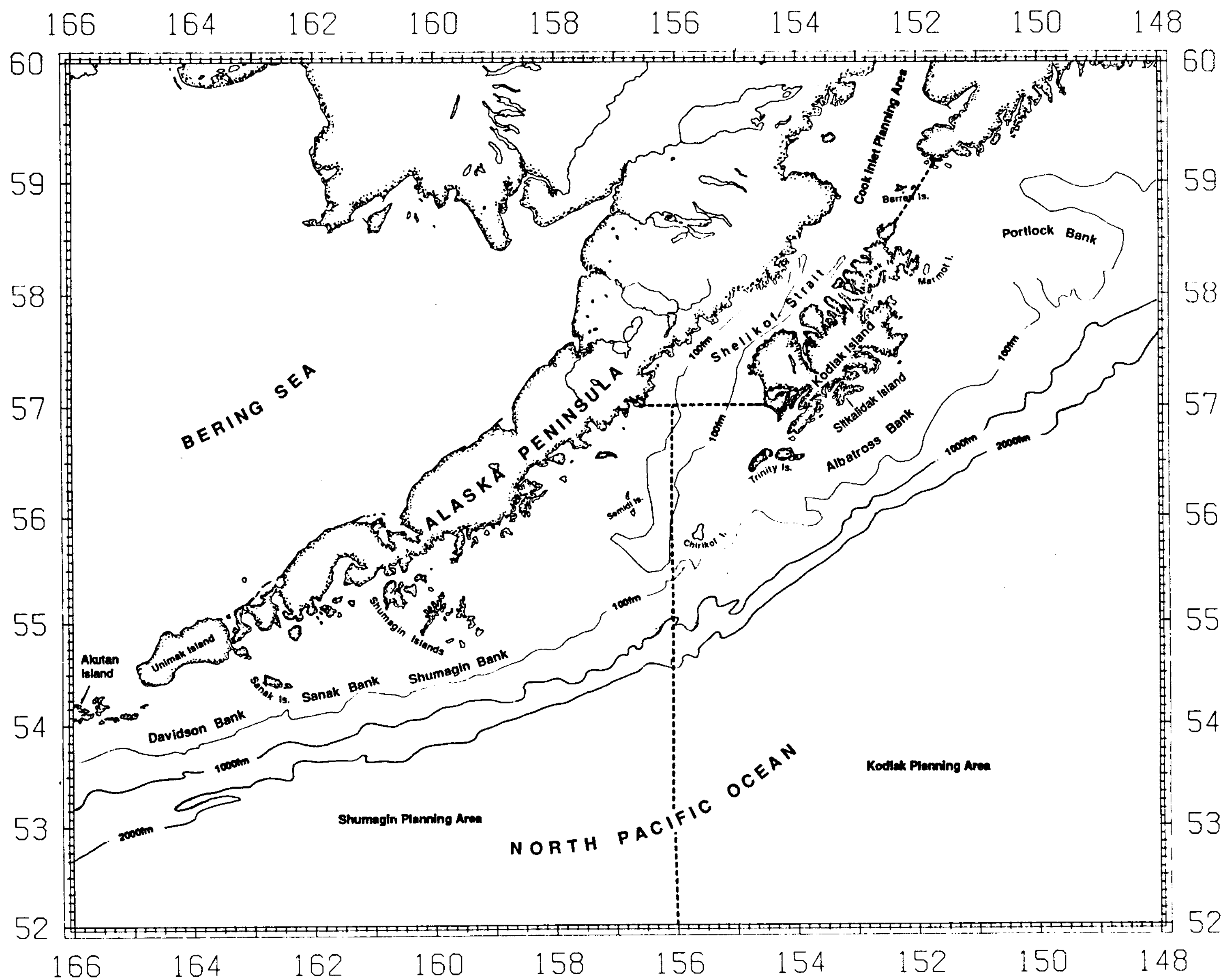


Figure 1.–Study area map showing place names and planning areas mentioned in the text.

METHODS

Survey Design and Procedures

This study was conducted simultaneously with a NMFS/PMEL study to investigate dispersal of larval walleye pollock produced in Shelikof Strait. Larval pollock were surveyed by conducting net tows at 145 stations systematically distributed across the outer continental shelf south of the Alaska Peninsula from Unimak Pass and to beyond Kodiak Island. Tow stations were distributed along transect lines located perpendicular to the coast. Marine mammals were surveyed along transect lines traveled between tow stations. The survey area encompassed most of the Shumagin and Kodiak planning areas and the southern half of the Cook Inlet Planning Area. Survey legs between stations were approximately 15 nmi in length.

Surveys for marine mammals were conducted by a single observer from the ship's flying bridge, 40 ft above the water line. The observer recorded data on animal sightings, environmental conditions, and location. Information on ship position, water depth, water temperature, and wind speed were provided to the observer by the officer on duty via walkie-talkie. The ship's speed between stations was generally 10-12 knots. The observer viewed a 45-degree area centered on the bow of the ship. Viewing was terminated when seas reached a Beaufort 6. To reduce the effects of fatigue, observers switched watches every 4 hours. For each group of marine mammals observed, sighting information included: group size, species, radial angle from the direction of travel by the ship, distance from ship estimated in 0.25-nmi intervals, direction of travel, number of calves, and an estimation of whether the sighting was probably a duplicate of a recent sighting. The radial angle was measured with a compass mounted on a stand and the distance was estimated with a sighting gauge graduated in 0.25-nmi intervals. Environmental information included sea state according to the Beaufort wind scale with sea state descriptors (Black and Adams 1983), visibility, and glare. Definitions of visibility and glare conditions are provided in Appendix A. Environmental conditions were evaluated by the observers at the beginning and end of each leg and whenever conditions changed. The position of the ship was recorded when environmental data were collected and when a marine mammal was sighted. Position was recorded to a tenth of a minute of latitude and longitude.

Three types of surveys were conducted during this study: systematic, random, and deadhead. Systematic surveys were the tracklines connecting the tow stations. Random surveys were conducted when traveling west to east from the end of one systematic survey line to the beginning point of the next one. Deadheads were off-effort surveys conducted when the ship was stopped or viewing conditions were unacceptable. Only random and systematic survey data were used in density and abundance analyses. Deadhead survey data were used in characterizing distributions of each species.

Analytical Procedures

Humpback and finback densities were estimated using a non-parametric Fourier series line transect estimator (Burnham *et al.* 1980). The set of perpendicular distances of whale groups from the transect line was used to develop a probability density function, which is the conditional probability of observing an object given that the object is a certain distance from the transect line (Burnham *et al.* 1980). The value of this function for perpendicular distance relative to 0 (on the trackline, where the probability is 1.0) can then be used to calculate a density based on the number of groups observed along a known length of trackline. Line transect sampling and Fourier series estimators are the standard approaches for estimating cetacean abundance (Hay 1982; Brueggeman *et al.* 1987).

Line-Transect Assumptions

The line-transect procedure was based on the following assumptions:

1) Either the population is distributed randomly within the study area or the transect line is located randomly.

2) All groups directly on the transect line are detected.

3) Groups do not move in response to the observer prior to being detected.

4) All distance and angle measurements are made without error.

5) Sightings are independent events.

Requirements for accurately estimating marine mammal density from a ship include:

1) The group size does not affect the group's probability of being observed.

2) Survey conditions (weather, visibility) do not influence the sightability of whales.

The degree to which the above assumptions were fully satisfied is unclear because of the difficulties involved in surveying mobile marine mammals. However, the following survey and analytical procedures were implemented to reduce biases in the results.

The first assumption was satisfied by traveling transect lines that were randomly located throughout the study area. The second assumption, that all groups directly on the line are detected, was probably satisfied because of the slow speed of the survey ship and the size of the larger whales. However, it is likely that some groups on the line were submerged and were not detected by the observers during the survey. The effect of missed animals on the density estimate was uncertain because studies were not conducted to develop site-specific correction factors. Failure to detect all whales probably resulted in estimates that were lower than actual numbers.

It was difficult to assess the assumption that the whales did not move in response to the vessel prior to being detected. Whales could have dived in response to the ship or they could have moved in some direction, which would have changed their perpendicular distances from the transect line. However, the shape of the detection curve of observed perpendicular distances showed no evidence of movement by large whales away from the transect line.

The assumption that measurements were free of error depended upon accurate estimates of the sighting angle and the straight-line distance to the point where the whales were first detected. The angle between the transect line and the vector from the vessel to the group was estimated with a large map compass mounted on the bridge rail. The distance from the vessel to the whale was estimated using a sighting gauge calibrated to read 0.25-nmi intervals of distance. The measurements were taken by trained observers familiar with this procedure. In addition, the sightability curves of perpendicular distances were truncated as recommended by K. Burnham (pers. commun.) to reduce the effect of long-distance measurements, which are typically less accurate, on the f(0). This helped produce a better fit of the detection curve to the data and reduced errors from these sources of bias in the estimate of f(0) (Burnham *et al.* 1980).

Because a group of whales, rather than each individual, was considered an observation, only in cases where two or more groups were close together was the independence of observations uncertain. Modest violations of this assumption do not affect the density estimate but do affect the variance of the density estimate (Burnham *et al.* 1980). The effects of weather and visibility conditions on the observer's ability to detect whale groups were investigated by conducting Chi-square analyses (Zar 1984) of observed and expected numbers of groups during various Beaufort sea states and visibility conditions. Any transect segments during which conditions significantly affected the observer's ability to detect whales were eliminated from further analyses. We also examined f(0) estimates to test the effect of different sighting conditions on sightability.

Line-Transect Calculations

Estimates were developed for the density and total number of whales in each planning unit and summed for all planning units. A variance was calculated for each estimate. The calculation procedures are described below.

The density of groups in each planning unit was estimated by the equation:

$$D_G = \frac{n \quad f(0)}{2L} \qquad \text{(Equation 1)}$$

where D_G is the density of groups (number/nmi^2), n is the number of groups observed, f(0) is the value of the probability density function on the trackline, and L is the trackline length (nmi). Program TRANSECT (Laake *et al.* 1979) was used to calculate f(0).

The total number of whales in a planning unit was calculated using the equation:

$$N_I = D_G\, A\, \overline{G} \qquad \text{(Equation 2)}$$

where N_I = number of individuals, A = area of study (nmi^2), and G is the mean group size.

An estimate of the sampling variance for abundance of whales in each planning area was derived by the equation:

$$V(N_I) = A^2\, [D_G^2\, V(\overline{G}) + \overline{G}^2\, V(D_G) - V(\overline{G})\, V(D_G)] \qquad \text{(Equation 3)}$$

where

$$V(\overline{G}) = \frac{\sum_{i=1}^{n} G_i^2 - \dfrac{\left(\sum_{i=1}^{n} G_i\right)^2}{n}}{n\,(n-1)} \qquad \text{(Equation 4)}$$

where n = number of groups and G = size of each group, and

where $V(D_G) = D^2\, (CV^2(f(0)) + CV^2(n))$

and CV^2 (f(0)) is the square of the coefficient of variation of f(0), and $CV^2(n)$ is the square of the coefficient of variation of the number of groups observed.

The total number of whales for the entire study area was estimated by adding the planning unit abundance estimates. The variance associated with the total estimate was calculated by the equation:

$$V(N_T) = V(f(0))\overline{G}^2 \left(\sum_{i=1}^{k} \frac{A_i n_i}{2L_i}\right)^2 + (f(0))^2 V(\overline{G}) \left(\sum_{i=1}^{k} \frac{A_i n_i}{2L_i}\right)^2 + (f(0))^2\overline{G}^2 \left(\sum_{i=1}^{k} \left(\left(\frac{A_i}{2L_i}\right)^2 V(n_i)\right)\right) \qquad \text{(Equation 5)}$$

where V(f(0)) is the variance of f(0), k is the number of planning units, A_i is the area within planning unit i, n_i is the number of groups observed in planning unit i, L_i is length of trackline in planning unit i, and $V(n_i)$ is the variance of the number of groups observed in planning unit i as calculated from the following equations.

$$V(n_i) = L\, \frac{\left(\sum_{i=1}^{R} \left(l_i \left(\dfrac{n_i}{T_i} - \dfrac{N}{L}\right)^2\right)\right)}{R - 1} \qquad \text{(Equation 6)}$$

where R = number of line segments and L = total trackline length, l_i = length of segment i, n_i = number of groups observed on segment i.

A group density was also calculated for the combined planning areas. The value was calculated by summing the group abundance estimates for each planning area and dividing that number by the total area in the study. The variance of this point estimate was calculated as:

$$V(D) = V(f(0)) \left(\sum_{i=1}^{k} \frac{n_i}{2L_i} \right)^2 + (f(0))^2 \left(\sum_{i=1}^{k} \left(\frac{V(n_i)}{(2L_i)^2} \right) \right) - V(f(0)) \left(\sum_{i=1}^{k} \left(\frac{V(n_i)}{(2L_i)^2} \right) \right) \quad \text{(Equation 7)}$$

where $V(n_i)$ is from Equation 6.

The results of our analyses are reported in English units of measure, since the nautical charts for the study area and the data from the navigation systems aboard the ship were in English units.

RESULTS AND DISCUSSION

Species Composition and Effort

Ten species of marine mammals, including 642 cetaceans, 89 pinnipeds, and 71 sea otters (Table 1) were observed along 2,034 nmi of random and systematic trackline (Figure 2) surveyed in the study area during June and July 1987. An additional 118 cetaceans, 8 pinnipeds, and 2 sea otters were observed along 353 nmi of deadhead surveys. Because the effort was not constant during deadhead surveys, these observations were used only to describe the general distribution of a species. Approximately two-thirds of the marine mammals were sighted in the Kodiak-lower Cook Inlet planning areas, where 55% of the effort was achieved.

Two of the six cetacean species observed in the survey are listed by the Federal Government as endangered throughout their range. A total of 69 groups of 150 humpback whales were recorded, of which 90% were observed in the Kodiak-lower Cook Inlet planning areas (the two planning areas were pooled because only a small portion of the Cook Inlet Planning Area was surveyed). In addition, 58 groups of 122 finback whales were recorded, approximately 59% of which were observed in the Shumagin Planning Area. Of the four nonendangered species, Dall porpoises (351) and killer whales (101) were the most abundant. Nineteen unidentified baleen whales and three unidentified porpoises were also observed in the survey.

Table 1.—Species composition and number of marine mammals observed in the three planning areas, June–July 1987.

Species	Shumagin (921 nmi)[a]		Kodiak and Lower Cook Inlet[b] (1,113 nmi)		Total (2,034 nmi)	
	Individuals	Groups	Individuals	Groups	Individuals	Groups
Cetacea						
Mysticeti						
Minke whale *(Balaenoptera acutorostrata)*	3 (1)[c]	2 (1)	7 (1)	6 (1)	10 (2)	8 (2)
Finback whale *(Balaenoptera physalus)*	63 (9)	30 (5)	32 (18)	16 (7)	95 (27)	46 (12)
Humpback whale *(Megaptera novaeangliae)*	15	6	112 (23)	52 (11)	127 (23)	58 (11)
Unidentified baleen	2 (1)	2 (1)	14 (2)	10 (1)	16 (3)	12 (2)
Odontoceti						
Killer whale *(Orcinus orca)*	0	0	101	2	101	2
Harbor porpoise *(Phocoena phocoena)*	0	0	3	3	3	3
Dall porpoise *(Phocoenoides dalli)*	110 (44)	29 (17)	178 (19)	72 (7)	288 (63)	101 (24)
Unidentified porpoise	2	1	0	0	2	1
Subtotal	195 (55)	70 (24)	447 (63)	161 (27)	642 (118)	231 (51)
Carnivora-Pinnipedia						
Otariidae						
Northern sea lion *(Eumetopias jubatus)*	29	1	25	17	54	18
Northern fur seal *(Callorhinus ursinus)*	17 (4)	13 (3)	17 (4)	16 (4)	34 (8)	29 (7)
Phocidae						
Harbor seal *(Phoca vitulina)*	0	0	1	1	1	1
Subtotal	46 (4)	14 (3)	43 (4)	34 (4)	89 (8)	48 (7)
Carnivora-Mustelidae						
Sea otter *(Enhydra lutris)*	13	9	58 (2)	34 (2)	71 (2)	43 (2)
Total	254 (59)	93 (27)	548 (69)	229 (33)	802 (128)	322 (60)

[a] Total distance surveyed on random and systematic surveys.

[b] The Kodiak and Cook Inlet planning areas were pooled.

[c] Additional number observed on deadhead surveys.

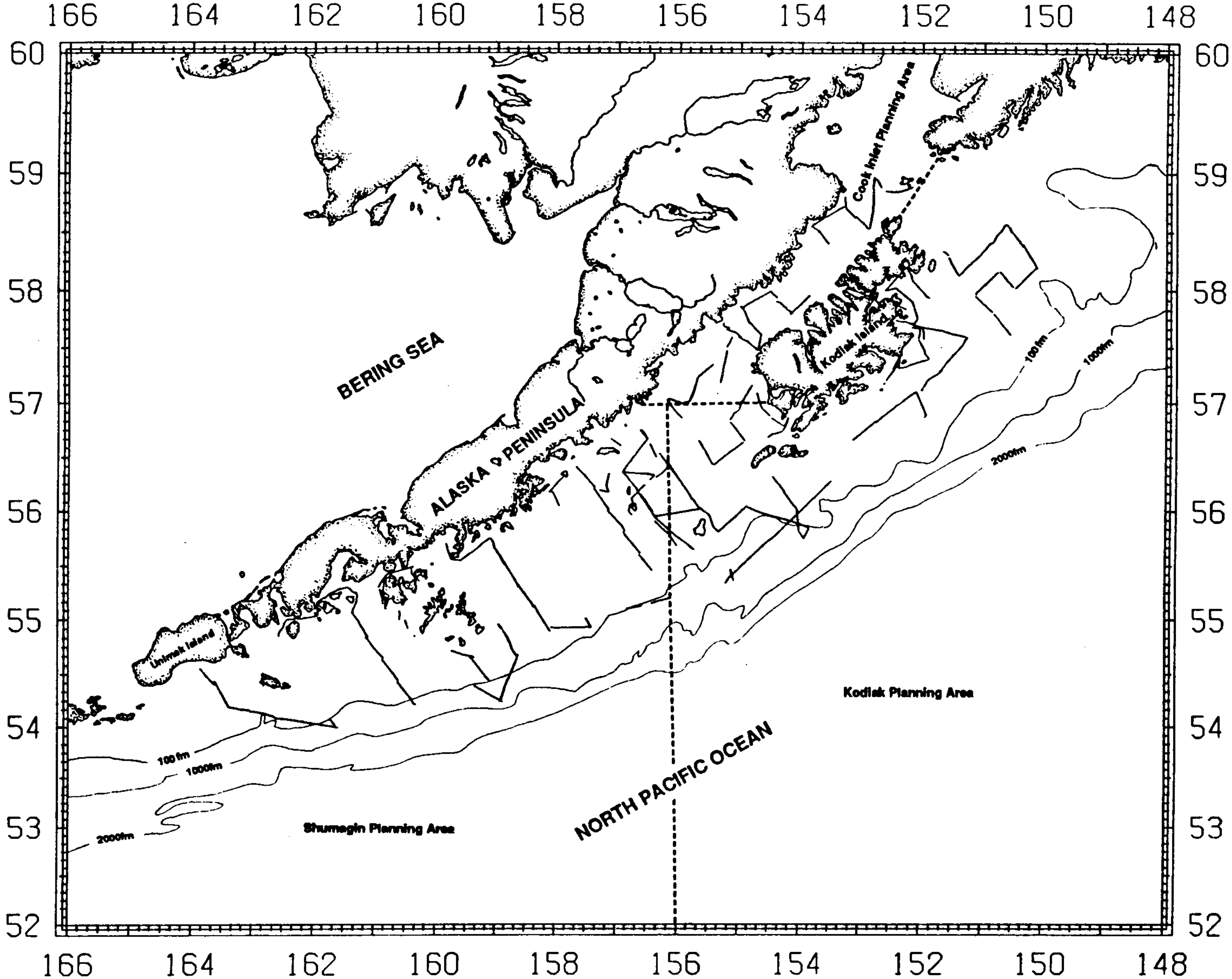


Figure 2.–Locations of systematic and random tracklines surveyed during June-July 1987 shipboard survey.

Three species of pinnipeds were recorded in the planning areas. Northern sea lions (54) were the most common pinniped, followed by northern fur seals (41) and harbor seals (1). The ship surveys avoided the shallow nearshore water where sea lions and harbor seals were most abundant.

Because environmental conditions affect the probability of detecting a whale, the survey data were examined for trends in the number of observations relative to Beaufort sea state and visibility (Figure 3). Chi-square analysis indicated that fewer humpback and finback whale groups than expected were observed when the sea state was Beaufort 5 or greater or when the visibility was poor or unacceptable ($p < 0.05$). Consequently, all quantitative analyses were based on data collected during excellent to fair visibilities and 0 to 4 Beaufort sea states, conditions which occurred on 1,577 nmi of the survey effort. This set of conditions is referred to as acceptable sighting conditions in the following sections of the report.

Humpback Whale

A total of 69 groups of 150 humpback whales were observed during this study. Six groups of 15 humpback whales were observed along 921 nmi of tracklines in the Shumagin Planning Area, and 52 groups of 112 humpbacks observed along 1,113 nmi of tracklines in the Kodiak-lower Cook Inlet planning areas during systematic and random surveys. An additional 11 groups of 23 humpbacks were observed on deadhead surveys in the Kodiak-lower Cook Inlet areas. Figure 4 shows the locations of all humpback whale sightings.

The distribution of humpback whales seen during acceptable sighting conditions ($n = 56$) in the planning areas was not uniform ($p < 0.05$), as they were heavily concentrated in the Kodiak-lower Cook Inlet areas (Figure 5). Observed numbers of humpbacks exceeded expected numbers ($p < 0.05$) between 150° and 154°W. Over 89% of the groups were observed in this area, whereas only 33% of the total effort was achieved there (Table 2). Most of these sightings were recorded over Portlock and Albatross banks on the seaward side of Kodiak Island (Figure 4).

Humpback whale groups were not uniformly distributed by water depth ($p < 0.05$) (Figure 6, Table 3). Nearly 93% of the humpback whale groups were observed in water depths between 25 and 100 fathoms, where 64% of the survey effort occurred (Table 3). Chi-square analysis indicated that numbers of humpback groups were higher than expected in waters 25-50 fathoms deep and lower than expected in waters greater than 100 fathoms deep. Frequent observations of humpbacks near the 50-fathom isobath coincide with the findings of the 1985 surveys (Brueggeman *et al.* 1987).

Humpbacks occupied the summer feeding grounds in clusters of small groups. The mean group size for humpback whales in the survey was 2.04 ± 0.15 SE ($n = 56$). Over 87% of the groups included between one and three animals (Figure 7), and group sizes of two were the most common (43%). The largest group size observed was five. Many of the groups

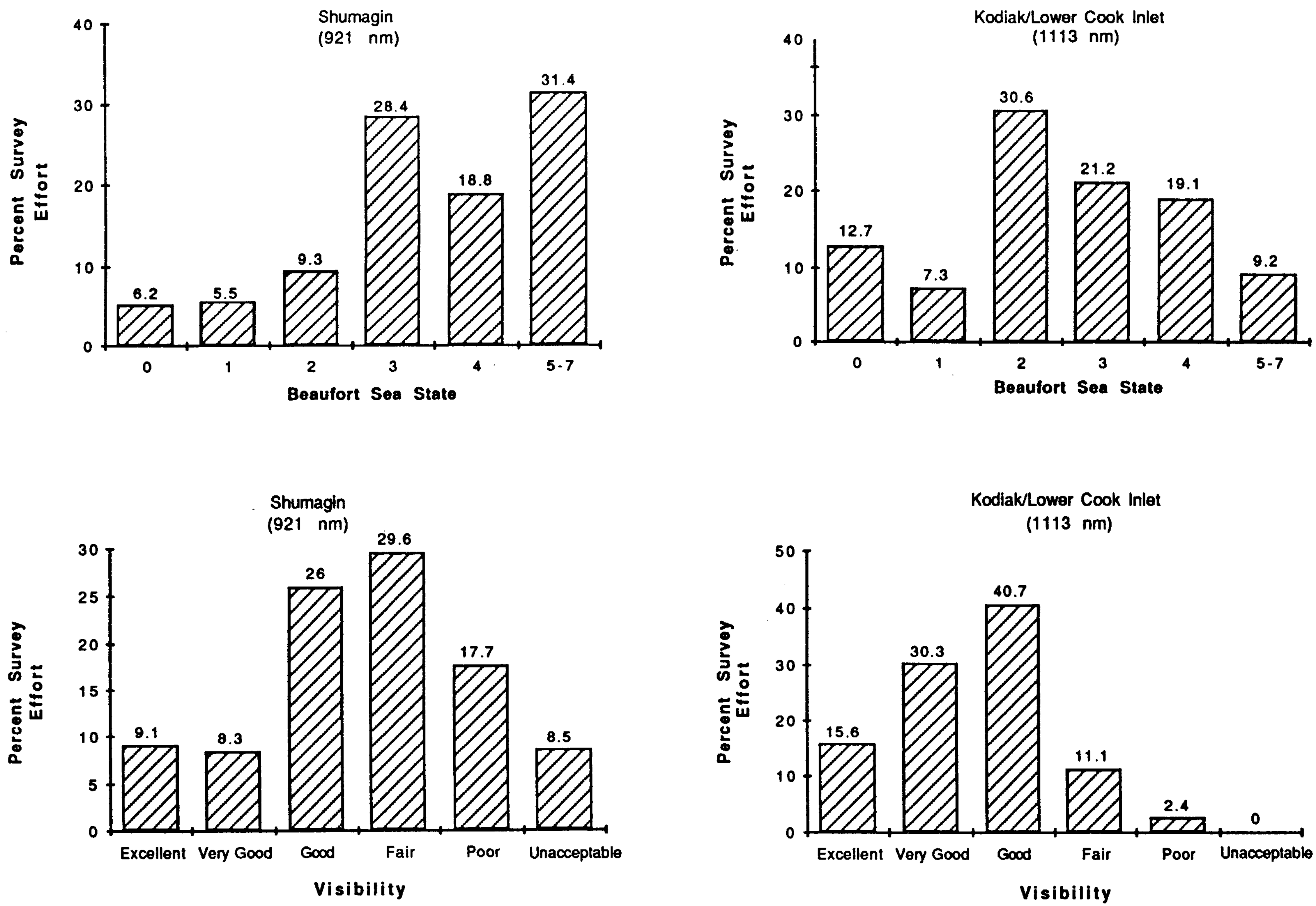


Figure 3.–Percentage of survey effort by Beaufort sea state and visibility in the Shumagin and Kodiak-lower Cook Inlet planning areas, 1987.

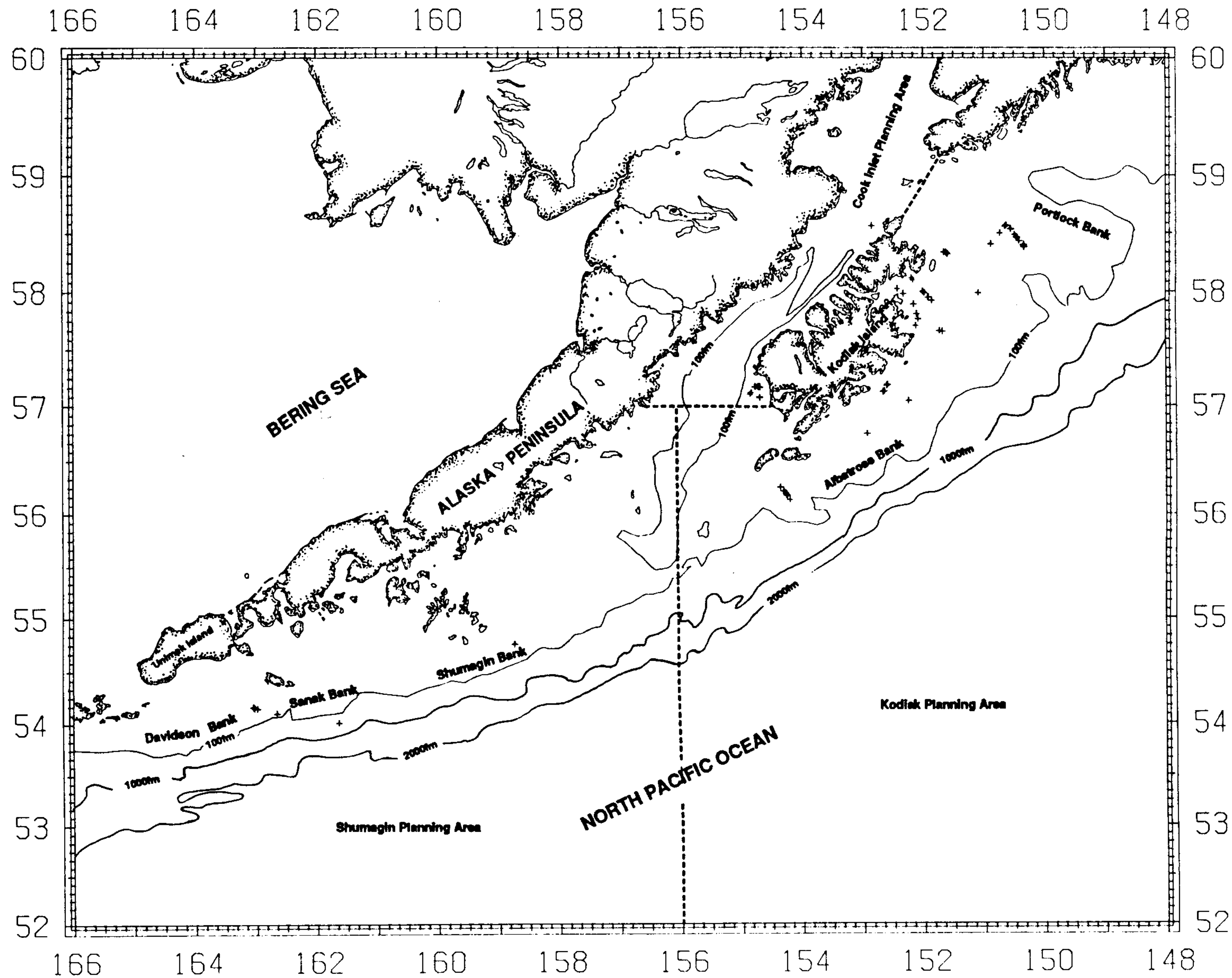
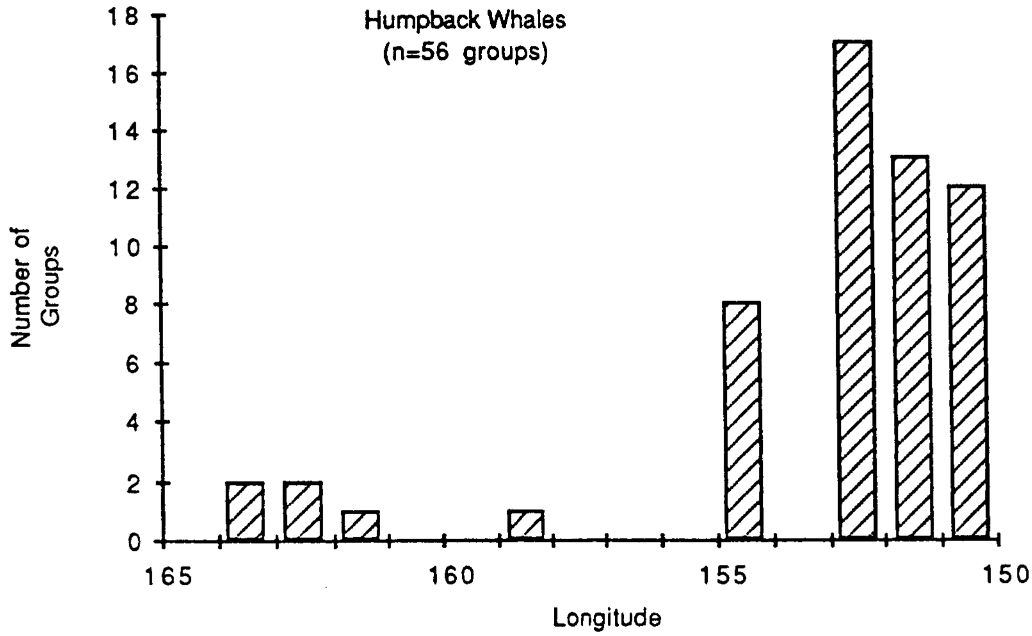


Figure 4.-Locations (+) of humpback whale sightings recorded during June-July 1987 shipboard survey.



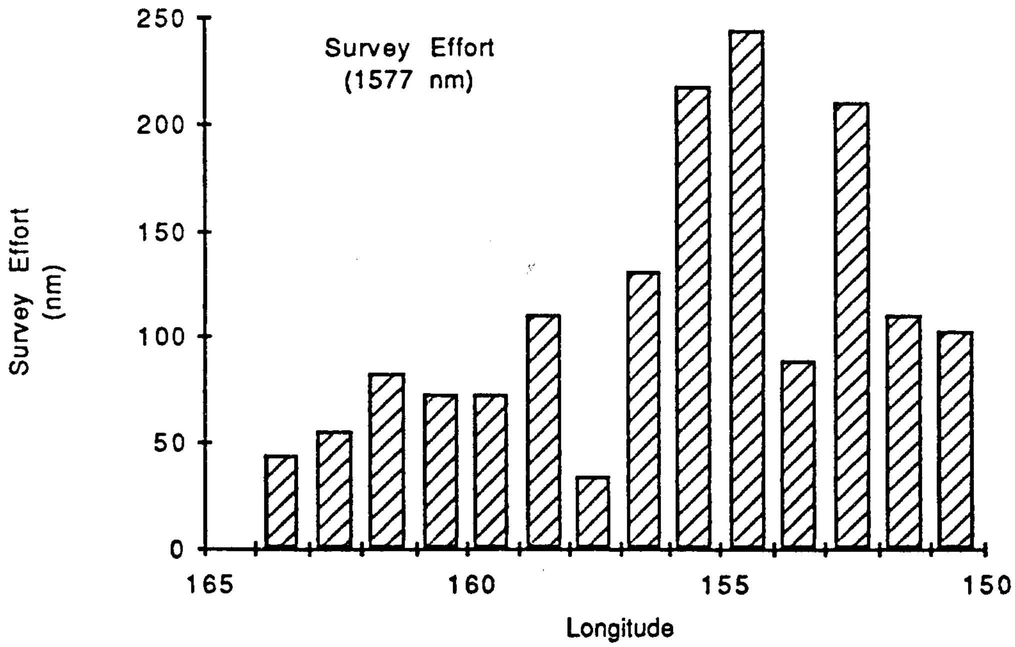


Figure 5.–Survey effort and number of humpback whale groups observed by longitude degree during random and systematic surveys.

Table 2.-Relative occurrence of humpback whale groups by longitude.

Longitude	Effort[a] (nmi)	Number of Groups Observed	Number of Groups Expected[a]	X^2	Preference[c]
150°-152°(W)	214[d]	25	7.6	39.84	+
152°-154°	299	17	10.6	3.86	+
154°-156°	461	8	16.4	4.30	–
156°-158°	164	0	5.8	5.80	–
158°-160°	184	1	6.5	4.65	–
160°-162°	155	1	5.5	3.68	0
162°-164°	100	4	3.5	0.07	0
Total	1,577	56	56	62.2[d]	

[a] Effort included random and systematic surveys during Beaufort 0-4 and fair to excellent visibility.
[b] Expected number of groups based on proportion of effort within each longitudinal zone.
[c] + indicates preference; – indicates avoidance; and 0 indicates no selection ($p < 0.05$, $X^2_{0.05,1}$ = 3.841).
[d] $X^2_{0.05,6} = 12.592$.

were observed in close proximity (<3 nmi) to other groups. The 1985 surveys recorded a similar figure for mean group size (1.72 ± 0.14 SE) and a similar percentage of groups with one to three animals (96%).

The majority of humpbacks observed appeared to be summering in the area, as the 23 groups of humpbacks evaluated did not exhibit the consistent directional orientation which would indicate a major movement pattern (Figure 8). Furthermore, photographic studies by Hall (1979), Rice and Wolman (1982), and Baker *et al.* (1985, 1986) further suggest that humpbacks summering in Alaska display strong fidelity to specific locations and seldom move between aggregation areas.

The behavior of the humpback whales was classified into five categories, recorded as information incidental to the surveys (Figure 9). The majority (68%) of the 51 whale groups evaluated were observed either traveling (a rapid directional movement) or in a fluke-raised dive. The remaining whales were observed milling, breaching, or feeding, categories which each accounted for 14% or less of total behavior. It was difficult for observers to accurately evaluate the behavior of the whales from the ship, especially feeding behavior observed from a long distance or in choppy seas.

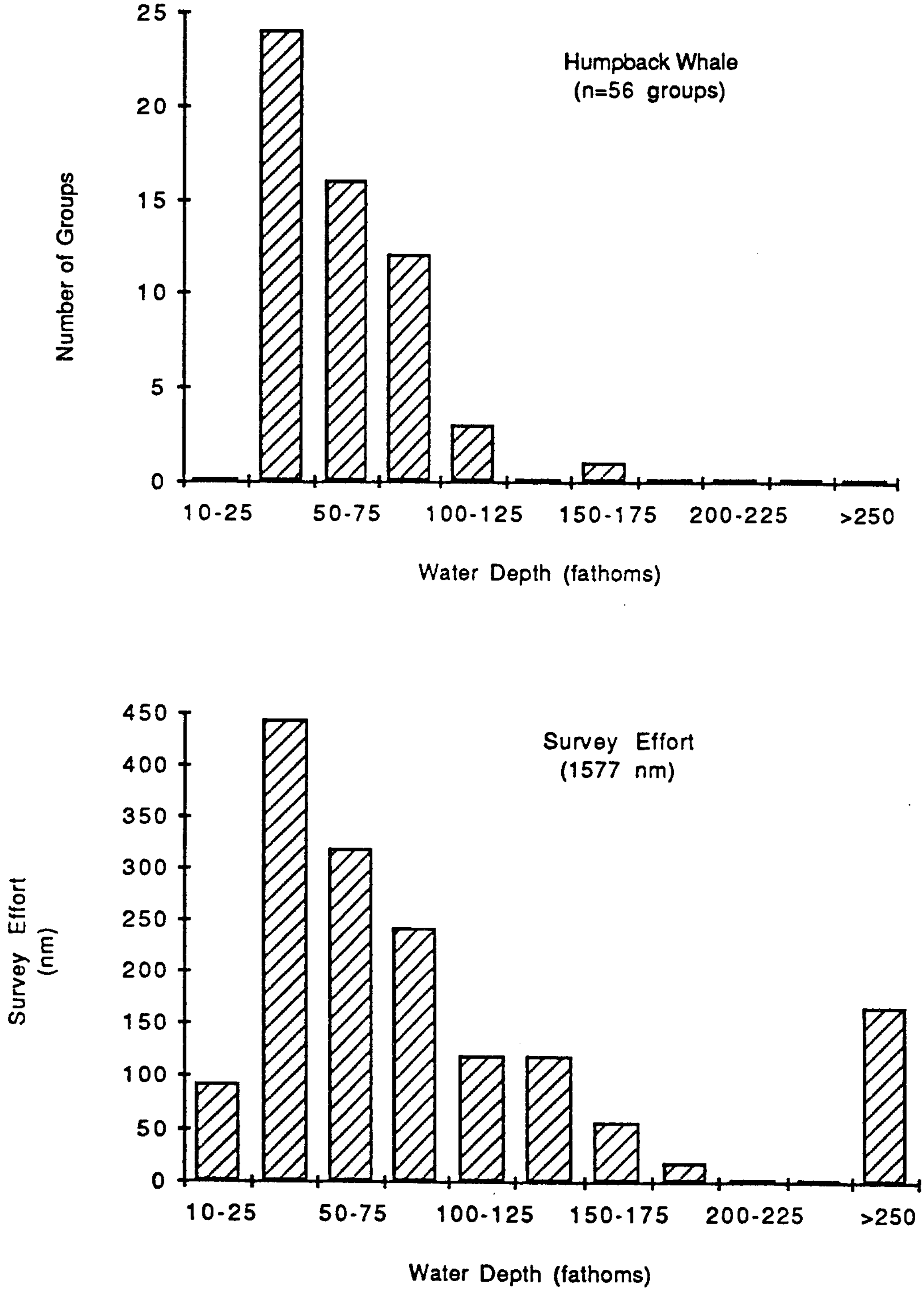


Figure 6.–Survey effort and number of humpback whale groups observed by depth class.

Table 3.–Relative occurrence of humpback whale groups by water depth.

Water depth (fathoms)	Effort[a] (nmi)	Number of groups: Observed	Number of groups: Expected[b]	X^2	Preference[c]
10-25	91[d]	0	3.2	3.20	0
25-50	444	24	15.8	4.26	+
50-75	318	16	11.3	2.00	0
75-100	242	12	8.6	1.34	0
≥100	482	4	17.1	10.04	–
Total	1,577	56	56	20.84[d]	

[a] Effort included random and systematic surveys during Beaufort 0-4 and fair to excellent visibility.
[b] Expected number of groups based on proportion of effort within each depth class.
[c] + indicates preference; – indicates avoidance; and 0 indicates no selection ($p < 0.05$, $X^2_{0.05,1} = 3.841$).
[d] $X^2_{0.05,4} = 9.488$.

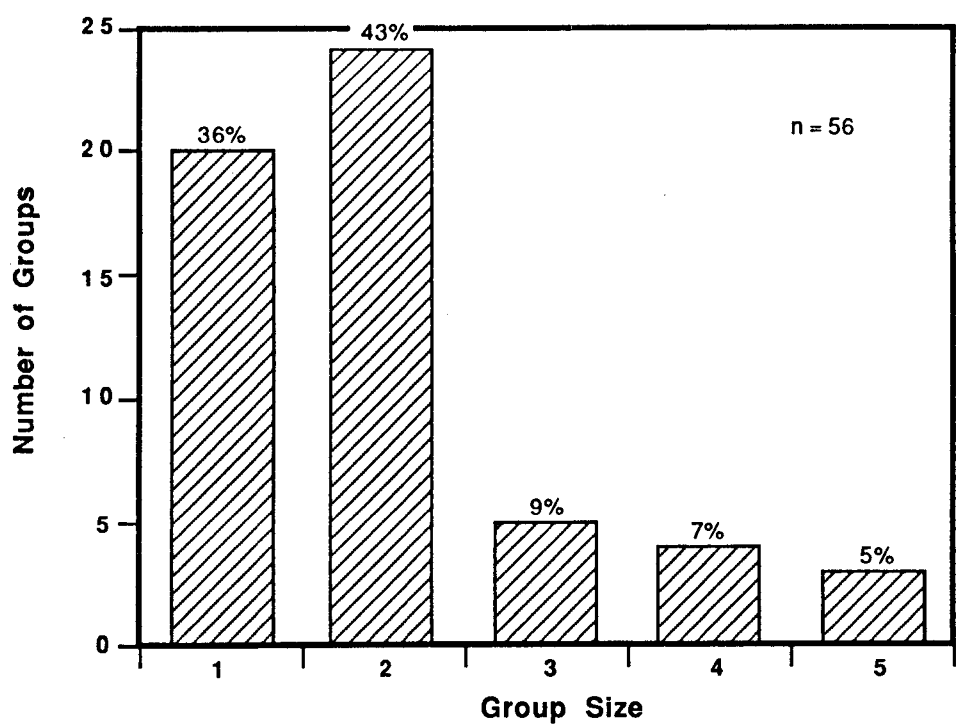


Figure 7.–Group size of humpback whales observed, 1987.

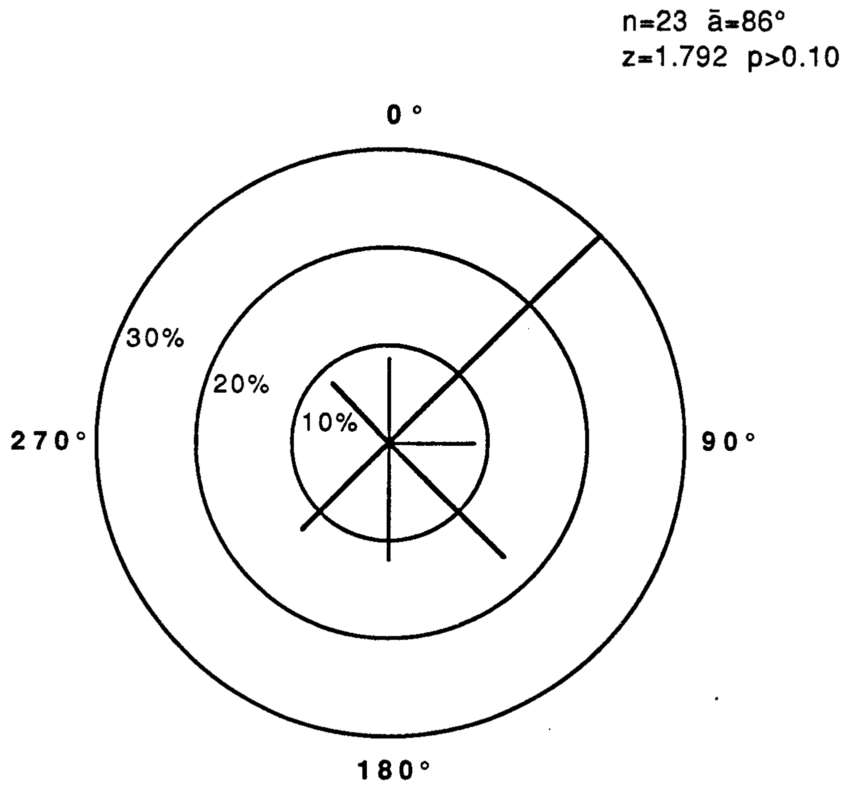


Figure 8.–Directional analysis of humpback whales, 1987.

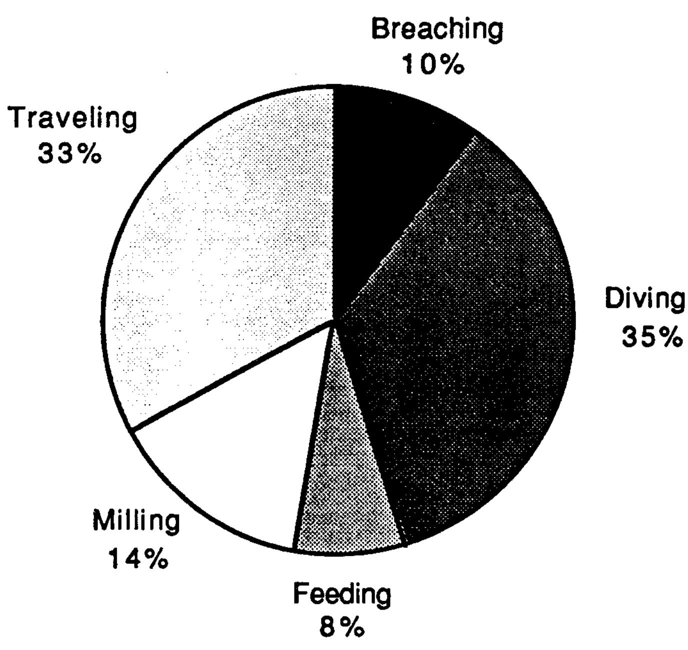


Figure 9.–Observed humpback whale behavior of 51 groups, 1987.

Density and Abundance

Humpback whale density and abundance estimates (Table 4) for the Shumagin and Kodiak-lower Cook Inlet planning areas were derived from systematic and random survey data only. The data were further screened to include only whales observed during fair to excellent visibility conditions and Beaufort sea states between 0 and 4. Too few whales were observed under each visibility or sea state category to analyze them separately according to each condition. Since no significant difference ($p > 0.05$) was found between f(0)'s for Beaufort 0-2 and f(0)'s for Beaufort 3-4, the data from all of these conditions were pooled.

The f(0) was calculated by combining the perpendicular distances recorded from both humpback and finback whale sightings in order to increase sample size. Combining sightings for the two species assumes that humpbacks and finbacks have equal probabilities of detection, which may not be true. However, both species have prominent blows, large body sizes (50 vs. 65 ft), and generally occur in small groups. The difference in average group size for the two species, 2.04 ± 0.15 SE ($n = 56$) for humpbacks and 1.87 ± 0.15 SE ($n = 45$) for finbacks, was not significant ($p < 0.05$). The f(0) values for each species were also not significantly different ($p < 0.05$). Therefore, we assumed the sightabilities of the two species were similar enough to justify combining them into a pooled estimate of f(0). Hay (1982) and Brueggeman *et al.* (1987) also combined humpback and finback whale sighting data to calculate an f(0) to estimate abundance, since they felt the two species had similar sighting cues.

The Fourier series fit of the perpendicular distances for combined humpback-finback sightings is given in Figure 10. The set of perpendicular distances was truncated at 2.16 nmi (mean plus 2 standard deviations) to improve the fit by eliminating the longest distance estimates (K. Burnham, pers. commun.). These are generally the least accurate distances to estimate from a survey platform. The truncation reduced the total number of combined humpback-finback whale distances from 101 to 98. The longest perpendicular distance deleted was 3 nmi. Based upon the shape of the detection curve, there did not appear to be a significant movement of the whales away from the transect line prior to being observed, as shown by the high probability value near the line.

Density and abundance estimates were calculated for the Shumagin and Kodiak-lower Cook Inlet planning areas (Table 4). The estimated f(0) and mean group size were assumed to be constant among the planning areas since sample sizes were too small to estimate them separately for each planning area. Densities were based on 48 sightings in the Kodiak-lower Cook Inlet planning areas and 6 sightings in Shumagin Planning Area. Humpback abundance was estimated at 220 (±127 SE) for the Shumagin Planning Area and 1,027 (±387 SE) for the Kodiak-lower Cook Inlet planning areas, a total of 1,247 (±392 SE) animals. These are minimum estimates because they do not account for submerged animals that were missed.

Table 4.—Summary of statistics used to calculate humpback whale density (groups) and abundance (individuals), 1987.

Planning area	Area (nmi^2)	Trackline length (nmi)	Number of groups	f(0)[a]	Group density ($n/nmi^2 \pm SE$)	Abundance ± SE
Shumagin	21,855	603	6	0.9952	0.005 ± 0.003	220 ± 127
Kodiak[b]	20,584	974	48	0.9952	0.025 ± 0.009	1,027 ± 387
Total	42,439	1,577	54	0.9952	0.014 ± 0.009	1,247 ± 392

[a] Derived from 98 sightings of humpback and finback whale groups.
[b] Includes southern half of Cook Inlet Planning Area.

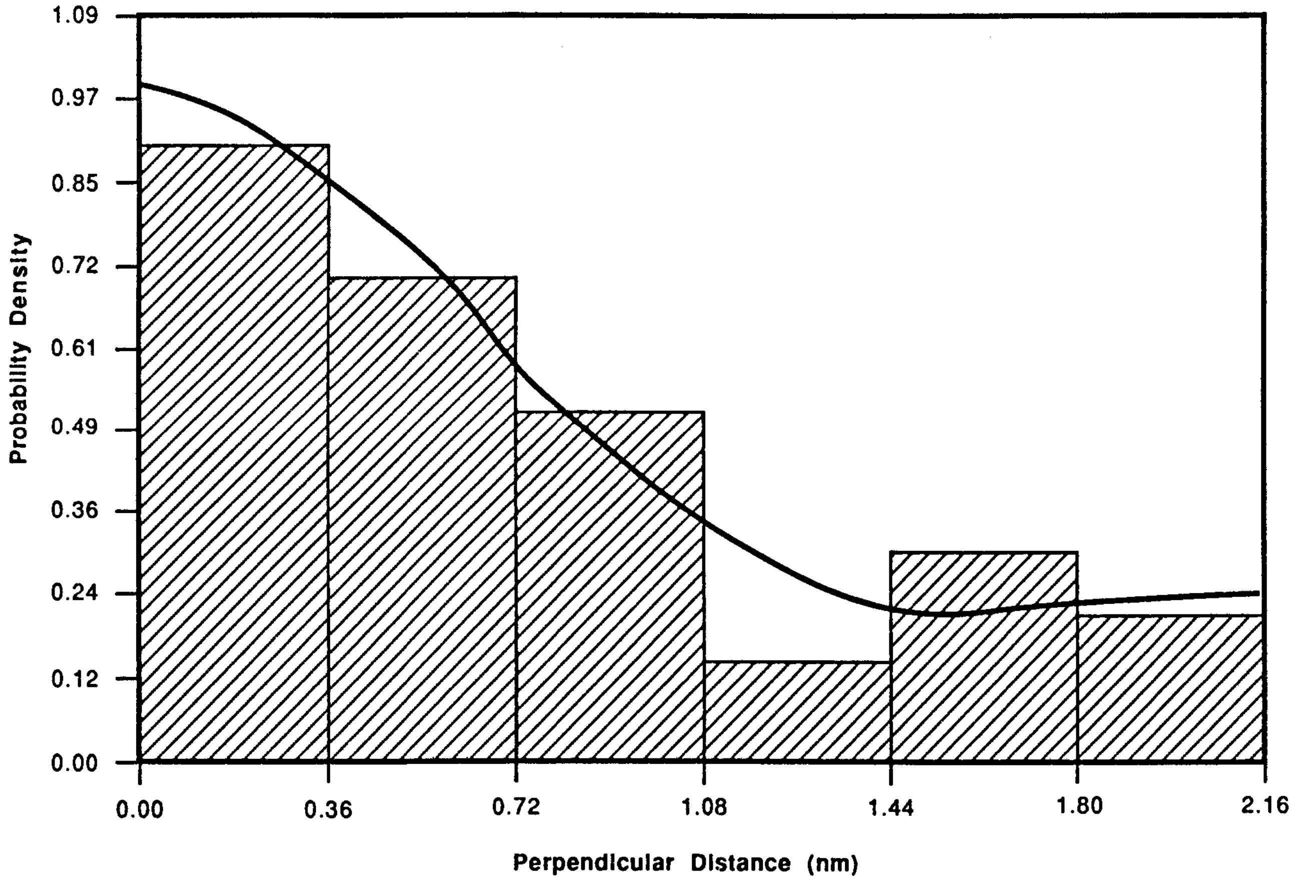


Figure 10.–Probability density function fit of the Fourier series to a frequency histogram of perpendicular distances of 98 sightings of humpback and finback whales, 1987.

Finback Whale

Finback whales were the third most common marine mammal observed, following Dall porpoises and humpback whales. Over the whole study area, 58 groups of 122 finback whales were observed (Table 1). During systematic and random surveys, 30 groups of 63 finback whales were observed along 921 nmi of tracklines in the Shumagin Planning Area, and 16 groups of 32 finback whales were observed along 1,113 nmi of tracklines in the Kodiak-lower Cook Inlet planning areas. In addition, five groups of 9 individuals were observed in the Shumagin and seven groups of 18 whales were observed in the Kodiak-lower Cook Inlet planning areas during deadhead surveys. Figure 11 shows the locations of finbacks sighted during this study.

The 45 finback whale groups seen during acceptable sighting conditions were not uniformly distributed in the study area (Figure 12, Table 5) The number of groups observed

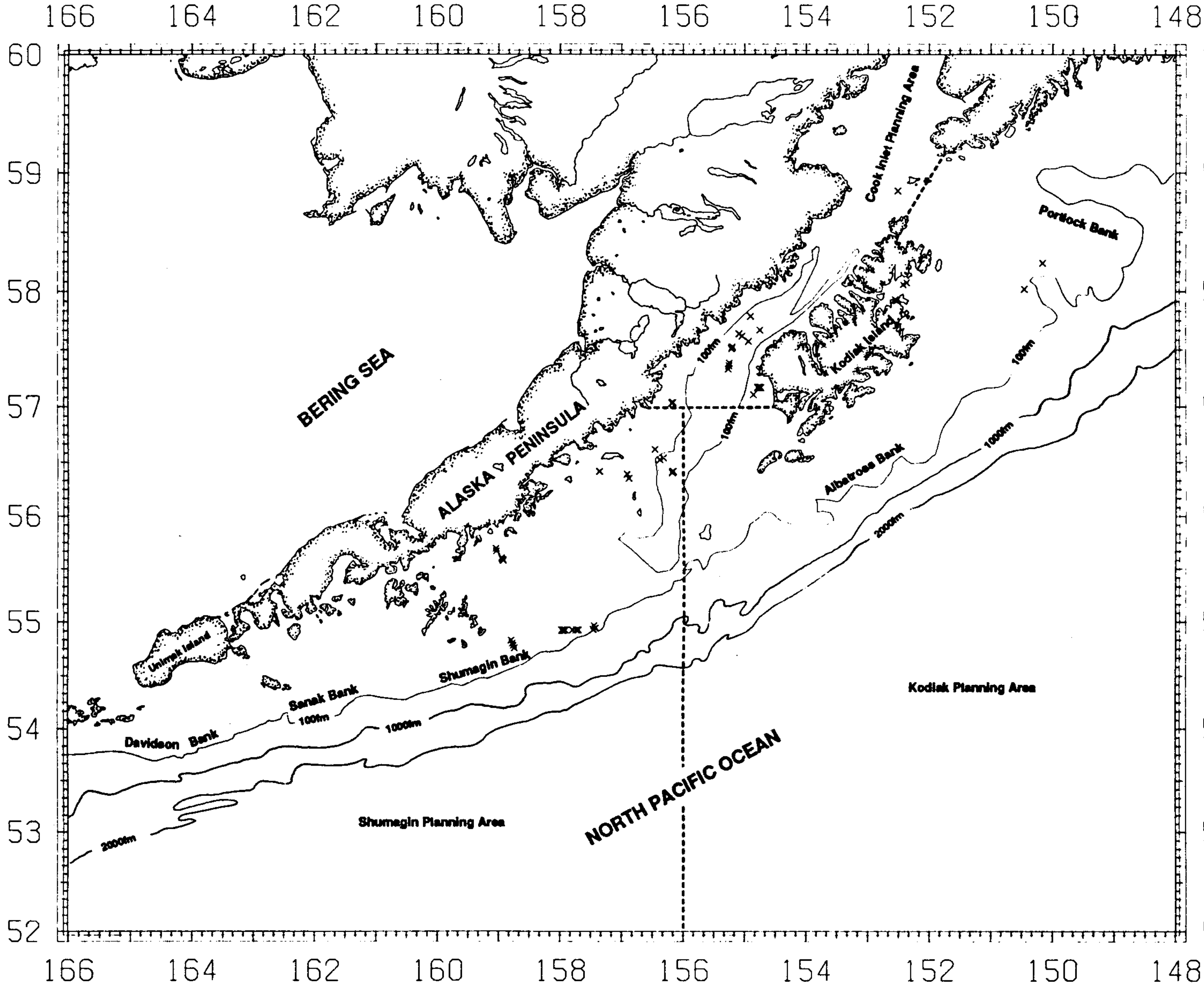


Figure 11.-Locations (X) of finback whale sightings recorded during June-July 1987 shipboard survey.

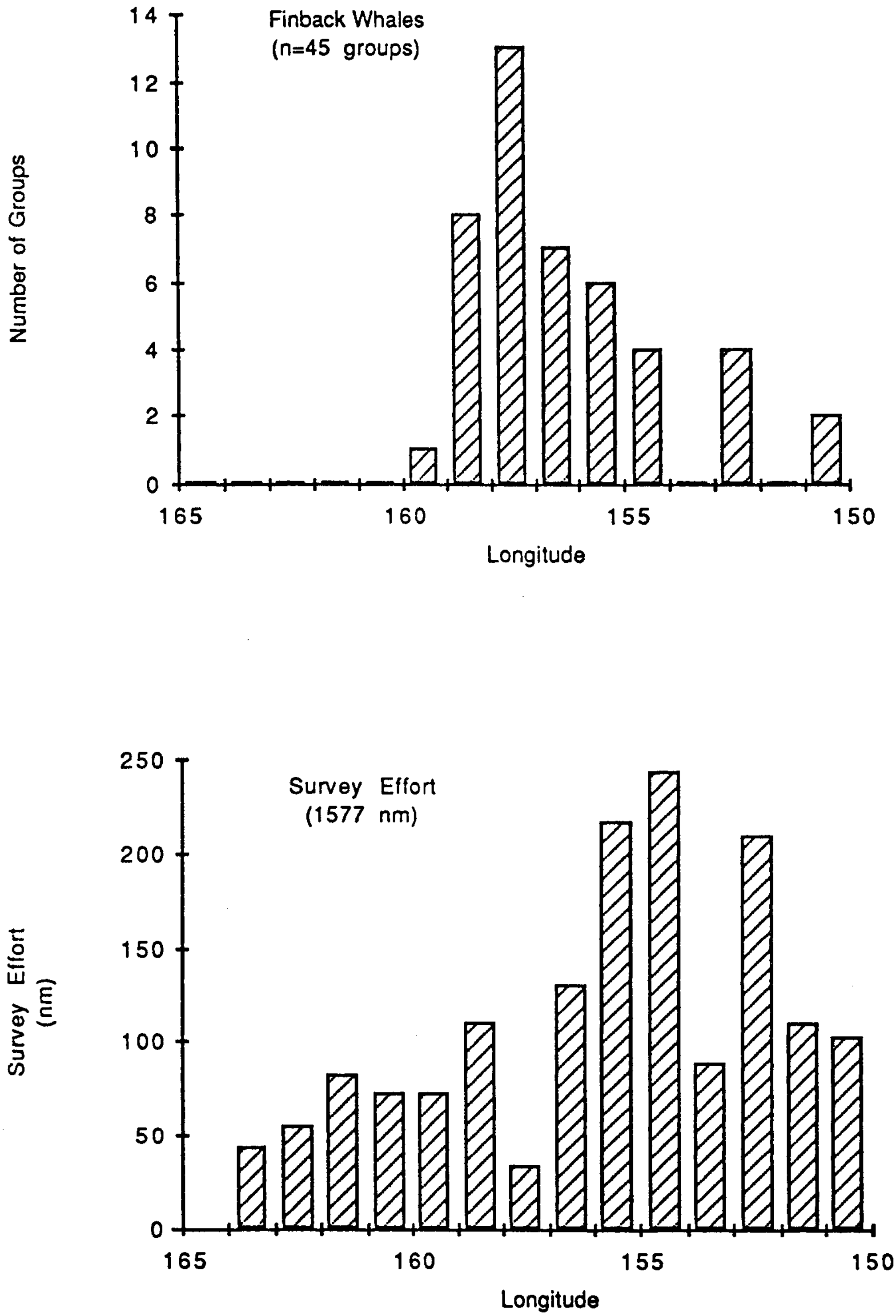


Figure 12.–Survey effort and number of finback whale groups observed by longitude degree during random and systematic surveys.

Table 5.–Relative occurrence of finback whale groups by longitude.

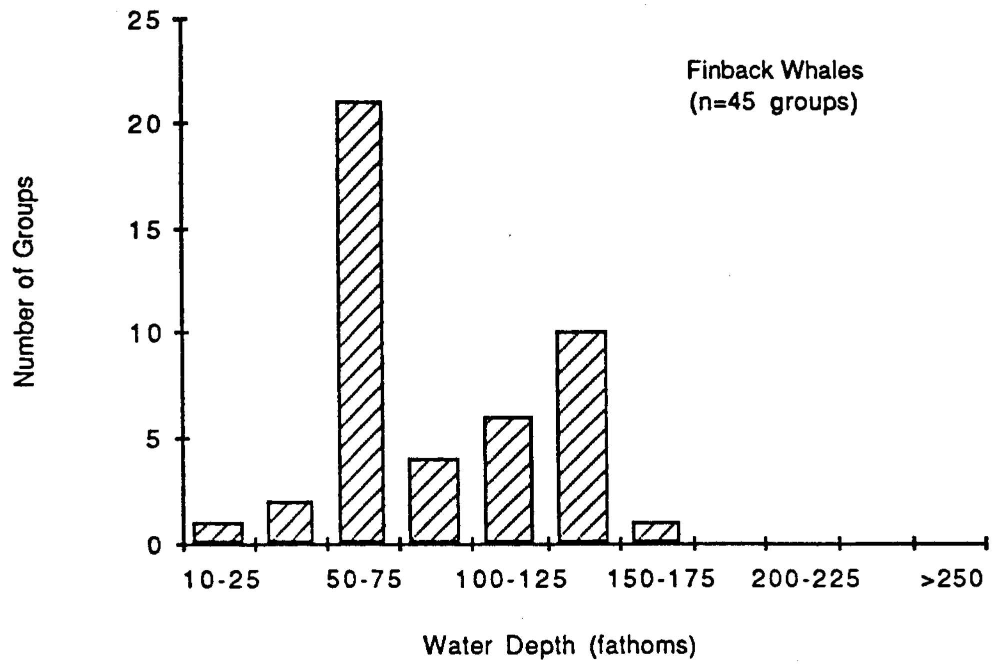
Longitude	Effort[a] (nmi)	Number of groups Observed	Expected[b]	X^2	Preference[c]
150°-152°(W)	214	2	6.1	2.76	0
152°-154°	299	4	8.5	2.38	0
154°-156°	461	10	13.2	0.78	0
156°-158°	164	20	4.7	49.81	+
158°-160°	184	9	5.2	2.78	0
160°-164°	255	0	7.3	7.30	–
Total	1,577	45	45	65.81[d]	

[a] Effort included random and systematic surveys during Beaufort 0-4 and fair to excellent visibility.
[b] Expected number of groups based on proportion of effort within each longitudinal zone.
[c] + indicates preference; – indicates avoidance; and 0 indicates no selection ($p < 0.05$, $X^2_{0.05,1} = 3.841$).
[d] $X^2_{0.05,5} = 11.070$.

at longitudes 156° to 158°W was greater than expected ($p < 0.05$), based on the proportion of the effort that occurred there. This area includes most of the Shumagin Bank and an unnamed bank 60 nmi east of Shumagin Bank, where many of the finbacks were observed. Aggregations of finback or humpback whales over these banks were also observed in 1985 (Brueggeman *et al.* 1987).

Finback whales were most frequently observed in waters between 50 and 150 fathoms deep (Figure 13, Table 6). Over 45% of the observations were in waters 50 to 75 fathoms deep. Observed numbers of finback whales exceeded expected numbers in the 50- to 75-fathom and 100- to 150-fathom water depth categories, whereas the number of whales observed in waters 25-50 fathoms deep and more than 150 fathoms was less than expected ($p < 0.05$). Areas of high topographic relief, where prey productivity may have been high, were associated with the former two depth categories. Similar findings were made in the Shumagin Planning Area by Brueggeman *et al.* (1987) in 1985.

As in 1985, finbacks occupied the summer feeding areas in small groups. The mean group size for finback whales observed during acceptable sighting conditions was 1.87 ± 0.15 SE (n = 45). Over 82% of the groups consisted of one or two animals (Figure 14), while the largest group included five. These values are virtually identical to those obtained in the 1985 surveys (Brueggeman *et al.* 1987), when mean group size was 1.88 (±0.15 SE), 80% of the groups had one or two animals, and the largest group was also five.



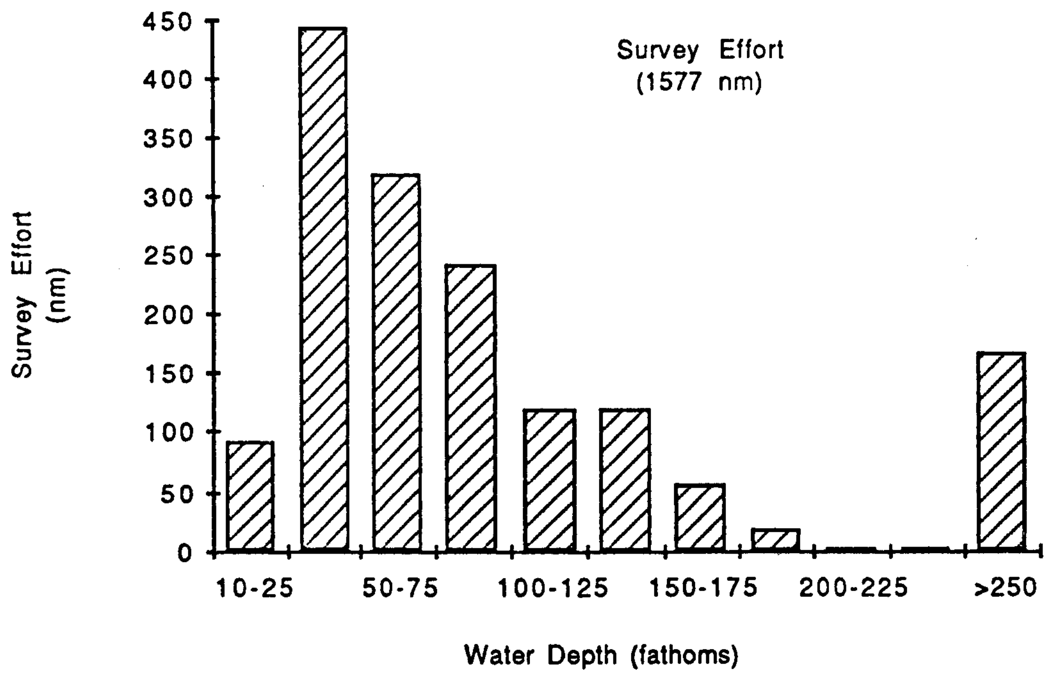


Figure 13.–Survey effort and number of finback whale groups observed by depth class.

Table 6.–Relative occurrence of finback whale groups by water depth.

Water depth (fathoms)	Effort[a] (nmi)	Number of groups: Observed	Number of groups: Expected[b]	X^2	Preference[c]
10-25	91	1	2.6	0.99	0
25-50	444	2	12.7	9.01	–
50-75	318	21	9.1	15.60	+
75-100	242	4	6.9	1.22	0
100-150	239	16	6.8	12.45	+
≥150	243	1	6.9	5.04	–
Total	1,577	45	45	44.31[d]	

[a] Effort included random and systematic surveys during Beaufort 0-4 and fair to excellent visibility.
[b] Expected number of groups based on proportion of effort within each depth class.
[c] + indicates preference; – indicates avoidance; and 0 indicates no selection ($P < 0.05$, $X^2_{0.05,1} = 3.841$).
[d] $X^2_{0.05,5} = 11.070$.

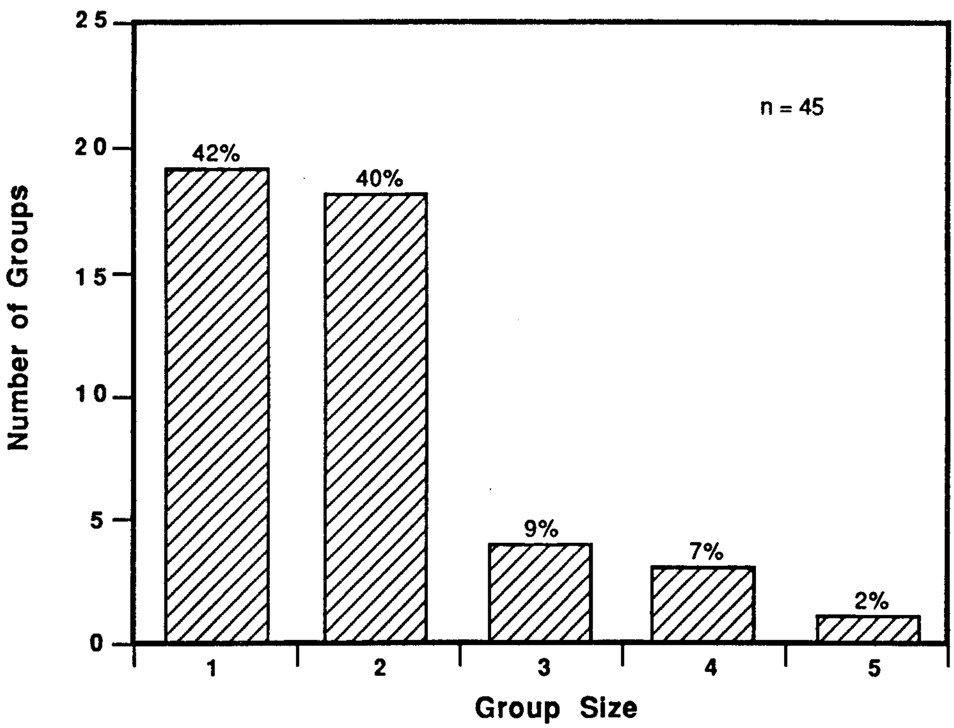


Figure 14.–Group size of finback whales observed, 1987.

The 30 groups of finbacks analyzed for movement patterns showed no consistent directional orientation (Figure 15). This suggests that the majority of the whales were summering in, rather than migrating through, the study area. Although most of the finback whales observed were exhibiting traveling behavior (Figure 16), it was difficult to accurately classify whale behavior from a moving ship.

Density and Abundance

Finback whale density and abundance estimates were derived from random and systematic surveys conducted during acceptable sighting conditions (Table 7). These estimates were calculated from the combined humpback and finback f(0) derived for the entire study area (see the Density and Abundance section for humpback whales).

Finback abundance was estimated at 943 (±536 SE) for the Shumagin Planning Area and 314 (±176 SE) for the Kodiak-lower Cook Inlet planning areas, or 1,257 (±563 SE) total animals. These are minimum estimates since they do not account for missed or submerged animals. The density of finbacks was based on 28 groups in the Shumagin Planning Area and 16 groups in the Kodiak-lower Cook Inlet planning areas. The f(0) and group size were assumed to be constant between areas, since sample sizes were small.

Other Cetaceans

Cetaceans other than humpback or finback whales observed in the project area included minke whales, killer whales, Dall porpoises, and harbor porpoises. The most commonly observed species was the Dall porpoise, of which 101 groups totalling 288 individuals were observed along systematic and random tracklines (Table 1). Over 71% of these sightings occurred in the Kodiak-lower Cook Inlet planning areas. Another 24 groups of 63 porpoises were observed on deadhead surveys. Although Dall porpoise locations were not analyzed by water depth, there was a propensity for sightings to occur approximately on the 100-fathom isobath near the shelf edge and along the Shelikof Strait canyon edge (Figure 17).

The most unusual sighting of the entire survey was a single group of approximately 100 killer whales observed over Portlock Bank on 13 July (Figure 18). The group was strung out in a nearly continuous line of animals for approximately a half-mile. Twenty-four were counted as bulls, based on the dorsal fins. As the ship approached closer, the whales segregated into three groups of approximately 30 animals each, except for a few solitary bulls. The observer counted a minimum of 83 animals. A lone bull was also observed on this date over Portlock Bank, approximately 20 nmi from the large group.

The 11 minke whales observed were spread over all three planning areas (Figure 18). Two groups of three whales were observed in the Shumagin Planning Area and six groups of seven whales were sighted in the Kodiak-lower Cook Inlet planning areas. A single minke whale was observed on deadhead surveys in both the Shumagin and Kodiak

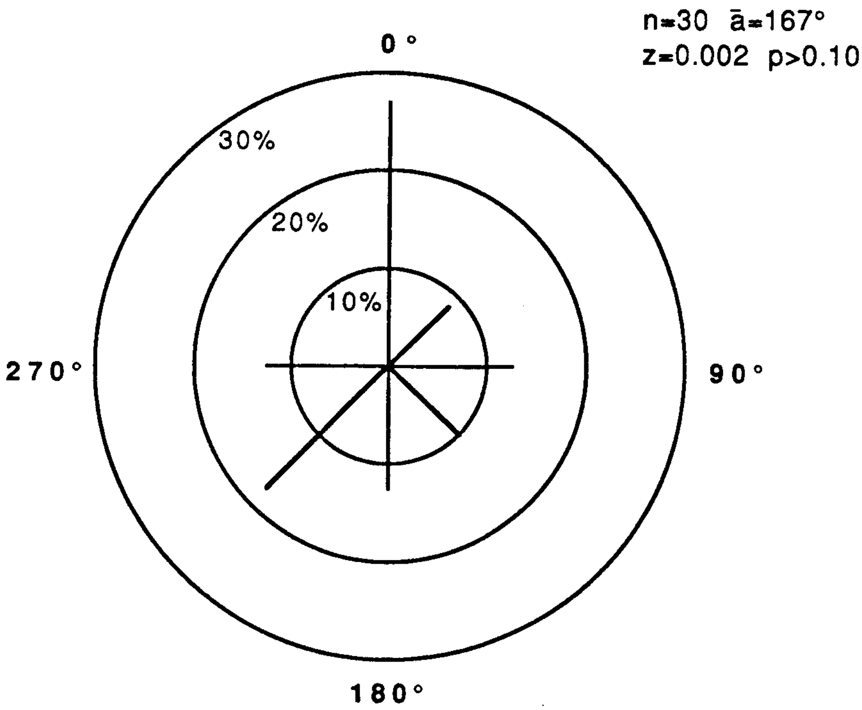


Figure 15.–Directional analysis of finback whales, 1987.

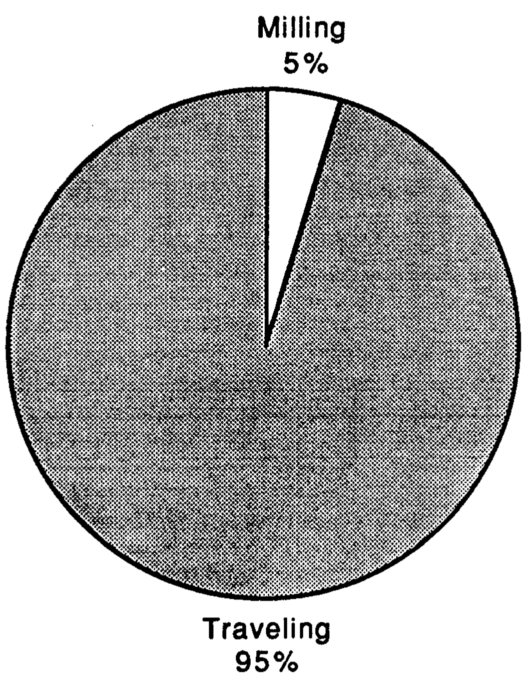


Figure 16.–Observed finback whale behavior, 1987.

Table 7.—Summary of statistics used to calculate finback whale density (groups) and abundance (individuals), 1987.

Planning area	Area (nmi^2)	Trackline length (nmi)	Number of groups	f(0)[a]	Group density ($n/nmi^2 \pm SE$)	Abundance ± SE
Shumagin	21,855	603	28	0.9952	0.023 ± 0.013	943 ± 536
Kodiak[b]	20,584	974	16	0.9952	0.008 ± 0.005	314 ± 176
Total	42,439	1,577	44	0.9952	0.016 ± 0.013	1,257 ± 563

[a] Derived from 98 sightings of humpback and finback whale groups.

[b] Includes southern half of Cook Inlet Planning Area.

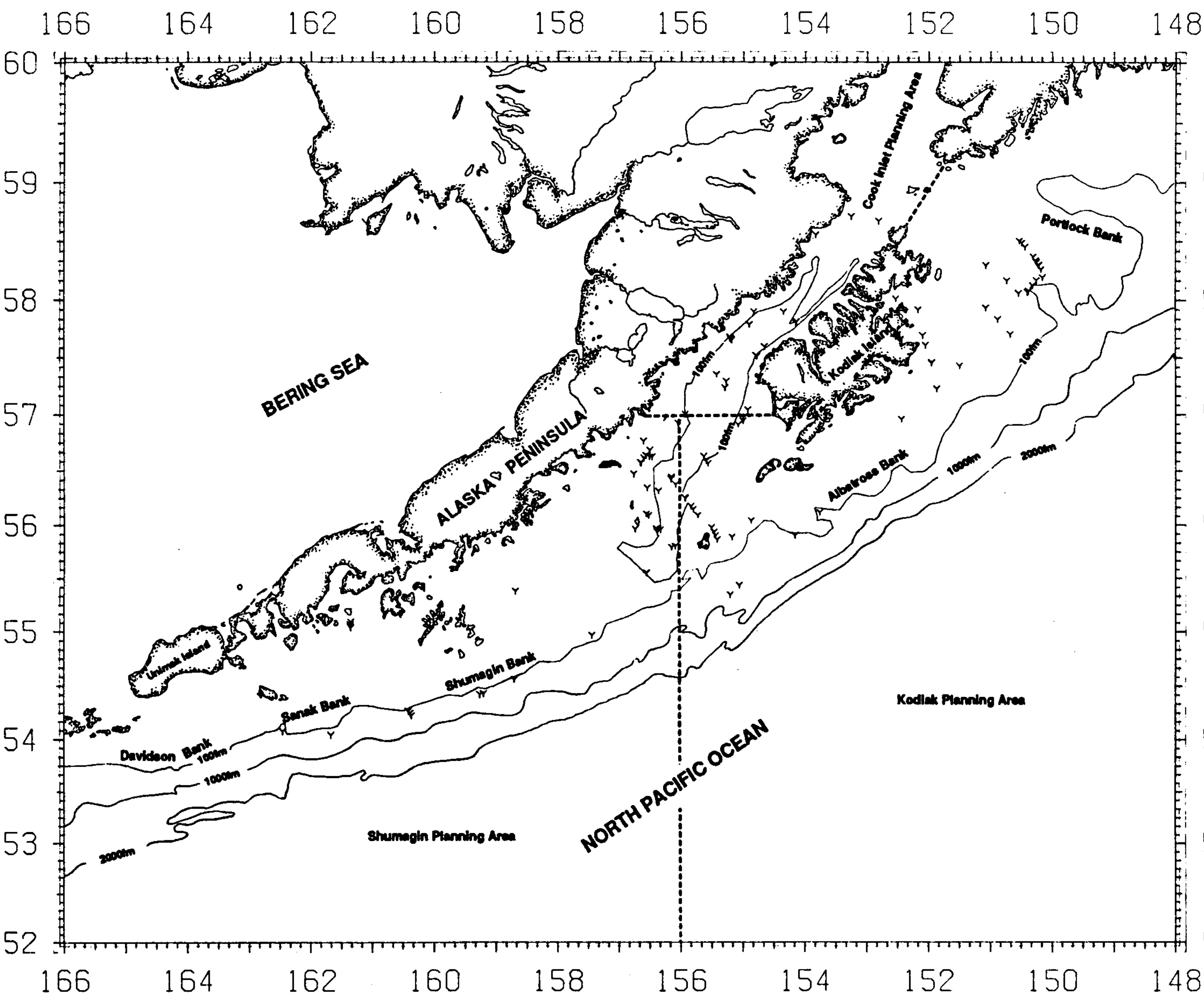


Figure 17.–Locations (Y) of Dall porpoise sightings recorded during June-July 1987 shipboard survey.

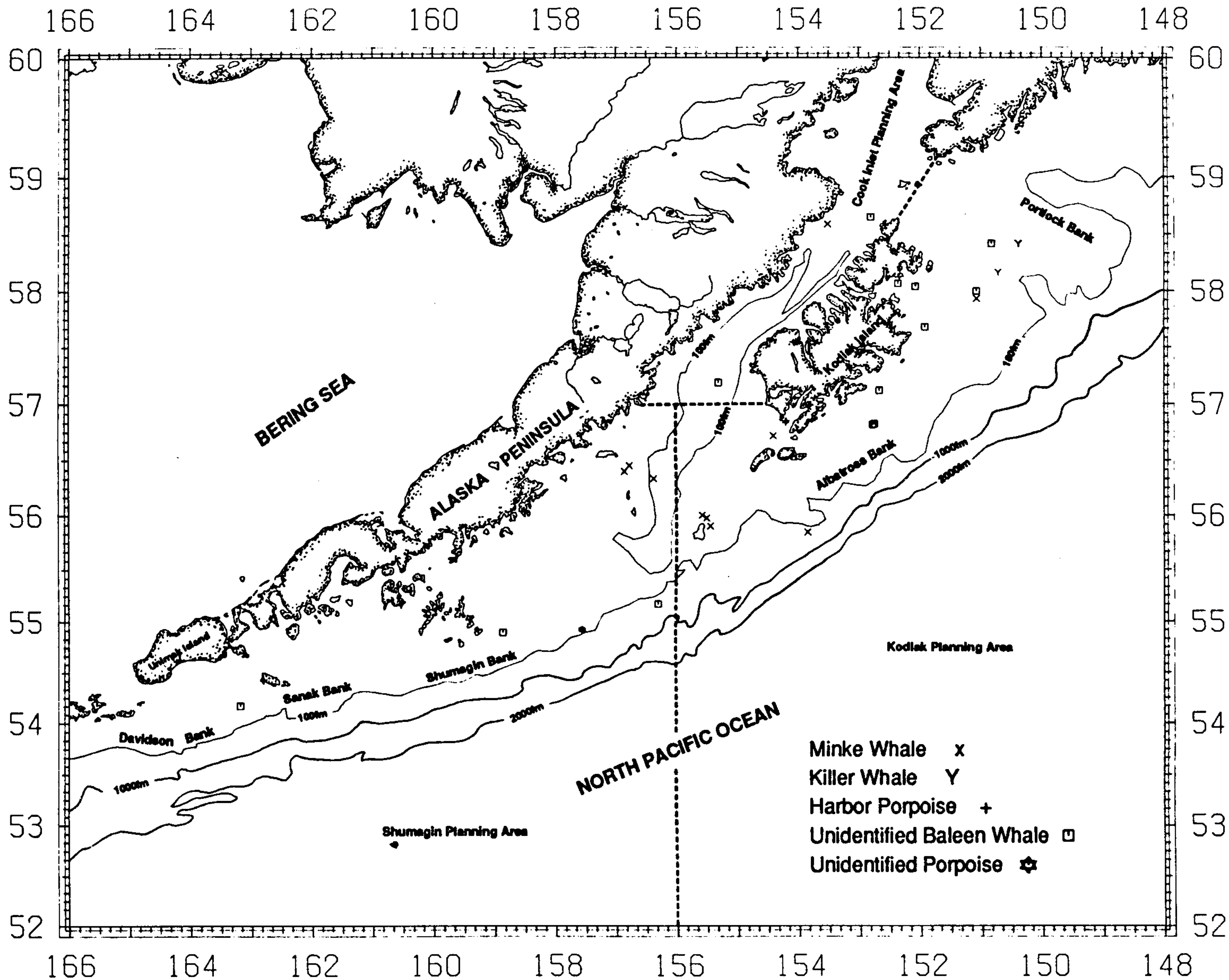


Figure 18.–Locations of nonendangered cetacean sightings recorded during June-July 1987 shipboard survey.

Planning areas. Six of these sightings occurred near Chirikof Island and the Semidi Islands. These results are similar to findings in other studies which show that minke whales are generally solitary animals, widely distributed, and observed in low abundance.

Three harbor porpoises were separately observed in the project area (Figure 18). Two porpoises were observed in Alitak Bay on the southeast end of Kodiak Island and the other one was within Whale Passage between Kodiak and Raspberry Island. Harbor porpoises inhabit nearshore areas which were difficult to survey because of the ship's deep-draft hull.

An additional 14 groups of 19 unidentified large baleen whales were observed in the study area (Table 1, Figure 18). Over 70% (10 groups) of these sightings were made over the Portlock and Albatross banks in the Kodiak Planning Area. These sightings were probably finback or humpback whales that could not be positively identified due to distance of the sighting, poor survey conditions, or inadequate sighting cues. Only one group of two porpoises was not positively identified (Table 1, Figure 18). However, because the animals were approximately 60 nmi from land and at the continental shelf edge, they were most likely Dall porpoises and not harbor porpoises.

Other Marine Mammals

Four other species of marine mammals (northern sea lion, northern fur seal, harbor seal, and sea otter) were observed in the study area (Table 1). Large numbers of these species were not observed, primarily because all but the northern fur seals occur most commonly in shallow nearshore waters which the ship could not reach. Eighty-one percent of the 73 sea otters were observed in the narrow channel of Whale Passage that separates Kodiak Island from Afognak and adjacent smaller islands (Figure 19). Only 54 sea lions were observed in the study area, which included 29 hauled out on one rock in the Shumagin Planning Area. One harbor seal, observed in Whale Passage, was recorded during the entire survey.

The 42 sightings of northern fur seals were equally divided between the Shumagin and Kodiak-lower Cook Inlet planning areas. The fur seals were primarily sighted near the shelf edge or in the deeper (>100 fathoms) waters near Shelikof Strait (Figure 19). The fur seal distribution was very similar to that of the Dall porpoise (Figure 17).

Marine Mammals Not Sighted

We did not observe various other cetaceans that inhabit these waters (Consiglieri and Braham 1982; Leatherwood *et al.* 1983; Brueggeman *et al.* 1985, 1986, 1987). Endangered species include the blue, sperm, gray, sei, and right whales. Blue and sperm whales normally use deep water habitats beyond the boundary of the study area. Gray whales occupy nearshore waters and migrate through the study area during seasons before

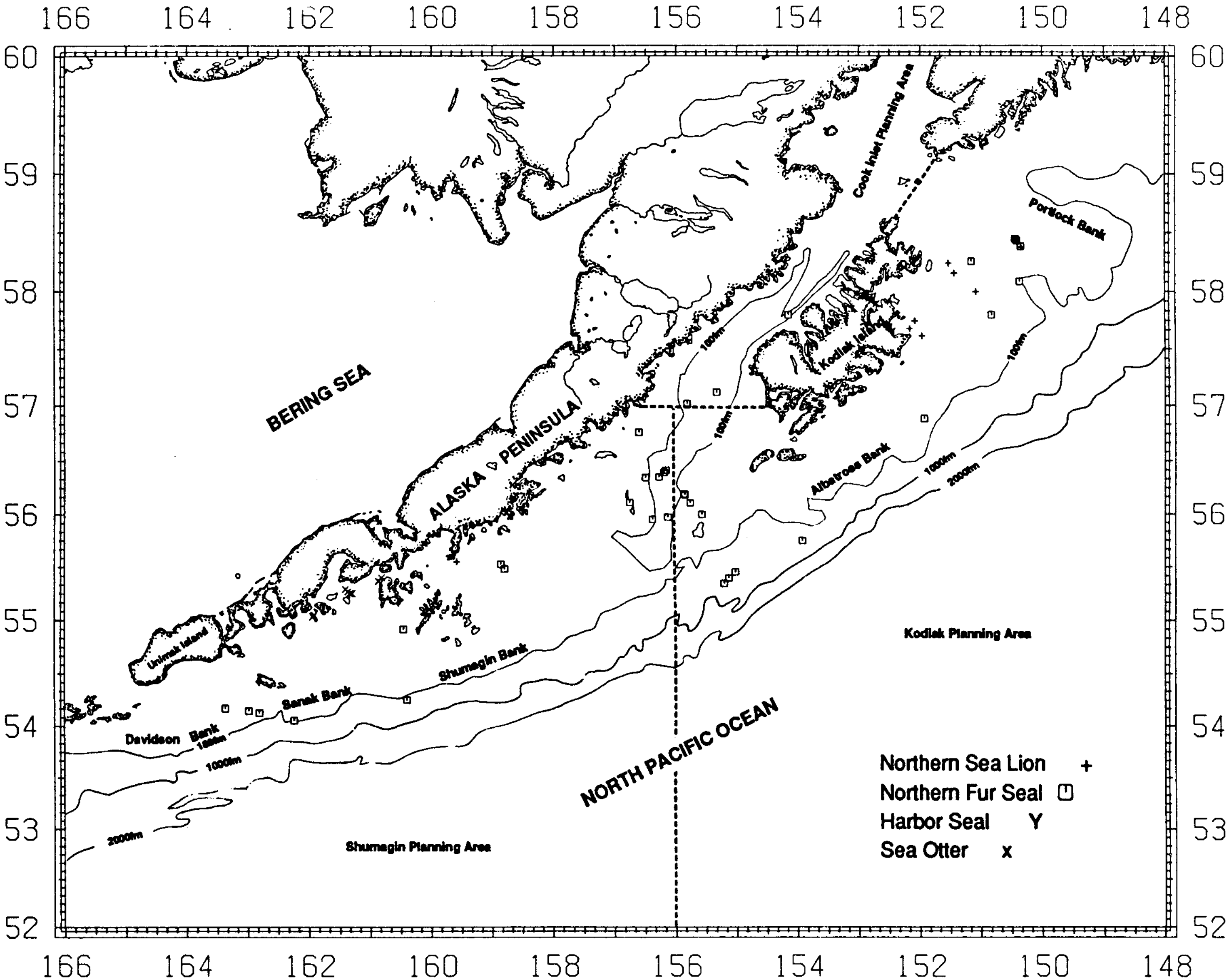


Figure 19.–Locations of pinniped and sea otter sightings recorded during June-July 1987 shipboard survey.

and after the survey period. Sei whales also occur in the shelf waters, but the infrequency of sightings suggests they are not common. Right whales, while abundant in the 1800s, were reduced in numbers by commercial whalers to the point that fewer than 200 animals are currently estimated to inhabit the North Pacific Ocean. Although right whales historically inhabited the shelf waters in the Gulf of Alaska, the probability of sighting one is extremely low. The last confirmed sighting in the North Pacific and Bering Sea was in 1982 when Brueggeman *et al.* (1984) reported two right whales northeast of St. Matthew Island. Other cetacean species not encountered but known to occur primarily in the Gulf of Alaska include three species of beaked whales which occur in deep waters (Brueggeman *et al.* 1987) beyond the area surveyed from the ship. The lack of sightings of any of these species confirms that they were either not abundant in the study area during the surveys (since they primarily occur outside the survey area or inhabit the study area at times of the year different from the survey period), or are uncommon.

Comparison of 1985 and 1987 Results

This section provides a comparison between marine mammal surveys conducted in 1985 (Brueggeman *et al.* 1987) and 1987. Aerial surveys were conducted in the St. George Basin, North Aleutian Basin, and Shumagin planning areas in 1985 during six 20-day periods between April and December. The comparison between the 1985 and 1987 surveys is limited to the summer feeding period and to marine mammals in the waters south of the Alaska Peninsula. For the 1985 surveys, this included the June to October periods in the Shumagin Planning Area. The 1987 survey, conducted in June-July, overlaps with these previous surveys in the Shumagin area. However, the 1985 surveys extended beyond the shelf break and included nearshore areas that were inaccessible to the ship. Consequently, marine mammals associated with these areas cannot be compared between the two surveys. The shelf-related species, primarily the humpback and finback whales, are discussed below.

A total of 14 species of marine mammals were recorded south of the Alaska Peninsula during the 1985 and 1987 surveys: 10 species of cetaceans, 3 species of pinnipeds, and the sea otter (Table 8). Six of the seven endangered species of cetaceans expected in the study area were recorded during the two survey periods, but only the humpback and finback whales were observed in both 1985 and 1987. Totals of 185 humpback and 149 finback whales were recorded in 1985, compared to 150 humpback and 122 finback whales in 1987. Gray whales were observed summering in the study area in 1985 and in 1986 during a sea otter survey (Brueggeman *et al.*, draft report), but not in 1987. Thus it can be concluded that these three species of endangered whales summer in the waters south of the Alaska Peninsula. These species have historically inhabited this area, according to commercial whaling records examined by Reeves *et al.* (1985). In addition, the other eight species of marine mammals recorded during both 1985 and 1987 surveys confirm findings reported by others (Consiglieri and Braham 1982; Leatherwood *et al.* 1983) that these species inhabit waters on or near the shelf.

Table 8.–Number of marine mammal observations recorded during the 1985 aerial surveys and 1987 shipboard surveys conducted south of the Alaska Peninsula.

Species	Habitat	1985 survey (25,059 nmi)[a]	1987 survey (2,034 nmi)
Minke whale	Shelf	4	12
Finback whale	Shelf/slope	149	122
Humpback whale	Shelf	185	150
Gray whale	Shelf	191[b]	0
Cuvier's beaked whale	Rise	2	0
Baird's beaked whale	Rise	9	0
Sperm whale	Slope/rise	23	0
Killer whale	Shelf	38	101
Harbor porpoise	Shelf	1	3
Dall porpoise	Shelf/slope/rise	103	351
Steller sea lion	Shelf	2,997	54
Northern fur seal	Shelf	4	42
Harbor seal	Shelf	282	1
Sea otter	Shelf	1,880	73

[a] Survey effort.
[b] Two observations were recorded during the summer; the others were recorded during the migration periods in April and November-December.

The results of the two survey periods show that while the distribution of marine mammals was widespread, humpback and finback whales are concentrated in generally separate areas. Humpback whales occurred from approximately Sanak Bank (163°W) to beyond Kodiak Island (150°W) (Figure 20). Numbers of humpbacks generally increased from west to east. Commercial whaling records show that the proportion of humpbacks harvested in the total catch was higher for the Port Hobron whaling station (64%), near Kodiak Island, than for the Akutan station (24%), further west near Unimak Pass (Reeves *et al.* 1985). Most whales we observed in the study area were near the 50-fathom isobath, often on a bank. Banks used by the whales included Sanak, Shumagin, Portlock, and Albatross, and an unnamed bank between 157 and 158°W. Humpbacks were observed on Sanak Bank during 1985 and 1987 where commercial whalers harvested humpbacks between 1912 and 1939. Surveys were also conducted over Davidson Bank in 1985 and 1987 but no whales were observed. These results show that humpbacks were largely associated with the 50-fathom isobath, particularly near oceanic banks which may be repeatedly occupied each year. Oceanographic conditions associated with the high relief of these banks provide abundant prey for marine mammals. Studies reported by Payne *et al.* (1986) show a similar association of humpback whales to banks on the East Coast, such as Georges Bank in the Gulf of Maine.

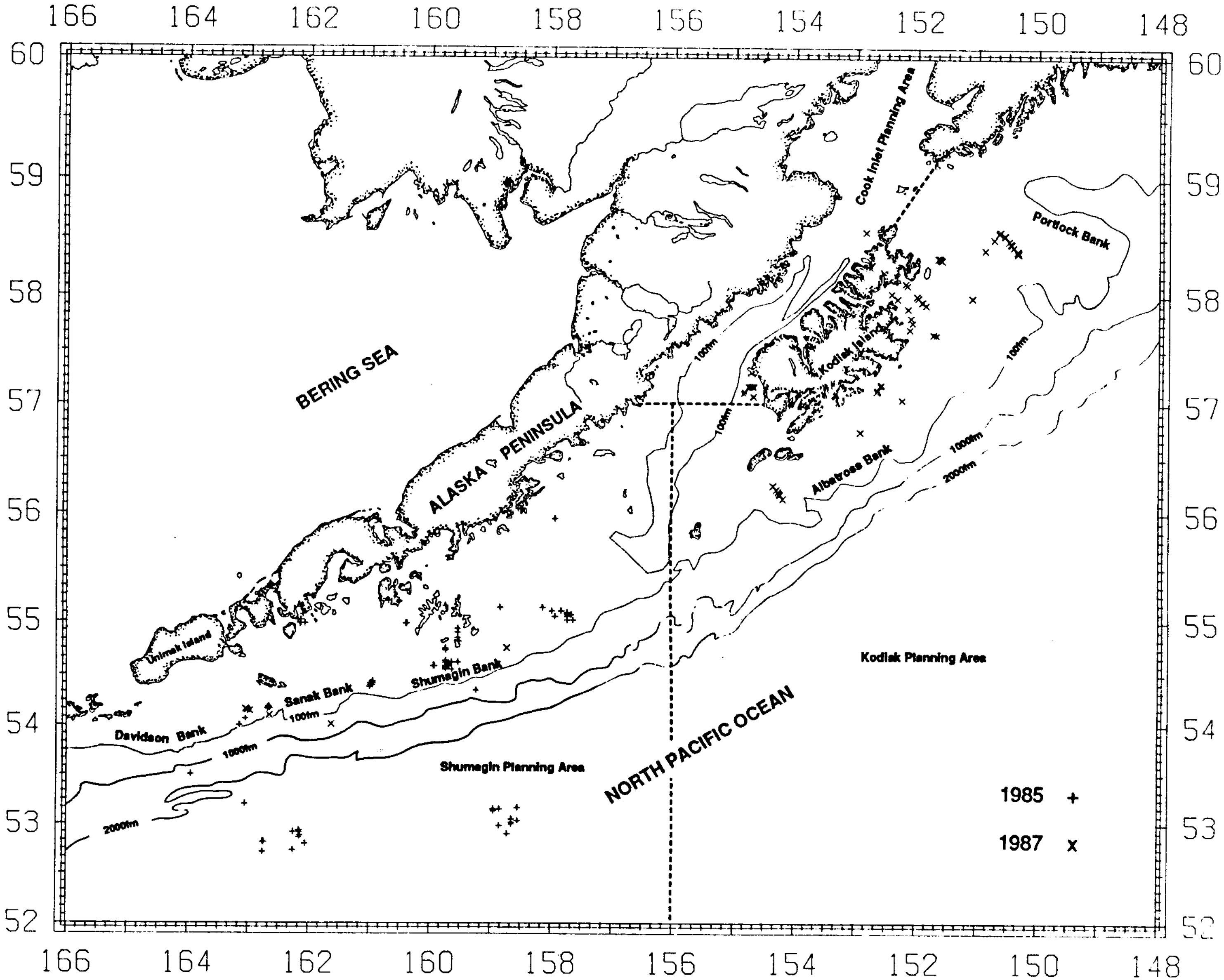


Figure 20.–Humpback whale locations recorded during the 1985 aerial surveys (Brueggeman *et al.* 1987) and 1987 shipboard surveys.

No humpback whale calves were observed in either the 1985 or 1987 study. Correspondingly, there were no calves with the 191 humpbacks recorded in the Gulf of Alaska by Rice and Wolman (1982). Calves have been reported to compose 0-18% of the population summering in Alaska (Jurasz and Palmer 1981; Perry *et al.* 1985) and 9-10% of the population wintering in Hawaii (Herman and Antinoja 1977; Herman *et al.* 1980). Using a conservative estimate that calves make up 5% of the population, 26 calves should have been observed during the three western Gulf of Alaska studies (Rice and Wolman 1982; Brueggeman *et al.* 1987; this study). Possible explanations for this discrepancy include: survey platforms were not suitable for observing calves, calves were subadult size by the time of surveys (D. Rice, pers. commun.), or cow-calf pairs do not use the less protected waters of the western Gulf of Alaska. Nearly all of the humpbacks observed in the three western Gulf of Alaska studies (except for Rice and Wolman's Prince William Sound observations) were in open water habitats. Calves, however, have been commonly observed in protected inland bays of Alaska (C. S. Baker, pers. commun.); therefore, cow-calf pairs may separate from the rest of the population. Inland bays were not surveyed during this study, and bay complexes are not as common in the Shumagin Planning Area as around Kodiak and southeastern Alaska. Furthermore, whalers based out of Akutan and Port Hobron occasionally took or reported finback and blue whale calves, but not humpback calves (Reeves *et al.* 1985). Consequently, humpback calves are either scarce or indistinguishable from adults when summering in Gulf of Alaska waters.

Finback whales were also widely distributed in the study area, but were generally found in areas not occupied by humpback whales (Figure 21). Finback whales were primarily observed between the Shumagin Islands and Semidi Islands in both 1985 and 1987. Most animals were associated with the Shelikof Strait submarine canyon and the nearby unnamed bank. Finback whales occurred on the unnamed bank (where we also saw enormous flocks of shearwaters in 1987) during both survey periods. Finback and humpback whales were found at similar depths, and on occasion were observed feeding together. However, with the exception of Shumagin Bank and the unnamed bank, finbacks were primarily found in the central portion of the study area, particularly along the edges of the Shelikof Strait submarine canyon, while humpbacks typically used the oceanic banks. This trend indicates that, at least to some degree, habitat is partitioned by the two species. On the other hand, these results demonstrate that both finback and humpback whales occur primarily in areas of high bathymetric relief where biological productivity is probably high.

No finback whale calves were observed during either the 1985 or 1987 surveys. The same explanations provided for the relative absence of humpback whale calves may apply in this instance as well. Fetus records of finbacks from the Akutan and Port Hobron whaling stations (Reeves *et al.* 1985) indicate that calves are 20 feet long when born during late fall and early winter. By the time the 1985 and 1987 surveys began (May-June), these calves were probably indistinguishable from adults.

The only other species having sufficient numbers of observations in both years to show distribution patterns was the Dall porpoise. This species was widespread, but the

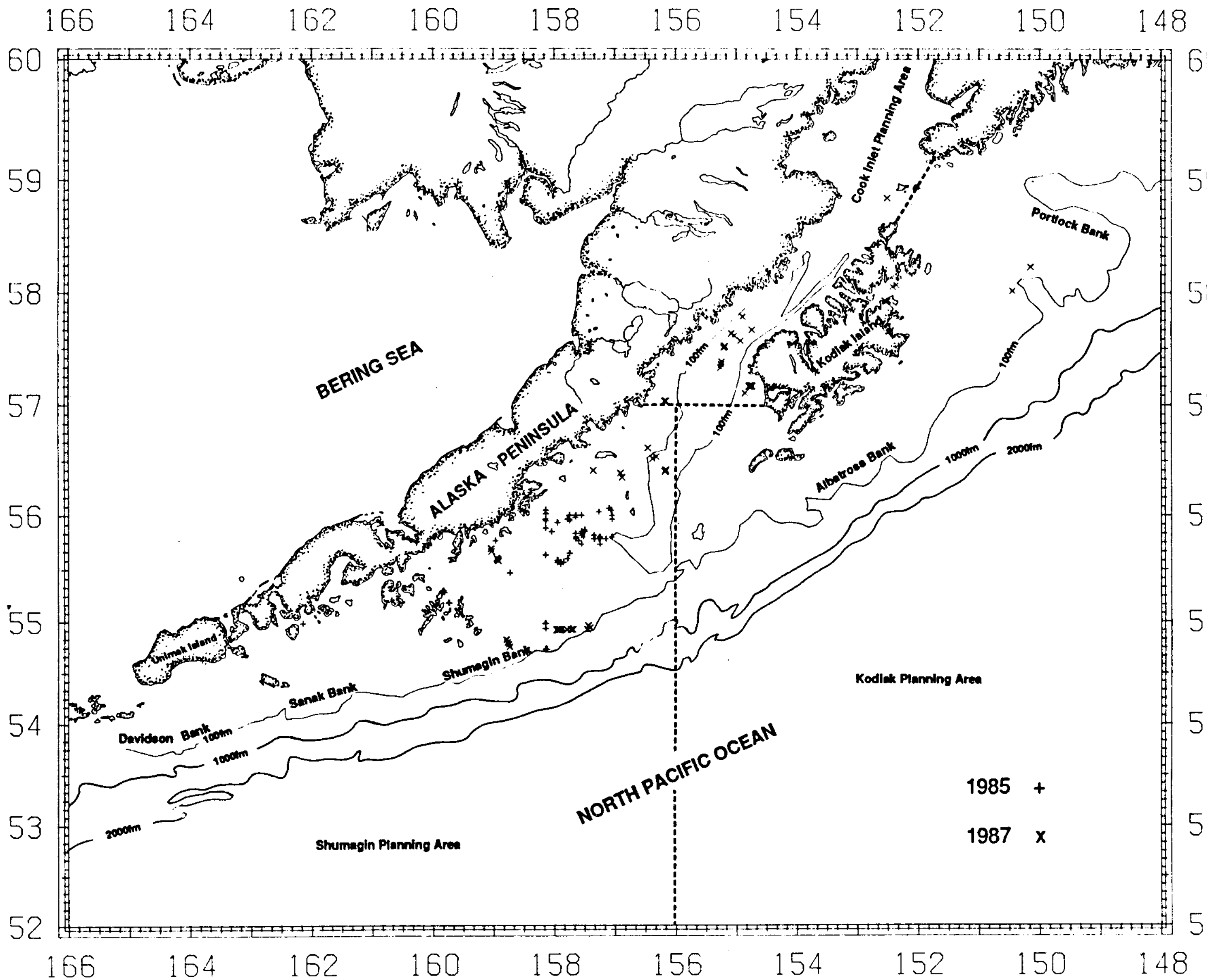


Figure 21.–Finback whale locations recorded during the 1985 aerial surveys (Brueggeman *et al.* 1987) and 1987 shipboard surveys.

animals were particularly associated with high relief areas along the shelf break and the Shelikof Strait submarine canyon. Other studies in Alaska (Consiglieri and Braham 1982; Leatherwood *et al.* 1983; Brueggeman *et al.* 1984) also found this species occurring in or near areas of relatively deep water.

Abundance was estimated for humpback and finback whales in 1985 and 1987. Humpback whale abundance was estimated at 1,247 (±392 SE) for the combined Shumagin and Kodiak-Cook Inlet planning areas in 1987. In the Shumagin Planning Area alone, abundance was estimated at 333 (±217 CI) in 1985 and 220 (±127 SE) animals in 1987. The former estimate is more reliable since it was derived from 34 groups, compared to 6 groups in 1987. Both surveys also made estimates for total humpback whale abundance in Alaskan waters. Brueggeman *et al.* (1987) developed an estimated humpback whale abundance for Alaska of 1,007 animals by adding the 333 animals estimated in the Shumagin Planning Area in 1985, 364 animals estimated in the Gulf of Alaska (Rice and Wolman 1982), and 310 (270-372) animals estimated in southeast Alaska (Baker *et al.* 1985). By comparison, the results of this survey indicate a total of 1,921 animals for Alaska, derived by adding the 1,247 animals we estimated for the combined Shumagin and Kodiak-Cook Inlet planning areas in 1987 to the values provided by Rice and Wolman (1982) and Baker *et al.* (1985).

These total estimates are uncertain, however, since they assume the animal counts were not duplicated among the three estimates. Furthermore, the confidence intervals for the 1985 and 1987 estimates are wide, and Rice and Wolman (1982) did not derive a confidence interval. Their estimate was calculated by expanding the observed density to the total area surveyed.

Despite the limitations, these estimates are the best available for Alaskan waters. Assuming these values are correct, the two total estimates we calculated suggest that the minimum number of humpbacks summering in Alaska is between 1,000 and 1,900 animals, or 45-90% of the estimated 2,100 animals composing the "Hawaiian" humpback whale population in the North Pacific Ocean (Darling and Morowitz 1986). Moreover, these results show that most of the animals summering in Alaska are found in the waters of the Shumagin and Kodiak-Cook Inlet planning areas.

Finback whale abundance in the Shumagin Planning Area was estimated to be much higher in 1987 than it was in 1985. Abundance was estimated at 943 (±536 SE) animals in 1987 compared to 184 (±90 CI) in 1985. Several factors contributed to the difference between the two estimates. In 1987, whales were encountered more frequently per unit of effort than in 1985, and the survey effort (in 1987) was higher in the eastern portion of the Shumagin Planning Area, where finback whales were more common. Other factors, such as survey platform biases, may have also contributed to the difference. The use of correction factors for missed whales could reduce the disparity between the two estimates, but such factors have not been developed by cetacean researchers.

Although the estimates do not closely agree, they suggest that approximately 1,000 finbacks or fewer summer in the Shumagin Planning Area. The 1987 Shumagin estimate combined with the estimate for the Kodiak and Cook Inlet planning areas further suggest that approximately 1,257 (±563 SE) finback whales, less than 10% of the estimated 14,620-18,630 (Braham 1984*b*) in the North Pacific population, summer in these planning areas. Abundance was not estimated for the other species because of small sample sizes, but the 1985 and 1987 results confirm that Dall porpoises were common in the study area.

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APPENDIX A

Visibility and glare criteria.

Table A-1. Criteria used to determine relative visibility.

Visibility	Highest Allowed Beaufort Sea State	Descriptors
Excellent	1	Calm and clear
Very Good	2	Surface ripple, some glare.
Good	4	Light chop, glare, fog
Fair	5	Chop, glare, shadows, fog but all animals on line visible
Poor	5	Same as Fair only some animals on line obscured
Unacceptable	--	Survey tract obscured

Table A-2. Criteria used to classify glare.

Glare Number	Percent area obscured by sun reflection, fog, or moisture on window surface
1	1 - 10 percent
2	11 - 25 percent
3	26 - 50 percent
4	51 - 75 percent
5	76 - 100 percent

APPENDIX B

Record of whales encountered in the Shumagin and Kodiak-lower Cook Inlet planning areas during June-July 1987.

SPECIES[a/]	DATE	NUMBER	LATITUDE (N)	LONGITUDE (W)
BA	708	2	56270	156470
	708	1	56239	156518
	708	1	56200	156230
	709	2	56000	155352
	709	1	55584	155308
	709	1	55540	155270
	709	1	55507	153513
	710	1	56429	154250
	712	1	58352	153316
	713	1	57557	151046
BP	621	2	54453	158444
	621	4	54453	158444
	621	2	54468	158454
	621	1	54496	158476
	622	5	55415	159025
	622	1	55362	158570
	622	1	55353	158561
	622	2	55353	158561
	622	2	55346	158553
	622	3	54552	157582
	622	3	54552	157582
	622	1	54552	157572
	622	2	54552	157563
	622	1	54553	157477
	622	2	54553	157477
	622	2	54553	157477
	622	1	54553	157439
	622	5	54553	157420
	622	1	54556	157275
	622	2	54556	157275
	622	2	54564	157252
	622	2	54577	157267
	625	2	56248	157216
	628	3	56321	156193
	628	3	56311	156229
	628	2	56368	156276
	630	2	56232	156547
	706	3	57552	152319
	707	1	57313	155114
	707	1	57310	155120
	707	1	57303	155125
	707	2	57228	155146
	707	2	57214	155151
	707	1	57021	156098
	707	2	57021	156097
	707	1	57019	156110

SPECIES	DATE	NUMBER	LATITUDE (N)	LONGITUDE (W)
BP	708	2	56210	156530
	708	2	56241	156107
	708	2	56244	156104
	709	2	56248	156099
	709	1	56250	156099
	710	5	57100	154440
	710	2	57100	154450
	710	3	57100	154450
	710	2	57100	154460
	710	3	57100	154470
	710	2	57099	154475
	710	2	57062	154514
	711	2	57381	155050
	711	1	57369	155021
	711	2	57341	154560
	711	1	57400	154447
	711	1	57471	154540
	712	2	58507	152307
	713	4	58140	150092
	713	4	58010	150270
	714	1	58043	152218
	714	3	58033	152252
MN	618	3	54096	163027
	618	1	54089	163014
	618	1	54087	162586
	618	4	54060	162392
	618	5	54006	161378
	621	1	54453	158444
	709	3	56081	154125
	709	2	56109	154163
	709	3	56119	154173
	709	1	56152	154222
	710	2	57041	154420
	710	4	57041	154420
	710	2	57046	154423
	710	3	57096	154416
	710	2	57100	154420
	710	3	57100	154420
	710	3	57100	154430
	710	2	57100	154430
	710	3	57100	154440
	710	2	57100	154460
	710	2	57100	154470
	710	3	57069	154506
	710	1	57060	154516

SPECIES	DATE	NUMBER	LATITUDE (N)	LONGITUDE (W)
MN	712	3	58335	152511
	713	3	58201	151397
	713	3	58201	151397
	713	5	58201	151397
	713	1	58200	151380
	713	2	58196	151371
	713	2	58195	151370
	713	1	58191	151360
	713	1	58191	151360
	713	2	58243	150533
	713	1	58299	150443
	713	2	58333	150392
	713	2	58339	150381
	713	2	58321	150337
	713	2	58318	150333
	713	1	58291	150295
	713	1	58279	150278
	713	1	58274	150270
	713	4	58259	150251
	713	3	58227	150204
	713	1	58230	150204
	713	1	58240	150207
	713	2	57592	151059
	714	1	57554	151516
	714	2	57570	151550
	714	2	57570	151555
	714	2	57593	151592
	714	2	58001	152006
	714	2	58059	152102
	714	1	58069	152117
	714	5	58014	152257
	714	1	57588	152196
	714	2	57588	152196
	714	1	57534	152093
	714	2	57484	152064
	714	4	57458	152049
	714	5	57113	152356
	714	2	57107	152364
	714	2	57079	152388
	714	2	57075	152396
	714	2	57075	152396
	714	2	57073	152402
	715	1	56447	152560
	715	2	57026	152148
	715	2	57391	151412
	715	1	57422	152075

SPECIES	DATE	NUMBER	LATITUDE (N)	LONGITUDE (W)
OO	713	100	58250	150238
	713	1	58098	150436
PD	618	1	54043	162272
	618	3	54043	162272
	618	7	54043	162272
	618	8	54022	161400
	619	2	55053	161209
	619	2	55030	161215
	619	3	55020	161210
	619	1	55040	161218
	619	2	54158	160245
	619	6	54146	160227
	619	10	54132	160216
	621	3	54254	159120
	621	2	54250	159157
	621	3	54333	158423
	621	2	54333	158423
	622	11	55226	158413
	622	2	54577	157267
	625	3	55329	156336
	626	2	56053	156317
	626	1	55569	156234
	626	2	55559	156233
	626	6	55473	156094
	626	2	55576	156448
	628	2	56372	156282
	628	10	56373	156307
	628	1	56456	156364
	630	5	56060	156338
	630	5	55578	156242
	701	2	55571	156200
	701	3	55480	156060
	702	5	55205	155127
	702	6	55259	155038
	702	12	55540	154102
	702	4	56069	153461
	707	1	57174	155166
	707	3	57140	155178
	707	2	57210	155257
	707	7	57000	155558
	707	2	56552	156030
	708	2	56408	156304
	708	3	56380	156343
	708	5	56366	156362
	708	3	56341	156396

SPECIES	DATE	NUMBER	LATITUDE (N)	LONGITUDE (W)
PD	712	2	58402	152487
	713	3	58176	151045
	713	3	58301	150320
	713	1	58291	150295
	713	2	58291	150295
	713	1	58269	150264
	713	2	58219	150183
	713	1	58200	150160
	713	2	58200	150160
	713	2	58191	150150
	713	1	58177	150132
	713	2	58177	150132
	713	2	58176	150128
	713	2	58155	150108
	713	6	58114	150094
	713	1	58099	150153
	713	2	58099	150153
	713	1	58073	150190
	713	2	58073	150190
	713	2	58045	150230
	713	3	58038	150239
	713	1	58033	150326
	713	1	58098	150440
	713	2	57557	151046
	713	1	57497	150529
	713	2	57419	150405
	714	2	58005	152319
	714	2	57547	152100
	714	4	57413	152056
	714	3	57363	152028
	714	2	57273	151569
	714	1	57270	151570
	714	6	57270	151570
	715	2	56573	152264
	715	4	57135	151520
	715	1	57256	151298
PP	706	1	58006	153100
	710	1	56499	154127
	710	1	56508	154126
UD	622	2	54554	157343
UW	618	1	54100	163113
	621	1	54537	158522
	625	1	55101	156191
	707	1	57112	155188
	712	1	58390	152490
	713	1	58250	150500

SPECIES	DATE	NUMBER	LATITUDE (N)	LONGITUDE (W)
PD	708	4	56280	156460
	708	3	56205	156329
	708	1	56189	156219
	709	5	56254	156098
	709	2	56254	156098
	709	1	56254	156098
	709	3	56254	156098
	709	3	56265	156095
	709	1	56265	156095
	709	2	56265	156095
	709	2	56224	156052
	709	2	56152	155565
	709	1	56147	155560
	709	2	56104	155505
	709	1	56087	155484
	709	2	56053	155440
	709	1	55584	155308
	709	3	55560	155282
	709	1	55540	155270
	709	1	55517	155254
	709	3	55531	155110
	709	2	56024	154524
	710	1	57024	154554
	710	2	56585	154598
	710	2	56585	154598
	710	2	56565	155000
	710	4	56545	155047
	710	3	56338	155341
	710	3	56353	155358
	710	4	56376	155383
	711	1	57407	155130
	711	2	57400	155118
	711	2	57391	155109
	711	1	57310	154476
	711	4	57310	154476
	711	3	57306	154466
	711	2	57356	154393
	711	6	57471	154540
	711	2	57539	154497
	711	2	57537	154208
	711	2	57480	154090
	711	2	57486	154083
	712	2	58333	153498
	712	2	58425	153154
	712	4	58425	153154
	712	3	58402	152487

SPECIES	DATE	NUMBER	LATITUDE (N)	LONGITUDE (W)
UW	713	1	57598	151048
	714	1	58024	152048
	714	3	58040	152220
	714	1	57071	152404
	714	2	57071	152404
	715	2	56489	152469
	715	2	56493	152450
	715	1	57405	151554

[a]/Species Codes:

BA=Minke whale
BB=Baird's Beaked whale
BP=Fin whale
DL=Belukha whale
ER=Gray whale
MN=Humpback whale
OO=Killer whale
PC=Sperm whale
PD=Dall's porpoise
PP=Harbor porpoise
ZC=Cuvier's Beaked whale

SEASONAL DISTRIBUTION AND RELATIVE ABUNDANCE OF MARINE MAMMALS IN THE GULF OF ALASKA

by

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Final Report
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PREFACE

This report is the result of several years of documenting incidental and empirical field sightings of marine mammals in the Gulf of Alaska. The vehicle for consolidating these data was through NOAA's Platforms of Opportunity Program (POP) which began in the early 1970s and was finally developed into an independent program at the National Marine Fisheries Service (NMFS), Northwest and Alaska Fisheries Center in 1975. Support for the research and documentation of the data was in part provided by the U.S. Department of the Interior, Bureau of Land Management through interagency agreement with the Outer Continental Shelf Environmental Assessment Program (OCSEAP) office, Juneau, Alaska by contract (R7120806) to the National Marine Mammal Laboratory (NMML).

The total period of coverage for this two-part contract, known as OCSEAP Research Unit 68, was 1 July 1975 to 30 March 1981. The initial contract period (1 July 1975 to 30 September 1977) called for documenting historical information from the literature; unpublished NMML data, especially from the pelagic fur seal program (1958-74); and sightings of opportunity from ships in the Gulf of Alaska. The Principal Investigators were Clifford Fiscus, Howard Braham, and Roger Mercer. An interim report of those data was provided by Fiscus *et al.* (1976). In addition, an annotated bibliography of marine mammals of Alaska was developed (Severinghaus 1979), and data management procedures and methods were documented (Mercer, Krogman, and Sonntag 1978; Consiglieri and Bouchet 1981). These reports were critical for developing a comprehensive review and data processing program.

The second contract period for RU#68 (11 January 1980 to 30 March 1981) was funded to document sighting data collected since 1978. The Principal Investigators for this period were Lewis Consiglieri, Linda Jones and Howard Braham. The following final report includes all data from 1958 to 1980 in the POP files for the Gulf of Alaska.

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INTRODUCTION

The pelagic and coastal waters over the Outer Continental Shelf of the Gulf of Alaska are expected to be important areas for oil and gas development and tanker traffic. Within the Gulf, four major oil-lease areas have been under consideration for development: (1) Kodiak Shelf, (2) Fairweather-Yakutat in the northeast Gulf of Alaska, (3) Middleton Platform in the northern Gulf of Alaska, and (4) Shelikof Strait-lower Cook Inlet (Figure 1). Coastal areas near oil-lease sites contain important habitat for breeding marine mammals such as the northern sea lion, *Eumetopias jubatus*, and seasonally migrating and feeding areas for such animals as the gray whale, *Eschrichtius robustus*. Pelagic offshore waters over the continental shelf are also biologically productive and thus important for feeding for most marine mammal species seasonally migrating into and out of the Gulf.

Twenty-six species of marine mammals permanently reside in or seasonally frequent the Gulf of Alaska. Many occur in large numbers in the Gulf each spring and summer, but are few in numbers during winter. This seasonality is especially true of the cetaceans (Table 1). The common and scientific names of all the species we report on for the Gulf are listed below. Species designated with an asterisk (*) are classified as endangered under the U.S. Endangered Species Act of 1973.

ORDER CETACEA
Suborder MYSTICETI

Family BALAENOPTERIDAE
- *Fin whale (*Balaenoptera physalus*)
- *Sei whale (*Balaenoptera borealis*)
- *Blue whale (*Balaenoptera musculus*)
- Minke whale (*Balaenoptera acutorostrata*)
- *Humpback whale (*Megaptera novaeangliae*)

Family ESCHRICHTIIDAE
- *Gray whale (*Eschrichtius robustus*)

Suborder ODONTOCETI (toothed whales)

Family PHYSETERIDAE
- *Sperm whale (*Physeter macrocephalus*)

Family DELPHINIDAE
- Killer whale (*Orcinus orca*)
- Short-finned pilot whale (*Globicephala macrorhynchus*)
- Dall porpoise (*Phocoenoides dalli*)
- Harbor porpoise (*Phocoena phocoena*)
- Pacific white-sided dolphin (*Lagenorhynchus obliquidens*)

Risso's dolphin (*Grampus griseus*)
Northern right whale dolphin (*Lissodelphis borealis*)

Family ZIPHIIDAE
Giant bottlenose whale (*Berardius bairdii*)
Goosebeak whale (*Ziphius cavirostris*)
Bering Sea beaked whale (*Mesoplodon stejnegeri*)

Family MONODONTIDAE
White whale (*Delphinapterus leucas*)

Order CARNIVORA

Family OTARIIDAE
Northern sea lion (*Eumetopias jubatus*)
Northern fur seal (*Callorhinus ursinus*)
California sea lion (*Zalophus californianus*)

Family PHOCIDAE
Harbor seal (*Phoca vitulina*)
Elephant seal (*Mirounga angustirostris*)

Family ODOBENIDAE
Walrus (*Odobenus rosmarus*)

Family MUSTELIDAE
Sea otter (*Enhydra lutris*)

The objective of our research was to provide current sighting information concerning seasonal distribution and relative abundance of all marine mammals in the Gulf of Alaska as an exercise in baseline resource assessment. This information thus can be used directly to determine whether certain species might be particularly vulnerable to OCS activities given the nature and extent of occurrence or habitat usage by the animals. To that aim we have emphasized endangered species and discussed individual lease sites separately so as to address particular problem areas dealing with Section 7 of the Endangered Species Act of 1973.

Although we are reporting sighting data from throughout the Gulf, our specific objectives were to provide information on coastal (but not onshore) and pelagic marine mammal occurrences from the northeast region of the Gulf (*i.e.*, from approximately southeast of Yakutat Bay) to west of Kodiak Island. Under subcontract to the Alaska Department of Fish and Game, Game Division, Anchorage, we received two reports in 1975 on distribution and abundance of marine mammals onshore and along the coast of the Gulf of Alaska (Calkins *et al.* 1975) and in Prince William Sound (Pitcher 1975). Data presented in this report primarily reflect observations made offshore. Cooperative efforts have been maintained with Gulf of Alaska OCSEAP Research Units 229 (biology of the harbor seal), 240 (abundance and

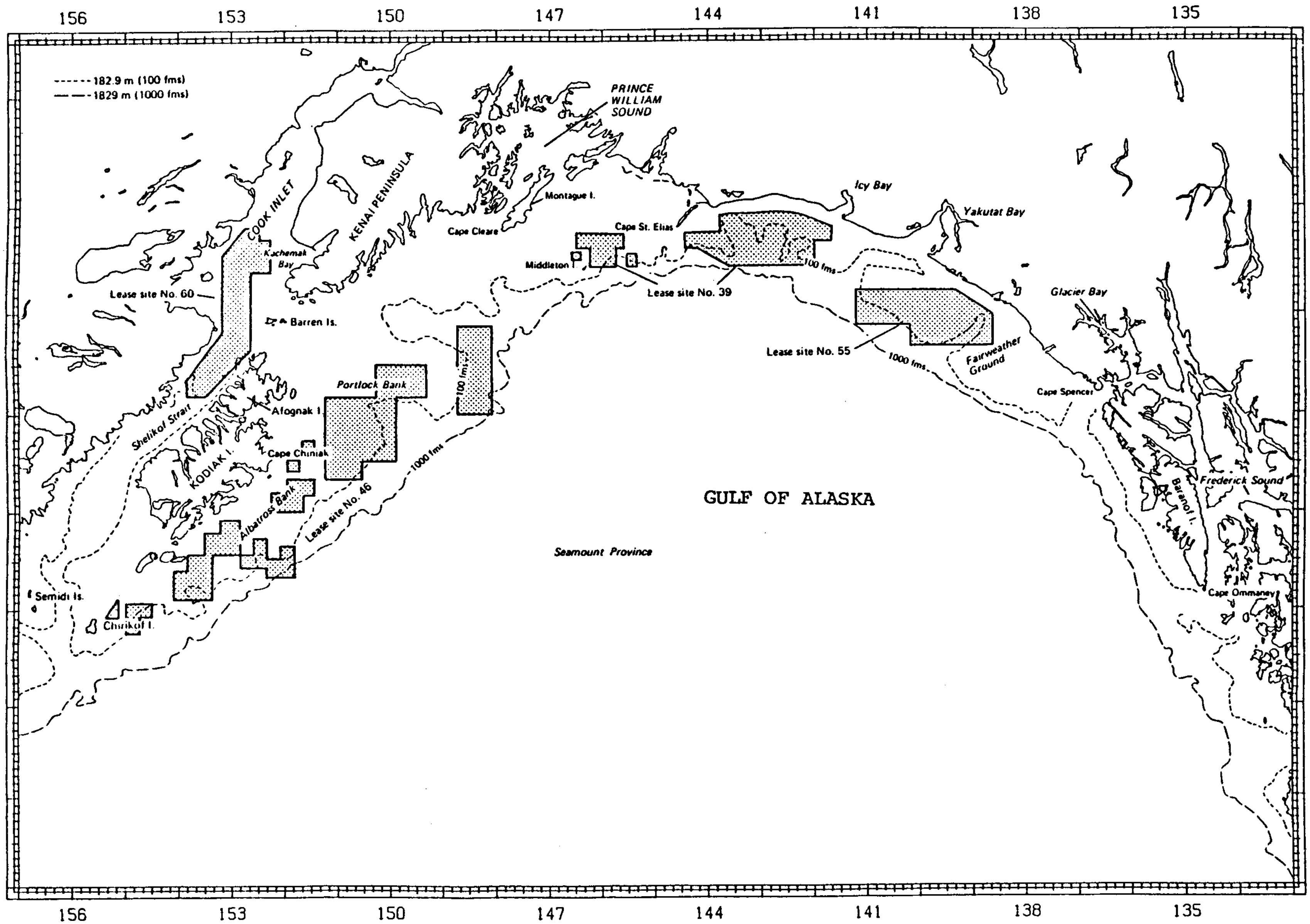

Figure 1.-Gulf of Alaska study area; proposed (as of 1978) Outer Continental Shelf oil and gas.

Table 1.–Checklist of marine mammals by season in the Gulf of Alaska (latitude 53°N to coast, longitude 133° to 157°W). 0 = regularly present, + = greatest frequency, R = rare visitor, – = not known or expected to occur, blank = no recent data available.

Species	Season			
	Winter Jan-Mar	Spring Apr-Jun	Summer Jul-Sep	Autumn Oct-Dec
Cetaceans				
Blue whale[a]	–	R	R	R
Fin whale	R	0	+	R
Sei whale	R	+	0	R
Humpback whale	R	0	+	0
Right whale[a]	–	R	R	R
Gray whale	+	0	R	0
Sperm whale	–	0	0	0
Minke whale[b](?)		+	+	
Killer whale[b]	0	0	0	0
White whale[b]	0	0	0	0
Pilot whale	–	–	R	–
Giant bottlenose whale		R	R	
Goosebeak whale[b]	0	0	0	0
Bering Sea beaked whale[b](?)				
Dall porpoise[b](?)	0	0	0	0
Harbor porpoise[b]	0	0	0	0
Pacific white-sided dolphin	R	0	+	R
Risso's dolphin	R	R	R	–
Northern right whale dolphin	–	–	R	–
Carnivores				
Northern fur seal	+	0	0	+
Steller sea lion[b]	0	0	0	0
Northern elephant seal	–	R	R	–
Harbor seal[b]	0	0	0	0
Sea otter[b]	0	0	0	0
Walrus	–	R	R	R

[a] Historically abundant seasonally.
[b] Resident.

distribution of the sea otter), and 243 (ecology of the northern sea lion) in order to assure area coverage continuity. Our report, therefore, does not cover coastal and onshore activities of sea lions, harbor seals, or sea otters.

STUDY AREA

The study area included the pelagic and nearshore waters of the Gulf of Alaska from 53°N, north to the Alaska coast, and from 133°W to 157°W (Figure 1). The specific OCS lease sites within the study area included the Northeast Gulf or Yakutat-Fairweather area (lease sale No. 55), Northern Gulf (lease sale No. 39), lower Cook Inlet-Shelikof Strait (lease sale No. 60), and Western Gulf-Kodiak (lease sale No. 46). Defined by the 100-fathom (183-m) contour (Figure 1), the continental shelf extends out to approximately 10 km off Yakutat Bay in the northeast Gulf, to 100 km from the entrance to Prince William Sound in the northern Gulf and to 200 km off Kodiak Island.

Prominent nearshore shoal areas over the continental shelf in the study area are Fairweather Ground in the northeastern Gulf, Middleton Platform in the northern Gulf, both at depths of 60-183 m, and Portlock and Albatross banks south and west of Kodiak Island. Many seamounts occur within the central portion of the study area near 56°N.

Much of the year the Gulf of Alaska is influenced by atmospheric low pressure systems which create cyclonic (counter-clockwise) winds (Royer 1972). Wind shear over the ocean surface is a major factor influencing the movement of subsurface currents. As a result, current flow in the Gulf of Alaska to as far west as the Aleutian Islands is onshore, a divergence away from the central Gulf gyre. The onshore, diverging water is replaced by the upward flow of colder deep-ocean water, causing upwellings rich in nutrients (Sverdrup *et al.* 1942; Favorite *et al.* 1976).

In the North Pacific there is a permanent halocline from the 100- to 200-m depth contours that restricts vertical mixing (Cooney 1972). Seasonal variations in temperature, dissolved oxygen, and nutrients result where large-scale upwellings occur. However, along the continental shelf in water less than 200 m deep, mixing occurs throughout the water column. This results in a zone relatively high in dissolved oxygen and nutrients, yet low in salinity because of seasonal precipitation and river runoff (Shurunov 1970).

METHODS

Data were collected from three main sources: (1) National Marine Mammal Laboratory (NMML) or contract personnel trained under this OCSEAP project and the NMML Dall Porpoise Research Program stationed aboard NOAA and Coast Guard ships from November 1975 through November 1980; (2) the NMML pelagic fur seal program (1958-74); (3) a 1980 OCSEAP dedicated summer vessel cruise (Rice and Wolman 1982); and (4) Platforms of Opportunity Program (POP) observers. POP observers included NOAA and U.S. Coast Guard ship's officers and crew members, U.S. Forest Service naturalists aboard Alaska state ferries, U.S. observers aboard foreign fishing vessels within our Fisheries Conservation Zone (FCZ), and numerous biologists and citizens onboard private boats. Vessel cruise efforts since 1958, reported here, are summarized in Appendix I.

With the exception of data collected by NMML scientists, most data came as sightings of opportunity; that is, no systematic or analytical procedures were used by the observers to standardize the sampling or the routes taken by the ships. Therefore, two basic types of data exist in our data base: (1) incidental sightings, and (2) sightings associated with effort. Incidental sightings, contributed mainly by POP observers, were chance observations recorded during a vessel's daily routine and consisted of only the sighting information at the time a marine mammal was observed. Effort-associated sightings consisted not only of sighting information at the time of an observation, but the beginning and ending times of the cruise track (during which a trained NMML or contract observer was maintaining a constant watch for marine mammals), ship positions, and environmental parameters (see Consiglieri and Bouchet 1981).

Approximately 40% of our data base contains sightings with quantified effort and virtually all of these occurred after 1975 when this OCSEAP research began. Effort plots are presented by season in Appendix II. Sighting data (combined incidental and effort associated) are presented as symbol plots by species and by season in the "RESULTS." "Seasons" were designated as: Winter – January, February, and March; Spring – April, May, and June; Summer – July, August, and September; and Autumn – October, November, and December.

Sighting records from inexperienced persons are generally unreliable, especially for unfamiliar cetaceans, and are often impossible to evaluate if not accompanied with a detailed description or photograph of the animal(s) sighted. Even under ideal environmental conditions, the identification of marine mammals at sea is difficult. Every effort was made to ensure that the data presented represent accurate species identifications. When possible, POP observers were given slide shows and briefed on marine mammal identification prior to sailing, and all observers were provided with copies of cetacean (Leatherwood *et al.* 1972) and pinniped (Seed 1972) field guides.

Incoming data were subjected to rigorous quality control steps, including computer analysis for errors. Our procedures are fully documented in Consiglieri and Bouchet (1981), our revised data documentation manual. Sightings were first verified by scrutinizing the accompanying species description, and then subjected to computer quality control programs. Our data management procedures are outlined in Figure 2. Many recordings of data collected over the past several years could not be used as "proof" of specific sightings or species identification. Questionable sightings were classified as tentative, relegated to unidentified status, or rejected. During the early years of our work (1975-77) this category frequently accounted for 50-75% of the data base. Since 1978 only 10-30% of the sightings were unacceptable. Tentative and unidentified sightings are not represented in the species plots in this report.

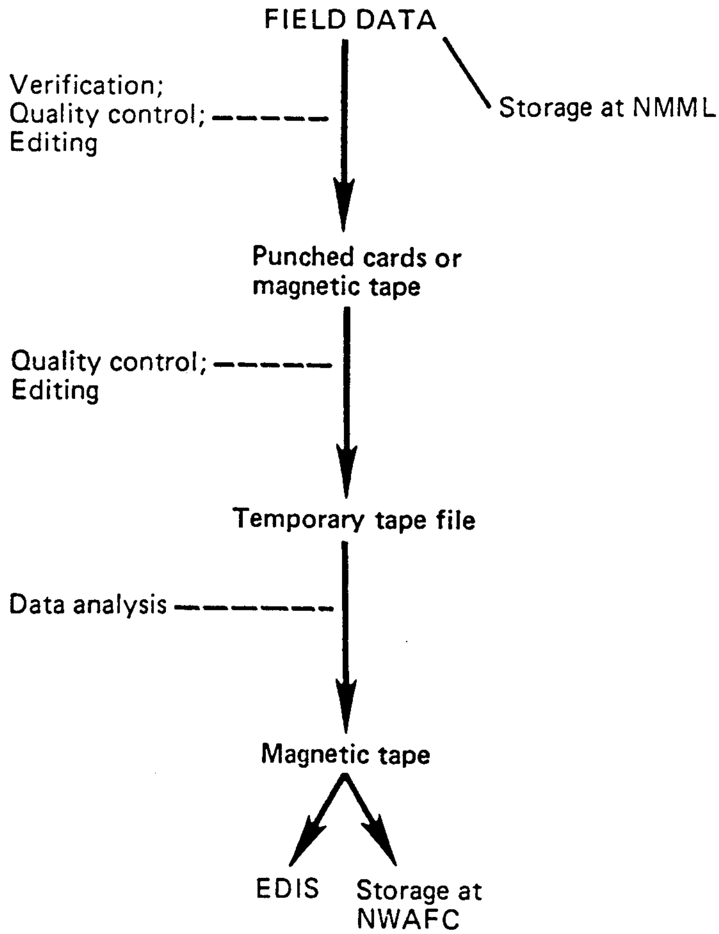

Figure 2.–Platforms of Opportunity Program data management.

We relied heavily on previously published accounts for distribution and abundance projections. Discussion of this historical information is included in the species accounts which follow. Commercial and aboriginal sealing and whaling results were useful in understanding historical distribution and abundance. These topics were discussed at length in Fiscus *et al.* (1976), and thus are not presented in their entirety in this report.

ENDANGERED CETACEANS

Fin Whale (*Balaenoptera physalus*)

The fin whale is the second largest of the six species in the family Balaenopteridae. Common names include finner and finback whale.

ABUNDANCE

The size of the North Pacific fin whale population is estimated to be 15,800-16,400 (Wada 1975, 1977), and includes the Pacific Ocean north of 20°N, from the coast of North America to 150°E. The size of the population prior to commercial exploitation was estimated at 42,000-45,000 (Ohsumi 1971; Tillman 1975).

The number of fin whales thought to inhabit the eastern North Pacific has been estimated at 7,890-10,130 (Omura and Ohsumi 1974), 8,520-10,970 (Ohsumi and Wada 1974), 9,000 (Rice 1974), 11,790 (Wada 1975), and 10,000-20,000 (Zhirnov *et al.* 1975). The area of the eastern North Pacific essentially includes waters north of 30°N and east to 180°. Our distribution data on fin whales along the coast of North America south of Alaska indicates that a large portion, if not most, of the eastern North Pacific fin whales occur in Alaska and British Columbia waters during spring and summer. As such, the population size of fin whales from the Gulf of Alaska to the Bering Sea probably does not exceed 10,000 animals.

The eastern North Pacific population of fin whales is thought to be well below the population level which will produce the maximum number of harvestable animals (Allen 1974; Rice 1974; Tillman 1975). Essentially, then, the population is below its former carrying capacity. Allen (1974) estimated that it would take 25-30 years for the population in the eastern North Pacific to recover to 90% of its original size since protection.

DISTRIBUTION

North Pacific fin whales spend the winter months in subtropical to temperate waters and then migrate to subarctic and arctic waters from the Gulf of Alaska to the Chukchi Sea, spring through fall, to feed and apparently rear their young (Nemoto 1959). During the 7- to 8-month period in Alaska, they spend much of their time near the continental shelf (Nemoto and Kasuya 1965). As such, and for OCS evaluation, they should be considered a seasonal nearshore inhabitant.

Winter (January-March)

Although little research effort has been made in the study area during the winter, the paucity of sightings suggests the species is essentially absent. In our data base only five sightings were made (Figure 3), including one sighting of four whales in Shelikof Strait (57°00'N, 154°14'W). These animals were apparently feeding on walleye pollock (Towner in press). The only other sighting occurred approximately 150 km southwest of Yakutat Bay beyond the 2000-m depth contour. In January 1963, 20 fin whales were observed in the Gulf of Alaska at 58°00'N, 148°03'W (Berzin and Rovnin 1966). Forsell and Gould (1981) observed a lone fin whale in Uganik Bay (Kodiak Island–57°44'N, 153°28'W) on 24 January 1980.

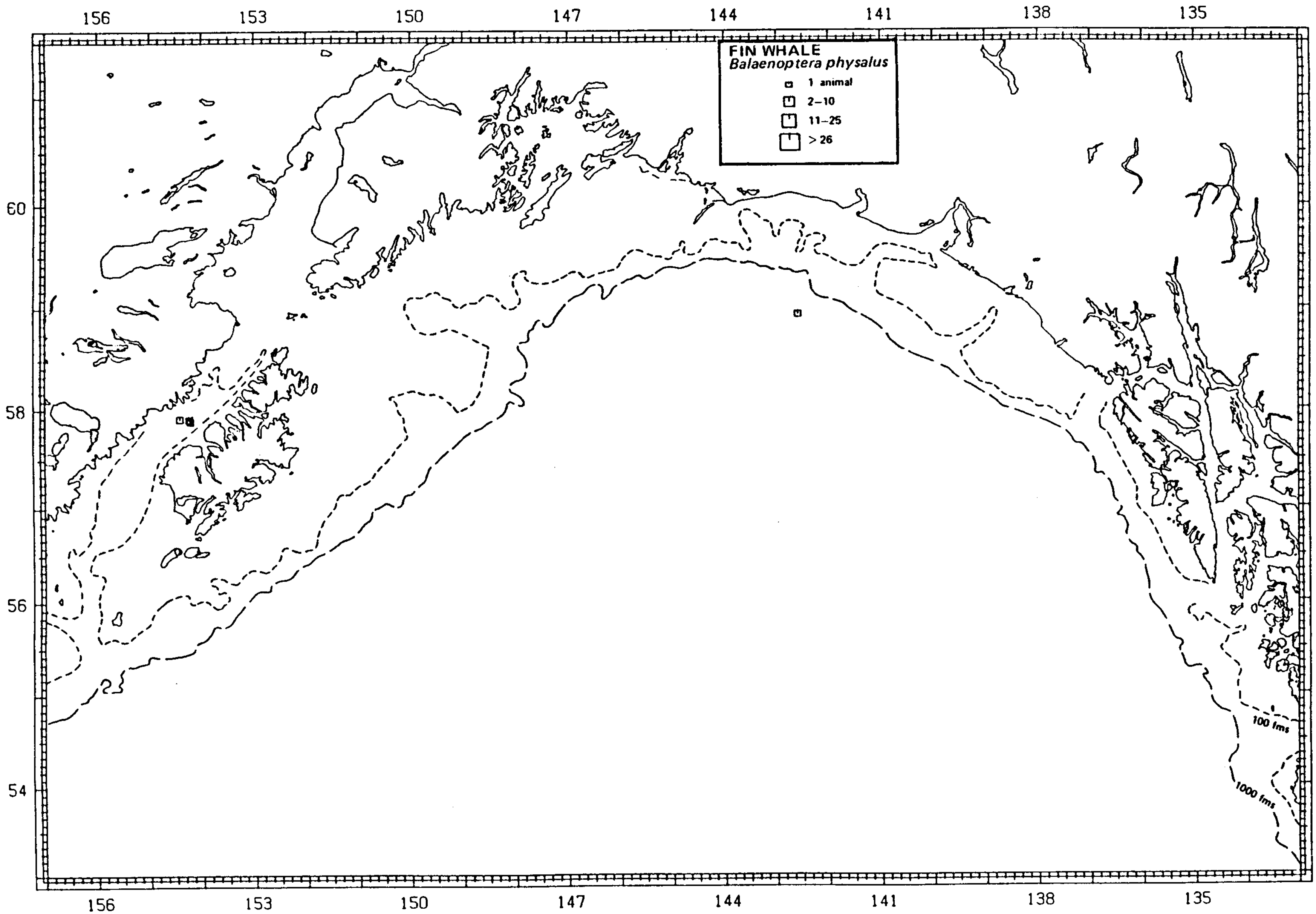

Figure 3.–Fin whale sightings, winter (January-March) 1958-80.

Spring (April-June)

Although a rather substantial number of survey cruises have been conducted in the spring throughout the study area (Appendix II), almost all of the fin whale sightings were made in the western Gulf of Alaska (Figure 4). Most sightings (83%, n = 106) were made over the continental shelf in the Gulf shoreward from the 200-m contour. The largest number of animals were seen south of Montague Island, with most others in the area of Portlock Bank between the east coast of Afognak Island and the continental slope south of Kodiak Island (Figure 4). Fin whales were present during systematic surveys in June 1980 in Prince William Sound by Rice and Wolman (1982); however, in July of the same year, no fin whales were observed. In June 1980, 21 and 63 animals (possibly the same groups) were observed in Shelikof Strait and just west of Chirikof Island (Figure 4).

One tentatively identified fin whale was sighted in March in the Bering Sea near Amak Island. This is the only spring sighting for the southeastern Bering Sea, yet many surveys were conducted there, suggesting that fin whales may not move into the Bering Sea before late May to early June. Animals in the Gulf of Alaska have been suggested to be early migrants into the Bering Sea (Shurunov 1970). However, the fewer sightings made from Kodiak to Unimak islands and near the Trinity Islands and Shumagin Island, may support Berzin and Rovnin's (1966) conclusion that Bering Sea fin whales may not come by way of the Gulf of Alaska, but rather from the North Pacific or Aleutian Islands southwest of our study area.

Summer (July-September)

Fin whales occur in greatest numbers in and adjacent to the study area during summer (Figure 5). They appear to frequent three areas: (1) Prince William Sound (Hall and Tillman 1977), and Hinchinbrook Entrance-Montague Island to Middleton Island; (2) the continental margin and slope from southwest Kodiak Island (Albatross Bank) to the Shumagin Islands. and (3) the continental slope in the southeast Bering Sea, especially near the Pribilof Islands. The absence of sightings in other areas indicates that fin whales are probably selective. A few sightings were made in Yakutat Bay (Figure 5). The nearshore waters from Yakutat Bay to British Columbia were formerly an important summer whaling ground for fin whales (Nasu 1966).

The concentration of fin whales south of Hinchinbrook Entrance and Montague Island, where numerous sightings were made over several years, demonstrates that certain areas of the study area are probably more important than others for this species. Of the 65 sightings in our data base, 88% were made over the shelf in water less than 200 m deep. The group sizes were the same in summer and spring: 40% were of single animals, 25% or more were in pairs, and 35% were of 3 or more.

Summer sightings of numerous fin whales over the past 12-14 years have been noted along the north coast of Kodiak Island (58°N, 153°W) and in bays and shallow waters of Shelikof Strait (T. Emerson, pers. commun. by letter 14 April 1980).

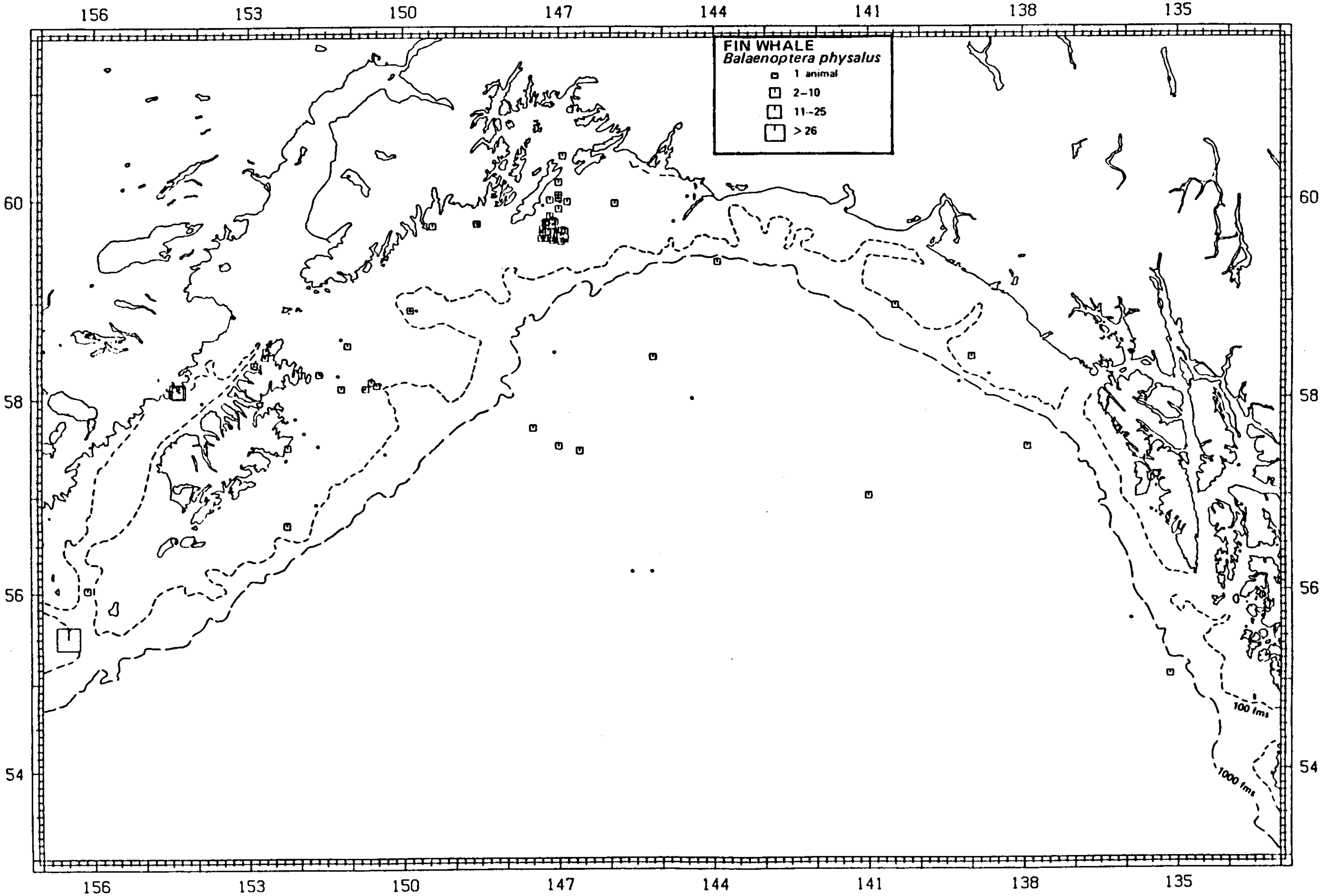

Figure 4.–Fin whale sightings, spring (April-June) 1958-80.

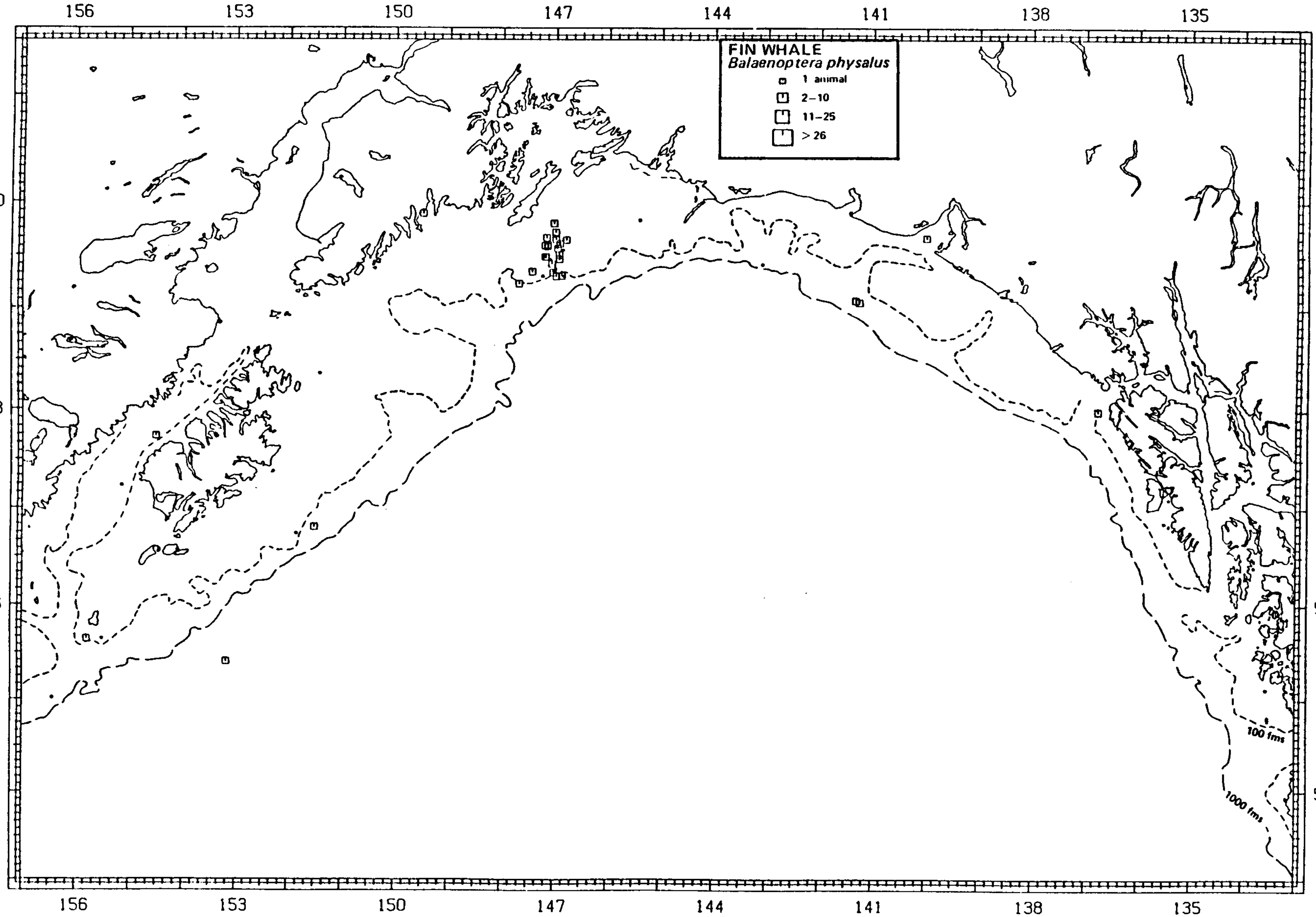

Figure 5.–Fin whale sightings, summer (July-September) 1958-80.

Autumn (October-December)

Because of sparse autumn coverage of the study area very few fin whales have been observed: five sightings (21 total animals), four in water more than 200 m deep (Figure 6). Of the 21 animals observed since 1958, 6 were seen in October, and none were seen in November. Survey coverage was more uniform, yet less during autumn than at any other time of year. Berzin and Rovnin (1966) stated that fin whales rapidly leave the Bering Sea in September. Perhaps the same holds for the Gulf of Alaska.

FACTORS INFLUENCING DISTRIBUTION

Oceanographic

During the height of commercial whaling in the North Pacific, fin whales were taken in areas where biological productivity was high due to the mixing of water masses (Shurunov 1970; Nasu 1974), near centers of gyres (Berzin and Rovnin 1966), and along oceanic fronts (Nasu 1957, 1974) of the continental slope and shelf throughout the study area (Uda 1954). Traditionally, they were taken in these areas in spring and summer, when their prey was at peak abundance. Results from our research also indicate that fin whales occur in areas of upwelling along the continental slope and shelf in the western Gulf of Alaska and to Unimak Pass into the southeastern Bering Sea (Figures 4 and 5).

Feeding and Food Resources

The distribution of fin whales and the timing of their migration patterns in Alaskan waters are governed by the availability of food (Nemoto 1957, 1959; Sleptsov 1961; Nasu 1963, 1966; Berzin and Berzin 1966; Nishiwaki 1966). Nemoto (1959) concluded that fin whales migrate back to the same regions at the same time each year because of favorable environmental conditions permitting blooms of phytoplankton and zooplankton. However, fin whales are known to shift their distribution to take advantage of changes in prey as a result of changing oceanographic conditions (Nasu 1974).

It is because of the dynamic, non-uniformity in weather, ocean conditions, and prey availability that fin whales have adapted a generalized feeding strategy. They feed on a variety of prey from zooplankton to fishes, in pelagic as well as coastal waters over the Alaskan continental shelf. Studies of fin whales on whaling grounds in Alaska indicate that they are opportunistic feeders, taking advantage of large dense patches of prey, frequently changing their diet during the season as certain prey become less available while a different prey species becomes more abundant (Nemoto 1959, 1970).

Polyphagous or generalized prey selection behavior by fin whales was suggested by Nemoto (1957) to be a result of the relative scarcity of euphausiids in the North Pacific as, for example, compared to Antarctica where fin whales are engaged in a more monophagous feeding regime on euphausiids. It seems equally likely that fin whales have selected a feeding strategy to take advantage of the great seasonality and high abundance of alternate prey items such as

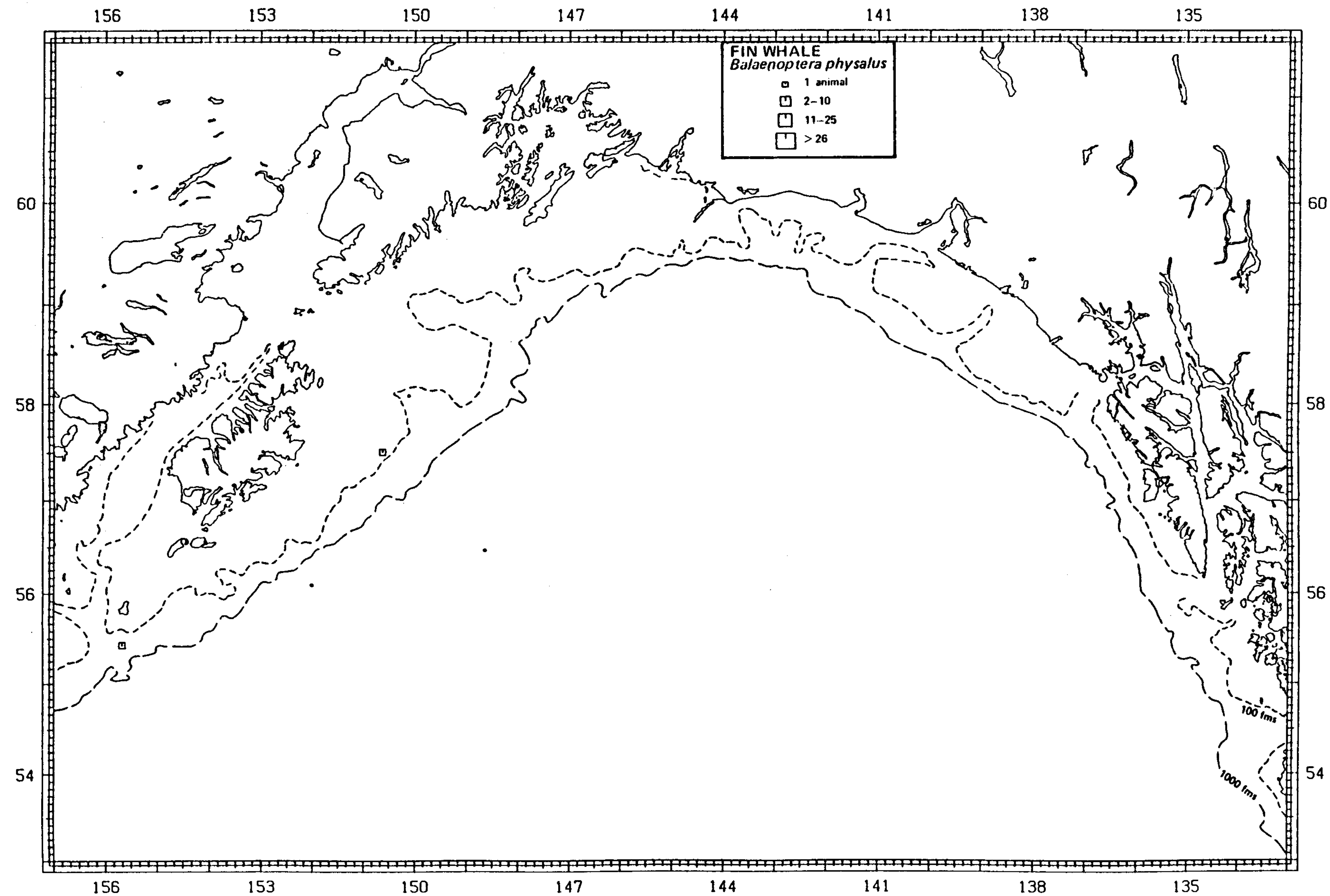

Figure 6.-Fin whale sightings, autumn (October-December) 1958-80.

copepods and fishes. From an analysis of several thousand fin whale gastrointestinal tracts by Japanese and Soviet scientists, a summary of "preferred" prey species was assembled and ranked according to percentage of total occurrence (Table 2). Most of these species are found in all areas in and adjacent to the study area. The geographic areas where certain prey were found in the fin whales landed, then, undoubtedly reflects both effort on the part of the whalers at various times of the year, and prey distribution.

Nemoto (1959) cited examples of prey composition in fin whales taken in the North Pacific, southeastern Bering Sea (58°-61°N), and the eastern Aleutian Islands. Of 4,140 fin whale stomachs examined around the eastern Aleutian Islands from 1954 to 1958, 50% were empty, 35% contained only euphausiids, 12% only copepods, 1.5% both euphausiids and copepods, and less than 1% contained fishes (including squid). Of 158 fin whale stomachs examined in the southeastern Bering Sea in 1957, 54% were empty, 44% contained pollock, and 2% contained copepods. Of 262 fin whale stomachs examined in the North Pacific south and east of the Aleutian Islands and into the Gulf of Alaska from 1952 to 1958, 65% had capelin, 26% pollock, 6% herring, >1% Atka mackerel, and <1% contained saury.

The occurrence of certain prey species coincides with concentrations of fin whales. Nasu (1963) reported that fin whales annually occur north of the eastern Aleutian Islands along the continental slope to Cape Navarin (USSR) during the summer, but few are in Bristol Bay. This correlates well with the occurrence of herring and Alaska pollock (Nemoto 1957, 1959). In March 1980, fin whales were observed apparently feeding on large schools of spawning pollock in Shelikof Strait (Towner, in press). Other areas of the North Pacific where whalers found fin whales were south of the Aleutian Islands along the continental shelf to south of Kodiak Island (near the Trinity, Shumagin, Chirikof, and Semidi islands), and into the Gulf of Alaska, especially near Montague Island and Cape St. Elias. These are the same areas where most fin whale prey species are found in abundance (Nemoto 1957, 1970; Nasu 1963; Nemoto and Kasuya 1965; Nishiwaki 1966).

In the North Pacific, copepods occur in abundance in spring, earlier in the year than euphausiids, which peak in summer (Nemoto 1959). Phytoplankton begin to bloom in the early spring, progressively spreading northwest throughout the North Pacific and Gulf of Alaska, with little lag time in the occurrence of the grazing copepods *Calanus cristatus* and *C. plumchrus* (Cooney 1972). By May, copepods become abundant in the upper 200 m of water, providing open-ocean food for northward migrating whales. Fin whales feed on copepods first as the whales migrate north in the spring (Nemoto 1959; Cooney 1972). The pattern of the whales' movement into the Gulf of Alaska and then west toward the Aleutian Islands and Bering Sea seems to be reflected in corresponding sequential changes in prey density. As *C. cristatus* (in copepodite stage V) leave the shallow water to depths below 500 m, usually by August, fin whales shift their prey selection to *C. plumchrus*, or, more likely, other abundant euphausiids and fishes (Nemoto 1963). Fin whales also shift to *C. plumchrus* as the whales move closer to shore where these copepods are more likely to be abundant in spring and summer (Cooney 1975). However, because *C. plumchrus* occurs in less dense concentrations than *C. cristatus,* fin whales may shift their prey selection to alternate copepods such as *C. pacificus*, *C. finmarchicus*, and *Metridia lucens* (Nemoto 1957). These prey species are taken

Table 2.–Fin whale prey species commonly found in the North Pacific, Gulf of Alaska (GOA), Aleutian Islands, and Bering Sea. Prey species within each group (euphausiids, copepods, fishes) are ranked according to preference. Data compiled from Nemoto (1957, 1959, 1963, 1964), Nemoto and Kasuya (1965), Berzin and Rovnin (1966), and Sleptsov (1961*b*). Seasonal and annual variation in prey availability by geographic area probably results in a shift in selecting one preferred prey item over another. Thus, this table of rankings is generalized to reflect an averaging of the available data, which came from the harvesting of fin whales primarily during the 1950s.

Prey group and preferred species	Dominant geographic area where taken
Euphausiids	
Euphausia pacifica	N. Pacific, GOA to SE Bering Sea
Thysanoessa inermis	GOA to SE Bering Sea
T. longipes	N. Pacific–E. Aleut. Is.
T. spinifera	GOA to E. Aleut. Is.–Shelf Slope
T. raschii [1]	Bering Sea shelf
Copepods	
Calanus cristatus	N. Pacific-GOA
C. plumchrus [1]	GOA shelf to Aleut. Is.
Fishes	
Mallotus catevarius (capelin)	N. Pacific-S. Bering Sea
Theragra chalcogramma (walleye pollock)	N. Pacific-S. Bering Sea
Clupea harengus pallasi (herring)	GOA to S. Bering Sea
Pleurogrammus monopterigius (Atka mackerel)	E. Aleutian Is.
Ommatostrophes sloanei-pacificus (squid)	E. Aleutian Is.
Cololabis saira (saury)[1]	E. Aleutian Is.

[1] Much less frequent.

less frequently, but are important for they are in turn eaten by fishes such as Atka mackerel and saury (Nemoto 1959). These fishes are, to a lesser degree, taken by fin whales.

Euphausiids seem to be the most frequently occurring prey found in fin whale stomachs (Nemoto 1957; Nemoto and Kasuya 1965; Table 2). *Euphausia pacifica, Thysanoessa inermis,* and *T. longipes* are the numerically dominant prey. The distribution of fin whales is directly correlated with the seasonal occurrence of these species, and although not found exclusively from the Gulf to the southeastern Bering Sea, *E. pacifica* is taken in neritic and pelagic waters south of the Aleutian Islands. *Thysanoessa inermis* appears to be taken primarily in the Gulf of Alaska and along the south side of the Alaska Peninsula in waters usually less than 300 m deep, while *T. longipes* predominates north and south of the eastern Aleutian Islands (Nemoto 1957, 1966; Nemoto and Kasuya 1965; Cooney 1975). In 1962, however, fin whales were feeding primarily on *T. longipes* in the Gulf of Alaska, suggesting to Nemoto (1965) that this species was important in regulating the migration pattern of fin whales for that year. *Thysanoessa raschii*, an arctic and subarctic species, occurs primarily over the continental shelf in the eastern Bering Sea. This is an area generally not frequented by fin whales, but T. raschii is a common prey item for fishes such as cod and pollock. These two fishes are also eaten by fin whales (Nemoto 1966). *Thysanoessa spinifera* is probably eaten in shallow waters (less than 100 m) in the Gulf of Alaska, where it is most abundant (Nemoto and Kasuya 1965).

The fact that fin whales were taken frequently with only one or two prey species in their stomachs suggests that fin whales move into an area and concentrate their feeding on aggregates of single zooplankton patches as those prey became abundant. The patchy nature of and need for large volumes of prey probably facilitated selection of a polyphagous feeding strategy. Such behavior meant that more diverse and widespread "habitat" could be utilized by the whales, thus increasing their carrying capacity.

Migration

Berzin and Rovnin (1966) stated that the eastern North Pacific population of fin whales begins its annual northward migration to Alaska in spring from southern breeding areas off California. This migration occurs (1) along the North American coast to the northeast Gulf of Alaska; (2) north in the North Pacific to Kodiak Island, then east into the northeast Gulf of Alaska; and (3) north in the North Pacific to Kodiak Island to Unimak Pass area, then north into the Bering Sea, and west along the Aleutian Islands.

Kellogg (1929) reported that fin whales began showing up first off Vancouver Island in March. Scammon (1874) reported them off Vancouver Island in February. By April and May fin whales begin arriving in the Gulf of Alaska and eastern Aleutian Islands (Nemoto 1959; Berzin and Rovnin 1966). Shurunov (1970) stated that they occur in the western part of the Gulf of Alaska earlier than in other parts of the North Pacific; this cannot be confirmed from our data, although there is a hint that animals show up earlier in the eastern than the western Gulf.

Migration into the Bering and Chukchi seas occurs from June and July to October (Berzin and Rovnin 1966). The southward movement, an apparent migration from the northern feeding grounds to winter calving and breeding areas, may begin by August (Nasu 1974), but usually occurs over a short time period in September. Their movements south are timed, apparently, with decreasing light and diminishing prey supply (Sleptsov 1961*a*,*b*). By September a large percentage of fin whales (not specified in the literature) leaves the Bering

Sea, but some remain north and south of the eastern Aleutian Islands until November (Berzin and Rovnin 1966).

Serological studies indicated that four subpopulations or stocks occur in the North Pacific (Fujino 1960). Fujino identified animals north of the Aleutian Islands having some distinct blood antigens from animals south of the Aleutian Islands near 50°N. Within each of these two regions, however, little yearly fluctuation in antigens has been observed. His conclusion was that fin whales migrate back into the same feeding area annually (Fujino 1960). Although all fin whales moving into the North Pacific and southern Bering Sea share the same general feeding area (Berzin and Rovnin 1966), the degree to which the "subpopulations" intermix is unknown.

To 1965, 847 fin whales were marked with discovery tags; 166 were recovered (WRI 1967). Although many inconsistencies occur in the data, primarily because time of year and location of recovered tags were not reported, recoveries indicated little east-west movement across the North Pacific (Kawakami and Ichihara 1958; Nemoto 1959; Fujino 1960; Ohsumi and Misaki 1975). This supports the hypothesis that fin whales are divided into eastern and western Pacific groups or stocks (Tomilin 1957; Nishiwaki 1966). At least one whale, however, was tagged in the Okhotsk Sea and killed in the Gulf of Alaska (Ivashin and Rovnin 1967). Although the tagging studies have demonstrated that little movement occurs across the North Pacific, the limited data do not disprove the notion that fin whales which migrate into the Gulf of Alaska and southern Bering Sea come from the eastern Pacific Ocean. In fact, there is a tendency to support this hypothesis. In addition, although no confirmed evidence is available to support a specific migration pattern (Kawamura 1975), it appears that the general migration pattern from approximately California to Alaska and return, as described by Berzin and Rovnin (1966) and Rice (1974), is supported by our seasonal distribution data.

FACTORS INFLUENCING POPULATION GROWTH

Reproduction

In the North Pacific, fin whales appear to breed from September to June, but with a clear peak from November to January (Tomilin 1957; Ohsumi *et al.* 1958). Gestation appears to last 11-12 months, and lactation is reported by Ohsumi *et al.* (1958) to end when calves reach 12-13.5 m (36-40.5 ft) lengths. Newborn calves are reported to be approximately 6.5 m (20-22 ft) in length. Physical maturity is reached at 22-25 years of age, with sexual maturity being reached at lengths greater than 21 m (63 ft) in males and 23 m (68 ft) in females (Ohsumi *et al.* 1958). As with many baleen species, females are larger than males; the average length attained by females is 24 m (71 ft), and by males is 23 m (68 ft) (Ohsumi *et al.* 1958). Because the bulk of scientific data on the reproductive biology of fin whales comes from the harvest of the whales by means of analysis of fetuses, May through September, interpretation of the data and predicting the reproductive cycles may be biased.

Mortality

Predation.–Killer whales are probably the only natural predators of fin whales, although we have had no reports of killer whales attacking fin whales.

Other causes.–Other causes of mortality in the study area are poorly understood. Strandings are few, and none are known to have been visible. We have no records of entanglement with fishing gear, nor of collisions with vessels.

Exploitation and development.–The fin whale was one of the most sought after baleen whales by commercial whalers in the North Pacific. Between 1952 and 1962 almost 13,000 were taken above 48°N (Nasu 1963). This total accounted for over 80% of all whales of all species taken on traditional whaling grounds located in the Gulf of Alaska, occurring primarily east of Cape St. Elias and along the south side of Kodiak Island as well as in the eastern Aleutian Islands, and over the continental slope in the southern Bering Sea (Nasu 1963; Berzin and Rovnin 1966).

Humpback Whale (*Megaptera novaeangliae*)

The humpback whale belongs to the family Balaenopteridae (the rorquals) and is the only member of the genus *Megaptera*. Other common names include humpbacked whale and humpy.

ABUNDANCE

Humpback whales have been protected by the International Whaling Commission (IWC) from commercial whaling by the IWC since 1966. A subsistence take is allowed under IWC charter, but none are taken in U.S. waters.

No estimate of abundance is available for the Gulf of Alaska, but probably only a few hundred regularly frequent the Gulf waters, including Prince William Sound which is believed to seasonally have 50 or more animals (Hall and Johnson 1978). Estimates of the size of the winter breeding population in Hawaii is 400-600 and in Mexico about 100 (Wolman 1978). The North Pacific population is estimated at 850 (Rice 1977) to 1,200 (Rice and Wolman 1982). The humpback whale is the second most depleted endangered species in the North Pacific, using the criteria of population size, following the North Pacific right whale (*Balaena glacialis*).

DISTRIBUTION

Winter (January-March)

Most humpback whales spend the winter months in warm subtropical breeding grounds off Mexico and Hawaii. Winter sightings in the study area are rare. Our winter data include several sightings from southeast Alaska and one (of two animals) near Cape Chiniak, Kodiak Island (Figure 7). Hall (1979) reported the sighting of a lone humpback in Prince William Sound in February. Forsell and Gould (1981) reported a tentative sighting of a lone humpback whale in Uyak Bay (57°45'N, 153°55'W) on 27 February 1980. Evidence exists that up to 40 humpback whales may overwinter in the inland waters of southeast Alaska (W. Lawton, pers. commun.).

Spring (April-June) and Summer (July-September)

During the spring, humpback whales begin arriving on the northern feeding grounds. Hall (1979) found humpback whales in Prince William Sound as early as May. Unpublished data from salmon trollers in Southeast Alaska (POP files) indicate that humpback whales begin to arrive in that area in early April.

The frequency of occurrence off Kodiak Island, Prince William Sound and southeast Alaska in spring and summer is predictable; that is, these locations are traditional places where humpbacks are seen. Our sightings data might suggest that they are clumped at these three locations (Figures 8 and 9), with very few sightings in between except offshore at Kodiak Island, Cape St. Elias, and Yakutat Bay. Relative sighting data for other species (*e.g.*, Dall porpoise) and effort throughout the Gulf (Appendix II) show that the areas where humpbacks are not generally seen are places where most other marine mammals are in abundance. Therefore, humpbacks are segregating in spring and summer to Kodiak Island (Portlock and Albatross banks), Prince William Sound, and southeast Alaska.

The notion of stock separation for these areas, however, is open to question. Analysis of humpback whale fluke photographs has shown that in some years a whale is found, for example, in Prince William Sound and a year or more later in southeast Alaska. Individuals do, therefore, use at least these two locations among years. How much interchange occurs among years, or even within the same year, is unknown. This is an important point because it has profound implications for managing the species. Under the Marine Mammal Protection Act and Endangered Species Act, both populations and subpopulations (or stocks) must be managed individually; assessment of the potential effects of OCS development on local stocks of a larger eastern North Pacific population fall within this management requirement. No photographs of humpback tail flukes off Kodiak Island are known to exist. A humpback whale photographic sorting system for the west coast (Lawton *et al.* 1980) is being developed, but requires much greater documentation and evaluation before utility is realized.

Sightings data from southeast Alaska salmon trollers and their comments (POP files) indicate that some humpbacks from southeast Alaska inland waters spend part of the summer on the Fairweather Ground, west of Cape Spencer, apparently feeding.

Further information on the distribution of humpback whales comes from old whaling records. Rice (1974:21) stated that "By the early 1960s, the only area remaining in the North Pacific where large numbers of humpbacks congregated in the summer was around the eastern Aleutians and south of the Alaska Peninsula, from 150° to 170°W longitude" and gave the

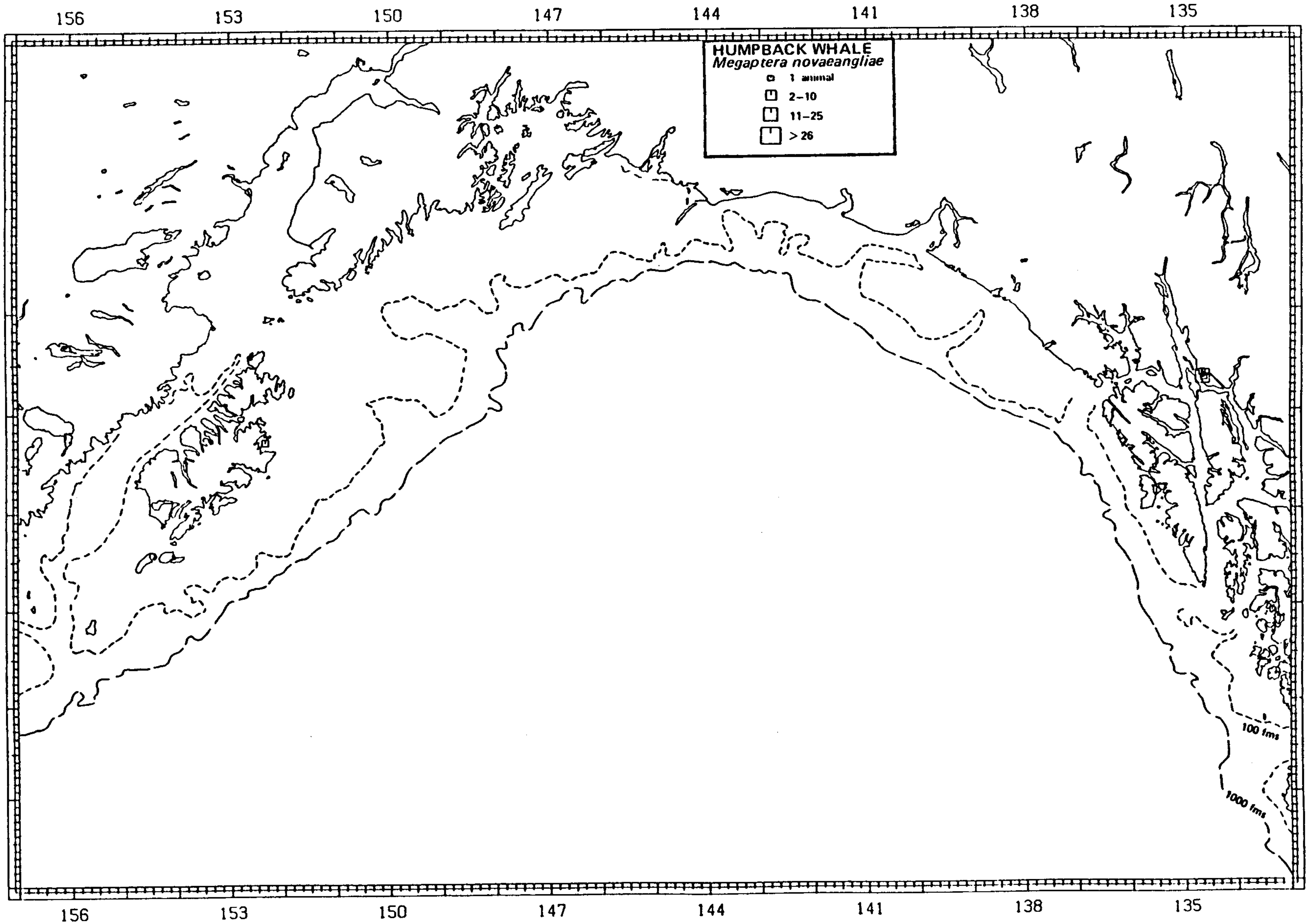

Figure 7.-Humpback whale sightings, winter (January-March) 1958-80.

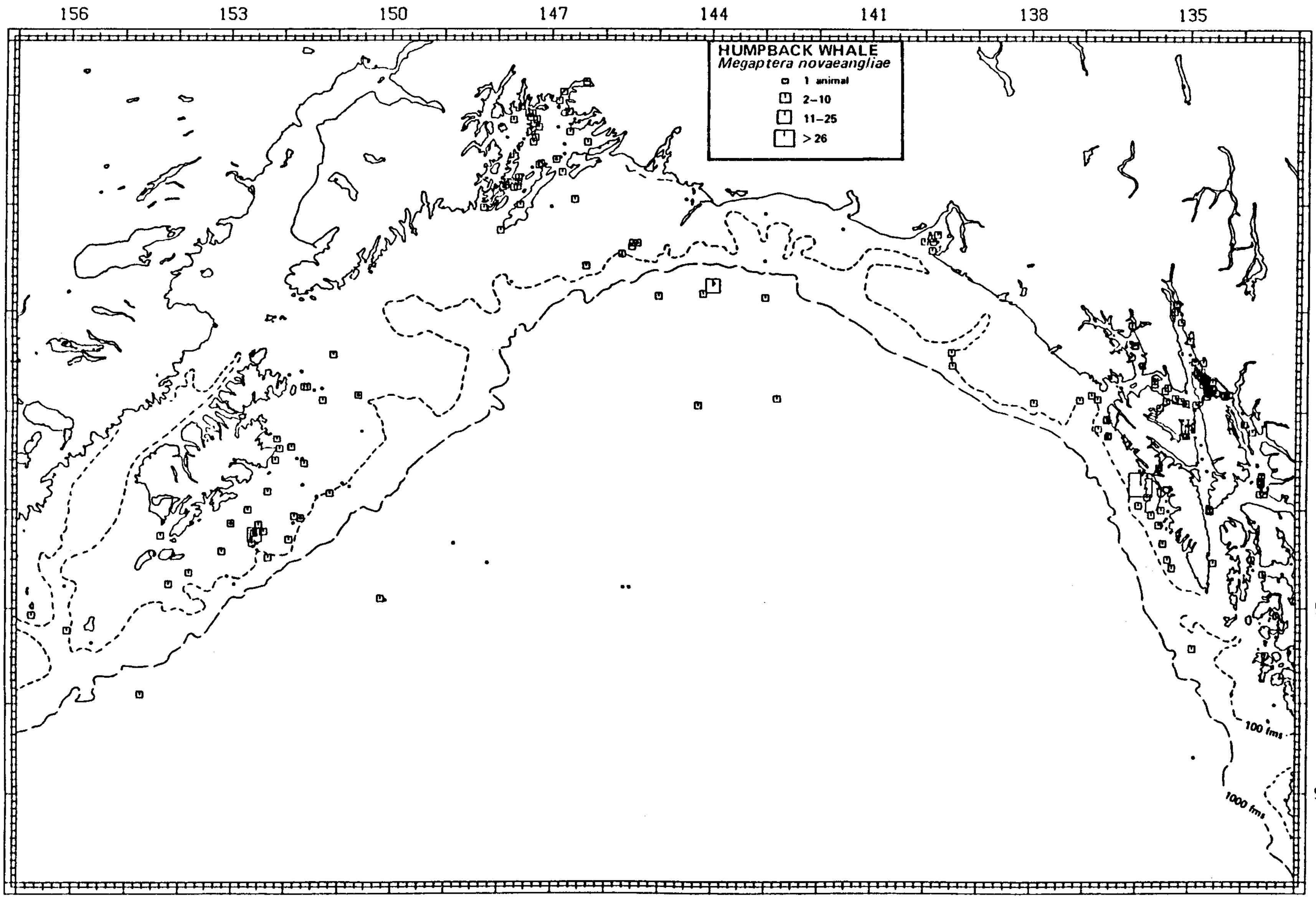

Figure 8.–Humpback whale sightings, spring (April-June) 1958-80.

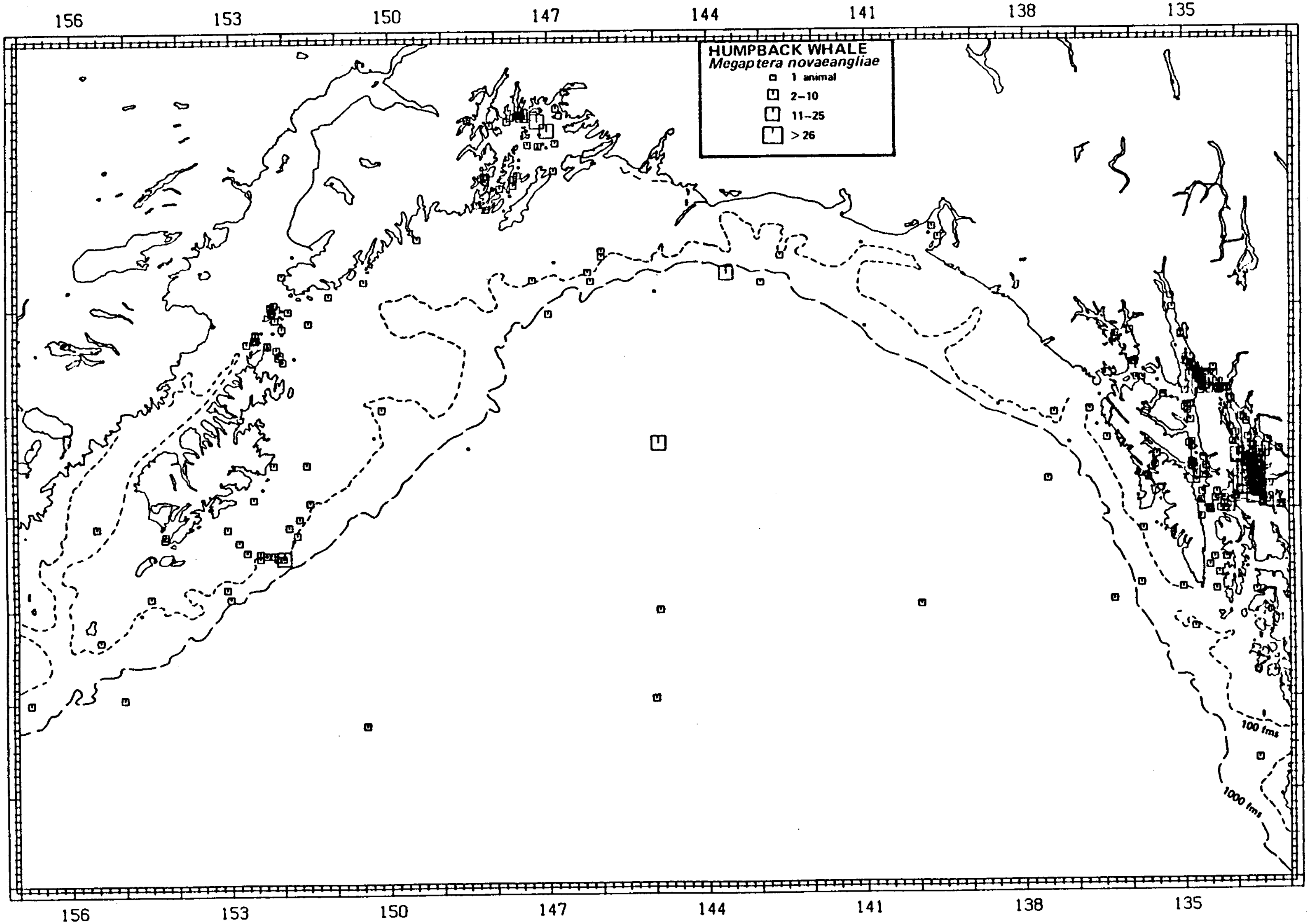

Figure 9.–Humpback whale sightings, summer (July-September) 1958-80.

southern summer limit as northern California. Berzin and Rovnin (1966) gave the distributional limit of summering as Vancouver Island, and the northern limit as the Chukchi Sea. They found large groups (>50 animals) off southeast Alaska, the Fairweather Ground, and the Shumagin Islands, with smaller groups occurring throughout the Gulf of Alaska, eastern Aleutian Islands, and southcentral Bering Sea. Nemoto (1964) noted that the large majority of sightings during summer months were of single animals or pairs. From sightings during a 1962 summer cruise, Berzin and Rovnin (1966) cited the western Gulf of Alaska and eastern Aleutian Islands as the area where humpback whales are likely to occur in summer. The paucity of recent sightings in these areas belies this assumption of today's distribution.

Autumn (October-December)

Humpback whales are present in the northwestern Gulf of Alaska through November, and in southeast Alaska inland waters through December (Figure 10). Hall (1979) found humpbacks in Prince William Sound through November.

FACTORS INFLUENCING DISTRIBUTION

Oceanographic

Winter distribution of humpback whales is associated with oceanic islands and warm waters close to continental coastlines (Berzin and Rovnin 1966; Rice 1974; Wolman and Jurasz 1977). This affinity for nearshore waters is maintained during the rest of the year on northern grounds in the study area. In describing a 1962 Soviet research cruise in the northeastern Pacific, Shurunov (1970) found that humpback whales formed localized concentrations and mainly kept near shore over the continental shelf.

The great majority of our sightings occurred in highly productive fjord-like inland areas (Prince William Sound and southeast Alaska), protected coastal areas and bays, and around islands (*e.g.*, Kodiak, Afognak, and Barren Islands). The few sightings from the central Gulf occurred in the vicinity of the Gulf of Alaska Seamount Province, but it is not certain that these offshore areas of upwelling provide summer-long habitat. It seems likely that these sightings merely represented animals in transit across the Gulf to nearshore areas.

Group size changes through the seasons, smallest in spring and largest in winter. The percentage of sightings of two or fewer animals was 74% for spring and summer and 53% for autumn and winter.

Feeding and Food Resources

Humpback whales, like all of the great rorquals, are seasonal feeders, feeding in the high latitude summer grounds and presumably living mostly off body fat reserves in the subtropical winter breeding grounds (Wolman 1978). "Fasting" in winter, however, is assumed and has not been tested. Though principal prey items appear to vary with location, humpbacks generally feed on schooling fishes and euphausiids.

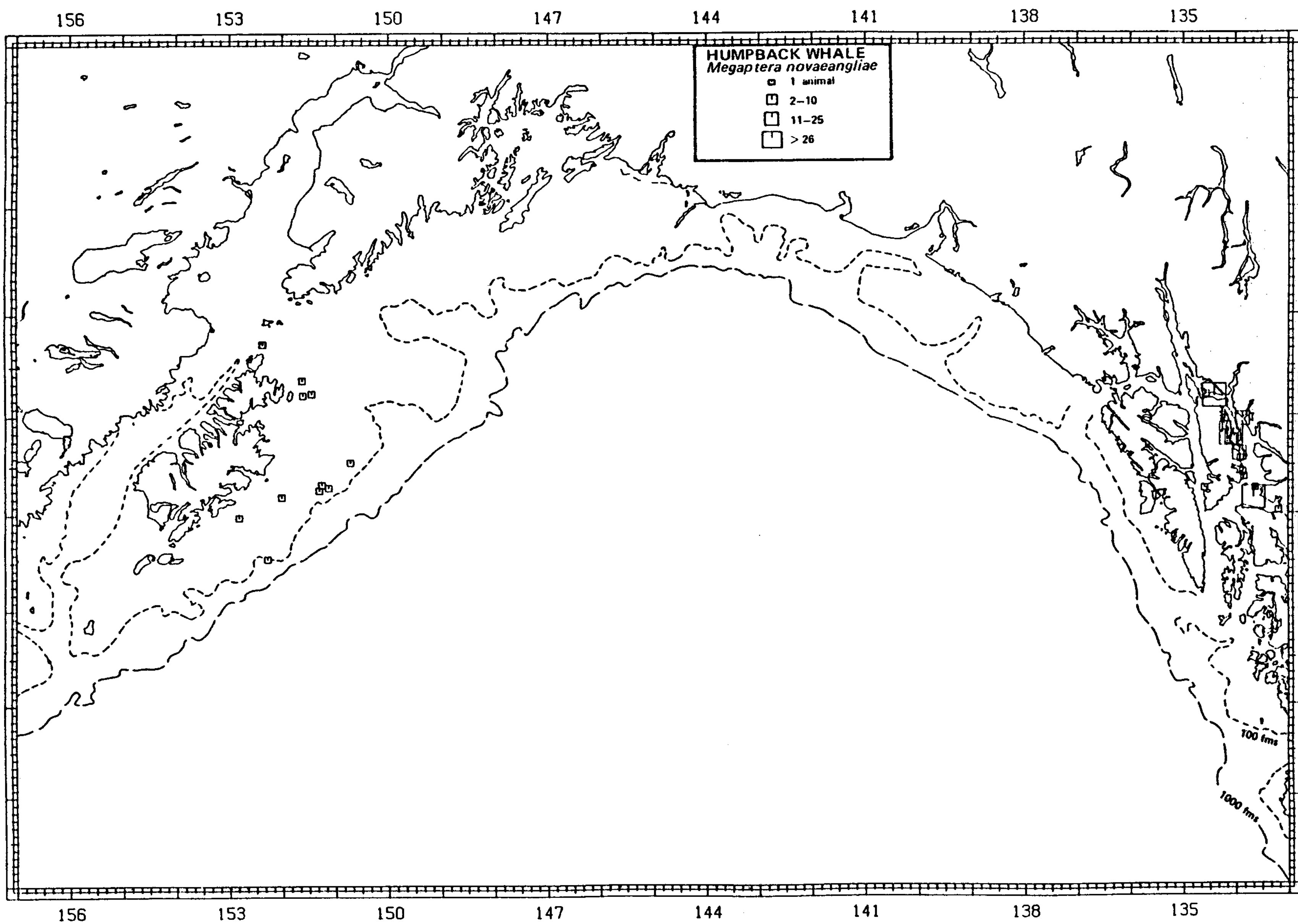

Figure 10.–Humpback whale sightings, autumn (October-December) 1958-80.

Nemoto (1959) found that humpback whales at the Near Islands (central Aleutian Islands) prey on Pacific mackerel (*Scomber japonicus*) and occasionally on small walleye pollock (*Theragra chalcogramma*). He listed their prey as swarming fishes: herring (*Clupea harengus*), walleye pollock, capelin (*Mallotus villosus*), Pacific mackerel, saury (*Cololabis saira*), and euphausiids. Klumov (1963) stated that humpback whales in the northern Pacific fed primarily on fishes, utilizing zooplankton occasionally, but taking no squid. In the Kurile Islands (western North Pacific), he found primarily walleye pollock in humpback whale stomachs, along with pink salmon (*Oncorhynchus gorbuscha*). In the Bering and Chukchi seas, he found humpback whales associated with aggregations of Arctic cod (*Boreogadus saida*), herring, and capelin.

Several methods of feeding on fish and euphausiids are exhibited by humpback whales (Jurasz and Jurasz 1979). In southeast Alaska they "lunge feed" with their open mouth by plowing through concentrated prey, or "flick feed," where they move their flukes forward at the surface, then dive forward through the concentrated feed. A third method reported involves blowing a ring of bubbles (called a "bubble net") around a school of fish, presumably causing the prey to bunch together. The whale then rises, with its mouth open, through the clumped prey.

Migration

There are three discrete wintering areas for North Pacific humpback whales (Berzin and Rovnin 1966; Rice 1977): (1) the coastal waters of Mexico, (2) Hawaiian Islands, and (3) on the Asiatic side, the Ryukyu, Bonin, and Marianas islands and Taiwan. About 2-1/2 months are spent on these wintering grounds (Wolman 1978). The ensuing migration northward to Alaskan waters lasts over 2 months.

Berzin and Rovnin (1966) proposed that the stock wintering in Mexican waters moves north and northwest in the spring and summer toward the eastern Aleutian Islands, with some groups remaining in Canadian coastal waters (southeast Alaska should probably have been included here). Nishiwaki (1966) noted that humpback whales are long distance migrators, citing an example of a group of six humpbacks tagged in the eastern Aleutian Islands being caught later near the Ryukyu Islands off Japan. Three humpbacks tagged off Unalaska in the Aleutian Islands in July and September were killed the next January and February off Okinawa Island, Japan (Kawakami and Ichihara 1958), a distance of approximately 2,500 nmi. Ohsumi and Masaki (1975:187), in reviewing marked and recaptured humpback whales, concluded that "the reliability of interchange between the east and west sides [of the North Pacific] is relatively high in this species." Hall and Johnson (1978) found a group of 15 animals entering Prince William Sound in October 1977 which apparently had not been sighted previously that year in the area. This indicated that movement of humpback whales from one area of the Gulf of Alaska to another does occur, at least occasionally.

We believe that humpbacks wintering in Hawaii and Mexico spend the summer in the Gulf of Alaska, and that humpbacks wintering in Asia summer in the Bering Sea, Aleutian

Islands, and perhaps to Kodiak Island. Some interchange between the Gulf and the Bering Sea may take place, however.

Both northward and southward migrations are staggered throughout spring and autumn, according to the reproductive status of individual whales (Wolman 1978). The first whales to head north are newly pregnant females and immatures of both sexes. Mature animals follow. Females late in lactation head south to breeding grounds first, followed by immatures, adult males, resting females, and, finally, pregnant females. Pregnant females remain on the Alaskan summer feeding grounds longer than others, presumably to accumulate the greater store of energy needed to support the rapidly developing fetus. The average speed of individuals migrating is less than 7 km/hour (Wolman 1978).

FACTORS INFLUENCING POPULATION GROWTH

Reproduction

Humpback whales reach sexual maturity at 6-12 yr of age (Nishiwaki 1959). Conception occurs during the winter months in the temperate and tropical breeding grounds, and may occur in the study area as well (overwintering animals?). Gestation is 12 months, with females usually resting at least 1 year after giving birth. A newborn calf may measure up to 5 m and weigh 1,800 kg. Lactation lasts for 11 months. A female humpback may have as many as 15 calves during her lifetime; her life span may last 47 years (Chittleborough 1960, 1965)--this from Southern Hemisphere data.

Mortality

Predation.-Killer whales are probably the only natural predators of humpback whales. We know of no documented attacks of humpback whales by killer whales in the eastern North Pacific. Killer whales are not believed to be an important mortality factor, however.

Other causes.-Other causes for natural mortality are poorly known. Strandings (presumably disease related) are few in the study area. Entanglements in fish nets, a somewhat frequent occurrence off the northeast coast of North America (compare Mitchell and Reeves 1981) (Lien and Merdsoy 1979), and collision with vessels are both undocumented in the study area.

Exploitation and development.-Extensive commercial exploitation of humpback whales in the northeastern Pacific did not begin until the 1960s (Berzin and Rovnin 1966). Prior to this period there were probably about 15,000 individuals in the entire North Pacific population; 28,000 humpback whales were killed between 1905 and 1965 (Rice 1977). The North Pacific population is thus recovering after having been reduced to less than 5% of its original size.

Gray Whale (*Eschrichtius robustus*)

The gray whale is the only species of the oldest living family of baleen whales, Eschrichtiidae. Common names include California gray whale (Rice 1974), devil-fish (Bailey and Hendee 1926), and summer whale (Hughes and Hughes 1960; and by Alaskan Eskimos). The gray whale is known as the winter whale by some local residents of Baja California, and is sometimes called "fin whale" by some Alaskan Eskimos (cf. Marquette and Braham 1982).

ABUNDANCE

In 1966 the IWC charter was amended and the gray whale was designated a Protected Stock; in 1979 it was redesignated as a Sustained Management Stock. A subsistence take by U.S. and Soviet Native Americans is allowed under IWC agreement. The 1980 quota was 179 whales. Two populations or stocks are identified, the eastern North Pacific stock and the western North Pacific or Korean stock.

The Korean stock is very rare (Brownell 1977). Since it may represent a now-isolated group from the eastern North Pacific stock and thus not likely to be influenced by any OCS activities off Alaska, it will not be considered in this report. The eastern North Pacific stock is now estimated to be 15,000-17,000 (Reilly *et al.* 1980; Reilly 1981), of which 13,000-17,000 enter the coastal waters of the Gulf of Alaska twice annually (Rugh and Braham 1979). Estimates of 11,000 (Rice and Wolman 1971) and 18,300 (Adams 1968) were based on fewer data and less rigorous analyses than the estimates by Rugh and Braham (1979) and Reilly (1981). The size of the summer (June-September) resident population in the Gulf, if it occurs regularly, is unknown but probably represents only a few hundred whales, if that. The gray whale population has apparently recovered from the commercial exploitation of the last half of the 19th century and first half of the 20th century, but probably is near its pre-commercial whaling carrying capacity (Reilly in press).

DISTRIBUTION

Winter (January-March)

Throughout December, gray whales migrate out of the Bering Sea (Rugh and Braham 1979) and can be observed from Unimak Pass to southeast Alaska well into January. Few are thought to be in the Gulf of Alaska in February, and, in fact, most leave the study area by mid-January.

The peak of breeding activity occurs south of Alaska during late winter (usually in late December to February). Calving and mating probably do not take place north of California (Rice and Wolman 1971). Pre-parturient females and recently weaned calves (those near the end of the summer feeding period) migrating south with the rest of the population probably represent the most likely (= sensitive) component of the population that could be influenced by OCS development in the Gulf during early winter.

Spring (April-June)

The northward migration into Alaskan waters begins in late March and continues through May (Figure 11). Gray whales are located throughout the Gulf in spring, usually within a few kilometers of shore (Figure 12). A buildup of whales occurs in spring, with more occurring in the Gulf at one time during the first half of spring than the last. Further research on this is required, however. There seems to be few if any major areas where they particularly congregate; however, they have been seen to stop or slow down to feed or interact among themselves and, on occasion, with sea lions, off (1) Cape St. Elias (Kayak Island) (Cunningham and Stanford 1979), (2) off the Barren Islands, (3) along the south coast of Kodiak Island, and (4) at various locations along the south side of the Alaska Peninsula, such as Chignik Bay, west of Kodiak Island (Braham 1978).

Summer (July-September)

The summer distribution of gray whales in the Gulf of Alaska is not well known. Because the migration into the Bering Sea is generally complete by the end of June or early July (Braham *et al.* 1977; Braham 1978), we believe that animals seen in the Gulf during summer and autumn may be resident for this period. Rice and Wolman (1982) saw no gray whales in a survey of the Gulf of Alaska from June to August 1980, although their surveys were generally farther offshore than we believe gray whales migrate. They spent some time near shore, where their lack of sightings further supports our belief that the migration northward is generally over by summer and that few animals remain as summer residents in the Gulf. Occasionally, however, gray whales are seen along the south side of Kodiak Island (especially), in Hinchinbrook Entrance (outside Prince William Sound), and between Cape St. Elias and southeast Alaska in summer (R. McIntosh, pers. commun.; Braham, pers. obs.); but again very near shore. Our plotted sightings are for Shelikof Strait and off Baranof Island (Figure 13). The significance of these sightings is unclear (*i.e.*, are these animals late spring or early autumn migrants, summer feeding groups, sick animals, or late post-parturient females?).

Autumn (October-December)

Gray whales begin entering the Gulf of Alaska in autumn during their southbound migration (Figure 14). Most of the population begins leaving the Bering Sea in early November (Rugh and Braham 1979; Rugh 1982), thus late autumn is when most gray whales are in the Gulf. Whales have been observed off the coast of British Columbia, Washington, and Oregon in September and October (Rice and Wolman 1971), although in small numbers. We believe they do little feeding during the autumn migration. Their speed of travel during autumn (about 7-9 km/hr) is twice as fast as in spring (Rice and Wolman 1971; Rugh and Braham 1979). Their distribution in the Gulf is greater in November, probably by two orders of magnitude, than in September, and more so toward the end of November than earlier. Unfortunately, almost no quantitative information has been gathered, and no systematic studies have been conducted on gray whales in the Gulf of Alaska from September to March (Figure 14).

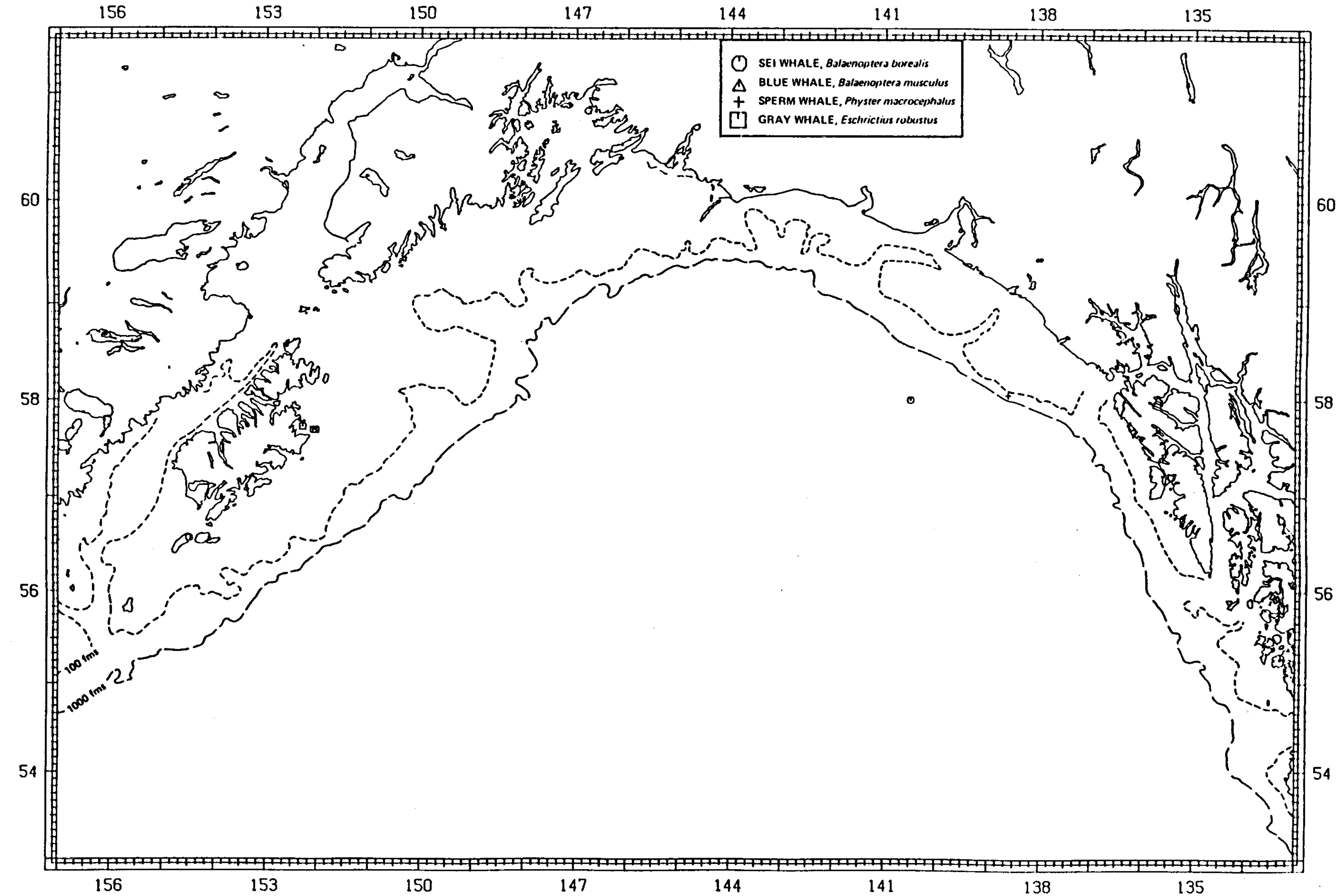

Figure 11.–Gray, sei, blue, and sperm whale sightings, winter (January-March) 1958-80.

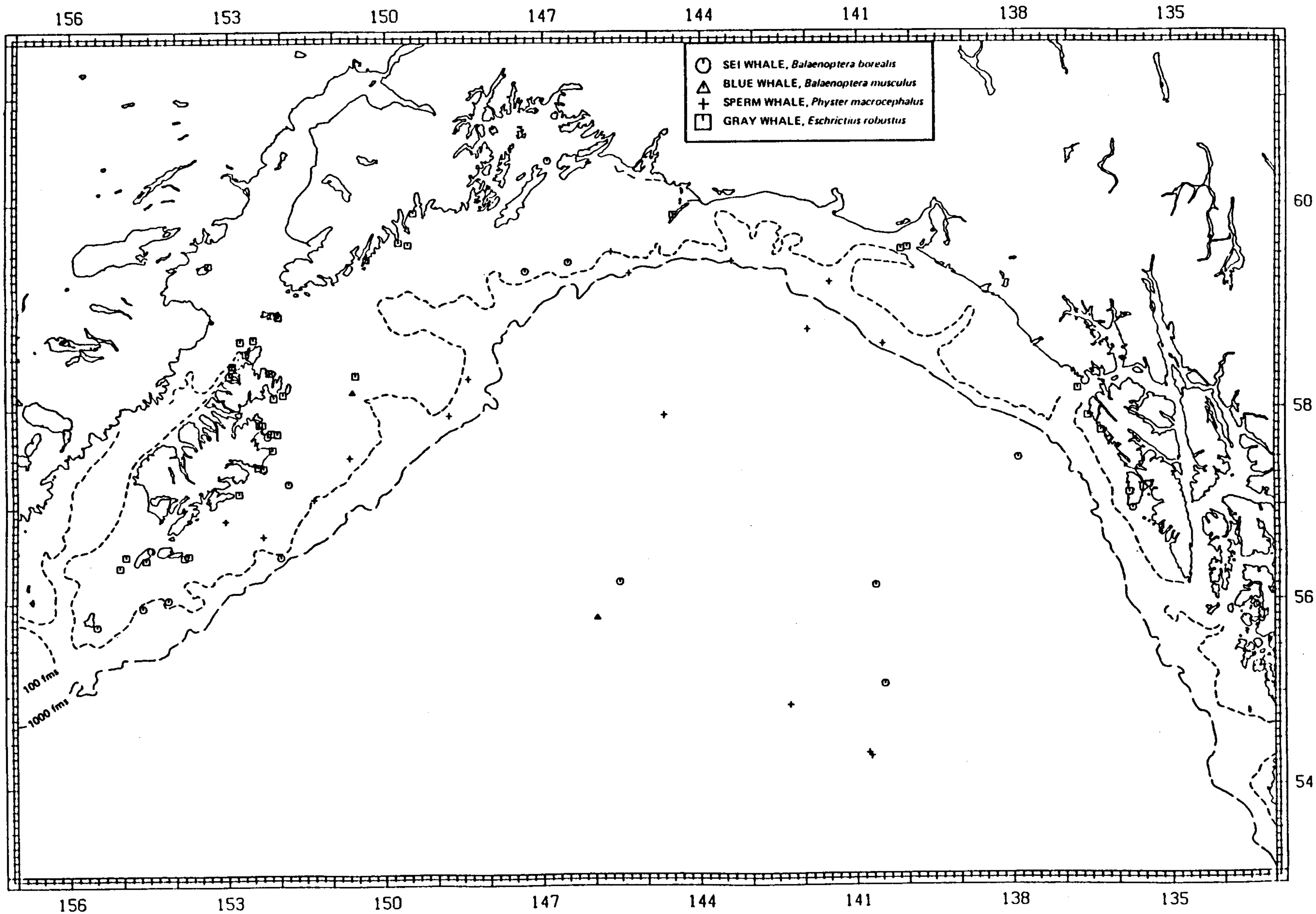

Figure 12.–Gray, sei, blue, and sperm whale sightings, spring (April-June) 1958-80.

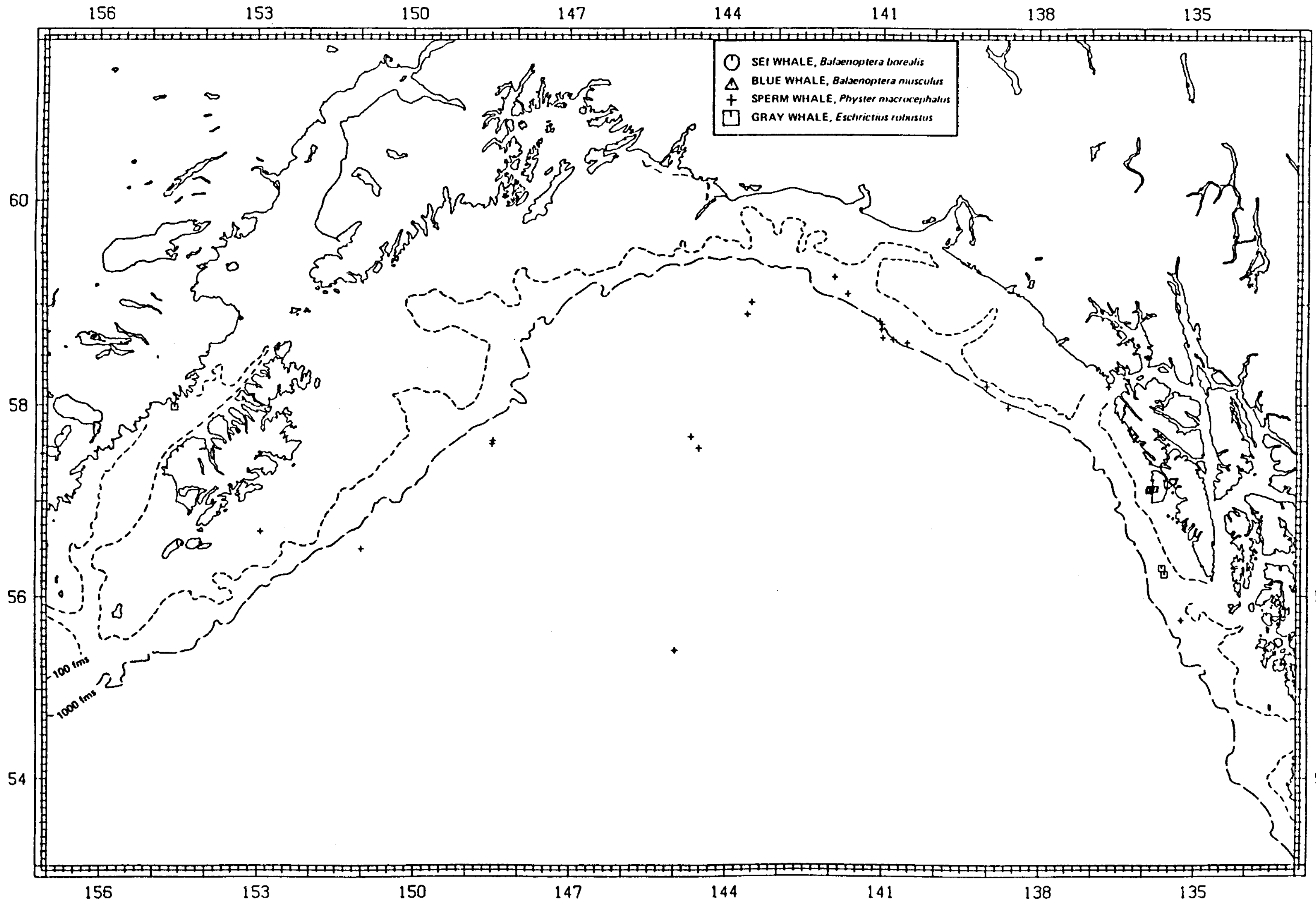

Figure 13.–Gray, sei, blue, and sperm whale sightings, summer (July-September) 1958-80.

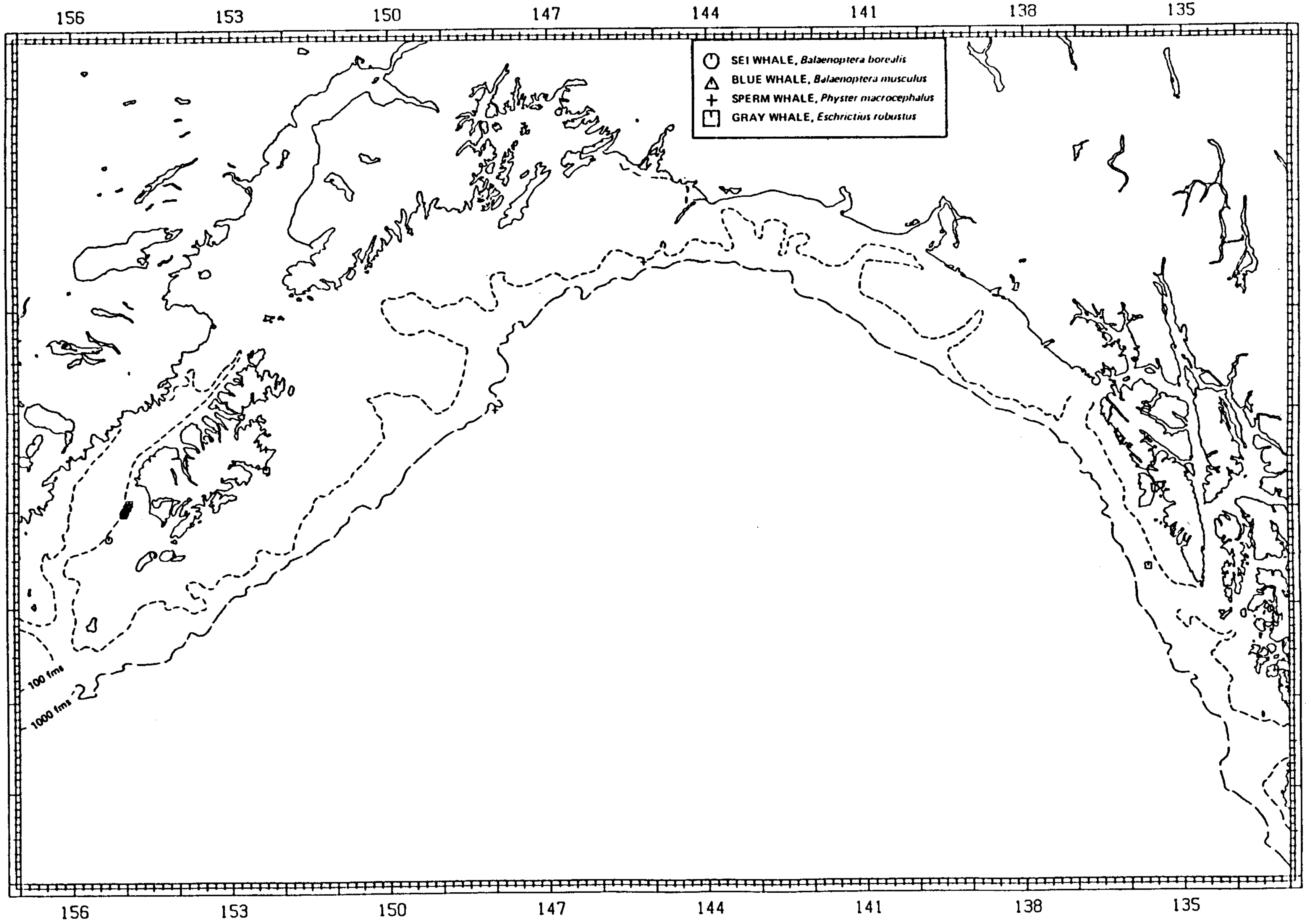

Figure 14.–Gray, sei, blue, and sperm whale sightings, autumn (October-December) 1958-80.

FACTORS INFLUENCING DISTRIBUTION

Oceanographic

There are no data to suggest that the distribution of gray whales in the Gulf of Alaska is influenced or limited by oceanographic features. It is clear, though, that they are a coastal species seldom found for long in waters beyond the 1,800-m isobath (Rice 1965), and are more commonly seen in water less than 100 m deep in Alaska. Hubbs (1958), Ichihara (1958), and Gilmore (1960) all thought the gray whale migration was offshore directly to and from the coast of California and Washington across the outer Gulf of Alaska to and from the Aleutian Islands. Gilmore (1960) hypothesized that their migration was closely associated with the prevailing oceanic currents out to sea, but this was disputed by Pike (1962), who showed that the water current system would probably work against the migration. Data we have collected since 1975 under the OCSEAP now confirms this coastal route throughout their range.

Pike (1962) speculated (accurately) that gray whales stay near the shore throughout their migration, although he had no data to present. He also hypothesized that their affinity for the shore was associated with migrational cues tied to the topography of the coastal mountains and promontories. Although he stated that whales in general may not see well in air, he proposed that gray whales take advantage of the coastal mountain ranges and hills as markers during migration and thus simply follow these cues around the coast and into the Bering Sea. Braham's (1978) hypothesis was that the northward gray whale migration route is most influenced by the availability (and perhaps consistency) of food resources.

Feeding and Food Resources

Gray whales enter Alaskan waters to feed and rear their young. It has previously been assumed that they do little if any feeding away from their feeding grounds in the northern Bering and Chukchi seas (Scammon 1874; Nemoto 1959; Gilmore 1960; Rice and Wolman 1971). Some authors, however, suggest that feeding may occur south of Alaska (Howell and Huey 1930; Pike 1962; Sund 1975; Wellington and Anderson 1978), and for those animals that do not make the complete migration north (Hatler and Darling 1974; Darling 1977). As a result of OCSEAP and other NMFS studies since 1975, Braham (1978) assembled several observations of gray whale feeding behavior and reports that gray whales do probably feed throughout their northward migration in Alaska (first reported in Braham *et al.* 1977). No known data are available, however, to indicate whether they feed in Alaskan waters during their autumn, southbound migration.

While in or near the Gulf of Alaska from March to May, gray whales have been observed to bring mud and sand to the surface and expel it in the same manner as observed when they are feeding in the northern Bering Sea. Three places are noteworthy: (1) along the outer coast of Baranof Island, (2) at Cape St. Elias, and (3) along the southeast coast of Kodiak Island. We have no idea what they may be feeding on; as benthic feeders, they favor ampelisced amphipods in the Bering Sea. They also take euphausiids, tubeworms, decapods, and polychaetes. However, the densities and coastal availability of amphipods are not documented in the literature. Howard Feder (Univ. Alaska, pers. commun.) reports that amphipods (mostly gammarids) are abundant nearshore in outer Cook Inlet, where soil type may be similar to that found in the northern Bering Sea by Stoker (1978). Sediment type and prey availability are unknown for much of the Gulf coast within a few kilometers of shore; presumably the surf zone where gray whales appear to be feeding consists of sand.

No conclusion is possible at this time as to the prey gray whales select while feeding in the Gulf, but from behavioral observations it is likely that some benthic or epibenthic invertebrates are the target. Schooling fishes, such as herring (*Clupea harengus*) and capelin (*Mallotus villosus*), are common in near coastal waters of Kodiak Island and southeast Alaska and thus fish may also represent a limited food resource during migration. Braham (pers. obs.) observed gray whales from the air (June 1976, 1977, 1978) apparently feeding at the entrances to Port Moller and Port Heiden (north side of Alaska Peninsula) in a somewhat different fashion than when they feed in the northern Bering Sea. These animals oriented themselves against the current-tide during presumed fish runs. The whales opened their mouths periodically while slowly drifting, or sometimes remained stationary by moving their flukes against the tide. It would be interesting to know if this is an important opportunistic response to tidal changes taken advantage of by whales who might be migrating by such a point–or whether portions of their migration route are timed to these tidal fish runs. Again, however, we cannot be sure the whales were feeding.

Migration

Spring.–Gray whales migrate 9,000-14,000 km each spring from their calving and mating areas off the west coast of Baja California, Mexico to feeding grounds in the Bering and Chukchi seas. Their migration route is entirely coastal, at least to Nunivak Island in the Bering Sea (Braham *et al.* 1977; Braham 1978). Most, if not the vast majority, stay within 2 km of shore while in Alaska, except between the entrance to Prince William Sound and Kodiak Island, and Kodiak Island to the south side of the Alaska Peninsula (Figures 11-14).

The migration usually begins, slowly, from late February to mid-March and ends by late June or early July. In the Gulf of Alaska the spring migration period is approximately April through June. Single adults, including pregnant females, and subadults generally begin first, followed by post-mating males and post-parturient females with their young (Rice and Wolman 1971). Braham *et al.* (1977; and NMFS unpubl. data) observed apparent subadults entering the Bering Sea first. Besides feeding, other behavior associated with mating, and perhaps play, have been observed at Cape St. Elias by Cunningham and Stanford (1979) and near Cape Chiniak, Kodiak Island by R. McIntosh (pers. commun.). Milling about, as well as feeding and sexual behavior, were common, perhaps associated with periods of rest during migration. The peak of the migration midway through the Gulf of Alaska (at Cape St. Elias) for the years 1977 and 1978 was the third week in April (Cunningham and Stanford 1979).

Autumn.–Gray whales leave the Bering Sea during their annual autumn migration south to Baja California and begin entering the Gulf of Alaska in late October; they are usually gone from the Gulf by early January. The peak of the migration in the Gulf is around the last week in November, although no empirical data are available. This estimate is an extrapolation from the field work of Rugh and Braham (1979) and Rugh (1982) at Unimak Pass and that estimated by Pike (1962) and Rice and Wolman (1971). Data from Kodiak Island (R. McIntosh, pers. commun. to Rugh 1982) and Yakutat Bay (D. Calkins, pers. commun. in Braham *et al.* 1977) suggest that the migration route is as close to the coast as it is in spring. Joyce (1979) observed a group of 20 gray whales approximately 20 km out to sea northeast of Kodiak Island heading in an east-northeasterly direction in November 1979 during poor weather conditions. Whether the animals were en route from Kodiak back to the north coast of the Gulf, or taking a course across the Gulf more out to sea than expected, is unknown.

FACTORS INFLUENCING POPULATION GROWTH

Reproduction

Gray whales mate and calve during their southbound migration along the west coast of the United States (and perhaps Canada) south of Alaska but usually in coastal waters adjacent to California and Baja California, Mexico (Rice and Wolman 1971). Females generally mate every other year, with conception generally occurring from late December into February. Recent (1981) observations of mating in Mexico strongly suggest conception may extend well into February (Braham pers. obs.) and perhaps March. Copulatory or sexual behavior has been observed beyond this period–April (Cunningham and Stanford 1979), summer (Darling 1977), June-July (Fay 1963)–but its significance relative to conception is unknown (*e.g.*, these may have been male-male interactions). Parturition occurs in January and February, but sightings of calves along the migration route (Sund 1975) and in or near the calving lagoons (Eberhardt and Norris 1964; Rice and Wolman 1971; Swartz and Jones 1979; Rice *et al.* 1981) suggest the period may be from late December to perhaps early March. Although it seems highly unlikely, some calving may take place in the Gulf of Alaska.

Lactation lasts to at least August (Rice and Wolman 1971); young calves and their mothers migrate through the Gulf of Alaska during about the second or third to fourth month of the calf's life during the period of lactation in spring and summer. A report to Braham in 1977 from Alaskan Eskimos living on St. Lawrence Island was that young gray whales are weaned by summer.

The total reproductive output of a female gray whale is unknown; however, if they have an active reproductive life of 40 years, mate every second year, begin mating no earlier than 8 years, and if most (85%, Rice and Wolman 1971) become pregnant during their annual reproductive season, then a female can expect to produce about 12 calves in her lifetime (which live to their first year, assuming 10% calf mortality). Reilly (pers. commun.) believes that some may breed annually. Females become sexually mature at about 12 m and males at about 11 m; female adults are longer than males (Rice and Wolman 1971). The population of gray whales in the eastern North Pacific is believed to have grown about 2.5% per year between 1968 and 1980 (Reilly 1981). It therefore appears to be a reproductively healthy population.

Mortality

Predation.–Killer whales are the only known natural predator of gray whales. Stranded gray whales in Alaska frequently show evidence of killer whale attacks (Fay *et al.* 1979). Several killer whale attacks have been sighted, but few documented in Alaska. In November 1978, a group of approximately six killer whales attacked a group of four gray whales in eastern Unimak Pass; a lone adult gray whale was isolated and attacked by all of the killer whales (R. Sonntag, pers. commun.). The head region of the gray whale was attacked first. The final outcome of the event was not observed, although blood from the gray whale was evident and it is unknown whether the remaining gray whales were also attacked. The gray whales scattered when the killer whales charged; but just prior to the initial charge the larger gray whales surrounded a juvenile animal in an apparent protective display. Baldridge (1972) saw five or six killer whales kill a gray whale calf. He suggested that the calf was held underwater and drowned; the tongue, jaw area, and ventral blubber were consumed.

Killer whale predation on gray whales was reported to Braham (1977, 1978, 1979) by Alaskan Eskimos on St. Lawrence Island. As with predation on bowhead whales (*Balaena mysticetus*), gray whales have been seen to be attacked near the mouth, flippers, and flukes. This would seem to be an effective way to quickly immobilize the prey. Below-surface attacks are usually not reported for obvious reasons, thus killer whale attacks may be more frequent than witnessed. However, we believe that this is not a significant factor in gray whale mortality. More work on stranded animals is needed to ascertain causes of mortality.

Shark predation is unknown to us, but is probably insignificant because of the size of a gray whale (calves excluded, of course) and their coastal migration behavior. Larger sharks generally occur farther offshore than gray whales and are found in more temperate waters than Alaska.

Other causes.–Other causes for natural mortality (*e.g.*, disease) of gray whales are little studied. Gray whales commonly strand along the coast from Mexico to Alaska, although generally this is spotty. Strandings seem to occur regularly in at least three areas (or at least we have noticed them there): (1) offshore to the calving lagoons in Mexico, (2) along the north coast of the Alaska Peninsula, and (3) off St. Lawrence Island. Strandings in Mexico are usually of calves; those animals observed by Braham in the southern Bering Sea appeared mostly to be subadults.

Few observations have been made in the Gulf of Alaska, perhaps because of less study in the area and because of the remoteness of the coastline. Most gray whales studied during strandings are too far decomposed to satisfactorily determine cause of death (Fay 1977; Moore *et al.* 1977). Causes of mortality for four animals (two adults and two immatures) along the coast of Washington State included collision with a boat, fishing net entanglement, and malnutrition (Moore *et al.* 1977). We suspect the greatest cause would be nutritional loss as a result of separation of a calf from its mother, or misdirected orientation of young, first-migrating animals (cf. Wellington and Anderson 1978), with death from killer whales (Fay *et al.* 1979) trailing behind. Mortality, its causes and quantitative estimates of strandings and their locations, needs much greater study, as does the relative nutritional state of various age and sex classes throughout Alaska, so that an evaluation can be made of differential susceptibility during the annual life cycle.

Exploitation.–The eastern North Pacific population was commercially harvested from 1846 to 1946 and was reduced to probably only a few hundred to a few thousand individuals (Rice and Wolman 1971; Reilly 1981). The original population size may have been at or higher than 15,000 (Scammon 1874; Henderson 1972), or as high as 24,000 (Reilly in press). Under international agreement, 179 whales were taken in 1980 by the Soviet government for the Chukchi Eskimos. Alaskan Eskimos are also allowed to take gray whales under this quota; they took two in 1980 (Marquette and Braham 1982). Since 1960, the Soviet Union has averaged an annual reported take of 167, increasing from a low of 10 in 1950 to a high of 207 in 1961 (Zimushko and Ivashin 1980). Since 1950, Alaskan Eskimos have averaged only one gray whale landed per year (Marquette and Braham 1982).

Disturbance

Only one documented case is known of an impact on any portion of the gray whale population from coastal development activities. The event took place from 1957 to 1972 in Laguna Guerrero Negro, Baja California, Mexico, which is one of the four major calving lagoons in Mexico. Beginning in 1957, Mexican salt barges entering and leaving the lagoon mouth and channel dredging inhibited the use of the lagoon and channels by the whales. This was, and is today, one of the three or four major calving lagoons. Over a period of 6 years, the number of gray whales entering the lagoon steadily declined to zero; for 7-8 years no whales returned (Gard 1974). When the dredging ceased (by federal action to protect the whales), the animals gradually returned over a 6-year period to their original numbers.

For an additional overview of this population, including a discussion of biological and industrial development and international cooperative efforts on behalf of the species, see Braham (in press).

Sei Whale (*Balaenoptera borealis*)

The sei whale (pronounced "say") belongs to the family Balaenopteridae (the rorquals). Two subspecies are recognized: *Balaenoptera borealis borealis*, in the Northern Hemisphere, and *B. b. schlegellii* in the Southern Hemisphere. The sei whale is sometimes referred to as Rudolphi's rorqual.

ABUNDANCE

Sei whales, like all other large baleen whales, are protected by U.S. law under the Marine Mammal protection Act of 1972 and Endangered Species Act of 1973, and international agreement under the Convention for the Regulation of Whaling (1946). It has been designated a Protection Stock by the IWC since 1966 in the North Pacific. The entire North Pacific population is estimated at 8,600 (Tillman 1977).

DISTRIBUTION

Winter (January-March)

The distribution of sei whales in the North Pacific during the winter is not well documented. The paucity of sei whale sightings much farther south, along the southern California and Mexico coasts, led Rice (1974) to speculate that they may spend the winter far offshore. Masaki (1976) stated that North Pacific sei whales are found between 20° and 30°N in January and February. Our POP data yielded only one sighting of five animals near the Fairweather Ground during the winter months (Figure 11). We assume that sei whales are very rare in the study area in winter.

Spring (April-June)

Spring is a period of northward migration from the winter resting and reproduction grounds to the summer feeding grounds above 40°N (Masaki 1976). Judging from our data, spring appears also to be the period of greatest relative abundance of sei whales in the Gulf of Alaska. Our data contain 16 (of 18 total for all seasons) sei whales sightings between April and June, distributed throughout the Gulf (Figure 12).

Summer (July-September)

During summer, sei whales are at the northern limit of their range, feeding and preparing for the ensuing southward migration. Using sighting data from Japanese scout vessels, Masaki (1976) depicted the northwestern and northeastern Gulf of Alaska as the areas of greatest sei whale density from May through August. A recent, extensive survey of the Gulf of Alaska (Rice and Wolman 1982) yielded not a single positive sei whale sighting (Figure 13). Sei whales begin their southward migration by late summer.

Autumn (October-December)

By the beginning of autumn, most sei whales depart the study area, moving south (Masaki 1976). Our data show a lone sighting (one animal) north of Chirikof Island (Figure 14).[1]

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[1] Even to the experienced eye, it is often difficult to differentiate between fin and sei whales at a distance. Many sightings logged as "either fin or sei" were transcribed as "unidentified whales" and not used in our distribution plots. Because of this verification problem, both sei and fin whale distributions are underrepresented in our data base.

FACTORS INFLUENCING DISTRIBUTION

Feeding and Food Resources

The sei whale has been characterized as a moderately euryphagous animal, preying on a variety of species over its range, yet exhibiting a high degree of prey selectivity within any one area (Klumov 1963). Sei whales are equipped with finer baleen than the other rorquals and can therefore feed on smaller organisms. They may utilize two types of feeding behavior–swallowing and skimming. In the swallowing, or gulping, mode, sei whales capitalize on tightly grouped prey organisms (*e.g.*, squid, macroplankton, fishes). In the skimming mode, they feed on sparsely distributed prey (*e.g.*, smaller plankton) (Nemoto 1959). The sei whale can also be characterized as a surface-oriented animal, having adapted more readily to the uppermost water column than to waters below 50 m (Klumov 1963).

Sei whales feed actively in the Gulf of Alaska. Kawamura (1973) found that 63% of sei whales examined over a 5-year period from Pacific waters north of latitude 40°N contained food in their stomachs, as opposed to less than 40% for animals south of 40°N.

Analyses of prey found in sei whales are available from the Gulf of Alaska (Nemoto and Kasuya 1965), the central North Pacific–Aleutian Islands area (Nemoto 1957), and the southern portion of the North Pacific (Kawamura 1973). Copepods (*Calanus plumchrus*, copepodite Stage V) were the main food item in the eastern North Pacific (Nemoto 1957; Kawamura 1973). In the Gulf of Alaska, *C. plumchrus* occurs from the surface to a depth of 500 m, and is most abundant in the spring (Cooney 1975).

Calanus cristatus is the other species of copepod eaten by sei whales in the North Pacific, mostly in areas well offshore (Nemoto and Kasuya (1965). Surprisingly, euphausiids are not a major prey item. Of sei whale stomachs sampled between 1952 and 1956 in the North Pacific, Nemoto (1957) found 107 (35%) contained only copepods, 12 (2.5%) contained only squid, and each of the following categories comprised less than 1%: euphausiids, copepods and fish, fish, and fish and squid. These findings led Klumov (1963) to state that the distribution of North Pacific sei whales is associated with calanoid copepods and, secondarily, with squid (*Ommatostrephes sloanei pacificus*). Klumov (1963) estimated that an average-sized sei whale requires about 600-800 kg of food per 24 hours.

Rice (1961) described a baleen infection or genetic condition which resulted in the deterioration and loss of the baleen of 8% (3 of 39 animals) of sei whales landed in northern California. Though none of the affected animals had copepods or euphausiids in the stomachs, two stomachs (from otherwise healthy animals) were full of anchovy (*Engraulis mordax*).

FACTORS INFLUENCING POPULATION GROWTH

Reproduction

Reproductive activity in sei whales occurs in the winter months, when the animals are in warmer southern waters. Most sei whales in the North Pacific are born around November, and conception occurs around December (Masaki 1976). Sexual maturity is reached at about 7 years of age in both sexes, and body length is about 13 m. Age at sexual maturity is 16 years. Gestation is estimated to take 10-11 months and lactation spans about 11 months. (Masaki 1976).

Mortality

Killer whales are probably the only predators of sei whales. Other causes for natural mortality are undocumented.

Exploitation and Development

The sei whale did not experience heavy commercial exploitation in the North Pacific until 1963 (Omura and Ohsumi 1974). Some 945 animals were caught by Japanese whalers in the Gulf of Alaska alone in 1963 and 1,082 in 1964. Averaging sighting and catch per unit effort results, Tillman (1977) estimated a pre-exploitation (1963) population size of 42,000 for the North Pacific. Comparing current estimates and removals, an 80% population decrease occurred within one decade after exploitation began.

Blue Whale (*Balaenoptera musculus*)

The blue whale is the largest member of the family Balaenopteridae. In the Northern Hemisphere one subspecies is recognized, *Balaenoptera musculus musculus*, and two other subspecies, *B. m. intermedia* and *B. m. brevicauda*, are recognized from the Southern Hemisphere. The other common name for the blue whale is sulphur bottom whale.

ABUNDANCE

The blue whale was classified as a Protected Species (all stocks) by the IWC in 1965.

Ohsumi and Wada (1972) artificially divided the North Pacific population into an Asian stock and an American stock, and estimated the initial (pre-modern whaling) populations at 1,200-1,300 and 3,500-3,600 animals, respectively. The total initial size of the North Pacific population then is estimated to be 4,800 animals. Based on whale marking results, Ohsumi and Wada (1972) believed that the total North Pacific population decreased from 1,400 in 1963 to about 1,000 (± 700) in 1965. They then used a population model to arrive at a 1972 estimate of 1,500. This "increase" (1,000 to 1,500) does not necessarily reflect an actual increase in individual animals, but probably the technique of estimation. The most recent (1975) North Pacific blue whale population estimate is 1,530 (Wada 1977), based on Japanese sighting data.

DISTRIBUTION

Winter (January-March)

During winter, blue whales are located in subtropical breeding grounds in the North Pacific between Baja California and Taiwan (Berzin and Rovnin 1966; Rice 1978*b*). Neither our data nor the literature can confirm that blue whales are in the study area during winter (Figure 11).

Spring (April-June)

Blue whales begin to arrive in the Gulf of Alaska in late spring. Our data show only two spring sightings in the study area: two individuals, May 1960 at 58°10'N, 150°37'W on Portlock Bank; and five individuals, June 1960 at 55°50'N, 145°58'W over the Gulf of Alaska Seamount Province (Figure 12).

Summer (July-September)

Most blue whales arrive on the North Pacific feeding grounds by June and July. From pelagic whaling results, two general areas of abundance in or near the study area were (Berzin and Rovnin, 1966; Ohsumi and Wada 1972; Rice 1974): (1) eastern Gulf of Alaska, from 130°W to 140°W, and (2) south of the eastern Aleutian Islands, from 160°W to 180°W.

Our data show only two sightings during summer: one individual, July 1975 at 57°07'N, 152°21'W on Albatross Bank; and one individual, August 1978 at 55°43'N, 154°54'W near Chirikof Island (Figure 13). No blue whales were observed during an extensive summer survey of the Gulf of Alaska in 1980 (Rice and Wolman 1982). Pike and MacAskie (1969) noted that off British Columbia, blue whales were found singly or in small groups of two or three individuals, occurring well offshore.

Autumn (October-December)

We have no autumn blue whale sightings in our data base (Figure 14). They usually migrate south out of the study area by September (Berzin and Rovnin 1966).

FACTORS INFLUENCING DISTRIBUTION

Feeding and Food Resources

In the North Pacific, blue whales feed almost exclusively on euphausiids (Nemoto 1957, 1970; Klumov 1963; Rice 1978*b*). Examination of their stomachs revealed the following euphausid species: *Euphausia pacifica*, *Thysanoessa inermis*, *T. longipes*, *T. spinifera*, and

Nematoscelis difficilis. Of 971 blue whales taken by Japanese pelagic whalers between 1952 and 1965 in the North Pacific, 455 contained only euphausiids, 5 contained euphausiids and copepods, 1 held shrimp (*Sergestes*), 6 held only copepods, and 504 were empty (Nemoto 1970).

Klumov (1963) cited a 1955 occurrence in which a right whale (*Balaena glacialis*) and a blue whale were killed in the same vicinity in the Sea of Okhotsk on the same day. The right whale's stomach contained only copepods (*Calanus plumchrus*) whereas the blue whale's stomach contained only euphausiids (*Euphausia pacifica*). Klumov interpreted this as confirming his belief that blue whales actively select their prey (euphausiids) and do not compete with the copepod-eating right or sei whales.

Rice (1978*b*) estimated that an average blue whale, weighing some 80 tons, probably consumes about 4 tons of krill daily during the summer months.

Migration

Based on a 1964 Soviet cruise, Berzin and Rovnin (1966) assumed the wintering grounds of blue whales to be from California west to about 160°W. Rice (1978*b*) also noted that some blue whales spend the winter between Taiwan and southwestern Honshu, Japan. According to Berzin and Rovnin (1966), the spring migration northward begins in April and May. The "American stock" moves along the west coast of North America to Vancouver Island, where it splits in two directions. A portion of the population moves north to the Queen Charlotte Islands and northern Gulf of Alaska. The rest of the population moves west toward the Aleutian Islands. Autumn migration begins in September and follows the same spring pattern but in reverse.

Catch data from the North Pacific indicate that blue whale abundance peaks in the eastern Gulf of Alaska in July, and near the eastern Aleutian Islands in June (Rice 1974). Marking studies revealed little apparent movement of blue whales on the feeding grounds. In summarizing Japanese whale marking results, Ohsumi and Masaki (1975*a*) found that of 14 blue whales marked in the North Pacific, 12 were recaptured in the same areas marked. Two whales marked in the western Gulf of Alaska moved to south of the eastern Aleutian Islands. They concluded that the blue whale migration in northern waters is limited or restricted geographically (or regionally) compared to the other large cetaceans. In summarizing Soviet marking results in the North Pacific, Ivashin and Rovnin (1967) noted that a blue whale marked off Vancouver Island, British Columbia, was killed a year later near the southern end of Kodiak Island. Klumov (1963) believed that individual populations (or stocks) do not mix.

FACTORS INFLUENCING POPULATION GROWTH

Reproduction

Breeding occurs on the tropical winter grounds and sexual maturity occurs at about 10 years of age (Rice 1978*b*). This corresponds to a size of about 20.5 m in males and 21.5 m in females (Pike and MacAskie 1969). Females grow longer than males at maturity. Gestation is about a year, with females resting 1-2 years between calves (Rice 1978*b*).

Mortality

Killer whales are probably the only natural predators of blue whales. Given the low population level of the North Pacific blue whale population, predation by killer whales may have a significant effect on population growth. That is, of course, speculative; any mortality of adults, however, will be important if annual gross recruitment is low. Since recovery does not appear to have been great since the end of commercial exploitation, recruitment is probably low.

Exploitation and Development

Some 6,900 blue whales were taken in the North Pacific between 1910 and 1965. Given an initial (pre-modern whaling) North Pacific population of 4,800 animals, a take of at least 6,900 undoubtedly resulted in severe depletion. Although North Pacific blue whales have been protected for 15 years, any increase in the population has not manifested itself in increased sightings in the Gulf of Alaska, an area of former abundance.

Vessel traffic has been documented as a possible cause of death to at least two blue whales. On 6 July 1980 the carcass of a 17-m male blue whale was retrieved from the bow of a ship upon arrival at Los Angeles, California. The young whale apparently was killed by the ship, according to preliminary findings. On 24 October 1980, a 175-m container ship (*Evershine*) bound for Seattle, Washington, from San Francisco, California, struck a 16.2-m blue whale and pushed it into port still pinned to the bow of the ship. While the master of the vessel noticed a significant decrease in speed, the whale was not discovered until the ship docked in Seattle. Whether the animal died as a result of the accident was not determined, but the animal was moderately decomposed when inspected.

Sperm Whale (*Physeter macrocephalus*)

The sperm whale is the largest member of the Odontoceti and belongs to the family Physeteridae. The specific name *catodon* appears in much of the older literature, but *macrocephalus* is now correctly recognized (Rice 1977). Another common name is cachalot.

ABUNDANCE

The International Whaling Commission currently recognizes two stocks of sperm whales in the eastern and western North Pacific (1980). The boundary between the two stocks roughly follows a line from Amchitka Pass in the western Aleutian Islands (50°N, 180°) southeast to the Hawaiian Islands (20°N, 160°W).

Population estimates of the commercially exploited components range from about 515,000 in 1947 (initial) to approximately 375,000 in 1978 (Table 3). Only exploitable males (> age 13) and mature females are included. The total North Pacific population, including all age classes, is estimated at 740,000 individuals (Rice 1978*c*).

DISTRIBUTION

Soviet and Japanese catch and effort records show little harvesting of sperm whales in the study area over the past several decades (Ohsumi 1980), indicating this species is not as abundant in the Gulf of Alaska as it is further south. Our relatively few sightings (Figures 11-14) confirm this.

Winter (January-March)

Sperm whales are distributed across the entire North Pacific between the equator and about 40°N during winter (Berzin 1970). We have only one sighting in our data, that in 1979 of a single animal on the Fairweather Ground (Figure 11).

Spring (April-June)

Pike and MacAskie (1969) reported that "maternity schools" appear off the coast of British Columbia in April, May, and early June, and that bachelor schools are present at least throughout spring and summer.

Sperm whales are characteristically located, and hunted, in deeper waters near the continental slope and off the shelf (Smith 1980; Ohsumi 1980). However, 55% (6 of 11) of our spring sightings were where water depths were less than 2,000 m, and most of these in water 200 m deep (Figure 12). If our data are representative of the actual distribution of the species, then they are widely distributed in the study area in spring, especially near the continental slope.

Summer (July-September)

During a 1980 summer survey of the Gulf of Alaska, Rice and Wolman (1982) sighted sperm whales "over deep water beyond the continental shelf on 6 occasions, totalling 37 individuals." This is characteristic of our data base for summer (Figure 13). Summer sightings may indicate that their distribution is shifted farther east in summer than in spring, for an unknown reason.

Autumn (October-December)

Sighting only a few sperm whales in the study area in autumn (Figure 14) is consistent with the report that the whaling season ended near the study area by early autumn, with animals moving south (Pike and MacAskie 1969).

Table 3.–Sperm whale population/stock estimates for the North Pacific in 1947 and 1978 (x10^3).

Year of estimate	Sex and age class	Western stock	Eastern stock	Combined
1947	Males (> age 13)	137.7	97.6	235.3
1947	Females (mature)	164.3	116.5	280.8
1978	Males (> age 13)	65.3	67.4	132.7
1978	Females (mature)	132.2	111.4	243.6
% 1978/1947 Males		47.4%	69.1%	
% 1978/1947 Females		80.5%	95.6%	

FACTORS INFLUENCING DISTRIBUTION

Oceanographic

Adult females and immature sperm whales are found primarily in offshore waters where surface temperatures are greater than 10°C (Nishiwaki 1966; Veinger 1980). Pike and MacAskie (1969) noted that the northern limit of females off British Columbia lies along the 15°C surface isotherm, near 50°N during the summer. Therefore, adult females and immature sperm whales (maternity schools?) are undoubtedly rare visitors to the study area.

Feeding and Food Resources

Sperm whales generally feed from midwater to the ocean floor (Berzin 1959). The preponderance of bottom-dwelling species in sperm whale stomachs, along with the occasional entanglements of sperm whales in submarine cables, led Heezen (1957) to speculate that the lower jaw plows the bottom sediment for food as the whale swims. This has not, of course, been confirmed. They undoubtedly feed in the water column as well.

There appears to be a shift in frequency of prey taken by sperm whales from squid in the northwestern Pacific to fish in the northeastern Pacific. The only pelagic sampling of sperm whale stomachs in the Gulf of Alaska (Okutani and Nemoto 1964) revealed that fish are indeed the predominant food. Okutani and Nemoto (1964) only reported on the squid found in these stomachs. The identity of the fish species taken by sperm whales is extrapolated from whales taken in the Bering Sea, after Berzin (1959). Most frequent in the stomach samples was the smooth lumpsucker *Aptocyclus ventricosus*, with ocean perch (*Sebastodes* sp.) the second most frequent species. In all, eight families of fishes were found in sperm whale stomachs: Agonidae, Scorpaenidae, Plagyodontidae, Rajidae, Petromyzonidae, Cottidae, Cyclopteridae, and Macruridae. Important squid species found in harvested whales from the Gulf of Alaska and west coast of the United States were *Moroteuthis robustus*, *Gonatopsis borealis*, and *Gonatus magister* (Rice 1963; Okutani and Nemoto 1964).

Migration

The complex social structure of sperm whales plays an important role in migration. Maternal family groups (after Ohsumi 1971), also known as harems, or maternity or mixed schools, are composed of adult females, immature females and males, and adult breeding males (schoolmasters). As the immature males approach sexual activity, they form bachelor schools separate from the family group. Adult males not participating in mating join the bachelor schools or become loners during the breeding season. These animals move farther north in spring and summer to productive feeding grounds in Alaska, whereas most females with young remain farther south, out of the study area.

FACTORS INFLUENCING POPULATION GROWTH

Reproduction

Both sexes reach sexual maturity at approximately 10 years, but males between 10 and 25 years of age probably do not mate (Ohsumi 1966). One or more older, breeding bulls may mate with the mature females in maternal family groups. Mating occurs from April to August in the temperate waters of the eastern North Pacific (extrapolated from California, after Rice 1968). Gestation and nursing last approximately 15 months and 24 months, respectively (Ohsumi 1966; Best 1968). Sperm whales may live up to 70 years (Ohsumi 1966).

Mortality

Predation.–Due to the sperm whale's deep diving capability and aggressive behavior when attacked, predation by killer whales is probably not a significant mortality factor. One would expect that some form of social control plays a part in stabilizing sperm whale populations, as well as in defense.

Other causes.–Sperm whales are known to strand in large groups outside of the study area. A recent mass stranding in the eastern North Pacific occurred at Florence, Oregon in June 1979. Forty-one sperm whales, nearly all mature, died. The cause of death of these animals is unknown.

Exploitation and Development

Harvesting sperm whales in the North Pacific has been continuous for more than three centuries (Berzin 1970). Post-World War II harvesting increased from less than 500 to 16,357 sperm whales by 1968 (Tillman 1976). The ratios of 1978/1947 males and females (see Population Status) indicates less intense harvesting of the eastern stock. Since 1966, all whaling for the North Pacific sperm whale has been reduced, averaging about 7,000 animals in the late 1970s (Rice 1978*c*). The 1980/81 catch limit imposed by the International Whaling Commission was 890 males, all to be taken in the western division (IWC 1980).

Right Whale (*Balaena glacialis*)

The right whale belongs to the family Balaenidae, and is one of two species in that group. The second species is the bowhead or Greenland right whale, *Balaena mysticetus*. Subspecies are recognized for the Northern Hemisphere (*Balaena glacialis glacialis*) and the Southern Hemisphere (*B. g. australis*). Other common names are the black right whale and Pacific right whale.

ABUNDANCE

The North Pacific right whale, though protected by international agreement since 1937 and protected under U.S. law by the Marine Mammal Protection Act of 1972 and Endangered Species Act of 1973, hovers on the brink of extinction. Recent estimates indicate that less than 200 animals compose the entire North Pacific population (Wada 1973, 1975). *Balaena glacialis* is the most depleted of all cetaceans in the North Pacific Ocean (Table 4).

DISTRIBUTION

During the nineteenth century, the "Kodiak Ground," which encompassed the entire waters of the Gulf of Alaska from Vancouver Island to the eastern Aleutian Islands, was renowned as one of the best summer areas for hunting right whales (Scammon 1874). This species also occurred in the southern Bering Sea and all across the North Pacific Rim at about 50°N latitude during the summer.

Whaling records indicate that within the study area this species was taken mostly in the shelf waters to the east and south of Kodiak Island, presumably because of higher densities in this area.

Omura *et al.* (1969) and Klumov (1962) reported seeing this species in the southern Bering Sea, Aleutian Islands, and the western Gulf of Alaska from May to August. They noticed an increase in the number of sightings in June and July in the coastal waters of Alaska and near land masses. Pike and MacAskie (1969) noted only three offshore sightings, each of single individuals seen in July or August from 1958 to 1969. Two were from 50°N, 145°W; one from 54°N, 155°W. Thirty-one sightings of right whales were reported by Rice and Fiscus (1968) and Gilmore (1956) off California and Mexico during 1955-67. A 1980 summer survey of the Gulf of Alaska found no right whales (Rice and Wolman 1982).

The POP data base contains only four sightings, all tentative, of right whales in the Gulf of Alaska, totaling seven animals: (1) one individual in July 1977 at 56°27.5'N, 135°38.4'W, off Cape Ommaney; (2) four individuals on 27 March 1979 at 59°35.8'N,

Table 4.—Rank order status of endangered whales in the North Pacific Ocean based on available information on indices of abundance, recovery from commercial exploitation, and apparent likelihood of recovery.

Species	Relative status[a]	Population size estimates		Present range	Annual harvest	Domain	Data source
		Present	Pre-exploitation				
N.E. Pacific right whale	nearing extinction?	Tens–150	unk.	North Pacific	None	contin. shelf	Wada (1973, 1975)
Humpback whale	very rare	1,200	15,000	Bering Sea, Chukchi Sea, GOA, Hawaii, Mexico, N. Japan	None	coastal	Rice (1978a)
Bowhead whale	very rare	>2,200[b]	20,000± >10,000	Bering, Chukchi, Beaufort, and Ohkotsk seas	17[c]	contin. shelf	Braham *et al.* (1979); Bockstoce and Botkin (1980);[d] Eberhardt and Breiwick (1980)
Blue whale	very rare	1,600	4,900–6,000	N.E. Pacific south	None	pelagic	Wada (1975, 1977)
Sei whale	uncommon	8,600	40,000–42,000	N. Pacific south	None	pelagic	Ohsumi *et al.* (1971); Tillman (1976)
Fin whale	locally common	14,000–19,000	44,000	N. Pacific, Bering and Chukchi seas	None	contin. shelf	Ohsumi and Wada (1974)
Gray whale	common	15,000–17,000	15,000–24,000	N.E. Pacific, N.W. Pacific, Bering Sea, and Arctic Ocean	180	coastal	Henderson (1972); Rugh and Braham (1979); Reilly *et al.* (1980)
Sperm whale	common	740,000	516,000[e]	N. Pacific Rim south	1,890[f]	pelagic	IWC (1980); Rice (1978c)

[a] Relative to their former, pre-commercial population level.

[b] Bering Sea-Arctic Ocean estimate only; Ohkotsk Sea estimate unknown, but probably is several hundred.

[c] 1981 IWC quota for landed animals; strike quota is approximately 32 anually for quota period 1981–83.

[d] Bockstoce and Botkin (1980).

[e] Exploitable component only.

[f] 1980/81 IWC catch limit, western stock only.

139°55.8'W, in Yakutat Bay; (3) one individual on 20 August 1979 at 58°52'N, 141°03'W, off Fairweather Ground; and (4) one individual on 16 October 1980 at 58°48.1'N, 145°00.3'W, approximately 56 km south southwest of Cape St. Elias.

FACTORS INFLUENCING DISTRIBUTION

Feeding and Food Resources

The little available data indicate that Pacific right whales primarily feed on at least three species of copepods (*Calanus plumchrus, C. finmarchicus,* and *C. cristatus*) and on a small quantity of euphausiids (*Euphausia pacifica*) (Klumov 1962; Omura *et al.* 1969).

Right whales are surface feeders and usually do not descend to depths greater than 15-20 m (Klumov 1962). The copepod *C. finmarchicus* occupies the 0- to 25-m surface zone, and does not move vertically during the 24-hour cycle.

Interspecific competition with copepod-eating sei whales has been mentioned as a possibly significant limiting factor in the recovery of right whales in the North Pacific (Mitchell 1974). Given the available abundance of food and the present low number of both right and sei whales, this seems highly unlikely.

Migration

Very little is known about seasonal movements of right whales in the Gulf of Alaska. Extrapolating from movements of other large whales and from sparse sighting data, it may be assumed that right whales breed in subtropical and temperate waters during the winter and spring and migrate to the temperate northern waters in spring, staying over the shelf. Gilmore (1956) believes that waters off British Columbia, Washington, Oregon, and California were former wintering grounds of North Pacific right whales.

FACTORS INFLUENCING POPULATION GROWTH

Reproduction

Right whales mate and calve in winter months in lower latitudes. Sexual maturity of females has been given at a length 15.5 m and for males at 15 m (Omura *et al.* 1969). Gestation is estimated at 1 year and calves are thought to be weaned by the age of 6-7 months. A newborn calf measured 5-6 m in length. Recent work by R. Payne (N.Y. Zoological Society, pers. commun.) indicates that female southern right whales off the coast of Argentina breed once every three years, and have a gross annual recruitment rate (total calves per total population sampled) of approximately 6-7%.

Mortality

Killer whales are probably the only predators of right whales. Given a very small population size such as exists in the North Pacific and the presumed susceptibility to attack by killer whales (right whales are slow swimmers), any predation-related mortality will have a significant effect on the recovery of this population.

Exploitation and Development

Whaling records (Townsend 1935) indicate that approximately 40% of 2,118 right whales harvested in the North Pacific were taken in the Gulf of Alaska. Whaling was so intense in the late 1800s and early 1900s that the right whale population rapidly declined to a level of commercial extinction. One of the reasons the right whale was such an attractive target for whalers is that it was a very slow swimmer, and was prized for its large amount of oil and baleen.

During the 1934-35 whaling season only two right whales were taken off Alaska (Norman and Fraser 1949) The most recent catches included one right whale taken accidentally by Canadian shore whalers near Vancouver Island in 1951 (Pike 1962), and three whales taken by Japan on Albatross Bank near Kodiak Island in 1961 for research under permit by the International Whaling Commission.

A recent case of a right whale washing ashore on Long Island, New York, with deep slashes on the carcass (presumably from the propeller of a large vessel) illustrates that this species may be more vulnerable than some other endangered whales, because of its low population size.

SMALL CETACEANS

Minke Whale (*Balaenoptera acutorostrata*)

The minke whale is the smallest of the rorquals (family Balaenopteridae). Three subspecies are recognized worldwide: *Balaenoptera acutorostrata davidsoni* (Scammon, 1872) in the North Pacific, *B. a. acutorostrata* in the North Atlantic, and *B. a. bonaerensis* in the Southern Hemisphere. Other common names associated with the minke whale include little piked whale, sharp-headed finner whale, lesser rorqual, pike whale, and Davidson's whale.

ABUNDANCE

Minke whales are currently designated as a Sustained Management Stock by the IWC. No North Pacific population estimates are available, though the species may be regarded generally as abundant in the North Pacific and the study area.

DISTRIBUTION

Winter (January-March)

During winter, Rice (1974) reported minke whales from coastal California south to the Islas Revillagigedos, Mexico. Our POP data show only five sightings (all of single animals) during winter: two about 10-20 nmi south of Icy Bay about 10-20 nmi and three near Sitka, in southeast Alaska (Figure 15). A 1979-80 winter bird survey of nearshore waters around Kodiak Island yielded no minke whale sightings (Forsell and Gould 1981).

Spring (April-June) and Summer (July-September)

Beginning in spring, minke whales commonly occur over the continental shelf to inland waters of the Gulf of Alaska. Well over 95% of all minke whales sighted were within the 183-m (100-fathom) contour; most were in shallow coastal waters (Figures 16 and 17). Their appearance in the Gulf is more ubiquitous than the other rorquals, owing in part to their presumed greater abundance than other species. They remain, however, a coastal species in the Gulf seemingly more dispersed in spring than in summer (Figures 16 and 17), where they seem to be concentrated near Kodiak Island, Prince William Sound, and in the northeast Gulf.

According to Rice (1974), minke whales are distributed from Baja California north to the Chukchi Sea, and are most abundant in Alaskan waters in summer. Scattergood (1949) noted that whalers found minke whales abundant at Port Hobron and Akutan Island (eastern Aleutian Islands), but not very common in British Columbia or southeastern Alaskan waters. A 1980 summer survey found minke whales scattered from southeast Alaska to Kodiak Island, mostly near shore (Rice and Wolman 1982). Only 3 sightings out of 33 occurred in the deep waters of the Gulf of Alaska. The master of a U.S. Fish and Wildlife Service vessel has observed minke whales in Viekoda, Uganik, and Uyak bays (Kodiak Island) during the summer months over the past dozen or so years (T. Emerson, pers. commun.). Personnel onboard a NOAA research vessel conducting hydrographic studies in Yakutat Bay observed at least one minke whale continuously over a 1-month period. Movements in summer may be limited; movements into (spring) and out (autumn) of the Gulf appear to be represented in our data plots, from scattered sightings (Figures 16-18). However, movements of individual animals cannot be confirmed.

Autumn (October-December)

Minke whales are virtually absent from many parts of the coastal waters of the Gulf during autumn but, again, we have little sighting effort in these areas (Appendix II). We have records of only three sightings since 1958 (Figure 18). In general, minke whales may leave the Gulf by October.

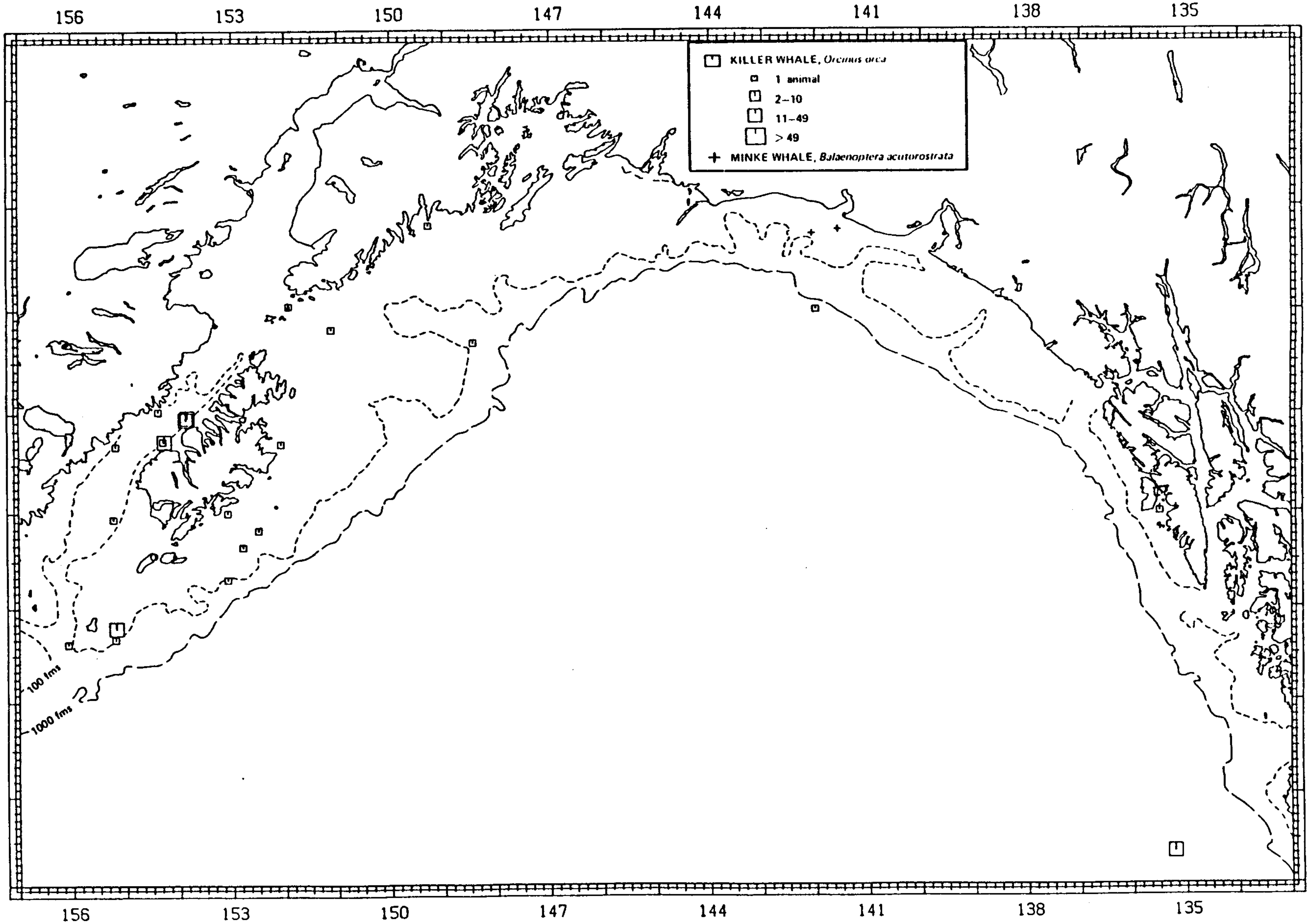

Figure 15.–Minke and killer whale sightings, winter (January-March) 1958-80.

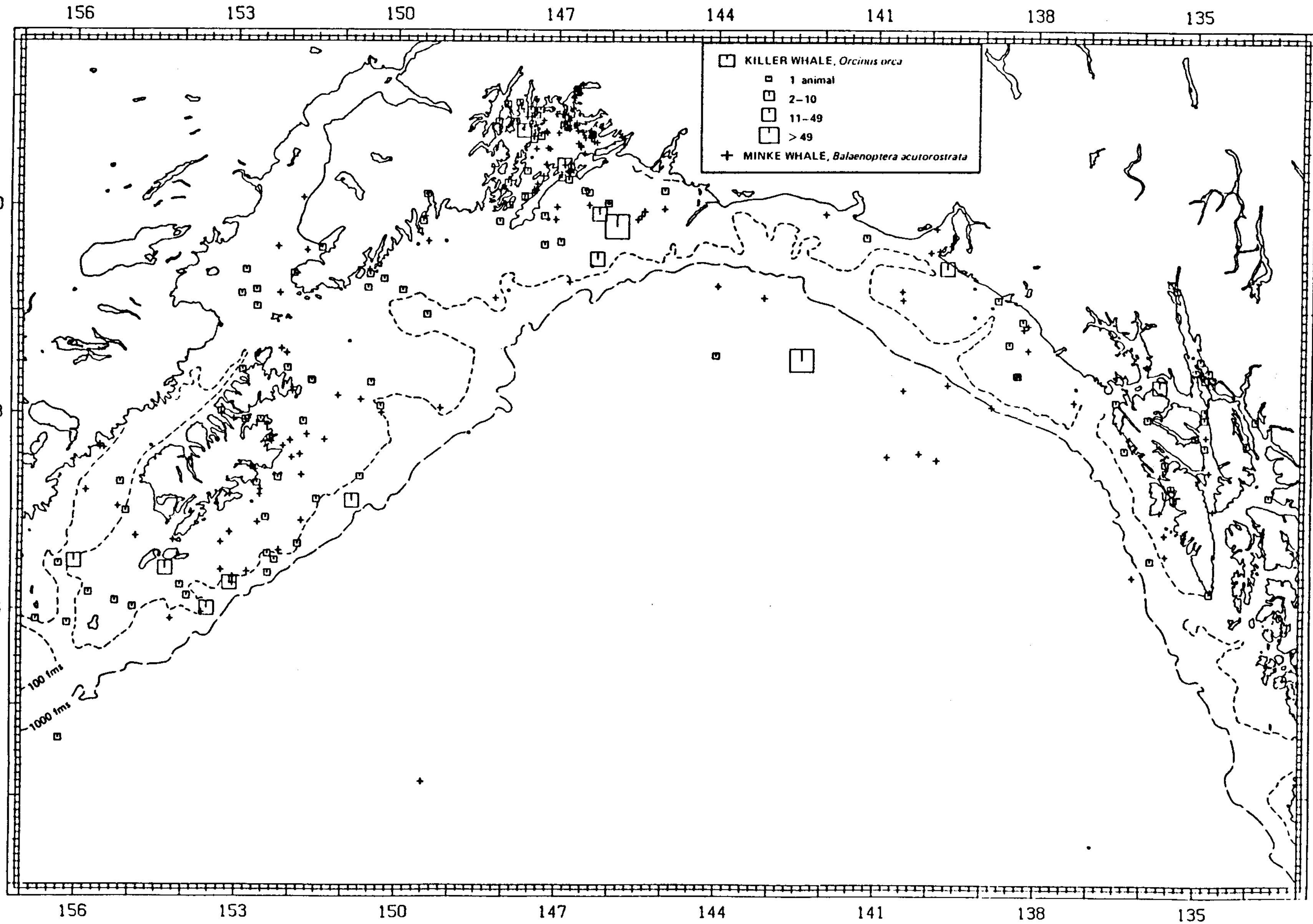

Figure 16.–Minke and killer whale sightings, spring (April-June) 1958-80.

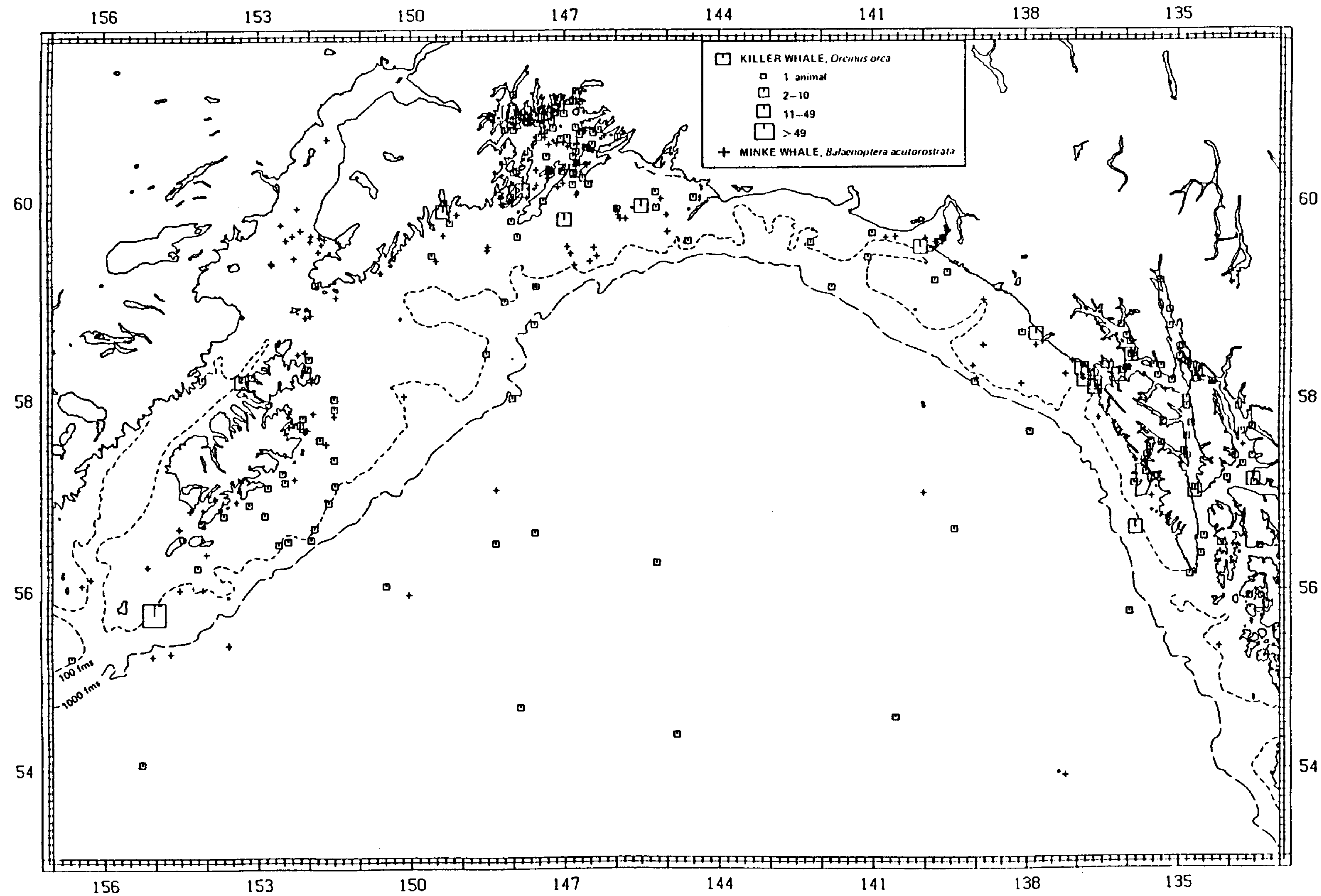

Figure 17.-Minke and killer whale sightings, summer (July-September) 1958-80.

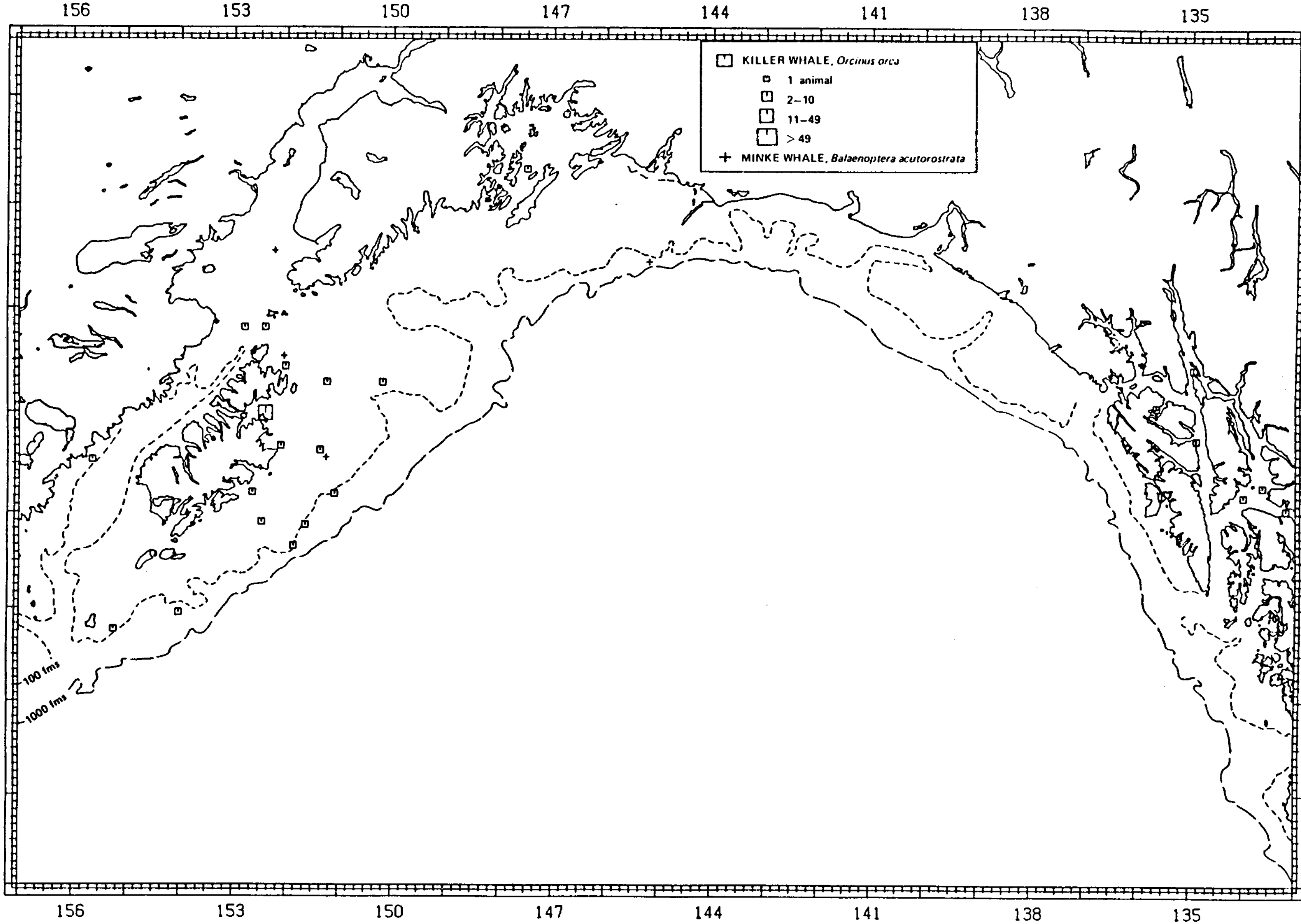

Figure 18.–Minke and killer whale sightings, autumn (October-December) 1958-80.

FACTORS INFLUENCING DISTRIBUTION

Feeding and Food Resources

Minke whales are polyphagous feeders, capitalizing on locally abundant fishes and euphausiids. They utilize the swallowing mode of feeding, as described by Nemoto (1959).

Euphausiids are the preferred prey of minke whales in the North Pacific, followed by swarming fish and copepods (Nemoto 1959). Nemoto further found that minke whales in the coastal waters of the Okhotsk Sea fed mainly on *Euphausia pacifica*, but also sand lance (*Ammodytes personatus*) and Alaska pollock (*Theragra chalcogramma*). In addition, Omura and Sakiura (1956) found cod (*Gadus macrocephalus*), herring (*Clupea harengus*), hake (*Laemonema morsam*), anchovy (*Engraulis japonica*), saury (*Cololabis saira*), and squid in the stomachs of minke whales taken off coastal Japan.

In the western North Atlantic, Sergeant (1963) found capelin (*Mallotus villosus*) to be the dominant food organism; cod, herring, salmon, squid, and shrimp were also eaten.

Migration

Omura and Sakiura (1956) suggested that minke whales migrate northward along the coast of Japan early in the spring, and southward in the autumn. They reported that sexual segregation occurs during migration, with mature animals and a portion of the adolescent population migrating to the northernmost feeding grounds; immature whales, especially males, remain in southern waters. They also stated that minke whales in Japanese waters were never taken in offshore waters beyond 185 km. Our understanding of minke whale migration in the northeast Pacific is very poor.

Dorsey (1982) recognized individual minke whales in Puget Sound, Washington over a 3-year period, tentatively identifying nonoverlapping home ranges, suggesting a seasonal population.

FACTORS INFLUENCING POPULATION GROWTH

Reproduction

Masaki (1979) calculated that the mean age at sexual maturity among antarctic minke whales dropped from 14 years prior to 1944 to about 6 years presently, and suspected that this change was associated with the overall decline in baleen whale numbers. The implication is that minke whales are reproducing at a younger age and capitalizing on abundant food sources now available because of reduced competition with blue, fin, and sei whales, which are severely reduced in numbers. This same phenomenon, if real, may have occurred in the study area, though it is impossible to document because minke whales have never been harvested (ergo, not sampled) intensively in the eastern North Pacific. Masaki (1979) estimated the mean age of recruitment as 6 years for males and 7 years for antarctic females. The minimum calving interval for antarctic females is 14 months, the gestation period about 10 months, and the physiological maximum pregnancy rate, 0.86 (IWC 1979; 1981). Reproductive parameter estimates are not available for the North Pacific.

Mortality

One documented case of a minke whale being pursued and eaten by killer whales in the Gulf of Alaska occurred on 29 April 1976 at 58°22'N, 138°21'W (M. Caunt, pers. commun.). It is not known to what degree minke whale populations are affected by killer whale predation or disease.

Exploitation and Development

Historically, the minke whale has never been harvested intensively in the eastern North Pacific. This fact led Rice (1971) to state that the population was probably at carrying capacity.

Killer Whale (*Orcinus orca*)

The killer whale belongs to the family Delphinidae and is the only the only member of the genus *Orcinus*. Other common names include orca, blackfish (correctly applied to pilot whales), and grampus (correctly applied to Risso's dolphin).

ABUNDANCE

No world or North Pacific population estimates are available. Ford and Ford (1981) reported that 26 pods, comprising 250-300 killer whales, inhabit British Columbia waters. Based on our sighting data, killer whales may be categorized as ubiquitous and perhaps abundant in the Gulf of Alaska.

DISTRIBUTION

Killer whales have been observed in all the major oceans and seas of the world (Leatherwood and Dahlheim 1978), and appear to increase in abundance as one moves shoreward and toward the pole in the colder waters of both hemispheres (Mitchell 1975). In the Pacific Ocean they are more likely associated with subarctic waters than polar or tropical. Killer whales are reported to be seasonal residents from the high Arctic and northwestern Alaska (Bailey and Hendee 1926; Cook 1926; Bee and Hall 1956; C. Fiscus observation 92 km north of Point Barrow); the western Chukchi Sea (Sleptsov 1961*a*) and Bering Strait (Nikulin 1946); the eastern Aleutian Islands, especially near Unalaska Island (Murie 1959; Kawamura 1975; Braham *et al.* 1977); the North Pacific Ocean (Scammon 1874; Ohsumi *et al.* 1976); and near Kodiak Island and in Prince William Sound (Pitcher 1975; Fiscus *et al.* 1976; Hall and Tillman 1977). Braham and Dahlheim (1982) reported that some killer whales are probably year-round residents, frequenting nearshore waters in the study area more than elsewhere in Alaska.

Autumn (October-December) and Winter (January-March)

Killer whales were numerous around Kodiak Island and adjacent shelf waters in autumn and winter, but not elsewhere in the Gulf of Alaska (Figures 15 and 18). Waters near Kodiak Island appear to contain habitat suitable for killer whales at virtually any time of the year. Forsell and Gould (1981) reported three sightings (10, 10, and 20 animals) from nearshore Kodiak waters in February 1980.

Spring (April-June) and Summer (July-September)

In spring, killer whales are distributed throughout the Gulf, but essentially only over the continental shelf in water less than 183 m (100 fathoms) deep (Figure 16). In summer, they seem to concentrate south and east of Kodiak, over Portlock Bank, in Prince William Sound, in inland waters of southeast Alaska, and to a lesser degree are seen in waters more than 100 nmi offshore (Figure 17). This latter occurrence is perhaps a reflection of some animals on migration south. Group size is larger in summer and spring (20% single animals) than in fall or winter (35% single animals), with group size varying from 1 to 100 except for one group estimated to be of 500 killer whales observed off Middleton Island (59°48'N, 145°53'W) on 29 April 1972 (Jim Branson, pers. commun.). This "group" actually occurred over several square miles.

FACTORS INFLUENCING DISTRIBUTION

Feeding and Food Resources

The distribution and movements of killer whales are in part related to availability of prey (Mitchell 1975; Dahlheim 1981). Inshore migration of finfish, such as salmon (*Oncorhynchus spp.*) and other shoaling fishes, are common killer whale prey in southeast Alaska, Prince William Sound, and along the north side of the eastern Aleutian Islands and Alaska Peninsula (Sleptsov 1961*b*; Rice 1968; Hall 1981).

The relative occurrence and density of other marine mammals that are potential prey for killer whales change from southeastern Alaska to northern Alaska. Predation on gray whales and walruses (*Odobenus rosmarus*) (Nikulin 1941; Fay *et al.* 1979) may be common in the Bering, Chukchi, and Beaufort seas. White whales (*Delphinapterus leucas*) and bowhead whales (Scammon 1872; Cook 1926; C. Oozeva, pers. commun.) may occasionally be taken by killer whales; however, the level of predation on these two species is unknown.

Northern and California sea lions (*Eumetopias jubatus* and *Zalophus californianus*), elephant seals (*Mirounga angustirostris*), minke whales, Dall porpoises (*Phocoenoides dalli*), and harbor porpoises (*Phocoena phocoena*) are commonly taken by killer whales near the Aleutian Islands, in the Gulf of Alaska, and generally in the eastern North Pacific (Nishiwaki and Handa 1958; Rice 1968; Barr and Barr 1972). Sleptsov (1961*c*) stated that killer whales in the western North Pacific switch to marine mammal prey species in summer when fish are less abundant or not available, and in winter months when fish descend to deep water. Hall

(1981) observed similar prey selection by killer whales in Prince William Sound. Sleptsov (1961*c*) and Hall (1981) also reported that when fish are abundant, killer whales appear to exclude marine mammals from their diet. Dall porpoises and northern sea lions frequently have been seen near and on occasion directly interacting with killer whales without direct aggression by the killer whales (pers. obs.). Over several years of observation in Puget Sound, Balcomb *et al.* (1980) observed only one incident of killer whale predation on other marine mammals, this on a harbor porpoise. Killer whales exhibit a high degree of group hunting, particularly when feeding on marine mammals.

Movements of killer whales in the North Atlantic are reported to be related to the migrations of rorquals, seals, and herring (*Clupea* spp.) (Sergeant and Fisher 1957; Jonsgård and Lyshoel 1970). In inland waters of the northeast Pacific their movements are reported to be related to the movements of fishes, such as salmon (Balcomb *et al.* 1980), particularly in summer and autumn.

FACTORS INFLUENCING POPULATION GROWTH

Reproduction

Nishiwaki and Handa (1958) believed that in the western North Pacific the peak of breeding for killer whales is between May and July, with a gestation period is 12-16 months. In Puget Sound, Balcomb *et al.* (1980) reported that newborns are seen during spring, summer, and autumn, and that a definite calving period had not yet been determined. Body lengths of 4.9 m for females and 6.7 m for males are given as measurements at sexual maturity (Jonsgård and Lyshoel 1970). The calving interval and age at sexual maturity remain uncertain, although Balcomb *et al.* (1980) reported that in Puget Sound the calving interval for adult females was 3-4 years, and the overall birth rate, 0.125. A differential fecundity rate was noted by Balcomb *et al.* (1980), with two females in a Puget Sound pod producing most of the calves over several years.

Mortality

The killer whale is not known to have any natural enemies, and mortality related to parasites or intraspecific aggression is undocumented. Strandings of this species are infrequent.

Exploitation and Development

Other than occasional catches by Japanese coastal whalers and infrequent live-catches for aquaria (now banned by law), there is no documented human-related mortality in the North Pacific. Killer whales have been taken on a sustained basis, with little or no data to show the effect of the harvest, by a directed Norwegian take off the coast of Norway. Soviet whalers took 906 killer whales in Antarctic waters in 1979-80. There is now an IWC moratorium on the taking of *Orcinus* in Antarctica.

Dall Porpoise (*Phocoenoides dalli*)

The Dall porpoise belongs to the family Delphinidae. It is one of the true porpoises and the only member of its genus. Other common names include Dall's porpoise and True's porpoise. True's may, however, be a separate subspecies, *Phocoenoides dalli truei.*

ABUNDANCE

Dall porpoises are protected under U.S. law by the Marine Mammal Protection Act of 1972. Bouchet (1981), using sighting data, estimated a North Pacific population (not including California, Oregon, and Washington coastal waters) of 837,460 to 1,342,518 animals and the Gulf of Alaska population at 136,671 to 253,865. His density estimates in the Gulf of Alaska range from 0.277 to 0.514 animals/nmi^2.

DISTRIBUTION

Dall porpoises are distributed from Baja California along the west coast of North America, across the North Pacific Ocean to the coastal waters of Japan. The northern limit of the species reported by Nishiwaki (1967) is Cape Navarin (62°N) in the Bering Sea. More recently, Dall porpoises were observed by U.S. observers as far north as 66°N (NMML unpubl. data), though few sightings occur north of 61°N.

Alaska is a region in which Dall porpoises have been reported to be abundant. Pike and MacAskie (1969) stated that the largest number of Dall porpoises occurs in regions over the continental shelf in the northern Gulf of Alaska between Kodiak Island and Icy Strait.

Autumn (October-December) and Winter (January-March)

Dall porpoises are present throughout the Gulf of Alaska during these periods (Figures 19 and 22). Their habit of approaching vessels and their conspicuous "roostertail" (spray thrown as a result of vigorous swimming activity) make these small cetaceans highly visible, even during poor observing conditions. The distribution of Dall porpoises does not appear to be correlated with the bathymetry of the Gulf during these periods. Most sightings during autumn and winter were of groups of 2-20 animals.

Spring (April-June) and Summer (July-September)

As during autumn and winter, Dall porpoises are ubiquitous in the Gulf of Alaska during the spring and summer (Figures 20 and 21). There are very few sightings of single animals; most are of groups of 2-20 animals. Sightings of larger (>20 animals) groups during this period occurred almost exclusively over the shelf and slope throughout the Gulf.

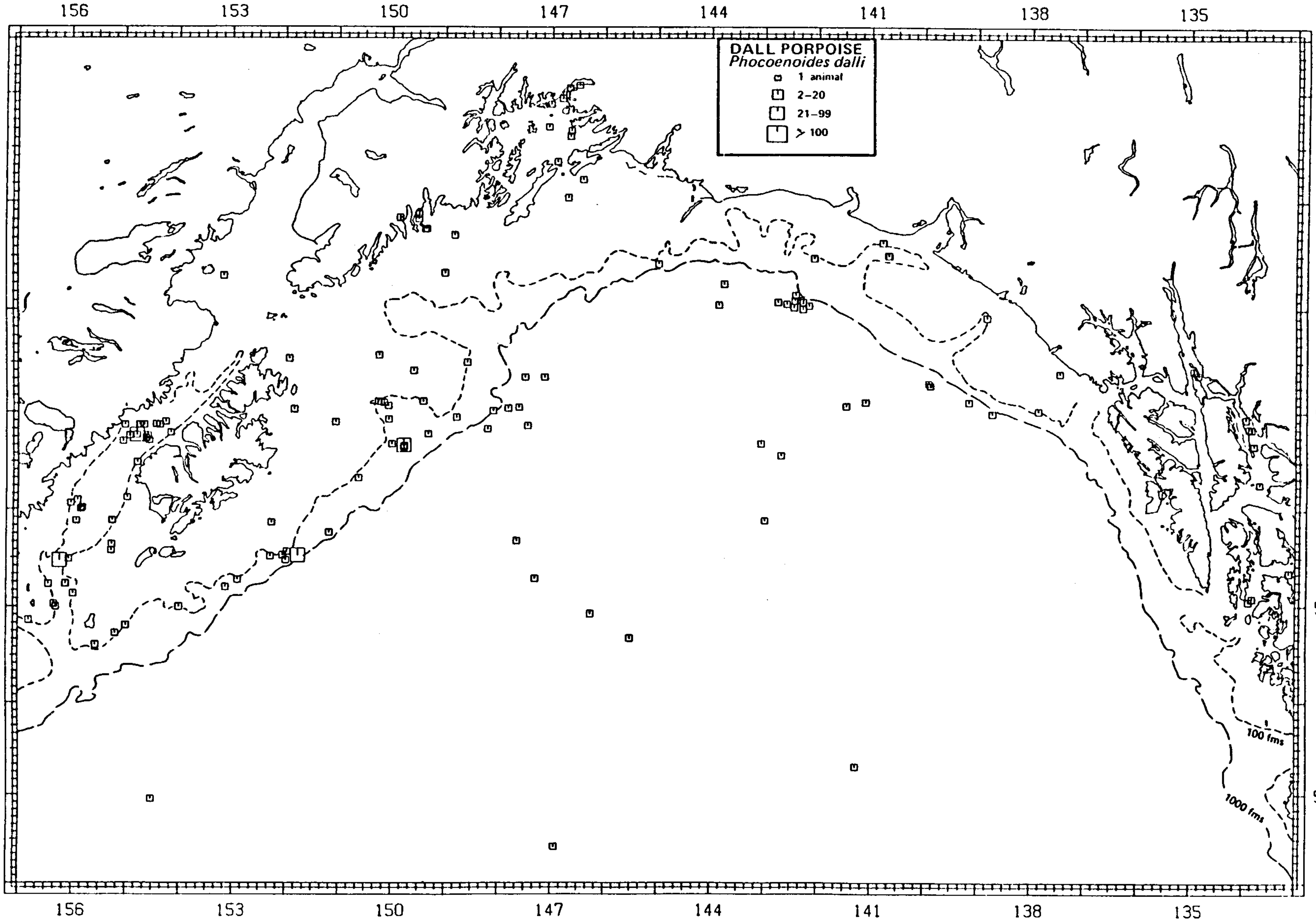

Figure 19.-Dall porpoise sightings, winter (January-March) 1958-80.

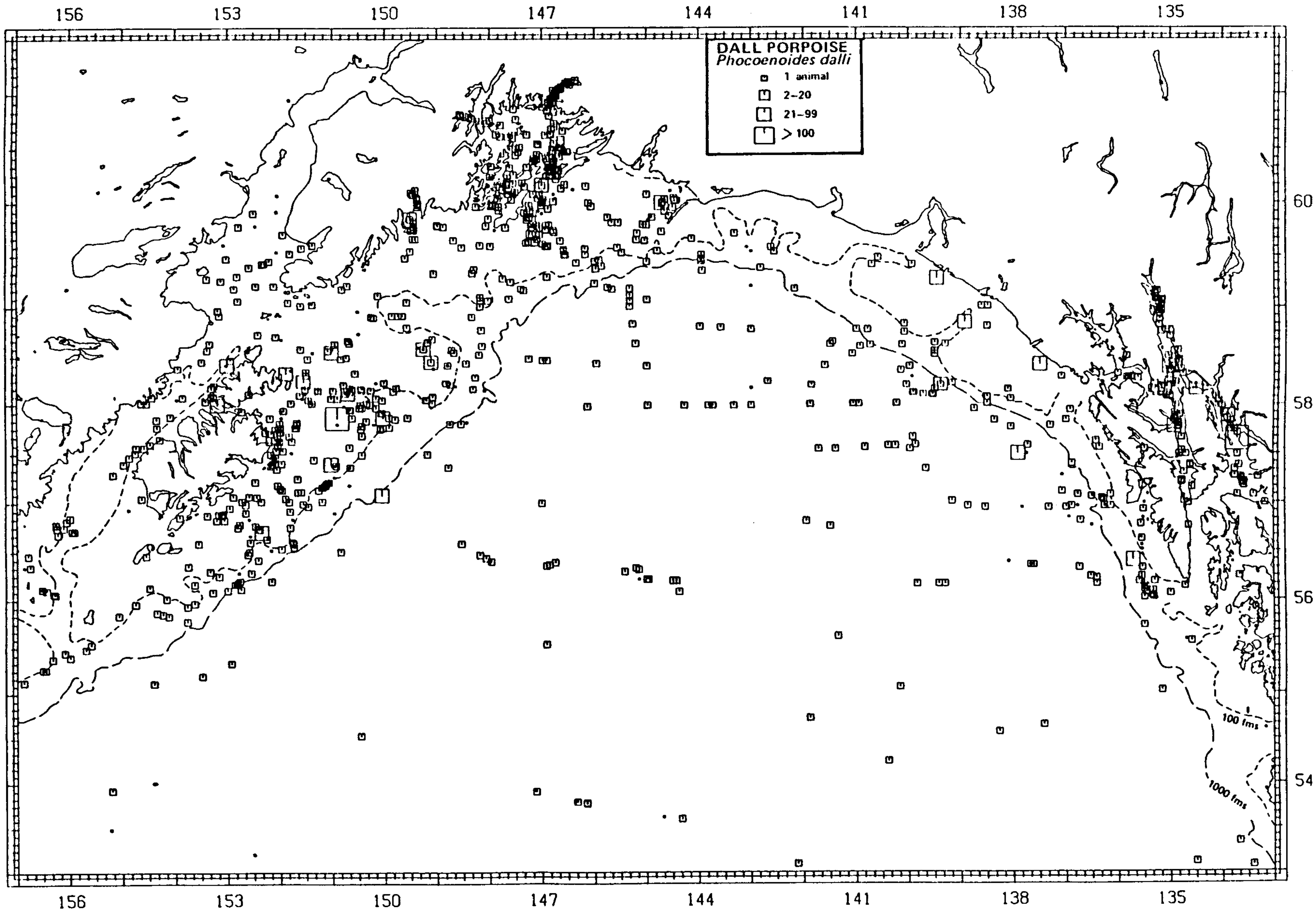

Figure 20.–Dall porpoise sightings, spring (April-June) 1958-80.

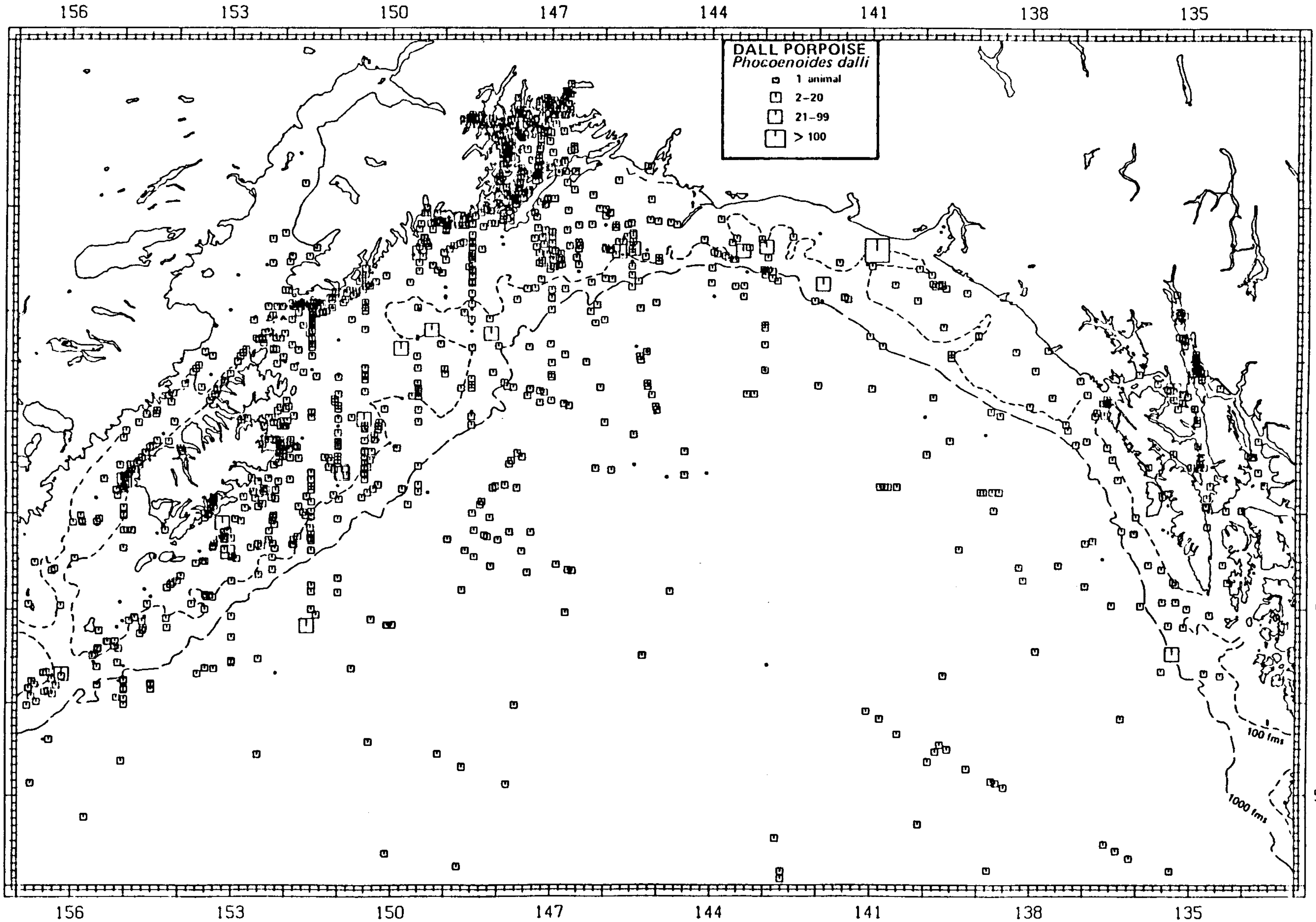

Figure 21.–Dall porpoise sightings, summer (July-September) 1958-80.

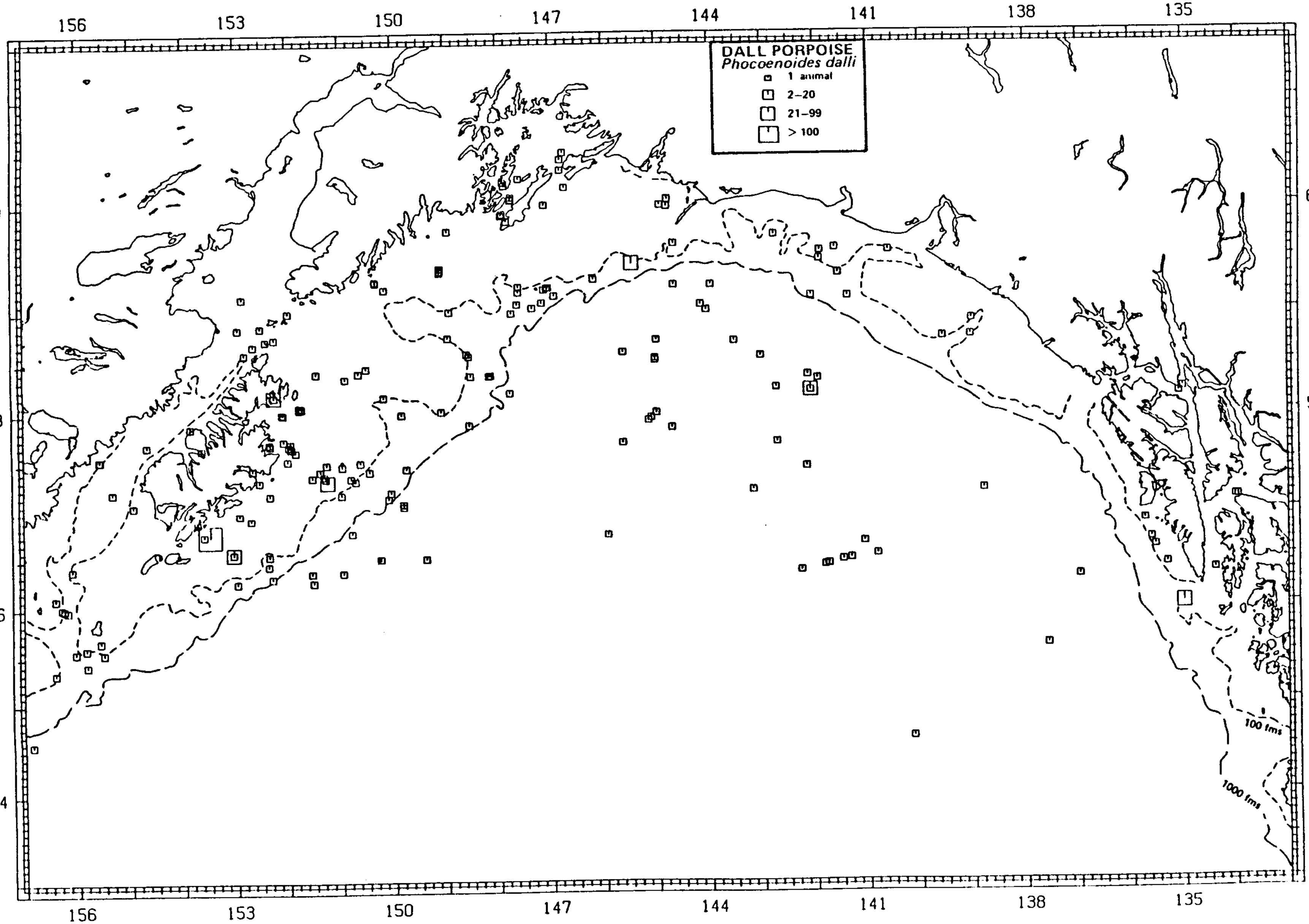

Figure 22.–Dall porpoise sightings, autumn (October-December) 1958-80.

FACTORS INFLUENCING DISTRIBUTION

Oceanographic

Scheffer (1949), from 72 observations totaling 350 individuals, reported that Dall porpoises tend to occur in wide straits and in areas where ocean currents merge. Cowan (1944) noted that the species tends to occur in channels between islands in Alaska. Hall (1979), working in Prince William Sound, observed that Dall porpoises were only rarely seen in water less than 10 fathoms deep. Our data (Figures 19-22) show that Dall porpoise are abundant throughout the Gulf of Alaska, over the continental shelf as well as offshore. The exceptions are shallow turbid areas such as upper Cook Inlet and Icy Bay.

Feeding and Food Resources

Data on the feeding habits of Dall porpoises in the study area are sparse. Scheffer (1949) found only capelin (*Mallotus villosus*) in the stomachs of two females taken during the summer in the Gulf of Alaska. He also reported hake (*Merluccius productus*), squid (*Loligo opalescens*), and a single horse mackerel (*Trachurus symmetricus*) from the stomachs of Dall porpoises taken off Oregon and northern California. Fiscus and Niggol (1965) found only squid (no species given) remains in stomachs from animals taken off California. In analyzing the stomach contents of 25 animals taken in Monterey Bay, California, Loeb (1972) found that hake and squid (*L. opalescens*) were the most frequent food items taken year-round, with herring (*Clupea harengus*), juvenile rockfish (*Sebastes* sp.), anchovy (*Engraulis mordax*), and squid (*Gonatus* sp.) also being preferred prey species. In the coastal waters of Japan, Wilke *et al.* (1953) found two species of squid (*Ommastrephes sloani pacificus* and *Watasenia scintillans*), lantern fish (myctophids), and a deep water gadid, *Laemonema morosum*, in Dall porpoises. Extensive sampling of stomachs from Dall porpoises taken incidentally in the Japanese high seas salmon gillnet fishery (50°N, 170°E) indicates that myctophids (primarily *Protomyctophum thompsoni*) were the most abundant food species for this area, with squid (*Gonatus* sp.) also being taken (Crawford 1981).

Migration

Kasuya (1976) found evidence that Dall porpoises may migrate northward in summer and southward in winter along the coast of Japan. On the other side of the Pacific, Leatherwood and Fielding (1974) describe seasonal onshore-offshore movements of Dall porpoises off southern California. Farther north, in Monterey Bay, Loeb (1972) found Dall porpoises present every month of the year. Fiscus and Niggol (1965) reported sighting Dall porpoises from the California, Oregon, and Washington coasts, between the 100-fathom contour and 75 miles seaward during winter months. Pike and MacAskie (1969) stated that Dall porpoises have been recorded from Ocean Station Vessel Papa (50°N, 145°W) for every season. Hall (1979) found that the Dall porpoise population in Prince William Sound declined from summer to fall and was "clearly lower" in spring and winter. Thus, the literature indicates that Dall porpoises are present year-round throughout the eastern North Pacific and that local migration may occur along the coast, and seasonal onshore-offshore movement occurs. There is no evidence of any long migration in the study area. As seen from our data, Dall porpoises are found during every season in the study area (Figures 19-22).

Dall porpoises usually travel in small schools of 2-10 animals. Modal group size is four. Larger groups of up to 226 Dall porpoises have been reliably recorded from the Gulf of Alaska, and in 1980 a group of approximately 3,000 animals was recorded in southeast Alaska, but such large groups are exceptional.

FACTORS INFLUENCING POPULATION GROWTH

Reproduction

A study of the literature as well as studies of fetuses, neonates, small juveniles, and adults indicated to Morejohn (1979) that Dall porpoises probably breed and calve year-round in northeastern Pacific waters from Alaska to southern California. In Prince William Sound, Hall (1979) reports sighting Dall porpoises with calves only during spring and late summer. In the western Pacific, Kasuya (1978) reported parturition from August to September. Examination of the reproductive status of Dall porpoises taken in the Japanese high seas salmon gillnet fishery indicates that breeding and parturition occur from June to August in this area (50°N, 170°E) (Newby 1982). Females breed annually in this area. Males are sexually mature at 5.7 years (183 cm), females at 3.3 years (171 cm). Neonates weigh about 16.5 kg and are 95 cm long. Weaning is thought to occur at 1 to 2 months. The birth ratio of males to females is 1:1, and there is no significant difference in length or age between males and females. Dall porpoises may live up to 24 years. However, current aging techniques (dentine or cementum of teeth) requires further study. As these figures are based on samples from a harvested population from the central North Pacific near the Aleutian Islands, some of the estimates (*i.e.* age at sexual maturity and calving interval) may not be representative for animals in the study area.

Mortality

Killer whales are natural predators of Dall porpoises (Barr and Barr 1972; Balcomb and Goebel 1976). Parasites were found in the livers (*Campula oblonga*, a fluke), lungs (*Halocercus dalli*, a nematode), and mammary glands (*Crassicauda* sp., a nematode) of Dall porpoises taken in the Japanese high seas salmon gillnet fishery in sufficient numbers as to possibly debilitate the porpoise and thereby reduce herd productivity and possibly predispose the affected animal(s) to other environmental trauma (Conlogue *et al.*, in press). Except for occasional entanglement in fishing gear (NMFS 1979), the Dall porpoise population in the Gulf of Alaska is apparently not affected directly by man, assuming Dall porpoises in the Gulf are not part of the population or stock taken incidentally by the Japanese high seas gillnet fishery. Information on incidental mortality from fishing operations in the study area is limited to Matkin and Fay's (1980) report of 41 Dall porpoises taken in a Prince William Sound gillnet fishery during the 1978 season. In the western North Pacific, the Japanese high seas and land-based salmon gillnet fishery entangled (and killed) an average estimate of 3,220 Dall porpoises annually from 1955 to 1975 (NMFS 1980). Given the abundance of this animal, it is unlikely that incidental take in the salmon gillnet fishery area significantly affects the Gulf of Alaska population, if a separate population. This requires further study.

Pacific White-Sided Dolphin (*Lagenorhynchus obliquidens*)

The Pacific white-sided dolphin belongs to the family Delphinidae and is one of six members of the genus *Lagenorhynchus*. Other common names include hookfin dolphin and, much less often, the Pacific striped dolphin or porpoise (more appropriately applied to *Stenella coeruleoalba*). It is nicknamed "lag."

ABUNDANCE

Nishiwaki (1972) reported a population of 30,000-50,000 animals near Japan alone. Fox (1977) estimated about 24,000 white-sided dolphins inhabit a 1,535,870 km^2 area off southern California and Baja California. No population estimates are available for the Gulf of Alaska, though the species may be regarded as seasonally abundant.

DISTRIBUTION

Pacific white-sided dolphins range from Baja California to the Aleutian Islands in the eastern North Pacific as well as off the coast of Japan in the western North Pacific (Nishiwaki 1972; Leatherwood and Reeves 1978). Recent sightings in the central North Pacific indicate that this species may occur at least seasonally across the entire North Pacific crescent (NMFS unpubl. data).

Scheffer (1950), in discussing the distribution of Pacific white-sided dolphins on the coast of North America, reported skeletal remains of single animals from Valdez, Montague Strait (Prince William Sound), and Sitka, but no sightings of live animals in Alaska waters. He concluded that the white-sided dolphin was uncommon in subarctic waters. Pike and MacAskie (1969) relate that research vessels operating in the northern Gulf of Alaska never reported observing white-sided dolphins, and reported only one sighting (50 animals) above latitude 52°N (June 15, 1961; at 55°00'N, 134°36'W). Our data indicate that this species occurs seasonally in the Gulf of Alaska.

Winter (January-March)

Our data base contains only six sightings during winter (Figure 23): east of Chirikof Island (55°45'N, 155°20'W) in the southwest portion of the study area, and over Fairweather Ground in the eastern Gulf. Two of the Chirikof Island groups were of approximately 100 and 800 animals. We were unable to find any previous published records of this species' occurrence in the Gulf of Alaska during winter. Our data indicate that Pacific white-sided dolphins are present during winter; however, the paucity of sightings suggests to us that they are rare during this time of year.

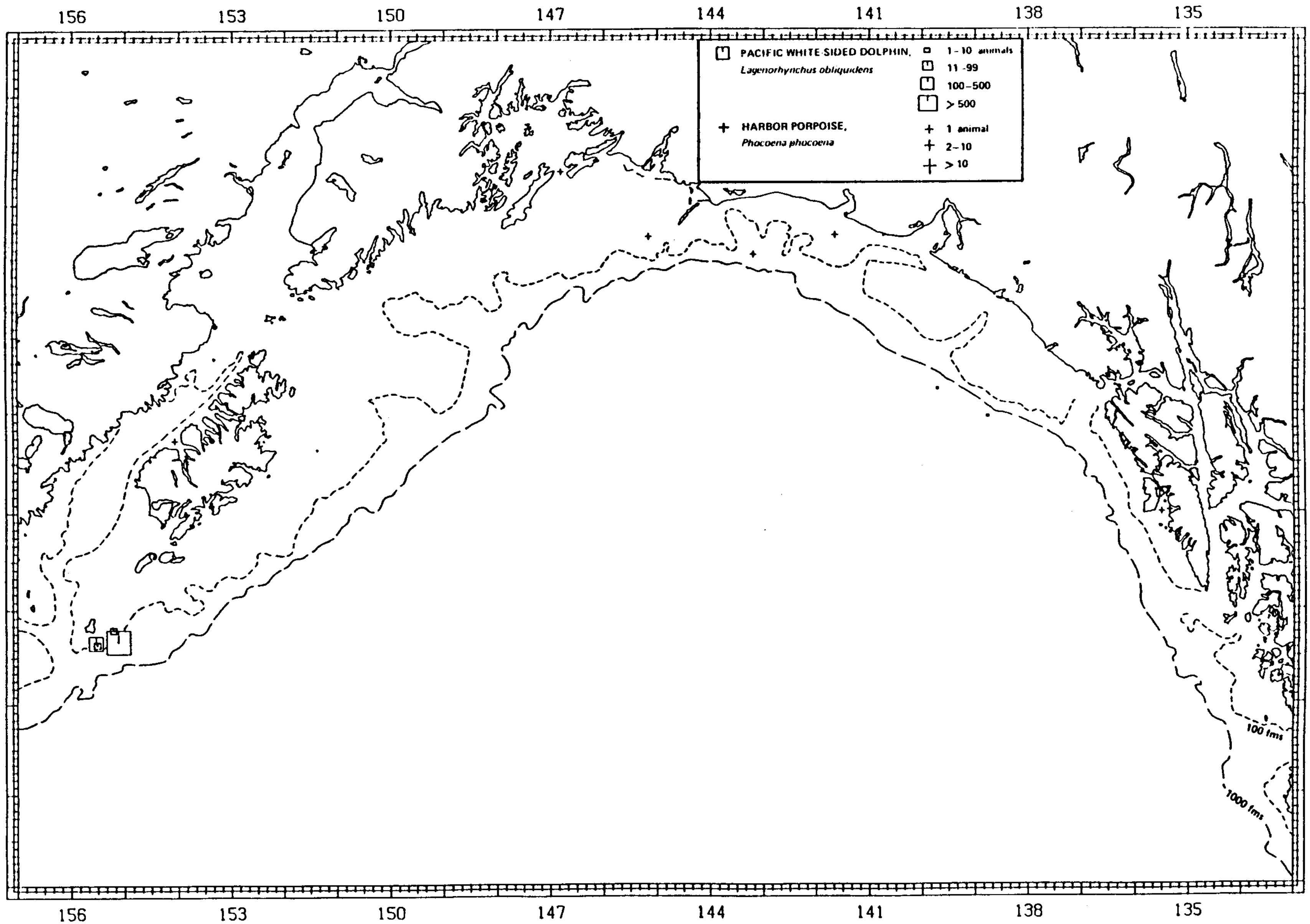

Figure 23.–Pacific white-sided dolphin and harbor porpoise sightings, winter (January-March) 1958-80.

Spring (April-June)

With the exception of one spring sighting over Portlock Bank (57°57'N, 150°33'W), all sightings were in the eastern Gulf of Alaska (Figure 24). Seven groups of more than 100 animals were seen; one consisted of approximately 2,000–the largest group on record in the eastern North Pacific above 40°N.

Summer (July-August)

During summer, Pacific white-sided dolphins appear to concentrate over the Fairweather Ground and Portlock Bank (Figure 25). Maximum group size was 1,000 individuals; 11 other groups consisted of 100 or more individuals.

Autumn (October-December)

Pacific white-sided dolphins are found in both the northeast and northwest Gulf of Alaska during autumn (Figure 26). Of 13 groups observed, only one comprised more than 100 animals. This group of 140 dolphins was sighted near Middleton Island on 18 October 1980 at 59°14'N, 147°02'W, and was accompanied by Dall porpoises. Hall and Tillman (1977) reported 500 white-sided dolphins sighted in October just outside Montague Strait, Prince William Sound.

FACTORS INFLUENCING DISTRIBUTION

Oceanographic

Our data (Figures 23-26) indicate that Pacific white-sided dolphins in the Gulf of Alaska are associated with the continental slope. Throughout the year, the great majority of sightings occurred near the 100-fathom isobath, most often between the 100- and 1,000-fathom isobaths. Very few sightings were made over depths greater than 1,000 fathoms.

Feeding and Food Resources

Available data indicate that Pacific white-sided dolphins are opportunistic feeders, eating a variety of fish species as well as squid. Houck (1961) reported that a stranded young white-sided dolphin from northern California had a stomach full of sauries (*Cololabis saira*), and one jack mackerel (*Trachurus symmetricus*) 33 cm long wedged in its esophagus. Prey species from 33 white-sided dolphins collected by Kajimura *et al.* (1981) off California 1-130 km seaward of the continental shelf included northern anchovy (*Engraulis mordax*), hake (*Merluccius productus*), saury, and several species of squid (*Loligo opalescens*, *Gonatus* sp., *Gonatopsis borealis*, and *Onychoteuthis borealijaponicus*). Wilke *et al.* (1953) reported that lantern fish (Myctophidae) and squid (probably *Watasenia scinteillans*) were major prey items, with anchovy (*Engraulis japonica*) and mackerel (*Scomber japonicus*) also present in white-sided dolphins taken from waters off Japan.

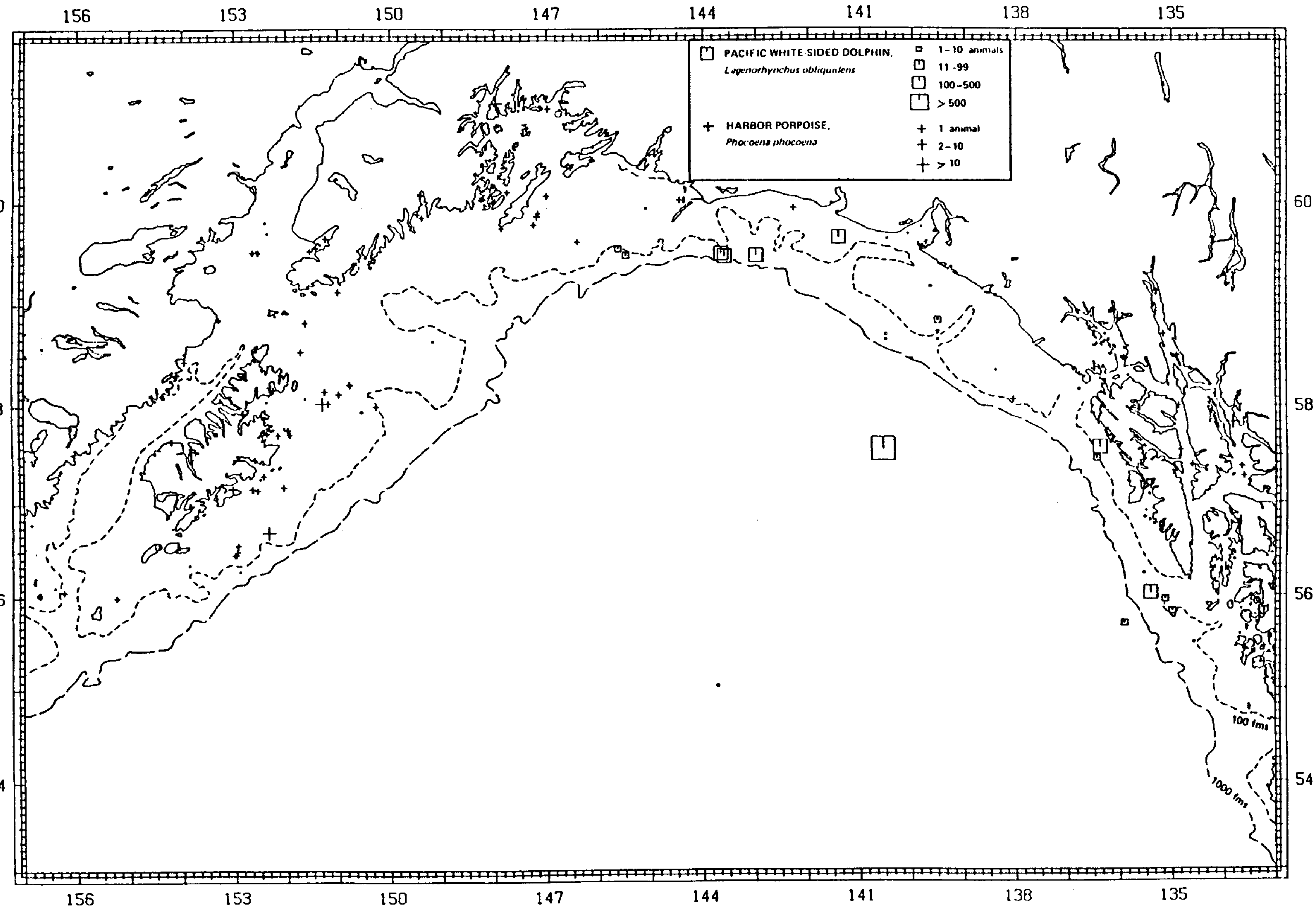

Figure 24.-Pacific white-sided dolphin and harbor porpoise sightings, spring (April-June) 1958-80.

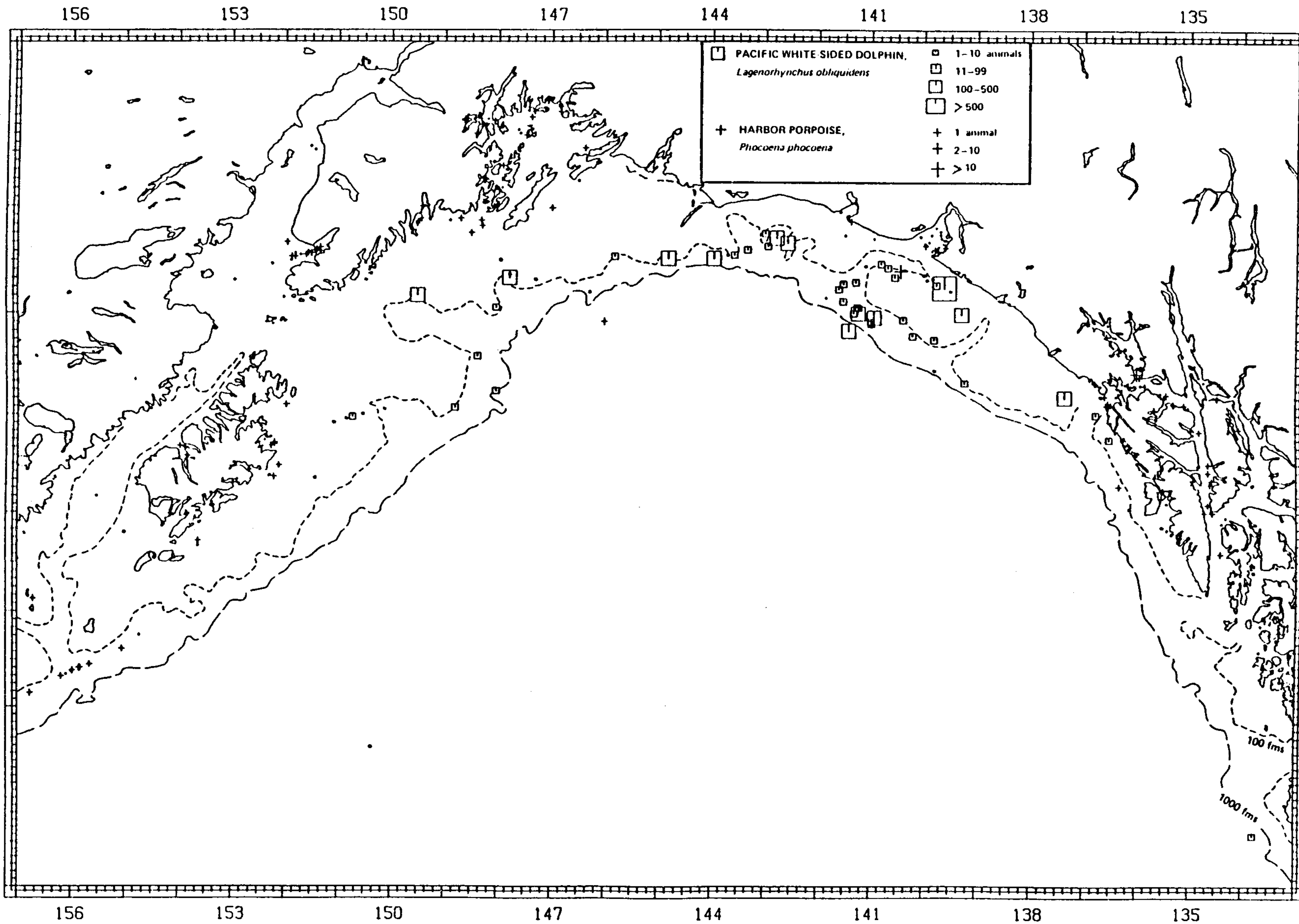

Figure 25.–Pacific white-sided dolphin and harbor porpoise sightings, summer (July-September) 1958-80.

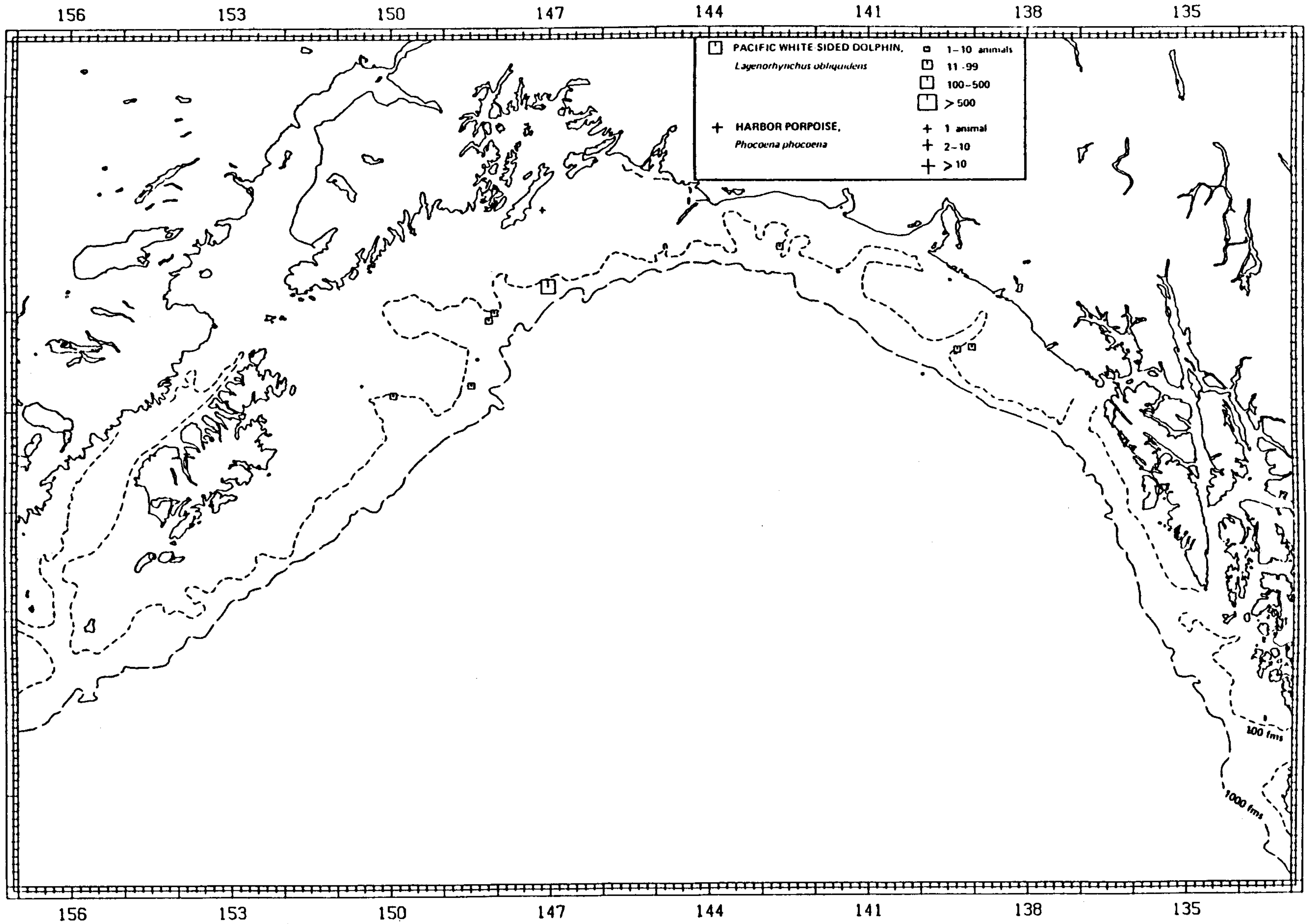

Figure 26.–Pacific white-sided dolphin and harbor porpoise sightings, autumn (October-December) 1958-80.

Migration

Leatherwood and Reeves (1978) stated that with the approach of summer, Pacific white-sided dolphins off southern California move north and offshore near the edge of the continental shelf. Presumably these and other animals in the mid-latitudes shift their distribution farther north, but it is premature to consider this a migration as thought of in other species. Migration needs much more study in most small cetaceans.

FACTORS INFLUENCING POPULATION GROWTH

Reproduction

Reproduction in Pacific white-sided dolphins is poorly understood. Mature males reported by Harrison *et al.* (1969) ranged from 170 to 180 cm. Tomilin (1957) reported lengths of 180 and 183 cm for two females carrying fetuses.

Mortality

Some natural mortality undoubtedly occurs from killer whales, and perhaps from large sharks; however, this is undocumented. Central nervous system infestation by air sinus trematodes has been reported by Dailey and Walker (1978) as a possible cause of occasional strandings of this species. Fifty-one white-sided dolphins were collected for live public display from 1966 to 1972 (Walker 1975). A small number of individuals are taken incidentally in tuna and bonito nets in tropical waters (NMFS 1980), but fishery-related mortality is not documented in the Gulf of Alaska.

Harbor Porpoise (*Phocoena phocoena*)

The harbor porpoise belongs to the family Delphinidae. It is one of four members of the genus *Phocoena*. The others are *P. sinus*, which occurs in the upper Gulf of California, Mexico, and *P. dioptrica* and *P. spinnipinnis*, which occur in the Southern Hemisphere. Other common names for the harbor porpoise include common porpoise, herring hog, and puffing pig.

ABUNDANCE

No population estimates for harbor porpoises are currently available for the entire North Pacific or Gulf of Alaska. Hall (1979) estimated a winter population of 590 in Prince William Sound, and 946 in the summer. Judging from the great amount of apparently suitable habitat throughout the Gulf of Alaska and our numerous POP sightings, the total Gulf of Alaska population size is undoubtedly large.

DISTRIBUTION

The harbor porpoise is a boreal-temperate zone species (Gaskin *et al.* 1974) found along much of the North Pacific coast between Point Barrow, Alaska (Hall and Bee 1954), and central California (Daugherty 1965; Nishiwaki 1966a; Gaskin *et al.* 1974) or as far south as Mexico (Pike 1956). Harbor porpoises are usually sighted singly or in pairs.

Spring (April-June) and Summer (July-September)

Spring sightings are numerous in the Kodiak Island area; two large groups (12 and 25 animals) occur here during this season (Figure 24). Kachemak Bay, Prince William Sound, Yakutat Bay, and southeast Alaska are other areas where harbor porpoises regularly occur during spring and summer (Figures 24 and 25).

Autumn (October-December) and Winter (January-March)

Sightings during autumn and winter were surprisingly sparse (Figures 23 and 26). The areas where harbor porpoises were sighted during spring and summer yielded very few autumn or winter sightings, which may be due in part to poor observing conditions and reduced coverage. Thus, though harbor porpoises are assumed to be year-round residents, this assumption is not evident when reviewing our sighting data. Forsell and Gould (1981) reported only 9 animals (on 368 transects) in November 1979 and 24 animals (on 499 transects) in February 1980 while conducting seabird surveys in the nearshore waters of Kodiak, but believed that *Phocoena* were probably much more abundant than their observations indicated. Cruise tracks of POP vessels in the Gulf are, for the most part, farther offshore than the expected normal nearshore distribution of *Phocoena*; therefore, harbor porpoise distribution in the study area is probably under-represented in our data.

FACTORS INFLUENCING DISTRIBUTION

Oceanographic

Harbor porpoises are generally seen in coastal environs such as harbors, bays, and the mouths of rivers (Tomilin 1957). Sightings have been made by Hall (1979) near Prince William Sound, and one of the authors (L.D.C.) saw animals concentrated in Icy Bay in and along the edge of turbid water plumes from river runoff.

Feeding and Food Resources

Harbor porpoises feed primarily on small gadoid and clupeoid fishes. Smith and Gaskin (1974) reported that stomach contents from eastern Canadian coastal specimens contained 50% cod, 30% herring, and 15% mackerel. They dive to depths of at least 70 m (presumably in search of food), as evidenced by two porpoises caught in a net set on the ocean bottom off the Washington coast (Scheffer and Slipp 1948). Hall (1979) speculated that the harbor porpoises he observed were feeding in the more turbid water from the Copper River, perhaps on forage species concentrated where Copper River water mixes with Gulf of Alaska water.

Migration

Researchers believe that there is a seasonal migration on the east coast of North America. Neave and Wright (1969) reported that harbor porpoises move north in late May and south in early October, while Gaskin *et al.* (1974) predicted an inshore movement in summer and an offshore movement in winter. Hall's (1979) previously discussed findings of a winter population only slightly more than half that of summer indicate some sort of winter dispersion; whether this dispersion is to other inshore habitats or offshore is unknown.

FACTORS INFLUENCING POPULATION GROWTH

Reproduction

Tomilin (1957) noted that there is little difference in time of breeding between North Atlantic, North Pacific, and Black Sea stocks. Mating for the Black Sea harbor porpoise occurred from the end of June until October, with a peak in occurrences in August (Tsalkin 1940, cited in Tomilin 1957). Slijper (1962) reported mating in the North Atlantic from July to October. Calves are born after a gestation period of 10-11 months. The peak calving period is in May and June (Tomilin 1957). Harbor porpoises reach sexual maturity at 3-4 years of age (Gaskin *et al.* 1974).

Mortality

Harbor porpoises are preyed upon by killer whales (Balcomb and Goebel 1976) and sharks. The most significant cause of natural mortality, however, appears to be parasitization. Major organs affected are the lungs (nematodes), and the liver and pancreas (trematodes) (Gaskin *et al.* 1974). Multiple parasitism associated with significant organ damage has been indicated in stranding mortalities on the East Coast (Dailey and Stroud 1978; Geraci and St. Aubin 1979).

Harbor porpoises are killed incidental to set and drift gillnet fishing throughout the West Coast (NMFS 1980). Though no overall estimate is available for incidental mortality, Matkin and Fay (1979) predicted that as many as 58 harbor porpoises would be killed in the Prince William Sound-Copper River fisheries in 1978. This may be a significant cause of mortality in the local population and warrants study.

White Whale (*Delphinapterus leucas*)

The white whale, more commonly called beluga or belukha, is one of only two species in the family Monodontidae. The other species is the narwhal, *Monodon monoceros*.

ABUNDANCE

White whales are abundant in Alaskan waters, particularly north of 60°N, and are neither endangered nor classified as protected. They are harvested by Alaskan Eskimos (and other native Americans) residing in coastal villages of the Bering, Chukchi, and Beaufort seas, who in recent years (1977-79) have landed approximately 187 white whales annually (Seaman and Burns 1981).

The Alaska state population is at least 9,000 (Braham *et al.* 1984) and perhaps as high as 16,000 (J. Burns, pers. commun.). The stock or population occurring in Cook Inlet and adjacent waters of the Gulf of Alaska is estimated to be 300-500 (Klinkhart 1966). Murray and Fay (1979) conducted surveys in Cook Inlet and believe that the size of that population has not changed appreciably since the 1960s. However, they believe that the actual population size is perhaps 3-4 times larger than the estimated 300-500, and attribute the discrepancy to underestimation due to the aerial survey methods employed by Klinkhart.

DISTRIBUTION

White whales are distributed throughout Alaskan waters, where at least two stocks are generally recognized: one in the Cook Inlet-Gulf of Alaska region and the second in the Bering, Chukchi, and Beaufort seas. The greatest numbers of animals occurs in the "Bering Sea population" (so named for this report) which may be further divided into groups occurring in Bristol Bay, Norton Sound, Kotzebue Sound, along the northwestern coast of Alaska, and those which migrate into the Canadian Beaufort Sea. At present, however, no clear evidence exists to confirm stock differences for these groups. Further studies are warranted.

Almost all white whales reported to our POP data base in the study area were seen north of 60°N in upper Cook Inlet (Figures 27 and 28; see also Murray and Fay 1979). This may be in part an artifact of increased observer effort, but we believe it is a true representation of their distribution at least for the spring and summer months. We have no autumn and winter sightings of white whales in Cook Inlet, but we have been told that they are present year-round, having been seen following boats through thin ice and in open water near Kenai and Nikishki (upper Cook Inlet) during winter and spring (R. Dahlheim, pers. commun.).

Documented sightings outside Cook Inlet are:

1) Barren Islands–3 individuals on 12 April 1978 at 58°48.9'N, 152°11.9'W (Figure 27).

2) Marmot Bay, between Kodiak and Afognak Islands–1 individual on 8 March 1977 at 58°00'N, 152°52'W (NMFS unpubl. data).

3) Yakutat Bay–26 individuals on 31 May 1976 at approximately 59°45'N, 139°50'W (Calkins 1977). A resident group of 10-20 is suspected (S. Hinckley, pers. commun.).

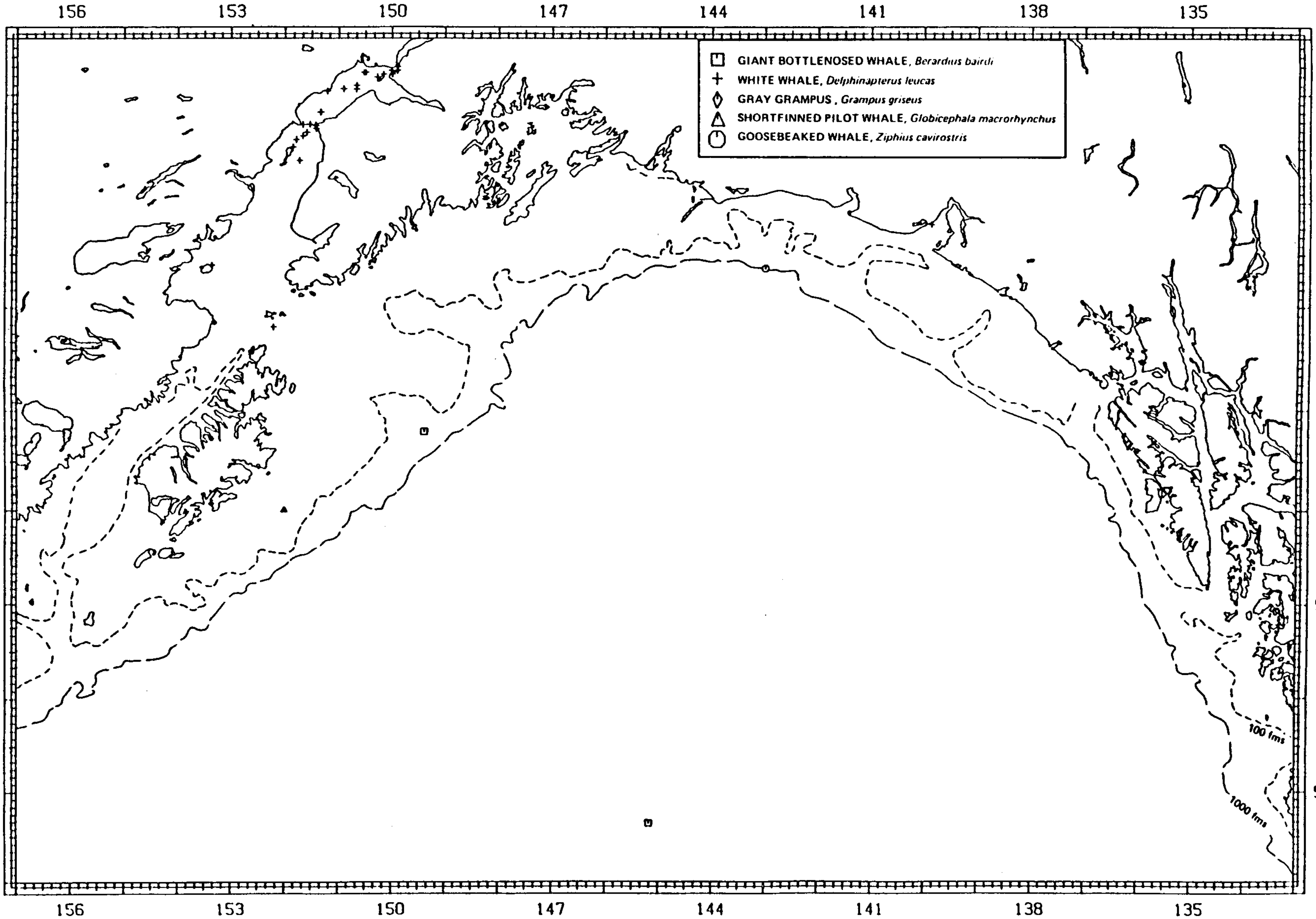

Figure 27.–White whale, giant bottlenose whale, goosebeak whale, shortfinned pilot whale, and Risso's dolphin sightings, spring (April-June) 1958-80.

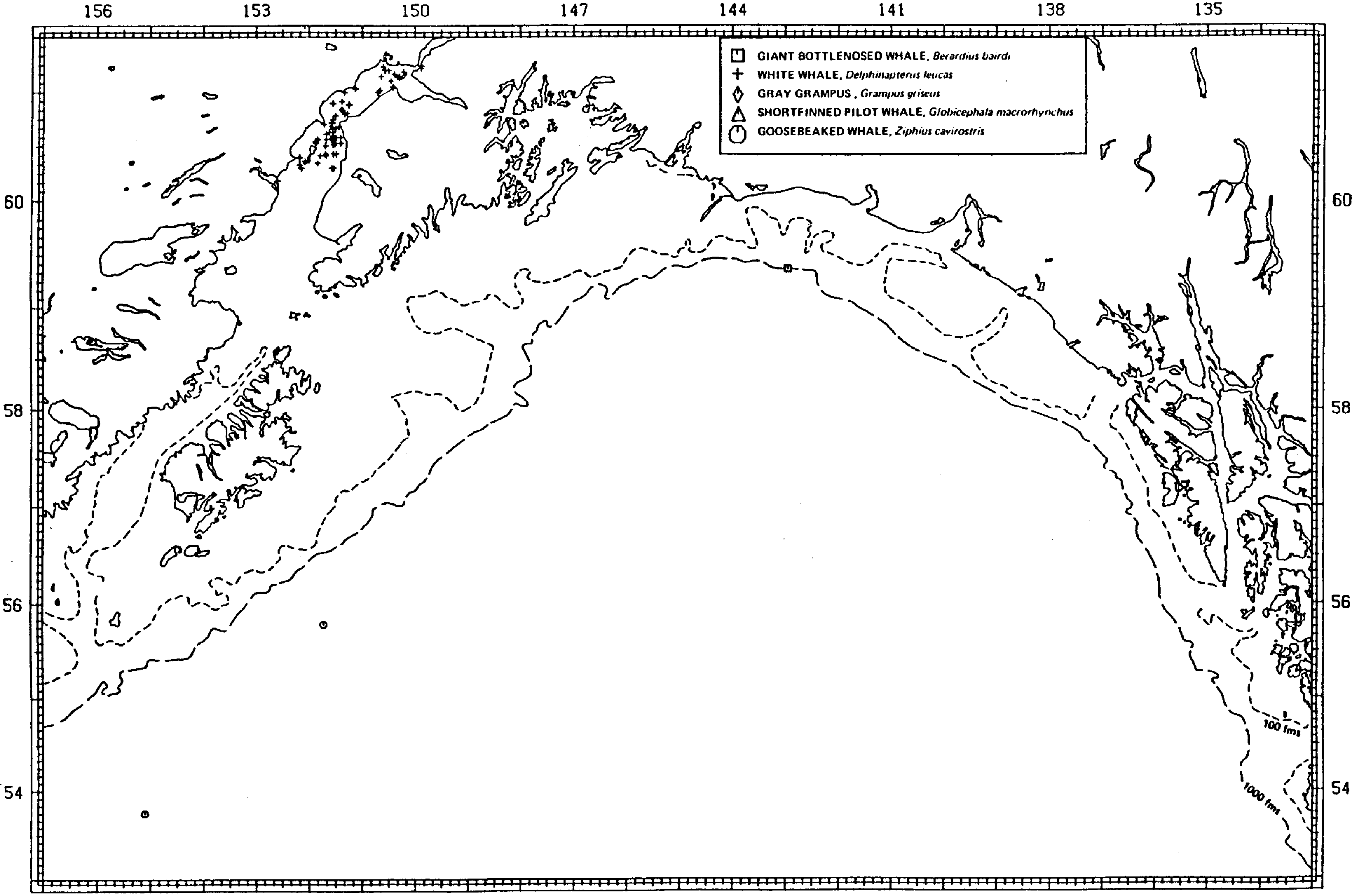

Figure 28.–White whale, giant bottlenose whale, goosebeak whale, shortfinned pilot whale, and Risso's dolphin sightings, summer (July-September) 1958-80.

4) Montague Island–1 individual on 29 March 1976 at 59°57'N, 147°22'W (Harrison and Hall 1978).

5) Shelikof Strait–2 individuals on 16 July 1975 at 58°00'N, 154°11'W (Harrison and Hall 1978).

6) Tacoma, Washington–a single tentative white whale on 23 April 1940 at 47°16'N, 122°33'W (Scheffer and Slipp 1948).

Local fishermen have observed 10-20 white whales in Yakutat Bay annually over the past decade (S. Hinckley, pers. commun.).

FACTORS INFLUENCING DISTRIBUTION

The movements and seasonal distribution of white whales in Cook Inlet and the Gulf of Alaska are influenced by the availability of fish, especially smelt and salmon smolt (Kleinenberg *et al.* 1964; Klinkhart 1966). The animals returning to Yakutat Bay annually apparently are following local salmon runs. Their movements in Cook Inlet are also limited by ice to at least Kenai, and the tide, which can reach a 10-m flux. Since they generally associate themselves with shallow waters, bays, and estuaries, which are frequently turbid and warmer than offshore waters and are important areas for fish runs, it is not surprising that most sightings in Cook Inlet (at least during summer) are north of 60°N and along the coast.

FACTORS INFLUENCING POPULATION GROWTH

Although only one study has been conducted in the Gulf on this species in the past 15 years, Murray and Fay (1979) concluded that the population has not changed in numbers. Presumably, the major factor limiting population growth is the availability of habitat (space and food). Because white whales seem to be generally confined to Cook Inlet and the population may not be increasing, we believe that the carrying capacity for white whales has been reached. In fact, their presence in Yakutat Bay may indicate the carrying capacity has been exceeded in Cook Inlet. Obviously, greater study of life history (especially recruitment), distribution, and data on availability of prey among years is needed to support this preliminary conclusion.

North Pacific Giant Bottlenose Whale (*Berardius bairdii*)

The North Pacific giant bottlenose whale belongs to the family Ziphiidae. The other common name associated with this species is Baird's beaked whale.

ABUNDANCE

There are no population estimates available for the giant bottlenose whale. The few POP sightings indicate that this species may not be very abundant in the Gulf of Alaska.

DISTRIBUTION

The giant bottlenose whale is endemic to the North Pacific, ranging from St. Matthew Island in the Bering Sea, through the Gulf of Alaska and south to southern California (Rice 1974).

No giant bottlenose whale sightings were logged during the cetacean survey of the Gulf of Alaska in 1980 (Rice and Wolman 1982). During a 1979 autumn survey of coastal waters of California, two schools of four animals each were observed north of San Francisco (Duffy 1980). Rice (1978*d*) observed pod sizes of 3-17 animals off California in the 1960s. Our data (Figures 27 and 28) show only three positive sightings in the study area since 1958:

1) 4 animals on 20 June 1976 at 53°39'N, 145°10'W.

2) 5 animals on 12 June 1977 at 57°48'N, 149°23'W.

3) 9 animals on 11 September 1977 at 59°22'N, 142°57'W.

FACTORS INFLUENCING DISTRIBUTION

Whaling records from Japan indicate a greater density of giant bottlenose whales in waters beyond the 1,000-m contour of the continental shelf (Nishiwaki and Oguro 1971).

Giant bottlenose whales feed primarily on squids and groundfishes (Nishiwaki 1972; Rice 1978*d*). Migration in the western North Pacific seems to coincide with the seasonal occurrence of squid, *Todorades pacificus*, and other cephalopods (*Gonatus* spp.)(Nishimura 1970). Deep sea fishes are consumed when available (Nishiwaki and Oguro 1971), and the stomachs of some specimens have contained benthic animals such as ascidians, sea cucumbers, starfishes, and crabs (Nishiwaki 1972).

FACTORS INFLUENCING POPULATION GROWTH

Studies of giant bottlenose whales off Japan indicate that mating peaks during October and November and that calving occurs from November to July, with a peak in March and April (Kasuya 1977). Similar periods for mating and calving are assumed to hold true for the eastern North Pacific. The predominance of males in catches off the coast of British Columbia may mean a geographical segregation between the sexes. Sexual maturity is attained at an age of 8-10 years and maximum longevity may be 70 years (Kasuya 1977).

Virtually nothing is known about natural mortality. Fisheries-related mortality in the North Pacific is limited to animals taken by Japanese coastal whaling operations. Since 1969, an average of 62 per year have been taken; 33 per year over the past 5 years (1976-80) (Committee for Whaling Statistics 1980).

Goosebeak Whale (*Ziphius cavirostris*)

The goosebeak whale is a toothed whale belonging to the family Ziphiidae (beaked whales), and is the only member of the genus *Ziphius*. Another common name for this species is Cuvier's beaked whale.

ABUNDANCE

No population estimates are available for the goosebeak whale. Though it may be the most abundant of the beaked whales in the eastern North Pacific, the lack of sighting data leads us to conclude that this species is scarce in the Gulf of Alaska.

DISTRIBUTION

The goosebeak whale is found in all oceans of the world, except the Arctic and Antarctic (Moore 1963). Mitchell (1968) noted that strandings of this species are widespread and presumed a continuous distribution from Alaska to Baja California. At sea sightings are rare in the Gulf of Alaska. Rice and Wolman (1982) reported two sightings (included in Figures 27 and 28), one animal at approximately 59°22'N, 143°W and six at 55°47'N, 151°43'W. The only other POP sighting, of a single animal, occurred at 53°45'N, 156°05'W on 30 July 1977. Harrison (1979) sighted a lone goosebeak whale just to the west of the study area (54°00'N, 160°35'W) in April 1977 over 2,560 m of water. Although there are few sightings in our data base, we believe goosebeak whales are more abundant than the available records indicate.

FACTORS INFLUENCING DISTRIBUTION

Goosebeak whales appear to inhabit the deeper waters of the Pacific. The three sightings from the Gulf of Alaska occurred where water depths were 1,200, 5,800, and 4,400 m, respectively. Off Japan, they are taken in the coastal small whaling operations where water depths are greater than 1,000 m (Omura *et al.* 1955; Nishiwaki and Oguro 1972).

Nishiwaki and Oguro (1972) reported squid and deep-sea fish (no species given) were found in the stomachs of goosebeak whales taken off Japan. Squid were found in the stomachs of an animal stranded on Amchitka Island, Alaska (Kenyon 1961), and another in California (Mitchell and Houck 1967).

FACTORS INFLUENCING POPULATION GROWTH

Data from Japanese coastal whaling operations indicate that males become sexually mature at about 5.3 m in length, and females at 5.5 m. Neonates are thought to be about 2.3 m at birth (Omura *et al.* 1955). Nishiwaki and Oguro (1972) noted that 87% of all goosebeak whales taken off Japan were mature and speculated that the population was stable.

Virtually nothing is known about causes of natural mortality. Their pelagic distribution and deep diving ability may protect goosebeak whales from killer whales. Goosebeak whales strand generally as singles, but stranding reports have emphasized their osteology rather than pathology. Fishery-related mortality is limited to a directed Japanese fishery in the western North Pacific: 85 animals were caught there during 1948-52, and 189 during 1965-70 (Omura *et al.* 1955; Nishiwaki and Oguro 1972).

Bering Sea Beaked Whale (*Mesoplodon stejnegeri*)

The Bering Sea beaked whale belongs to the family Ziphiidae, and is one of eleven members of the genus *Mesoplodon*. Other common names include Stejneger's beaked whale and sabertooth whale.

ABUNDANCE

No population estimates are available for this species. Judging from the complete lack of sighting records, the Bering Sea beaked whale may be scarce in the Gulf of Alaska.

DISTRIBUTION

The known range of *M. stejnegeri* extends from Akita Beach, Japan, north to the Commander and Pribilof islands in the Bering Sea, through the Gulf of Alaska south to Yaquina Bay, Oregon (Moore 1963). The distribution of this species is based upon rare strandings and sightings such as a floating carcass examined off Cape Edgecumbe in the Gulf of Alaska (Fiscus *et al.* 1969). Although very little is known about the distribution and abundance of these whales, it is possible that they principally inhabit the deeper waters of the continental shelf, as has been suggested for the Atlantic species *M. bidens* (Moore 1966). During a June-July northern sea lion vessel survey in the central Aleutian Islands, Loughlin *et al.* (in press) sighted seven groups of *Mesoplodon* in water between 730-1,280 m deep. Pod size ranged from 5 to 15 animals. We have no sighting data on *M. stejnegeri* in the Gulf of Alaska. Undoubtedly, this is due in part to their pelagic distribution and inconspicuousness at sea.

FACTORS INFLUENCING POPULATION GROWTH

Virtually nothing is known about the food habits, reproductive biology, or natural mortality of *Mesoplodon* species.

Risso's Dolphin (*Grampus griseus*)

Risso's dolphin belongs to the family Delphinidae, and is the only member of the genus *Grampus*. Other common names include grampus, gray grampus, and white-headed grampus.

ABUNDANCE

Risso's dolphins are protected under the Marine Mammal Protection Act of 1972 (Public Law 92-522) and as amended. Although no abundance estimates are available, this species is common in the lower latitudes and rare in subarctic waters such as the Gulf of Alaska.

FACTORS INFLUENCING DISTRIBUTION

In their comprehensive review of Risso's dolphin distribution in the northeastern Pacific, Leatherwood *et al.* (1980) reported that sightings between 45° and 51°N occurred mostly in summer, and essentially beyond the continental shelf. They related these northern sightings to warming ocean surface temperatures. Normal distribution is from the equator to central California. Guiget and Pike (1965) reported four sightings of Risso's dolphins from Ocean Station Vessel Papa (50°N, 145°W) during 1958-60. More recently, Reimchen (1980) reported a March 1978 sighting of 14 Risso's dolphins at 54°11'N, 133°01'W–close to shore off the northwest tip of Queen Charlotte Island. No spring to autumn sightings are in our data base (Figures 27 and 28).

Three winter sightings were made, one providing the northernmost record for the species in the North Pacific (Braham 1981). On 9 and 12 March 1976, Braham observed three groups of Risso's dolphins totaling seven animals: three individuals at 49°50'N, 128°30'W, two at 49°52'N, 128°37'W, and two at 55°49'N, 145°56'W. All were heading north toward the Gulf of Alaska; the 12 March sighting was in the Gulf. These sightings, and those of Reimchen (1980), occurred approximately 3-4 months earlier than when these dolphins are generally seen (cf. Guiguet and Pike 1965; Leatherwood *et al.* 1980). Whether these early seasonal sightings were chance, representative of their normal temporal and spatial distribution, or related to unseasonably warmer surface temperatures or prey availability, is unclear. Water temperatures may be the limiting factor for this tropical and temperate warm water species. During a 1980 Gulf of Alaska marine mammal survey, no Risso's dolphins were observed (Rice and Wolman 1982). Cephalopods are the major prey of this species (Nishiwaki 1972).

FACTORS INFLUENCING POPULATION GROWTH

Life history information on Risso's dolphin is sparse. Males become sexually mature at about 3 m and newborns are about 1.5 m long (Leatherwood, in press). Little is known about causes of natural mortality. Guiget and Pike (1965) reported a heavy intestinal parasite load in one animal collected in British Columbia, but estimates of debilitation were lacking. Other than an occasional shooting of a Risso's dolphin (Orr 1966), there is no evidence of human-related effects; but again, research is lacking.

Short-Finned Pilot Whale (*Globicephala macrorhynchus*)

The short-finned pilot whale belongs to the family Delphinidae, which comprises two species. The other is the long-finned pilot whale, *G. malaena*. Subspecies of the short-finned pilot whale with alternate specific names are *G. scammonii* and *G. sieboldii*. Other common names include blackfish and pothead.

ABUNDANCE

No population estimates are available for pilot whales in the eastern North Pacific, but the species may be categorized as rare in the study area (Reilly 1978).

DISTRIBUTION

Pilot whales normally range no farther north than California. They are known from Alaskan waters on the basis of only a few published accounts. A specimen reported as *G. scammonii* (sometimes applied to pilot whales off California) was taken near Kanatak on the Alaska Peninsula in September 1937 (Orr 1951). Four pilot whales were sighted in the Gulf of Alaska from the MV *Fort Ross* in August 1957 at 54°48'N, 143°47'W, about 400 miles west of Dixon Entrance (Pike and MacAskie 1969). Our data show a single sighting in May 1977 at 57°N, 152°W of five pilot whales (Figure 27).

FACTORS INFLUENCING DISTRIBUTION

The preferred food of the pilot whale is squid, and the abundance of pilot whales in several areas has been correlated with the abundance of these cephalopods (Leatherwood and Dahlheim 1978).

Pilot whales travel in groups of a few to several hundred animals and are frequently observed in association with other cetaceans. Although their seasonal movements are poorly known, populations may shift northward in the summer and south in the winter in response to changes in water temperature (Leatherwood *et al.*, in press). Migrations may also be the result of breeding or calving activities (Norris and Prescott 1961).

FACTORS INFLUENCING POPULATION GROWTH

Little is known about the reproductive characteristics of the shortfinned pilot whale. Preliminary indications from pilot whales taken in the coastal waters of Japan are that males become sexually mature at about age 14 and females at age 8, and that gestation is about 14.5 months (Kasuya 1981). The oldest pregnant female Kasuya found was 35 years old, indicating a relatively long reproductive life for these small cetaceans. Age determinations indicate that short-finned pilot whales are long-lived animals, frequently reaching 50 years (Sergeant 1962, Kasuya 1981).

Other than predation by killer whales, virtually nothing is known about natural causes of mortality. Pilot whales are known to strand *en masse* in warmer waters, but not in the study area. The only harvesting of short-finned pilot whales in the eastern North Pacific is occasional live capture for aquaria. Pilot whales are taken in the Japanese coastal whaling operation, and since 1969 the take has ranged from 3 to 181, with only 17 per year taken since 1975 (Committee for Whaling Statistics 1980).

Northern Right Whale Dolphin (*Lissodelphis borealis*)

The northern right whale dolphin belongs to the family Delphinidae. The other member of the genus, *L. peronii*, inhabits the Southern Hemisphere.

ABUNDANCE

Nishiwaki (1972) estimated a total North Pacific population of 10,000 animals. Leatherwood and Walker (1975) believed this was a conservative estimate, but offered no new estimate.

DISTRIBUTION

The northern right whale dolphin is usually found in temperate waters between 30°N and 50°N (Leatherwood and Walker 1975). Scammon (1874) and Nishiwaki (1966) reported sightings as far north as the southern Bering Sea. Pike and MacAskie (1969) reported sighting two right whale dolphins at 50°N, 145°W on 2 July 1959. Guiguet and Shick (1970) reported a school of approximately 200 northern right whale dolphins on 13 February 1970 near 48°23'N, 126°52'W. These two sightings are the northernmost well-documented sightings in the eastern North Pacific that we know of. A recent summer survey of the Gulf of Alaska yielded no sightings (Rice and Wolman 1982). The POP data base contains no positive sightings of right whale dolphins in the study area. Three tentative sightings from the study area are as follows:

1) One animal on 13 July 1977 at 55°48'N, 155°10'W.

2) Two animals with a group of Pacific white-sided dolphins (100 total) on 26 February 1980 at 55°39'N, 155°24'W.

3) Two animals on 28 July 1980 at 58°40'N, 143°00'W.

A potential problem with right whale dolphin identification in the North Pacific is their strong resemblance to northern fur seals (*Callorhinus ursinus*) when the seals are porpoising. From a distance, or in rough weather, the two species appear similar in color and aspect (slender torso, dorsal fin absent).

FACTORS INFLUENCING DISTRIBUTION

Northern right whale dolphins are often found in the company of Pacific white-sided dolphins in lower latitudes. Yet, though white-sided dolphins move into the Gulf of Alaska with regularity during the spring and summer months, right whale dolphins do not. It may be that right whale dolphins have a narrower sea temperature tolerance.

From a very small number of stomachs examined for contents (strandings and collected animals from California), it was found that mesopelagic fishes (primarily Myctophidae, but also Bathylagidae, Melamphidae, and Paradepidae) were the most frequent food items present (Leatherwood and Walker 1975). Leatherwood and Walker (1975) mentioned that squid, *Loligo opalescens*, appears to be an important food item for this species.

FACTORS INFLUENCING POPULATION GROWTH

From a sample of 20 animals (10 each, male and female), it is apparent that sexual maturity occurs in males at about 210-220 cm in length, and in females at about 200 cm (Leatherwood and Walker 1975). This is the extent of current knowledge on reproductive parameters for this species.

Predation on northern right whale dolphins by other species is undocumented, and strandings are infrequent and most often of single animals. There are no recent reports of mortality incidental to fishing activities in the eastern North Pacific (NMFS 1980).

CARNIVORES

The emphasis of our research was on pelagic sightings of marine mammals, especially cetaceans, and, since seals, sea lions, and the like are more frequent inhabitants of coastal waters or on land, we have fewer data in general for the carnivores. In addition, there are numerous recent papers and reports covering these species' biology and natural history; thus our discussion here is abbreviated and principally addresses distribution. Only data with effort were plotted.

Northern Fur Seal (*Callorhinus ursinus*)

The range of the northern fur seal is from the east coast of Asia to the west coast of North America from 35°N (subarctic boundary) to approximately 60°N. A few sightings have been made beyond this range. Even though they can be found over a wide range of the North Pacific, their greatest concentration is found in the summer and early fall near their breeding islands. Of the total fur seal population of approximately 1.5-1.75 million, the majority, an estimated 1.0-1.3 million, return to the Pribilof Islands in the Bering Sea. The remainder go to the Commander Islands (USSR) in the southwestern Bering Sea, San Miguel Island off southern California, the Kurile Islands (USSR) in the western North Pacific, and Robben Island (USSR) in the Sea of Okhotsk.

Not all the fur seals return to their birth places during the summer; some immature seals (those 1 to 2 years old) may remain at sea year-round. Fur seals can be found in the Gulf of Alaska year-round, although the majority of sightings in the Gulf were in spring (Figures 29-32). This is not a result of sighting effort since the greatest effort among all seasons has been in summer.

In May and early June, mature males show up on the Pribilof Islands in advance of pregnant and estrous females. Breeding and post-parturient activities take place through the remainder of summer. As such, fewer animals, in total, are expected to be in the Gulf of Alaska than in the southern Bering Sea. The incidence of single animals, an index to group size, changes from 49% single sightings in the Gulf in winter to a high of 80% in summer (Figure 33).

Some of the fur seals, most likely older males, may overwinter in the Gulf (Alexander 1953). Younger males and females are most often found farther south along the edge of the continental shelf of British Columbia, Washington, Oregon, and California. A large concentration of wintering fur seals apparently occurs nearshore to Baranof Island (see inset Figure 29). If these animals return to the Pribilof Islands each year, then their route is likely to take them across the Gulf near or through some OCS lease areas (*e.g.*, Fairweather Ground). Fur seals were seen in the Gulf of Alaska during winter on the edge of Portlock Bank and in the center of the Gulf in deep water. Unfortunately, the amount of survey effort during winter is low.

Animals occurring in the southern part of their range begin their northward migration in spring and by late April, May, and in June they are found in the Gulf in large numbers (Figure 30). Sightings in spring undoubtedly reflect those animals which have left the Bering Sea in autumn and winter for warmer Gulf waters as well. A majority of the animals in spring were seen within 100 miles of the shelf break between southeast Alaska and the southwest tip of Kodiak Island. Most occurred along the shelf break towards Kodiak Island, although this may in part be biased by observer effort.

In summer there have been many fewer sightings in the Gulf than earlier in the year, and those occurred along the shelf edge and principally in the western Gulf near Kodiak Island (Figure 31). This may indicate that seals coming up from south of the Gulf of Alaska just head straight across the Gulf once they reach southeast Alaska in spring and summer. The summer concentrations of sightings continue west from Kodiak Island near the shelf break to Unimak Pass. Virtually no fur seals have been seen in Shelikof Strait, and this pattern continues in inland waters throughout the Gulf, in all seasons.

Very few fur seals have been sighted in the Gulf of Alaska during autumn (Figure 32). All sightings were scattered throughout the central to western Gulf. Most of the fur seals seen during autumn were found from just south of Unimak Pass to the Pribilof Islands in a broad strip approximately 200 miles wide, 250 miles long, north-northwest of Unimak Pass.

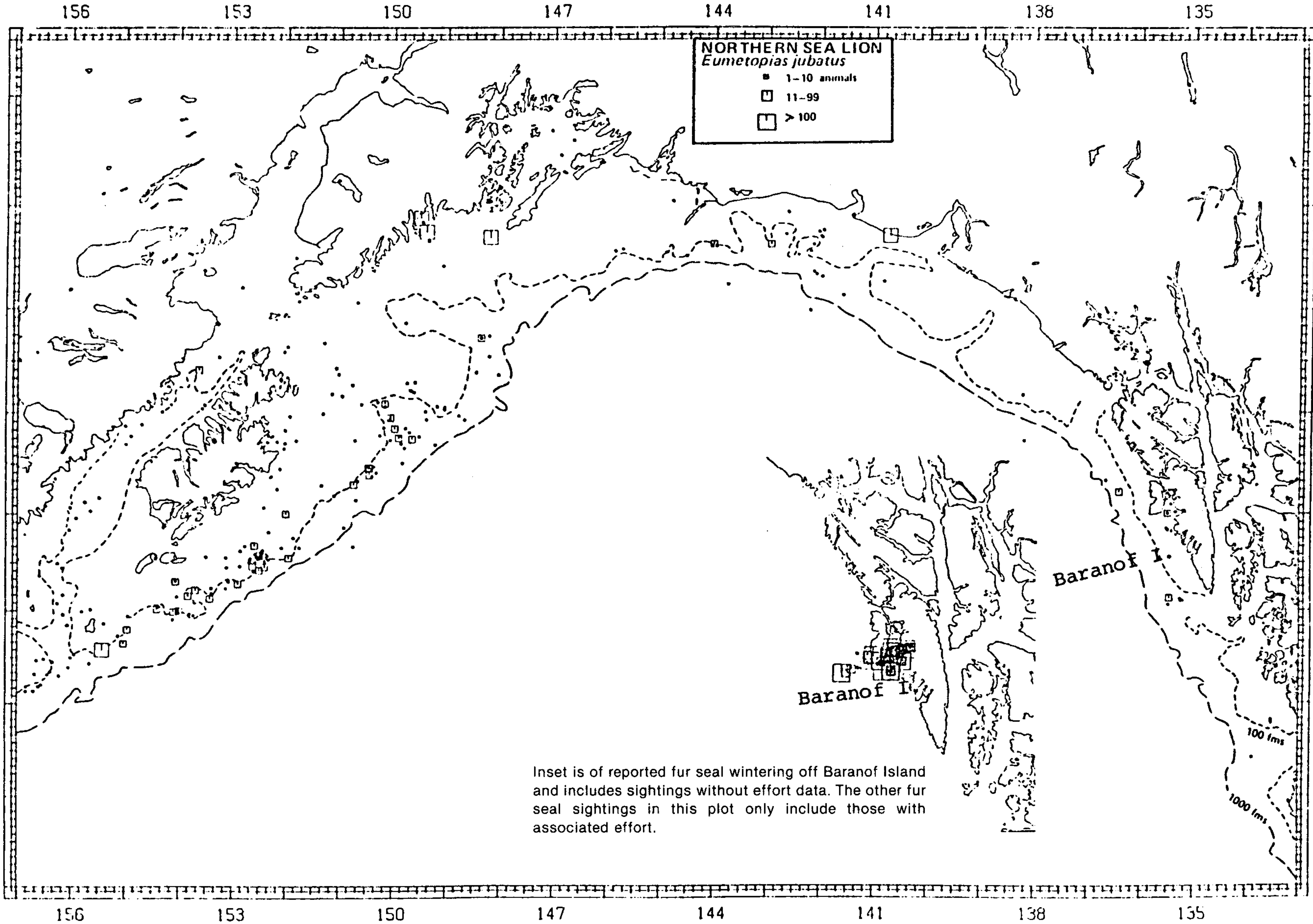

Figure 29.-Northern fur seal sightings, winter (January-March) 1958-80.

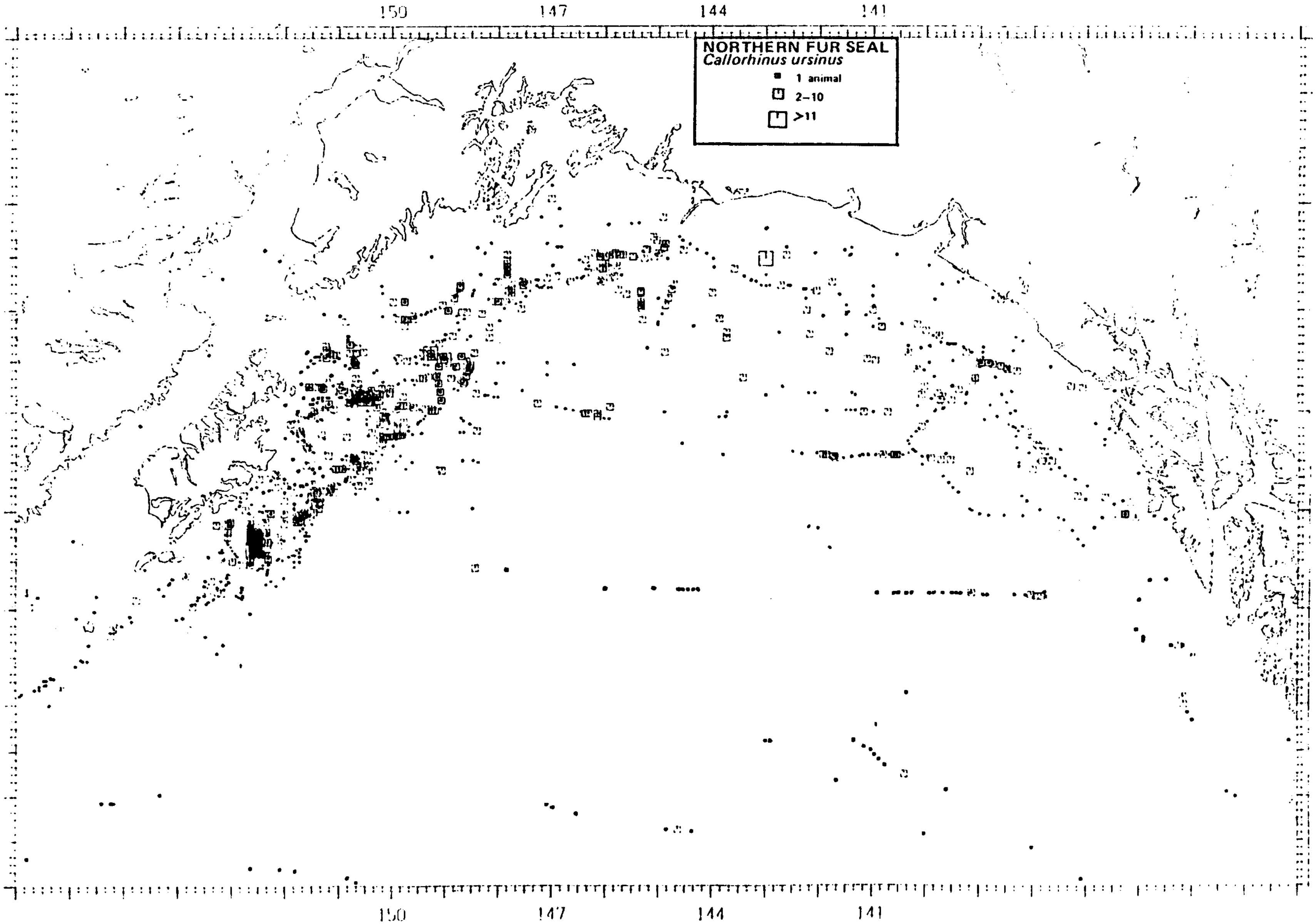

Figure 30.–Northern fur seal sightings, spring (April-June) 1958-80.

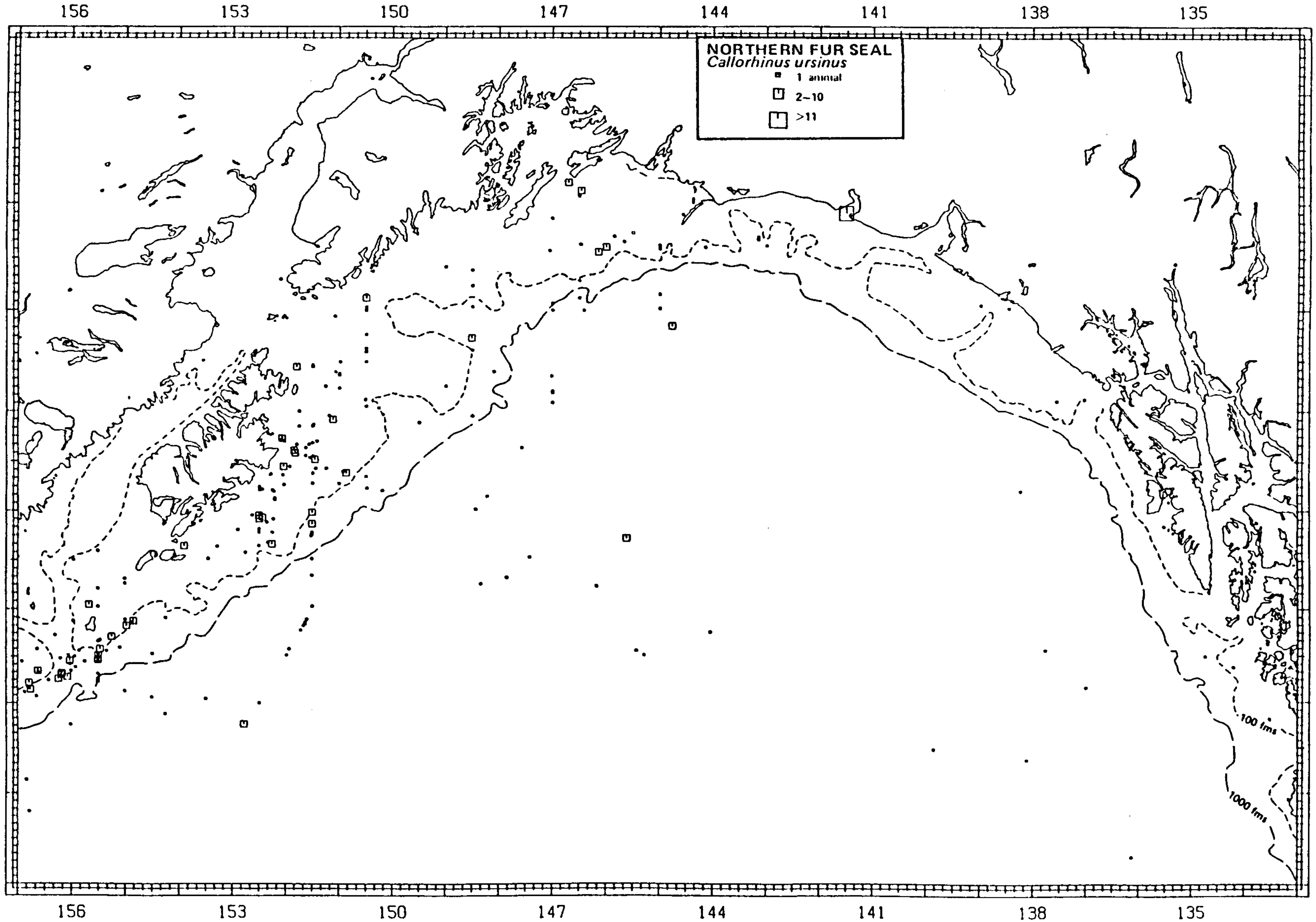

Figure 31.–Northern fur seal sightings, summer (July-September) 1958-80.

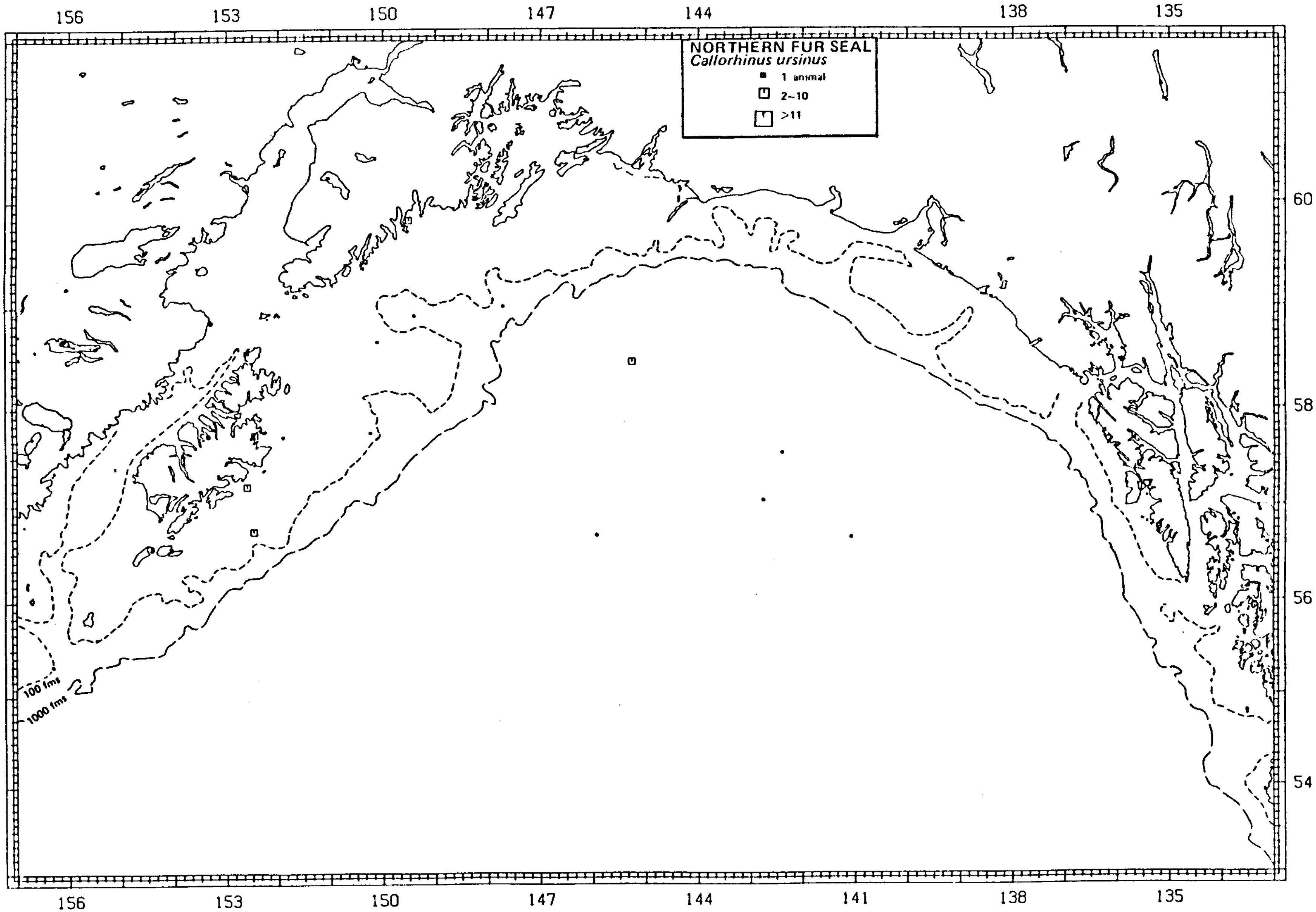

Figure 32.-Northern fur seal sightings, autumn (October-December) 1958-80.

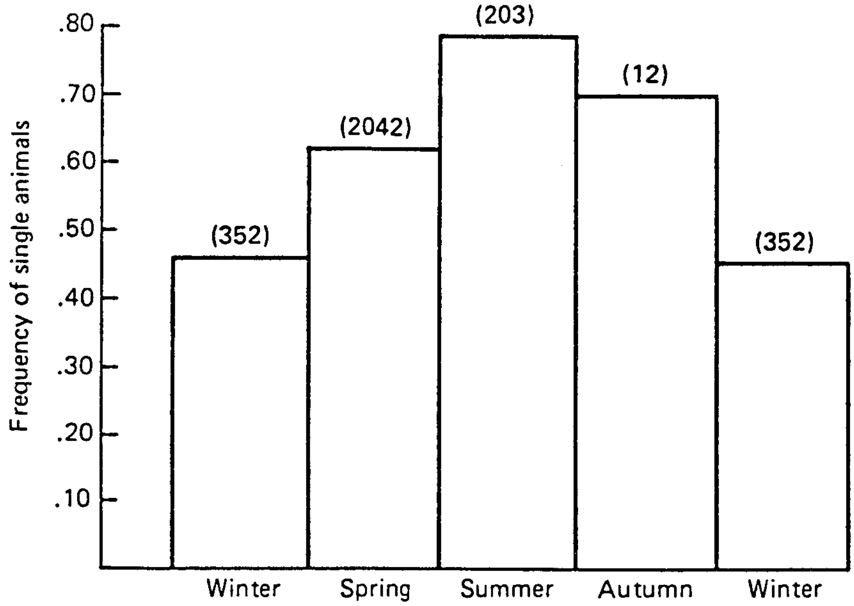

Figure 33.–The proportion of single fur seals by season and total sightings of all groups (numbers in parentheses) in the Gulf of Alaska, 1958-80. Data was not standardized for effort among seasons or years.

Northern sea lion (*Eumetopias jubatus*)

The northern or Steller sea lion is ubiquitous over the continental shelf of the Gulf of Alaska. Calkins *et al.* (1975) described in detail the various haulout areas and rookeries for sea lions. They found 91 different rookeries and hauling areas in the northeast Gulf of Alaska alone, from Cape Elias to Pt. Elrington. Pitcher Inlet at Sugarloaf Island supports one of the largest rookeries in the northern Gulf (Calkins *et al.* 1975). Marmot Island, off Afognak Island (north of Kodiak Island), equals Sugarloaf Island in numbers of sea lion population, and Cape Barnabas and Two-headed Island on and near Sitkalidak Island also support large numbers of sea lions (Calkins *et al.* 1975). The adults begin to gather on breeding rookeries in late May and leave in late June or early July.

Northern sea lions, at sea, frequent continental shelf waters virtually to the exclusion of waters deeper than 2,000 m, and during much of the year they occur in greatest numbers near the 200-m depth contour.

In winter sea lions were found primarily around Kodiak Island, and most sightings were near the continental shelf break on Portlock and Albatross banks (Figure 34). Whether this is

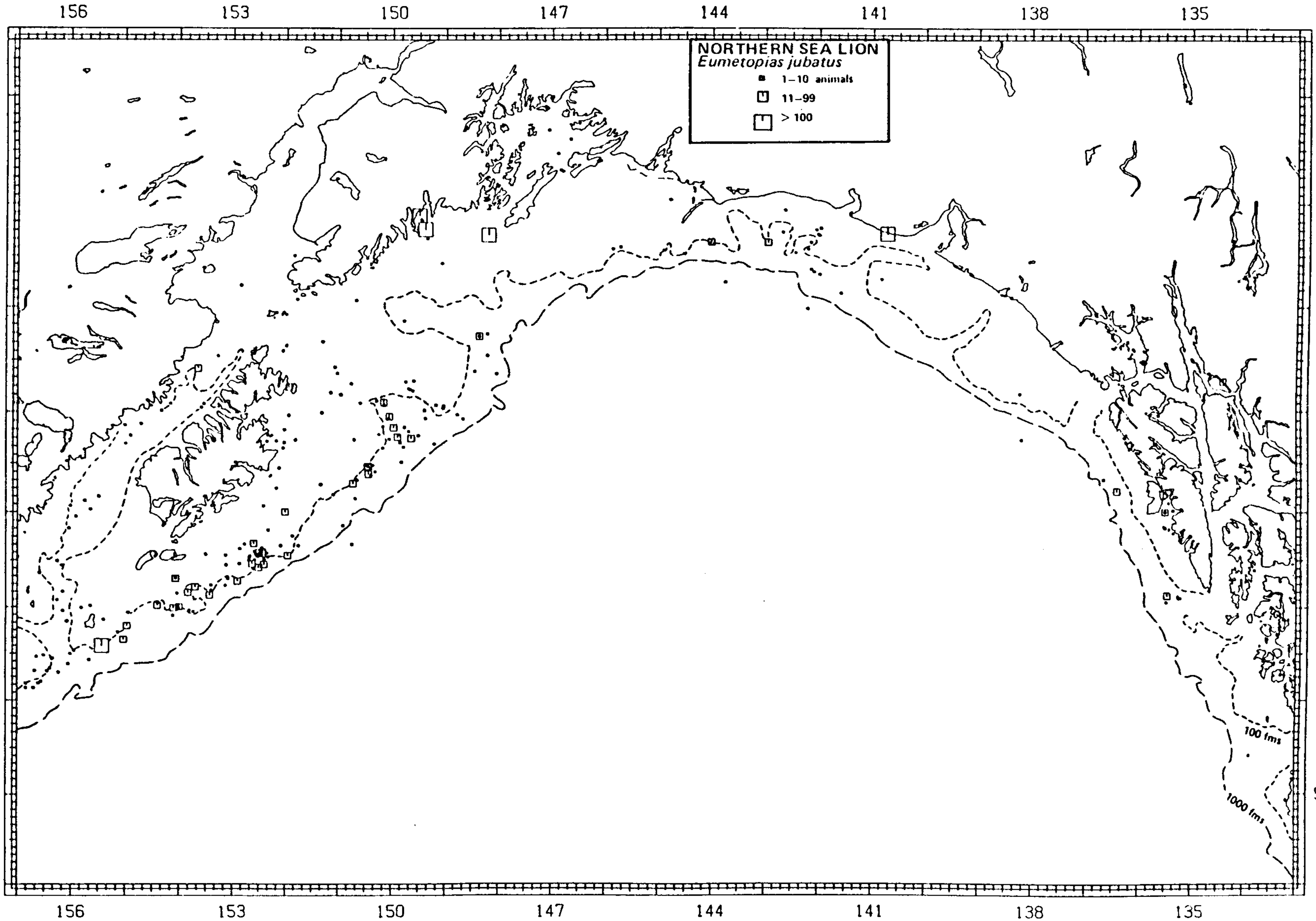

Figure 34.–Northern sea lion sightings, winter (January-March) 1958-80.

an artifact of watch effort is unknown. In the northeast Gulf there were three significant concentrations nearshore between Icy and Yakutat bays, and off Montague Island to the Kenai Peninsula. As in summer and autumn, sea lions appear farther offshore (to the 200-m contour) than in spring (Figures 34-37). The areas of large numbers of sea lion sightings are: Kayak Island area, Montague Island, Portlock Bank (east of Afognak Island), south edge of Kodiak Island, and the Trinity Islands.

Summer sightings (Figure 36), like those in spring, occurred more often from Yakutat Bay to Unimak Pass, but large numbers were off Kodiak Island. Group sizes were larger off southwest Alaska and at Kodiak Island than elsewhere. Sightings were more widespread shoreward from the 200-m contour than in other months, probably a reflection of animals moving shoreward to haul out and to breed.

In summer, adult sea lions are on or close to the breeding rookeries, but during the rest of the year, except perhaps winter, large groups of sea lions make feeding forays that range from 5 to up to 15 miles from shore. Those that do venture farther to sea are more likely to be found as singles or in smaller groups of 2-12 (Fiscus and Baines 1966). Plots of sea lion sightings in summer showed large groups near important breeding areas, as well as at or near the 200-m contour, especially from the Trinity Islands to Yakutat Bay (offshore). It is noteworthy that many sightings occur off the 200-m contour while adjacent sightings are at that depth. This suggests that perhaps something other than the shelf break at these depths is influencing their distribution. Since it is most likely that animals sighted out at sea are feeding, we presume their distribution reflects areas of fish distribution and abundance, and perhaps areas of important upwellings.

In autumn, sea lions were seen mainly on Albatross and Portlock banks and along the continental shelfbreak to the Shumagin Islands (Figure 37). Few sightings were reported from the Shumagin Islands to Unimak Pass. The fewer sightings in autumn is a reflection of reduced effort; however, it is also likely that significant numbers of animals in early autumn (*e.g.*, September and October) were hauled out on land to moult.

California Sea Lion (*Zalophus californianus*)

The first, and only, known California sea lion sighting in the Gulf of Alaska is that of an adult male on Elrington Island, Prince William Sound, in June 1973 (K. Schneider, pers. commun.)

The California sea lion's major breeding area is off the coast of Baja California, Mexico to San Miguel Island in southern California (Peterson and Bartholomew 1967). The population is estimated to be more than 100,000 animals (Maser *et al.* 1981). Following the pupping and breeding season in May and June many of the adult males move north. During winter there have been regular sightings of California sea lions in southern British Columbia, with the greatest numbers seen in February (Bigg 1973). There are no Platforms of Opportunity

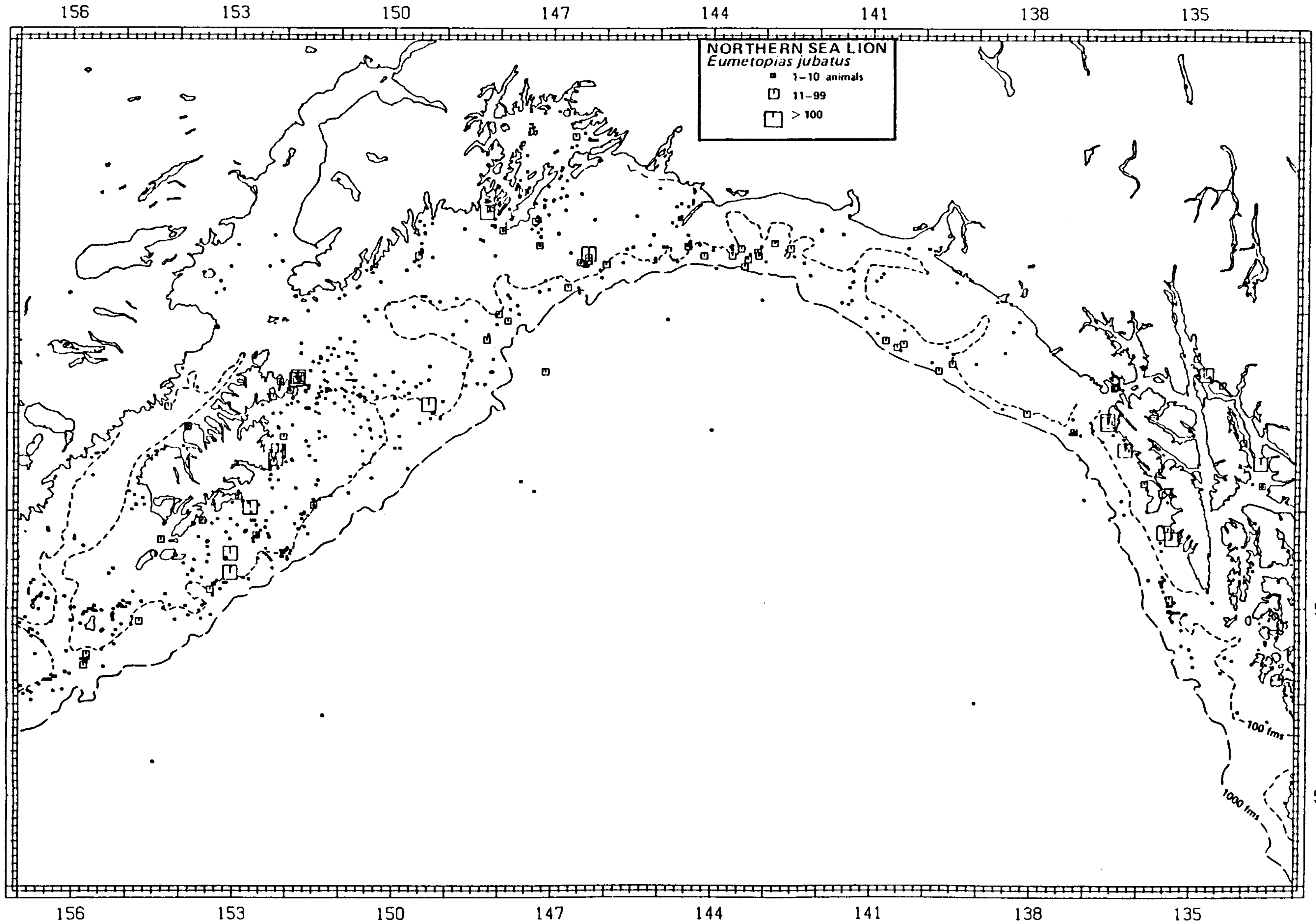

Figure 35.–Northern sea lion sightings, spring (April-June) 1958-80.

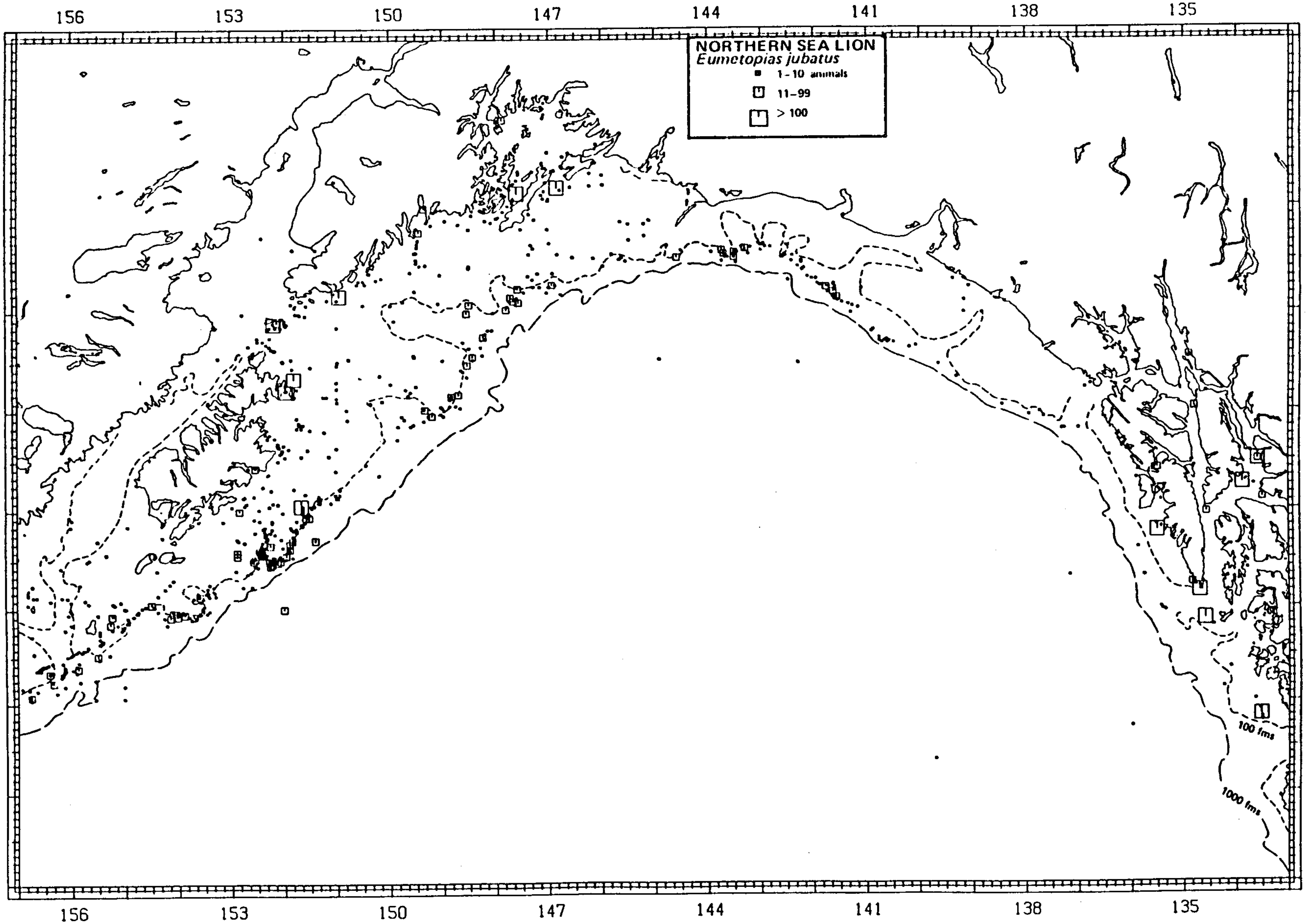

Figure 36.–Northern sea lion sightings, summer (July-September) 1958-80.

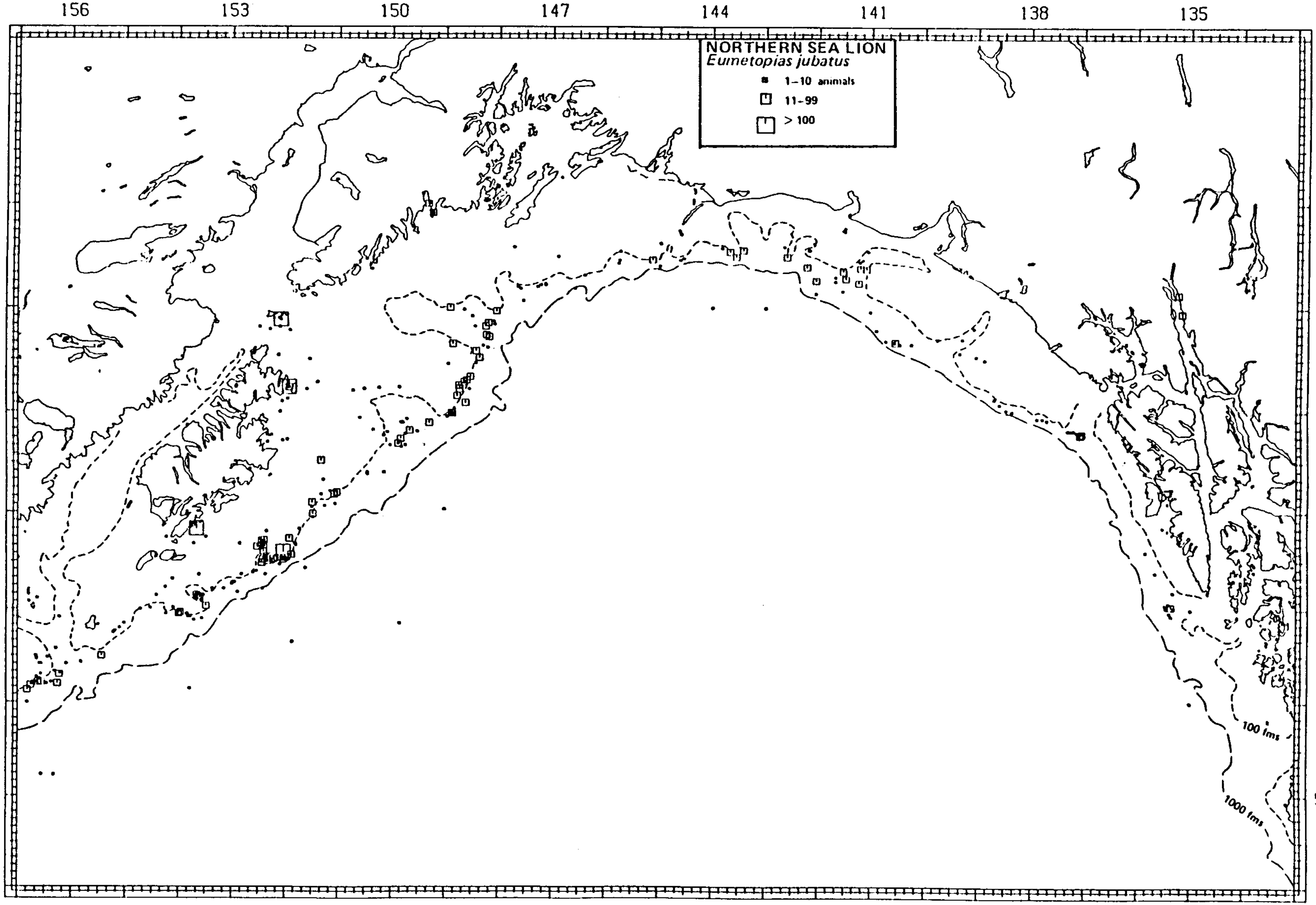

Figure 37.–Northern sea lion sightings, autumn (October-December) 1958-80.

sightings in the Gulf of Alaska, although this does not preclude the possibility of stray animals in this area, as illustrated by Schneider's sighting.

Harbor Seal (*Phoca vitulina*)

The harbor seal is distributed along virtually the entire rim of the Gulf of Alaska (Pitcher and Calkins 1979). It is generally found near shore and in relatively sheltered waters (Figures 38-41), but occurs occasionally well offshore. Figures 39 and 40 show a number of sightings offshore, though still over the shelf. Pitcher (1977) reported a number of harbor seals being spotted up to 50 miles off the coast, these usually being single animals.

The world's largest breeding colony of harbor seals is found in the Gulf of Alaska on Tugidak Island, southwest of Kodiak Island. In September 1976 the minimum population was estimated to be 13,000 seals (Pitcher and Calkins 1977).

In the Gulf of Alaska male harbor seals reach sexual maturity at 5 to 6 years of age and females usually by 5 years. Ovulation and breeding take place in late June to late July, with pupping occurring from 20 May to 25 June (Pitcher and Calkins 1979).

Using frequency of occurrence as an indicator of prey importance, fishes made up approximately 74% of the harbor seal diet, cephalopods 22% and decapod crustaceans 4%. Pollock (*Theragra chalcogramma*), octopus (*Octopus* sp.), and capelin (*Mallotus villosus*) were the most important prey species overall, with Pacific cod (*Gadus macrocephalus*), herring (*Clupea harengus*), and sand lance (*Ammodytes hexapterus*) also being eaten (Pitcher and Calkins 1979).

Harbor seal habitat, feeding habits and distribution are thoroughly covered by Pitcher and Calkins (1979), for the Gulf of Alaska, and by Pitcher (1977) for Prince William Sound.

Northern Elephant Seal (*Mirounga angustirostris*)

Though the northern elephant seal is normally found in its breeding range of Cabo San Lazaro, Baja to Point Reyes in California during the months of November through February, it has been known to occasionally venture north into Alaskan waters (De Long 1978). The northward migrants are usually bulls, perhaps moving north to take advantage of the waters rich in food because of their need to match food intake to their rapid growth (Radford *et al.* 1965). The population was estimated to be approximately 60,000 in 1977 (LeBoeuf and Bonnell 1980).

We know of seven sightings from Alaskan waters (Table 5).

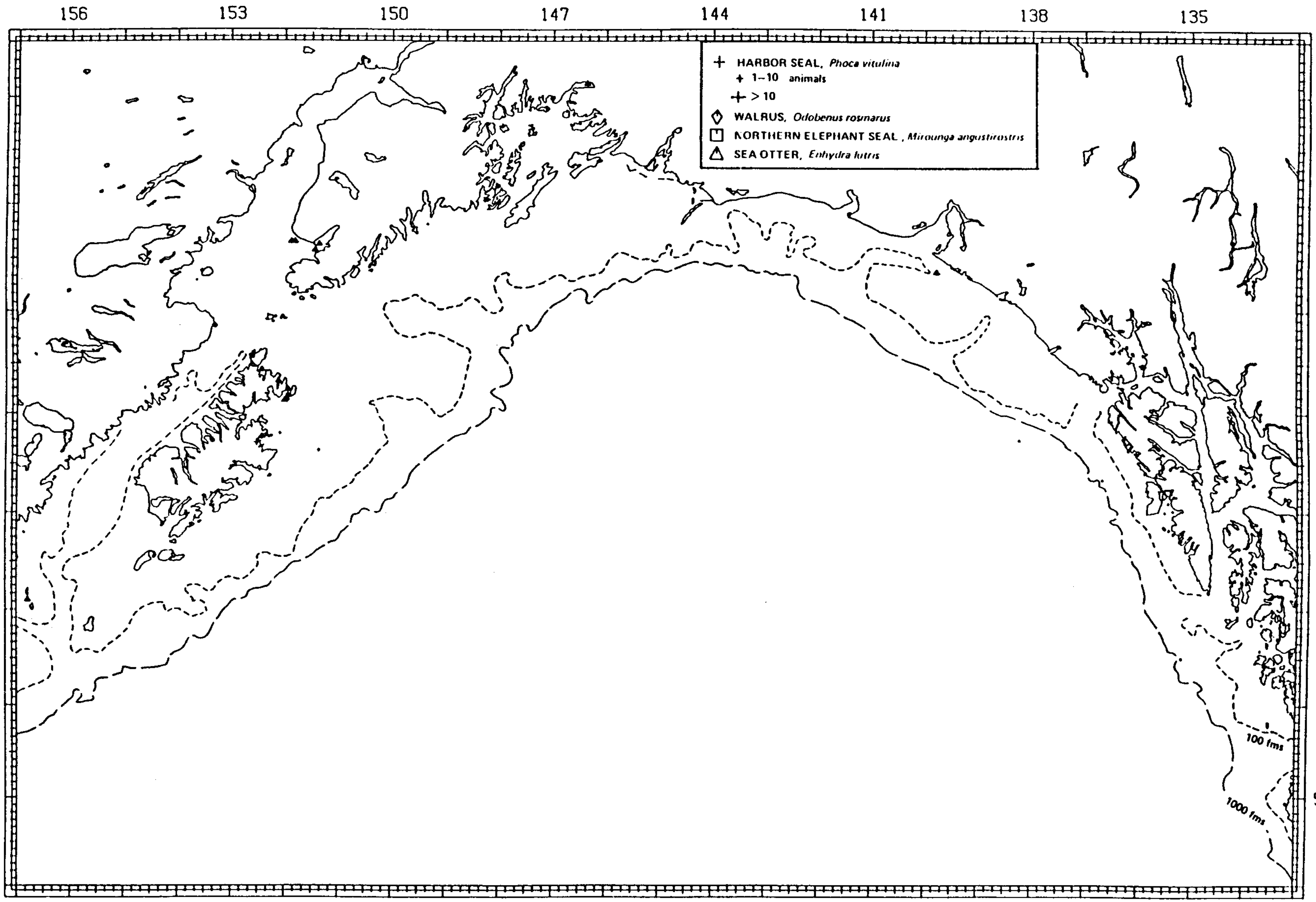

Figure 38.–Harbor seal, northern elephant seal, walrus and sea otter sightings, winter (January-March) 1958-80.

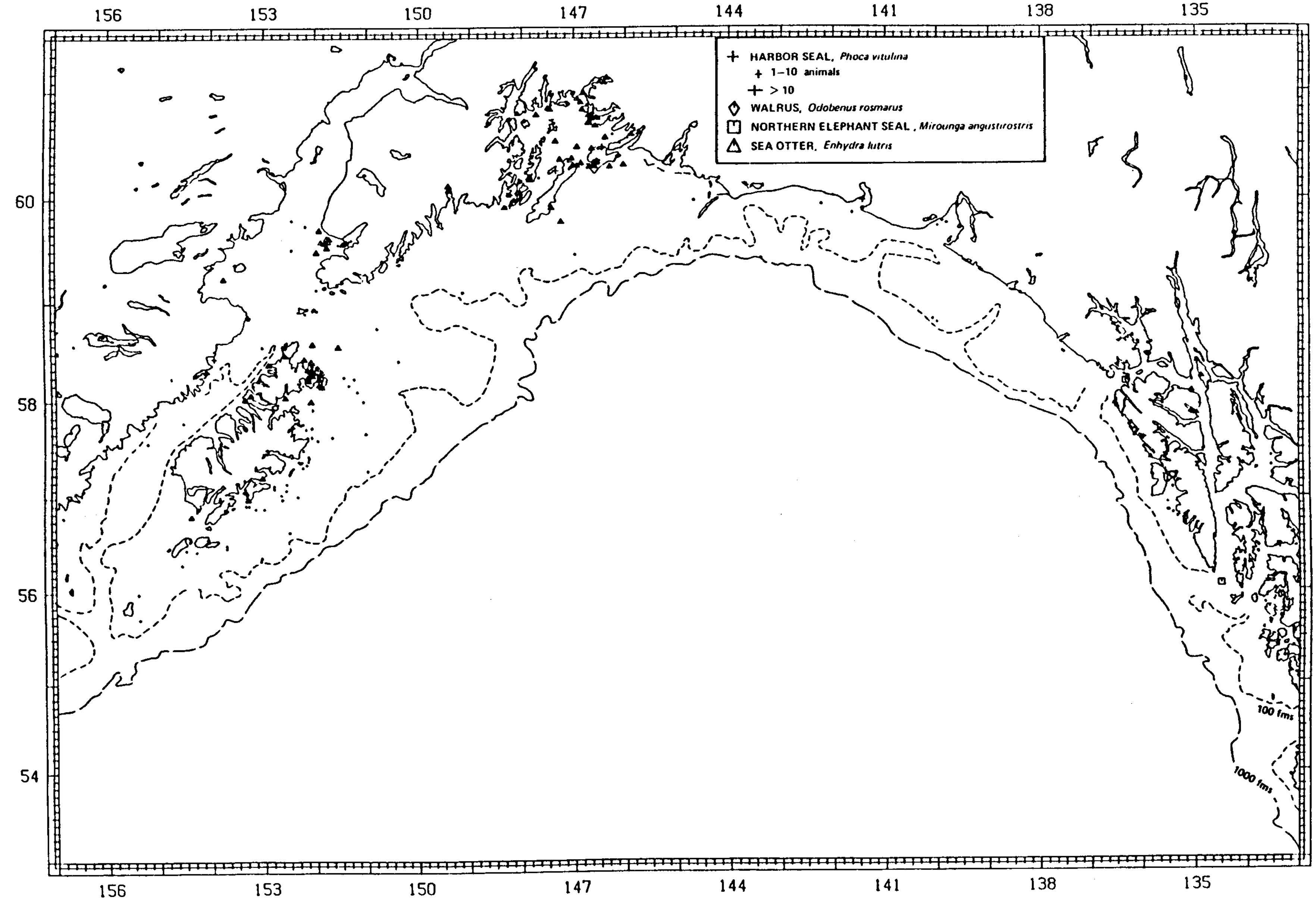

Figure 39.–Harbor seal, northern elephant seal, walrus and sea otter sightings, spring (April-June) 1958-80.

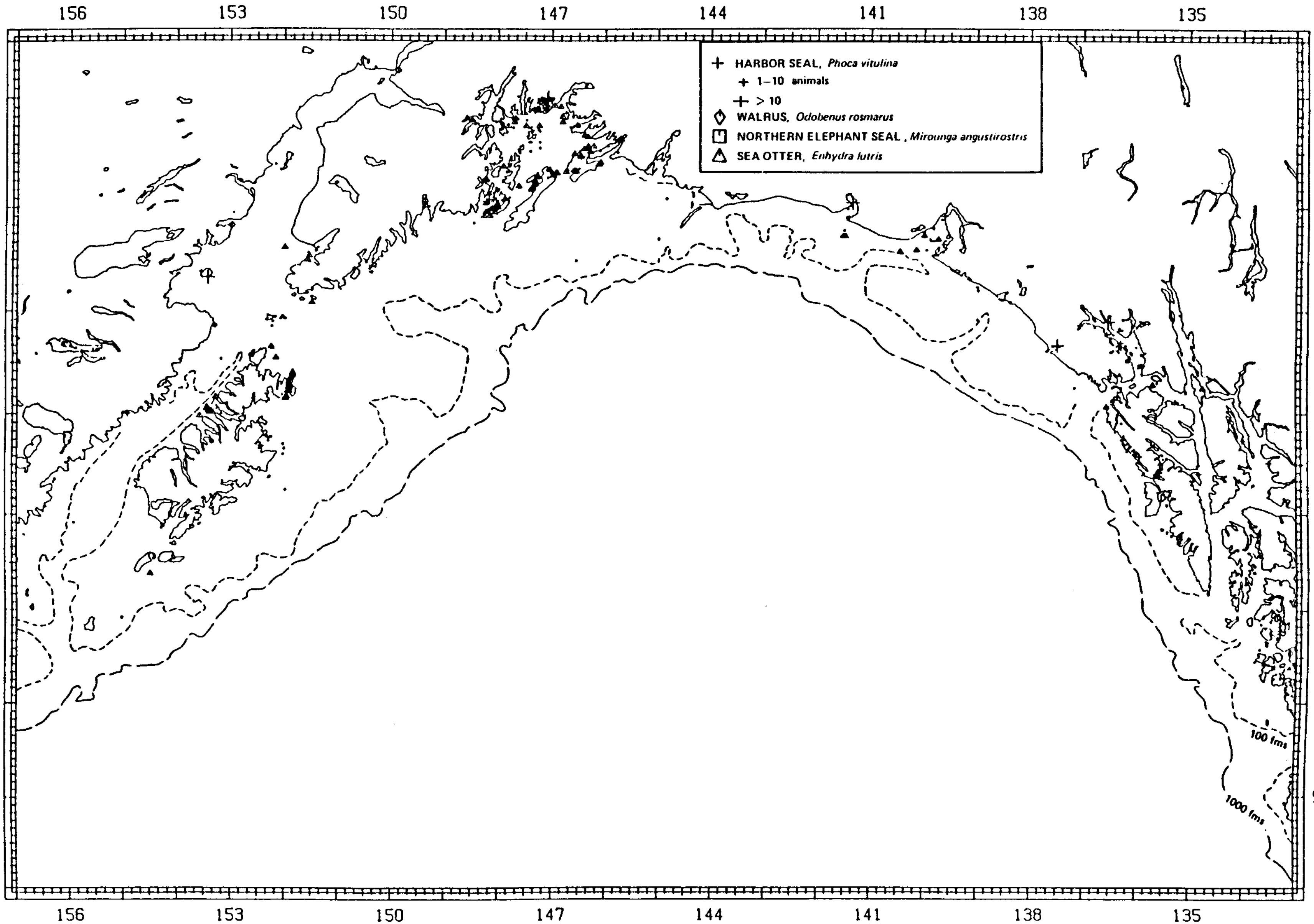

Figure 40.–Harbor seal, northern elephant seal, walrus and sea otter sightings, summer (July-September) 1958-80.

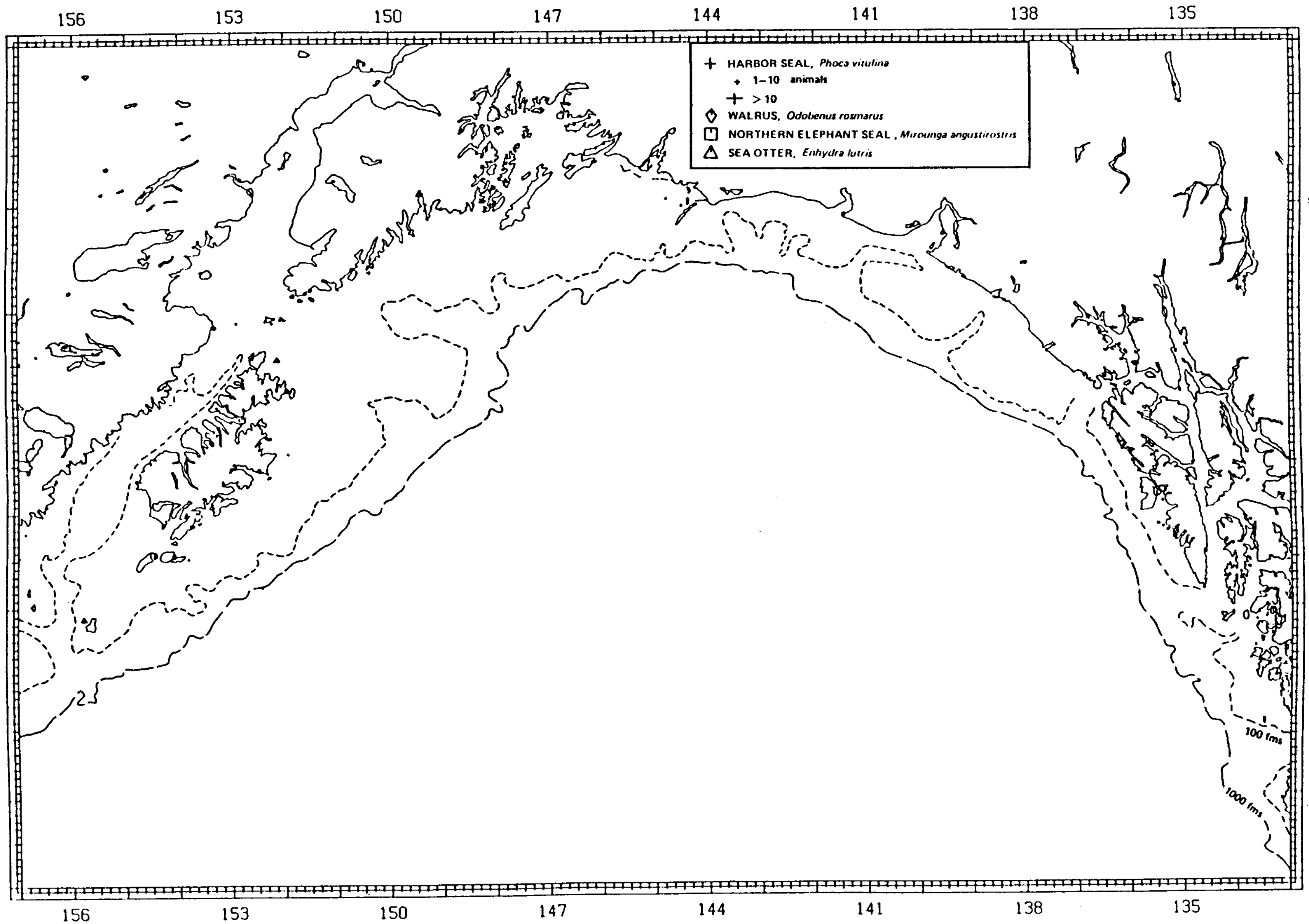

Figure 41.–Harbor seal, northern elephant seal, walrus and sea otter sightings, autumn (October-December) 1958-80.

Table 5.–Sightings of elephant seals in Alaskan waters.

Date	Location	Description	Source
February 1940	Prince of Wales Island, SE Alaska	Dead adult male	Willet 1943
5 May 1962	56°04'N 134°31'W	A live male	POP files (Figure 38)
1 June 1972	58°12'N 136°21'W	Dead	POP files (Figure 38)
April 1975	Middleton Island	Dead immature male	D. Calkins, pers. commun.
29 May 1975	59°21'N 145°51'W (near Middleton I.)	Alive	POP files
4 July 1977	Ugamak Island (Unimak Pass)	Young male	D. Withrow, pers. commun.
July 1978	Ugamak Island	Young male	D. Withrow, pers. commun.

Walrus (*Odobenus rosmarus*)

The normal range of the Pacific walrus extends from Bristol Bay in the southeastern Bering Sea to the Chukchi Sea, and, for the most part, is closely associated with the movement of pack ice. Aerial surveys flown in 1975 resulted in a population estimate of about 200,000 animals (± 40%) in the Bering and Chukchi seas (Estes and Gilbert 1978). Though most of these animals follow the ice northward in late spring and summer, a large and increasing number spend the summer on Round Island, in northern Bristol Bay. The Round Island population (composed almost exclusively of males) increased from about 2,000 in 1958 (Kenyon 1978) to 8,000-10,000 in 1976 (Krogman *et al.* 1979), to 12,000-18,000 by 1981, (J. Taggart, pers. commun.). As this population has increased, so has the number of sightings south of the Alaska Peninsula and in the Gulf of Alaska.

Murie (1959) reported records of walrus sightings from the 1700s to the early 1900s, though not in any numbers. Calkins *et al.* (1975) reported sighting records of walruses in Prince William Sound and Cook Inlet. Bailey and Faust (1981) sighted a single walrus at both Spitz and Mitrofania islands on 5 July 1979 and reported an observation of three walruses in Chignik Bay in July 1979. The Alaska Department of Fish and Game has received sightings of walruses over the past 4 years from the south side of the Alaska Peninsula to Icy Bay, most frequently around Sanak Island, 60 nmi east of Unimak pass (J. Burns, pers. commun.).

Two walrus sightings, both from Cook Inlet, are in the POP files (Figure 40). Personnel aboard the NOAA ship *Rainier* sighted a lone walrus at 61°15'N, 149°53'W on 2 July 1979. From the NOAA ship *Fairweather* a lone sighting of a walrus was made at 59°50'N 152°59'W on 14 July 1979.

Given the current high (expanding) Bering Sea walrus population, it is reasonable to expect some occasional sightings in the Gulf of Alaska.

Sea Otter (*Enhydra lutris*)

Sea otters were sighted near shore during all seasons (Figures 37-40). Sightings were restricted to coastal waters, mainly near Afognak Island and Prince William Sound. Tentative sightings farther offshore (not depicted) in all probability represent storm-blown sea otters or misidentified northern fur seals.

DISCUSSION

Northeast Gulf (Site No. 55)

Endangered Cetaceans

The northeast Gulf of Alaska is (or was historically) a seasonal feeding or migratory area for all species of endangered cetaceans, especially the area adjacent to Fairweather Ground and southeast of Yakutat Bay. Virtually the entire population of gray whales migrates nearshore between the sale site and the coast twice annually, with some animals undoubtedly entering at least the mouth of Yakutat Bay. Increased boat traffic associated with oil development may also have a negative impact on gray and humpback whales. As previously related, vessel traffic in Baja California displaced breeding gray whales. On the other hand, migrating gray whales pass through areas of heavy vessel traffic off California twice annually and apparently are little disturbed. If anything, heavy vessel traffic around Yakutat Bay may cause an offshore dip in the normal migratory route.

Studies are currently in progress to determine what effects vessel traffic is having on the humpback whale population in southeast Alaska. The results of these studies will be directly relevant, as some of the humpbacks found in or near lease site No. 55 probably spend some time in southeast Alaska waters and/or Prince William Sound as well, during any year. Some 5-10 humpback whales have been noted in Yakutat Bay over the past decade by local fishermen, often in association with herring runs in late June and early July. These animals move in and out of the bay (thus they could be different groups using the area). During the summer of 1981, only a few humpback whales were sighted in the bay (Sarah Hinckley, NMFS, pers. commun.). Whether this apparent decrease in use of the bay is related to increased vessel activity or natural environmental changes (*i.e.*, a shift in prey abundance) is uncertain.

The northeast Gulf of Alaska was not known as a former area of particular abundance for the highly endangered right whale, yet these cetaceans are coastal in nature and the nearshore waters of the eastern Gulf were probably part of the migratory corridor for right whales moving from coastal Californian and Mexican breeding grounds to summering grounds in the western Gulf and eastern Aleutian Islands. It is of interest to note that three of the four tentative sightings of right whales since 1977 occurred in the northeast Gulf of Alaska, though these cannot be cited as proof that right whales occur there. Right whale numbers are so low throughout the North Pacific that they are probably on the verge of extinction. Any type of disturbance, direct or indirect, from OCS development would be especially deleterious.

Blue and sei whale sightings have been very rare in the entire study area over the past 20 years, yet the northeast Gulf is an area of previous high density. We believe that blue and sei whale populations are significantly depleted throughout the Gulf of Alaska, especially blue whale populations, and thus, as in the case of right whales, any disturbance related to OCS development would have a negative impact on them.

Fin whales appear to favor the central and western areas of the Gulf of Alaska during summer months, with few apparently remaining in the eastern Gulf. They do, however, pass through lease site No. 55 during spring and autumn.

Sperm whales occasionally traverse lease site No. 55; mostly solitary old bulls and gregarious young males. Their generally offshore distribution, along with their benthic feeding habits, should ensure relatively little disturbance to the population in the northeast Gulf of Alaska.

Small Cetaceans

Six species of small cetaceans appear to use the northeast Gulf as summer feeding grounds: minke whale, killer whale, white whale, Pacific white-sided dolphin, Dall porpoise, and harbor porpoise.

Minke whales are known to be seasonal residents of Yakutat Bay and to visit the shelf, slope, and deepwater areas to the south and southeast. Both killer whales and white whales are observed annually entering Yakutat Bay in connection with salmon runs–killer whales in small groups, and white whales in groups of 10 to 20. The white whales have been observed for the past decade, yet their numbers remain low. The nearest population of white whales resides in Cook Inlet, over 360 nmi distant.

Dall porpoises have been observed both in the open areas of Yakutat Bay and throughout the waters of the northeast Gulf. Ten to twenty harbor porpoises have been observed in Yakutat Bay. The presence of calves with adults indicates local breeding may occur. Pacific white-sided dolphins apparently use lease site No. 55 as an important summer feeding area. Of the entire Gulf of Alaska, most sightings of white-sided dolphins occurred over this lease site. As this species tolerates vessel traffic and often bowrides in southern California waters, disturbance due to increased OCS-related vessel activity should be minimal. However, as white-sided dolphins often travel in groups of 100 to several thousand animals and are surface oriented, the potential for direct contract with oil in the case of a leak or blowout is greatest at lease site No. 55, more so than at other lease sites in the Gulf of Alaska.

Northern Gulf (Site No. 39)

Endangered Cetaceans

The northern Gulf of Alaska is an important feeding ground for at least one species of endangered cetacean, and is an important migratory corridor for two others. Fin whales appear to congregate in the northern Gulf around Middleton Island during the summer months, some moving farther north into Prince William Sound. Humpback whale sightings in this area are relatively sparse. As lease site No. 39 lies directly between two recognized humpback whale summering grounds, it should be considered an important transition area for animals moving between Prince William Sound and southeast Alaska. This needs study because we do not know how much, if any, exchange occurs. The migratory route of gray whales takes these endangered cetaceans along the nearshore waters of the northern Gulf. A potential area of disturbance to gray whales during migratory periods (November-January and March-June) is the eastern shore of Kayak Island. Gray whales have been observed right in the surf of Kayak Island and there may be some bunching of whales at this place as pulses of animals prepare to round Cape St. Elias.

Bull sperm whales and sei whales are present, but apparently not in large numbers during spring and probably summer. Right whales were historically present in the northern Gulf of Alaska, yet we have no positive sightings. We assume that right whales are present in this area during spring, summer, and early autumn, but in very low numbers. Blue whale sightings in this area are likewise nonexistent, yet their historical centers of abundance lay to the east and west in the Gulf.

Small Cetaceans

Killer whales and minke whales are present in the northern Gulf during spring and summer, and possibly year-round, though sightings are sparse in autumn and winter. The few white whales that move into Yakutat Bay during summer salmon runs probably pass through lease site No. 39 en route from Cook Inlet. Goosebeak and giant bottlenose whales inhabit the deep waters around the southern perimeter of this sale site, but are rare. Dall porpoises are abundant in the northern Gulf from spring through autumn, and are probably year-round residents, though winter sightings are few. Harbor porpoise sightings are sparse, though this species is abundant in nearby Prince William Sound, and the Copper River delta. Pacific white-sided dolphins appear to favor the slope between the 100- and 1,000-fathom contours in the northern Gulf. Several sightings of large groups (> 100 animals) of white-sided dolphins are on record during both spring and summer.

Western Gulf-Kodiak (Site No. 46)

Endangered Cetaceans

The migratory path of gray whales takes most of the entire population along the eastern nearshore edge of Kodiak Island, numbers being highest during April and May and in late November and December. Except near the Trinity Islands and Chirikof Island (south of Kodiak Island), gray whales probably pass near shore rather than through the sale site blocks proper. Direct effects from an oil well blowout, coupled with persistent onshore winds and currents, would likely only occur shoreward from the lease sites. Present vessel disturbance is expected to be minimal in this area, as most traffic is fisheries-related and occurs during the late spring, summer, and early autumn when gray whales are generally not present. An exception might be when vessel traffic is moving into nearshore coastal waters of Kodiak. An unquantified but small number of gray whales are known to migrate through Shelikof Strait. The effects of increased use of vessels or other OCS activities on the gray whale migration are unknown, but alternate use of Shelikof Strait by gray whales during their migration may be one clue to its displacement, should it occur.

Humpback whales use the entire lease area for feeding during spring, summer, and autumn, occurring very close to shore and seaward over Albatross and Portlock banks. As with southeast Alaska and Prince William Sound, lease site No. 46 and the coastal waters of Kodiak Island are principal areas frequented by humpback whales for at least 7-8 months per year. These areas probably include vital and certainly important habitat for this species in the eastern North Pacific.

Sperm whales occur along the slope and over the deep water in and near lease site No. 46, yet are apparently few and disturbance to the population in this area from OCS development should be minimal. Females with calves remain in warmer southern waters all year.

Fin whales are seen throughout lease site No. 46, most often in small groups. However, in July of 1980 a group of approximately 63 animals was sighted between Chirikof Island and the Trinity Islands. This sighting represents the largest known group ever observed in this study area. These animals apparently were traveling. Calves were present. The significance of such a large group is not certain, but we believe the animals were capitalizing on nearby locally abundant food resources.

Sightings of blue whales, right whales, and sei whales were very infrequent, or nonexistent, over the past decade in the western Gulf of Alaska. Lease site No. 46 was historically a popular whaling area for these species, hence we believe these whales are still present but in numbers too small to provide an abundance or density estimate. Blue and right whale populations in the North Pacific may be particularly vulnerable to any adverse activities, thus delineation as to numbers and habitat use would be valuable information for investigating possible OCS development.

Small Cetaceans

Year-round small cetacean residents in lease site No. 46 include killer whales, Dall porpoises, and harbor porpoises. We currently have no documented resident pods of killer whales (*i.e.*, repeat sightings of recognizable individual animals), yet they are seen with enough regularity, and their local food resources are generally abundant, that we assume some occur year-round. Dall porpoises have been sighted in all seasons throughout Alaska south of the Bering Sea, and are ubiquitous and abundant in the study area. They are attracted to vessels, on occasion, but the effects of this and subsequent development and increased traffic are unknown. Studies of ship avoidance have not been conducted. Harbor porpoises likewise are present year-round singly or in small groups, and almost always are seen in coastal, shallow waters. Sightings taper off as the continental slope is approached. Certain areas seem to support populations of harbor porpoise in the presence of light, seasonal ship traffic (Monterey, California; Copper River Delta, Alaska). However, in other areas (San Francisco Bay, California; Puget Sound, Washington), with year-round heavy vessel traffic and development activity, population declines have been witnessed (Leatherwood and Reeves 1978). Given the serious lack of behavioral and life history data on harbor porpoises in the North Pacific, it is difficult to do more than speculate on particular areas of vulnerability. We believe, however, that harbor porpoises will be impacted by coastal development, especially concentrated onshore support facilities.

It is unclear whether minke whales remain in the western Gulf of Alaska during the late autumn and winter. The numerous bays and coastal areas that provide habitat for humpback whales and harbor porpoises similarly provide seemingly ideal habitat for minke whales. However, our records contain no winter sightings in this area, and only a few autumn sightings. They are a coastal and nearshore species in the Gulf, feed heavily on fishes, and frequent the lease areas. Thus, they too might be vulnerable to impact (at least individuals), but the level or extent, of course, is unknown.

Pacific white-sided dolphins appear to move west along the edge of the continental shelf as far as Portlock Bank during the summer, although sightings are fewer in the western than the eastern Gulf of Alaska. Data on goosebeak whales and Bering Sea beaked whales are insufficient to make any assessment. White whales, northern right whale dolphins, giant bottlenose whales, Risso's dolphins, and short-finned pilot whales are rare visitors to this area and their centers of population abundance appear farther south (except the white whale). The effects of OCS development on these populations are likely to be minimal or negligible.

Lower Cook Inlet-Shelikof Strait (Site No. 60)

Endangered Cetaceans

Only three species of endangered cetacean are expected to occur in lease site No. 60: humpback whale, fin whale, and gray whale. We have no sightings of any of these three species in the actual sale site, yet each species has been seen in close proximity to the site. Effort in this area is sparse and may account, in part, for the few sightings of all species.

Humpback whales begin moving into the northwest Gulf of Alaska during the spring and use the area around the Barren Islands as a summering ground. Fin whales, as evidenced by sightings in central Shelikof Strait in March 1980, at least occasionally overwinter in or migrate early into this area. A group of approximately 21 fin whales was observed nearshore in Kinak Bay (58°05'N, 154°22'W), Shelikof Strait in June 1980 very near the southern perimeter of lease site No. 60. Thus it is likely that fin whales occupy at least the southern section (upper Shelikof Strait) of this lease site from late winter through late spring, and possibly through summer as well. An unknown, but small, percentage of the entire gray whale population passes through (or very near) the southern section of lease site No. 60 twice annually during spring and autumn migrations.

Small Cetaceans

Killer and minke whales inhabit this sale site at least from spring through autumn. The resident white whale population in Cook Inlet appears to remain mostly in the upper end, though we expect some animals to occupy the lower end as well. Surprisingly few sightings of harbor porpoises were made in this area, though they are probably year-round residents here. Dall porpoises were found during all seasons in this lease site.

CONCLUSIONS AND RECOMMENDATIONS

Catch per unit effort (CPUE) data for population estimates have not been available for the balaenopterid whales (blue, sei, fin, minke, humpback) since their protection in the 1960s and early 1970s and do not exist for the right whale. Sperm whale population estimates have varied widely over the past decade, though numbers based on catch per unit effort are current and indicate healthy stocks. In fact, the gray whale is the only endangered cetacean for which we have good confidence of how many pass through the Gulf of Alaska.

Offshore migratory routes and patchy distributions of endangered cetaceans result in limited success of vessel surveys over large areas. A 1977 Japanese vessel survey, covering 22,143 linear nautical miles of the North Pacific, yielded sightings of 11 fin, 33 sei, 7 blue, 6 humpback, and 4 right whales (Wada 1979). Obviously, indices of abundance and population estimates extrapolated from such low figures are of limited utility. Rice and Wolman (1982) covered 3,303 linear nautical miles in the Gulf of Alaska in 1980 and saw too few endangered cetaceans to calculate statistically valid population estimates. They estimated a Gulf of Alaska summer population of 159 fin whales (based on 13 animals seen during transects) and 306 (25 animals seen) humpback whales (without confidence limits), yet other 1980 POP data indicate that their fin whale estimate was low. Sightings of 21 and 63 fin whales (two groups) were made in the general area bounded by the Semidi Islands, Chirikof Island, and middle Shelikof Strait in June 1980 (unpubl. POP data).

This example of differing counts of fin whales is where the utility of our marine mammal Platforms of Opportunity Program is realized. At very little cost, suspected areas of high cetacean density may be discovered, incorporated into the POP system and made available for planning studies in the Alaska region. To provide greater meaning to abundance and distribution assessment, the accumulation of greater amounts of data including systematic studies in known or probable high density areas will be necessary.

Based on our combined shipboard experience of over 150,000 nmi in Alaskan waters during all seasons since 1958, we believe that prevailing sea states and low ceilings eliminate the practicality of offshore aerial surveys except during summer. Scott and Winn (1980:3), comparing aerial and vessel surveys of humpback whales, concluded that "the shipboard platform yielded sampling estimates that were both more accurate and precise than the aerial estimates and that shipboard platforms be used when practical." The utility of aerial survey is greater coverage in a shorter time period at somewhat reduced expense, depending on aircraft versus vessel charter costs.

After assessment of the estimated population sizes, evidence for recovery (potential), and seasonal use of habitat in or adjacent to the four OCS lease sites in the Gulf of Alaska, we believe that a ranking can be made of the potential for vulnerability by species by lease area (Table 6). The gray whale ranks high among all species because it might be the species most likely affected throughout the Gulf from onshore activities such as tanker traffic and coastal oil spills. However, the right and humpback whales are clearly the more "vulnerable" species because of their low population sizes. In term of endangered status, right and humpback whales are of particular concern.

The following abbreviated research subjects are recommended for the endangered species. These studies should add to our understanding of habitat use, areas of concentration, and population structure.

Fin Whales

1. Conduct aerial or vessel surveys of the Shelikof Strait, Kodiak Island, and Semidi Island area to ascertain the seasonal distribution and density of fin whales. Systematic surveys would help determine temporal or spatial use patterns near and adjacent to the existing oil lease areas from lower Cook Inlet to Kodiak Island. These areas, and to a lesser degree off Yakutat (Fairweather Ground), are identified areas of fin whale occurrence.

Table 6.–Relative rankings of endangered whales by lease site in the Gulf of Alaska believed to be affected by oil and gas activities should any effects result. Ranks were judged to be related to each species population status (relative to each other) and evaluated on the basis of abundance, time spent in or adjacent to each lease site, and habitat use patterns. These are subjective judgements by the authors.

Northern GOA (Lease No. 39)	Kodiak (Lease No. 46)	Northeast GOA (Lease No. 55)	Shelikof Strait-Lower Cook Inlet (Lease No. 60)
Gray whale	Humpback whale	Gray whale	Humpback whale
Humpback whale	Gray whale	Humpback whale	Fin whale
Right whale	Right whale	Right whale	Gray whale
Fin whale	Fin whale	Blue whale	Right whale
Blue whale	Blue whale	Sei whale	
Sei whale	Sei whale	Fin whale	
Sperm whale	Sperm whale	Sperm whale	

2. Aerial photogrammetry of individual sizes of each group may provide insight to herd (or population) composition and give some indication of production. Generally speaking, no data are available on the presence of fin whale calves in the Gulf of Alaska.

3. Radiotagging of individuals in large groups may provide insight into group cohesiveness and movements from this area to other areas in the Gulf of Alaska. This may provide further information on the identity of stocks or geographic units which remain in one area during the year, or whether the animals are diffusely distributed and simply move in and out of the study area among seasons.

Gray Whales

1. Aerial surveys and onshore observations canvassing the waters north of Kodiak and Afognak islands during spring and autumn migration should be conducted to determine what percentage of this population migrates through Shelikof Strait rather than along the southeastern coast of Kodiak Island.

2. Aerial surveys and shore observations at proposed lease site support shore facilities (Kodiak Island, Yakutat Bay, others) to document the frequency versus offshore migratory patterns are needed.

3. Feeding and behavior observations during migration should be conducted to determine what time is spent feeding and to document feeding areas, and thus assess the importance of feeding and these areas to the movements of gray whales.

Humpback Whales

1. Collection of fluke photographs throughout the Gulf of Alaska to determine interchange between apparently local populations, and provide clues to migratory routes between winter and summer grounds and within Alaskan waters; and potential stock identity.

2. Documentation of previously unreported summering areas. Recent studies have focused on Prince William Sound and southeast Alaska. Our data indicate Yakutat Bay, the Barren Islands, and other coastal waters and bays (*e.g.*, Chiniak Bay and Alitak Bay) of Kodiak Island are areas which also provide important seasonal habitat (food supplies?). Little or no documentation of numbers, movements, or behavior are available, however.

Right, Blue, and Sei Whales

It seems likely that the numbers of right and blue whales in the Gulf of Alaska are so low that any population increases (and there is no basis to assume these two populations are increasing) would go undetected for at least several decades. The North Pacific sei whale population, on the other hand, appears to be viable, yet sightings in the Gulf of Alaska are few. They are likely found farther south in summer. However, their apparent scarcity may be due to their habit of traveling singly or in very small groups.

Continuation and upgrading of the POP through cooperation with more groups, supplying better training for more individuals, and greater dedication to quantifiable observer effort is warranted before any additional conclusion can be reached concerning the presence and possible vulnerability of right, blue, and sei whales–of most whales, for that matter.

Sperm Whale

As few sperm whales enter the study area (relative to their more southern center of distribution), no specific studies are recommended. Most pelagic studies can be generalized to study all species. Coastal or site-specific studies have special relevance (*e.g.*, gray whale migration, humpback or fin whale concentrations off Kodiak or Shelikof Strait, respectively).

Other Cetaceans

Other than Hall's (1979) estimate of 1,946 harbor porpoises inhabiting Prince William Sound and the nearby Copper River delta, no abundance or refined distribution estimates are available in the Gulf of Alaska for this species. The same may be said of minke and killer whales as well. As these three species frequent nearshore waters, their distribution is underrepresented in our data base. The amount of presumably acceptable habitat in the Gulf of Alaska is large, particularly around Kodiak Island and Shelikof Strait. A habitat classification scheme (based on presumed requirements) may prove useful in extrapolating distribution and abundance estimates. Further study of the food resources and oceanographic literature is recommended as an extension of our study. Nearshore aerial or small craft surveys conducted during periods of (presumed) maximum (summer) and minimum (winter) abundance would delineate current habitat use, or at least presence and absence, and provide the basis for density or abundance estimates as well.

In addition, such surveys, when combined with offshore vessel surveys, should aid in determining seasonal onshore-offshore movements of these small cetaceans as well as of fin, gray, and humpback whales which seasonally frequent nearshore waters.

C. Harrison (pers. commun.) sighted 117 groups of Dall porpoises during aerial surveys in the Gulf of Alaska and Bering Sea, yet observed no roostertailing behavior. Thus it may be that roostertailing occurs mainly as a response to vessels. If Dall porpoises slow-roll normally, then vessel sighting surveys may miss a (significant?) portion of the animals present due to their inconspicuousness. Simultaneous aerial-vessel studies are needed to determine: (1) Dall porpoises attraction/avoidance to vessels, and (2) a rough percentage of Dall porpoises which roostertail (thus increasing the likelihood of being observed) in the presence of vessels. Appropriate correction factors may then be applied to current estimation techniques (Bouchet 1981).

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APPENDIX A

List of vessel cruises, 1958-80, from which marine mammal sighting data were used. Data came from National Marine Mammal Laboratory (NMML) personnel during pelagic fur seal (PFS), OCSEAP (OCS) related, and Dall porpoise (DP) research, and from vessels which contributed as part of the marine mammal Platforms of Opportunity Program (POP). "Dates" are the approximate cruise periods.

Dates	Vessel	Observers
23 Feb - 11 Jun 1958	Lindy (C)*	NMML (PFS)
11 May - 1 Jun 1958	Trinity (C)	NMML (PFS)
3 Mar - 2 Jun 1960	Tacoma (C)	NMML (PFS)
21 Apr - 25 Aug 1960	Windward (C)	NMML (PFS)
6 Feb - 5 Mar 1961	Harmony (C)	NMML (PFS)
5 May - 20 Sep 1962	Tacoma (C)	NMML (PFS)
October 1962	Harmony (C)	NMML (PFS)
24 Jun - 11 Sep 1963	Harmony (C)	NMML (PFS)
June 1964	Harmony (C)	NMML (PFS)
18 May - 24 Aug 1968	New St. Joseph (C)	NMML (PFS)
21 Mar - 24 Aug 1974	Fairweather (N)	POP
28 Jan - 5 Mar 1975	Oceanographer (N)	POP
5 Mar - 15 Aug 1975	McArthur (N)	POP
3 Apr - 13 Jul 1975	Oregon (N)	POP
22 Apr - 26 Aug 1975	Rainier (N)	POP
28 Apr - 9 Jun 1975	Townsend Cromwell (N)	POP
6 May - 22 Oct 1975	Davidson (N)	POP
9 May - 23 Jun 1975	Discoverer (N)	POP
31 May - 10 Aug 1975	Tordenskjold (C)	POP
5 Aug - 5 Dec 1975	Discoverer (N)	POP
7 Apr - 30 Apr 1976	Discoverer (N)	POP
29 Apr - 22 Jun 1976	Polar Star (G)	POP
9 Mar - 2 Apr 1976	Surveyor (N)	NMML (OCS)
6 Jun - 25 Jun 1976	Surveyor (N)	NMML (OCS)
8 Jun - 22 Jun 1976	Miller Freeman (N)	NMML (OCS)
18 Feb - 3 Nov 1976	Davidson (N)	POP
19 Feb - 27 Oct 1976	McArthur (N)	POP
19 Feb - 21 Sep 1976	Rainier	POP
29 Feb - 16 Sep 1976	Midgett (G)	POP
6 Apr - 28 Oct 1976	Discovery (C)	POP
26 Jun - 13 Dec 1976	Surveyor	POP
21 May - 21 Sep 1976	Tordenskjold (C)	POP
4 Aug - 27 Aug 1976	Moana Wave (RV)	NMML (OCS)
20 May - 17 Aug 1976	Discoverer (N)	POP
27 Apr - 16 Jun 1977	Discoverer (N)	POP
22 Jun - 13 Jul 1977	Surveyor (N)	POP
16 Feb - 25 Mar 1977	Miller Freeman (N)	NMML (OCS)
18 Jul - 29 Sep 1977	Miller Freeman (N)	POP
10 Apr - 1 Sep 1977	Oregon (N)	POP
2 Jun - 21 Sep 1977	Professor Siedlicki (RV)	POP

APPENDIX A (Continued)

Dates	Vessel	Observers
21 Mar - 20 Oct 1977	Discovery (C)	POP
23 Oct - 16 Dec 1977	Morgenthau (G)	POP
10 Sep - 31 Oct 1977	Rush (G)	POP
10 Jun - 10 Sep 1977	Alaska Ferries (F)	POP
3 M y - 22 Aug 1977	McArthur (N)	POP
13 Apr - 28 Aug 1977	Rainier (N)	POP
17 May - 13 Sep 1977	Fairweather (N)	POP
13 Mar - 23 Apr 1977	Discoverer (N	POP
20 Jul - 21 Nov 1977	Surveyor (N)	POP
1 Jun - 2 Nov 1977	Davidson (N)	POP
6 Mar - 5 May 1977	Surveyor (N)	POP
27 Jul - 17 Nov 1977	Discoverer (N)	POP
26 May - 4 Sep 1977	Alaska Ferries (F)	POP
15 Jul - 7 Sep 1977	Midgett (G)	POP
25 Aug - 24 Oct 1977	Boutwell (G)	POP
13 Jul - 28 Jul 1977	Rush (G)	POP
5 Jan - 24 Dec 1977	For. Vessel Obs. Program	POP
21 May - 11 Jun 1978	Discoverer (N)	NMML (DP)
14 Jun - 14 Jul 1978	Western Viking	NMML (OCS)
18 Jun - 1 Sep 1978	Commander (C)	NMML (DP)
20 Jun - 9 Jul 1978	Surveyor (N)	NMML (DP)
21 Jun - 29 Jun 1978	Cobb (N)	NMML (DP)
21 Jun - 15 Jul 1978	Seahawk (C)	NMML (DP)
8 Aug - 15 Sep 1978	Surveyor (N)	NMML (DP)
26 Oct - 28 Nov 1978	Rush (G)	NMML (DP)
13 Jan - 1 Aug 1978	Mellow (G)	POP
20 Jan - 7 Sep 1978	Fairweather (N)	POP
22 Jan - 16 Jun 1978	Midgett (G)	POP
11 Feb - 9 Jun 1978	Miller Freeman (N)	POP
14 Feb - 20 Apr 1978	Surveyor (N)	POP
1 Mar - 15 May 1978	Discoverer (N)	POP
21 May - 29 Nov 1978	Jarvis (G)	POP
8 Apr - 23 Oct 1978	Oregon (N)	POP
4 Jun - 4 Sep 1978	Alaska Ferries (F)	POP
24 Jun - 19 Dec 1978	Storis (G)	POP
16 Apr - 29 Jul 1978	Jolene (P)	POP
19 Apr - 28 Aug 1978	Rainier (N)	POP
8 May - 21 Oct 1978	Discovery (C)	POP
24 May - 21 Aug 1978	McArthur (N)	POP
27 Jun - 5 Oct 1978	Davidson (N)	POP
10 Aug - 16 Dec 1978	Morgenthau (G)	POP
20 Aug - 28 Oct 1978	Boutwell (G)	POP
26 Aug - 20 Nov 1978	Miller Freeman (N)	POP
8 Nov - 26Dec 1978	Shore-R. MacIntosh	POP

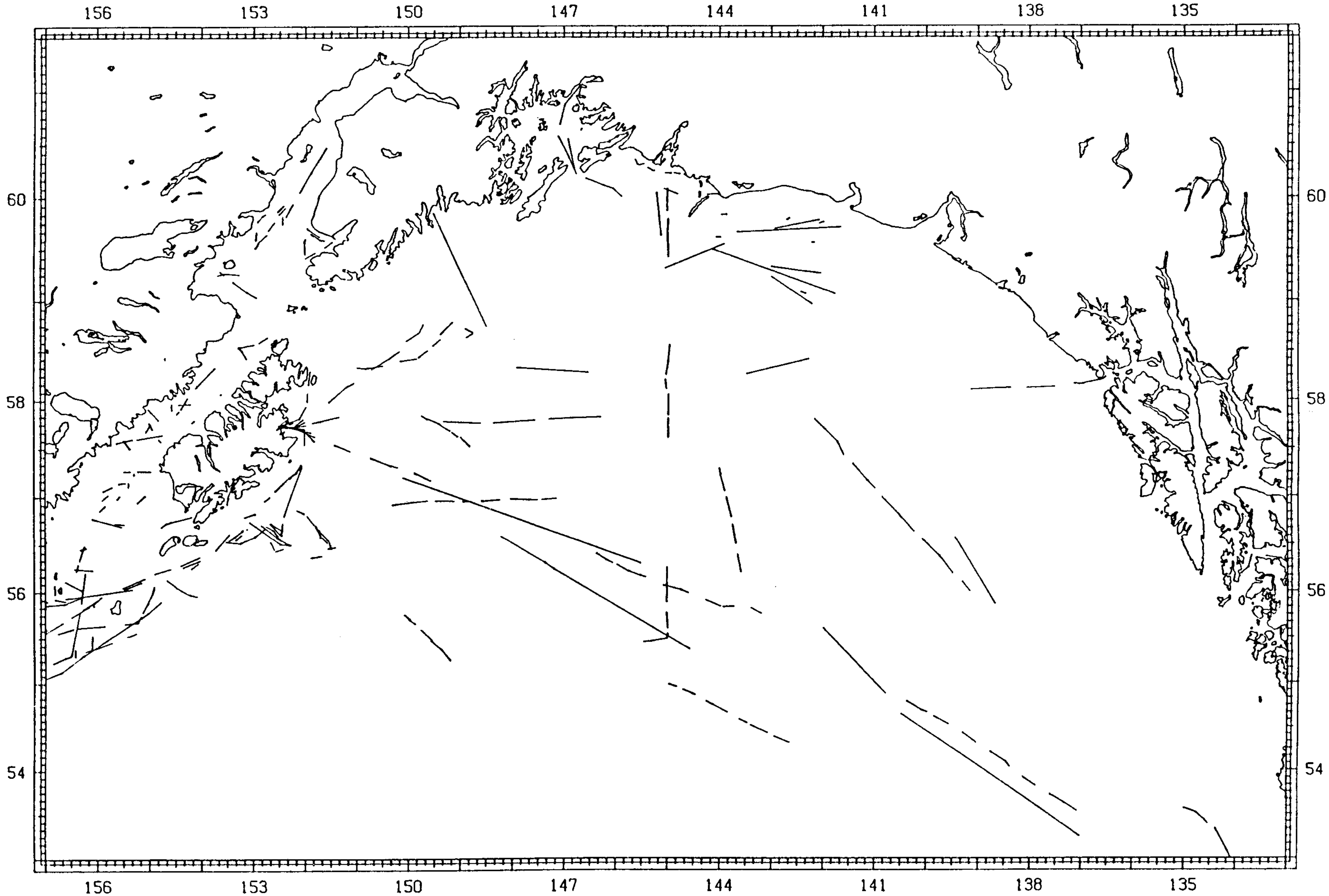
APPENDIX A (Continued)

Dates	Vessels	Observers
14 Jan - 10 Dec 1978	For. Vessel Obs. Program	POP
6 Jun - 11 Aug 1979	Oshoro Maru (RV)	NMML (DP)
7 Jan - 17 Nov 1979	Discoverer (N)	POP
17 Jan - 22 Dec 1979	Miller Freeman (N)	POP
28 Jan - 6 Sep 1979	Fairweather (N)	POP
31 Jan - 13 Dec 1979	McArthur (N)	POP
3 Feb - 18 Nov 1979	Surveyor (N)	POP
19 Feb - 27 Jun 1979	Midgett (G)	POP
3 Mar - 9 Apr 1979	Boutwell (G)	POP
21 Feb - 2 May 1979	Davidson (N)	POP
29 Mar - 20 Aug 1979	Rainier (N)	POP
11 Apr - 3 Nov 1979	Jarvis (G)	POP
19 Jun - 1 Aug 1979	Munro (G)	POP
10 Jun - 11 Sep 1979	Alaska Ferries (F)	POP
3 Jul - 16 Aug 1979	Paragon II (C)	POP
7 Jul - 18 Aug 1979	Boutwell (G)	POP
22 Feb - 12 Apr 1979	Polar Sea (G)	NMML (OCS)
1 Jan - 28 Dec 1979	For. Vessel Obs. Program	POP
18 Jul - 26 Aug 1980	US Dominator (C)	NMML (OCS)
6 May - 18 Sep 1980	Davidson (N)	POP
8 Oct - 30 Oct 1980	Miller Freeman (N)	NMML (PFS)
13 Jun - 11 Aug 1980	Arete (F)	POP
12 May - 12 Nov 1980	Lt. Station Five Fingers (G)	POP
19 Jun - 21 Jul 1980	Stellar (F)	POP
7 Aug - 13 Sep 1980	Munro (G)	POP
16 Jun - 14 Sep 1980	Resolute (G)	POP
25 May - 14 Jul 1980	Midgett (G)	POP
7 Jun - 22 Jul 1980	Storis (G)	POP
9 Feb - 15 Jun 1980	Firebush (G)	POP
5 Apr - 14 Aug 1980	Fairweather (N)	POP
21 May - 10 Oct 1980	Oceanographer (N)	POP
31 May - 6 Sep 1980	Alaska Ferries (F)	POP
30 Jul - 10 Sep 1980	Rush (G)	POP
5 Jun - 13 Aug 1980	Oshoro Maru (RV)	NMML (POP)
2 Jan - 28 Dec 1980	For. Vessel Obs. Program	POP
31 May - 5 Oct 1980	Surveyor (N)	NMML (OCS)
19 Aug - 27 Aug 1980	Rainier (N)	NMML (OCS)
11 Jan - 11 Mar 1980	Midgett (G)	NMML (OCS)
5 Feb - 30 Mar 1980	Discoverer (N)	NMML (OCS)
15 Jan - 7 Mar 1980	Miller Freeman (N)	NMML (OCS)
12 Mar - 28 Mar 1980	Miller Freeman (N)	NMML (OCS)
22 Apr - 2 May 1980	Miller Freeman (N)	NMML (OCS)

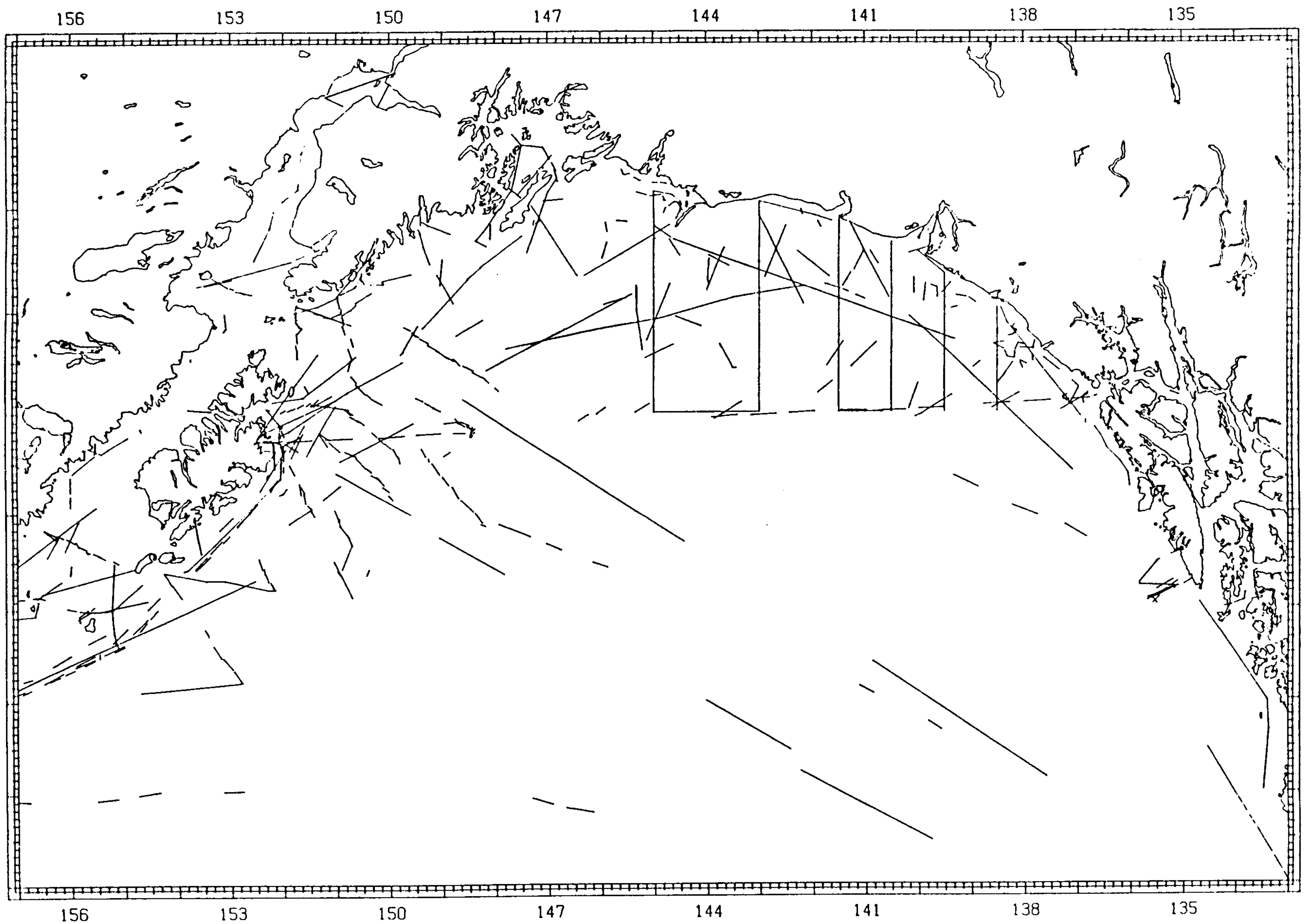
* (N) - NOAA; (G) - Coast Guard; (C) - Charter; (F) - Forest Service; (RV) For. Government or University Research Vessel; (P) - Privately owned.

APPENDIX B

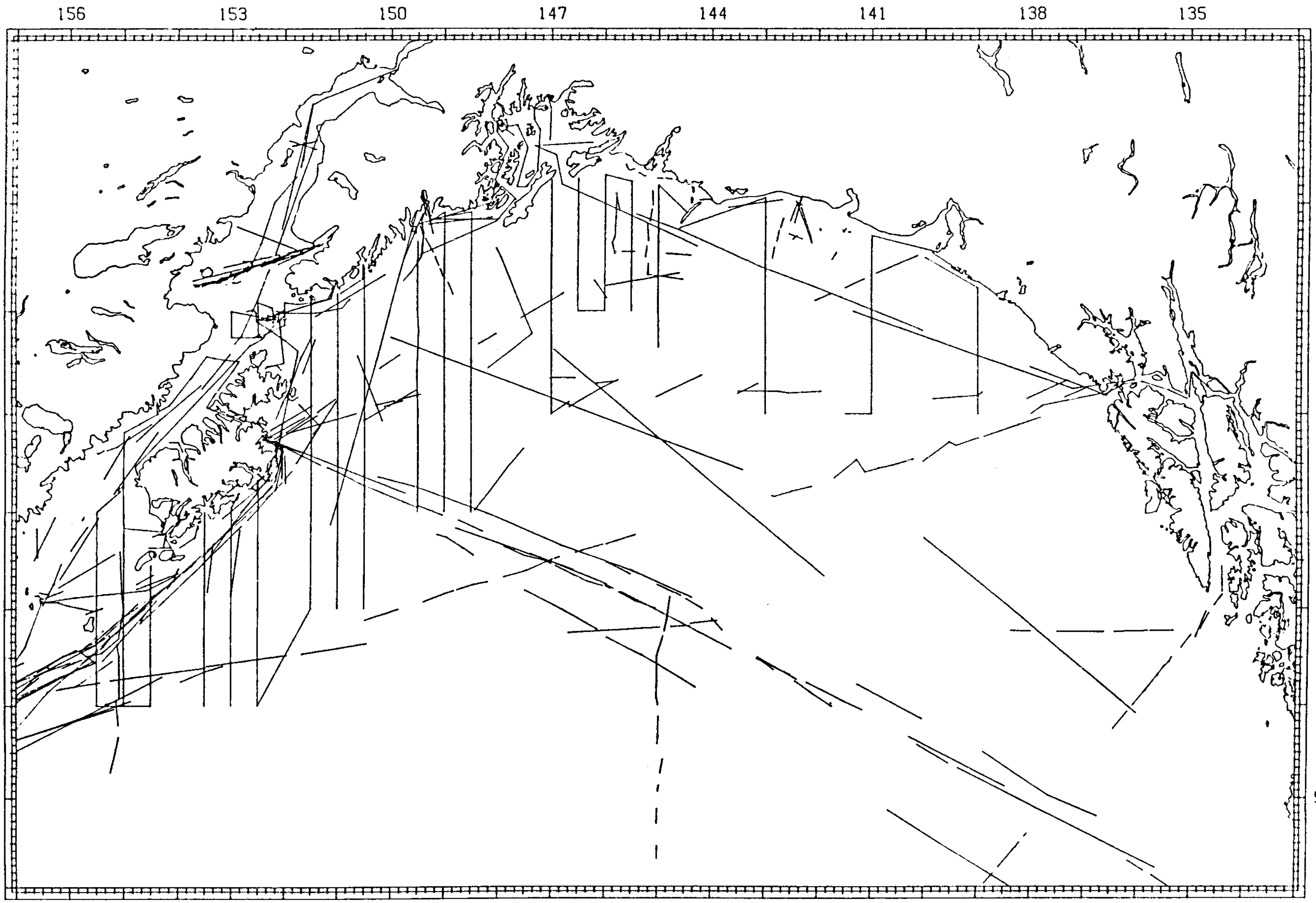
Effort plots: cruise tracks for ships where there was specific watch effort for marine mammals. Effort included beginning and ending time and position of each cruise leg when an observer was actively scanning the sea surface for marine mammals; and sighting position. Most data are from 1975 to 1980.



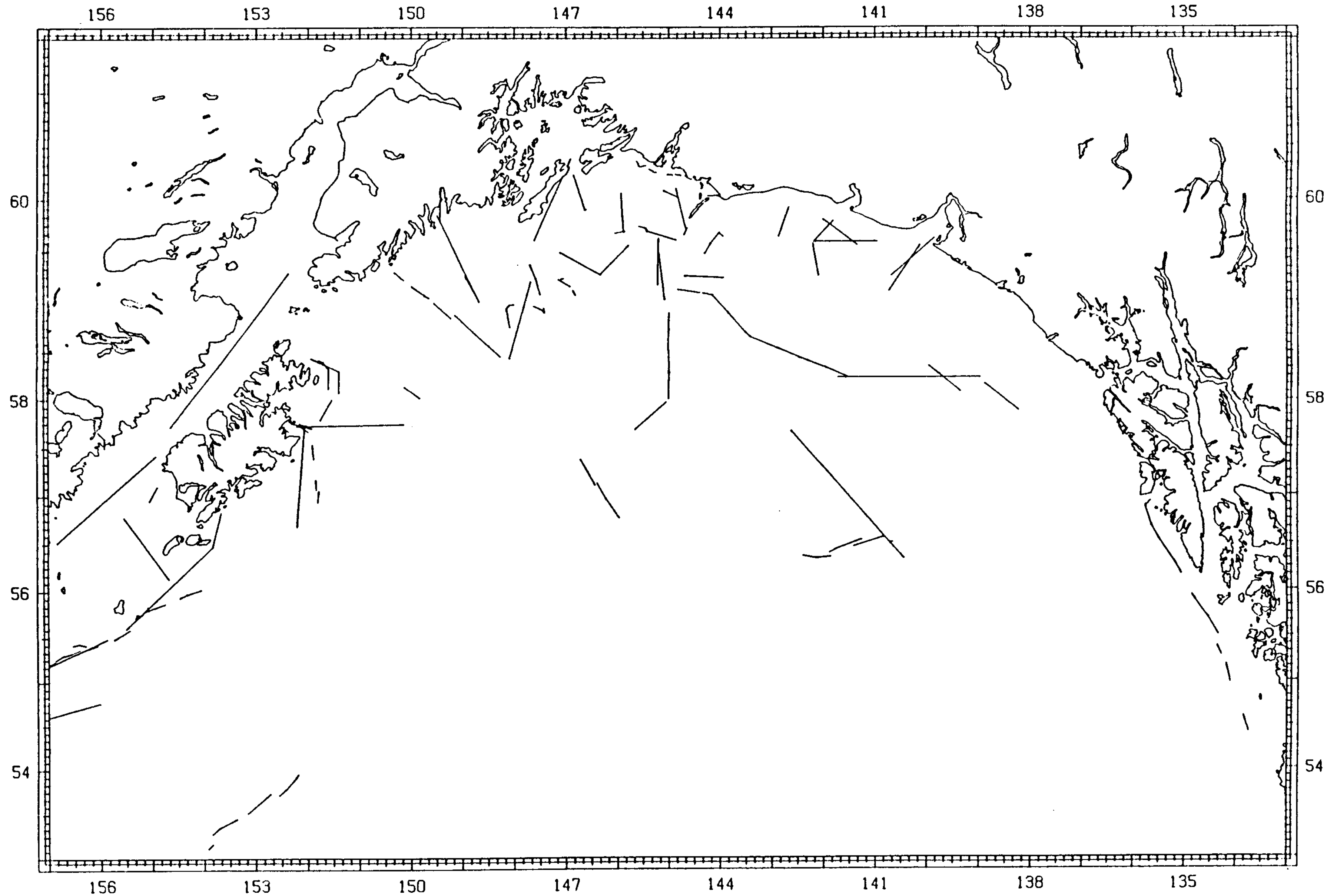
Appendix B **Figure 1.**–Winter (January-March) ship effort tracks, 1958-80.



Appendix B **Figure 2.**--Spring (April-June) ship effort tracks, 1958-80.



Appendix B **Figure 3.**–Summer (July-September) ship effort tracks, 1958-80.



Appendix B **Figure** 4.–Autumn (October-December) ship effort tracks, 1958-80.

RINGED SEAL MONITORING: RELATIONSHIPS OF DISTRIBUTION AND ABUNDANCE TO HABITAT ATTRIBUTES AND INDUSTRIAL ACTIVITIES

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Assistance in the field was provided by Howard Golden, Sue Hills, Gerald Garner, Dawn Hughes, and Val Uhler who acted as observers and data recorders and helped to solve problems as they arose. Many thanks to them all for long hours of hard work, always accomplished with enthusiasm and a sense of humor that kept everyone smiling throughout the project.

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SUMMARY

This is the final report of a 3-year study intended to develop a program for monitoring the abundance of ringed seals in Alaska through aerial surveys. This report presents the results of aerial surveys of ringed seals on the shorefast ice of the eastern Chukchi Sea and Beaufort Sea in May-June 1987 and compares them with the results of similar surveys conducted in 1985 and 1986.

Surveys were flown at approximately 130 knots in a Twin Otter aircraft equipped with bubble windows, a GNS-500 navigation system and a radar altimeter. Counts of hauled-out seals were made during late May and early June along a series of transects oriented east-west (Chukchi Sea) or north-south (Beaufort Sea). Observers (usually two) each counted seals in a strip transect either 1,350 ft (300-ft altitude) or 2,250 ft (500-ft altitude) wide.

The selected data base in 1987 included 4,317 nmi of trackline and 2,166 nmi^2 of area (both fast and pack ice) actually surveyed. In the Chukchi Sea, between Kotzebue Sound and Point Barrow, we surveyed 16% of all fast ice; in the Beaufort Sea we surveyed 14% of all fast ice between Point Barrow and the U.S.-Canada demarcation line. Coverage was similar to that in 1985 and 1986.

The density of seals on the fast ice in 1987 was highest in the Chukchi Sea from Kotzebue Sound to Point Lay; mean density was 4.0 seals/nmi^2. Density in the northern Chukchi Sea was considerably lower (2.6 seals/nmi^2). In the Beaufort Sea, the observed density of seals was lowest between Barrow and Lonely (3.1 seals/nmi^2), much higher between Lonely and Flaxman Island (8.1 seals/nmi^2) and between Barter Island and the U.S.-Canada demarcation line (7.7 seals/nmi^2), and highest between Flaxman Island and Barter Island (12.0 seals/nmi^2).

Replicate surveys were conducted at altitudes of 300 ft and 500 ft in 1986 and 1987 to determine whether density estimates at different altitudes were comparable. For five systematic altitude comparisons, the density of seals at holes surveyed from 500 ft was 76% of that determined from 300 ft, or conversely, 1.32 times more seals were counted at 300 ft. Based on these data, all density estimates for seals at holes which were made from counts conducted at 500 ft were multiplied by a correction factor of 1.32. Only corrected data were used in annual and geographic comparisons.

Comparisons of experienced and inexperienced observers indicated that counts by inexperienced observers were usually 5 to 42% lower. Counts of different experienced observers were similar. Tests using two experienced observers counting a single strip suggested that a single, trained observer sees about 82% of the seals hauled out on the ice. This is a relatively high proportion compared to estimates for other species in different environments, but nonetheless means that density estimates for hauled-out seals based on aerial surveys by experienced observers are probably low by at least 18%. This does not include seals that are in the water and cannot be counted.

Analysis of the relationship between the variance of the mean and the number of transects selected demonstrated that the variance dropped rapidly until approximately 50% of all possible transects were selected from the data base, after which the variance declined gradually. Analysis of the combined Chukchi-Beaufort data base indicated that coverage of 60% of all possible transects reduced variance in data sets to reasonable levels, but that coverage of 90% resulted in considerably greater precision. The variance was lowest for seals at holes.

For 1985-87, the smallest 95% confidence limits for density of seals at holes occurred in Chukchi Sea sector C1 and Beaufort Sea sectors B1 and B3 (±9-23%). Confidence limits for the Beaufort Sea as a whole were ±9-10% for seals at holes and ±14-33% for all seals; comparable values for the Chukchi Sea were ±9-13% and ±11-13%.

The relationship between ice deformation and seal distribution and density was consistent from year to year; seals were less abundant in rougher ice (>20% deformation). Even after data were adjusted to express density in relation to area of flat ice only, seals were more abundant in areas of lower deformation. This indicates that areas of flat ice were preferred.

Ringed seals were generally less abundant within 2 nmi of the coast than they were farther from shore, particularly in the Chukchi Sea where the coastline is simple, with no offshore barrier islands. In the Chukchi Sea there was no clear overall pattern in density relative to distance from the fast ice edge for 1985-87. In the Beaufort Sea prior to the beginning of breakup, seals were less abundant near the edge. After the ice began to crack, densities within 4 nmi of the edge were as high as 12 seals/nmi^2, with most seals occurring along cracks, and decreased rapidly both toward shore and seaward. We believe this increase in density is due to an influx of seals from other areas into the highly fractured boundary zone between fast and pack ice, rather than a redistribution of seals from immediately adjacent areas.

Yearly variations in densities recorded for pack ice were large. Much of the pack ice surveyed was near the fast ice edge, where distribution changes markedly as breakup begins, and probably was not typical of the pack ice as a whole. In the Beaufort Sea, density in pack ice decreased with distance from the edge, and the density of seals at holes appeared to stabilize about 10 nmi from the edge at about 1 seal/nmi^2.

In all sectors of the Chukchi Sea, the density of total seals in the fast ice was 1.6-1.7 times greater in 1986 than in either 1985 or 1987. The total estimated number of seals and 95% confidence limits in the Chukchi Sea ranged from 18,400 ± 1,700 in 1985 to 35,000 ± 3,000 in 1986. The 1987 estimate of 20,200 ± 2,300 was similar to 1985. Densities were consistently higher south of Point Lay than to the north.

In the Beaufort Sea, annual and geographic variations in density were less regular. Survey timing relative to breakup differed among years: 1986 surveys occurred before breakup, 1987 surveys occurred after the beginning of breakup, and 1985 surveys occurred both before and after. The densities in all sectors except B1 were higher in 1986 than in 1985. For the area between Barrow and Flaxman Island, the density of total seals increased from 2.7 to 3.5 seals/nmi^2 from 1985 to 1986, and the estimated number of seals within the 20-m depth contour increased from 9,800 ± 1,800 to 13,000 ± 1,600. In 1987, the density and estimated number of seals for that area were considerably higher, 5.24 seals/nmi^2 and 19,400 ± 3,700 seals, respectively, but this probably included seals that had moved in from other areas as ice began to break up.

Observed changes in group size, percentage of seals at cracks, and distribution relative to the fast ice edge in 1985-87, in combination, suggested that a substantial influx of ringed seals into the Beaufort Sea occurred as the ice began to crack and break up. Before breakup, group size was about 1.3 seals/group, increasing to 1.6 or more seals/group later on. Similarly, during breakup the percentage of seals at cracks increased from less than 20-30% of total seals to often more than 50%.

Industrial activity in the Beaufort Sea from 1985 to 1987 consisted mostly of the construction and operation of artificial islands. There was a steady decline in activity from 1985, when both seismic exploration and artificial island activity were under way, to 1987 when there was little or no offshore activity in the study area. Our data indicate that in 1985-86 there were no apparent broad-scale effects of industrial activity that could be measured by aerial surveys. However, while aerial surveys are useful in monitoring long-term trends in abundance over large areas, they are not well suited to detecting small-scale differences in geographically restricted areas. The 1985-87 aerial survey data do not eliminate the possibility that local effects may occur which would more appropriately be detected by other techniques, or that regional effects could occur at greater levels of industrial activity.

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INTRODUCTION

Study Rationale

Ringed seals (*Phoca hispida*) are a major ecological component of the arctic and subarctic marine fauna. Their importance to northern peoples living on the shores of ice-covered seas has been well described by Smith (1973:118): "This medium-sized hair seal . . . has provided the primary and most constant source of protein and fuel for the coastal dwellers since the development of the Eskimo maritime culture some 2,500 years ago." Despite a trend in recent years toward decreased hunting in some areas, many thousands of ringed seals are still harvested annually in the United States, U.S.S.R., and Canada (Davis *et al.* 1980; Lowry *et al.* 1982).

Ringed seals are the major prey of polar bears (*Ursus maritimus*) (Smith 1980; ADF&G unpubl. data), and in some areas they may be significant sources of food for Arctic foxes (*Alopex lagopus*) (Smith 1976) and walruses (*Odobenus rosmarus*) (Lowry and Fay 1984). Ringed seals prey on small fishes and crustaceans (Lowry *et al.* 1980) and may compete for food with other pinnipeds (Lowry and Frost 1981) as well as seabirds, Arctic cod (*Boreogadus saida*), and bowhead whales (*Balaena mysticetus*) (Lowry *et al.* 1978; Frost and Lowry 1984). An understanding of patterns of ringed seal abundance and distribution and the factors which influence observed patterns is essential to understanding ecological processes and interactions in the waters of northern Alaska.

Factors limiting the abundance of ringed seals are poorly understood. In some areas, the combined removals by polar bears and humans may equal the sustainable yield of local populations (Smith 1975). Habitat attributes such as food availability and ice conditions undoubtedly affect ringed seal numbers and productivity, but the actual determining factors are far from clear (Stirling *et al.* 1977; Lowry *et al.* 1980; Smith and Hammill 1981). Human activities such as those associated with exploration and development of offshore oil and gas reserves may also influence ringed seal numbers.

In recognition of the ecological importance of ringed seals and the possibility that they may be impacted by human activities, the Outer Continental Shelf Environmental Assessment Program (OCSEAP) has, since 1975, sponsored studies of the biology and ecology of ringed seals in Alaska. Studies have addressed basic biological parameters (Burns and Eley 1978; Frost and Lowry 1981), food habits and trophic relationships (Lowry *et al.* 1978, 1980, 1981*a*, 1981*b*; Lowry and Frost 1981), distribution, characteristics, and use of lairs (Burns and Kelly 1982; Kelly *et al.* 1986; Burns and Frost 1988), and distribution and abundance of seals hauled out during the molt (Burns and Eley 1978; Burns *et al.* 1981*a*; Burns and Kelly 1982). These studies have also, to some extent, addressed the possible effects of Outer Continental Shelf (OCS) exploration and development activities on the distribution, density, and behavior of ringed seals (Burns *et al.* 1981*a*; Burns and Kelly 1982; Kelly *et al.* 1986; Burns and Frost 1988; Frost and Lowry, in press; Kelly *et al.*, in press).

In 1984, the National Oceanic and Atmospheric Administration (NOAA) and the Minerals Management Service (MMS) requested the submission of proposals to begin a program of monitoring the ringed seal population off Alaska with particular attention to possible effects of OCS activities. The contract was awarded to the Alaska Department of Fish and Game (ADF&G), and work began on 1 January 1985. In February 1985, a research protocol was developed by ADF&G and finalized in consultation with NOAA and MMS. From January to June 1985, ringed seal aerial survey data collected by ADF&G during 1970-84 were reanalyzed. Results of the analyses, including plots of all transects and ringed seal sightings, were submitted to NOAA and MMS in a progress report in July 1985 (Frost *et al.* 1985*a*), and have been incorporated in geographical and temporal comparisons of ringed seal distribution and abundance in this report. Because the earlier surveys were conducted using different methodology and less accurate navigation, and in the Chukchi Sea were flown on much later dates and therefore in different ice conditions, their utility was limited to very general comparisons.

Ringed seal aerial surveys based upon the 1985 research protocol were flown during May and June of 1985, 1986, and 1987. The surveys were satisfactorily completed and the data have been analyzed to determine:

1) factors affecting survey counts;

2) regional and temporal trends in ringed seal abundance;

3) habitat factors affecting distribution and abundance; and

4) the effects of industrial activities on seal density.

Results of 1985 and 1986 aerial surveys were presented in Frost *et al.* (1985*b*, 1987). The results of 1987 surveys, as well as comprehensive analyses of the 3 years of surveys combined, are presented in this report.

Background on Ringed Seal Biology

The distribution of ringed seals in Alaskan waters is strongly correlated with that of sea ice (Burns 1970; Fay 1974). In the Bering, Chukchi, and Beaufort seas, ringed seals are most abundant in association with seasonal ice, although they occur in multiyear ice in the far north polar region. The seasonal expansion and contraction of the sea ice habitat requires that a significant proportion of the population is "migratory" over the annual cycle, while other animals are relatively sedentary or undertake only short seasonal movements. The dynamics of these seasonal movements are poorly understood. Marking studies undertaken in the Canadian Beaufort Sea have demonstrated both local and long-distance (e.g., to Alaska and Siberia) movements (Smith and Stirling 1978; T. G. Smith, pers. commun.).

Ringed seals move in conjunction with the sea ice. During summer and early autumn they are abundant in nearshore ice remnants in the Beaufort Sea and in the pack ice of the Chukchi and Beaufort seas (Burns *et al.* 1981*b*; Frost and Lowry 1981). They also occur in ice-free waters of the Beaufort Sea and in open water close to the ice edge in the Chukchi Sea. With the onset of freeze-up, many ringed seals move southward and are common in grease and slush ice in areas south of the advancing pack. They become increasingly abundant in the coastal zone throughout autumn and early winter. In midwinter they are abundant in the Chukchi Sea, Bering Strait, and northern Bering Sea. They occur as far south as Nunivak Island and Bristol Bay, depending on ice conditions in a particular year, but are generally not abundant south of Norton Sound except in nearshore areas (Lowry *et al.* 1982). By about mid-March, directional movements are no longer apparent.

During March and April, adult seals are occupied with establishing and maintaining territories, bearing and nurturing pups, and breeding. Partitioning of habitat based on age, sex, reproductive status, or a combination thereof apparently occurs during late winter and spring, with adults predominating in and near the fast ice, subadults in the flaw zone, and both occurring in drifting pack ice (McLaren 1958; Fedoseev 1965; Burns *et al.* 1981*b*). Few ringed seals are found in the ice front and in the fringe zones at the southern extent of seasonal sea ice in the Bering Sea (Burns *et al.* 1981*b*).

Northward movement, mainly by subadults, begins in April and is well under way by May. Adults migrate as the fast ice breaks up, pups remain in the ice remnants or move into the adjacent pack, and immature animals are most numerous in the pack. Many ringed seals pass through Bering Strait in May and June. A small proportion of the population, mainly juveniles, may remain in ice-free areas of the Bering Sea and southern Chukchi Sea during summer, but most move farther north with the receding ice (Burns *et al.* 1981*b*; Lowry *et al.* 1982).

Although some scientists have in the past considered the possibility of censusing ringed seals from ships during the summer open-water season (McLaren 1961), aerial surveys have become the standard census method in recent years (e.g., Burns and Harbo 1972; Stirling *et al.* 1977, 1981*a*, 1981*b*; Kingsley *et al.* 1985). Since ringed seal surveys are flown in late spring, biological characteristics of seals that influence their distribution during that period are particularly significant for the design of surveys and the interpretation of results.

Although cracks may form occasionally once the shorefast ice is established, seals primarily depend on breathing holes for access to air from about November until May or June. These holes may initially be formed by breaking through thin ice with the head or nose, but as the ice thickens they are kept open by abrading with the front flipper claws. Since many seals may surface in cracks and leads when they occur, the pattern of freeze-up may greatly influence the ultimate distribution pattern of seals in the shorefast ice (see Smith *et al.* 1979, fig. 4).

As the winter progresses, snow may accumulate over some or all of a seal's breathing holes. Deeper snow drifts form principally on the leeward and windward sides of pressure ridges and hummocks, resulting in snow depths of 1-2 meters. Sometime during the winter, seals will enlarge one or more of their breathing holes to a diameter large enough to allow them to haul out onto the surface of the ice and excavate a lair. The minimum depth of snow required for lair formation is 20-30 cm (Smith and Stirling 1975; Burns and Kelly 1982; Burns and Frost 1988).

Lairs are used for resting and social functions such as the birth and care of pups. Lairs are of two basic types – haulout lairs, which are single-chambered structures usually more or less oval in shape; and pupping lairs, which are more complex structures, usually with several chambers and one or more side tunnels. Characteristics and dimensions of lairs have been well described by Smith and Stirling (1975) and Burns and Frost (1988).

As day length and temperature increase in the spring, increasing numbers of ringed seals appear hauled out on the ice near breathing holes or lairs. This hauling out is associated with the annual molt which occurs in May-July (McLaren 1958). Seals in different fast ice areas often follow a different chronology of hauling out. Thus, the numbers of seals seen hauled out in particular fast ice areas varies with this chronology and with possible influxes of seals from adjacent areas. McLaren (1961) first recognized that timing of the haulout period varies with latitude, and that the peak of haulout occurs progressively later in more northerly areas. Smith and Hammill (1981) working at Popham Bay (64°17'N) recorded seals hauled out as early as 9 May, with peak densities reached on 1 June in part of the study area. In another portion of their study area peak densities were not reached until 21 June, possibly due to an immigration of seals. Finley (1979) watched seals at Freemans Cove (75°06'N) and Aston Bay (73°43'N). The haulout began in this region in early June, with the maximum number of basking seals counted on 22 June in Freemans Cove and 29 June in Aston Bay. He thought the late June peak at Aston Bay, which occurred on the last day of the study, was due to an influx of seals from unstable ice areas. Off the north coast of Alaska, Burns and Harbo (1972) found that the maximum numbers of seals were hauled out in the second and third weeks of June.

OBJECTIVES

An understanding of patterns of ringed seal abundance and distribution, and the factors that influence these patterns, is essential to understanding ecological processes and interactions in the waters of northern Alaska. This research project was designed to address those questions. Specific objectives were to:

1) identify temporal and spatial trends in ringed seal abundance and relate these to current and historic population status;

2) identify habitat attributes that affect the distribution and abundance of ringed seals;

3) compare the distribution and abundance of ringed seals in areas subjected to industrial activities and in appropriate control areas; where appropriate, make recommendations for mitigating any adverse environmental effects; and

4) develop, implement, and refine a monitoring protocol for long-term studies on the distribution and abundance of ringed seals in Alaskan coastal waters.

METHODS

Study Area

In 1985-87 aerial surveys were conducted over the shorefast ice and some areas of adjacent pack ice of the Chukchi and Beaufort seas from southern Kotzebue Sound north and east to the United States-Canada border. The study area was divided into 11 sectors that corresponded to those used in previous surveys and reports (Burns and Harbo 1972; Burns and Eley 1978). Sector boundaries corresponded to easily identifiable landmarks such as capes, points, villages, or radar installations (Figure 1). The only sector boundary that has changed since the first surveys in 1970 is the one between sectors B3 (Oliktok to Flaxman) and B4 (Flaxman to Barter Island). That line was moved from Bullen Point to mid-Flaxman Island during the analysis of data from the early 1980s because of confusion between Flaxman Island and "Flaxman Airforce Base," a name used on some older charts for Bullen Point (Burns *et al.* 1981*a*; Burns and Kelly 1982). The mid-Flaxman boundary was used in analysis of 1985-87 data and was also incorporated in any reanalysis of historical data.

Shorefast ice begins to form along the coast in October or November as day length shortens and air and water temperatures cool. In some years, when weather is cold and calm, freeze-up may occur quite rapidly, resulting in extensive areas of flat, shorefast ice. In other years when storms occur during freeze-up or temperatures fluctuate greatly, freeze-up may occur over a more extended period and result in shorefast ice containing rubble fields, hummocks, and pressure ridges. These areas accumulate snow and are suitable for the excavation of ringed seal lairs.

Freeze-up commences earliest in most northerly areas, occurring as soon as early October in the Beaufort Sea, and progressively later to the south. In the northern Bering Sea, freezing of the shorefast ice may not occur until mid- to late November. Conversely, breakup occurs earliest to the south and progresses northward. In large embayments, like Kotzebue Sound, shorefast ice may remain until June, melting and rotting in place. Along the open Chukchi Sea coast, cracking and breaking of the shorefast ice usually begin in mid- to late May, compared to early to mid-June along the Beaufort Sea coast. There is considerable annual variability in the progression of freeze-up and breakup.

The shorefast ice grows in thickness and extent throughout the winter, until about April or May, depending on latitude. Its seaward extent depends on coastal topography,

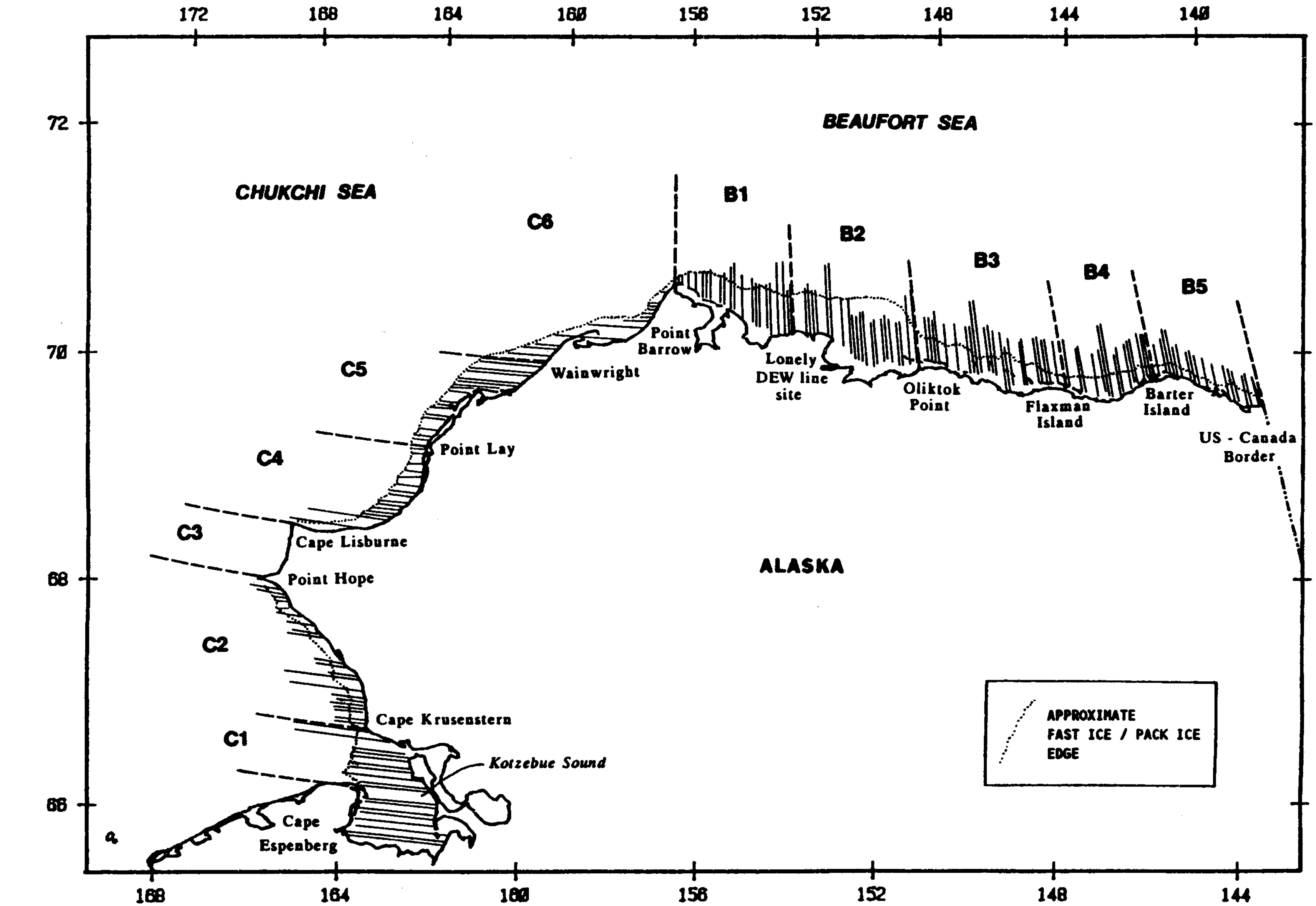


Figure 1.–Map of the Chukchi and Beaufort seas showing sectors referred to in this report, and selected transect lines used in analysis of 1987 ringed seal survey data.

bathymetry, and weather (all of which affect the ridging, grounding, and, therefore, stability of the ice), but generally coincides roughly with the 20-m contour (Stringer *et al.* 1982). Near major promontories, such as Cape Lisburne, the shorefast ice may extend only a mile or two, in contrast to the central Beaufort Sea where it extends tens of miles.

Contact between the shorefast ice and the drifting ice is marked by a well-defined shear line (Reimnitz and Barnes 1974) or less distinct shear zone (Burns 1970; Shapiro and Burns 1975). In the Chukchi Sea by mid-May, the interface between shorefast and pack ice is well defined by the open water of the Chukchi polynya (Stringer *et al.* 1982). In the Beaufort Sea at the time of our surveys in June, the seaward extent of the shorefast ice is less obvious and is marked by a fairly broad zone of large pressure ridges created when the pack ice impinged on the edge of shorefast ice. Often there are large expanses of attached ice seaward of this zone of ridges which form a temporary extension of the shorefast ice (Shapiro and Barry 1978).

As the ice begins to break up in June, the attached fast ice is the first to break off, followed by sequential cracking and breaking at ridge systems progressively closer to shore. Thus, what is part of the "attached" shorefast ice one day may be detached and part of the drifting pack ice just a few days later.

Aerial Survey Design

Surveys of 10 sectors (all those shown in Figure 1 except C3) were flown each year between 21 May and 16 June during the 3 years 1985-87, beginning with the southernmost sector in Kotzebue Sound and proceeding north and east. Surveys in the Chukchi Sea generally occurred during late May and those in the Beaufort Sea during early June.

Surveys were conducted between 1000 and 1600 hours true local time to coincide with the time of day when the maximum numbers of seals haul out (Burns and Harbo 1972; Smith 1975; Finley 1979; Smith and Hammill 1981). This diel pattern follows daily fluctuation in temperature and incident radiation (Finley 1979). On a few days when survey conditions were considered excellent, the survey window was extended to 1700 hours to allow completion of a sector.

The aircraft used was a Twin Otter equipped with over-sized, custom-made bubble windows, auxiliary internal fuel tank, radar altimeter, and GNS-500 navigation system. An on-board data recording system, which was linked to the GNS-500 and radar altimeter, was used to mark time, altitude, and latitude and longitude at beginning and end points of each transect, as well as other positions of interest. The aircraft and data-recording system were provided by NOAA. All surveys were flown at an indicated airspeed of approximately 120 knots, and true ground speed of 110-130 knots. In the Chukchi Sea, most surveys were flown at 500 ft of altitude in 1985 and 1986. In 1987, sector C1 was surveyed at 500 ft. All other sectors in the Chukchi Sea (C2-C6) were flown at 300 ft because of extensive surface meltwater which made seals difficult to see at 500 ft.

In the Beaufort Sea, low cloud ceilings and persistent fog necessitated a survey altitude of 300 ft in all years. In some sectors (C1, C6, and B1), some lines were flown at altitudes of both 300 ft and 500 ft to enable an assessment of the effect of altitude on survey results.

Three scientific personnel participated in each survey: a navigator who recorded weather, ice conditions, and navigational information, and two observers stationed on either side of the aircraft just forward of the wings. On some days, the navigator or a fourth person served as a backup observer. each observer counted the seals in the strip on his or her side of the aircraft. Strip width varied according to altitude and was determined by inclinometer angles which were indicated by marks on the windows. At 500 ft, the transects began 0.125 nmi out from the centerline and extended out to 0.5 nmi for an effective width of 0.375 nmi (2,250 ft). At 300 ft, the inclinometer angles remained the same and the effective strip width was reduced to 0.225 nmi (1,350 ft) (Figure 2).

Within sectors, transects were flown along lines of latitude in the Chukchi Sea and longitude in the Beaufort Sea. The positions of the shoreward ends of all transect lines were verified against USGS topographic maps as a check on the accuracy of the GNS. In the Chukchi Sea, transects were intended to be a standard 16 nmi long, or in sector C1, from one shore of Kotzebue Sound to the other. Because the shorefast ice band was very narrow in some areas, and the lead between fast and pack ice as much as 50 nmi wide, many transects were, in fact, considerably shorter than 16 nmi. In the Beaufort Sea, transect length was 24-26 nmi. In most sectors (except those with extensive open water) several transects were extended to 40 nmi offshore to provide additional coverage of the pack ice. The edge of the fast ice along transects was recorded during the survey whenever it was identifiable. In those instances when it was not, the edge was determined based on satellite photographs taken during the same time period. The data were coded accordingly.

The survey was flown according to a stratified random strip transect design. Transect lines were spaced at approximately 2 nmi intervals between centerlines (2' of latitude, 6' of longitude); within each sector, approximately 60% of the possible transects were randomly selected and flown. Replicate surveys were flown in some sectors on one or more days.

All data were recorded by consecutive 1-minute intervals. When the aircraft came on transect, the navigator called a mark to observers; all three simultaneously started digital stopwatches. Each observer recorded sightings or other observations, by minute, on data sheets. The ending time of each transect was noted to the nearest second.

All seals hauled out on the ice were identified to species (either ringed or bearded [*Erignathus barbatus*] seals), counted, and noted as being by holes or cracks. Seals at different holes were counted as separate groups, while those around a single hole were considered as part of the same group. When seals were seen spaced out along cracks, the total number within the transect was recorded rather than a listing of individuals. In addition to seals, all polar bears, polar bear tracks, belukhas (*Delphinapterus leucas*), and bowhead whales were recorded, as was any evidence of on-ice human activity such as artificial islands, seismic trails, ice roads, and drill ships.

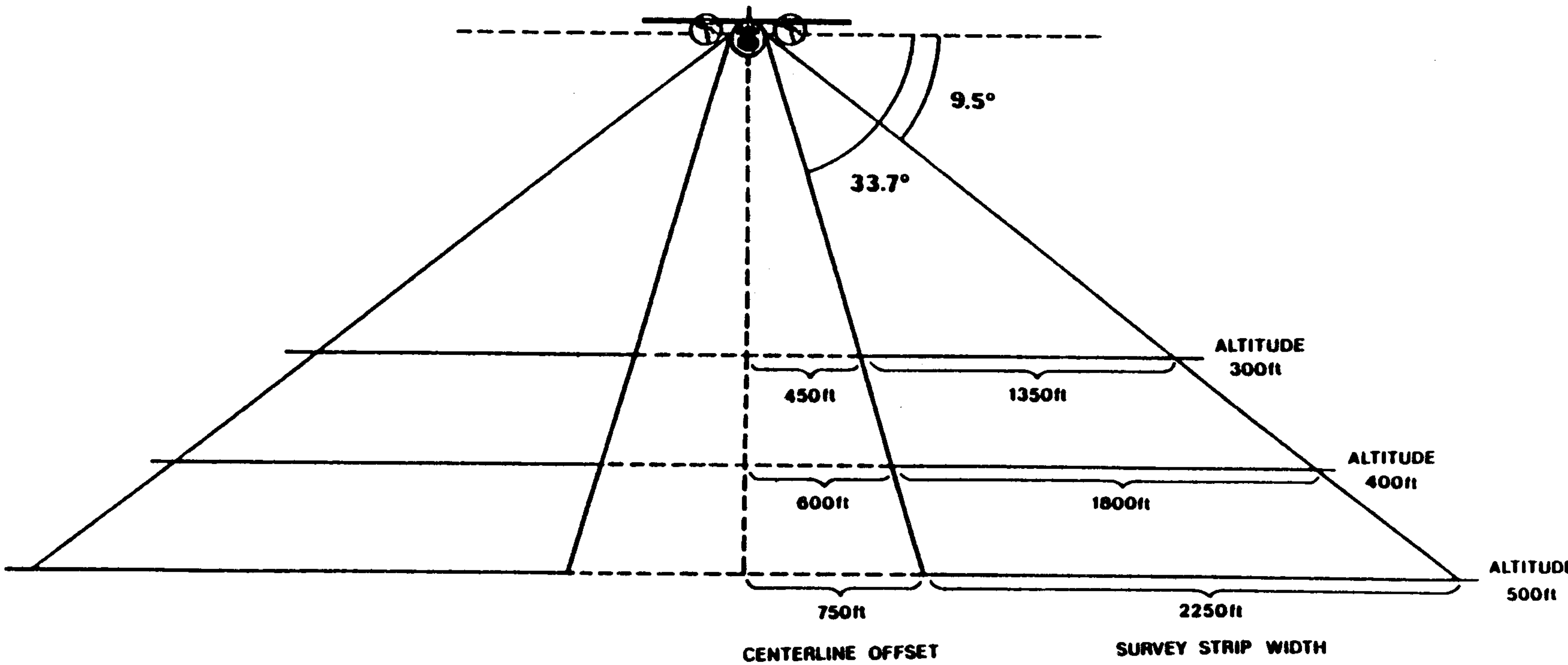


Figure 2.–Diagram showing inclinometer angles, centerline offsets, and survey strip widths for ringed seal aerial surveys.

Four ice variables were recorded: type, cover, deformation, and meltwater (Table 1). Type was classified as either fast ice or pack ice. Cover was recorded in octas (eighths) and was in almost all instances 8 octas. Deformation and meltwater were estimated by percentage of coverage; categories included 0-5%, 5-10%, 10-20%, and thence by 10% increments to 100%. Any ridging, drifts, or jumbled areas were considered deformed ice. The meltwater category included overflow from river runoff as well as actual standing meltwater.

Weather reports were obtained at regular intervals from flight service stations at the airport facilities nearest to the area being surveyed. Variables recorded included air temperature, wind speed and direction, visibility, and cloud cover (Table 1). Notations were also made by survey personnel regarding local visibility and cloud cover at the beginning and ending points of each line. In addition, wind and temperature readings were obtained by the aircraft at survey altitude.

Coastal winds and temperatures were sometimes substantially different from offshore conditions at survey altitude, and neither may have been representative of conditions on the ice where the seals were hauled out. The absence of open water in the fast ice and the melted condition of the snow usually precluded the inference of surface winds from indicators such as whitecaps or blowing snow.

Data Analysis

Counts of seals at cracks and at holes were added separately for each 1-minute interval. Ending times of transects were recorded to the nearest second but rounded up or down to the nearest whole minute for analysis. The lengths of transect lines were calculated from beginning and ending GNS positions and divided by total elapsed time to obtain ground speed. The area surveyed per minute interval was calculated by multiplying speed times interval times strip width. Each minute interval, therefore, had assigned to it latitude and longitude (of the beginning point), area (nmi^2), local time, counts of seals at holes and cracks, and ice and weather conditions. Each minute block was assigned to a sector by comparing its position to sector boundaries. In addition, the shortest straight-line distances from shore and from the fast ice edge were determined for each minute block by comparing positions for each interval to digitized data files for the coastline (based on USGS 1:250,000 topographic maps) and for the ice edge (based on either actual field observations or, in parts of the Beaufort Sea, on satellite photographs).

Densities of seals were calculated using the ratio estimator (Cochran 1977); i.e., number of seals counted divided by the area surveyed. Variance of the density was calculated using the model unbiased estimator (Cochran 1977, formula 6.27) modified to account for total sampling area (Estes and Gilbert 1978). For the calculations, a sample unit was a survey leg or portion thereof (e.g., minute interval) that conformed to requirements of the analysis.

For each year, a selected data base was created for each sector, to be used in geographic and between-year comparisons. The selected data were screened to eliminate duplicate lines

Table 1.–Environmental data recorded during aerial surveys.

Variable	Value(s)	Definition
Ice type	Fast	Shorefast, anchored to the beach, solid cover with or without occasional cracks, pressure ridges, and shear lines.
	Pack	Ice drifting and separated from the fast ice by a lead approximately parallel to the shore, and/or a major shear zone.
Ice cover	0-8	Ice cover in octas (eighths). Ice of 8/8 coverage may have cracks and/or small leads in it.
Ice deformation	0-9	Proportion of the ice surface that is deformed by broken ice, ice jumbles, pressure ridges, snow drifts; 0 = 0-5% deformed; 1 ≐ 5-10%; 2 = 10-20%; 3 = 20-30%, etc.
Meltwater	0-9	Proportion of the ice surface covered by water, including river runoff or standing meltwater. Categories the same as for ice deformation.
Wind speed/ direction		From nearest weather station or calculated by aircraft GNS. Direction to nearest degree true. Speed recorded as 0-5, 6-10, 11-15, 16-20, and >20 knots.
Cloud cover	0-9	Cloud cover in octas (1-8) with 9 representing an obscured sky, and 0 a clear sky.
Temperature	°C	Air temperature determined at nearest weather station or by aircraft at survey altitude.
Visibility	nmi	Distance from aircraft that observers can see at survey altitude.

and all transects flown in less than optimal survey conditions (e.g., wind speed ≥20 knots, excessive sun glare, fog or snow that reduced visibility). For 1986, when some surveys were conducted both before and after the beginning of breakup, only those occurring before breakup were included in the selected data base.

Non-selected data included transects flown in poor weather or at alternate altitudes, replicate surveys of the same lines, and surveys occurring after breakup had begun. These non-selected data were used to assess the effects of parameters such as altitude or date of survey on survey results.

RESULTS OF 1987 AERIAL SURVEYS

Survey Effort

During aerial surveys in May-June 1987, we expended approximately 84 hours of flight time in the successfully completed sectors, divided almost equally between the Beaufort and Chukchi seas. The aircraft flew an estimated 10,080 nmi during survey flights, of which approximately 6,000 nmi were on survey tracklines (Table 2). In the Chukchi Sea, coverage was greatest in sector C1, which had the greatest area of fast ice. In the Beaufort Sea, coverage was greatest in sectors B1 and B3, where replicate flights were made to compare results at different altitudes and to investigate day-to-day variability in counts. In sectors C1 and C2, several sets of replicate lines were flown to test the effects of altitude and different sun angles on observer counts. In sector C6, all lines except one were flown twice at the same altitude, several days apart. In sector B1, one set of seven lines was flown twice at 300 ft of altitude, 2 days apart, and another set of eight lines was flown once at 500 ft and three times at 300 ft, over a period of 11 days. Much of sector B3 was surveyed twice at 300 ft, 5 days apart. Sector B5 was surveyed completely for the first time in 1987; in previous years, either time constraints or ice conditions precluded its completion.

The selected data set from which density calculations for the fast ice were made contained 186 transect lines and an area of 1,517 nmi^2 (Table 3, Figure 1). This represented 62% of the total number of possible lines at 2-nmi intervals, and coverage by area of 16% of all fast ice in the Chukchi Sea and 14% of all fast ice in the Beaufort Sea study areas.

Factors Affecting Survey Counts

Observer Comparisons

During most surveys, a single experienced observer counted seals on each side of the aircraft. Right- and left-side observers remained the same throughout the survey period. From 22-24 May, several inexperienced backup observers participated in the surveys and provided comparative counts. Rear observation posts did not have bubble windows but visibility was otherwise satisfactory. Results of comparisons of primary and secondary observers are presented in Table 4. In all comparisons combined, inexperienced backup observers counted 78% as many seals as did experienced observers, with a range of 67 to 85% on individual flights.

Counts of left and right observers were compared for each survey flight. Left and right sides were significantly different ($p < 0.05$), as measured by a chi-square test, on 10 of 29 flights (Table 5). Some of the differences were attributable to large numbers of seals at cracks, and for others there was no obvious explanation. Overall, when all flights on all days were combined, there was less than a 1% difference in the total counts of seals made by left and right observers (6,553 vs. 6,595); the difference was not significant by either paired t or Wilcoxon signed rank tests (paired $t = 0.13$, $df = 28$, $p > 0.8$; $z = 1.157$, $p > 0.2$, ns).

Table 2.–Dates, number of legs, miles on track, and total area surveyed for each sector during ringed seal aerial surveys conducted 20 May-16 June 1987. Table includes all data collected.

Sector	Sector boundaries	Date	Number of legs	Altitude (ft)	Miles (nmi) on track	Area (nmi^2) surveyed Fast	Pack
C1	Cape Espenberg-Cape Krusenstern	21 May	8	500	365	274	0
		22 May	10	500	381	233	53
			4	300	130	59	0
		24 May	6	500	63	47	0
			6	300	63	28	0
C2	Cape Krusenstern-Point Hope	23 May	21	300	360	63	99
			6	300	99	18	27
		24 May	8	300	164	16	58
C4	Cape Lisburne-Point Lay	28 May	19	300	370	117	50
C5	Point Lay-Wainwright	29 May	12	300	143	64	0
		31 May	6	300	203	92	0
C6	Wainwright-Barrow	31 May	12	300	168	76	0
		4 June	13	300	176	79	0
B1	Barrow-Lonely	31 May	7	300	66	30	0
		2 June	6	500	124	62	31
			21	300	430	161	32
		5 June	8	300	141	55	8
		13 June	8	300	163	49	25
B2	Lonely-Oliktok	3 June	17	300	463	183	25
		5 June	4	300	128	44	13
		11 June	4	300	63	28	0
B3	Oliktok-Flaxman	6 June	20	300	530	105	133
		7 June	3	300	73	7	26
		11 June	24	300	382	102	70
B4	Flaxman-Barter	7 June	15	300	396	53	125
B5	Barter-Demarcation	12 June	18	300	307	45	93

Table 3.–Number and percentage of lines surveyed, miles on track, and area surveyed by sector for selected data only, 1987. Only these data were used in density calculations.

Sector	Number of lines	% of lines in sector	Miles on track (nmi)	Area surveyed (nmi^2) Fast	Pack
C1	18	58	746	507	53
C2	21	57	360	63	99
C4	19	73	370	117	50
C5	18	69	346	156	0
C6	12	50	168	76	0
B1	21	62	430	161	32
B2	21	62	591	227	38
B3	23	61	603	112	159
B4	15	63	396	53	125
B5	18	67	307	45	93
Total	186	62	4,317	1,517	649

Table 4.–Comparative counts of ringed seals made by primary and inexperienced secondary observers, May 1987.

Date	Number of legs	Primary observer: Number of seals	Primary observer: $\bar{x}$ seals/leg	Secondary observer: Number of seals	Secondary observer: $\bar{x}$ seals/leg	Paired t-test
2 May	6	213	35.5	144	24.0	$t = 5.02$ $df = 5$ $p < 0.01$
3 May	22	382	17.4	309	14.0	$t = 2.67$ $df = 21$ $p < 0.02$
	6	149	24.8	125	20.8	$t = 4.00$ $df = 5$ $p < 0.02$
4 May	20	175	8.8	142	7.1	$t = 2.26$ $df = 19$ $p < 0.04$

Table 5.–Results of chi-square analyses of the differences in counts between left and right observers for ringed seal surveys, 1987.

Survey date	Number of seals: Left	Right	Expected	X^2 (df = 1)	p[1]
21 May	360	374	367	0.27	ns
22 May	251	305	278	5.24	<0.025
	151	186	168.5	3.64	ns
	59	92	75.5	7.21	<0.01
23 May	16	12	14	0.57	ns
	366	374	370	0.09	ns
	149	181	165	3.10	ns
24 May	20	13	16.5	1.48	ns
	16	12	14	0.57	ns
	139	183	161	6.01	<0.025
28 May	167	217	192	6.51	<0.025
	152	88	120	17.07	<0.005
29 May	71	77	74	0.24	ns
31 May	106	149	127.5	7.25	<0.01
	93	112	102.5	1.76	ns
	33	46	39.5	2.14	ns
2 June	269	276	272.5	0.09	ns
	83	63	73	2.74	ns
3 June	392	462	427	5.74	<0.025
4 June	99	102	100.5	0.04	ns
5 June	108	101	104.5	0.23	ns
	107	112	109.5	0.11	ns
6 June	575	605	590	0.76	ns
7 June	210	176	193	2.99	ns
	553	499	526	2.77	ns
11 June	1,142	910	1,026	26.23	<0.005
	69	62	65.5	0.37	ns
12 June	609	517	563	7.52	<0.01
13 June	188	289	238.5	21.39	<0.005
Total	6,553	6,595	6,574	0.13	ns

[1] ns = not significant

Altitude

Prior to 1987, all sectors in the Chukchi Sea were surveyed at 500 ft of altitude and those in the Beaufort Sea at 300 ft. In 1987, due to advanced melt conditions in the Chukchi Sea, all Chukchi sectors except C1 were flown at 300 ft. As in previous years, all Beaufort Sea sectors were flown at 300 ft due to the regular occurrence of low cloud ceilings, fog, or both.

Portions of sectors C1 and B1 were surveyed at both 300 ft and 500 ft to determine comparability of counts at the two altitudes. Test lines were flown consecutively at one altitude and then, on the return flight, at the other. Small differences in time of day and lighting were considered to have a negligible effect on results.

For all 1987 altitude comparisons, densities of seals at holes based on counts at 500 ft were 71-76% of those at 300 ft; all comparisons were statistically significant (Table 6). For the three flights combined, the 500-ft density was 75% of that determined at 300 ft or, conversely, 1.33 times as many seals/nmi were counted at 300 ft as at 500 ft.

Meltwater

In 1987, spring weather had already begun melting snow on the surface of the fast ice by the time our surveys began. Unlike the two previous years when little or no surface melt was present, in late May 1987 there were extensive areas of dirty ice and meltwater. Because of this, survey altitude in the Chukchi Sea was reduced from 500 ft to 300 ft for all sectors except C1. In Sector C1, which was flown at 500 ft, 26% of the ice was classified as having greater than 30% meltwater. The density of seals in 0-30% meltwater was 3.57/nmi, compared to 2.27/nmi in greater than 30% meltwater. In sectors C2-C4 combined, flown at 300 ft, the density in 0-30% meltwater was 4.95/nmi, and in greater than 30% meltwater it was 2.79/nmi. Thus, 1.6 to 1.8 times as many seals were counted in areas without extensive surface meltwater. It is unknown whether the lower densities were due to fewer seals on the ice or to difficulty in seeing seals in areas with coloring caused by meltwater.

Habitat Factors Affecting Distribution and Abundance

Ice Deformation

The percentage of the ice surface that was deformed by pressure ridges, ice jumbles, or snow drifts was recorded by 10% increments for each minute of all survey transects. The 0-10% category was further subdivided as 0-5% or 5-10% deformation.

In the Chukchi Sea in 1987, 99% of all fast ice was less than 40% deformed, and 79% was less than 10%. The density of seals was highest (4.6 seals/nmi) in the 0-5% category, where 67% of the number of seals occurred on 56% of the fast ice area, and decreased steadily with increasing deformation (Table 7). Seal density in 0-10% areas was over 1 seal/nmi greater than in the next deformation category. Ice in Kotzebue Sound was considerably flatter than in more

Table 6.–Comparison of densities of ringed seals at holes derived from surveys flown at 300-ft and 500-ft altitudes in sectors C1 and B1 during May-June 1987, fast ice only.

Sector		300 ft # of legs	Area (nmi^2)	Seals/ nmi^2	SD	500 ft # of legs	Area (nmi^2)	Seals/ nmi^2	SD	Student's t-test
C1	5/22	4	59	2.58	0.19	4	120	1.91	0.35	$t = 3.365$, $df = 6$, $p < 0.02$
	5/24	6	28	0.98	0.24	6	47	0.70	0.09	$t = 2.676$, $df = 10$, $p < 0.05$
B1	6/2	6	39	2.94	0.47	6	62	2.23	0.28	$t = 3.19$, $df = 10$, $p < 0.01$

northern Chukchi Sea sectors. In sector C1, 98% of all fast ice was less than 10% deformed, compared to 62% in sectors C2-C6. Cracks, and therefore seals at cracks, were not abundant in the Chukchi Sea. However, virtually all seals at cracks occurred in ice of 0-5% deformation.

In the Beaufort Sea, the pattern of seal density in relation to ice deformation was similar to that in the Chukchi Sea, with more seals occurring in flat ice than in rougher ice. Ninety-nine percent of all fast ice was less than 40% deformed, but, unlike the Chukchi Sea, only 41% was less than 10% deformed. The density of seals was greatest in the 0-10% category, where 48% of the seals occurred on 41% of the fast ice area (Table 8). As in the Chukchi Sea, the density of seals in 0-10% ice was over 1 seal/nmi greater than in 10-20% ice.

Cracks were more numerous and more broadly distributed in the Beaufort Sea than in the Chukchi Sea. The density of seals at cracks in the Beaufort was greatest (3.48/nmi^2) in 0-5% deformation and considerably less (1.27-2.25/nmi^2) in other deformation categories. Cracks are most often present and visible in large expanses of flat ice.

Distance from Shore and Fast Ice Edge

The effect of distance from shore and from the fast ice edge on the density of hauled-out seals was examined for each sector by comparing the density of seals by 2-nmi increments. In all comparisons in both the Chukchi and Beaufort seas, seals at holes were less abundant 0-2 nmi from shore than they were 2-4 nmi offshore (Tables 9 and 10). In most sectors, the density within 2 nmi of shore was the lowest on any part of the fast ice.

A similar analysis of density with distance from the fast ice edge indicated that in the Chukchi Sea, seals were generally more numerous within 0-4 nmi of the fast ice edge than

Table 7.–Ringed seal density (total seals) in relation to ice deformation in the Chukchi Sea in 1987, fast ice only.

Deformation (%)	Area surveyed		Seals		Density
	nmi²	%	Number	%	(seals/nmi²)
0-5	435.5	56.4	2,013	67.2	4.62
5-10	171.5	22.2	572	19.1	3.34
0-10 (combined)	607.0	78.6	2,585	86.3	4.26
10-20	124.0	16.1	324	10.8	2.61
20-30	31.5	4.1	73	2.4	2.32
30-40	6.4	0.8	7	0.2	1.09
>40	2.9	0.4	6	0.2	2.07
Total	771.8		2,995		

Table 8.–Ringed seal density (total seals) in relation to ice deformation in the Beaufort Sea (sectors B1-B4) in 1987, fast ice only.

Deformation (%)	Area surveyed		Seals		Density
	nmi²	%	Number	%	(seals/nmi²)
0-5	100.7	18	693	23	6.88
5-10	125.7	23	758	25	6.03
0-10 (combined)	226.4	41	1,451	48	6.41
10-20	170.3	31	904	30	5.31
20-30	117.4	21	548	18	4.67
30-40	34.2	6	82	3	4.09
>40	5.4	1	10	<1	1.85
Total	553.7		2,995		

Table 9.–Density of ringed seals at holes on shorefast ice of the Chukchi Sea in relation to distance from shore, May-June 1987.

Distance from shore (nmi)	Sector density (seals/nmi²)				
	C1	C2	C4	C5	C6
0-2	1.53	2.43	2.79	2.44	1.84
2-4	3.86	3.03	4.80	2.60	2.70
4-6	3.91	3.63	3.25	2.92	5.33
6-8	3.38	8.98	4.03	2.88	2.55
8-10	5.40		3.87	2.05	2.87

Table 10.–Density of ringed seals at holes on the shorefast ice of the Beaufort Sea in relation to distance from shore, May-June 1987.

Distance from shore (nmi)	Sector density (seals/nmi²)				
	B1	B2	B3	B4	B5
0-2	1.40	1.91	2.75	3.08	5.66
2-4	2.10	3.00	2.89	3.55	5.47
4-6	2.57	3.99	5.37	4.23	7.75
6-8	3.21	5.84	3.53	1.90	16.90
8-10	3.59	5.80	3.08	3.95	

farther away (Table 11). The exception was sector C5, from Point Lay to Wainwright, were seals were half as abundant within 2 nmi of the edge as elsewhere. Seals at cracks were present in substantial numbers only in sector C4, and density was greatest near the edge. For all Chukchi Sea sectors combined, the density of seals at holes on the fast ice was 28% higher within 2 nmi of the edge than 2-4 nmi away (Figure 3A). This analysis excluded sector C1, where distance from the edge was not applicable for most lines since all of Kotzebue Sound was fast ice.

In the Beaufort Sea (sectors B1-B4), the density of seals at holes on fast ice was highest within 0-6 nmi of the edge, and was similar across that entire region (Table 12). Seals at cracks were abundant only in sectors B3 and B4, but they, too, were most numerous within 6 nmi of the edge.

Pack Ice

In the pack ice, densities were lower and seals at cracks were more broadly distributed, but the density of both seals at holes and those at cracks was highest within 2 nmi of the edge (Figure 3B). Total coverage of the pack ice in the Chukchi Sea in 1987 was 176 nmi^2, all in sectors C1-C4. The combined Chukchi Sea density of total seals on pack ice was 3.67 seals/nmi^2. Most of those were seals observed at holes.

In the Beaufort Sea, total coverage of pack ice in sectors B1-B4 was 355 nmi^2. An additional 93 nmi^2 was surveyed 1 week later in sector B5. The density of total seals in pack ice in sectors B1-B4 combined was 3.32 seals/nmi^2. In marked contrast to the Chukchi Sea, 62% of those (2.05/nmi^2) were seals at cracks. Densities of seals at holes were similar in sectors B1-B4 (range = 1.1-1.5 seals/nmi^2). However, seals at cracks ranged from less than 0.5/nmi^2 in sectors B1 and B2, to over 2 seals/nmi^2 in sectors B3 and B4. Sector B5 was flown about a week later than the other sectors and the density in pack ice (8.3 seals/nmi^2) was about 2.5 times higher than in sectors B1-B4 combined.

The trend in density on the pack ice relative to the fast ice edge was similar to that on fast ice: more seals were seen close to the edge (Figure 3). For both seals at holes and seals at cracks in the Beaufort Sea, the density was highest within 2 nmi of the edge, intermediate 2-10 nmi from the edge, and lowest 10-20 nmi distant. The density of total seals nearest the edge was 6.6/nmi^2, compared to 3.2/nmi^2 between 2 and 10 nmi, and 2.3/nmi^2 seaward of 10 nmi. A smaller area of pack ice was surveyed in the Chukchi Sea, but the trend was similar, with 4.4 seals/nmi^2 within 4 nmi of the edge, 3.2/nmi^2 between 4 and 10 nmi, and 2.2 beyond 10 nmi.

Temporal and Spatial Patterns of Abundance

Regional Patterns

Densities of total seals on the fast ice of the Chukchi Sea in 1987 were greatest south of Point Lay (sectors C1-C4) and were considerably lower to the north (Table 13). The mean

Table 11.–Density of ringed seals at holes on shorefast ice of the Chukchi Sea in relation to distance from the fast ice edge, May-June 1987.

Distance from fast ice edge (nmi)	Sector density (seals/nmi²)				
	C1	C4	C5	C6	Total
0-2	8.82	4.33	1.29	3.35	4.20
2-4	3.68	4.13	2.56	3.54	3.48
4-6	2.41	3.46	2.62	2.11	2.66
6-8	2.13	3.10	2.47	2.02	2.55
8-10		2.57	2.22	1.82	2.24

Table 12.–Density of ringed seals at holes on shorefast ice of the Beaufort Sea in relation to distance from the fast ice edge, June 1987.

Distance from fast ice edge (nmi)	Sector density (seals/nmi²)				
	B1	B2	B3	B4	B1-4
0-2	3.60	2.66	4.07	3.62	3.65
2-4	3.59	4.24	4.40	3.63	3.97
4-6	3.58	3.11	4.22	3.96	3.82
6-8	2.34	3.10	2.28	3.36	2.67
8-10	1.94	3.08	3.43	3.14	2.70

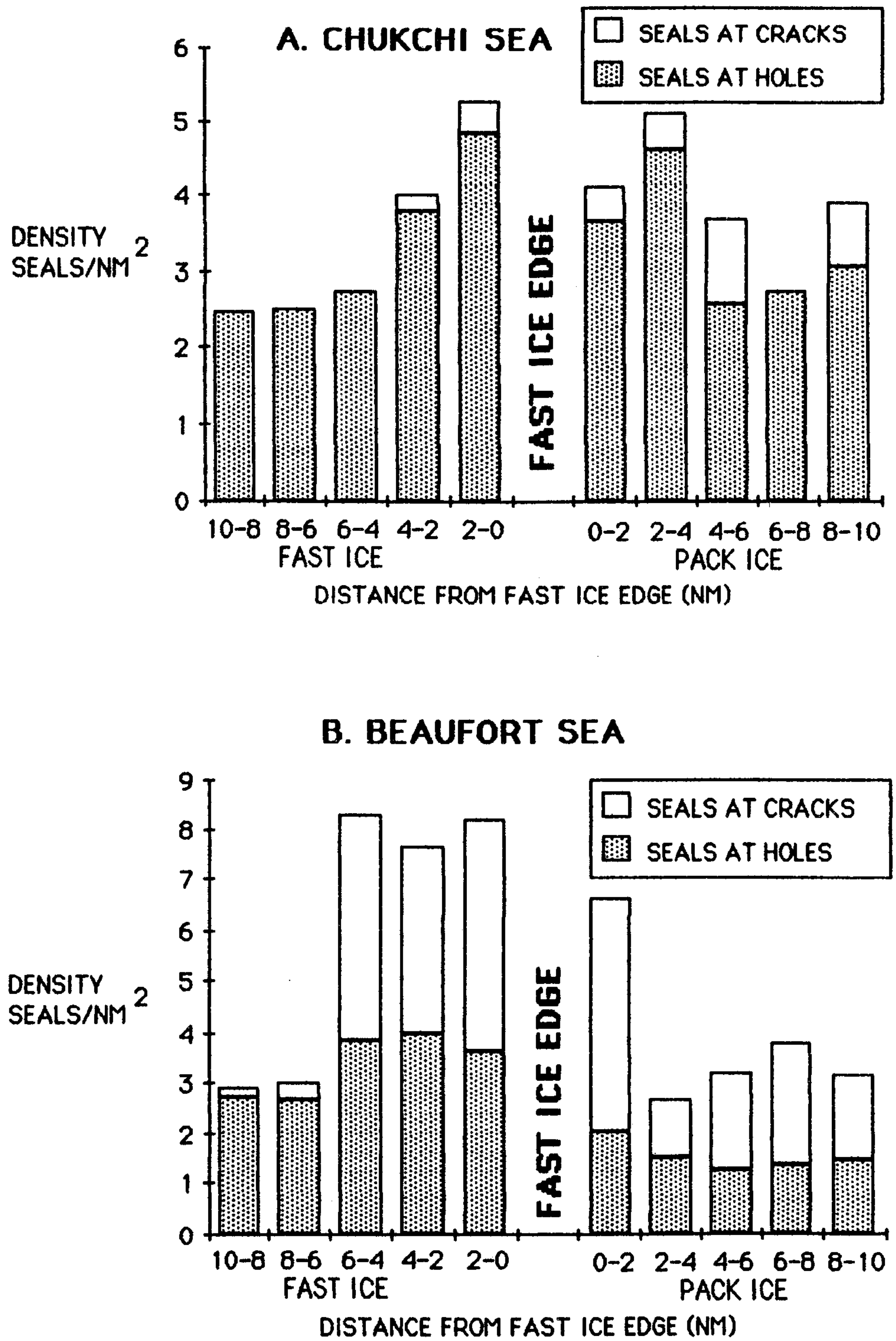


Figure 3.–Relationship between ringed seal density (seals/nm^2) and distance from the fast ice edge in 1987. A–Chukchi Sea, not including sector C1; B–Beaufort Sea, sectors B1-B4.

Table 13.–Density of ringed seals on shorefast ice and pack ice in the Chukchi and Beaufort seas, May-June 1987.

	Fast ice				Pack ice			
		Seals/nmi²				Seals/nmi²		
Sector	nmi²	Holes	Cracks	Total	nmi²	Holes	Cracks	Total
Chukchi[1]								
C1	506	3.92	0.01	3.92	53	2.76	0.15	2.91
C2	63	4.53	0.03	4.56	99	3.82	0.74	4.57
C4	92	3.57	0.23	3.80	23	1.57	0.00	1.57
C5	156	2.59	0.00	2.59	0	–	–	–
C6	76	2.65	0.05	2.70	0	–	–	–
ALL	892	3.58	0.03	3.62	176	3.20	0.47	3.67
Beaufort								
B1	161	3.00	0.11	3.10	32	1.14	0.25	1.39
B2	227	4.35	0.08	4.44	39	1.17	0.49	1.66
B3	112	3.57	4.51	8.08	159	1.48	2.65	4.13
B4	53	3.52	8.53	12.05	125	1.09	2.23	3.31
B5	45	6.69	1.02	7.71	93	2.70	5.65	8.35
B1-B3	501	3.74	1.08	4.82	230	1.38	1.95	3.33
B1-B4	554	3.72	1.79	5.51	355	1.28	2.05	3.32
B1-B5	599	3.94	1.74	5.68	449	1.57	2.80	4.37

[1] In 1987, snow melt occurred much earlier than in the previous 2 survey years. Sector C1 was surveyed at 500 ft, but observers subsequently decided that the remaining Chukchi Sea sectors should be flown at 300 ft due to extensive meltwater and poor sightability of seals at 500 ft. All densities of seals at holes in C1 have been multiplied by the correction factor 1.32 to make them comparable to data from other sectors that were surveyed at 300 ft.

density of total seals for the three southernmost sectors combined (C1-C4) was 4.0 seals/nmi^2, compared to 2.6 seals/nmi^2 for the more northern sectors C5 and C6. Most of the seals counted in the Chukchi Sea were seen at holes. Seals at cracks accounted for 1% of the total seals in sectors C1-C6 combined (range 0-6%).

In the Beaufort Sea, densities were lowest in the west between Barrow and Lonely (3.1 seals/nmi^2), over twice as high in the central Beaufort region between Lonely and Flaxman Island (8.1 seals/nmi^2) and the eastern Beaufort between Barter Island and Demarcation Point (7.7 seals/nmi^2), and four times as high between Flaxman and Barter Island (12.0 seals/nmi^2). However, the sector B3-B5 data may not be comparable to data from sectors B1 and B2. Breakup was apparently well advanced by the time we flew sectors B3-B5, despite the relatively early date.

Observed densities of seals were extrapolated to estimate the total number of ringed seals hauled out on the shorefast ice of the Chukchi and Beaufort seas in May-June 1987 by multiplying the density in each sector by the area of fast ice coverage (Table 14). Calculations indicated means and 95% confidence intervals of 20,200 ± 2,300 total seals hauled out on fast ice in the Chukchi Sea, and 24,100 ± 6,800 in the Beaufort Sea. These estimates do not account for seals that were in the water at the time of the surveys, seals that were missed by observers, or seals in the pack ice. The Beaufort Sea estimate includes very high numbers of seals at cracks in sectors B3-B5.

Temporal Variability

During 1987 surveys, portions of several sectors were flown more than once to test for temporal variability. In the Chukchi Sea (sectors C2 and C6), two sets of lines were flown twice, up to 4 days apart. There was no significant difference in the density of seals at holes or total seals in either comparison (Table 15).

In the Beaufort Sea, five replicate data sets were compared. Two sets of lines in sector B1 were flown 2-3 days apart under similar ice conditions. There was no significant difference in the density of total seals in either comparison. Three pairs of surveys (sectors B1 and B3) occurred 5-11 days apart. In all three, the density of seals at holes and of total seals was significantly greater on the later date.

In sector B1 the position of the ice edge and, therefore, the area of fast ice surveyed, remained similar throughout our surveys. In sector B3 the ice edge was breaking up quite rapidly, and the total fast ice area was reduced by approximately 23% between the 6 June and 11 June surveys. To ensure that density comparisons for sector B3 were made between comparable areas, we compared (1) only the area within 6 nmi of land and (2) all ice, both fast and pack. In both comparisons, significantly more seals were hauled out on the later date (4.90 vs. 11.75 seals/nmi^2 within 6 nmi of land and 4.91 vs. 11.38 seals/nmi^2 for fast and pack ice combined). The increase was greatest for seals at cracks.

Table 14.–Density and estimated numbers (95% confidence limits) of total ringed seals hauled out on the fast ice in the study area during aerial surveys conducted in May-June 1987.

Sector	Density - seals/nmi² (±95% confidence interval)	Fast ice area (nmi²)	Estimated number of hauled-out seals
B1	3.10 (±0.37)	1,050	3,260 ± 390
B2	4.44 (±0.53)	1,770	7,860 ± 940
B3	8.08 (±2.96)	780	6,300 ± 2,310
B4	12.05 (±11.94)	410	4,940 ± 4,900
B5	7.71 (±2.45)	240	1,850 ± 590
Beaufort Total	5.68 (±1.61)	4,250	24,140 ± 6,840
C1	3.92 (±0.69)	2,390	9,370 ± 1,650
C2	4.56 (±1.74)	655	2,990 ± 1,140
C4	3.80 (±1.20)	715	2,720 ± 860
C5	2.59 (±0.31)	995	2,580 ± 310
C6	2.70 (±1.27)	830	2,240 ± 1,070
Chukchi Total	3.62 (±0.41)	5,585	20,220 ± 2,290
Grand Total		9,835	44,360 ± 9,130

Table 15.—Comparison of ringed seal densities derived from replicate surveys of the same lines flown on different days. Only seals on shorefast ice are included.

Sector (altitude)	Number of legs	Replicate 1				Replicate 2				Student's t-test
			Density (seals/nmi^2)				Density (seals/nmi^2)			
		Date	Holes	Cracks	Total	Date	Holes	Cracks	Total	
C2	6	23 May	6.32	0.0	6.32	23 May	6.10	0.06	6.16	holes t=0.170, df=10, n.s. total t=0.124, df=10, n.s.
C6	12	31 May	2.65	0.05	2.70	4 June	2.60	0.0	2.60	holes t=0.231, df=22, n.s. total t=0.468, df=22, n.s.
B1	7	31 May	2.64	0.0	2.64	2 June	2.52	0.22	2.74	holes t=0.459, df=12, n.s. total t=0.374, df=12, n.s.
B1	8	2 June	3.06	0.15	3.21	5 June	3.70	0.0	3.70	holes t=2.70, df=14, p<0.02 total t=2.07, df=14, n.s.
B1	8	5 June	3.70	0.0	3.70	13 June	8.06	0.51	8.58	holes t=8.89, df=14, p<0.001 total t=10.25, df=14, p<0.001
B1	8	2 June	3.06	0.15	3.21	13 June	8.06	0.51	8.58	holes t=10.77, df=14, p<0.001 cracks t=3.01, df=14, p<0.01 total t=11.97, df=14, p<0.001
B3	15	6 June	3.71	2.51	6.23	11 June	5.11	6.08	11.19	holes t=7.07, df=28, p<0.001 cracks t=4.61, df=28, p<0.001 total t=5.83, df=28, p<0.001

We also calculated average group size (the number of seals hauled out at a single hole) and the density of groups for early and mid-June surveys in the Beaufort Sea (Table 16). In sector B3 the average group size was significantly greater for the later surveys (1.5 vs. 1.8, $t = 2.311$, $p < 0.05$). In sector B1, the difference was not significant (1.3 vs. 1.4, $t = 1.518$, $p > 0.1$). Density of groups increased in both sectors, with the greatest increase in B1. Group size was also comparatively large in sectors B4 and B5, which were surveyed late in the study period.

Density of Seals in Relation to Industrial Activities

In spring of 1987 there was little industrial activity in the study area. We saw no evidence of on-ice seismic surveys, or ice roads other than those leading to artificial islands.

During 1987 aerial surveys, as in the 2 previous years, there were three artificial islands located in the study area in the region between Oliktok and Prudhoe Bay (Figure 4). They were: (1) Seal Island, located 10 nmi west of Prudhoe Bay; (2) Northstar Island, located 4 nmi west-northwest of Seal Island; and (3) Sandpiper Island, located 5.5 nmi west-northwest of Northstar Island. All three islands were inactive during winter and spring of 1986-87.

Surveys were conducted in the vicinity of the three islands twice in 1987, on 6 and 11 June. The shortest straight-line distances from artificial islands to each minute sighting block were determined by comparing positions for each interval to positions for the islands. Densities were then calculated for 2-nmi concentric circles centered at the artificial islands, out to a distance of 10 nmi. Since the islands were less than 10 nmi apart and interactive effects were possible, densities in relation to all islands were also calculated using the minimum distance from any of the three islands for each 1-minute sighting block.

There was no consistent trend in seal density with distance from the three non-operational islands (Table 17). Seals were more numerous near Seal Island, less numerous near Northstar, and differed between the two surveys at Sandpiper. At Seal Island, where the density was very high near the island, there was a large crack in the ice running perpendicular to the shore, both to the north and to the south. This crack, which appeared to be caused by the island, may have provided an avenue along which seals penetrated into the nearshore fast ice.

When all three islands were considered in aggregate, the densities in the 0- to 2-nmi distance interval were 12-30% lower than those in the 2- to 4-nmi interval. However, the density differences between these two intervals were not significant on either day (t-tests, $p > 0.05$). Sample sizes were very small in the distance intervals closest to the island: 5 minutes and 4.5 nmi^2 in the 0- to 2-nmi and 2- to 4-nmi intervals combined on 6 June, and 10-14 minutes and 9.0-12.5 nmi^2 in those intervals on 11 June.

Data from the 1987 surveys were also analyzed according to the 1986 industrial and control blocks (Figure 4) even though there was little or no offshore industrial activity. In the absence of industrial activity, density of total seals in the industrial block was significantly higher ($p < 0.02$) than in either control area for both surveys (Table 18).

Table 16.–Comparison of average group size and density of groups for seals at holes in the fast ice in the Beaufort Sea, June 1987.

Sector	Date	Seals/nmi²	Groups/nmi²	Group size
B1	2 June	3.06	2.32	1.25
	13 June	8.06	5.81	1.39
B2	3,5 June	4.35	3.27	1.33
B3	6,7 June	3.71	2.41	1.53
	11 June	5.11	3.10	1.78
B4	7 June	3.52	1.80	1.96
B5	12 June	6.69	3.14	2.13

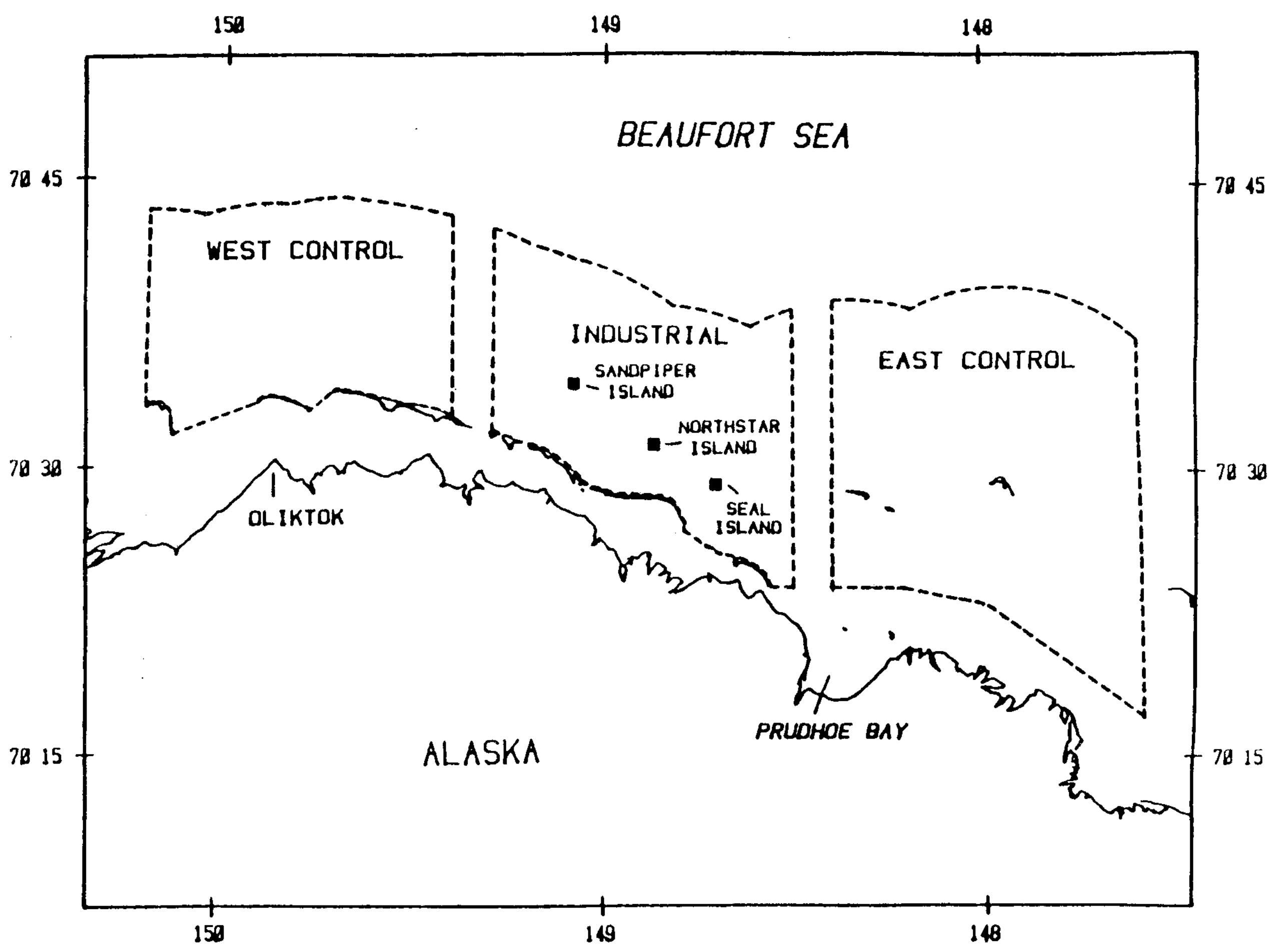


Figure 4.–Map of the central Beaufort Sea showing locations of artificial islands and industrial and control blocks used in 1986 and 1987 data analyses.

Table 17.–Density of ringed seals at holes in relation to distance from three artificial islands in the Beaufort Sea, June 1987.

Island	Survey	nmi² surveyed	Distance (nmi) 0-2	2-4	4-6	6-8	8-10
Seal	87-1	26	-	1.1	2.9	2.7	5.5
	87-2	32	14.4	9.5	10.4	5.9	4.8
Northstar	87-1	23	1.1	3.3	5.6	4.1	5.2
	87-2	34	3.8	8.4	14.2	6.3	6.1
Sandpiper	87-1	27	7.1	7.6	2.2	4.2	3.9
	87-2	34	6.8	5.5	6.6	5.2	11.9
Any island	87-1	45	4.7	6.7	2.4	4.1	4.0
	87-2	50	7.1	8.1	9.5	5.8	5.4

Table 18.–Densities of ringed seals (seals/nmi²) within 10 nmi of land in industrial and control blocks in the Beaufort Sea, June 1987. Standard deviations are given in parentheses.

Block	# legs	Seals at holes Density (SD)	Seals at cracks Density (SD)	Total seals Density (SD)
Test 1 (5-6 June)				
Industrial	4	3.80 (1.05)	3.38 (1.11)	7.17 (1.55)
Control West	5	3.84 (0.57)	0.61 (0.37)	4.45 (0.77)
Control East	7	2.04 (0.56)	1.51 (0.55)	3.55 (0.70)
Test 2 (11 June)				
Industrial	9	8.10 (1.41)	6.73 (4.51)	14.83 (5.23)
Control West	9	5.90 (0.40)	2.36 (2.23)	8.25 (2.34)
Control East	9	3.36 (0.55)	3.33 (2.43)	6.69 (2.43)

The industrial block was an area in which some type of industrial activity (such as seismic surveys or artificial islands) had occurred in 1986, and included the ice within 10 nmi of land. Control blocks were located to the east and west of the industrial block and were areas with no obvious industrial activity. Although they were controls in the sense that there was no industrial activity there in 1986, they may or may not have been environmentally comparable in terms of bathymetry, ice conditions, prey availability, and other variables.

DISCUSSION AND CONCLUSIONS

Survey Effort

The total amount of survey effort, in terms of area surveyed of fast ice and pack ice, is summarized for each sector in Table 19. The total area surveyed was 3,409 nmi^2 (92% fast ice) in 1985, 3,405 nmi^2 (74% fast ice) in 1986, and 2,958 nmi^2 (71% fast ice) in 1987. Variations in total and proportional coverage were due mostly to intentional adjustments in survey design. The reduced fast ice coverage in the Beaufort Sea in 1986 and 1987 was due largely to the decision not to attempt 90% coverage of all lines in sectors B2 and B3. The intensive grid around artificial islands (lines spaced 1 nmi apart) was flown only in 1985. Survey design in 1986 and 1987 included, where possible, two to four lines per sector extending 40 nmi offshore in order to provide coverage of pack ice. There was no systematic attempt to obtain pack ice coverage in 1985. Overall, there was considerable variability in pack ice coverage due to annual variations in the location of the fast ice edge and the relationship between timing of surveys and the beginning of breakup.

Although we initially intended to gather data on seal density for all portions of the Chukchi and Beaufort sea coasts, it was impossible to do so. In all 3 years, the shorefast ice from Point Hope to Cape Lisburne (sector C3) consisted of a very narrow band, seaward of which was a lead of variable width and a very extensive shear zone. These conditions made aerial strip transect surveys impractical. Furthermore, steep cliffs south of Cape Lisburne cause severe downdrafts near shore and make flying over the narrow band of fast ice difficult and unsafe. In addition, while seals do occur in such habitats, this is not the type of region which supports large numbers of resident animals. We also did not obtain adequate coverage in the Beaufort Sea east of Barter Island (sector B5). Reasons for this include limited extent of shorefast ice, early and complex patterns of breakup, and limitations on the number of survey hours available. A concerted effort to obtain data for this region in 1987 resulted in only 45 nmi^2 of fast ice surveyed.

Survey coverage of fast ice, expressed as a percentage of total fast ice area in relation to survey area in the selected data base, was quite consistent (Table 20). The difference between the Chukchi Sea and Beaufort Sea in 1985 and 1986 is due to the fact that in those years all Chukchi Sea sectors were surveyed at 500 ft (strip width 2,250 ft) and all Beaufort Sea sectors were surveyed at 300 ft (strip width 1,350 ft). In 1987, all sectors except C1 were surveyed at 300 ft and the difference in coverage was much less. When data for the Chukchi

Table 19.–Total area surveyed (nmi^2) in fast and pack ice during ringed seal aerial surveys conducted in May-June 1985-87. All data collected are included.

Sector	Sector boundaries	1985		1986		1987	
		Fast	Pack	Fast	Pack	Fast	Pack
C1	Cape Espenberg-Cape Krusenstern	542	20	491	3	641	53
C2	Cape Krusenstern-Point Hope	58	136	101	77	97	184
C3	Point Hope-Cape Lisburne	0	0	0	0	0	0
C4	Cape Lisburne-Point Lay	167	0	212	0	117	50
C5	Point Lay-Wainwright	134	0	204	34	156	0
C6	Wainwright-Barrow	115	0	272	157	155	0
	Total Chukchi Sea	1,016	156	1,280	271	1,166	287
B1	Barrow-Lonely	382	7	456	145	357	96
B2	Lonely-Oliktok	820	0	378	12	255	38
B3	Oliktok-Flaxman	631	63	345	305	214	229
B4	Flaxman-Barter	279	11	70	143	53	125
B5	Barter-Demarcation	13	31	0	0	45	93
	Total Beaufort Sea	2,125	112	1,249	605	924	581
	Total	3,141	268	2,529	876	2,090	868

Table 20.–Aerial survey coverage (nmi^2) during ringed seal aerial surveys conducted in May-June 1985-87, selected data only.

Year	Region	Area of fast ice	Area of fast ice surveyed	Percentage of coverage	Area of pack ice surveyed
1985	Chukchi	4,890	946	19	128
	Beaufort	7,745	861	11	97
1986	Chukchi	5,800	1,073	19	128
	Beaufort	6,535	693	11	20
1987	Chukchi	5,858	919	16	202
	Beaufort	4,250	598	14	447

and Beaufort seas are combined, effort as reflected in the selected data base was virtually identical among years: 14.3% coverage in 1985, 14.3% coverage in 1986, and 15.0% coverage in 1987.

The total area of fast ice surveyed (Table 19) can be compared to the area included in the selected data base (Table 20) as a partial evaluation of survey performance. In 1985, 58% of all data collected was used in the selected data base; this value increased to 70% in 1986 and 73% in 1987. This increase reflects both the results of analysis of 1985 data that refined our definition of the survey window (Frost *et al.* 1985*b*) and an increased ability of survey personnel to anticipate appropriate survey conditions.

Aerial Survey Methodology

Influence of Weather

Previous studies have shown that weather affects the haulout behavior and, therefore, the observed densities of ringed seals (Burns and Harbo 1972; Finley 1979; Smith and Hammill 1981). Our survey methodology incorporated the findings of those studies, which largely precluded further tests of weather effects since we did not survey during extreme conditions that might have markedly affected observed densities. Analysis of weather effects is further complicated by the fact that weather reports were available only from a limited number of coastal stations and may not have accurately represented conditions in the survey areas on the ice surface.

The data collected in 1985 contained some legs flown at wind speeds of 21-25 and 26-30 knots, and air temperatures of -6° to -10°C. Analysis of the data indicated a significantly lower density of seals on transects flown at wind speeds of greater than 25 knots (Frost *et al.* 1985*b*). Temperatures below -5°C and wind chills below -20°C also produced lower density estimates, but those comparisons were considered inconclusive because of small sample sizes. It was recommended that, whenever possible, future surveys should be flown at wind speeds not exceeding 15 knots.

No surveys in 1986 or 1987 were intentionally flown at wind speeds greater than 20 knots; most were flown in 5- to 15-knot winds but some legs were flown in 16- to 20-knot winds. A multiple regression analysis of the effect of wind and temperature on the density of seals at holes indicated that wind speed, but not temperature, was correlated with seal density (Frost *et al.* 1987). Since less than 2% of the sample variability was attributable to wind, we believe that all data collected at wind speeds of 20 knots or less can be considered comparable.

Altitude Effects

Previous aerial surveys of ringed seals have generally been flown at altitudes of 300 ft to 500 ft. The preferred altitude has usually been 500 ft, with 300 ft considered an acceptable alternative when necessitated by low cloud ceilings or fog (Stirling *et al.* 1977, 1981*a*, 1981*b*; Kingsley *et al.* 1982, 1985; Burns *et al.* 1981; Burns and Kelly 1982). Density estimates derived at the two altitudes have been compared or combined without the use of correction factors. When the protocol for our surveys was developed, we proposed a standard survey altitude of 500 ft unless conditions required otherwise.

In 1985, the ice in the Chukchi Sea was flat and clean, cloud ceilings were relatively high, and all sectors were therefore flown at 500 ft. Some of the Beaufort Sea sectors were initially flown at 500 ft, until it became apparent to observers that greater ice deformation, dirtier ice, and sometimes extensive meltwater made it difficult to detect seals at that altitude. Furthermore, cloud ceilings and fog were often below 500 ft. In response, all sectors, and parts of sectors, were also surveyed at 300 ft. The observed mean densities at the 300-ft survey altitude were from 23% to almost 300% greater than those at 500 ft (Frost *et al.* 1985*b*). Although these comparisons were not made on identical data sets and were not necessarily under the same weather and ice conditions, the difference was large enough to warrant further investigation.

Altitude comparisons were conducted in two sectors (C6 and B1) in 1986 (Frost *et al.* 1987) and in two sectors (C1 and B1) in 1987. For all comparisons in which the same lines were flown on the same day at both altitudes, the densities of seals at holes based on counts at 500 ft were 71-80% of those at 300 ft (Table 21). All comparisons were statistically significant ($p < 0.05$). For the five systematic altitude comparisons combined, the 500-ft density of seals at holes was 76% of that determined at 300 ft, or, conversely, 1.32 times as many seals/nmi^2 were counted at 300 ft as at 500 ft ($p < 0.001$).

In 1986, we conducted separate analyses of flat (0-20% deformation) ice and rough (20-40% deformation) ice for the data sets used in altitude comparisons (Frost *et al.* 1987). These comparisons suggested that ice deformation might have an interactive effect with survey

Table 21.–Comparison of densities of ringed seals at holes derived from surveys flown at 300-ft and 500-ft altitudes in sectors C1, C6, and B1 during May-June 1986-87, fast ice only.

			300 ft			500 ft			
Sector	Date	# of legs	Area nmi^2	Seals/ nmi^2	SD	Area nmi^2	Seals/ nmi^2	SD	Student's t-test
C1	5/22/87	4	59	2.58	0.19	120	1.91	0.35	$t = 3.365$ $df = 6$ $p < 0.02$
	5/24/87	6	28	0.98	0.24	47	0.70	0.09	$t = 2.676$ $df = 10$ $p < 0.05$
	5/30/86	15	68.6	2.93	0.41	113.7	2.35	0.40	$t = 3.90$ $df = 28$ $p < 0.001$
B1	5/31/86	8	77.0	2.38	0.25	128.4	1.71	0.22	$t = 5.62$ $df = 14$ $p < 0.001$
	6/2/87	6	39	2.94	0.47	62	2.23	0.28	$t = 3.19$ $df = 10$ $p < 0.01$
All		39	271	2.49	0.18	471	1.88	0.16	$t = 15.61$ $df = 76$ $p < 0.001$

altitude, and that the different counts at 300 ft and 500 ft occurred primarily in flat ice. However, when ratios of seals in flat or rough ice were compared for the entire 1986 data base, that did not appear to be the case. Data from 1987 surveys were also analyzed as flat or rough ice and have been included in comparisons using all suitable ringed seal survey data (Table 22). Based on data sets from 5 years, altitude has no apparent effect on the observed ratio of densities (D) of seals in flat and rough ice. At 300 ft altitude, the ratio of D flat: D rough ranged from 1.0 to 1.8, and at 500 ft from 0.9 to 1.7. The ratios of densities in flat ice or rough ice at the two altitudes were also similar, and generally approximated the 1.32 correction factor developed for altitude based on 1986 and 1987 data sets (D flat 300: D flat 500 = 1.2-1.6; D rough 300: D rough 500 = 0.9-1.8).

Other investigators have discussed the factors affecting sightability of animals from the air. Caughley (1974) stated that the three most important factors are probably ground speed, strip width, and altitude, and that sightability declines with increases in all three. Data examined for sightability biases by Caughley (1974) and Caughley *et al.* (1976) indicated

Table 22.–Densities of total ringed seals (seals/nmi^2) in flat and rough ice for surveys conducted at 300-ft and 500-ft altitudes, 1981-87. Data from 1985-87 are from this study. Data from 1981 and 1982 were collected by ADF&G as part of RU 232 and reanalyzed as part of this study.

		300-ft ice deformation			500-ft ice deformation		
Year	Area	0-20% "flat"	20-40% "rough"	D flat / D rough	0-20% "flat"	20-40% "rough"	D flat / D rough
1981	Beaufort	1.6	1.6	1.0			
1982	Beaufort				1.8	1.3	1.4
1985	Beaufort	3.3	3.1	1.1	2.7	1.7	1.6
1986	Beaufort	5.1	3.4	1.5	3.9	2.4	1.7
	Altitude test only	2.9	1.8	1.6	1.8	1.9	0.9
1987	Beaufort	5.9	4.5	1.3			
	Chukchi	3.7	2.1	1.8			
	Altitude test only	2.6	2.7	1.0	1.8	1.7	1.1

that for elephants a 50% reduction in survey altitude resulted in a 25% increase in the number counted. Their analyses of wildebeest surveys indicated that more variability was associated with strip width than with altitude, and that doubling strip width (from 200 m to 400 m) resulted in about a 50% reduction in estimated density. Survey speed was also found to affect density estimates.

In all 1985-87 surveys of ringed seals, air speed was held constant. However, altitude and strip width varied between areas and among years. Our survey protocol specified that inclinometer angles defining strip width would remain constant, regardless of altitude, to minimize disruption and recalibration by observers during changes in altitude. However, this meant that changes in strip width always occurred concurrently with changes in altitude, and the biases associated with the two variables could not be tested independently. Thus, we could not determine whether the lower densities observed at 500 ft vs. 300 ft were attributable to increased altitude, increased strip width, or both.

Data collected in 1981 and 1982, however, utilized a 0.5-nmi survey strip that was subdivided into inner and outer 0.25-nmi bands for which counts were kept separately. We compared densities for inner and outer strips and those for inner strips and total strips for 1981 surveys conducted at 300 ft and 1982 surveys conducted at 500 ft. In both years, the densities calculated for the inner 0.25-nmi strips exceeded those for the outer strips and for the total 0.5-nmi strips, implying that fewer seals were missed closer to the aircraft (Table 23). Inner strip densities exceeded the total strip densities by 10-18%. Such comparisons indicate that the actual distance between observer and animal, as well as increased strip width, affects density estimates.

Observer Comparisons

During most of the ADF&G aerial surveys for ringed seals in 1985-87, a single trained observer counted seals on each side of the aircraft. The right-side observer (Frost) was the same in all 3 years. The left-side observer was Gilbert in May 1985 and all of 1986 and Golden in June 1985 and all of 1987. Total counts of the numbers of seals seen by left and right observers for all survey days in a given year were compared through paired t and Wilcoxon signed rank tests (Table 24). In no year was the difference between left and right observers significant by either test. Total counts of the left observer ranged from 7% less to 8% more than the right observer.

Other investigators conducting aerial surveys of ringed seals have also investigated the effects of observer bias by comparing counts of seals on the left and right sides of the aircraft during simultaneous transects. Stirling *et al.* (1977) found no significant differences in eight comparisons of ringed seal counts made in 1974 and 1975. Stirling *et al.* (1981*a*, 1981*b*) reported differences of 2 to 25% in surveys conducted during 1974-79 in the eastern Beaufort Sea and Canadian High Arctic, but none of the differences were significant. Tests of potential observer bias must be made on relatively large samples, such as data from entire survey days, rather than on a transect-by-transect basis, because habitat variability and clumped distribution of seals can cause substantial differences within a single transect. Ice conditions on the left and right sides of the aircraft may be considerably different, and although one would expect this to average out as more lines are surveyed, it is still possible for a few very large groups of seals, or a few areas (such as newly refrozen leads) where seals are very abundant, to result in large differences in counts between the two sides of the aircraft.

During 1985-87 aerial surveys for ringed seals, backup observers participated and provided comparative counts on 13 occasions (Table 25). Rear observation posts did not have bubble windows but visibility was otherwise satisfactory. Seals occasionally dove into the water before they came into view of the second observer, which, depending on the search pattern of the backup observer, may have resulted in some seals being missed. Participants agreed that this generally was not a major problem.

Of the 13 comparisons, 7 were between an experienced primary observer and an inexperienced backup observer. In five of those comparisons, the experienced observer counted significantly more seals ($p < 0.05$). In six comparisons between experienced observers, or with a novice observer who had received some training, differences were not significant ($p > 0.1$). Inexperienced observers undercounted by 5-42% in all but one comparison. In contrast, when both observers were experienced, neither observer regularly had the highest count.

Table 23.–Density of ringed seals in inner and outer 0.25-nmi survey strips based on aerial surveys conducted by ADF&G in May-June 1981 and 1982. Inner and outer strips for 1981 extend from 750 to 2,250 ft and 2,250 to 3,750 ft from the aircraft, and in 1982 from 0 to 1,500 ft and 1,500 to 3,000 ft.

Year	Sector	Area (nmi^2)	Seals/nmi^2 Inner	Outer	Total	Ratio Inner/Outer	Inner/Total
1981 (300 ft)	B1	70	1.62	1.77	1.69	0.92	0.96
	B2	592	1.43	1.06	1.24	1.35	1.15
	B3	516	1.49	1.07	1.28	1.39	1.16
	B4	130	1.67	1.93	1.76	0.87	0.95
	All	1,308	1.48	1.19	1.34	1.24	1.10
1982 (500 ft)	B1	106	1.31	0.67	0.99	1.96	1.32
	B2	94	1.68	1.23	1.45	1.37	1.16
	B3	243	1.85	1.32	1.58	1.40	1.17
	B4	47	1.11	1.00	1.05	1.11	1.06
	All	490	1.63	1.13	1.38	1.44	1.18

Table 24.–Comparison of the number of seals counted by left and right observers for ringed seal aerial surveys, May-June 1985-87.

Date	N	Number of seals Left	Right	Paired t-test	Wilcoxon signed rank
May 1985	10	2,272	2,478	t = 1.409, df = 9 p > 0.1, ns	z = −0.459, p > 0.6, ns
June 1985	13	1,751	1,859	t = 0.996, df = 12 p > 0.3, ns	z = −0.943, p > 0.3, ns
May-June 1986	29	7,229	6,688	t = 1.79, df = 28 p > 0.05, ns	z = −1.774, p > 0.05, ns
May-June 1987	29	6,553	6,595	t = 0.13, df = 28 p > 0.9, ns	z = −1.157, p > 0.2, ns

Table 25.–Comparison of counts of ringed seals made by experienced and inexperienced observers during aerial surveys conducted during May-June 1985-87.

Date	# legs	Primary observer Number of seals	Primary observer $\bar{x}$ seals/ leg	Secondary observer Number of seals	Secondary observer $\bar{x}$ seals/ leg	Paired t-test
Backup inexperienced						
22 May 1985	14	442	31.6	420	30.0	$t = 0.598$, $df = 13$, $p > 0.5$, ns
22 May 1985	14	393	28.1	436	31.1	$t = 1.74$, $df = 13$, $p > 0.1$, ns
23 May 1986	14	564	40.3	427	30.5	$t = 2.386$, $df = 13$, $p < 0.04$
31 May 1986	22	227	10.3	132	6.0	$t = 3.762$, $df = 21$, $p < 0.001$
22 May 1987	6	213	35.5	144	24.0	$t = 5.019$, $df = 5$, $p < 0.01$
23 May 1987	28	531	18.9	434	15.5	$t = 3.485$, $df = 27$, $p < 0.002$
24 May 1987	20	175	8.8	142	7.1	$t = 2.260$, $df = 19$, $p < 0.04$
Backup experienced						
30 May 1985	28	320	11.4	306	10.9	$t = 1.077$, $df = 27$, $p > 0.2$, ns
24 May 1986	6	339	56.5	347	57.8	$t = 1.512$, $df = 5$, $p > 0.1$, ns
25 May 1986	27	489	18.1	458	17.0	$t = 1.686$, $df = 26$, $p > 0.1$, ns
26 May 1986	5	84	16.8	78	15.6	$t = 0.48$, $df = 4$, $p > 0.6$, ns
27 May 1986	14	88	6.3	93	6.6	$t = 0.219$, $df = 13$, $p > 0.8$, ns
27 May 1986	8	42	5.3	58	7.3	$t = 0.928$, $df = 7$, $p > 0.3$, ns

Using the counts of primary and experienced backup observers, calculations were made to estimate the proportion of total seals present that were seen by a single observer. Calculations were made using the formula from Caughley (1974) in which, based on the different counts of two observers, he determined the probability that a group of elephants was seen by one observer (p), seen by both observers (p^2), seen by one or the other ($2p(1-p)$), or missed by both ($(1-p)^2$). The probability p can be estimated from the relationship:

$$2p(1-p)/p^2 = S/B$$

from which

$$p = 2B/(2B+S)$$

where S is the number of groups seen by a single observer only and B is the number seen by both. The number missed is represented by $M = S^2/4B$. Based on four comparisons (Table 26), p = 0.83 for groups (range = 0.79-0.86) and 0.82 for individual seals (range = 0.74-0.86). In other words, the counts suggest that a single observer sees about 83% of the groups and 82% of the seals hauled out on the ice. This is a relatively high proportion compared to the estimated 40% determined by Caughley for elephants in wooded areas of Uganda.

Using these data, the probability that seals were seen by both observers was 0.7, and that they were seen by only one or the other was 0.3. It is evident that, while the numbers of seals counted by experienced primary and backup observers were not statistically different, neither observer saw all of the seals present, nor did the two observers see all of the same seals. Individual observers missed, on the average, 18% of the seals in the survey strip. This indicates that, at a minimum (i.e., not taking into account the proportion of seals that are in the water and thus not able to be counted) the density estimates resulting from these aerial surveys are low by about 18%.

Survey Coverage

In order to arrive at a sampling plan for our initial 1985 surveys, we analyzed the relationship between variance and sampling intensity using a set of transects from 1981 ringed seal aerial surveys in the Beaufort Sea. That analysis indicated that the variance (square of the standard deviation) of the mean density estimate dropped rapidly until about 50% of all possible transects were selected from the data base, with a slower, steady decrease as additional transects were incorporated. Based on that, sampling intensity was set at 60% of all possible lines within each sector, except for sectors B2 and B3 where coverage was 90% of all lines.

This relationship was reanalyzed using data collected in sectors B2 and B3 in 1985 and the same pattern was found (Frost *et al.* 1985*b*). In addition, we analyzed and plotted the ratio between 1.96 standard deviations of the mean and the mean density for each sector. This ratio measures the confidence interval around the mean density such that a value of 0.10 would indicate that the 95% confidence limits are equal to the mean plus or minus 10%. A test of the regression line indicated that there was no significant difference in the size of the

Table 26.–Number of groups of seals and numbers of seals seen by one or both observers during comparative counts by primary and experienced backup observers. P = probability that a given seal is seen by a given observer. S_A = number seen only by observer A. S_B = number seen only by observer B. B = number seen by both observers. M = number missed. See text for formulas and explanation.

Date		S_A	S_B	B	M	Estimated total #	P
30 May 1985	groups	33	26	174	5	238	0.86
	number						0.85
24 May 1986	groups	40	23	142	7	212	0.82
	number						0.78
16 June 1986	groups	10	10	38	3	61	0.79
	number						0.86
28 May 1987	groups	9	12	40	3	64	0.79
	number						0.74
Combined samples	groups	92	71	394	17	574	0.83
	number						0.82

confidence interval with sampling intensities ranging from 38 to 92%. With a sampling intensity of 60%, density estimates should have 95% confidence intervals of ±5-15%.

For 1986 surveys, we attempted to obtain 90% coverage in sector B3 and 60% coverage in other areas. However, due to a storm that occurred during the survey period, adequate data were obtained from only 15 of 38 lines in sector B3 (39.5% coverage). We analyzed the relationship between the number of transects selected from the 1986 data base and the variance of the mean for sectors C1 and B2/B3 combined, and examined the ratio between 1.96 standard deviations and mean density for each sector in 1985 and 1986. Sampling intensity of 50-60% of all possible lines was judged adequate, and 95% confidence intervals for all Chukchi and all Beaufort sea data were equal to the mean plus or minus 9-10% (Frost *et al.* 1987).

The relationship between the number of transects selected from the data base and the variance of the mean is shown by year for four sectors or sector combinations in Figures 5-8. Each point represents the mean of six separate calculations which randomly selected the indicated number of transects from the data base. Several patterns are evident from these figures. In all cases, the variance dropped rapidly until approximately 50% of all possible transects were selected from the data base, after which the variance declined gradually. Variance was very erratic when only a few transects were selected. In all cases, the variance

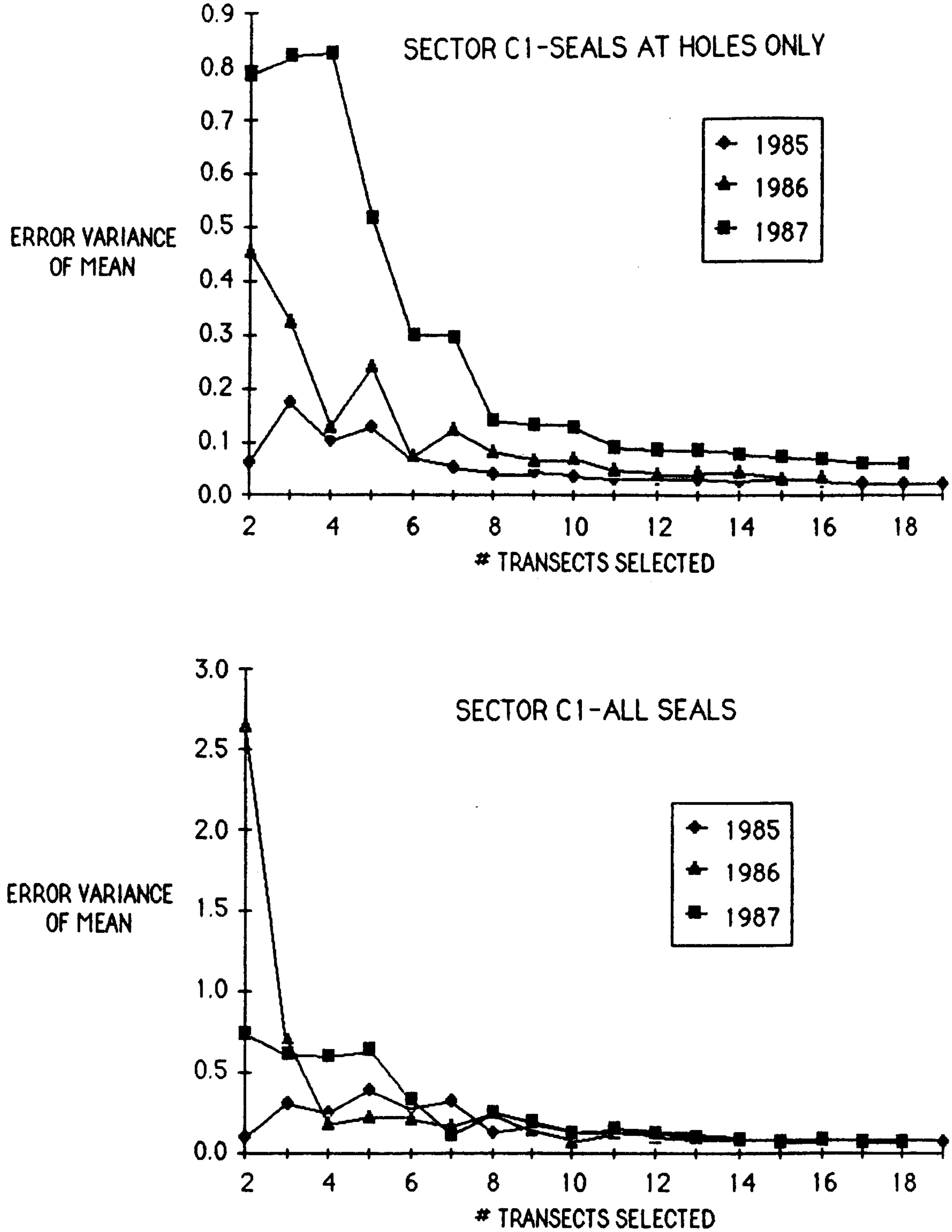
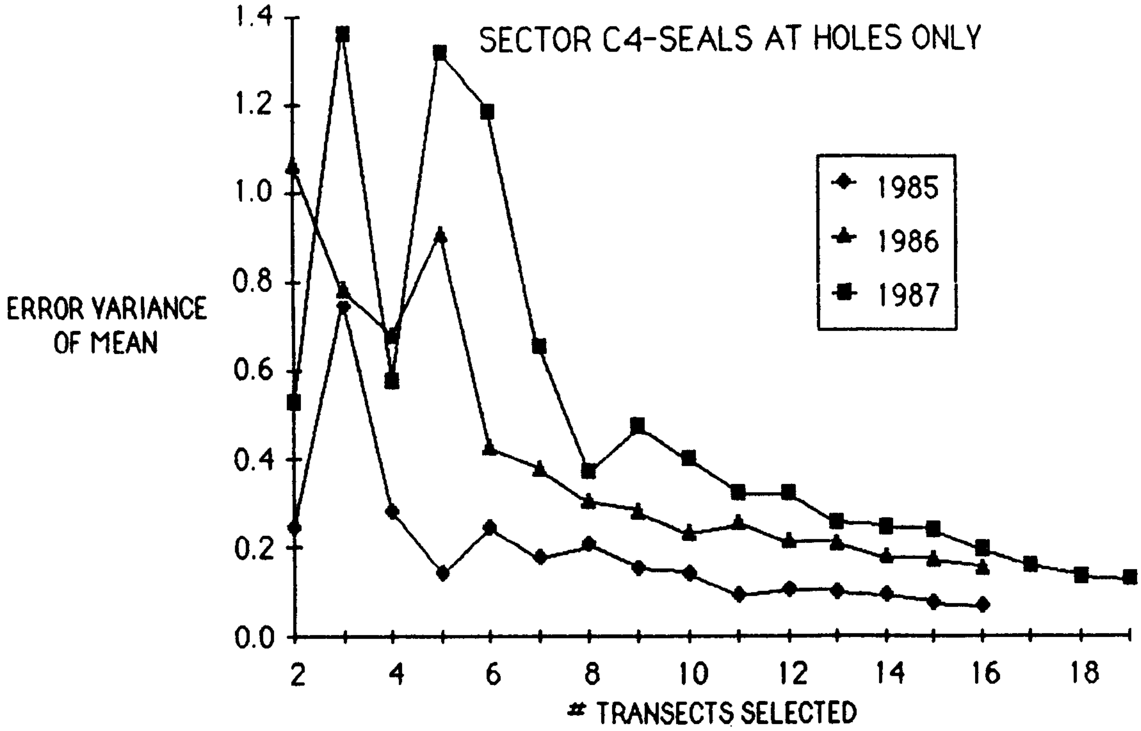


Figure 5.–Relationship between the number of transects selected from the data base and the error variance of the mean density estimate for sector C1. Each point represents the mean of six separate calculations.



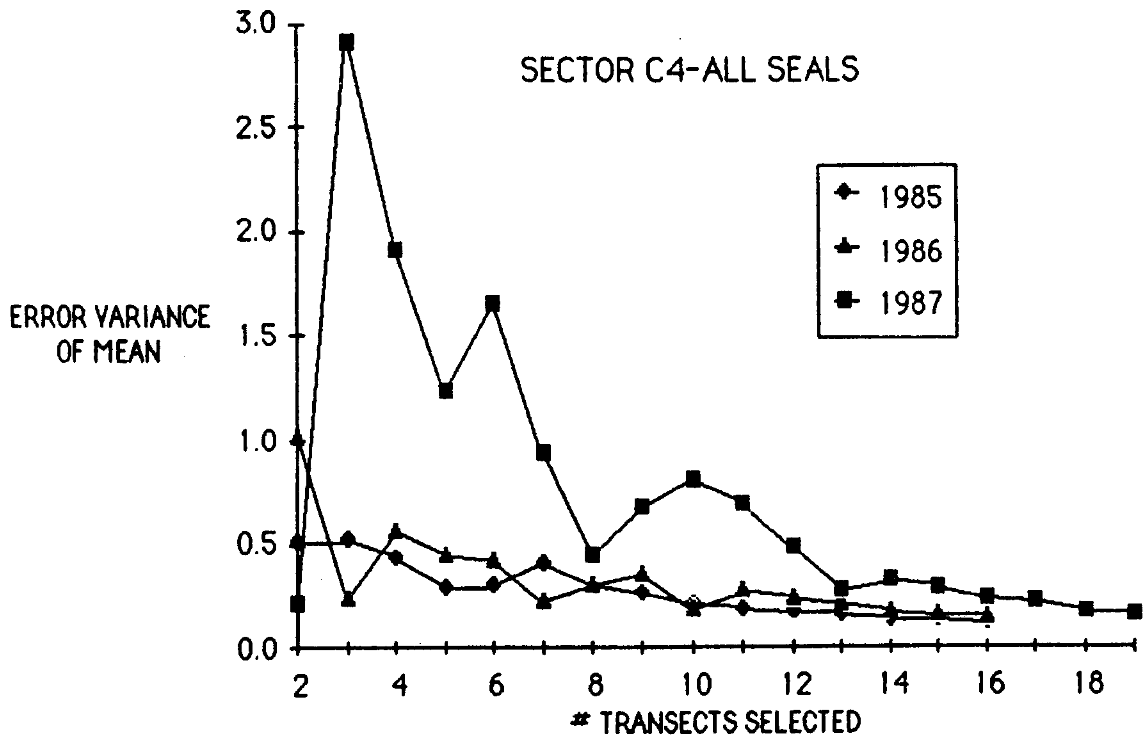


Figure 6.–Relationship between the number of transects selected from the data base and the error variance of the mean density estimate for sector C4. Each point represents the mean of six separate calculations.

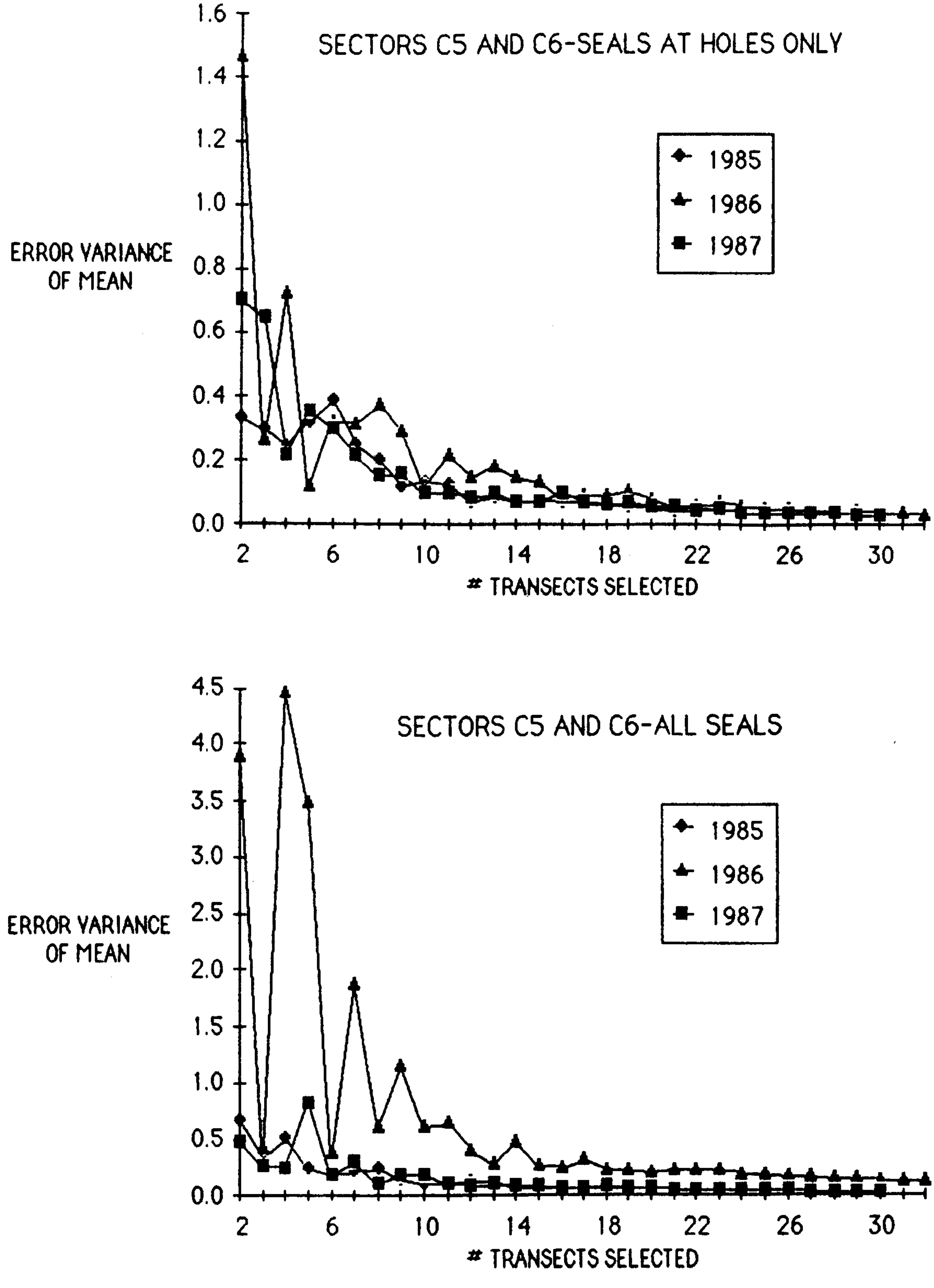
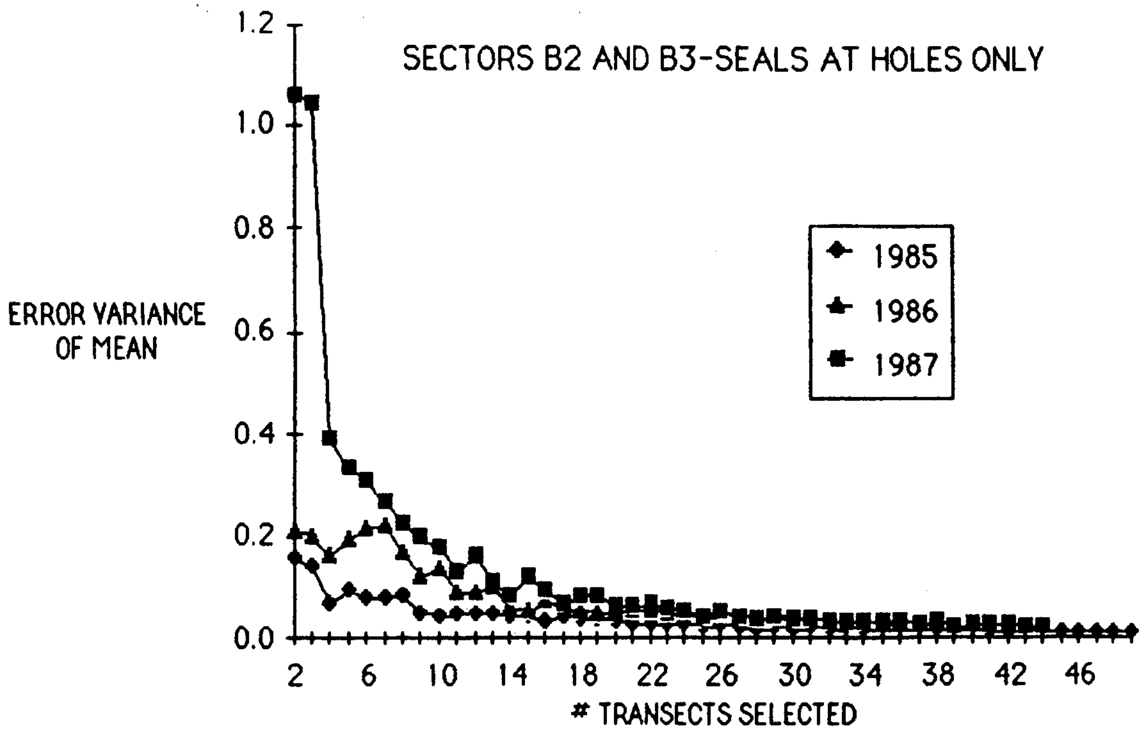


Figure 7.–Relationship between the number of transects selected from the data base and the error variance of the mean density estimate for sectors C5 and C6 combined. Each point represents the mean of six separate calculations.



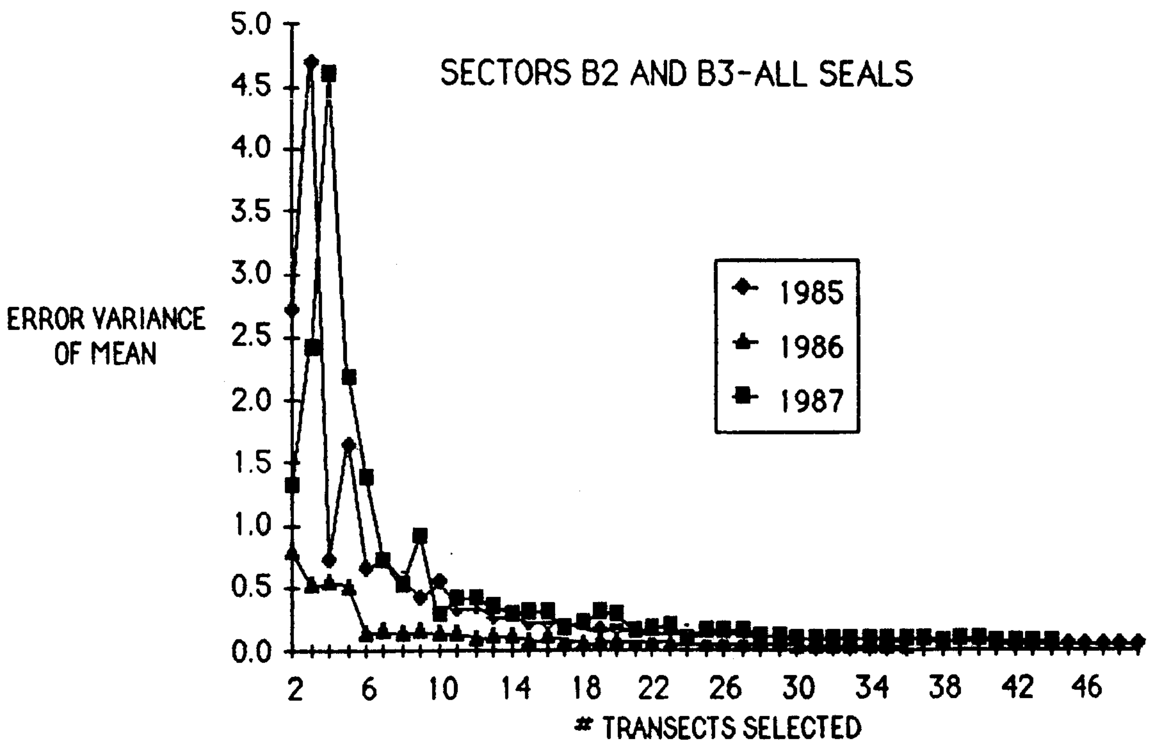


Figure 8.–Relationship between the number of transects selected from the data base and the error variance of the mean density estimate for sectors B2 and B3 combined. Each point represents the mean of six separate calculations.

was much lower when only seals at holes were included in the data. There was some evidence of year-to-year differences in variability in data sets: data for sectors C1, C4, and B2/B3 combined were most variable in 1987, while data for sectors C5/C6 combined were most variable in 1986.

The information shown in Figures 5-8 is summarized in Table 27. Again, it is evident that data sets that include only seals at holes are less variable than those that include all seals. In addition, the variability becomes less as data sets include more legs. If the variance indicated by including all legs surveyed in the data base represents the realistic minimum for a given area, these figures can be used to indicate how much greater the variance is when only 60% or 90% of possible lines are flown. If 60% of possible lines are flown, variance is predicted to be 1.24-3.35 times greater for seals at holes and 1.09-4.19 times greater for all seals. If 90% of all possible lines are flown, variance would be 1.0-1.36 times greater for seals at holes and 1.05-1.34 times greater for all seals. In aggregate, these analyses indicate that while coverage of 60% of all possible legs reduces variance in data sets to reasonable levels, coverage of 90% results in considerably greater precision.

Although we attempted to obtain 60% coverage in all sectors in all years, for various reasons the actual percentage of all possible transects in the selected data ranged from 38 to 90%. We divided the value for 1.96 standard deviations by the mean density estimate for all seals in each sector for each year, and plotted that value against the percentage of all possible legs flown (Figure 9A). Although there was a slight trend evident (i.e., the greatest coverage [90%] had the lowest value [0.06]), the relationship was not statistically significant ($R = 0.167$, $p > 0.39$). If the sector with 90% coverage is deleted (Figure 9B), there is virtually no trend ($R = 0.036$, $p > 0.85$). This indicates that the amount of variability was constant over the range of sampling intensities accomplished during this study.

Because this calculated value (1.96 standard deviations/mean density) is an index of the size of the 95% confidence limits around mean density estimates, it can be used to compare the variability of density estimates among sectors and years (Table 28). The individual sectors with the smallest confidence limits for density of seals at holes were C1 (±9-23%), B1 (±12-20%), and B3 (±14-19%). Confidence limits for total seals were somewhat greater, especially where cracks were numerous as occurred in sectors B3 and B4 in 1987. Variability was greatly reduced when several sectors were combined to make larger data sets. Confidence limits for the Beaufort Sea as a whole were ±9-10% for seals at holes and ±14-33% for all seals; comparable values for the Chukchi Sea were ±9-13% and ±11-13%. Obviously, seals along cracks had a much greater influence on variability in density estimates in the Beaufort Sea than in the Chukchi Sea.

Factors Affecting Abundance of Seals

Ice Deformation

The results of our 1985-87 surveys in the Chukchi and Beaufort seas indicate that the relationship between ice deformation and seal distribution and density was highly consistent

Table 27.–Relationship between variance of the mean (σ^2) and the percentage of all possible transects selected for selected sectors, 1985-87.

			Percentage of transects selected					
			Seals at holes only			All seals		
Sector	Year	# Legs	60%	90%	100%	60%	90%	100%
C1	1985	19	0.031	0.024	0.025	0.125	0.074	0.068
	1986	16	0.069	0.042	0.034	0.072	0.080	0.066
	1987	18	0.091	0.069	0.060	0.145	0.075	0.060
C4	1985	16	0.144	0.090	0.066	0.207	0.139	0.115
	1986	16	0.230	0.178	0.156	0.191	0.176	0.145
	1987	19	0.324	0.159	0.130	0.696	0.222	0.166
C5 & C6	1985	24	0.071	0.047	0.043	0.065	0.045	0.043
	1986	32	0.104	0.040	0.031	0.218	0.145	0.118
	1987	30	0.063	0.036	0.030	0.076	0.034	0.030
B2 & B3	1985	49	0.021	0.013	0.011	0.086	0.057	0.049
	1986	36	0.054	0.031	0.027	0.070	0.037	0.032
	1987	44	0.055	0.025	0.023	0.147	0.087	0.069

from year to year (Table 29). Seals were less abundant in rougher ice. The greatest difference was for ice of 0-20% deformation, where densities were generally 1.5 to 2 times higher than in ice of greater deformation.

Numerous investigators have noted that ice conditions affect the distribution of ringed seals and, in particular, that stable shorefast ice is their preferred breeding habitat (McLaren 1958; Burns 1970; Smith 1973). Studies conducted in the Canadian Arctic have addressed the effects of ice conditions in terms of coverage (from unbroken fast to broken open pack) or degree of cracking (solid, cracking, or rotten) (Stirling *et al.* 1981*b*; Kingsley *et al.* 1985). These studies found that seals preferred areas with little open water and seemed to avoid areas of rotten, flooded ice. Ice conditions in Alaska at the time of our surveys were quite different from those experienced during surveys in Canada. Surveys were flown over mostly unbroken fast ice and not in areas where significant amounts of open water were present. Our surveys were intended to occur before substantial cracking and melting of the fast ice occurred. Although in some years breakup commenced earlier than usual, and such conditions were present during our surveys, the variables used in Canadian studies have not been relevant to our data.

Burns *et al.* (1981*a*) first reported on ringed seal distribution relative to the percentage of ice surface that was deformed by hummocks and pressure ridges. They found that ringed seals showed a significant preference for less-deformed fast ice, with the density in ice of 0-30% deformation about 1.3 times higher than in ice of 30-50% deformation, and two times higher

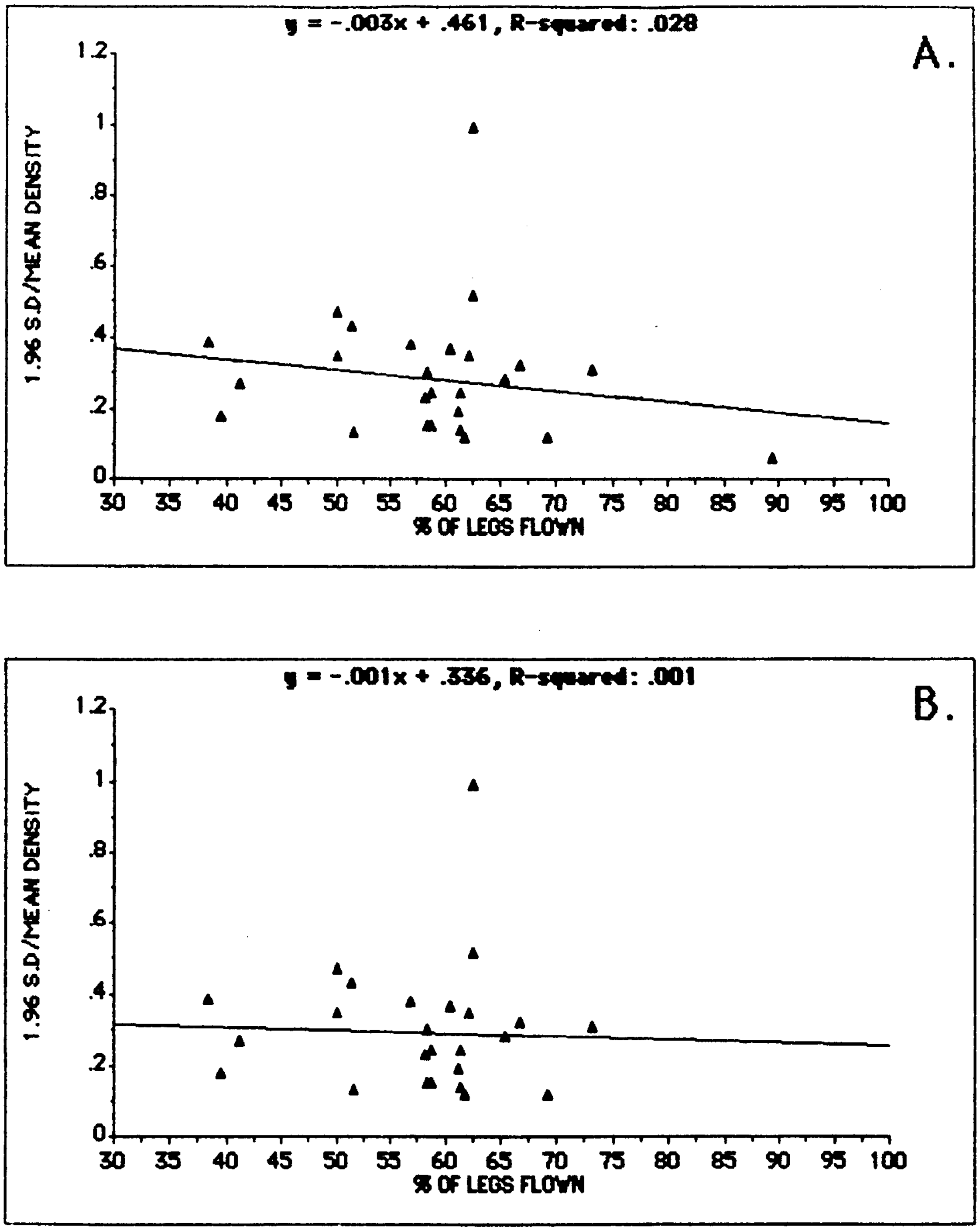


Figure 9.–Relationship between 1.96 standard deviations divided by the mean density of all seals and percentage of all possible legs flown for each sector 1985-87. A–all sectors included. B–data from sector B3 in 1985 (89.5% coverage) deleted.

Table 28.–Comparison of the 95% confidence limits on ringed seal density estimates (1.96 standard deviations divided by mean density of seals) for sectors surveyed in May-June 1985-87.

	95% confidence interval					
	Seals at holes			Total seals		
Sector	1985	1986	1987	1985	1986	1987
C1	0.10	0.09	0.23	0.19	0.14	0.23
C2	0.49	0.30	0.38	0.43	0.36	0.38
C4	0.22	0.16	0.26	0.24	0.14	0.31
C5	0.39	0.27	0.12	0.39	0.29	0.12
C6	0.30	0.33	0.49	0.30	0.53	0.47
All Chukchi	0.10	0.09	0.13	0.12	0.11	0.13
B1	0.20	0.15	0.12	0.24	0.15	0.12
B2	0.26	0.11	0.12	0.26	0.12	0.12
B3	0.14	0.15	0.19	0.23	0.18	0.37
B4	0.15	0.30	0.24	0.16	0.35	0.99
All Beaufort	0.10	0.10	0.09	0.14	0.16	0.33
B1-B3	0.11	0.10	0.08	0.16	0.11	0.20

Table 29.–Density of ringed seals (total seals/nmi^2) in relation to ice deformation in the Beaufort and Chukchi seas, 1985-87.

	Seals/nmi^2					
	Chukchi			Beaufort		
Deformation (%)	1985	1986	1987	1985	1986	1987
0-10	3.2	5.6	4.3	2.1	5.0	6.4
10-20	2.5	4.2	2.6	3.7	3.9	5.3
20-30	2.4	3.9	2.3	3.4	2.6	4.7
30-40	1.5	2.4	1.1	2.9	2.0	4.1
>40	–	1.8	2.1	2.2	1.9	1.9

than in >50% deformation. Burns and Kelly (1982) reported similar results from data collected in 1982.

The results of 1985-87 surveys in the Chukchi and Beaufort seas corroborate these earlier studies (Figure 10). In all years, regardless of whether annual densities were high or low, hauled-out seals were less abundant in rough ice.

To assess whether seals actually preferred large, flat areas for hauling out, or whether lower abundance in rough ice was related to the absolute availability of flat areas on which to lie, we examined whether the reduced densities in rough ice were proportional to the reductions in available flat areas.

Results of a linear regression of density on ice deformation for all years combined (Figure 1981A) indicated that density was highly correlated with deformation ($R = 0.98$, $p < 0.01$). To determine whether the lower densities in rougher ice were simply proportional to the availability of flat ice areas, we corrected all densities as density per area of flat ice; for example, in an area of 30-40% deformation, total area in that category was multiplied by 0.65 and a corrected density calculated based on that corrected area (Table 30). Corrected density was then regressed against percent deformation (Figure 11B). This relationship was also significant ($R = 0.86$, $p < 0.05$), indicating that the relationship between flatness and higher density is not simply due to the availability of flat ice to haul out on, but that areas with large amounts of rougher ice are less desirable and that flat ice areas are preferred. The slope of the line was less in the comparison using corrected densities, indicating that absolute availability of flat ice areas is of some importance. The reasons why ringed seals prefer flatter ice are unknown, but may have to do with their ability to detect approaching predators in more open areas.

The preference by ringed seals for flatter ice was evident in all surveys flown during early June, before breakup began. However, when 1986-87 data from later surveys were analyzed, results indicated that once the ice had begun to crack and break up, there was no longer an apparent correlation between density and deformation (1986 – $R = 0.47$, $p > 0.5$; 1987 – $R = 0.88$, $p > 0.1$). Densities were as high or higher in rougher ice as they were in flat ice (Table 31).

Distance from the Fast Ice Edge

In the Chukchi Sea there was no clear overall pattern in density relative to distance from the fast ice edge for 1985-87 (Figure 12). In some sectors, seals were more abundant within 0-4 nmi of the edge while in others the reverse was true, and within sectors differences were not consistent between years. For example, in sector C6, seals were least abundant near the edge in 1985, most abundant near the edge in 1987, and showed no clear trend in 1986. By themselves, the 1987 data (Figure 3) suggest a relationship between the fast ice edge and seal density, but when all 3 years are considered, no firm conclusions can be drawn.

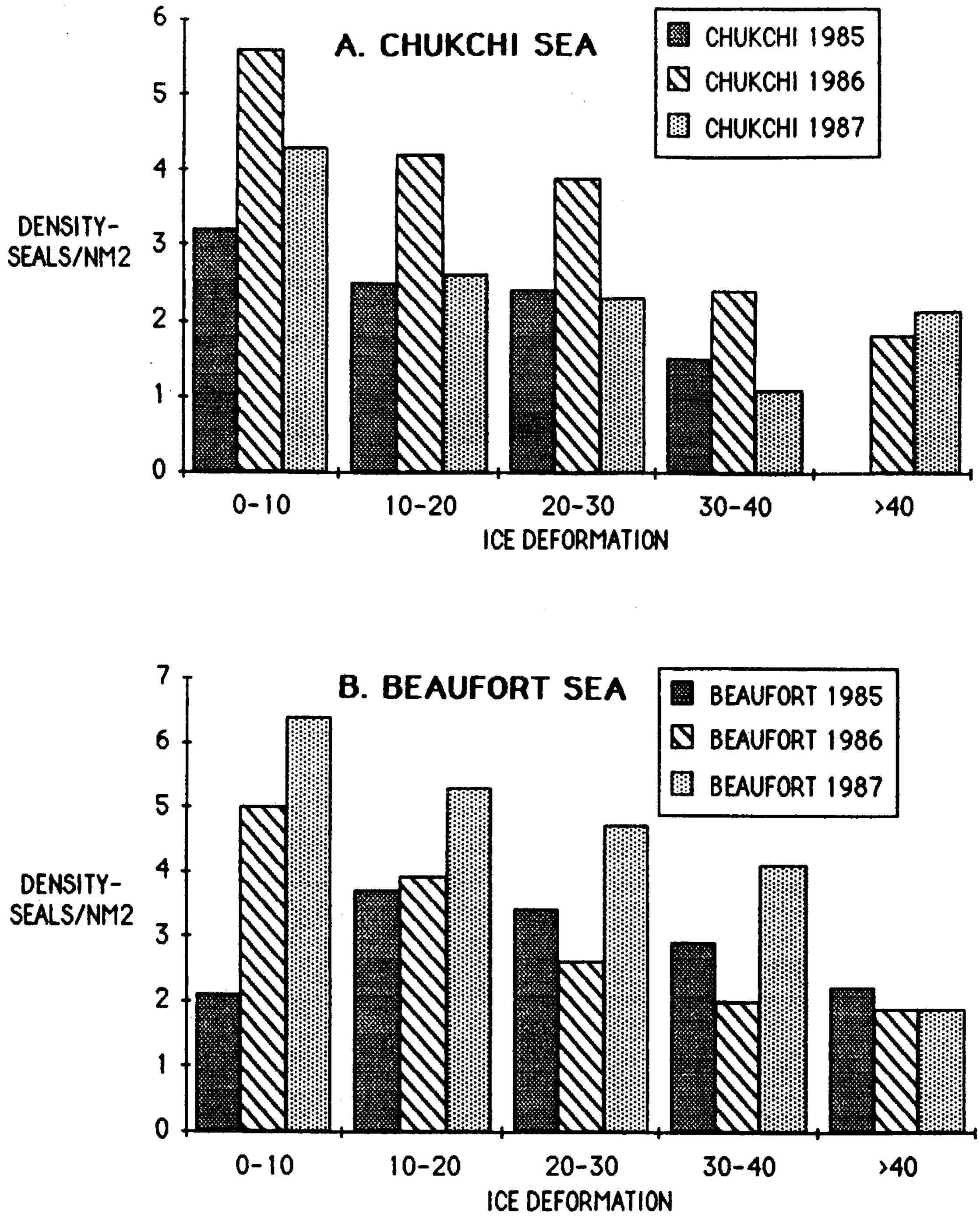


Figure 10.–Ringed seal density in relation to ice deformation in the Chukchi and Beaufort seas, 1985-87. A–Chukchi Sea, B–Beaufort Sea.

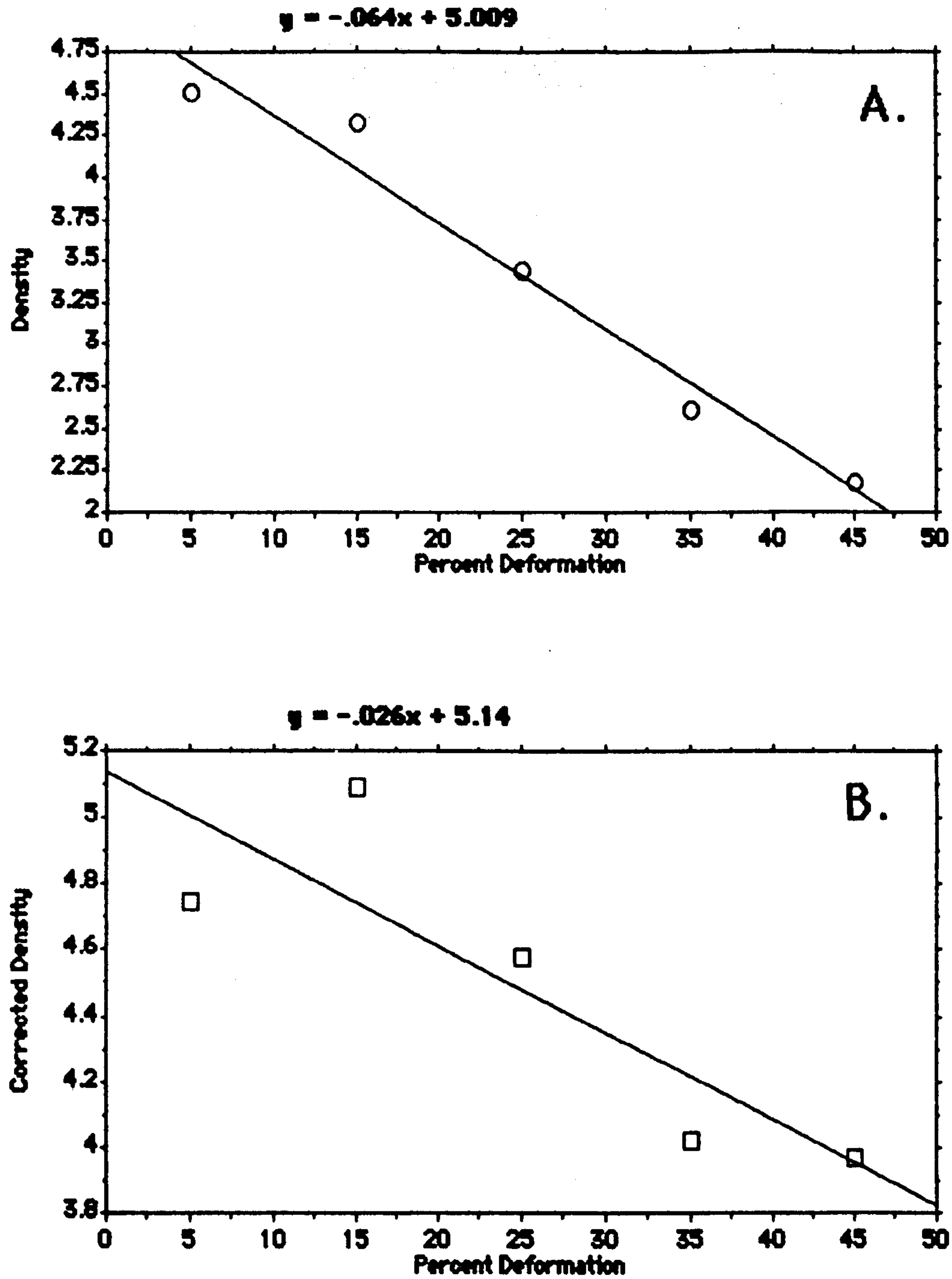


Figure 11.–Relationship between seal density and ice deformation for Chukchi Sea and Beaufort Sea data, 1985-87 combined. A–uncorrected density. B–density corrected for flat ice areas only. See text for explanation.

Table 30.–Combined densities (1985-87) of ringed seals (total seals/nmi^2) in relation to ice deformation in the Beaufort Sea.

Deformation (%)	Area	Area of flat ice	Number of seals	Density	
				All ice	Flat ice only
0-10	712	676	3,209	4.51	4.75
10-20	516	439	2,233	4.33	5.09
20-30	476	357	1,636	3.44	4.58
30-40	246	160	643	2.61	4.02
>40	142	78	310	2.18	3.97

Table 31.–Density of ringed seals (total seals/nmi^2) in relation to ice deformation in the Beaufort Sea in early and mid-June 1986-87.

Ice deformation	June 1986		June 1987	
	early	middle	early	middle
0-10	5.0	7.6	6.4	9.3
10-20	3.9	9.8	5.3	8.5
20-30	2.6	6.4	4.7	11.3
30-40	2.0	6.9	4.1	15.0
>40	1.9	–	1.9	–

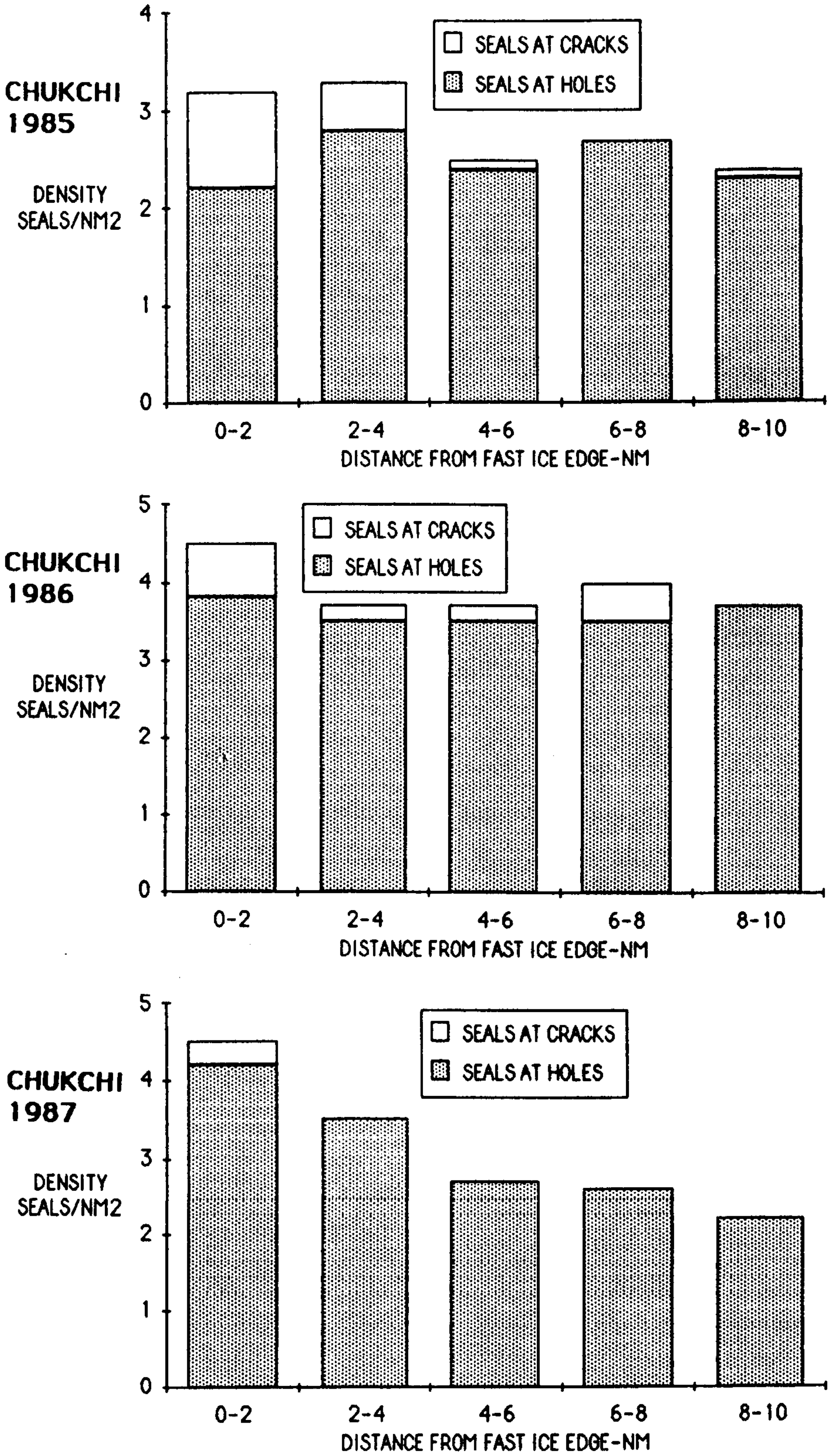


Figure 12.–Relationship between density of ringed seals on the fast ice and distance from the fast ice edge for the Chukchi Sea, 1985-87.

In the Beaufort Sea, analysis of density relative to distance from the fast ice edge was complicated by difficulties in determining the exact location of the "edge." The delineation between fast ice and pack ice was usually abrupt in the Chukchi Sea, and was often marked by an open lead. In the western Beaufort Sea (sector B1) this was also usually the case. However, in the central and eastern Beaufort Sea, particularly sectors B2 and B3, identifying the edge from the survey aircraft was often difficult. Here the edge was not a sharp break to obviously different ice, but rather a transition zone of pressure ridges, shear lines, and refrozen leads. Identification of the edge was further complicated by the fact that, in the Beaufort Sea, large expanses of "attached fast ice" (Stringer *et al.* 1982) form seaward of the true fast ice zone. Early in the survey period the attached fast ice is contiguous with stable shorefast ice and the two are extremely difficult to differentiate during surveys. As breakup begins, the attached fast ice sheet begins to fracture along ridge and shear lines, approximately parallel to shore, and the area of "fast ice" may decrease substantially in only a few days. It is usually possible to determine the location of the fast ice edge from satellite photographs. However, because of the large scale of these photos, the accuracy of ice-edge positions is probably plus or minus 2-4 nmi.

These factors cause problems in determining patterns in seal abundance relative to the fast ice edge. Nonetheless, based on 1985-87 data, there was a fairly clear relationship in the Beaufort Sea between seal abundance and distance from the edge (Figure 13). When surveys were conducted prior to the beginning of breakup, seals were less abundant near the edge. For all sectors combined in the pre-breakup 1986 data set, density within 4 nmi of the edge was 1.8 seals/nmi^2, compared to 2.5/nmi^2 beyond 4 nmi.

In 1986, additional surveys were flown a week later after a storm and after the attached fast ice had started to break up (Frost *et al.* 1987). In these post-storm surveys, the density of seals in sector B3 was approximately 12/nmi^2 within 4 nmi of the edge, with about half of those occurring at cracks. Densities beyond 4 nmi from the edge were about 50% lower. In 1987, all surveys were flown after the ice had begun to break up under conditions similar to those during 1986 post-storm surveys. As in the 1986 post-storm data, 1987 densities near the edge were also higher: 7.6 seals/nmi^2 within 0-4 nmi of the edge compared to 3.3/nmi^2 from 4-10 nmi away (Figure 13). In sector B3, there were over 12 seals/nmi^2 within 4 nmi of the edge, and about two-thirds of them were at cracks.

Analysis of 1985 data was more complicated. Preliminary analyses of density with distance to the ice edge presented in Frost *et al.* (1985) indicated that densities were low near the edge and higher farther away. However, reexamination of the 1985 satellite ice photos indicated that in sector B3 the actual fast ice edge was much closer to shore than we placed it in the 1985 report, and that the "edge" referred to then was the seaward extent of the attached fast ice. It is now obvious, after additional experience in the area, that an early breakup was under way in sector B3, and that in terms of seal distribution patterns the fast ice edge was better approximated by the 20-m depth contour than by the apparent "edge" determined in 1985. Therefore, 1985 data were reanalyzed as distance from the 20-m depth contour. That analysis, as in 1986 and 1987 under breakup conditions, indicated that density in mid-June was highest near the edge: 3.6 seals/nmi^2 within 4 nmi of the "edge" compared to 2.5 beyond

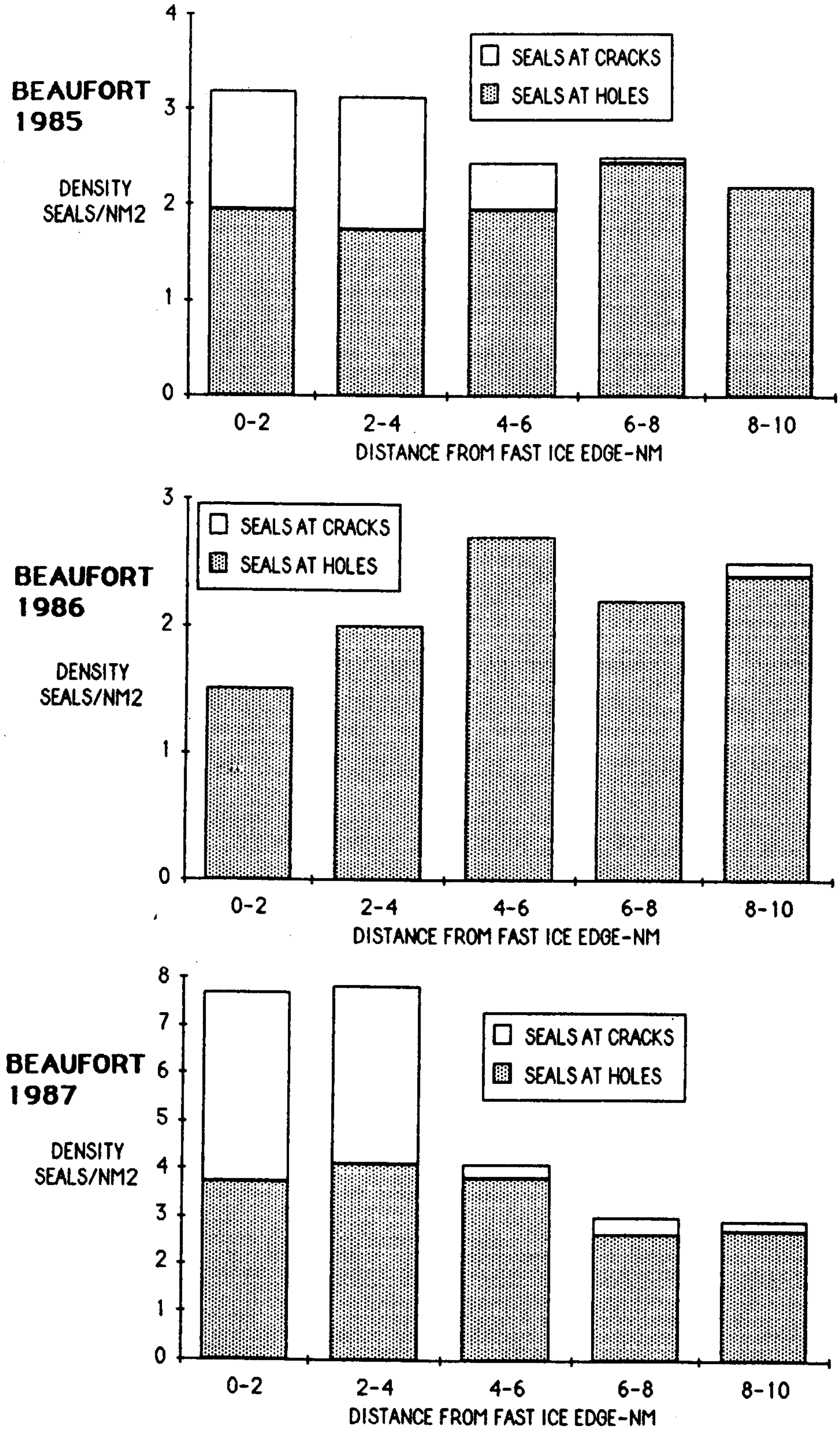


Figure 13.–Relationship between density of ringed seals on the fast ice and distance from the fast ice edge for the Beaufort Sea, 1985-87.

4 nmi. Early June data, before breakup began, showed similar densities within and beyond 4 nmi of the edge (1.6 vs. 1.5 seals/nmi^2).

In aggregate, these data suggest that the distribution and abundance of ringed seals in the Beaufort Sea relative to the ice edge change as breakup begins. The distribution shifts from one where seals are relatively widely distributed at holes away from the unstable fast ice edge, to one where large numbers of seals occur near the edge, especially along newly formed narrow cracks. We believe this increase in density is due to an influx of seals from other areas into the highly fractured boundary zone between fast and pack ice, rather than simply a redistribution of seals from immediately adjacent areas or a change in haulout behavior. Whereas the density of seals at holes 4-10 nmi from the fast ice edge of sector B3 in 1986 increased 1.7 times after the ice began to break up (from 2.8 seals/nmi^2 to 4.7 seals/nmi^2), the density near the edge increased four-fold (from 1.6 seals/nmi^2 to 6.5 seals/nmi^2). Comparisons of early and late surveys in sector B1 in 1985 and 1987 also indicated an increase in density between the two that occurred mostly near the fast ice edge. In 1985, the increase within 4 nmi of the edge was also almost 400%, from 0.8 to 3.1 seals/nmi^2, compared to a 24% increase at 4-10 nmi from the edge. In 1987, density within 4 nmi of the edge increased from 3.9 to 14.5 seals/nmi^2, and beyond 4 nmi, from 2.6 to 6.9 seals/nmi^2.

Canadian investigators also found that ringed seals occurred in highest densities in cracking ice, rather than on unbroken fast or rotten, melting ice (Stirling *et al.* 1981*a*, 1981*b*; Kingsley *et al.* 1985). They suggested that cracking occurs near or behind the edge and that the associated high densities of seals represent either a collapse in the winter underwater social structure and the opportunity for more animals to haul out at newly available sites, or an influx of seals from other areas. Smith (1973) also believed that the increase in seals in his study area near Home Bay after 15 June was due to an influx from other areas.

Distance from Shore

Based on results of all 3 years of surveys, ringed seals were generally less abundant within 2 nmi of the coast than they were farther from shore (Table 32, Figure 14). This tendency was the most consistent and pronounced in the Chukchi Sea ($R = 0.906$, $p < 0.05$) where the coastline is simple with no offshore barrier islands, and where depth increases quite rapidly with distance from shore. In the Beaufort Sea, coastal topography differs greatly among sectors, there are numerous barrier islands and several large, very shallow embayments (Harrison Bay, Camden Bay, and Smith Bay), and the width of the fast ice is quite variable. Sectors B1 and B2, with relatively simple coastline and extensive fast ice, showed the same pattern as the Chukchi Sea, with densities within 2 nmi of land consistently lower than farther from shore. Sectors B3 and B4 were less consistent, probably because the fast ice edge was much closer to shore, extensive barrier islands occur in these sectors, and in 1987 breakup was under way during our surveys and there had already been a large influx of seals at cracks. When seals at cracks were omitted from the 1987 data (there were very few seals at cracks in the selected data base for other years), the trend of increasing density with distance from shore for 1985-87 combined was significant for sectors B1-B3 ($R = 0.96$, $p < 0.01$, Figure 14B).

Table 32.–Density of ringed seals (total seals) in relation to distance from shore in the Chukchi and Beaufort seas, 1985-87.

Sector	Year	Distance from shore (nmi) 0-2	2-4	4-6	6-8	8-10
C1	1985	2.6	2.6	2.8	3.1	2.9
	1986	3.6	4.7	4.8	7.7	6.7
	1987	1.5	3.9	3.9	3.4	5.4
C2	1985	3.1	2.6	2.7		
	1986	3.0	3.6	6.8	6.8	
	1987	2.5	3.0	3.6	9.0	
C4	1985	1.2	3.6	4.2	2.5	3.4
	1986	4.5	4.9	5.2	6.9	4.7
	1987	2.8	5.7	3.3	4.0	3.9
C5	1985	1.3	3.3	2.1	1.8	1.3
	1986	1.9	3.1	2.7	2.7	2.1
	1987	2.4	2.6	2.9	2.9	2.1
C6	1985	1.3	2.3	2.2	2.3	1.3
	1986	1.7	2.2	3.0	3.7	2.6
	1987	1.8	2.9	5.3	2.6	2.9
B1	1985	1.3	1.8	3.1	2.8	2.2
	1986	1.9	2.7	2.8	2.5	1.9
	1987	1.4	2.2	2.6	3.6	3.6
B2	1985	0.2	2.0	1.9	2.0	2.0
	1986	2.6	3.9	3.5	3.9	3.9
	1987	1.9	3.0	4.1	5.8	5.8
B3	1985	1.3	2.1	3.3	4.1	6.8
	1986	4.8	3.8	5.5	3.5	4.1
	1987	6.2	5.0	13.3	7.3	7.3
B4	1986	0.2	1.8	2.2	2.8	2.5
	1986	4.5	5.4	19.9	10.3	6.9
	1987	26.9	30.0	5.2	4.7	4.0

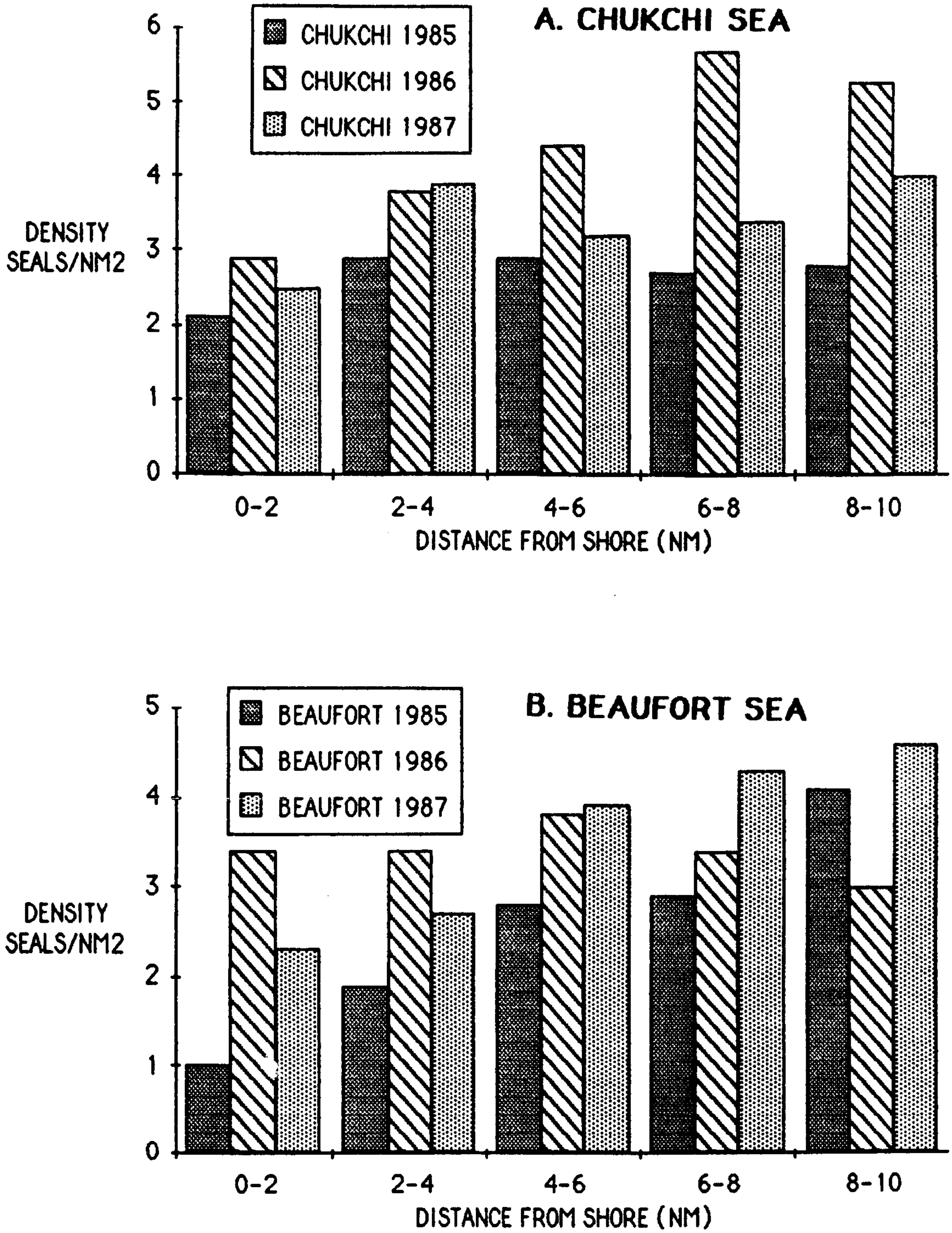


Figure 14.–Relationship of seal density with distance from shore. Data for Beaufort Sea 1987 is seals at holes only, all other data are total seals (see text for explanation). A–Chukchi Sea, B–Beaufort Sea.

In their 1970 surveys, Burns and Harbo (1972) also found a tendency for density to increase with increasing distance from shore in sector B2 (their sector IV). In Hudson Bay, Smith (1975) found no clear relationship of density relative to distance from shore. In Home Bay (Baffin Island), Smith (1973) found that seals were much less abundant beyond 18 miles from shore.

The factors contributing to onshore-offshore abundance patterns are poorly understood, but may include such variables as depth, ice topography, proximity to active ice areas, and prey availability. In the very nearshore region, ice may freeze all the way to the bottom, entirely excluding seals.

Pack Ice

Although the primary objective of our surveys was to determine the distribution and abundance of ringed seals on the shorefast ice, some survey lines extended into the pack ice. In general, coverage of the pack ice in these and earlier aerial surveys has not been extensive in any year, and has not included every sector every year.

Annual variations in densities recorded for pack ice were large, with values for the same sector differing by as much as a factor of 8 or 9 between years. For example, in sector C2 we counted 8.0 seals/nmi^2 on pack ice in 1985 compared to 1.3 seals/nmi^2 in 1986 and 4.6/nmi^2 in 1987. Whereas densities in fast ice since 1970 have fluctuated from about 50% below to 40% above the mean, densities in pack ice have fluctuated by over 100%. Part of this may be because much of the pack ice surveyed was near the fast ice edge, which is an area where distribution changes markedly as breakup begins. Surveys conducted in the same calendar week may reflect vastly different ice conditions or breakup chronology from one year to the next.

In the Beaufort Sea, density in the pack ice generally decreased with distance from the fast ice edge. Regressions of seal density on distance from the edge out to 20 nmi were significant for seals at holes and total seals in all 3 years (Table 33). In 1985 and 1987, years when the ice was beginning to crack and break up during some of our surveys, the density of seals at cracks was significantly higher within a few miles of the edge, and lower but generally similar in the pack ice farther from shore. In the early June 1986 surveys, seals at cracks were not more abundant near the edge; there was no significant trend in density with distance from the edge ($R = 0.429$, $p > 0.2$). However, 1 week after breakup had begun, distribution of seals at cracks was similar to that in 1985 and 1987: seals at cracks were much more abundant near the edge ($R = 0.845$, $p < 0.002$).

Pack ice densities based on surveys conducted very near the edge should not be used to estimate the number of seals in offshore areas. This is particularly true if there is any indication that breakup and aggregation of seals near the edge was under way at the time of the surveys. The data for 1985-87 suggest that, for all surveys, densities of seals at holes stabilize about 10 miles from the fast ice edge at just under 1 seal/nmi^2 (Table 34). The density

Table 33.–Density of ringed seals in the pack ice relative to distance from the fast ice edge, Beaufort Sea, 1985-87.

	Seals at holes/nmi² (total seals)			
Distance (nmi)	1985	1986 early	1986 late	1987
0-2	1.7 (3.9)	2.6 (2.7)	2.5 (12.9)	2.0 (6.6)
2-4	1.8 (3.9)	1.7 (1.8)	1.8 (7.4)	1.5 (2.7)
4-6	1.6 (3.8)	2.0 (2.1)	0.9 (4.4)	1.3 (3.2)
6-8	1.7 (3.6)	1.7 (1.8)	0.7 (5.5)	1.3 (3.8)
8-10	1.5 (2.6)	0.9 (2.0)	0.9 (3.3)	1.4 (3.2)
10-12	0.9 (2.0)	1.1 (1.7)	0.7 (3.2)	0.6 (2.1)
12-14	1.1 (2.1)	0.7 (0.9)	0.4 (3.5)	0.8 (1.6)
14-16	1.0 (1.8)	0.4 (0.4)	0.9 (3.1)	0.9 (2.7)
16-18	0.6 (1.7)	1.1 (1.4)	0.9 (2.0)	1.7 (3.1)
18-20	0.1 (1.9)	0 (1.2)	0.5 (1.4)	0.3 (0.3)

Table 34.–Density of ringed seals (seals/nmi²) in the pack ice from 0-10 and 10-20 nmi from the fast ice edge, Beaufort Sea, 1985-87. Values without parentheses are for seals at holes only; values in parentheses are for total seals.

	0-10 nmi		10-20 nmi	
Year	Mean	Standard deviation	Mean	Standard deviation
1985	1.6 (3.6)	0.16 (0.35)	0.9 (2.0)	0.16 (0.28)
1986 Early	1.8 (2.1)	0.21 (0.22)	0.8 (1.2)	0.19 (0.23)
Late	1.4 (6.9)	0.22 (0.66)	0.6 (2.7)	0.09 (0.46)
1987	1.9 (5.1)	0.22 (0.59)	0.9 (2.6)	0.13 (0.59)

of seals at cracks was more variable, but the range (0.4-2.1/nmi^2) was considerably less farther offshore than nearer the edge (0.3-5.5/nmi^2).

Ringed Seal Abundance

Chukchi Sea

Aerial surveys for ringed seals conducted in 1985-87 were the most extensive and systematic ever flown in the Chukchi Sea, and the first for which between-year statistical comparisons were possible. In all sectors of the Chukchi Sea, the density of total seals on the fast ice was significantly greater in 1986 than in either 1985 or 1987 (Table 35). The combined Chukchi Sea density of total seals in 1986 was 1.6 times the 1985 density and 1.7 times the 1987 density. Seals at holes were also more abundant in 1986 in every sector except C2 where 1986 and 1987 densities were similar. In all 3 years for all sectors combined, the density of seals at cracks was quite low, only 1-6% of total seals. Sector C2 in 1985 and 1986 (11% and 17%) and sector C6 in 1986 (22%) were the only sectors where more than 10% of the total seals were located along cracks.

Based on 1985-87 data, densities in the Chukchi Sea south of Point Lay (sectors C1-C4) were consistently higher than densities to the north in sectors C5 and C6 (Table 36). This was not the case in data reported by Burns and Eley (1978) for June 1976, when sector C1, Kotzebue Sound, had the lowest density in the entire Chukchi Sea (0.93/nmi^2) and sector C6 had the second highest (4.96/nmi^2) (Frost *et al.* 1985*b*). However, 1976 surveys were flown during the second week in June, almost 3 weeks later than our surveys. We think the low density in Kotzebue Sound, and probably the high density in C6, reflect the different timing of the surveys rather than a lower density of seals. In 1986 and 1987 when we returned to Kotzebue Sound in mid-June to conduct belukha whale surveys, we saw very few ringed seals hauled out on the ice. Although the fast ice was still in place, the ice was rotten and melting and conditions were very poor for hauling out. Since we observed considerably higher densities of seals in the Beaufort Sea in mid-June than in early June it is reasonable to think that the northern Chukchi Sea experiences a similar increase.

The analysis of pre-1986 northern Chukchi Sea aerial survey data presented in Frost *et al.* (1985*b*) indicated a steady decline in the density of ringed seals in the northern Chukchi Sea from 1970 through 1985. When 1986 and 1987 data are added to that analysis, it appears that the 1985-87 densities, although variable from year to year, are consistently lower than those reported for the 1970s (Figure 15). The difference in densities is, in actuality, probably greater than Figure 15 indicates, since some of the earlier surveys were flown at 500 ft, which results in estimates lower than those obtained at 300 ft. It is unclear whether this apparent recent decrease in densities between Point Lay and Wainwright is a real reflection of changing seal abundance, or is an artifact of survey methodology. Surveys conducted in the 1970s consisted of lines flown parallel, instead of perpendicular, to the coast, and thus, depending on the location of lines relative to the fast ice edge, could reflect higher densities found near the edge. In two of our three recent survey years, densities within 0-4 nmi of the edge in sector C6

Table 35.–Comparison of the densities (seals/nmi^2) of ringed seals hauled out on the fast ice in the Chukchi and Beaufort seas, 1985-87. All data from surveys flown at 500 ft have been corrected to make results comparable to data collected at 300 ft.

	Mean density (SD)								
	Seals at holes			Seals at cracks			Total		
Sector	1985	1986	1987	1985	1986	1987	1985	1986	1987
C1	3.68 (0.14)	7.29 (0.26)	3.92 (0.35)	0.29 (0.26)	0.25 (0.19)	0.01 (0.00)	3.97 (0.30) n = 19	7.54 (0.40) n = 16	3.92 (0.35) n = 18
C2	3.29 (0.62)	4.46 (0.51)	4.53 (0.89)	0.40 (0.15)	0.92 (0.35)	0.03 (0.02)	3.69 (0.63) n = 17	5.38 (0.78) n = 22	4.56 (0.89) n = 21
C4	4.37 (0.37)	6.64 (0.41)	3.57 (0.47)	0.26 (0.18)	0.17 (0.08)	0.23 (0.17)	4.63 (0.43) n = 16	6.81 (0.38) n = 16	3.80 (0.61) n = 16
C5	2.69 (0.41)	3.55 (0.37)	2.59 (0.16)	0.00 (0.00)	0.04 (0.04)	0.00 (0.00)	2.69 (0.41) n = 16	3.59 (0.40) n = 17	2.59 (0.16) n = 18
C6	2.44 (0.28)	3.10 (0.40)	2.65 (0.66)	0.00 (0.00)	0.90 (0.52)	0.05 (0.08)	2.44 (0.28) n = 14	4.00 (0.88) n = 15	2.70 (0.65) n = 12
All Chukchi	3.54 (0.14)	5.74 (0.21)	3.58 (0.20)	0.23 (0.10)	0.32 (0.11)	0.03 (0.03)	3.77 (0.18) n = 76	6.06 (0.26) n = 86	3.62 (0.21) n = 85
B1	2.32 (0.21)	2.07 (0.16)	3.00 (0.19)	0.18 (0.09)	0.06 (0.00)	0.11 (0.06)	2.50 (0.27) n = 20	2.07 (0.16) n = 20	3.10 (0.19) n = 21
B2	2.15 (0.29)	3.60 (0.21)	4.35 (0.27)	0.59 (0.22)	0.03 (0.03)	0.08 (0.04)	2.74 (0.37) n = 14	3.63 (0.22) n = 21	4.44 (0.27) n = 21
B3	1.61 (0.11)	3.70 (0.28)	3.57 (0.35)	1.72 (0.35)	0.29 (0.20)	4.51 (1.46)	3.33 (0.39) n = 35	3.99 (0.37) n = 15	8.08 (1.51) n = 23
B4	1.65 (0.12)	4.21 (0.65)	3.52 (0.44)	0.37 (0.12)	5.24 (2.04)	8.53 (6.01)	2.01 (0.16) n = 14	9.44 (1.67) n = 12	12.05 (6.09) n = 15
B1-B3	1.89 (0.12)	3.21 (0.16)	3.74 (0.17)	1.12 (0.24)	0.10 (0.06)	1.08 (0.47)	3.01 (0.24) n = 69	3.31 (0.18) n = 56	4.82 (0.49) n = 65
All B1-B4	1.87 (0.10)	3.30 (0.16)	3.72 (0.16)	1.03 (0.18)	0.20 (0.30)	1.79 (0.91)	2.90 (0.23) n = 88	3.81 (0.32) n = 68	5.51 (0.93) n = 80

Table 36.–Comparison of ringed seal densities (total seals/nmi²) on the shorefast ice of the Chukchi Sea, 1985-87. All data from surveys flown at 500 ft have been corrected to make results comparable to data collected at 300 ft.

	1985		1986		1987	
Sector	Density	Rank	Density	Rank	Density	Rank
C1	3.97	2	7.54	1	3.92	2
C2	3.69	3	5.38	3	4.56	1
C4	4.63	1	6.81	2	3.80	3
C5	2.69	4	3.59	5	2.59	5
C6	2.44	5	4.00	4	2.70	4
C1-C6	2.77		6.06		3.62	

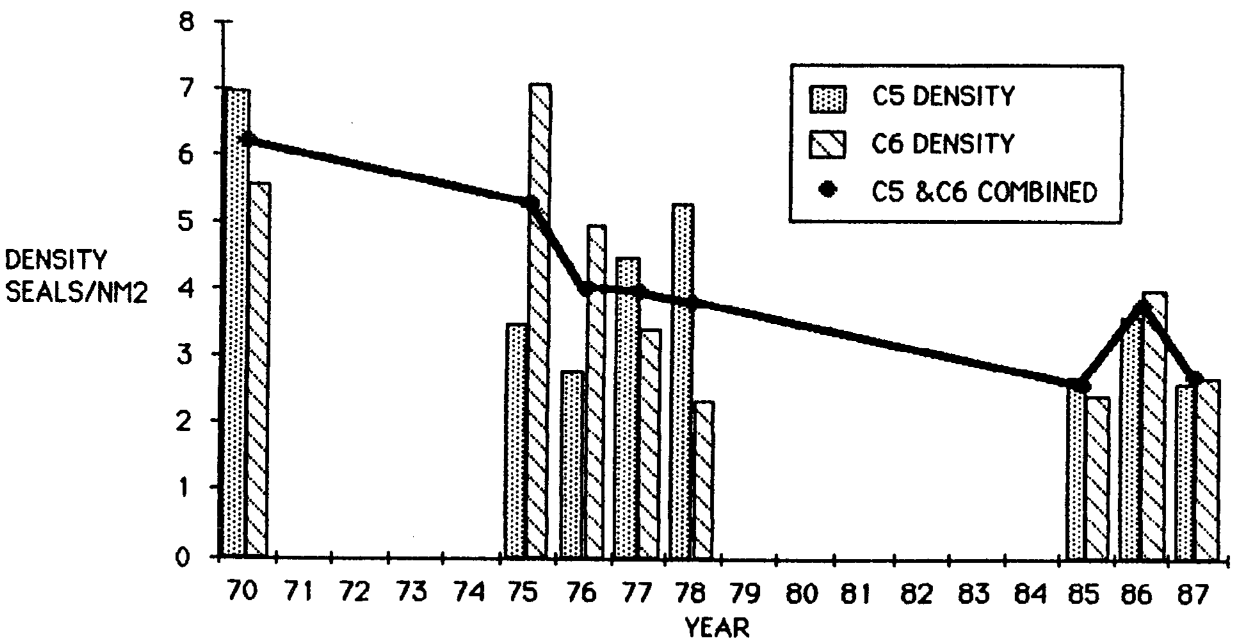


Figure 15.–Densities of ringed seals in sectors C5 and C6, Point Lay to Point Barrow, for 8 years between 1970 and 1987.

were 1.6-1.7 times greater than densities away from the edge. The surveys in the 1970s were also conducted as many as 2 weeks later than the 1985-87 surveys, which means that they may reflect a seasonal increase of hauled-out seals similar to what we found in the Beaufort Sea. We conclude that recent surveys cannot be considered comparable to those conducted in the 1970s, which were flown using different survey methodology and at a later date.

Sector densities were multiplied by total area of fast ice to estimate the numbers of seals hauled out on fast ice of the Chukchi Sea in 1985-87 (Table 37). The total estimated number of seals in sectors C1-C6 ranged from 18,400 ± 1,700 in 1985 to 35,100 ± 3,000 in 1986. The 1987 estimate, 20,200 ± 2,300, was similar to 1985. The area of fast ice was variable from year to year. In some areas, both density and area increased or decreased from one year to the next, causing large differences in the estimated number of seals. In other areas, changes in density were partially masked by opposite changes in density and in the area of fast ice.

Beaufort Sea

Annual and geographic variations in density were less regular in the Beaufort Sea than in the Chukchi Sea (Table 35). In 1985, the density of seals at holes was highest in sector B1 and lowest in B3, but because of substantial numbers of seals at cracks, the density of total seals was highest in sector B3. In 1986, densities of seals at holes and total seals were significantly greater than in 1985 in all sectors except B1, where the density was significantly lower. In sectors B1 and B2 in 1987, all densities were significantly greater than in the two previous years. In sector B3, the density of seals at holes was similar to 1986, but seals at cracks were far more numerous (4.5 vs. 0.3/nmi^2). In both 1986 and 1987, the densities of all types of seals were very high in sector B4, primarily because of the large numbers of seals at cracks (4.5-8.5/nmi^2). Breakup was clearly under way in this sector when it was surveyed, with extensive fracturing and cracking of the fast ice, suggesting that the densities were probably not indicative of overwintering seal abundance. No pre-breakup surveys were available for sector B4 in 1986 for comparison, so changes in distribution and abundance could not be assessed as they could be in the central Beaufort Sea where both pre- and post-breakup surveys were conducted.

In the central Beaufort, the density of total seals was lowest in 1985, intermediate in 1986, and highest in 1987, but densities for 1986 and 1987 do not reflect the same ice conditions relative to breakup. Annual variability in the arrival of spring and the onset of breakup makes it difficult to conduct surveys under exactly the same conditions from year to year. Although the timing of surveys relative to calendar date can be held constant from year to year, the timing relative to breakup is more difficult to assess and control. For example, in some years, ice in the Beaufort Sea remains white, unbroken, and relatively free of meltwater until the second week in June. In 1985, several days of warm, sunny weather produced mid-June conditions by June 2. In 1986, a storm from 7 to 11 June caused major changes in ice conditions. In 1987, by the time we surveyed the central Beaufort Sea during 3-7 June, breakup was under way. The chronology of breakup substantially affects the total area of fast ice coverage and, consequently, estimates of the total number of seals on the fast ice. In some areas, the ice breaks up at such a rapid rate that what is classified as fast ice one day may be

Table 37.—Density and estimated numbers (95% confidence limits) of total seals hauled out on fast ice of the Chukchi Sea during aerial surveys conducted in May–June 1985–87. Densities based on counts made at 500 ft have been multiplied by 1.32 to make them comparable to densities obtained at 300 ft.

	1985			1986			1987		
Sector	Fast ice area (nmi^2)	Density	Estimated number of hauled-out seals	Fast ice area (nmi^2)	Density	Estimated number of hauled-out seals	Fast ice area (nmi^2)	Density	Estimated number of hauled-out seals
C1	2,590	3.97 (±0.59)	8,800–11,800	2,515	7.54 (±0.78)	17,000–20,900	2,390	3.92 (±0.69)	7,800–11,000
C2	370	3.69 (±1.23)	900–1,800	650	5.38 (±1.53)	2,500–4,500	655	4.56 (±1.74)	1,800–4,100
C4	845	4.63 (±0.84)	3,200–4,600	990	6.81 (±0.74)	6,000–7,500	715	3.80 (±1.20)	1,900–3,600
C5	610	2.69 (±0.80)	1,200–2,100	905	3.59 (±0.78)	2,500–4,000	995	2.59 (±0.31)	2,300–2,900
C6	475	2.44 (±0.55)	9,00–1,400	740	4.00 (±1.72)	1,700–4,200	830	2.70 (±1.27)	1,200–3,300
Chukchi Total	4,890	3.77 (±0.35)	16,700–20,100	5,800	6.06 (±0.51)	32,200–38,100	5,585	3.62 (±0.41)	17,900–22,500

called pack ice several days later. This was true in the Beaufort Sea in 1986 when the area of fast ice in sector B3 (Oliktok to Flaxman Island) decreased by almost 2,000 nmi^2 between 6 and 12 June.

Breakup further complicates the interpretation of density information by increasing the incidence of cracks and seals at cracks. Whereas seals at holes in fast ice are assumed to be winter residents of an area, the status of those at newly formed cracks or in broken ice is less certain. Because breakup proceeds generally from south to north, and seals migrate north as breakup progresses, many of the seals in cracked and broken ice may represent an influx of nonresident, migrating seals. In the Chukchi Sea this probably had little effect on our surveys of the fast ice, since surveys were conducted prior to significant breakup of the fast ice sheet. In the Beaufort Sea, however, major changes in fast ice conditions, with concurrent changes in seal distribution, occurred during the survey period. In 1986 a 5-day period of high winds caused major changes in the position of the ice edge and in the incidence of cracks. Replicate flights conducted 3-4 days apart, either before or after the storm and under similar ice conditions, produced statistically comparable results, but data from surveys before and after the period of high winds were significantly different. Both the observed density of total seals and the proportions of seals at cracks increased greatly after the storm, when ice conditions indicated the beginning of breakup. This increase could have been due to one or more of several factors: (1) more resident seals hauling out as the season progressed; (2) more hauled-out seals becoming visible as snow melted and haulout lairs collapsed; (3) seals abandoning holes and hauling out at newly formed cracks, as suggested by concurrent increases in the density of seals at cracks and decreases in the density of seals at holes in sector B2; (4) seals moving into an area from another region, as suggested by increases in total density and increases in the density of seals at cracks which far exceeded the relatively small decreases in seals at holes; and (5) seal pups increasing in size and molting to adult pelage, thus making them more visible to observers. Any or all of the above factors may have been operating in a particular sector.

The distribution of seals relative to each other and to the fast ice edge changed markedly during our surveys. In early June 1985 and 1986, prior to the onset of breakup, the density of seals at holes was similar (1985) or lower (1986) within 0-4 nmi of the edge than it was elsewhere. Very few seals at cracks were observed. Later in June in 1986, distribution changed: near the edge (0-2 nmi) seals at holes increased from 1.1 seals/nmi^2 to 6.9/nmi^2, and seals at cracks increased from zero to 7.2/nmi^2 (in sector B3). In 1987, when all surveys were flown after the beginning of breakup, densities near the edge were also very high: over 12 seals/nmi^2 occurred within 4 nmi of the edge in B3, and over 7 seals/nmi^2 for all Beaufort Sea sectors combined. Most of the seals were at cracks.

The average group size of seals at holes tended to increase with date, as did the percentage of total seals found at cracks. Between early and mid-June surveys in 1986, group size in sectors B1-B3 increased from about 1.3 seals/group to over 1.6 seals/group. In other years, the differences were less pronounced, but the tendency was the same (Table 38). The percentage of seals at cracks also generally increased with date, particularly in the central Beaufort Sea (Table 39). In sector B4, seals at cracks made up 18% of the total seals in 1985 and over 50% in 1986 and 1987. In contrast, in sector B1 seals at cracks never made up more

Table 38.–Average group size of ringed seals on fast ice of the Beaufort Sea, 1985-87.

	Average number of seals/group					
	June 1985		June 1986		June 1987	
Sector	Early	Middle	Early	Middle	Early	Middle
B1	1.29	1.30	1.26	1.59	1.25	1.39
B2	1.36	1.55	1.27	1.78	1.33	–
B3	1.45	1.37	1.35	1.74	1.53	1.78
B4	1.12	1.22	–	1.87	1.96	–

Table 39.–Percentage of total ringed seals seen at cracks in the fast ice of the Beaufort Sea, 1985-87.

	Percentage of seals at cracks					
	June 1985		June 1986		June 1987	
Sector	Early	Middle	Early	Middle	Early	Middle
B1	0.0	7.2	2.9	9.7	3.6	6.4
B2	12.8	21.5	0.8	47.2	1.8	–
B3	23.2	51.6	7.3	54.8	55.8	49.3
B4	–	18.4	–	55.5	70.8	–

than 10% of the total seals. In sectors B2 and B3, year-to-year differences were substantial, ranging from less than 10 to over 50%.

In combination, we think these observed changes in group size and in percentage of seals at cracks suggest that a substantial influx of ringed seals occurs in the Beaufort Sea as breakup begins. Before breakup begins, group size is about 1.3 seals/group, seals at cracks make up less than 20-30% of total seals, and densities are not particularly high near the fast ice edge. After breakup begins and new seals move into the area, distribution changes considerably. In 1986, when surveys occurred both before and after the beginning of breakup in sector B3, we were able to compare areas under both conditions. These comparisons indicated that most of the incoming seals were found near the fast ice/pack ice boundary zone. Comparable increases in observed density did not occur near shore; although seals at cracks were more abundant after the ice began to break up, the density of seals at holes was actually slightly lower. In 1986, a similar influx of seals probably also occurred in sectors B2 and B4, as suggested by both the high proportion and high absolute density of seals at cracks in those areas.

The dynamics in sector B1 were considerably different. Cracks, and seals at cracks, were not common in any year in either early or mid-June surveys, probably because of the effect Point Barrow has on stabilizing the fast ice in that area. Ice conditions in sector B1 changed very little during the 1986 storm and the proportion and density of seals at cracks were similar in early and mid-June surveys. Unlike sectors B2 and B3 where the density of groups actually decreased slightly in later surveys, in sector B1 the density of groups of seals as well as of individual seals increased (Frost *et al.* 1987). As in the other sectors, this could have been due to an influx of nonresident seals which, in the absence of cracks, hauled out at other seals' holes or lairs. Kelly *et al.* (1986) found that in most instances a seal maintains more than one lair. We think it is possible that the nonresidents use these empty lairs before cracks form. Alternately, the concurrent increases in sightings and density may have reflected a higher proportion of seals hauled out on the later date, a higher proportion visible due to the collapse of lair ceilings as the snow melted, or both. Studies in Kotzebue Sound and the Beaufort Sea have shown that the duration of haulout events doubles from March to June and that the onset of basking (hauling out on the surface of the ice instead of inside a lair) varies considerably among individuals (Kelly *et al.* 1986). Since those studies terminated in early June, it is unknown whether or not haulout duration continues to increase after that time.

Other investigators have reported similar increases in density or changes in distribution as the spring season advances. Helle (1980) documented a 10-fold increase in density of hauled-out ringed seals in the Baltic Sea between mid-April and late May and concluded that mid-April was too early for surveys. Smith (1973) found that counts in Home Bay were approximately stable from 26 May until 5 or 6 June, increased and fluctuated around a higher peak from 5 to 15 June, and increased again after 15 June. He suggested that increases after mid-June were probably due to an influx of seals from another area.

Finley (1979) found that in some areas of the Canadian Arctic, densities of ringed seals remained relatively stable from early June into July, whereas in others there were great increases in density. He, like Smith, attributed such increases to influxes of seals from other areas. As density increased in these areas, Finley noted that seals congregated in larger numbers at holes and in very large groups along cracks. In Aston Bay, the ratio of seals to holes increased from 0.33:1 to 2.63:1 as the season progressed, with as many as 19 seals found around a single hole. Finley suggested that social structure may break down as areas receive influxes of seals from areas of unstable ice, resulting in the larger groups seen later in the season. He proposed, as we have, that large groups of seals at holes and the presence of many seals at cracks may be indicative of seals that are nonresident, whereas small group size and few seals at cracks represent relative stability in the local population.

In a further attempt to determine the cause and geographic extent of the apparent influx of nonresident seals, and to determine whether there was any portion of the fast ice where densities remained more constant, we compared 1986 densities for all fast ice with that for fast ice within 6 nmi of land. Whereas pre- and post-storm comparisons for all fast ice indicated differences of greater than 1 seal/nmi^2 (25 to over 100% increases or decreases), the change near shore was much less. Within 6 nmi of land (sectors B1-B3 combined), the density of seals at holes increased only 6%, from 3.5 to 3.7 seals/nmi^2. Although the difference was significant ($t = 4.763$, $p < 0.001$), there was considerable overlap in the 95% confidence interval of the estimated number of seals (5,017 ± 739 vs. 5,380 ± 767, area = 1,450 nmi^2).

We suggested (Frost *et al.* 1987) that if for unavoidable reasons future surveys must take place after breakup has begun and cracks are widespread, it might be possible to use the nearshore portion of transects for annual comparisons. However, a closer analysis of the 1986 data showed that, although the combined sector B1-B3 densities of seals at holes were similar within 6 nmi of shore for the two survey periods, the individual sector densities were not (Table 40). The density of seals at holes increased 26% between surveys in sector B1, and decreased 17% in sector B3.

Although all of our surveys in 1987 occurred after the beginning of breakup, we did have replicate surveys in sectors B1 and B3, flown about a week apart. The density of seals at holes within 6 nmi of shore increased 83% during that period in sector B1, and increased 52% in sector B3. In combination, the figures in Table 40 indicate that the area within 6 nmi of shore is not any more suitable for between-year comparisons of data collected under different ice conditions than is the entire fast ice zone.

We conclude that in order for meaningful comparisons to be made between years, surveys must be conducted prior to the onset of breakup and before seals have started to move in from other areas and congregate in large groups near the fast ice edge. In some years, such as 1987, this may occur in early June, whereas in other years the ice may be suitable for surveys until mid-June. The best indications of whether or not conditions are suitable are the percentage of seals at cracks relative to total seals, group size, the presence of numerous cracks, and whether the attached fast ice in the central Beaufort Sea has begun to crack and break off from the actual shorefast ice. If this process is well advanced it can be determined from satellite photographs of the ice. Early in the process, reconnaissance flights at low altitude are necessary.

Table 40.–Density of seals within 6 nmi of shore in early and mid-June 1986-87.

Year		B1-B3 combined		B1		B3	
		Early	Middle	Early	Middle	Early	Middle
1986	Hole	3.46	3.71	2.38	3.00	4.56	3.79
	Crack	0.01	2.66	0.00	0.86	0.02	3.04
	Total	3.47	6.37	2.38	3.85	4.58	6.84
1987	Hole	2.91	4.53	1.93	3.53	3.19	4.86
	Crack	2.19	4.28	0.04	0.78	2.04	5.78
	Total	5.10	8.81	1.97	4.31	5.23	10.64

Early in the season when ice conditions are most suitable for surveys it is also most difficult to determine the location of the fast ice edge. In some sectors the problem is more acute than others. In sector B1 the edge is usually well defined. However, in sectors B2 and B3 it is very difficult at low altitude to differentiate fast ice from pack ice. We therefore analyzed our data in several different ways to see if there was a fixed parameter that could be used to determine ending coordinates of transect lines before the surveys, and which would produce densities similar to those for fast ice as a whole. Using data from sectors B2 and B3, where distinguishing the ice edge is most problematic, we compared densities for all fast ice (edge usually determined by matching satellite photographs with field notations) with those for ice within 10 and 20 nmi of shore and for all ice within the 20-m depth contour, which, according to Reimnitz and Kempema (1984) and Stringer (1982), approximately delimits the seaward edge of fast ice (Table 41). According to Reimnitz and Kempema (1984) there is a band of shoals in the central and western Beaufort Sea that lies approximately along the 18- to 20-m depth contour. These shoals cause pack ice to ground and form a protective zone of ridges which protects and stabilizes the fast ice. For seals at holes and total seals, density within the 20-m contour most closely approximates density on the fast ice (Figure 16). Whereas the 20-m depth contour correlates with position of the fast ice edge, the 10-nmi and 20-nmi bounds are arbitrary and may fall in very different places relative to the fast ice edge in different sectors. We therefore suggest that future surveys use the 20-m depth contour to delimit the seaward end of survey lines, and between-year comparisons be made only for ice within the 20-m contour. By so doing, a comparable area is included in the data from year to year. Furthermore, this is the area most likely to be impacted by human activities.

The total number of seals within the 20-m depth contour in the Beaufort Sea was estimated by multiplying the density of seals by the area of all ice between shore and the 20-m depth contour. Shallow areas (<3 m) of large embayments (Harrison and Smith bays) were excluded from the analyses because they freeze to the bottom. The estimated numbers of seals at holes and total seals within the 20-m depth contour were higher in sectors B2-B4 in 1986 than in 1985, with no overlap of 95% confidence limits. Although the density in sector B1 was significantly lower in 1986, the 95% confidence limits overlapped considerably (Table 42).

Table 41.–Density (seals/nmi²) of ringed seals on different portions of the ice in sectors B2 and B3, 1985-87.

Year	Zone	nmi	Holes Density	Holes SD	Total Density	Total SD
1985	<20 m	322	1.98	0.14	2.80	0.14
	fast	564	1.76	0.12	3.17	0.30
	10 nmi	246	1.87	0.17	2.36	0.31
	20 nmi	477	1.82	0.12	3.22	0.37
1986	<20 m	320	3.99	0.21	4.15	0.24
	fast	463	3.64	0.17	3.77	0.20
	10 nmi	163	3.93	0.26	4.02	0.27
	20 nmi	346	3.82	0.18	3.98	0.21
1987	<10 m	354	4.15	0.23	6.16	0.69
	fast	340	4.09	0.22	5.64	0.69
	10 nmi	226	3.44	0.28	6.19	0.81
	20 nmi	442	3.35	0.25	5.39	0.45

Comparisons between early June 1986 surveys and 1987 surveys indicate that substantially more total seals were hauled out on ice within the 20-m contour in 1987. The number of seals at holes was more variable, with more seals in some sectors and less or similar numbers in others. As pointed out in earlier discussions, the 1986 and 1987 surveys, although occurring on approximately the same dates, represented different ice conditions. The mid-June 1986 surveys in sector B3, conducted after breakup had begun, are more comparable to 1987 surveys. Estimates of the numbers of seals for those surveys are similar to the 1987 estimates: 7,200 ± 900 for mid-June 1986 and 6,700 ± 2,200 for 1987.

Historical data also indicate substantial year-to-year variability in the occupancy of nearshore areas by ringed seals. Data are available for the Alaskan Beaufort Sea since 1970 (Burns and Harbo 1970; Burns and Eley 1978; Burns *et al.* 1981*a*; Burns and Kelly 1982, reanalyzed in Frost *et al.* 1985).

During that period, the density of ringed seals on the fast ice of the Beaufort Sea as a whole dropped from a high of 3.3 seals/nmi² in 1975 to a low of 1.1 seals/nmi² in 1977, and subsequently steadily increased to 3.5 seals/nmi² by 1986 (Figure 17). The density in any particular year ranged from 50% below to 40% above the mean density for 8 years of surveys (1987 was not included because breakup had already begun).

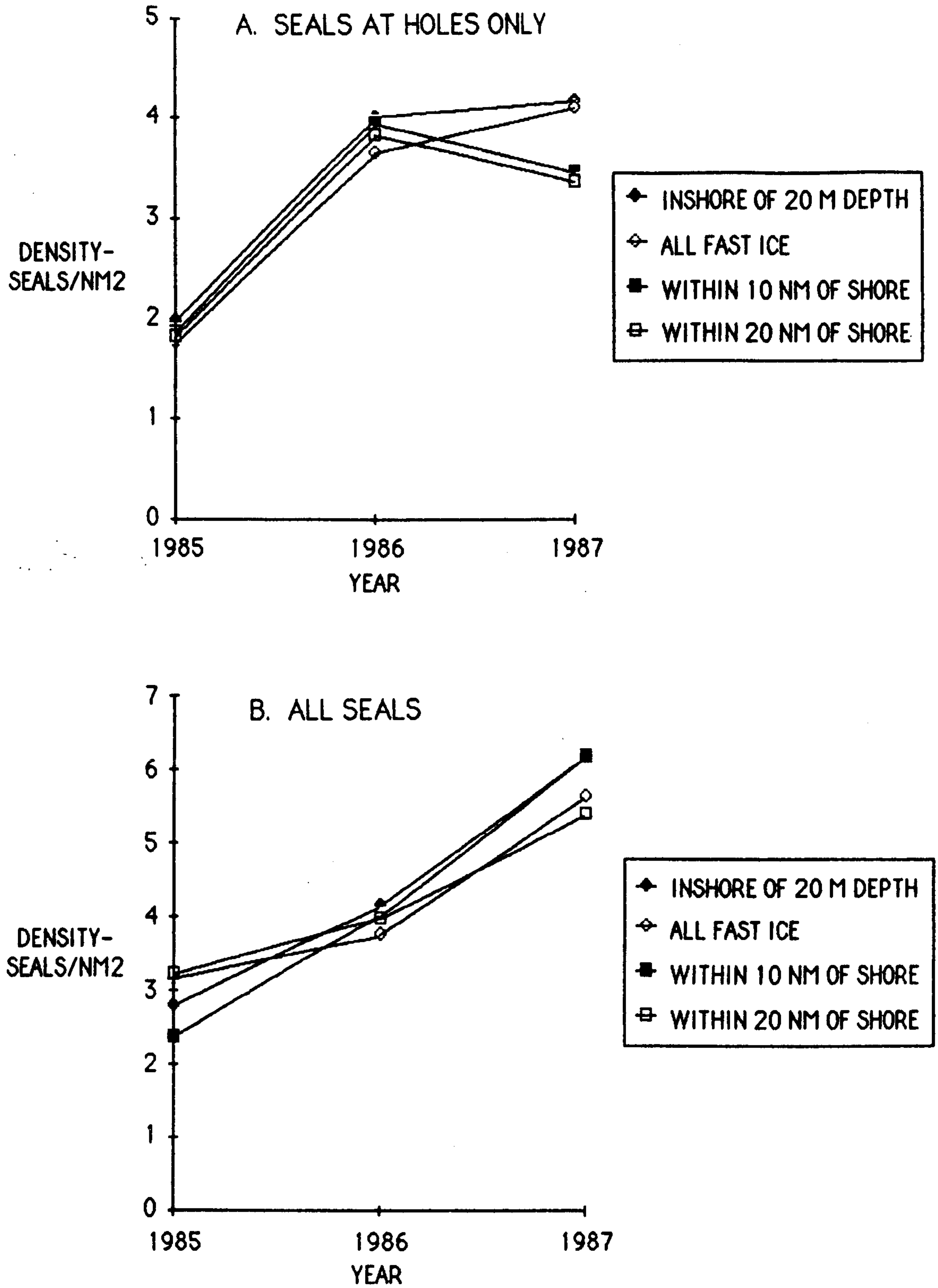


Figure 16.–Densities of ringed seals in sectors B2 and B3, Lonely to Flaxman Island, 1985-87.

Table 42.—Density and estimated numbers (95% confidence limits) of ringed seals hauled out on fast ice within the 20-m depth contour during aerial surveys conducted in the Beaufort Sea, June 1985–87.

Sector	nmi^2 within 20-m contour	1985		1986		1987	
		Density	Number	Density	Number	Density	Number
Seals at Holes							
B1	1,100	2.28 (±0.40)	2,100–2,900	2.08 (±0.41)	1,800–2,700	2.98 (±0.37)	2,900–3,700
B2	1,800	2.06 (±0.49)	2,800–4,600	3.73 (±0.45)	5,900–7,500	4.57 (±0.53)	7,300–9,200
B3	800	1.93 (±0.34)	1,300–1,800	4.57 (±0.79)	3,000–4,300	3.51 (±0.68)	2,300–3,400
B4	450	1.77 (±0.43)	600–1,000	4.08 (±1.25)	1,300–2,400	3.16 (±0.84)	1,000–1,800
B1–B3	3,700	2.09 (±0.23)	6,900–8,600	3.40 (±0.38)	11,200–14,000	3.80 (±0.35)	12,800–15,400
All Seals							
B1	1,100	2.40 (±0.46)	2,200–3,200	2.08 (±0.41)	1,800–2,700	3.10 (±0.38)	3,000–3,800
B2	1,800	2.31 (±0.54)	3,200–5,100	3.77 (±0.46)	6,000–7,600	4.75 (±0.56)	7,500–9,600
B3	800	3.12 (±0.98)	1,700–3,300	5.01 (±0.90)	3,300–4,700	8.33 (±2.72)	4,500–8,800
B4	450	1.99 (±0.38)	700–1,100	9.12 (±3.75)	2,400–5,800	10.90 (±11.34)	0–10,000
B1–B3	3,700	2.66 (±0.49)	8,000–11,700	3.51 (±0.42)	11,400–14,500	5.24 (±1.00)	15,700–23,100

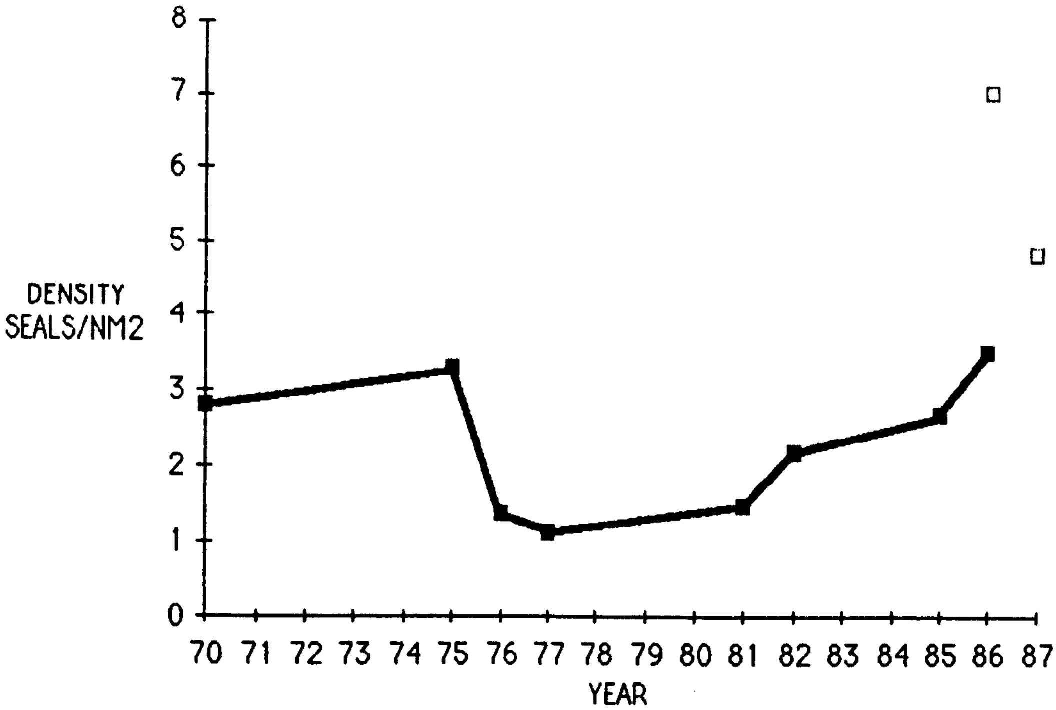


Figure 17.–Density of ringed seals (total seals/nmi^2) in the Beaufort Sea (sectors B1-B4), 1970-87. Open squares indicate post-breakup values for 1986 and 1987. Densities for 1985-87 are for total seals within the 20-m depth contour.

Density of Seals in Relation to Industrial Activities

Construction and operation of artificial islands were the principal industrial activities in our study area during 1985-87. Data were obtained for all three years of the survey and for three artificial islands: Seal, Northstar, and Sandpiper (Table 43). In 1985, all three of the islands were active: Seal was engaged in drilling operations and Northstar and Sandpiper were under construction. For all comparisons, the density of seals at holes was 20-80% lower within 2 nmi of the islands than it was 2-4 nmi away.

During the 1986 surveys Seal Island was inactive and had been so all winter, Northstar was inactive at the time of survey but had been in operation through April, and Sandpiper was currently active. The area was surveyed before breakup on 6 June, and after breakup had commenced during 13-16 June. Unlike 1985, densities were not consistently lower within 2 nmi of the islands than they were elsewhere; results for individual islands were contradictory. Near Northstar (active until April) the density for both surveys was slightly lower (3-15%) within

Table 43.–Density of ringed seals at holes in relation to distance from three artificial islands in the Beaufort Sea, June 1985-87.

Island	Survey	Distance from any island (nmi) 0-2	2-4	4-6	6-8	8-10
1985						
Seal	85-1	0.7	1.2	1.1	1.7	1.3
	85-2	–	1.9	1.0	3.3	2.2
Northstar	85-1	0.8	1.6	2.2	1.4	0.9
	85-2	0.8	1.0	5.8	1.5	1.5
Sandpiper	85-1	0.6	3.1	1.0	1.0	1.1
	85-2	2.6	4.4	1.8	1.9	1.6
1986						
Seal	86-1	6.1	5.8	4.6	2.3	5.1
	86-2	–	4.6	6.5	5.0	5.6
Northstar	86-1	5.0	5.2	6.8	4.2	2.1
	86-2	5.0	5.9	5.7	8.8	5.3
Sandpiper	86-1	8.3	3.3	6.5	3.2	3.6
	86-2	5.2	6.2	6.8	9.1	9.1
1987						
Seal	87-2	14.4	9.5	10.4	5.9	4.8
Northstar	87-1	1.1	3.3	5.6	4.1	5.2
	87-2	3.8	8.4	14.2	6.3	6.1
Sandpiper	87-1	7.1	7.6	2.2	4.2	3.9
	87-2	6.8	5.5	6.6	5.2	11.9

2 nmi of the island than 2-4 nmi away. Near Sandpiper the density was higher within 2 nmi of the island on one survey, and lower on the other.

During winter and spring of 1986-87, all three artificial islands were inactive. Neither construction nor drilling operations occurred. As in previous years, the islands were surveyed twice in 1987, on 6 and 11 June. There was no consistent difference in seal density with distance from the three nonoperational islands. Seals were more numerous near Seal Island, less numerous near Northstar, and differed between the two surveys at Sandpiper.

Interpretation of the data regarding differences in density around individual islands was complicated, and the utility of such data limited, by several factors: sample sizes were small (17-80 nmi^2 total per survey), particularly within 2 nmi of the islands where the sample for a survey usually consisted of 1-3 minutes (1-6 nmi^2) of data; the islands were close enough together (particularly Seal and Northstar islands which were only 4 nmi apart) for interactive effects to occur; and not all islands were in similar operational status either within or between years. Consequently, the data set shown in Table 43 could not be treated as 18 replicate tests of the effect of an artificial island on seal density.

To address the first two of these problems we determined the minimum distance from any island in the data set from each survey (Table 44). In five of the six comparisons the density of seals at holes was 12-72% lower within 2 nmi of any island than it was 2-4 nmi away. Inspection of the raw data indicated that for the single exception (survey 86-1) the higher density at 0-2 nmi was probably a result of the way position was assigned to the minute survey interval. Although the density of seals was lower near the islands in both 1985 when all islands were active and 1987 when none were active, the magnitude of the difference was much greater during activity (50-70%) than in its absence (12-30%).

A block comparison of industrial and adjacent control areas was also done for all 3 years. In 1985, industrial activity, including seismic lines, ice roads, and islands, was widespread, resulting in an industrial block approximately 60 nmi across. In 1986, the only obvious activities were the artificial islands and associated ice roads, resulting in an industrial block which was only 16 nmi across. During 1987 surveys there was no offshore industrial activity; however, data were analyzed according to the 1986 industrial and control blocks for comparative purposes.

In both 1985 and 1986 the density of total seals was significantly higher in the industrial block than in the control blocks (Figure 18). In 1987, in the absence of any offshore industrial activity, density in the "industrial" block was also higher than either control, suggesting that some characteristics other than the presence or absence of activity were responsible for the difference.

Annual and long-term variability in the occupancy of nearshore areas by ringed seals make it necessary to conduct regular and relatively extensive surveys of areas in which smaller-scale comparisons are to be made. For example, the density of ringed seals in the central Beaufort Sea (sectors B2 and B3) decreased in the mid- to late 1970s and subsequently increased in the mid-1980s. This could be attributed to changes in industrial activity, which intensified in the late 1970s and early 1980s, then gradually decreased. However, the western Beaufort Sea (sector B1), which experienced little or no seismic or other industry activity, showed the same fluctuations in density during this time period. Furthermore, the major decline in density which occurred in the study area between 1975 and 1977 also occurred in the Canadian Beaufort Sea (Stirling *et al.* 1981*a*).

Although aerial surveys are useful in monitoring long-term trends in abundance over large areas, they are not well suited to detecting small-scale differences in geographically restricted areas. In this study, aerial survey data indicated a possible local effect of artificial islands on the density of ringed seals. However, interpretation was complicated by the

Table 44.–Density of ringed seals at holes in relation to distance from any of three artificial islands in the Beaufort Sea, June 1985-87.

Survey	nmi^2	Distance from any island (nmi)				
		0-2	2-4	4-6	6-8	8-10
85-1	103	0.7	2.5	1.0	1.8	1.2
85-2	67	1.5	3.2	2.0	1.9	1.4
86-1	34	6.5	3.9	6.6	2.0	3.7
86-2	75	5.1	6.3	5.4	11.4	6.4
87-1	45	4.7	6.7	2.4	4.1	4.0
87-2	50	7.1	8.1	9.5	5.8	5.4

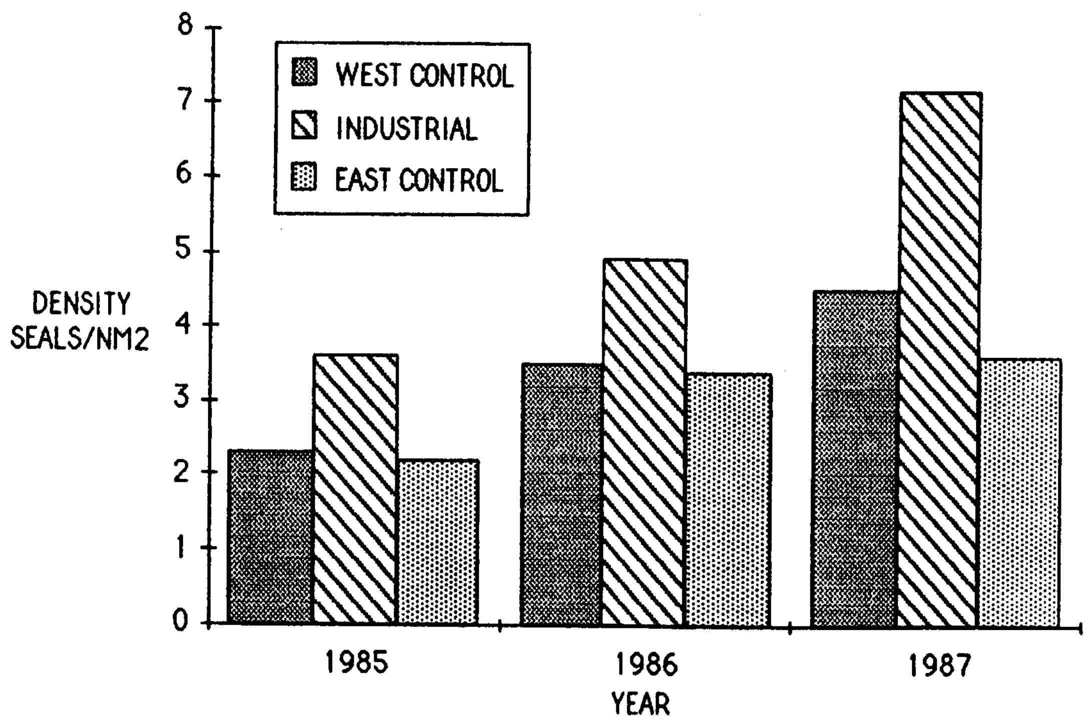


Figure 18.–Seal density (total seals/nmi^2) in industrial and control blocks in the central Beaufort Sea, 1985-87.

following factors: the minimum sighting unit was 1 minute or 2 nmi; land and the edge of shorefast ice, which may both affect seal densities, were variable distances from the three islands; and the precision of navigational equipment sometimes varied by ±1 nmi. In analyses of industrial and control blocks, the greatest difficulties were in obtaining an accurate measure of industrial activity and in designating comparable control blocks. There is considerable east-west variability in the Beaufort Sea in ice topography, extent of shorefast ice, and bathymetry. Control and industrial blocks were not necessarily comparable simply because they were adjacent, as is indicated by higher densities in the "industrial" blocks with or without industrial activity.

Together, analyses of historical and recent aerial survey data emphasize the importance of matching research technique to the question at hand. Our data indicate that in 1985-86, industrial activity had no apparent large-scale effects on the density of ringed seals as measured by aerial surveys. Burns and Frost (1988) reached the same conclusion for aerial surveys conducted in 1981-82 in areas with and without on-ice seismic exploration, but they also concluded that aerial surveys are not well suited to detecting small-scale differences in geographically restricted areas. The aerial survey data do not eliminate the possibility of local effects which would be more appropriately detected by other techniques, or the possibility that regional effects could occur at different levels of industrial activity. Most aerial surveys conducted during peak years of industrial activity in the central Beaufort Sea did not have sampling effort or design suitable for statistical analyses of differences between relatively small areas. By conducting on-ice studies, Burns and Kelly (1982) found that although aerial surveys showed no significant difference in densities along seismic and control lines, the rate of alteration or refreezing of lairs and breathing holes within 150 m of seismic lines was approximately double the rate at distances greater than 150 m. Kelly *et al.* (1986, in press) also reported results of on-ice studies which indicated that ringed seals do respond to manmade disturbances. Burns and Frost (1988) found that seal structures were abandoned at three times the rate in disturbed areas (31% of all structures) as they were in areas free of human-caused disturbance (10% of all structures).

Implications of Survey Results to Monitoring Program

Analyses of 1985-87 survey data have identified several areas of potential concern regarding the methodology of aerial surveys to monitor changes in the distribution and abundance of ringed seals.

1) Comparisons of experienced and inexperienced observers indicate that novice observers see significantly fewer seals than do experienced observers. Survey personnel must be adequately trained to count ringed seals and classify ice conditions before serving as primary observers. Training should include flying as backup for an experienced observer until comparable counts are repeatedly obtained in a variety of survey conditions.

2) Surveys flown at 500 ft result in density estimates which are significantly lower than those for surveys of the same area conducted at 300 ft. We recommend that all surveys

be conducted at 300 ft. When surveys that were conducted at different altitudes are compared, densities must first be corrected to make the results comparable. Densities of seals at holes for surveys at 500 ft should be multiplied by 1.32 to make them equivalent to surveys at 300 ft. Estimates of seals at cracks were not significantly different, perhaps because seals aggregated along linear features are easier to see, and need not be corrected.

3) Surveys within the same sector or geographic region should be conducted under similar ice conditions within and between years. Although calendar date provides a rough guideline for assuring similar conditions, there is considerable annual variability in the onset of breakup. Counts of seals on fast ice that are made after breakup begins are likely to include large influxes of seals from other areas, and should not be considered representative of the overwintering, resident population. Factors such as the amount of cracking, the distribution of seals relative to the edge, and the abundance of seals at cracks must be used to interpret data and assess whether or not significant changes in seal distribution have begun to occur.

4) In the Chukchi Sea, survey lines should extend from shore to the edge of fast ice, which is easily recognizable at survey altitude. In the Beaufort Sea, where the edge of fast ice is often difficult to locate without the use of satellite photographs, survey lines should extend from shore to the 20-m contour line, which coincides approximately with the edge of fast ice. In large, very shallow embayments such as Smith Bay and Harrison Bay, transect lines should begin at the 3-m depth curve.

RECOMMENDATIONS FOR FUTURE STUDIES

Future Aerial Monitoring Surveys

We recommend that MMS continue a program of monitoring the abundance of ringed seals on the shorefast ice of the Chukchi and Beaufort seas. Surveys conducted during 1985-87 have allowed a substantial refinement of survey protocol and have provided a large amount of baseline data on ringed seal distribution and abundance during May and June. During 1985-87 oil and gas activity in the OCS region was minimal in the Beaufort Sea and nonexistent in the Chukchi Sea. We were, therefore, not able to measure or monitor possible effects of OCS industrial activities on ringed seal distribution and abundance.

Although it is impossible to accurately predict the probable timing and magnitude of OCS activities, recent sales in the Beaufort Sea (sale 97) and Chukchi Sea (sale 109) suggest that activity will increase within the next few years. We therefore recommend that a 3-year series of ringed seal monitoring surveys be conducted in 1991-93. Those surveys should follow the protocol developed in this study and should incorporate the following:

1) Surveys should include and emphasize areas leased in sale 97 (sectors B1-B4) and sale 109 (C4-C6).

2) Surveys should be conducted before breakup in order to ensure that data are comparable.

3) Survey coverage should extend from shore to the 20-m depth contour in the Beaufort Sea, and from shore to the fast ice edge in the Chukchi Sea.

Effects of Disturbance on Ringed Seals

Aerial surveys provide the best means to look at large-scale patterns and changes in ringed seal distribution and abundance. Results of aerial surveys indicate that industrial activities (primarily on-ice seismic profiling) to date have not caused large-scale changes in seal distribution (Frost and Lowry, in press). However, other studies (Kelly *et al.*, in press) indicate that seismic surveys and other activities can cause localized changes in seal distribution and behavior. Further studies are required if the possible magnitude and significance of disturbance on ringed seals are to be assessed. Such studies should examine fine-scale distribution (using trained dogs to locate lairs and breathing holes) and behavior (using telemetry) near representative sources of disturbance, such as artificial islands, active drilling rigs, seismic shot lines, and ice roads or air strips.

Factors Affecting Ringed Seal Abundance

It is clear from this and other studies that the density of seals during the spring haulout period varies geographically and temporally. Causes of these variations are poorly known, but both physical factors (e.g., ice characteristics, weather, and oceanography) and biological processes (e.g., food availability, predation, and territoriality) are likely to be involved. Research into all possible factors that could control ringed seal distribution and abundance is needed in order to understand natural variability, and to better interpret results of the monitoring program.

Other Aspects of Ringed Seal Distribution

Ringed seals are widely distributed year-round in waters of northern Alaska, but there is very little information on their distribution and abundance except for on the shorefast ice in spring. This study has supplemented previously available data on abundance of ringed seals in the flaw zone and nearshore areas of pack ice during May-June. Substantial numbers of seals inhabit these areas, and their interaction with seal density on the fast ice during breakup is significant and warrants further study. In order to produce a valid estimate of the total size of the ringed seal population off Alaska, more information is needed on densities in the offshore pack ice. Ringed seal distribution and abundance during the open-water season should be investigated in order to evaluate important habitats and processes, and potential effects of OCS activities that occur during July-November.

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RINGED SEAL WINTER ECOLOGY AND EFFECTS OF NOISE DISTURBANCE

by

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ABSTRACT

Ringed seals abandon subnivean breathing holes and lairs at higher than normal rates in response to seismic (Vibroseis) surveying and, probably, other human-made noises. The significance of such abandonment was assessed in a telemetric study of lair occupation by ringed seals.

Temporal and spatial haulout patterns of 13 radio-tagged seals were recorded from early March through early June in the Beaufort Sea and in Kotzebue Sound. Both male and female ringed seals haul out in more than one, and as many as four, alternative subnivean lairs. At least one lair was used by more than one seal. Distances between lairs used by individual seals were as great as 4 km with numerous breathing holes between those sites.

The percentage of once-hourly monitoring periods in which seals were hauled out in lairs increased from 11.5% in March to 17.8% in April, 20.4% in May, and 27.2% in June. Individual haulout bouts averaged 5.4 hours; non-haulout bouts averaged 18.9 hours. Post-parturient females hauled out most regularly and did so in significantly longer bouts during the nursing period than before or after that period. Diel haulout patterns tended to be weak or absent in March and April but became pronounced with midday peaks in late May and early June.

Heat dissipated from the underlying sea water maintained air temperatures in subnivean lairs above -10°C despite outside equivalent windchill temperatures lower than -35°C. The presence of a seal in a lair increased the air temperature by at least 3°C and by as much as 10°C. Air temperature in one lair averaged 27.0°C warmer than outside windchill temperatures in March, 26.2°C warmer in April, and 16.4°C warmer in May. After the first week of May, outside windchill temperatures tended to be warmer than internal lair temperatures.

Ringed seals abandoned subnivean lairs and breathing holes that were within 150 m of seismic lines significantly more often than they abandoned sites at greater distances from seismic lines. Radio-tagged ringed seals departed lairs by diving into the water in greater than 50% of instances when helicopters flew over at or below an altitude of 305 m. Seals departed lairs in response to snow machines operating at distances of 0.5 to 2.8 km. An operating Vibroseis and associated equipment caused a seal to exit a lair at a distance of 644 m. People moving on foot or skiis generally did not cause seals to depart lairs until within 200 m. Seals departed significantly more often in response to people walking than in response to skiers. In all cases where seals departed lairs in response to human-made noises, they subsequently returned to the lair and hauled out. The seal that departed in response to seismic equipment on the ice may have abandoned his lair five days later.

The effectiveness of aerial surveys of basking ringed seals could be increased by telemetrically monitoring haulout patterns during the basking season.

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INTRODUCTION

Background

Ringed seals, of all northern pinnipeds, are recognized as the most adapted to areas of annual sea ice cover (McLaren 1958; Burns 1970; Smith and Stirling 1975). These small phocids can inhabit areas of complete ice cover by virtue of their ability to make and maintain breathing holes through the ice with the strong claws on their foreflippers. Some of these holes are covered by snow drifts, into which the ringed seals excavate lairs where they haul out to rest and give birth.

The female gives birth to a single pup in a subnivean lair between late March and mid-April (McLaren 1958; Smith and Stirling 1975; Lukin and Potelov 1978). Each pup retains its white, woolly lanugo pelage for most of the 4- to 6-week nursing period, during which time they develop a thick blubber layer. Nursing overlaps with mating, which occurs in late April and May (McLaren 1958). At that time, the rutting males become odoriferous, a condition referred to as "tigak" by Inupiaq-speaking Eskimos. The odor is imparted to the snow at breathing holes and lairs used by the males.

Subnivean lairs have been found to provide protection from predators (McLaren 1958; Smith 1980) and extremely cold temperatures (Lukin 1980). The lairs are generally abandoned in late May, and the adults then begin to bask in the sunlight as they molt. After the ice breaks up, generally in late June or July, the seals are mainly pelagic until they again inhabit the ice the following winter.

The existence of ringed seal lairs was known long ago to the Eskimo people, who used dogs to locate them (Hall 1866; Stefansson 1913). Only recently, however, have those structures been investigated by biologists. Lukin and Potelov (1978) investigated the distribution and abundance of pupping lairs in the White Sea using a trained dog to locate those structures. Smith and Stirling used Labrador retrievers to locate subnivean seal structures (breathing holes and lairs) in the Canadian Arctic (Smith and Stirling 1975). They and their coworkers have investigated the distribution and abundance of the structures and predation on ringed seals (Smith and Stirling 1975, 1978; Smith 1976, 1980; Smith and Hammill 1981).

Shorefast ice has been considered the most important habitat for breeding ringed seals (McLaren 1958; Burns 1970; Smith 1973*a*). In the Chukchi and Beaufort seas, the fast ice is also used as a substrate for petroleum exploration and development activities, including seismic surveying and gravel island construction. To a large degree, those activities take place on ice that is believed to be optimal ringed seal habitat (Burns and Kelly 1982).

Relevance to Problems of Petroleum Development

Petroleum exploration and development may affect ringed seals through (1) direct contact with crude oil from a spill, (2) destruction or displacement of prey, or (3) displacement from portions of their habitat due to noise disturbances. Effects of contact with, and ingestion of, crude oil included temporary soiling of the pelage, eye irritation, kidney lesions, and possible liver damage (Geraci and Smith 1975; Smith and Geraci 1975). Six ringed seals immersed for 24 hours in crude oil shortly after capture survived, but three held in captivity for a longer period died within 71 minutes of immersion, apparently as the combined result of stress and exposure to the oil (Smith and Geraci 1975). Indirect effects on the seals through impacts on prey populations are difficult to assess but generally are considered to be of minor importance (Sekerak 1979; Craig 1984; Truett 1984).

Disturbance by noise is likely to be more widespread in time and space, but the long-term significance of such disturbance is difficult to predict. Burns and Eley (1978) suggested that low numbers of ringed seals in the immediate vicinity of coastal villages was due to displacement from noise disturbance as well as hunting pressure. Based on aerial surveys in 1970, Burns and Harbo (1972) concluded that "ringed seals were not appreciably displaced" by under-ice seismic exploration (dynamite method), although their surveys were not well-stratified with respect to experimental (seismic) areas and control (nonseismic) areas (Burns and Kelly 1982). Aerial surveys conducted in June of 1975, 1976, and 1977 also were not designed to test for displacement of ringed seals by industrial activities, but reanalysis of those data suggested that densities of seals in areas subjected to seismic exploration were approximately half of the densities in undisturbed areas (Burns and Kelly 1982). In 1981, this project conducted aerial surveys specifically designed to assess the impact of on-ice seismic activity on ringed seal distribution and numbers (Burns *et al.* 1981*a*; Burns and Kelly 1982). Those surveys also suggested displacement of ringed seals by on-ice seismic exploration, but the results were confounded by an early ice breakup and a questionable relationship between seal distribution in winter and in the June survey period.

Also in 1981, Kelly (with the aid of Dr. Thomas Smith and his colleagues) trained a Labrador retriever to locate subnivean seal structures by smell. In the spring of 1982, the Labrador was used to survey subnivean seal structures in areas of seismic exploration and in control areas. Each structure was examined repeatedly to determine whether it remained in active use by a seal. Seals abandoned 29.2% of the structures ($n = 48$) within 150 m of seismic lines and 10.8% of the structures ($n = 37$) beyond 150 m of the same seismic lines (Burns and Kelly 1982). A log-likelihood ratio goodness-of-fit test indicated that the difference was significant ($G = 5.530$, $df = 1$, $0.01 < p < 0.025$). Abandonment rates did not differ significantly with distance from control lines ($G = 0.071$, $df = 1$).

Three ringed seals were radio-tagged in 1982, and their daily and seasonal haulout patterns were monitored by means of the radio signals. A brief summary of those results was reported by Burns and Kelly (1982).

While local displacement of ringed seals occurred in areas of seismic exploration, assessment of the impacts at the population level required additional information. Major concerns included: (1) the significance of different geographical areas to overwintering ringed seals, (2) the ecological importance of lair use by seals, (3) responses of individual seals to noise disturbances, and (4) the nature of the acoustic environment of seals in areas with and without industrial activity. The first of these concerns was addressed by Burns and coworkers in Part I of RU 232, and the second and third are the subject of this report; the fourth was addressed by TRACOR, Inc., as RU 636.

To address these different concerns simultaneously, an additional Labrador retriever was trained in the art of "seal sniffing." Lil, a three-year-old bitch was trained, with the aid of Clyde, the experienced Labrador. Her training took place initially along the Seward Peninsula in early March 1983 and continued on the job in the Beaufort Sea.

Objectives

The ecological importance of lair use and the responses of individual ringed seals to noise disturbance were studied telemetrically over three years. The objectives were:

1) To determine the number of subnivean lairs utilized by individual ringed seals and the spatial distribution of those lairs.

2) To determine the patterns of daily and seasonal use of subnivean lairs by ringed seals.

3) To determine the thermal advantage realized by ringed seals occupying subnivean lairs.

4) To determine how lair occupancy is affected by noise disturbances including seismic exploration.

Additionally, we supported the acoustic measurements of RU 636 by locating subnivean seal structures and aiding with logistics.

Study Areas

Telemetric studies were conducted in the vicinity of Reindeer Island (70°29.1'N, 148°21.5'W), Beaufort Sea in 1982 and 1983 and in southern Kotzebue Sound (66°04'N, 162°26'W), Chukchi Sea in 1984 (Figure 1). The Beaufort Sea study area was subjected to seismic exploration (Vibroseis method) during the month before radio-tagging was begun in 1982. In 1983, the area was subjected to a simulated seismic survey after most study animals had been radio-tagged. Kotzebue Sound was chosen as the study area in 1984 because it was not impacted by industrial activities and could serve as a control area. Kotzebue Sound offered

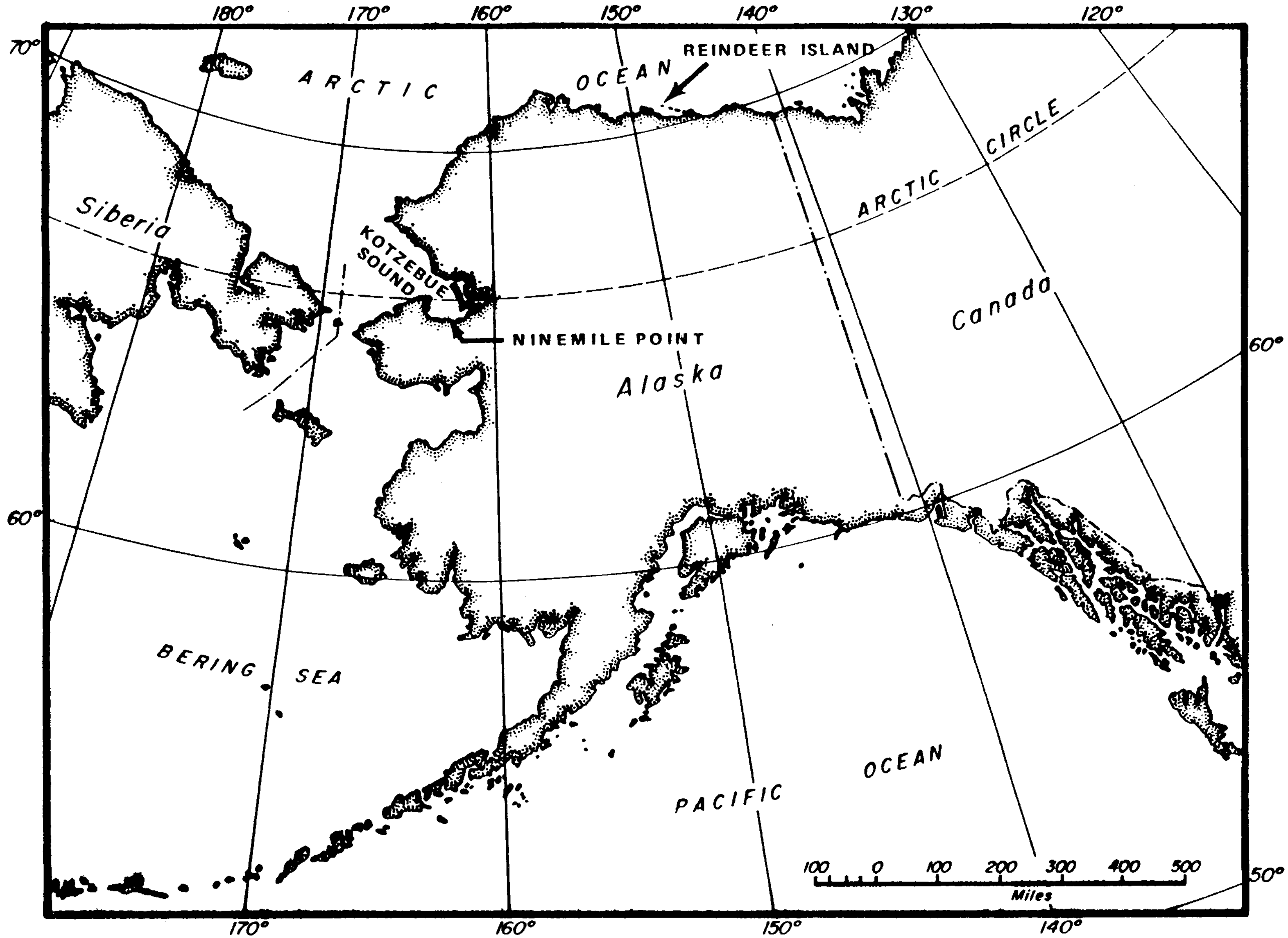

Figure 1.–Locations of study areas: Reindeer Island (1982 and 1983) and Ninemile Point, Kotzebue Sound (1984).

the additional advantage of higher densities of seals, thus expediting the tagging and tracking procedures.

The 1982 and 1983 study area in the Beaufort Sea encompassed the shorefast ice within an approximately 13-km radius of Reindeer Island (Figure 2). Water depth in the study area was generally less than 15 m and increased only gradually offshore of Reindeer Island. The island is composed of sand and gravel, as are most of the bottom sediments in the vicinity.

The sea around the island usually is ice-covered from October to July with annual ice attaining a thickness of 2 m. Variable numbers of large pressure ridges trend more or less parallel to the shoreline and are most numerous seaward of the barrier islands. Snow drifts adjacent to surface deformations, such as pressure ridges and grounded floes, predominantly run northeast to southwest, since the prevailing winds are out of the northeast. Except for those drifts, snow depth is generally less than 20 cm, which is the minimum required for lair excavation by seals (Smith and Stirling 1975; Burns and Kelly 1982).

Water circulation under the fast ice is very slow, and current speeds generally are less than 2 cm/sec. (Barnes and Reimnitz 1973). Water temperature under the ice remains very close to the freezing point, which decreases with increasing salinity through the winter months (Newbury 1983).

Kotzebue Sound, the 1984 control area, averages 13 to 16 m in depth with a sand and gravel bottom. Water temperature under the ice was measured at -2°C. The Sound is typically covered with annual ice from November to July (Barry 1979), and in April we found the ice to average 1.5 m in thickness. Between freeze-up and breakup, the ice is very stable since its enclosure in the Sound mostly protects it from the force of the drifting pack. Except for narrow (1 to 3 km wide) bands of flat ice along the shoreline, the ice in most of the Sound was deformed by ridges and hummocks, most of which were 1 to 2 m in height, with some reaching 9 m. Snow accumulation was extremely low in 1984 and seldom reached 20 cm except in the southern part of the Sound. There, consistent westerly winds resulted in drifts of accumulated snow on the east and west sides of ice deformities. The northern part of the Sound, however, was subjected to winds from various directions, and few snow drifts were deeper than a few centimeters. Telemetric studies of ringed seals took place in the vicinity of Ninemile Point in the southern part of the Sound (Figure 3).

METHODS

Subnivean structures (breathing holes and lairs) were located in the vicinity of camps established for around-the-clock monitoring of radio transmitters. Three camps were employed in 1982 (Figure 2): one on the ice approximately 1.2 km northeast of Reindeer Island (20 - 29 April), the second on the ice approximately 3.7 km north of that island (30 April - 22 May), and the third on Reindeer Island itself (23 - 29 May). Two monitoring camps were employed concurrently in 1983 (Figure 2): one on Reindeer Island (20 March - 6 June) and the other on

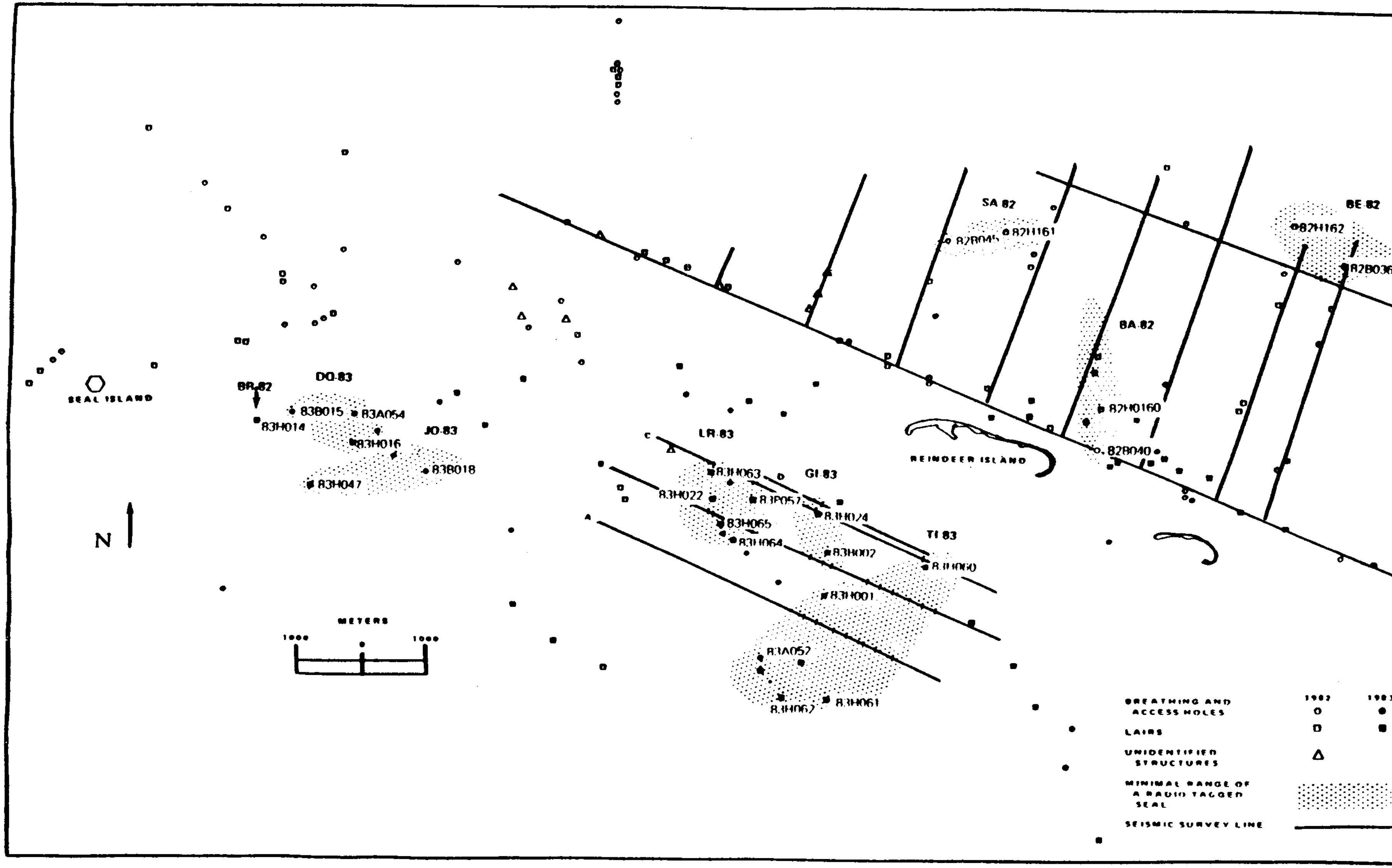

Figure 2.–Reindeer Island study area showing locations of seal structures found by trained dogs and seismic survey lines vibrated in 1982 (north of island) and 1983 (south of island).

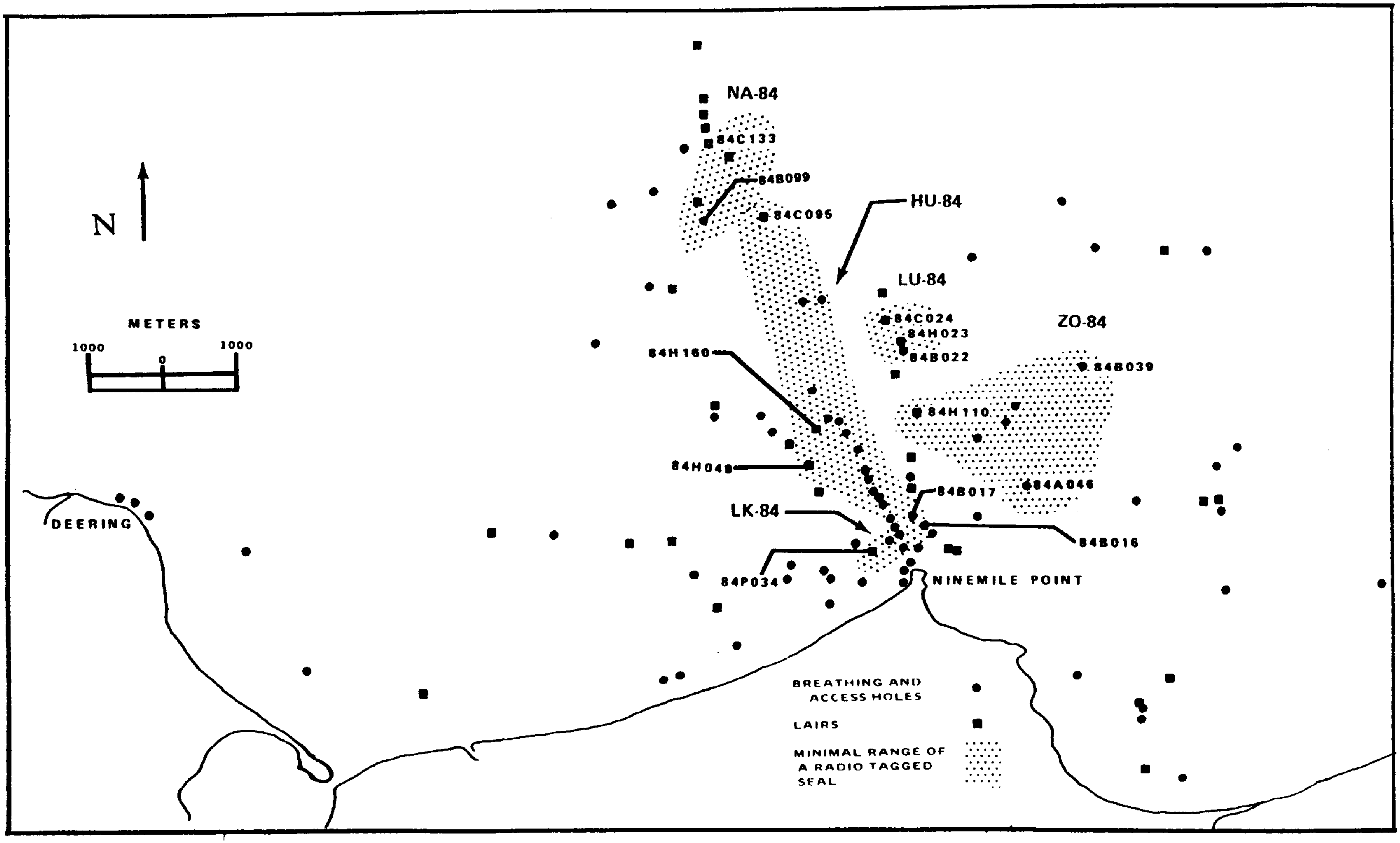

Figure 3.–Ninemile Point, Kotzebue Sound study area showing locations of seal structures found by trained dogs in 1984.

Seal Island (70°29.5'N, 148°41.6'W), which is a manmade gravel island (14 April - 30 May). In Kotzebue Sound, one camp on Ninemile Point (66°04.0'N, 162°27.5'W) was occupied from 2 March - 16 May 1984 (Figure 3). All camps, with the exception of Seal Island, used 5- by 5-m portable huts fitted with oil heaters. At Seal Island, we monitored from an oil-drilling camp operated by Shell Western E & P, Inc.

Field studies consisted of (1) locating and mapping subnivean seal structures, (2) radio tagging and monitoring the haulout behavior of seals, (3) monitoring the internal temperature of lairs, (4) testing the reactions of tagged seals to seismic exploration and other noise disturbances, and (5) monitoring the number of radio-tagged seals hauled out during visual aerial surveys in the early basking season.

Locating and Mapping Seal Structures

In 1982, the selection of areas to be searched for subnivean structures was dictated mainly by the distribution of seismic survey lines (Burns and Kelly 1982). In the next two years, we selected areas on the basis of ice and snow conditions that appeared most favorable for subnivean lairs.

A series of snow machine trails, ranging from 1.6 to 12.0 km in length, was established in each area to be searched. Subnivean structures on or near the trails were detected by a trained Labrador retriever. The retriever was directed to run ahead of a snow machine along these trails. When the dog detected seal odor, he/she would follow the scent to its source and indicate the location of the structure by digging in the snow above it. Whenever possible, the dog was run perpendicular to the wind direction to maximize the area of detection.

We probed each site with aluminum rods (1-cm diameter) and, in most instances, uncovered a part of the structure to examine and measure it. Structures that we excavated were carefully re-covered. Structures were classified as:

1) **breathing holes**, holes maintained in the ice by seals for obtaining air but not large enough to be used for emergence from the water.

2) **basking holes**, holes through which seals emerged from the water, but not within a lair.

3) **access holes**, holes through which seals emerged from the water into lairs.

4) **resting lairs**, single-chambered cavities excavated in the snow above a hole in the ice.

5) **complex lairs**, multichambered cavities excavated in the snow above a hole in the ice.

6) **pupping lairs**, lairs in which positive evidence of a pup's presence was found. Evidence included the actual presence of a live or dead pup, afterbirth and blood at a birth site, lanugo hair, and "pup tunnels" (tunnels too small to accommodate seals larger than pups).

7) **unidentified structures**, breathing holes or lairs not identified to specific type.

The location of each seal structure was mapped by triangulation using bearings to at least two landmarks of precisely known location. Each structure was assigned an identification number that was recorded with the date and time of discovery. Measurements of each structure included snow depth, percentage deformation of the ice within a 200-m radius, and the diameter of the hole maintained by the seal. At lairs, the length, width and depth of each chamber were measured as well. The height of ice deformities that produced the snow drift and the compass orientation of the drift also were recorded. Evidence of tigak odor, pupping, and signs of Arctic foxes or polar bears were noted. The condition of the hole in each structure gave an indication of how recently it had been used, since the ice must frequently be abraded from the hole to prevent it from freezing over. Generally, a hole will freeze over within one day if unattended. Not infrequently, lair access holes were found partially frozen, indicating that the seals were using them merely as breathing holes. The status of each structure was recorded as: (1) **open**, if it was maintained by a seal to maximal diameter; (2) **partially frozen**, if it was frozen such that less than the maximal diameter was open; (3) **frozen**, if the entire hole was refrozen; (4) **obstructed**, if the lair had an open or partially frozen hole but access to the lair was obstructed, for example by a collapsing ceiling. Each time a structure was examined, the nature and extent of the examination were noted.

The number of subnivean structures per unit area were calculated for the areas most intensively searched in 1983 and 1984, assuming that all structures were located. Although those areas were searched repeatedly and in a variety of wind conditions, the resulting estimates of density can only be considered minima.

Radio Tagging and Monitoring

Seals were snared at breathing holes, weighed, and their minimal age determined from counts of claw annuli. Alternating light and dark bands on the claws are laid down annually, and counting those bands provides an indication of age up to about the tenth year (McLaren 1958). After that, wear at the claw tip generally removes the earliest annuli. One or two of the most proximal annuli are covered by soft tissue and not visible in live seals with intact claws. We recorded ages as X+, where "X" is the number of annuli visible, and "+" indicates that the seal is older than "X" by at least one year.

The transmitters were glued (fast-curing epoxy) to the pelage of the dorsum in a manner similar to that described by Fedak *et al.* (1983). We chose an attachment site on the dorsum midway between the tail and the point of maximum girth, so the transmitters would not interfere with the seals' passage through holes in the ice. Also, because that area on the back is the last to shed hair in the annual molt (Fay *et al.* 1983; pers. obs.), the transmitter could be expected to stay attached until late June.

The transmitters were Model L2B5 manufactured by Telonics Inc., Mesa, Arizona. Each transmitter weighed approximately 100 g with dimensions of 50 by 35 by 25 mm. Transmitter frequencies were between 164.000 and 165.999 MHz, with pulse widths of 15 to 18 milli-sec and pulse rates of 75/min. After each transmitter was glued firmly in place, the seal was released at the breathing hole at which it had been captured.

The receiving system in 1982 was a Telonics TR-2 receiver, TS-1 scanner, and two-element Yagi antenna (4 dBd gain); in 1983 and 1984, five-element antennas (9 dBd gain) were used. Each site was equipped with two antennas, one horizontal and one vertical, mounted on rotating masts, 7-25 m above the ice.

Each deployed transmitter was monitored half-hourly in 1982 and hourly in 1983 and 1984. At each monitoring, the antennas were rotated through 360 degrees. Signals were receivable only when the transmitters were above the ice surface, thus indicating that the seals were out of the water. Signal reception varied with orientation of the transmitting and receiving antennas and with local ice deformities. Reception of the signals ranged from 3 to greater than 8 km. Whenever feasible, signals were ground-truthed to determine the location of lairs and basking sites. Ground-truthing was accomplished by skiing or walking around the signal source while monitoring the signal via a hand-held directional antenna. Generally, we were able to ski or walk within 200 m of an occupied lair without alarming the seal and causing it to dive from the lair.

In addition to the hourly monitoring, 458 hours of continuous monitoring were accomplished with a Telonics TDP-2 digital processor and a strip chart recorder in 1983. Up to five frequencies were monitored simultaneously, resulting in over 1,000 "seal hours" of continuous monitoring.

For the investigation of diel haulout patterns, local times were converted to "sun time," in which 1200 hours is defined as the time when the sun is at its greatest angle of inception (Stirling *et al.* 1982).

The seal-borne transmitters were also monitored during seven aerial surveys of basking ringed seals, between 29 May and 4 June 1982. Those surveys were flown in a Bell 204 helicopter at altitudes of 150 to 1100 m. Seal-borne transmitters were also monitored between 24 March and 13 May 1983 from altitudes of 300 to 1200 m during 22 helicopter flights. All surveys were conducted between 1000 and 1700 hours (local time), to coincide with periods of maximum numbers of seals on the ice (Burns and Harbo 1972; Smith 1973*b*). Most of the aerial monitoring was done on flights between Deadhorse, Reindeer Island, and Seal Island. Four flights (11 April, 4, 5, and 6 May 1983) were designed specifically to survey haulout sites outside the range of the monitoring camps. Those surveys were over the shorefast ice from Pingok Island (70°39.5'N, 149°30.0'W) to Narwhal Island (70°24.0'N, 147°30.0'W). The Seal Island camp was established when a lair of one of the radio-tagged seals was located by aircraft within reception range of that island but outside the range of Reindeer Island. In 1984, we monitored the seal-borne transmitters from the air whenever aircraft support was available. Aerial surveys of Kotzebue Sound south of Cape Blossom were flown on 21 and 29 March, 6 April, and 14, 15, 16, and 17 May. The aircraft used for those surveys were a Bell 204 helicopter, a Cessna 185, and a Cessna Super Cub. Survey altitudes generally were 900 m with portions of some as low as 125 m. All aircraft were fitted with a pair of Yagi antennas, one on each side.

Monitoring Lair Temperatures

Air temperature within lairs and ambient temperature were monitored with Telonics L2B5 transmitters fitted with thermistors. Temperatures were coded as pulse period (time between pulses) which was measured on a digital processor (Telonics, TDP-2). Accuracy was ±0.5°C.

The temperature sensor (50 by 35 mm) of each transmitting thermistor was inserted through a hole in the roof of the lair. The transmitter was suspended such that it protruded less than 10 mm below the inner surface of the lair, at the point of maximum height of the ceiling. The insertion hole was then sealed with snow and filled to the original roof thickness.

Ambient air temperature was measured in 1983 via a transmitting thermistor mounted 1 m above the lair. In 1984, ambient air temperature was measured via a telethermometer (Yellow Springs Instruments, 42SC), the sensor of which was mounted 1 m above the snow near the monitoring camp. Wind speeds were measured by hand-held anemometer, 2 m above the snow at the camp.

Temperatures were monitored at 1- to 2-hour intervals in 13 lairs for periods ranging from 1 to 8 weeks. When removing the thermistors, a thorough examination was made of the lairs to determine their status and the nature and extent of any recent seal activity.

Reactions of Seals to Noise Disturbances

A simulated seismic survey was conducted on the south side of Reindeer Island in 1983 in order to test the direct effects on the radio-tagged seals. Approximately 20 km of "shot-line" were surveyed by TRACOR and NOAA personnel on snow machine and on foot on 20 April 1983 (Figure 2).

The seismic survey convoy included a drill truck, a bulldozer, the vibrator truck (Vibroseis), and a fuel truck. The drill truck carried a power auger which bored holes through the ice, generally every 67 m along the survey lines, to test the ice thickness. The bulldozer, a D6 Caterpillar, leveled ice along the survey lines. Every 67 m, the Vibroseis vibrated the ice ten times in 16 second sweeps from 10 to 70 Hz. The fuel truck followed at the end of the convoy. Underwater sounds, airborne sounds, and vertical and horizontal vibrations produced by the convoy were measured by TRACOR at an abandoned lair site, a few meters north of line D (Figure 2).

Lines A and B were vibrated on 21 April, and lines C and D were vibrated on 22 April (Figure 2). Line A was vibrated a second time on 27 April. We were unable to monitor the frequencies of the radio-tagged seals during much of the seismic survey period because of radio interference from TRACOR's transmitting equipment.

Reactions of seals to human-made noises from other than seismic equipment were recorded whenever possible. While locating lair sites used by radio-tagged seals and conducting normal field activities, we recorded the responses of radio-tagged seals to the sounds of various human activities. When people and equipment approached lairs containing radio-tagged seals, the closest point of approach and the seal's response (departed or remained in lair) were noted.

RESULTS

Locating and Mapping Seal Structures

Clyde, the Labrador retriever trained in 1981, located most of the structures (breathing holes and lairs) in our 1982 effort. When he indicated the presence of seal odor, we almost always were able to verify that a seal structure or odor was present. Under optimal scenting conditions, he located seal structures from as far as 1,500 m.

Most searches in 1982 were conducted in the vicinity of Reindeer Island (Figure 2). From approximately 295 km of survey lines (including some repeats of the same lines), the dog located 157 seal structures, an average of 0.53 seal structures per kilometer searched. Search conditions varied widely, hence the effective transect width along each search line also varied and was not readily determined. The number of structures per linear kilometer searched thus is not convertible to structures per square kilometer but is only a crude index for comparative purposes. Of the 157 structures located, 72 were breathing holes (including 2 that were basking holes open to the surface when found), 73 were lairs, and 12 were not identified by type (Table 1).

Most of the seal structures investigated in 1983 and 1984 were located by Lil, a female Labrador retriever. In locations that she indicated the presence of seal odor, we consistently found seal structures. Under optimal scenting conditions, she detected seal structures from as far as 3,500 meters.

In 1983, approximately 81 km of survey lines were searched (some repeatedly) within 13 km of Reindeer Island (Figure 2). Twenty breathing holes, including five basking holes, and 37 lairs were located (Table 1). The average number of structures per linear kilometer searched was 0.70.

Table 1.–Percentages of ringed seal breathing holes and lairs found by trained dogs.

Structure type	Beaufort Sea 1982 (%)	Beaufort Sea 1983 (%)	Kotzebue Sound 1984 (%)
Breathing holes	50.0	35.0	69.0
Lairs	50.0	65.0	31.0
Pupping lairs[1]	12.3	5.4	8.2
Sample size	145	57	157

[1] Percentage of total number of lairs showing positive evidence of a pup's presence.

In 1984, a total of 173 km of trails were searched in three areas of Kotzebue Sound. Overall, those searches yielded 157 structures or 0.91/km (Table 1). Approximately 25 of the 173 km searched were near the shore of the Choris Peninsula, where only nine structures (0.36/km) were located. In the south-central part of the Sound, approximately 84 km of line were searched (a few repeatedly) and 115 structures (1.36/km) were located. About 64 km of trails were searched in northern Kotzebue Sound, within 30 km to the west and southwest of Cape Blossom, and these yielded 33 structures (0.51/km).

The number of breathing holes and lairs per square kilometer was estimated for areas where search efforts were most intensive in 1983 and 1984 (Table 2). In areas that were searched two or more times by the same dog, under optimal scenting conditions, we believe that virtually all seal holes were found.

Many of the breathing holes (13 out of 31) located in northern Kotzebue Sound between 18 and 21 March 1984 were either open basking holes or showed evidence of having recently been used as basking holes. In the southern part of the sound, only 6 of 77 breathing holes were open basking holes or showed evidence of recent use as basking holes. Two of those, as with the basking holes in the northern sound, were found during an unusually warm spell in the second week of March, when air temperatures varied from -1.5 to -15.0°C. Basking holes were not found after that time until air temperatures consistently remained above -10°C (starting on 7 May).

Only two of the structures that we located in northern Kotzebue Sound between 18 and 21 March were ringed seal lairs. Another ringed seal lair and a bearded seal lair were found by J. J. Burns (in litt.) in the same vicinity (66°41.1'N, 162°55.9'W) on 29 March. The bearded seal lair and one of the ringed seal lairs consisted of natural cavities in ice piles, rather than excavations in snow drifts.

Table 2.–Estimated densities of subnivean seal structures in two areas of repeated search efforts.

	Beaufort Sea (1983)	Southern Kotzebue Sound (1984)
Area of repeated searches (km^2)	42	27
Breathing holes/km^2	0.21	1.74
Lairs/km^2	0.60	0.74
Total structures/km^2	0.81	2.48

The relatively low ratio of lairs to breathing holes in Kotzebue Sound (Table 1) corresponded to an extremely low accumulation of snow, especially pronounced in the northern portion (Table 3). Snow depths at breathing holes in the northern sound were significantly lower than in the southern sound ($t_s = 1.76$, $p < 0.05$). The one active ringed seal lair we located in northern Kotzebue Sound was excavated in a snow drift 38 cm deep, barely deeper than the minimum internal height of lairs located in southern Kotzebue Sound. Snow depths in southern Kotzebue Sound were significantly lower than in the Beaufort Sea at both breathing holes ($t_s = 3.17$, $p < 0.0025$) and resting and complex lairs ($t_s = 5.03$, $p < 0.0005$). Only at pupping lairs were the snow depths equivalent for both study areas ($t_s = 0.11$).

Lairs occurred disproportionately more often in snow drifts on the leeward sides (relative to the prevailing wind direction) of ice deformities than on the windward side. Generally, both sides of deformities accumulate similar snow depths. In the Beaufort Sea study area, drifts predominately were oriented northeast and southwest as the result of prevailing northeasterly winds. In a sample of 30 lairs investigated there in 1983, 28 were in drifts on the southwest side and 2 on the northeast side of deformities ($X^2 = 11.87$, $p < 0.005$). In southern Kotzebue Sound, the winds were very consistently out of the west and virtually all snow drifts were oriented in an east-west direction. Of 33 lairs in southern Kotzebue Sound, 28 were on the east side, while 5 were on the west side of deformities ($X^2 = 16.04$, $p < 0.005$).

The relative proportions of open, frozen, partially frozen, and obstructed seal holes for each year of the study are given in Table 4. There were no significant differences in the proportions of open structures between 1982 and 1983 in the Beaufort Sea, but those proportions were significantly lower than in the 1984 sample from Kotzebue Sound ($Z = 2.05$, $p < 0.05$), indicating higher rates of abandonment of structures by seals in the Beaufort Sea study area.

We saw no evidence of polar bear (*Ursus maritimus*) predation on ringed seals in our study areas. Arctic foxes (*Alopex lagopus*) were not present in Kotzebue Sound but became increasingly common in the Beaufort Sea study area after the onset of the seal pupping season.

Table 3.–Snow depths (mm) at three types of seal structures.

Structure type		Beaufort Sea 1982	Beaufort Sea 1983	Kotzebue Sound North 1984	Kotzebue Sound South 1984
Breathing holes	$\bar{X}$	378	379	169	243
	S.D.	217	236	103	209
	Min.	0	50	20	0
	Max.	1160	700	320	1100
	N	66	7	29	41
Resting and complex lairs	$\bar{X}$	782	787	210	554
	S.D.	256	214	170	135
	Min.	290	450	40[1]	300
	Max.	1500	1300	380	850
	N	66	28	2	37
Pupping lairs	$\bar{X}$	962	610	–	945
	S.D.	171	–	–	386
	Min.	660	–	–	650
	Max.	1190	–	–	1600
	N	9	1	0	4

[1] Lair in ice cavity.

Table 4.–Percentages of ringed seal breathing holes and lair access holes that were fully open, partially frozen or obstructed, and completely frozen when found.

Condition of hole	Beaufort Sea 1982	Beaufort Sea 1983	Kotzebue Sound 1984
Open	81	77	88
Partially frozen or obstructed	7	21	7
Completely frozen	12	2	5
Sample size	145	57	157

Arctic foxes entered 14 of 73 lairs examined in 1982 and one of 37 lairs in 1983. Ringed seal pups were killed by Arctic foxes in three of nine pupping lairs in 1982 but at neither of two pupping lairs in 1983. Evidence of red foxes (*Vulpes vulpes*) and wolves (*Canis lupus*) was seen on the ice in Kotzebue Sound but with no signs of attempts to prey upon ringed seals.

Radio Tagging

Radio tags were placed on nine ringed seals in the Beaufort Sea and on five seals in Kotzebue Sound (Table 5). Capture sites and haulout sites located by radio tracking are shown in Figures 2 and 3. Two females, BA-82 and BE-82, and possibly one male, HU-84, were sexually immature; all others were sexually mature. Based on age, size, and haulout patterns, we surmised that SA-82 and LR-83 were lactating females with pups before and after they were tagged. That LR-83 was nursing a pup was confirmed by tracking her signal to a birth lair. The age and weight of LK-84 and LU-84 suggested that they were both pregnant when captured in early March. LK-84 was tracked to a pupping lair in which long and regular haulout bouts suggested that she was nursing a pup. Conversely, the haulout patterns of LU-84 indicated that she may have abandoned her pup before weaning.

Haulout Site Fidelity

Most of the radio-tagged seals were found to occupy more than one lair. The known number of lairs per seal ranged from 1 to 4 (mean = 2.85, S.D. = 2.51) and was based on variable numbers of attempts to ground-truth each seal's haulout locations. Those cases in which only one lair was found per seal corresponded to relatively few attempts to ground-truth the haulout locations. All structures known to be maintained by an individual seal were within 4.5 km of one another.

Table 5.–Ringed seals radio-tagged in the Beaufort Sea (1982 and 1983) and Kotzebue Sound (1984).

Seal no.	Sex	Age (yrs) indicated by claws	Weight (kg)	Date tagged	First signal received	Last signal received	Known minimum no. of lairs
BA-82	F	2	~46	4/17/82	4/19/82	6/04/82	2
SA-82	F	5	~68	4/22/82	4/23/82	6/03/82	1
BE-82	F	1	~40	4/25/82	4/26/82	6/04/82	1
TI-83	M	8	~135	3/22/83	4/09/83	6/02/83	3
GI-83	M	8	~110	3/23/83	3/24/83	4/26/83	2
DQ-83	M	8	68	3/30/83	4/11/83	5/19/83	2
BR-83	M	7	68	3/31/83	–	–	–
JO-83	M	8	73	3/31/83	4/23/83	5/20/83	1
LR-83	F	7	60	5/08/83	5/09/83	6/04/83	4
LK-84	F	5	77	3/04/84	3/07/84	5/11/84	3
LU-84	F	5	73	3/04/84	3/07/84	4/24/84	2
HU-84	M	5	68	3/05/84	3/06/84	4/19/84	3
ZO-84	M	7	72	3/13/84	3/15/84	5/14/84	1
NA-84	M	7	~77	3/26/84	3/27/84	5/15/84	2

However, only one (BA-82) of the three seals radio-tagged in 1982 was known to have used more than one lair. During 6 out of 45 recorded haulout bouts between 19 and 24 April, she was found in lair 82H160, 650 m north of her capture site, 82B040 (Figure 2). On the seventh attempt (5 May) to locate her, the signal seemed to come from a position more than two kilometers to the northwest of lair 82H160, but she left that position before it could be positively located.

Four of SA-82's 26 recorded haulout bouts were ground-truthed successfully between 30 April and 28 May. She was in lair 82H161, 900 m northeast of her capture site (82B045), each time (Figure 2). Thirty-six haulout bouts were recorded for BE-82, but we ground-truthed the signal only once, on 7 May, when she was located in lair 82H162, 1000 m northwest of 82B036, her capture site (Figure 2).

Radio signals from each seal tagged in 1982 were consistent in strength and direction during April and the first weeks of May. In the last week of May, however, signal reception from two of the seal transmitters (SA-82 and BE-82) became erratic at Reindeer Island. On 28 May 1982, strong signals from those transmitters were detected from a helicopter (457 m altitude) but not from the monitoring camp on Reindeer Island. The locations of SA-82 and BE-82 at that time were not determined precisely, but apparently, based on the changes in the received signal strength, both seals were hauled out in locations (lairs or basking sites) other than the ones previously detected. The decreased strength of signals received at Reindeer Island may have occurred because these new haulout locations were further away from the camp or in areas of rougher ice.

Radio signals were received from five of the six seals tagged in 1983. No signals were received from BR-83, the only seal not captured at a breathing hole or a partially frozen access hole. His capture site (83H014) was a hole above which an incipient lair, not yet large enough to hold a seal, was being excavated. At least four of the five seals from which signals were received utilized more than one lair (Figure 2).

TI-83, a very large (approximately 135 kg) male, smelling strongly of rut, was captured in the partially frozen access hole of a lair (83H001). We were unable to determine whether the lair had once been occupied by TI-83 or he only used it as a breathing hole. The access hole already was partially frozen when located by the dogs on 17 March.

Thirty-three haulout bouts by TI-83 were monitored and his haulout sites were ground-truthed 16 times between 16 April and 31 May. In that time, he used three lairs (83H060, 83H061, 83H062) and one basking site next to an uncovered basking hole, 83A052 (Figure 2). The greatest distance between any two of those haulout sites (83H060 and 83H062) was approximately 3 km; the closest two (83H062 and 83H061) were separated by about 1 km. The hole in which TI-83 was captured (83H001) was approximately midway between his northernmost and southernmost lairs.

TI-83 was located in 83H060 during seven ground-truthings between 19 April and 20 May and in 83H061 during six ground-truthings between 16 April and 23 May, suggesting that he used those two lairs about equally. He was first located in 83H062 on 26 May and again on 29 May. On 31 May he was seen basking on the ice in the vicinity of 83H062, next to a basking hole (83A052) in a refrozen lead.

GI-83, also an odiferous male, was captured and tagged at a breathing hole (83B002) and subsequently monitored during 25 haulout bouts. In at least five of seven attempts to ground-truth his signal between 26 March and 24 April, he was located in lair 83H024, approximately 600 m from his capture site (Figure 2). Results of an attempt to locate him on 24 March were ambiguous, but indicated that he was in either that same lair or another 600 m to the northwest. On 23 April, we received a weak signal from him from southwest of lair 83H024, but its source was not further defined. The last signal from GI-83 was received on 26 April from an undetermined location.

Lair 83H024 was opened and examined on 17 May. The single-chambered lair was excavated in a 55- to 65-cm deep snow drift on the southwestern side of a 0.55- to 1.0-m high ice hummock. The lair measured 2.04 by 1.05 m, with a maximum internal height of 47 cm. The access hole measured 53 by 37 cm and was located in a refrozen lead. The lair showed signs of recent occupation by a seal.

A third adult male, DQ-83, was captured at breathing hole 83B015 (Figure 2) on 30 March. He too had the tigak odor but less strongly than TI-83 or GI-83. We monitored 27 haulout bouts by DQ-83 and located his haulout site 11 times between 11 April and 18 May. On 11 April, DQ-83 was found in lair 83H016, a lair that had been located and investigated on 29 March. The lair was situated in an 85-cm deep snow drift on the southwestern side of a 1.5-m tall ice hummock. The single chamber measured 1.62 by 0.77 m with a maximum internal height of 32 cm. The access hole was situated in the northeastern end of the chamber and was 57 cm in diameter.

On 6 May, a signal from DQ-83 was traced to a lair 100-200 m north of 83H016, but the exact location of this northern lair was not determined. On 7 and 8 May, this seal was seen lying next to a basking hole (83A054) 500 m north of 83H016. He was again in lair 83H016 on 12 May. That location was determined not by ground-truthing but by the exact match between the time his signal was received and the time marked temperature changes were recorded by a thermistor in lair 83H016 (see Lair Temperatures). On 13, 14, and 15 May, DQ-83 was seen lying at basking hole 83A054. On 16 May, his haulout signal again coincided exactly with a marked temperature increase and subsequent decrease within lair 83H016, indicating that he hauled out there. He again lay at basking hole 83A054 on 17 and 18 May. Poor visibility prevented our locating him on 19 May, the last day his radio signal was received. A seal, possibly DQ-83 without his transmitter, was seen at basking hole 83A054 on 21, 26, and 27 May.

Temperature changes characteristic of a haulout bout occurred only in lair 83H016 when signals were simultaneously received from DQ-83, suggesting that no other seal used the site during the study period.

JO-83, an adult male also with a strong tigak odor, was captured and tagged at breathing hole 83B018 and monitored during 12 subsequent haulout bouts. On two attempts to locate his haulout site, on 7 and 18 May, he occupied lair 83H047 (Figure 2). That lair was opened on 30 May and found to be 1.92 by 0.86 m, with the access hole near the center of the long axis. Access to one side of the lair was blocked, however, by a wall of splash ice that extended from floor to ceiling along half of the perimeter of the access hole, which measured 38 cm in diameter. The lair thus was divided into a 0.85-m long accessible chamber and a 1.07-m long inaccessible chamber. The maximum internal heights of the two chambers were 43 and 52 cm, respectively. The lair was in a 0.77-m deep snow drift on the southwestern side of a 1.0-m tall ice hummock.

An adult female seal, LR-83, was captured and radio-tagged on 8 May at obstructed lair 83H022 and subsequently monitored during 20 haulout bouts. Dilation and reddening of the vulva suggested that she was at or near estrus. In five ground-truthing sessions, we tracked her to four different lairs, all within a 750-m radius of her capture site (Figure 2). On 9 May, she was located in lair 83H063, approximately 370 m northeast of 83H022. She was found in lair 83H064, approximately 700 m southwest of 83H022, on 23 May. Lair 83H065, approximately 400 m southeast of 83H022, was her haulout site on 27 and 28 May. She was located about 600 m east of 83H022 on 4 June, when we uncovered a melting complex lair (83P057), one chamber of which had a bloodstained floor, indicative of a birth site. Two chambers, 3.83 m and 1.80 m in length, formed a right angle with the access hole at the intersection. The lair was situated on the southwest side of a 1.0-m high ice ridge. The snow drift measured 0.61 m deep, but much melting had already taken place, and the access hole was draining a rapid flow of melt water.

Four of the five seals radio-tagged in Kotzebue Sound in 1984 were tracked to more than one lair. LK-84, a female caring for a pup, was ground-truthed 13 times during 69 recorded haulout bouts. Her signal was tracked 11 times to 84P034, a small, single-chambered lair that had a frozen access hole when first located by the dogs on 9 March. That lair was 900 m southwest of the hole (84B016) in which she had been captured. She was tracked to lair 84P034 on 25, 26, 27, and 31 March and on 1, 2, 3, 4, 8, 10, and 11 April. An attempt to locate a weak and erratic signal from her on 9 April indicated that she was hauled out in a different lair, but we could not locate the site, despite searching an area in excess of 65 km^2.

On 12 April, we opened her lair (84P034) a second time and found that its access hole was clear of ice, and that the lair had been expanded into two chambers, 2.01 m and 4.30 m long. We inserted a transmitting thermistor and a highly sensitive transmitting microphone into the lair. Neither instrument detected activity at the lair until 17 April, when splashing, scratching of ice, and seal vocalizations were transmitted via the microphone. Early on 18 April, similar sounds were heard from the lair, and later that day, a signal from LK-84 was traced to the immediate vicinity of that lair. Nonetheless, neither the thermistor nor the microphone indicated the presence of a seal in lair 84P034. Although LK-84 must have been in another lair within a few meters of 84P034, our attempts with a dog to locate that other lair were unsuccessful.

On 25 April, we again opened lair 84P034 and discovered that its entire depth (30 to 40 cm) had been flooded with sea water. Only a small area at one end of a chamber, including a pup tunnel, was not submerged. The water had seeped up through a crack in the ice and submerged the lair chambers, apparently because the ice along the crack had subsided under the weight of the snow drift. That drift, on the east side of a 3.5-m high ice hummock, measured 0.85 m deep on 9 March, 1.20 m on 4 April, and 1.60 m on 25 April.

LU-84, also an adult female, was captured at 84B022 and monitored during 15 haulout bouts between 7 March and 24 April 1984. She was successfully traced to lairs in seven of nine attempts. On 7 March she was traced to a large and complex lair (84C024), 450 m north of breathing hole 84B022 where she had been captured (Figure 3). She was traced to single-chambered lair 84H023 on 25, 26, and 31 March, as well as on 11, 16, and 18 April. Both lairs were in snow drifts on the eastern side of the same 1.0- to 1.5-m high ice ridge and were approximately 300 m apart. LU-84's transmitter signal was last received on 24 April, but a thermistor and microphone in lair 84H023 indicated that it was still utilized by her or some other seal(s) after that date. Sounds of a seal breathing, splashing, and scratching the ice (but apparently not hauling out) were heard from that lair from 27 April to 3 May, at which time the microphone was removed. Subsequently, the thermistor registered temperature changes indicative of haulout bouts in that lair on 9 and 13 May.

Lair 84C024 was opened and examined on 8 and 20 March and on 15 May. The access hole was fully open each time and the lair appeared to be in continuing use except on the final visit when a low roof over the hole indicated that a seal had not hauled out recently. A thermistor in the lair from 8 March to 15 May, however, indicated no haulout bouts. The lair consisted of three chambers, the longest of which exceeded 3.00 m. Its access hole was over 50 cm in diameter. Maximum snow depth over the lair was 65 cm and the snow roof generally measured 40 cm thick.

Lair 84H023 was examined four times. On 29 February, it was opened and found to have a partially frozen access hole. On 26 March, the access hole was fully open and measured 62 cm in diameter. The greatest length of the lair was 1.98 m; its depth was 55 cm and the roof thickness was 15 cm. At that time, a thermistor and microphone were placed in the lair. The access hole was slightly smaller in diameter when examined on 15 May, and a small build-up of ice around its rim confirmed that a seal had used it for a breathing hole but not recently for a haulout.

HU-84, a small male without the tigak odor, was captured and tagged on 5 March and was monitored during 17 haulout bouts between 6 March and 19 April. His haulout site was located successfully six times between 8 March and 26 March. On 8 March he was found in a lair (84H160) approximately 1.75 km northwest of the breathing hole (84B017) at which he was captured (Figure 3). He hauled out in another lair (84H049), 500 m south of that first lair, on 10 March. His signal was traced to a large, complex lair (84C095), 4.5 km north-northwest of his capture site on 12, 17, 21, and 26 March. Furthermore, a transmitting thermistor placed in lair 84C095 on 22 March confirmed that each of HU-84's haulout bouts recorded (by radio-transmitter) after that date were inside that lair. Those haulout bouts were recorded on 26 March, 1, 3, 7, 13-14, 14-15, and 18-19 April. The thermistor additionally indicated six haulout bouts when no signals were received from HU-84; 24-25 March, 11, 23-24, 27-28 April, 30 April-1 May, and 4 May (Figures 32-39), indicating that at least one other seal occasionally occupied the same lair.

Two of HU-84's lairs were opened and examined. Lair 84H049 was in a 0.62-m deep snow drift on the west side of an ice hummock that was less than 1.0 m in height. On 14 March the access hole of that lair was fully open to an 82-cm diameter and the lair was measured at 1.28 m long and 43 cm deep. The roof of the lair consisted of 7 cm of hard, metamorphosed snow. The access hole was partially frozen and, apparently, only used as a breathing hole through 24 April. The odor of a rutting male was detected at the hole on 23 and 24 April. On 25 April, the access hole was completely frozen, but it was fully open again on 11 May with signs of a recent haulout. A small opening had been scratched through the roof from the inside.

Lair 84C095 (Figure 3) was first examined on 22 March. It consisted of two chambers at right angles to one another, 1.56 and 1.92 m in length. The smaller chamber was in a snow drift on the east side of a 1.5-m tall ice hummock, the larger one was in snow that had drifted under a 20-cm thick slab of ice. The maximum internal height of the lair was 37 cm. The lair was examined again on 15 May and showed evidence of recent occupation, including large clumps of molted, adult hair and stratum corneum.

A rutting male, ZO-84, was captured and tagged on 13 March and monitored during 10 haulout bouts from 15 March to 14 May. His haulout sites were located during five haulout bouts between 3 and 18 April. On 3 and 9 April, he was located in a lair (84H110) approximately 2.3 km west-southwest of breathing hole 84B039, his capture site (Figure 3). That lair was not present in early March and, therefore, must have been excavated in late March or the first days of April. On 15, 17, and 18 April, he was seen lying next to an open basking hole (84A046), approximately 1.8 km south-southwest of his capture site. On 27 April, he hauled out at an undetermined site but not at 84A046 where another seal was basking. There were no further signals received from him at the monitoring camp, but a haulout bout beyond the range of the camp was detected from a helicopter (915-m altitude) on 14 May. The actual location of that haulout was not determined. A seal other than ZO-84 was seen basking next to the hole where ZO-84 had been captured (84B039) on 12, 13, 15, and 16 May.

Lair 84H110 was situated in a snow drift on the east side of a 0.50-m high ice ridge and approximately 80 m west of another resting lair (Figure 3). On 4 April, the snow drift was 45 cm deep, while the internal height of the lair was 42 cm, leaving a roof thickness of only 3 cm. The access hole was fully open. When the lair was next examined on 26 April, both ends of it had been expanded, giving a total length of 1.73 m. The access hole remained fully open and measured 60 cm in diameter. The lair depth was 45 cm, and the snow drift had deepened to 56 cm, but much of the ceiling remained as thin as 15 mm. On 15 May, the access hole remained open, but the roof of the lair had collapsed to a few centimeters above the floor, indicating that the lair was no longer used as a haulout site.

NA-84, a mature male with no detectable tigak odor, was captured and tagged on 26 March and monitored during 21 haulout bouts. On 17 and 19 April, he was traced to a complex lair approximately 1.0 km north of his capture site (84B099). That lair (84C133) was opened on 23 April and again on 5 May, and both times the access hole was found to be partially frozen to a diameter too small for a seal to transit. Thus, a haulout bout by NA-84 on 24 April probably was in some other lair. The last radio signal received from him was on 15 May, during a helicopter survey, but that signal was not detectable from the Ninemile Point camp. This suggests that NA-84 may have had yet another lair, out of range of the camp.

Lair 84C133 was complex and peculiar in having two access holes, one of which was frozen and the other partially frozen when we investigated it. The lair was located in snow filling a large crack in the ice and it consisted of two parallel chambers 1.22 m and 1.69 m long, each with its own access hole. The chambers appeared to have been excavated originally as separate lairs that were later joined by excavating a short tunnel between them. The maximum internal heights of the chambers were 32 and 35 cm, each with a snow roof thickness of 15 cm.

Structures (breathing holes, basking holes, and lairs) used by individual female seals generally were much closer together than were structures used by individual males. The distances between structures used by an individual female ranged from 125 to 1100 m, while distances between structures used by an individual male ranged from 450 to 4438 m. The mean distance between structures used by individuals was 638 m for females and 1738 m for males. The difference was highly significant ($t_s = 5.25$, $p < 0.0001$).

Frequency and Duration of Haulout Bouts

The radio-tagged seals were out of the water from 3.5 to 30.8% of the time (Table 6). Three seals began hauling out outside of lairs (basking) before we ceased monitoring. Each of those seals showed slight increases in the percentage of time hauled out after the onset of the basking period, but the differences were not significant ($p > 0.05$). Greater differences might have been observed if we had monitored haulouts later in the basking period. The length of haulout bouts varied from less than 1 to 20 hours, with a mean bout length of 5.4 hours (Table 7).

Periods when radio signals were not received from the tagged seals ranged from less than one hour to over 160 hours (mean = 18.9). The absence of signals indicated that the seals were either in the water or out of range of the monitoring camps. Monitoring from aircraft, we found no evidence of radio-tagged seals hauling out beyond radio range of the camp during the main study periods. Exceptions occurred during the last days of the study periods in 1982 and 1984 when some signals were detected beyond the range of the monitoring camps. Data from those periods were excluded for comparisons of "in-water periods." The lengths of those in-water periods for seals in the Beaufort Sea were very similar in 1982 and 1983; the in-water periods for seals in Kotzebue Sound, however, tended to be considerably longer (Table 8).

Sampling bias may account for some of the disparity in percentages of time that different seals spent out of the water. In each of the three years of the study, the seals that were most frequently recorded as hauled-out (SA-82, GI-83, and LK-84) were those whose known lair sites were closest to the monitoring camps (Table 6). This suggested that the low percentages of out-of-water time recorded for some of the other seals may have been due to their occasional occupation of lairs beyond radio range of our camps. A slight negative correlation ($r = -0.30$) between percentage of time hauled out and distance to farthest known lair site, however, was not significantly different from $r = 0$.

Monthly increases in the percentage of time seals hauled out were observed in 11 out of 16 cases (Table 9). For many individuals, the number of monitoring periods sampled was quite small and it was necessary to combine data to test the significance of monthly changes. Combining data from all seals (Table 9), the percentage of time hauled out more than doubled from March to June ($X^2 = 85.0$, $p < .005$). Deviations in that pattern were evident in the cases of SA-82, BE-82, GI-83, HU-84, and LK-84.

Based on a large number of monitoring periods, HU-84 showed a decrease in the proportion of time out of water between March and April. Furthermore, the number of

Table 6.–Percentages of monitoring periods in which radio-tagged ringed seals were out of the water and the distances from the monitoring camps to the farthest known lair of each seal.

Seal no.	Percentage time out of water[1]		Number of monitoring periods	Distance between camp and farthest known lair (km)
	Pre-basking	Basking		
BA-82	21.6	–	1,104	3.0
SA-82	29.2	–	914	0.8
BE-82	20.7	–	917	4.0
TI-83	16.6	17.8	1,499	4.5
GI-83	30.8	–	504	2.2
DQ-83	26.2	28.6	946	3.9
JO-83	9.7	–	958	3.6
LR-83	15.7	–	752	3.3
LK-84	19.9	–	1,546	0.7
LU-84	8.7	–	1,142	3.5
HU-84	17.9	–	1,023	5.4
ZO-84	3.5	6.6	1,026	2.2
NA-84	12.9	–	641	6.0

[1] Time out of water is shown for the "pre-basking" period when seals hauled out only in lairs and the "basking" period when seals hauled out in the open as well as in lairs. The basking period began on 31 May for TI-83, 7 May for DQ-83, and on 15 April for ZO-84.

Table 7.–Duration of haulout bouts of radio-tagged ringed seals.

Seal no.	Length of haulout bouts (hours)				
	Mean	S.D.	Minimum	Maximum	N
BA-82	3.22	3.78	0.33	14.00	34
SA-82	9.70	5.99	0.50	18.50	12
BE-82	4.34	4.19	0.50	15.00	19
TI-83	4.87	3.21	0.25	12.00	25
GI-83	5.21	5.99	0.50	19.52	9
DQ-83	6.91	4.10	0.33	16.72	20
JO-83	4.03	2.91	0.50	7.83	11
LR-83	3.24	3.09	0.75	11.00	14
LK-84	4.12	4.15	0.50	17.00	68
LU-84	6.03	2.87	0.77	9.00	13
HU-84	10.24	4.69	2.50	20.00	16
ZO-84	4.61	3.11	1.32	11.00	9
NA-84	3.76	2.16	0.50	8.00	19

Table 8.–Length of periods when radio-tagged ringed seals were believed to be in the water between haulout bouts. Data from late spring, when some radio-tagged seals were known to haul out beyond range of the camps, were excluded.

Seal no.	Time in the water (hours)				
	Mean	S.D.	Minimum	Maximum	N
BA-82	8.20	9.95	0.42	43.50	32
SA-82	18.14	13.28	2.50	39.00	10
BE-82	14.41	13.99	0.50	44.50	16
TI-83	8.51	9.16	0.50	36.00	22
GI-83	5.90	4.51	0.57	14.65	9
DQ-83	16.22	11.93	2.17	42.70	20
JO-83	22.38	21.76	1.92	71.42	9
LR-83	11.99	7.33	2.00	27.50	15
LK-84	13.69	25.98	0.65	156.50	70
LU-84	39.45	47.48	3.00	160.50	15
HU-84	32.85	34.54	3.83	123.33	16
ZO-84	30.00	26.48	1.50	81.00	8
NA-84	23.51	29.65	2.00	134.00	21

Table 9.–Monthly percentages of monitoring periods when radio-tagged ringed seals were out of the water.

Seal	March		April		May		June	
	% Out	N	% Out	N	% Out	N	% Out	N
BA-82	–	–	16.5	200	22.7	904	–	–
SA-82	–	–	61.8	34	28.0	880	–	–
BE-82	–	–	61.3	31	19.3	715	–	–
TI-83	0	12	14.5	539	19.2	770	41.0	61
GI-83	75.0	20	28.3	495	–	–	–	–
DQ-83	–	–	26.3	297	27.2	649	–	–
JO-83	–	–	9.5	294	9.8	664	–	–
LR-83	–	–	–	–	15.9	573	20.8	130
LK-84	11.5	616	30.4	677	11.9	253	–	–
LU-84	8.3	617	9.1	525	–	–	–	–
HU-84	19.4	612	5.6	411	–	–	–	–
ZO-84	1.9	429	6.2	597	–	–	–	–
NA-84	11.8	119	13.2	522	–	–	–	–
Combined	11.5	2425	17.8	4622	20.4	5579	27.2	191

consecutive days on which he did not haul out increased from a mean of 0.43 in March to 2.00 in April ($t_s = 2.897$, $p < 0.05$). No signals were received from HU-84 after 19 April. As noted earlier, at least one other seal began hauling out in HU-84's primary lair (84C094) on 24 March and did so increasingly throughout April and into May.

LK-84 spent almost three times as much time hauled out in April as in March or May ($X^2 = 66.32$, $p < 0.005$). We believe that she was nursing a pup during late March and most of April and, as a consequence, spent almost a third of that period in a lair. She hauled out for part of every day from 24 March to 23 April, with the possible exceptions of 6 and 7 April when monitoring was incomplete due to strong winds (45 to 50 km/hour). She did not haul out on 24 or 25 April, and on the evening of 25 April, we found her primary lair (84P034) to be flooded and abandoned.

LU-84 also was believed to be pregnant when radio-tagged in early March. Like LK-84, she hauled out at least once every day, beginning on 24 March, but that ended abruptly after 31 March. In the first ten days of April, no signals were received from her transmitter, and from 11 April to 24 April, the date of her last recorded haulout bout, she was recorded as out of the water on an average of every third day. If she was nursing a pup in late March, she must have lost or abandoned it early in April.

Two other females were believed to be lactating when they were radio-tagged in late April (SA-82) and early May (LR-83). SA-82 was recorded as out of the water more than twice as often in April as in May, but the number of monitoring periods sampled in April was small.

The overall trend of increase, from March to June, in time seals spent out of the water may be attributed in part to a tendency toward longer haulout bouts (Table 10). However, increases in haulout bout lengths mostly were slight for individual seals, and none was statistically significant (t-tests). Conceivably, some of this apparent increase in duration could have been due to more frequent haulouts, which should have been evident in decreased length of periods in the water between haulout bouts. The high variances observed for the latter, however, do not indicate such an effect (Tables 8 and 11).

Haulout behavior relative to the 24-hour cycle was investigated by continuous monitoring (Table 12). Continuous monitoring was defined as listening for the seal's transmitter signal hourly or at least once every 2 hours throughout the 24-hour period. On average, the seals spent one-fourth or less of each 24-hour period hauled out. The lone exception was GI-83, whose daily mean (11.5 hours) was calculated from only 5 days of continuous monitoring within 1 week.

In 1984, sample sizes were sufficient to permit monthly comparisons of the amount of time that the seals spent out of the water within the 24-hour period. Only LK-84 showed significant monthly changes in that parameter. In April her mean time hauled out per 24-hour period was 7.06 hours versus 2.58 hours in March ($t_s = 3.356$, $p < 0.01$) and 1.89 hours in May ($t_s = 2.551$, $p < 0.05$).

Table 10.–Duration of haulouts of twelve radio-tagged ringed seals in March, April, and May.

Seal no.	Durations of haulouts (hours)								
	March			April			May		
	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
BA-82	–	–	–	2.7	3.7	18	3.8	3.9	16
SA-82	–	–	–	11.9	7.4	4	8.6	5.4	8
BE-82	–	–	–	2.4	2.1	7	5.6	4.9	11
TI-83	–	–	–	4.1	1.8	9	5.3	3.8	16
GI-83	–	–	–	5.2	6.0	9	–	–	–
DQ-83	–	–	–	6.3	3.3	8	7.2	4.6	12
JO-83	–	–	–	3.4	2.9	4	4.4	3.1	7
LK-84	3.8	4.1	19	4.1	3.9	46	6.3	9.2	3
LU-84	6.3	2.8	8	5.6	3.2	5	–	–	–
HU-84	10.2	5.4	11	10.4	3.2	5	–	–	–
ZO-84	8.0	0	1	4.2	3.0	8	–	–	–
NA-84	4.7	1.2	3	3.6	2.2	16	–	–	–

In contrast to the three males, females LK-84 and LU-84 went through extended periods in which they hauled out for part of every day. We think that these were nursing periods. For LK-84 that period extended from 24 March to 23 April and for LU-84 it was from 24 March to 31 March. The mean haulout time for both seals within the 24-hour cycle during those assumed nursing periods was significantly longer than during the periods before and after (Table 13).

Figures 4 through 16 show the percentage of monitoring periods per hour in which a radio signal was received from each seal during the 24-hour cycle. In effect, therefore, each figure shows the percentage of time per hour during which the seal was hauled out. Various periods from early March to early June were sampled, depending on the dates each seal was radio-tagged and when their last signals were received (Table 5).

Overall, there was a trend toward nocturnal or arrhythmic haulouts until early to mid-May when the trend shifted to midday haulouts. Four seals (BA-82, SA-82, BE-82, and TI-83) were monitored for sufficient lengths of time before and after 11 May to permit comparisons

Table 11.–Length of time when radio-tagged seals were believed to have remained in the water between haulout bouts in March, April, and May. Data from late spring, when some radio-tagged seals were known to haul out beyond range of the camps, were excluded.

	Time between haulout bouts (hours)								
	March			April			May		
Seal no.	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
BA-82	–	–	–	32.4	7.5	3	12.7	10.8	6
SA-82	–	–	–	7.0	8.9	17	9.9	11.5	14
BE-82	–	–	–	25.2	15.5	5	9.5	10.6	11
TI-83	–	–	–	5.9	7.4	8	10.0	10.0	14
GI-83	–	–	–	5.9	4.5	9	–	–	–
DQ-83	–	–	–	12.3	11.1	5	16.0	11.2	14
JO-83	–	–	–	13.9	15.6	4	29.2	25.2	5
LR-83	–	–	–	–	–	–	12.0	7.3	15
LK-84	24.8	38.4	19	6.8	5.2	47	33.0	9.9	2
LU-84	36.8	48.0	9	43.4	50.9	6	–	–	–
HU-84	36.8	26.1	10	6.9	3.5	5	–	–	–
ZO-84	–	–	–	30.0	26.5	8	–	–	–
NA-84	3.5	2.1	2	19.6	15.9	18	–	–	–

Table 12.–Number of hours spent hauled out per 24-hour cycle by radio-tagged ringed seals.

Seal no.	Hours of haulout / 24-hour cycle					Sampling period
	Mean	S.D.	Min.	Max.	N	
BA-82	4.9	4.1	0	13.5	19	4/22 - 5/26
SA-82	6.3	4.8	0	15.0	17	5/01 - 5/26
BE-82	5.3	5.1	0	14.5	17	5/01 - 5/26
TI-83	3.6	3.6	0	11.0	14	4/18 - 6/05
GI-83	11.5	8.4	0	21.5	5	4/13 - 4/26
DQ-83	6.2	4.7	0	16.0	19	4/18 - 5/19
JO-83	1.7	2.8	0	8.0	21	4/18 - 5/20
LR-83	4.0	3.6	0	8.0	7	5/11 - 6/05
LK-84	4.4	6.8	0	16.0	57	3/06 - 5/09
LU-84	1.7	3.0	0	12.0	43	3/06 - 4/23
HU-84	4.2	5.2	0	17.0	39	3/06 - 4/19
ZO-84	0.8	1.5	0	5.0	39	3/14 - 4/27
NA-84	2.2	2.2	0	8.0	24	3/27 - 4/23

Table 13.–Hours spent hauled out per 24-hour cycle by two female ringed seals before, during, and after periods of daily haulouts.

Seal no.		Period: Pre-daily haulouts	Daily haulouts[1]	Post-daily haulouts
LK-84	Mean	0.3	8.4	1.2
	S.D.	0.3	17.6	16.9
	Min.	0.0	1.0	0.0
	Max.	2.0	16.0	16.0
	N	16	27	14
		$t_s = 7.62$ ($p < 0.001$)		$t_s = 5.24$ ($p < 0.001$)
LU-84	Mean	0.8	4.2	1.4
	S.D.	7.1	4.2	8.6
	Min.	0.0	1.5	0.0
	Max.	11.0	8.0	12.0
	N	16	8	19
		$t_s = 3.19$ ($p < 0.01$)		$t_s = 2.45$ ($p < 0.01$)

[1] Period of daily haulouts included 24 March to 23 April for LK-84 and 24 to 31 March for LU-84.

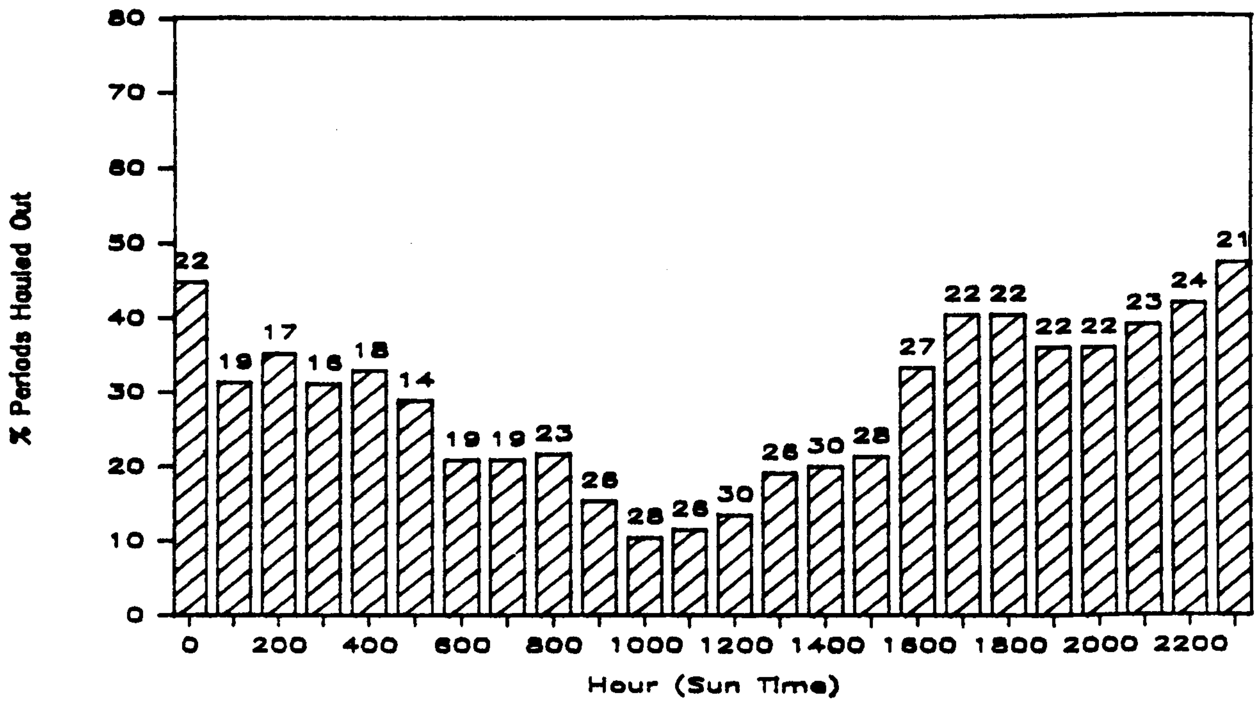

Figure 4a.–Diel haulout of radio-tagged seal SA-82 from 23 April to 11 May 1982. The number of times each hour was sampled is given above the percentage bar.

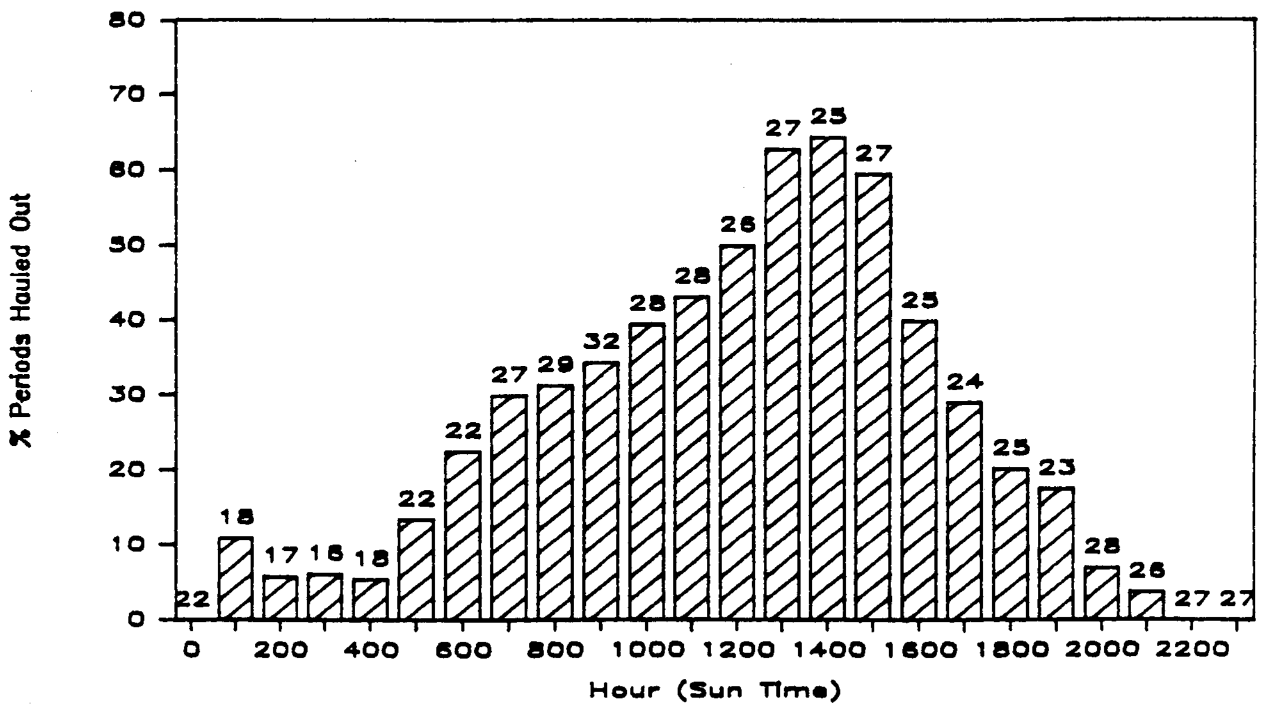

Figure 4b.–Diel haulout of radio-tagged seal SA-82 from 12 May to 3 June 1982. The number of times each hour was sampled is given above the percentage bar.

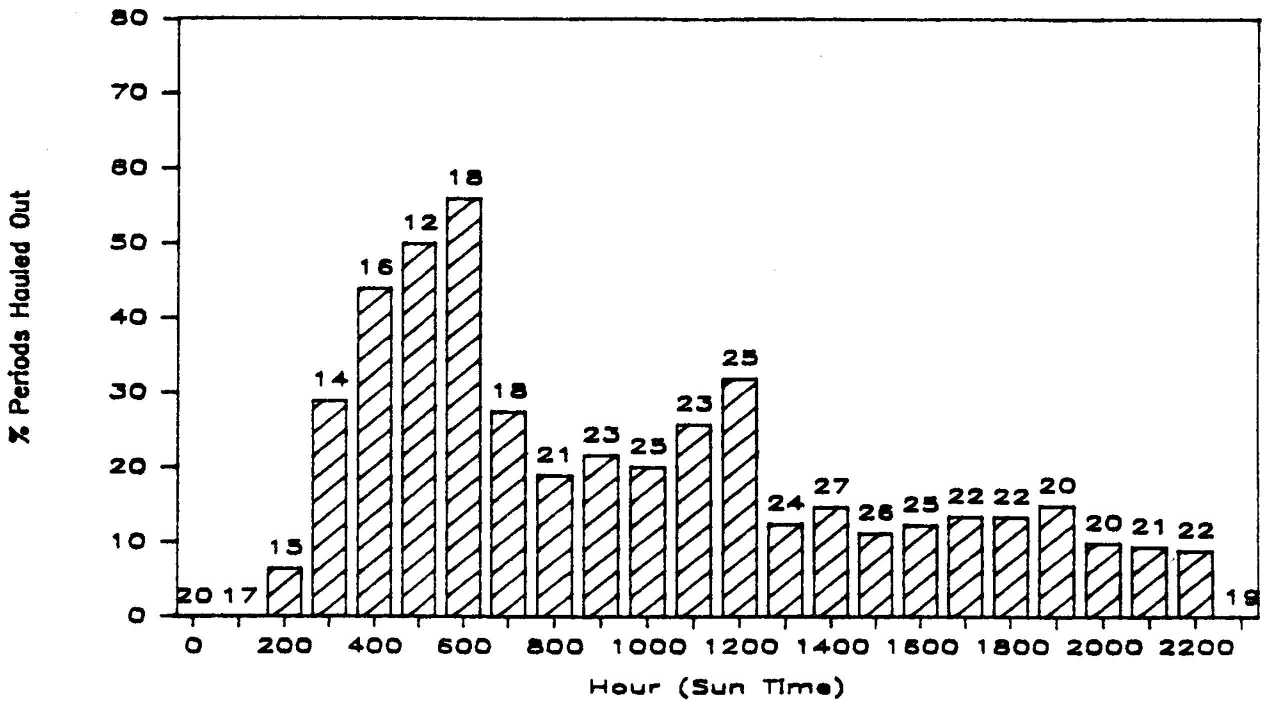

Figure 5a.–Diel haulout of radio-tagged seal BE-82 from 26 April to 11 May 1982. The number of times each hour was sampled is given above the percentage bar.

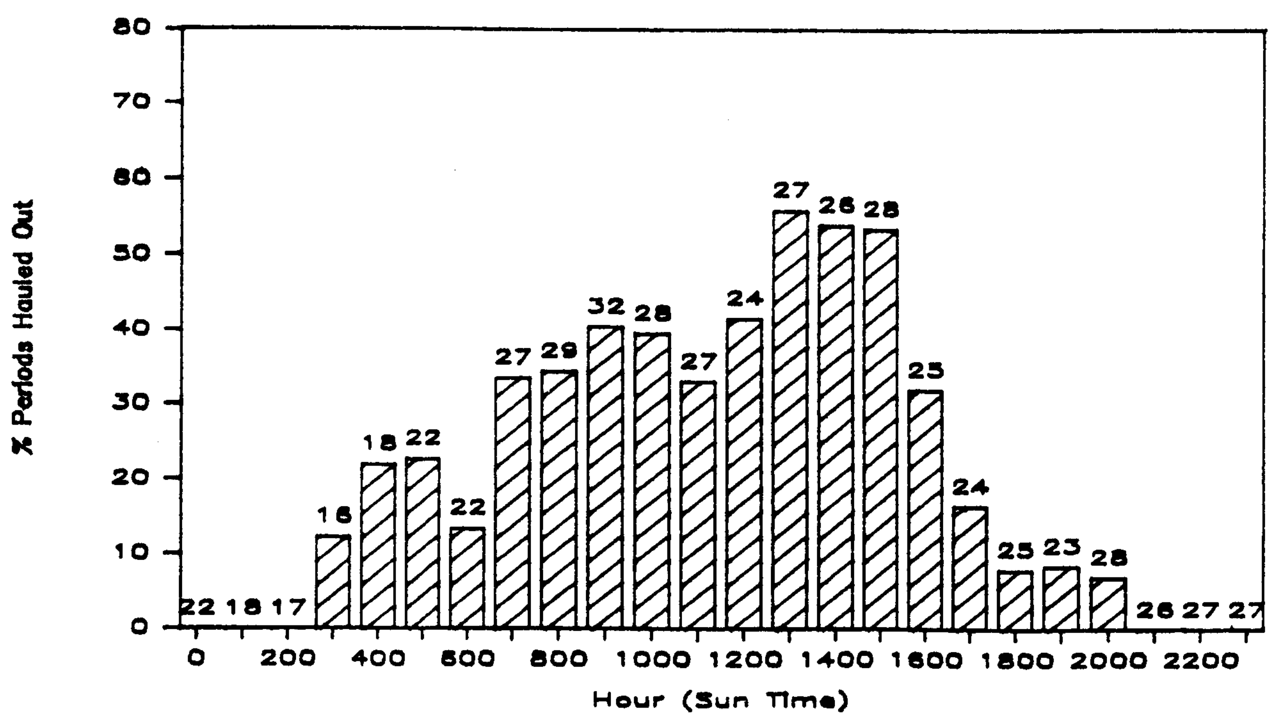

Figure 5b.–Diel haulout of radio-tagged seal BE-82 from 12 May to 4 June 1982. The number of times each hour was sampled is given above the percentage bar.

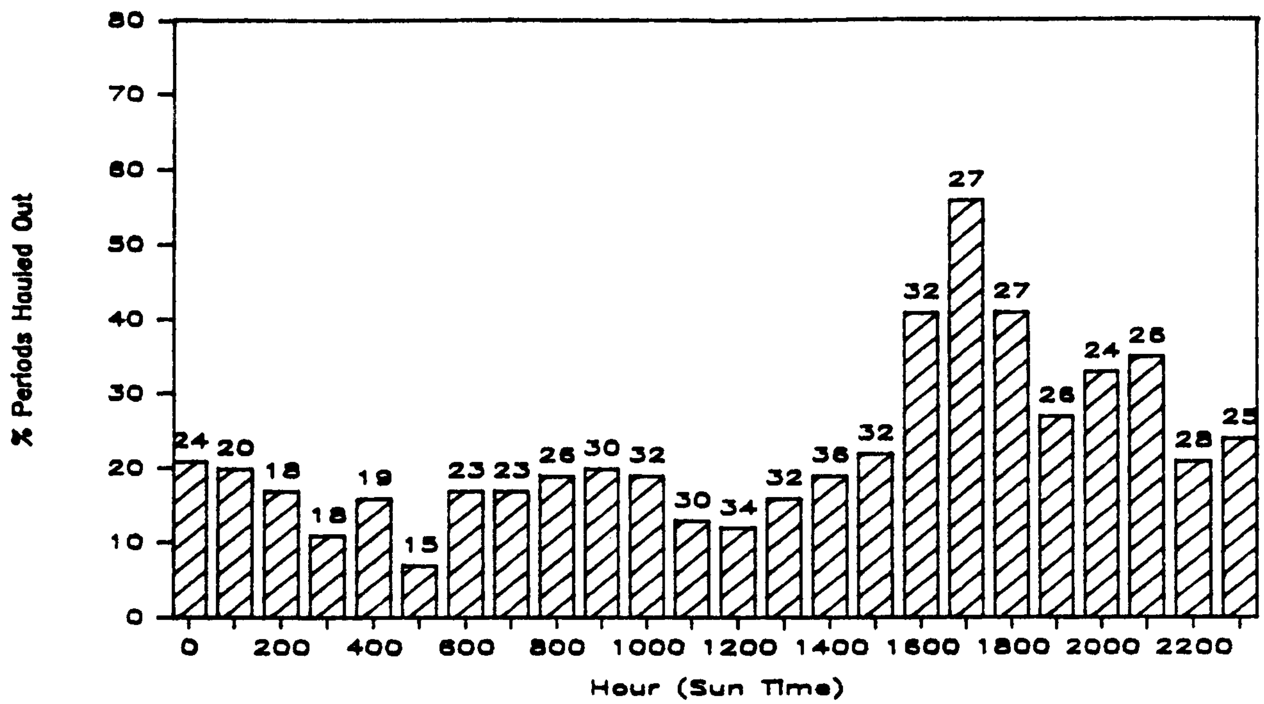

Figure 6a.–Diel haulout of radio-tagged seal BA-82 from 19 April to 11 May 1982. The number of times each hour was sampled is given above the percentage bar.

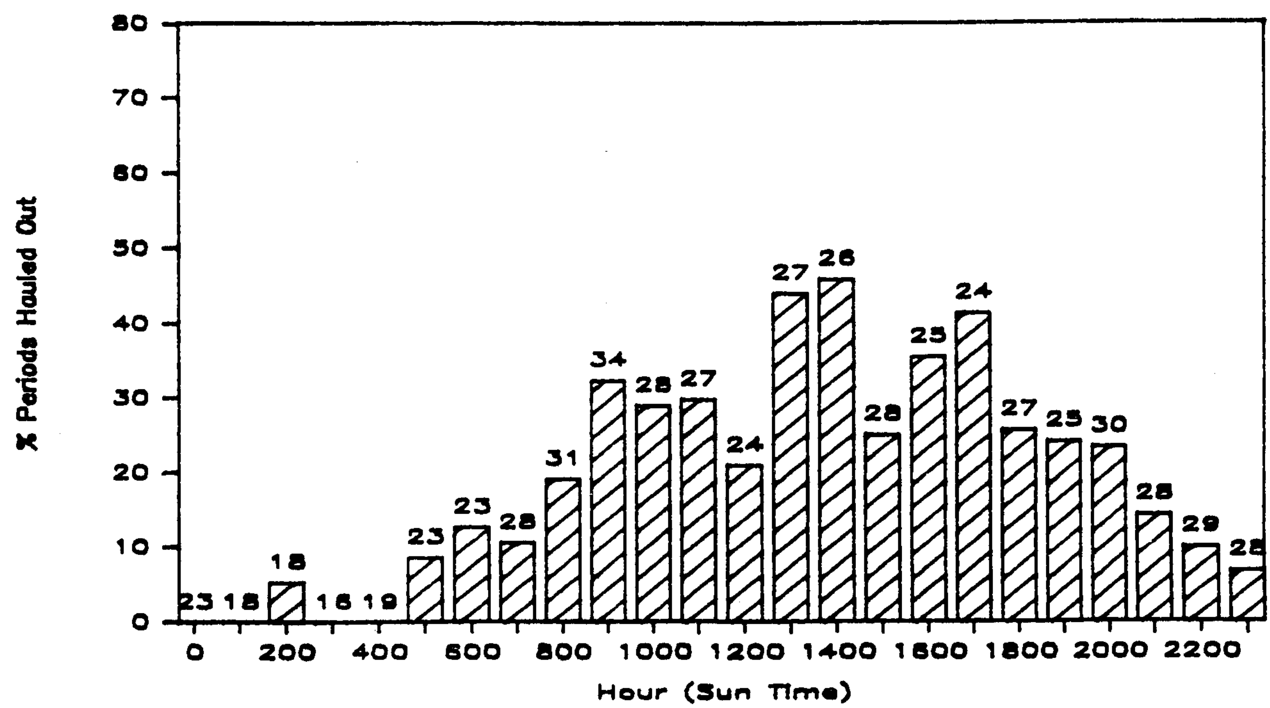

Figure 6b.–Diel haulout of radio-tagged seal BA-82 from 12 May to 2 June 1982. The number of times each hour was sampled is given above the percentage bar.

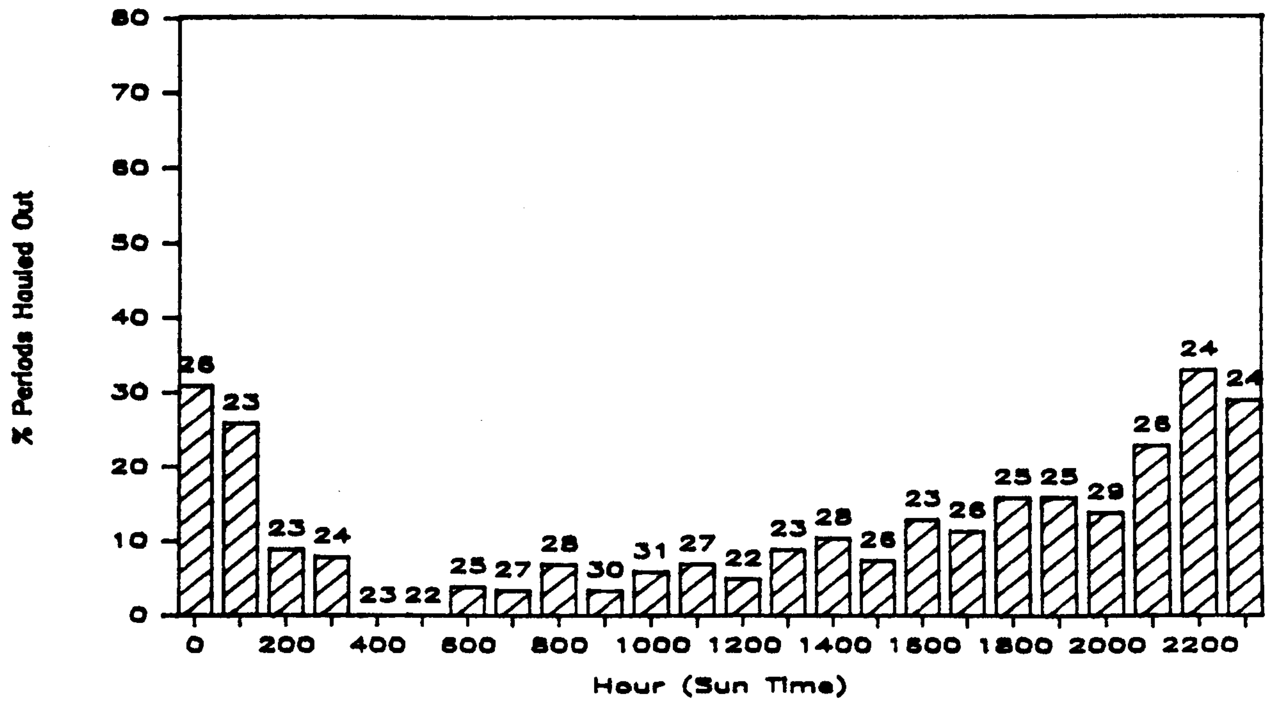

Figure 7a.–Diel haulout of radio-tagged seal TI-83 from 1 April to 11 May 1983. The number of times each hour was sampled is given above the percentage bar.

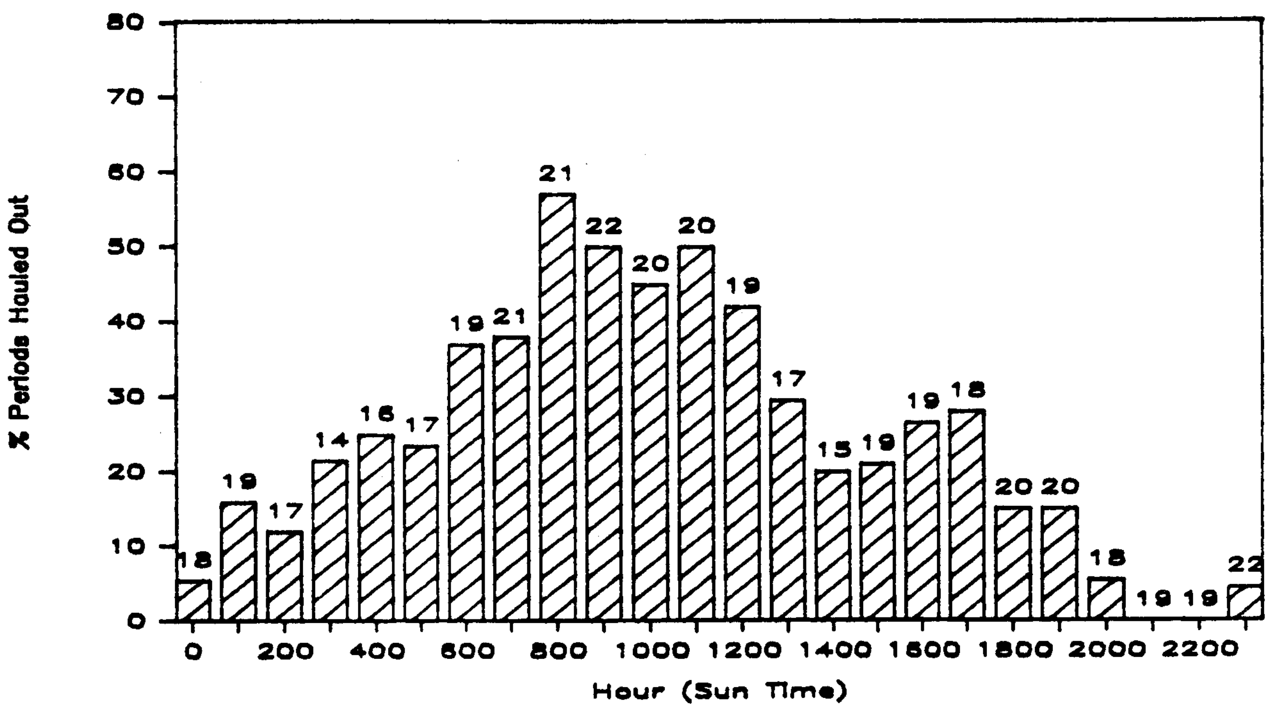

Figure 7b.–Diel haulout of radio-tagged seal TI-83 from 12 May to 2 June 1983. The number of times each hour was sampled is given above the percentage bar.

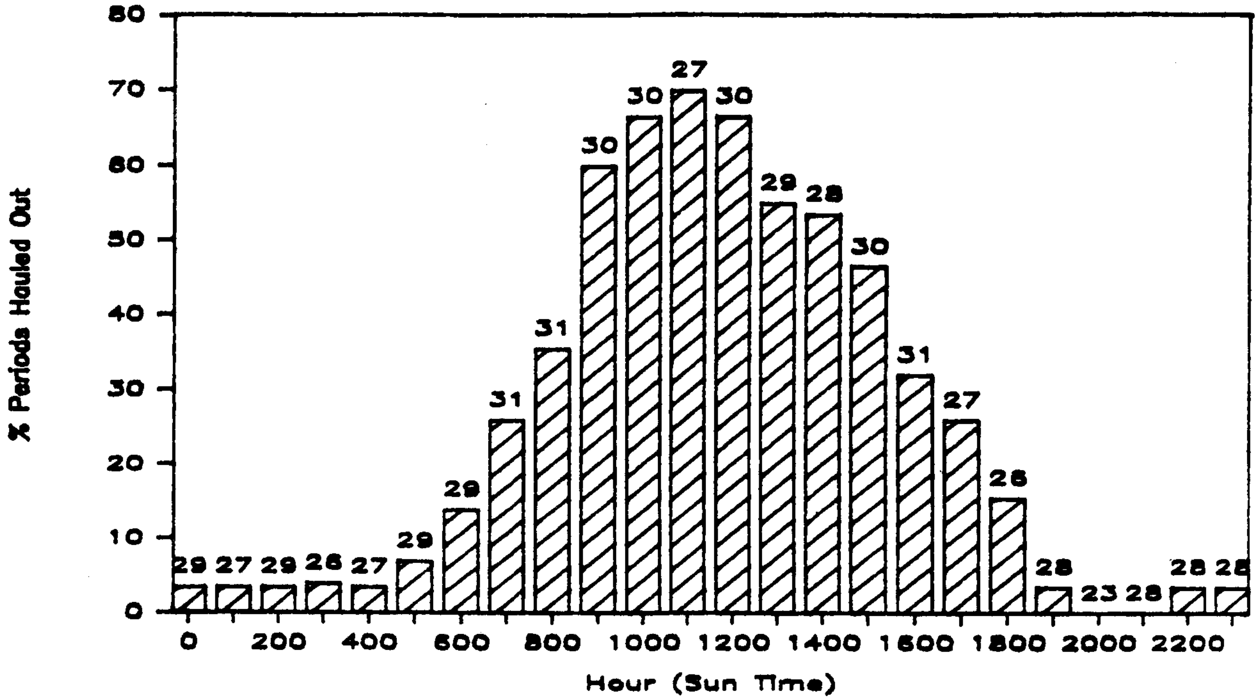

Figure 8.–Diel haulout of radio-tagged seal DQ-83 from 14 April to 19 May 1983. The number of times each hour was sampled is given above the percentage bar.

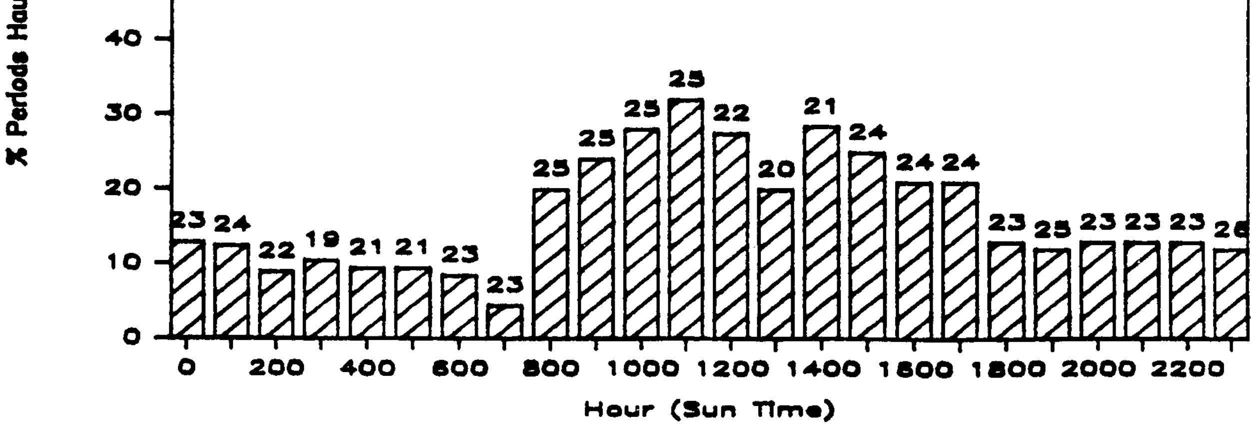

Figure 9.–Diel haulout of radio-tagged seal LR-83 from 8 May to 4 June 1983. The number of times each hour was sampled is given above the percentage bar.

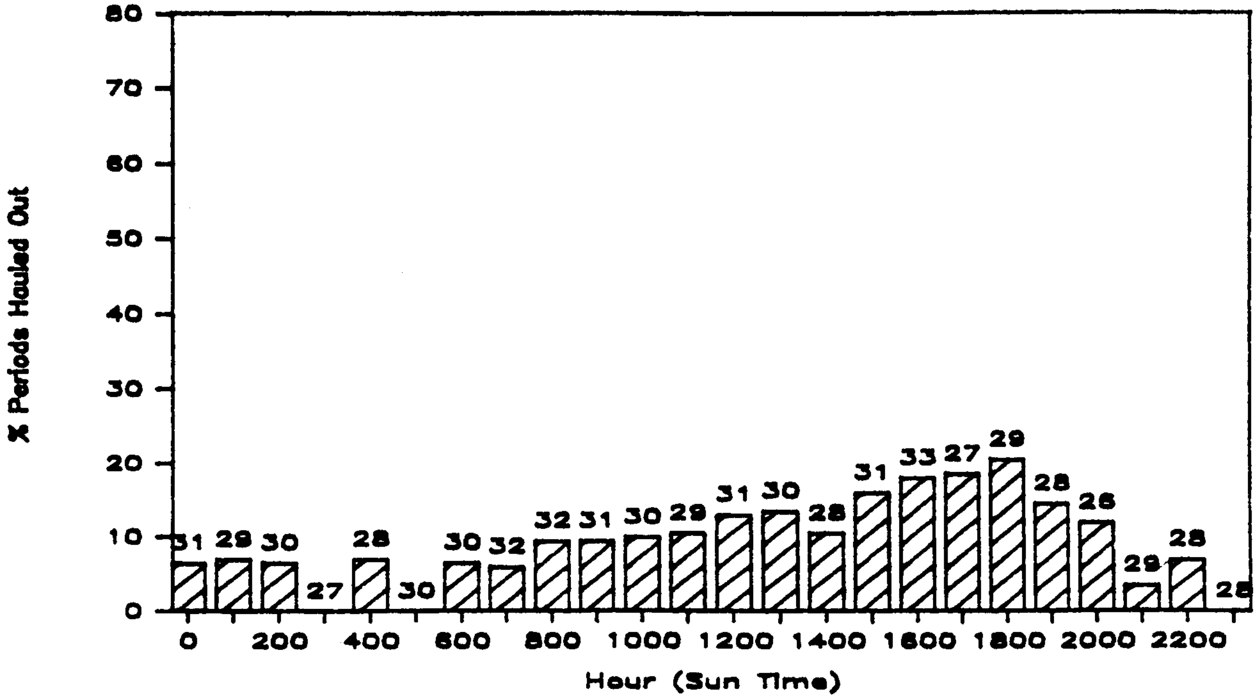

Figure 10.–Diel haulout of radio-tagged seal JO-83 from 14 April to 20 May 1983. The number of times each hour was sampled is given above the percentage bar.

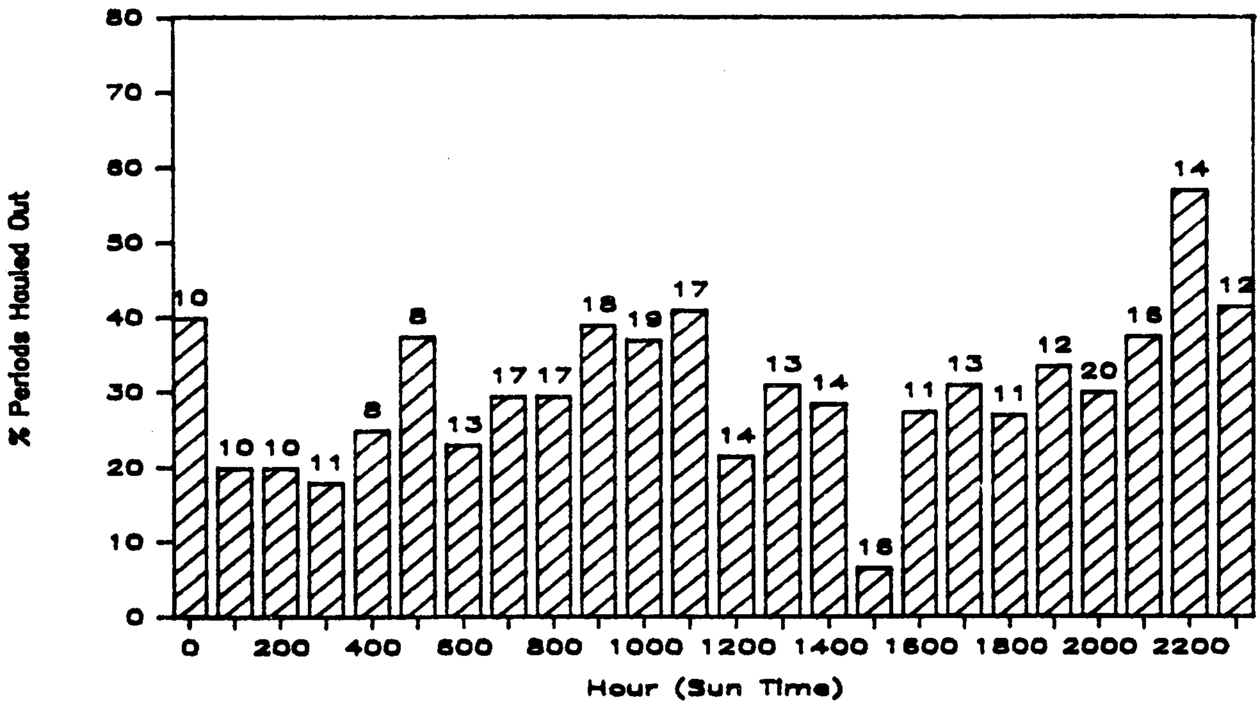

Figure 11.–Diel haulout of radio-tagged seal GI-83 from 24 March to 26 April 1983. The number of times each hour was sampled is given above the percentage bar.

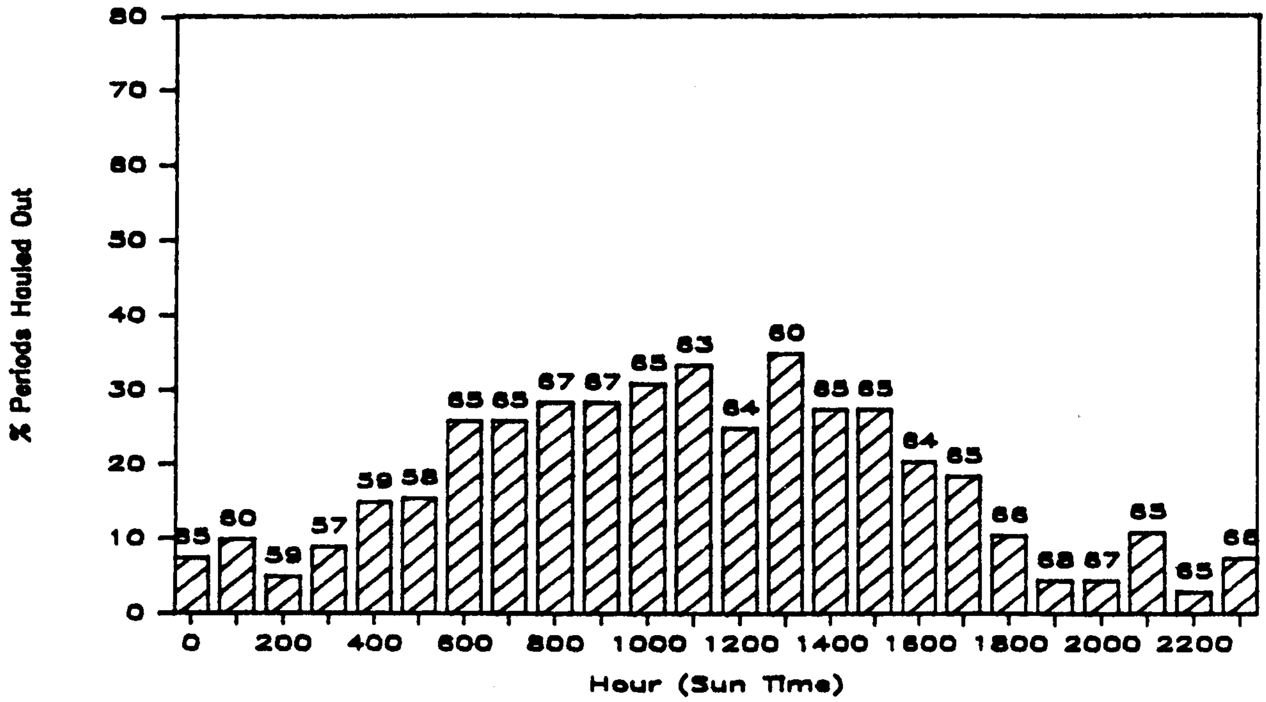

Figure 12.–Diel haulout of radio-tagged seal LK-84 from 4 March to 11 May 1984. The number of times each hour was sampled is given above the percentage bar.

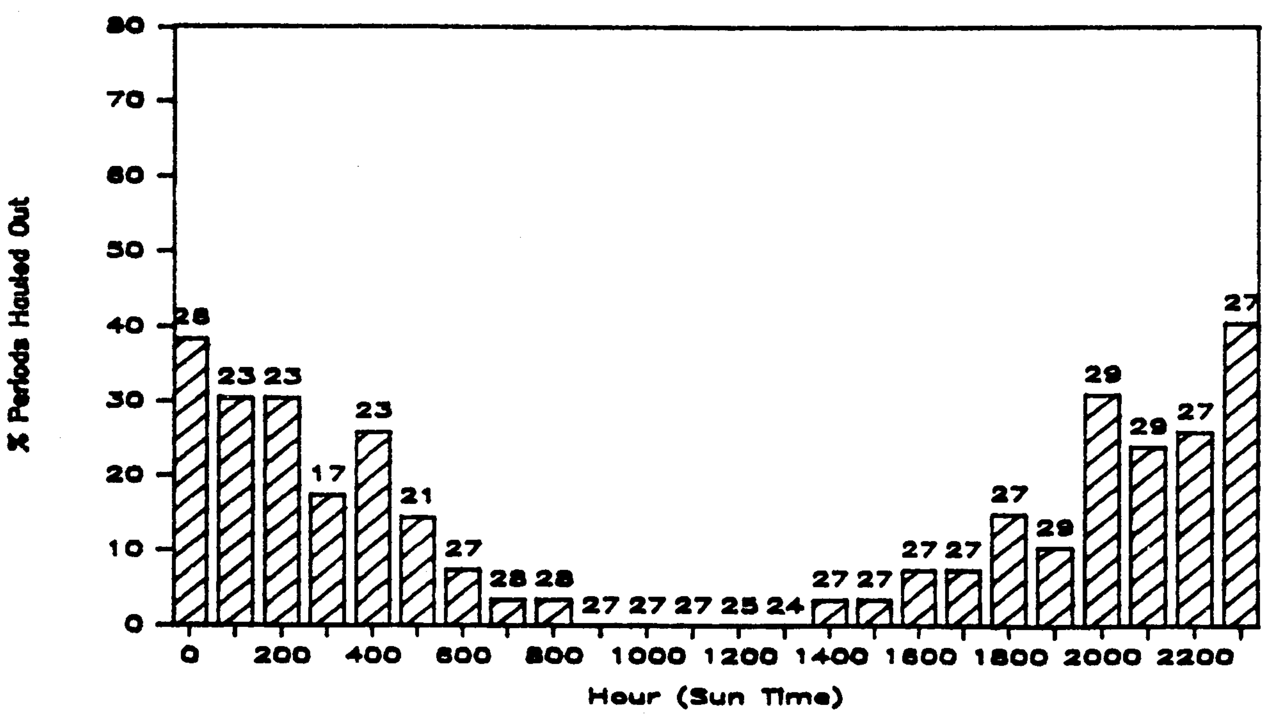

Figure 13.–Diel haulout of radio-tagged seal NA-84 from 26 March to 24 April 1984. The number of times each hour was sampled is given above the percentage bar.

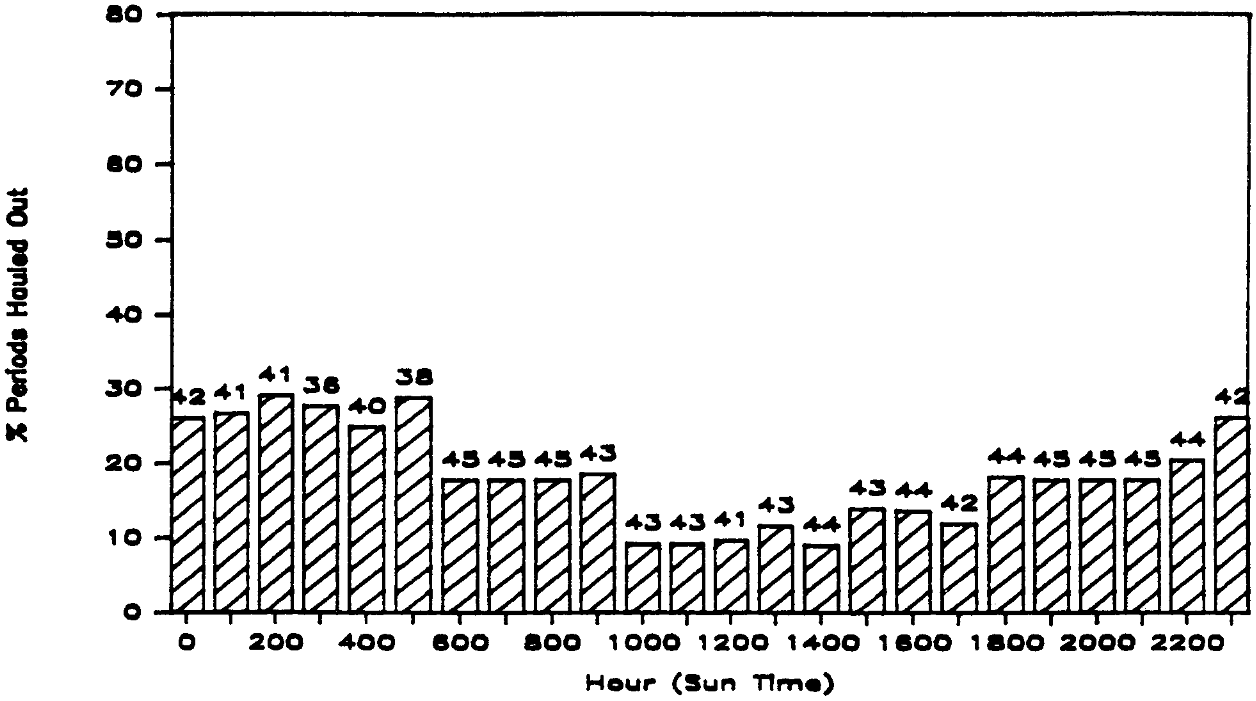

Figure 14.–Diel haulout of radio-tagged seal HU-84 from 5 March to 19 April 1984. The number of times each hour was sampled is given above the percentage bar.

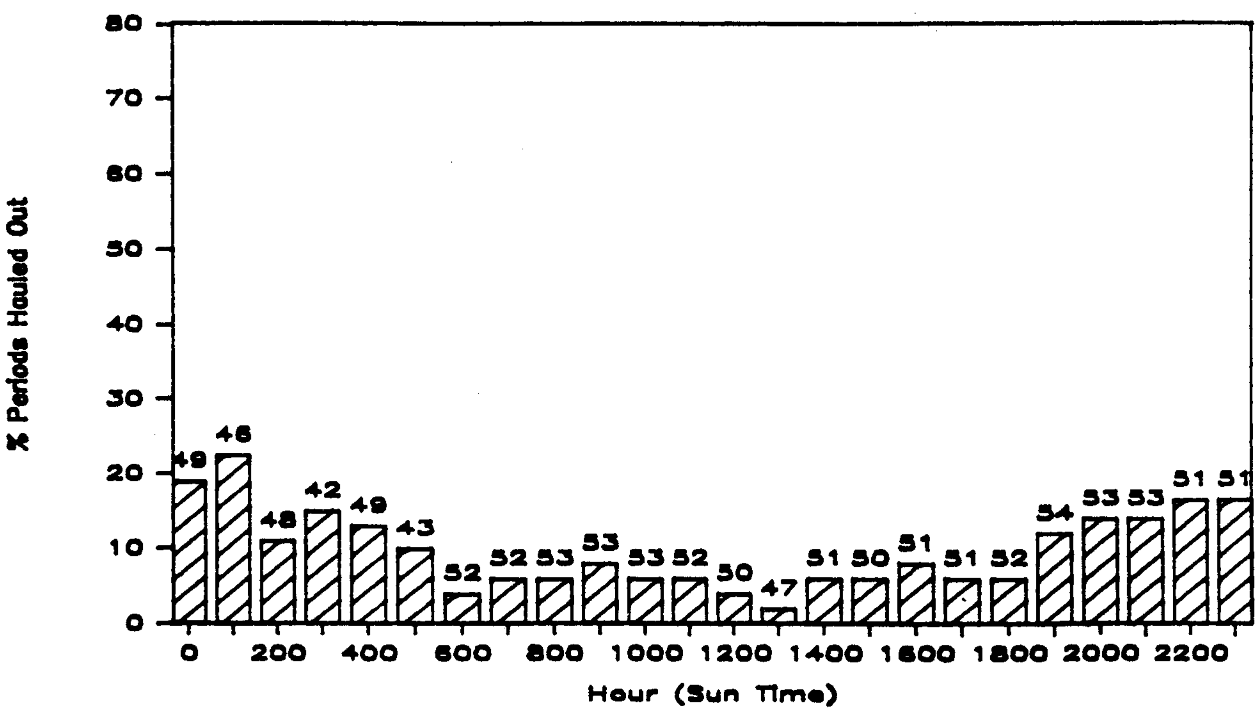

Figure 15.–Diel haulout of radio-tagged seal LU-84 from 4 March to 24 April 1984. The number of times each hour was sampled is given above the percentage bar.

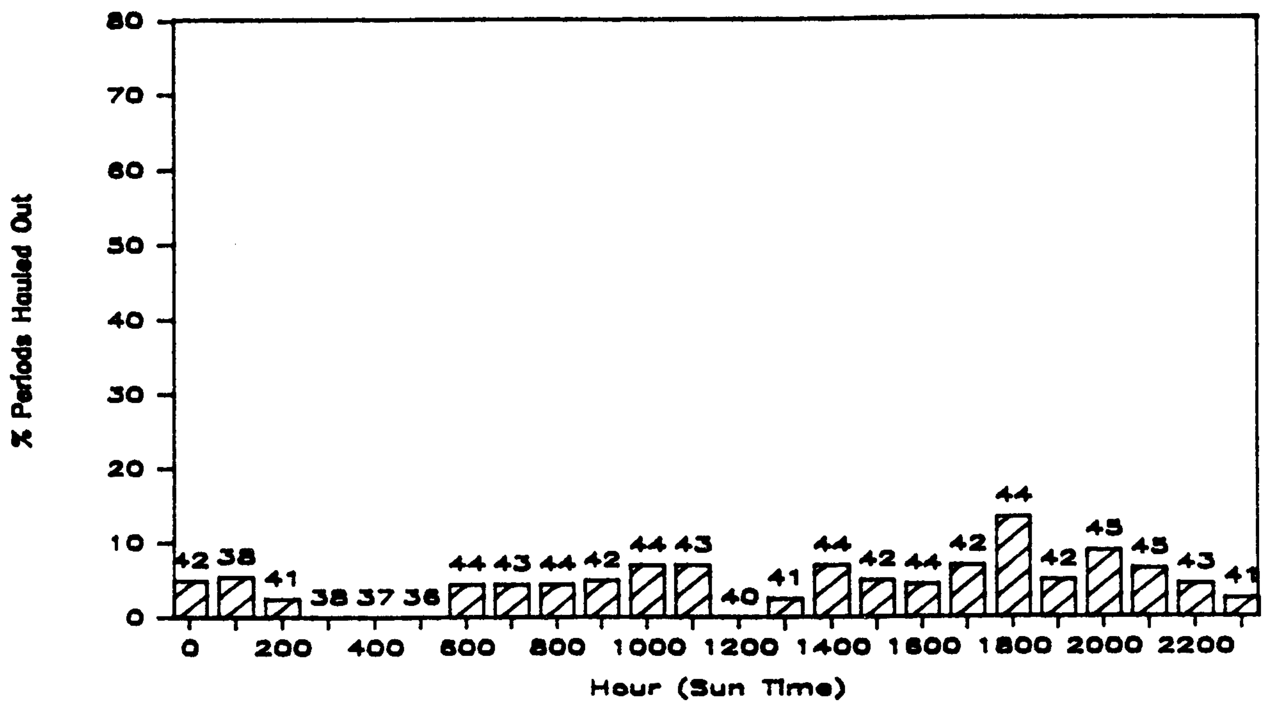

Figure 16.–Diel haulout of radio-tagged seal ZO-84 from 13 March to 27 April 1984. The number of times each hour was sampled is given above the percentage bar.

of diel haulout trends through and after that date. The probability that the observed trends were random was tested in each case via a runs test for trend data (Sokal and Rohlf 1969).

In late April and early May, the hourly percentages of SA-82 (Figure 4) and BE-82 (Figure 5) were significantly different from random (t_s = -3.52 and -3.18 respectively, $p < 0.05$), but those of BA-82 (Figure 6) were not different from random (t_s = - 0.353). SA-82 was hauled out more than 30% of the time from 1600 to 0400, with a peak at 2300. BE-82 was hauled out in more than 30% of the samples from 0400 to 0700 and between 1200 and 1300 with the peak at 0600. In mid-May to early June, a tendency to haul out mostly in the afternoon hours was observed in BA-82 (t_s = -2.470, $p < 0.05$), SA-82 (t_s = -2.823, $p < 0.05$), and BE-82 (t_s = -2.823, $p < 0.05$). Both SA-82 and BE-82 generally were out greater than 30% of the time between 0700 and 1600 (peaks at 1300-1400) during that period. BA-82 generally hauled out from 0900 through 1800 during that period, with the peak at 1400.

Only two of five seals radio-tagged in 1983 showed diel haulout trends significantly differing from random. TI-83 showed a significant trend toward midday haulouts from mid-May to early June and DQ-83 showed a trend toward midday haulouts in mid-April to mid-May. Trends appeared to be similar among the other three seals tagged in 1983 but sample sizes and dates of monitoring were limited in those cases. In April and early May, TI-83 (Figure 7) hauled out mainly late at night, exceeding 30% of the time only between 2200 and 0000 hours, but that trend was not significant (t_s = 0.354). During mid-May to early June, however, he showed a strong peak in late morning to midday (t_s = -7.566, $p < 0.05$). In that period he was out of the water more than 30% of the time from 0600 to 1200 (peak at 0800). DQ-83 (Figure 8) showed a strong preference for midday haulouts during the period from mid-April to mid-May (t_s = -2.816, $p < 0.05$). He was hauled out more than 25% of the time from 0700 to 1600 (peak at 1100) in that period. LR-83 was out 20% or more of the time from 0800 to 1700 in early May to early June (Figure 9), but the trend was not significant (t_s = - 1.760). JO-83 showed a weak tendency for late afternoon haulouts in mid-April to mid-May (Figure 10), but these did not differ significantly from random. GI-83's haulouts in late March to late April (Figure 11) also did not differ significantly from random.

Monitoring of seals radio-tagged in 1984 ceased in mid-May, and only two showed haulout trends that differed significantly from random. LK-84 showed a strong tendency to haul out between early and midday in March, April, and early May (t_s = -3.872, $p < 0.05$). She was in her lair more than 25% of the time from 0600 to 1500 hours, with a peak at 1300 hours (Figure 12). In contrast, NA-84 (Figure 13) occupied a lair 25% or more of the time from 2000 to 0200 hours and not at all during 0900 to 1300 hours (t_s = -2.816, $p < 0.05$). HU-84 and LU-84 also showed a tendency to haul out mainly during the night and early morning (Figures 14, 15), but neither those nor ZO-84's haulouts (Figure 16) differed significantly from random.

Lair Temperatures

Air temperature was recorded inside four lairs in 1983 and nine lairs in 1984 (Table 14). Only one of the lairs (83H016) monitored in 1983 appeared to be utilized for haulouts after insertion of a thermistor. Lair 83H016 showed signs of being actively used when it was first examined on 29 March and again on 30 May, and it appeared to be in use throughout the study period. Air temperatures inside the lair were compared with outside air temperatures (Figures 17-19) without correction for windchill effect. Reliable wind speed measurements were not obtained at times that the lair temperature was sampled. Before the thermistor was inserted in the lair, it was known to be used, at least occasionally, by a radio-tagged seal (DQ-83). On two occasions abrupt temperature increases and subsequent decreases in the lair corresponded with haulout bouts recorded via the transmitter attached to DQ-83. On 12 May the seal's haulout was followed by a 4.2°C increase in lair temperature and on 16 May by a 2.9°C increase (Figure 18).

Even without a seal's presence, internal temperatures of all lairs tended to remain higher than ambient as a result of heat dissipated from the underlying sea water. Internal lair temperatures in 1983 ranged from -9.1 to +0.3°C, while ambient temperatures (exclusive of windchill effect) ranged from -34.6 to +7.8°C (Table 15).

Table 16 gives internal and ambient temperatures for 83H016, the one lair monitored for temperature in 1983 which remained in active use, over a 4-week period. Through the first three weeks the internal temperature averaged higher than ambient. In the fourth week, however, ambient temperatures tended to be higher than those inside the lair.

Table 14.–Ringed seal lairs in which air temperature was monitored.

Lair	Maximum lair dimensions (m) Length	Width	Height	Drift depth[1] (m)	Roof thickness[2] (m)	Dates monitored
83H022	1.55	1.00	–	1.05	–	4/12 - 4/29/83
83C023	1.72	1.70	–	1.00	–	4/15 - 4/29/83 5/07 - 5/12/83
83H016	1.62	0.77	0.32	0.88	0.40	5/05 - 5/29/84
83H047	1.92	0.87	0.52	0.77	0.36	5/21 - 5/29/84
84H018	1.90	0.70	0.37	0.50	0.15	3/06 - 3/22/84
84H021	1.30	–	0.30	0.55	0.23	3/06 - 3/20/84
84H020	1.75	0.85	0.30	0.53	0.23	3/06 - 3/15/84
84H024	3.00	–	0.22	0.80	0.42	3/08 - 4/12/84
84C044	3.28	2.20	0.47	0.68	0.21	3/20 - 4/11/84
84C095 (2 chambers)	1.56 1.92	– –	0.37 –	– –	– –	3/22 - 5/15/84
84H113	–	–	–	0.78	–	4/11 - 5/14/84
84P034 (2 chambers)	4.30 2.01	– –	0.40 0.30	1.60 –	1.20 –	4/12 - 4/25/84
84H023	1.98	–	0.55	0.70	0.15	4/26 - 5/14/84

[1] Snow depth at deepest portion of lair.
[2] Measured as thickest portion of lair roof.

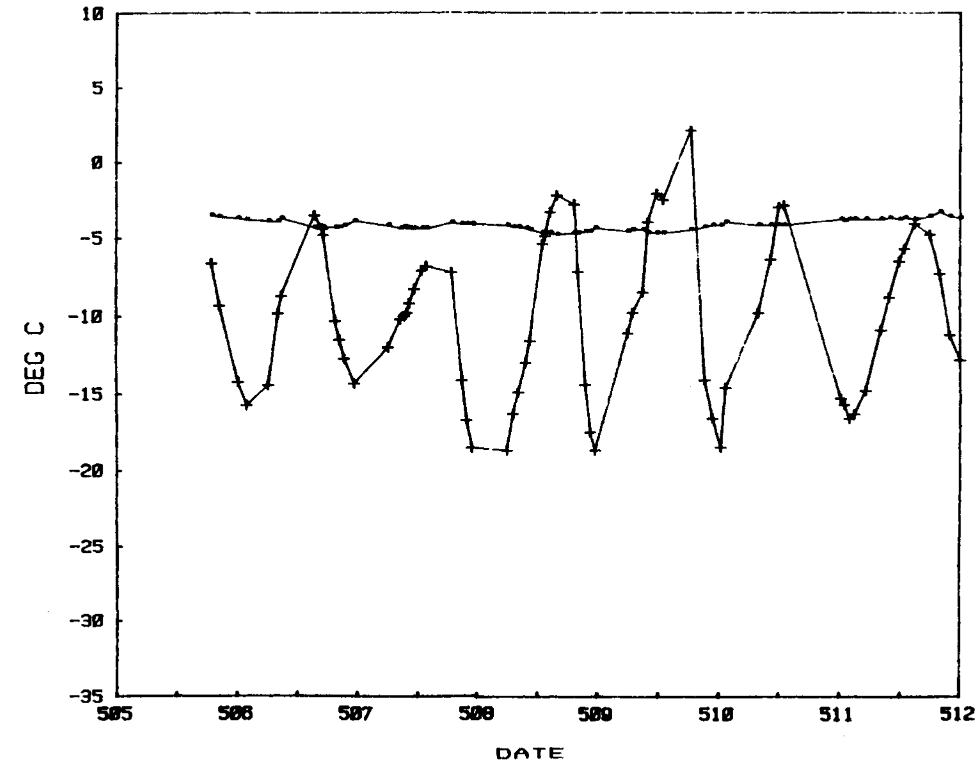

Figure 17.–Internal (line with dots) and outside (line with crosses) air temperature at lair 83H016 between 5 and 11 May 1983. No correction was made for windchill effect.

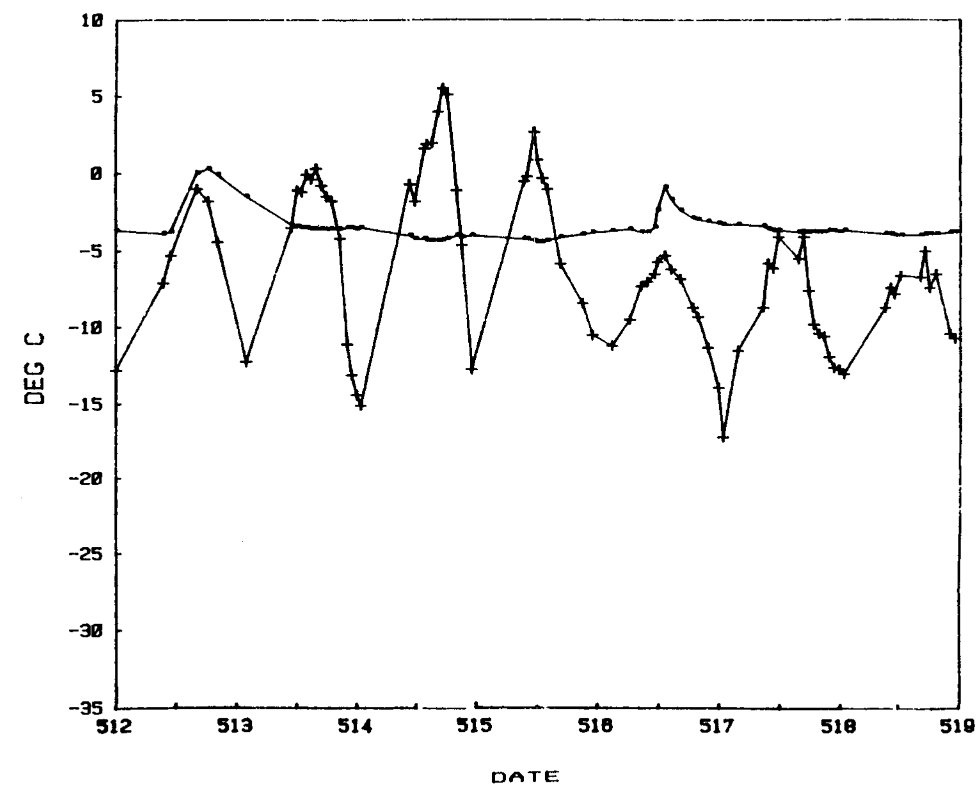

Figure 18.–Internal (line with dots) and outside (line with crosses) air temperature at lair 83H016 between 12 and 18 May 1983. No correction was made for windchill effect.

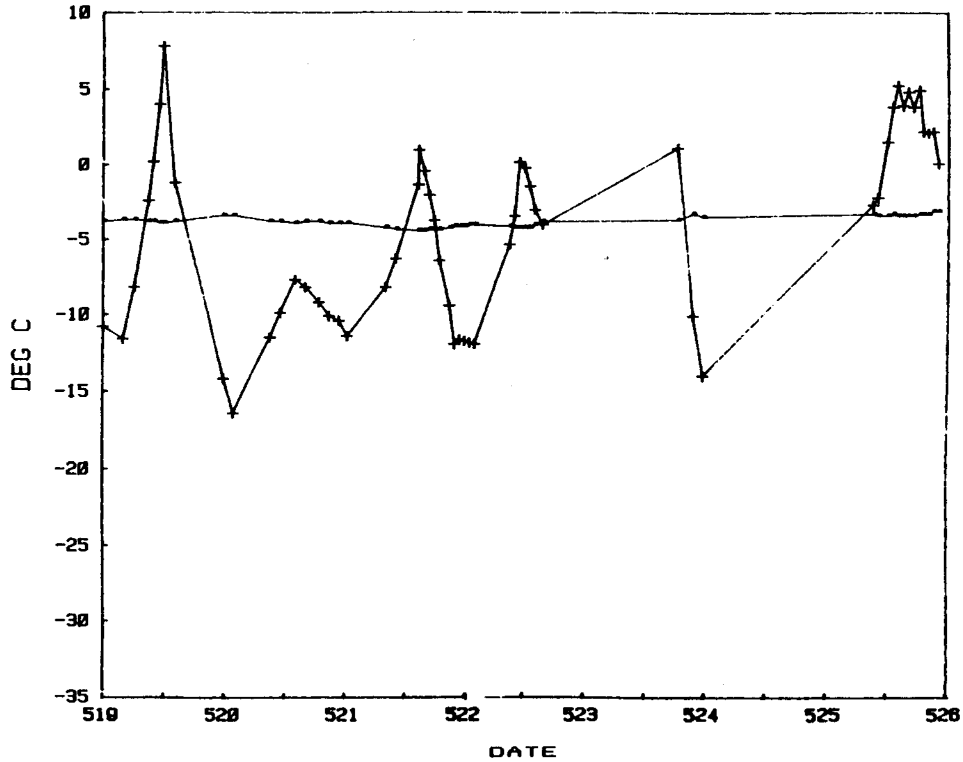

Figure 19.–Internal (line with dots) and outside (line with crosses) air temperature at lair 83H016 between 19 and 25 May 1983. No correction was made for windchill effect.

Lair temperatures were monitored in nine lairs in 1984 (Table 14), four of which were used by seals for haulout bouts while being monitored. Wind speed was measured with each sampling of outside air temperature, and the air temperature within lairs was compared with outside temperatures corrected for windchill effect (Figures 20-38).

Air temperature in lair 84H018 increased from -5 to +6°C within 2 hours on 14 March and within 3 hours on 15 March (Figures 20-22). Those temperature increases did not correspond with signals received from any of the radio-tagged seals and must have resulted from haulout bouts by some other seal(s).

Lair 84C095 experienced 13 such abrupt temperature increases (Figure 23-30) with a mean increase per incident of 7.8°C (S.D. = 1.70). Seven of those warming events coincided exactly with haulout bouts by HU-84 who was traced by his radio signal to this lair. At least two of the temperature increases (24 - 25 March and 23 - 24 April) were not caused by HU-84 but by another seal, as evidenced by the lack of transmitter signal from HU-84 during those events. Four warming periods in the lair after the last signal was received from HU-84 (19 April) may have been caused by him (if he had lost his transmitter) or by another seal. Abrupt temperature increases averaging 5.8°C (S.D. = 1.98) also were recorded on eight occasions in lair 84H113. Figures 31-35 show the temperature records for lair 84H113 and the corresponding ambient temperature (corrected for windchill effect).

Table 15.–Internal and ambient air temperatures (°C) at four ringed seal lairs in 1983.

	Lair (dates monitored)							
	83H022 (12-29 April)		83C023 (15-29 April)		83H016 (5-29 May)		83H047 (21-29 May)	
	Lair	Ambient	Lair	Ambient	Lair	Ambient	Lair	Ambient
N	92	92	80	80	232	232	80	80
Mean	-6.4	-13.5	-5.3	-8.9	-3.6	-6.2	-3.9	-2.7
S.D.	1.5	9.3	1.5	6.7	0.9	5.9	0.6	4.5
Min.	-8.2	-34.6	-9.1	-26.8	-4.8	-18.7	-5.0	-14.0
Max.	-3.3	5.0	-3.2	3.6	0.3	7.8	-2.8	5.2

Table 16.–Internal and ambient air temperatures (°C) at lair 83H016 between 5 and 30 May 1983.

	5-11 May		12-18 May		19-25 May		26-30 May	
	Lair	Ambient	Lair	Ambient	Lair	Ambient	Lair	Ambient
N	69	69	80	80	55	55	29	29
Mean	-4.2	-10.1	-3.5	-5.9	-3.8	-4.3	-2.2	-1.3
S.D.	0.4	5.1	0.9	5.2	0.4	6.2	0.9	2.8
Min.	-4.8	-18.7	-4.4	-17.2	-4.4	-16.4	-3.0	-5.5
Max.	-3.3	2.1	0.3	5.5	-3.1	7.8	-0.3	3.7

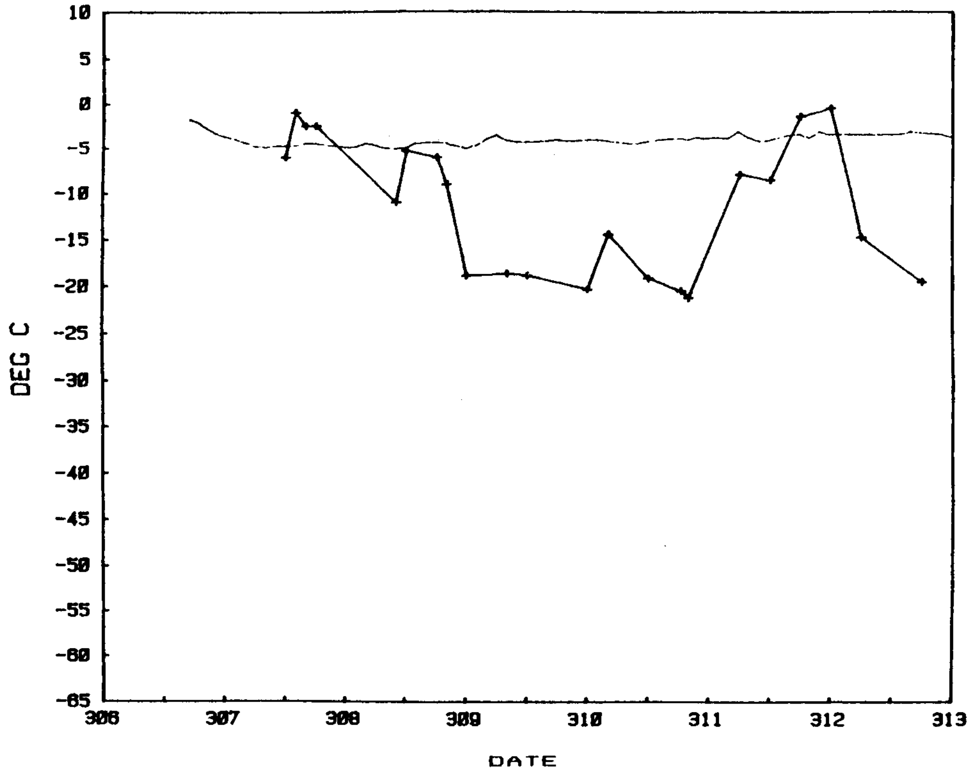

Figure 20.–Internal (solid line) and outside (line with crosses) air temperatures (corrected for windchill effect) at lair 84H018 between 6 and 13 March 1984.

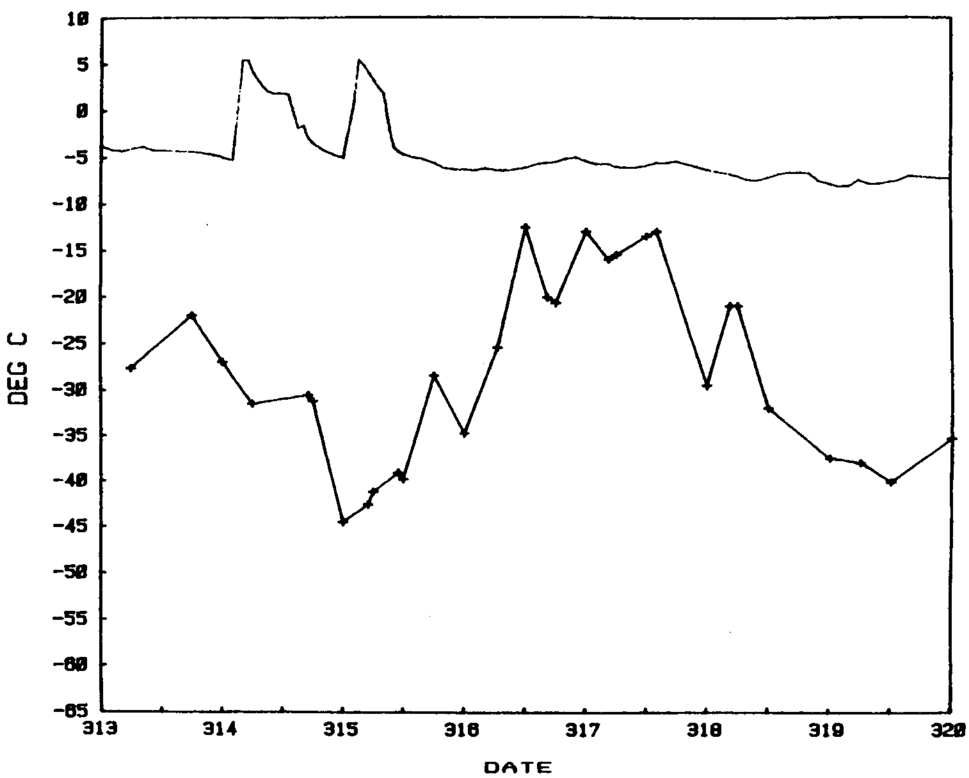

Figure 21.–Internal (solid line) and outside (line with crosses) air temperatures (corrected for windchill effect) at lair 84H018 between 13 and 20 March 1984.

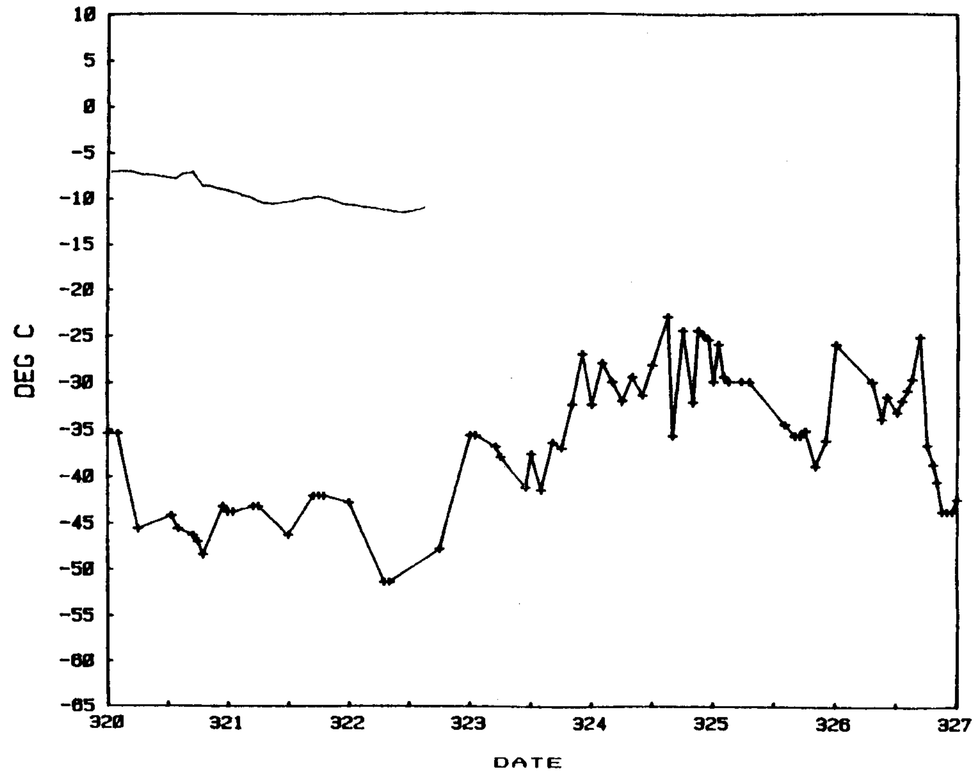

Figure 22.–Internal (solid line) and outside (line with crosses) air temperatures (corrected for windchill effect) at lair 84H018 between 20 and 27 March 1984.

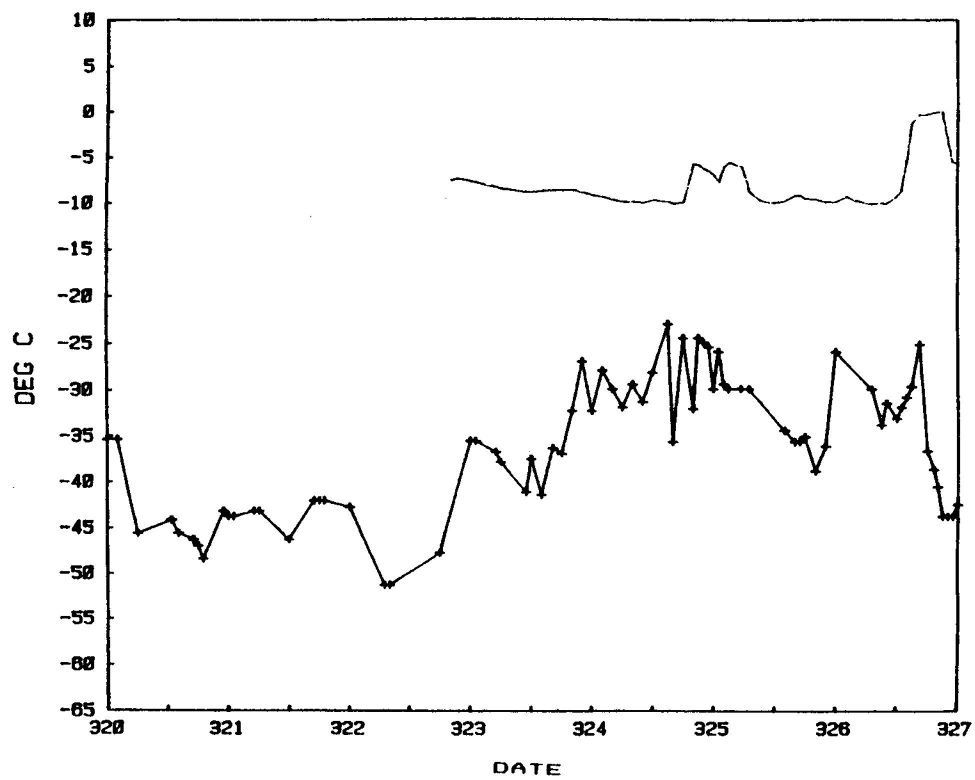

Figure 23.–Internal (solid line) and outside (line with crosses) air temperatures (corrected for windchill effect) at lair 84C095 between 20 and 27 March 1984.

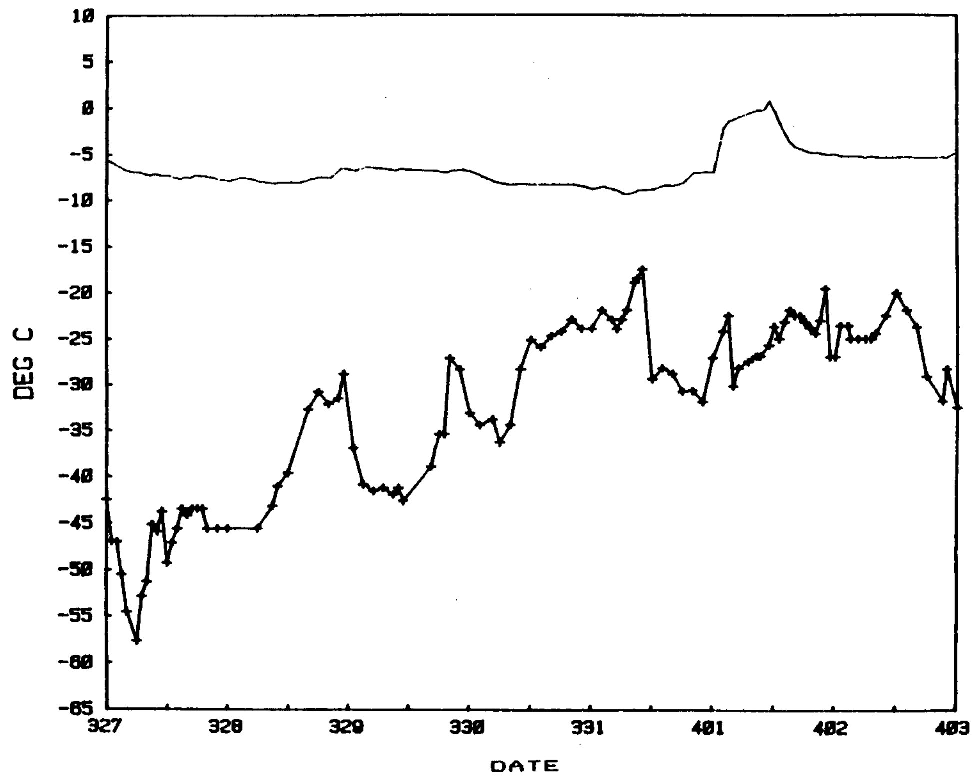

Figure 24.–Internal (solid line) and outside (line with crosses) air temperatures (corrected for windchill effect) at lair 84C095 between 27 March and 3 April 1984.

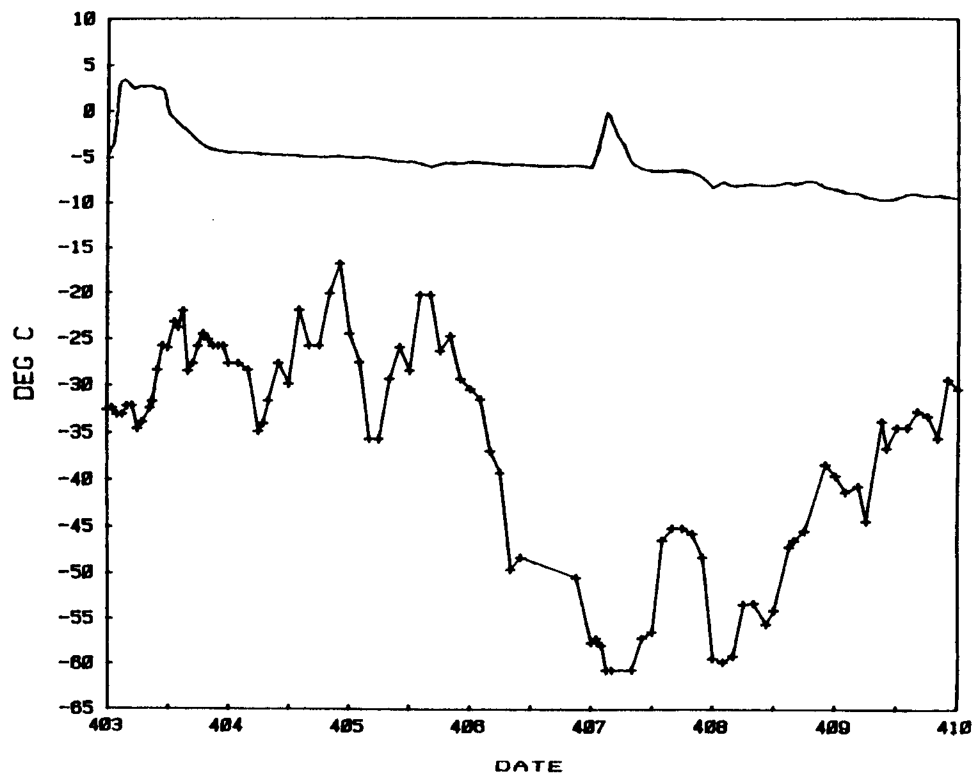

Figure 25.–Internal (solid line) and outside (line with crosses) air temperatures (corrected for windchill effect) at lair 84C095 between 3 and 10 April 1984.

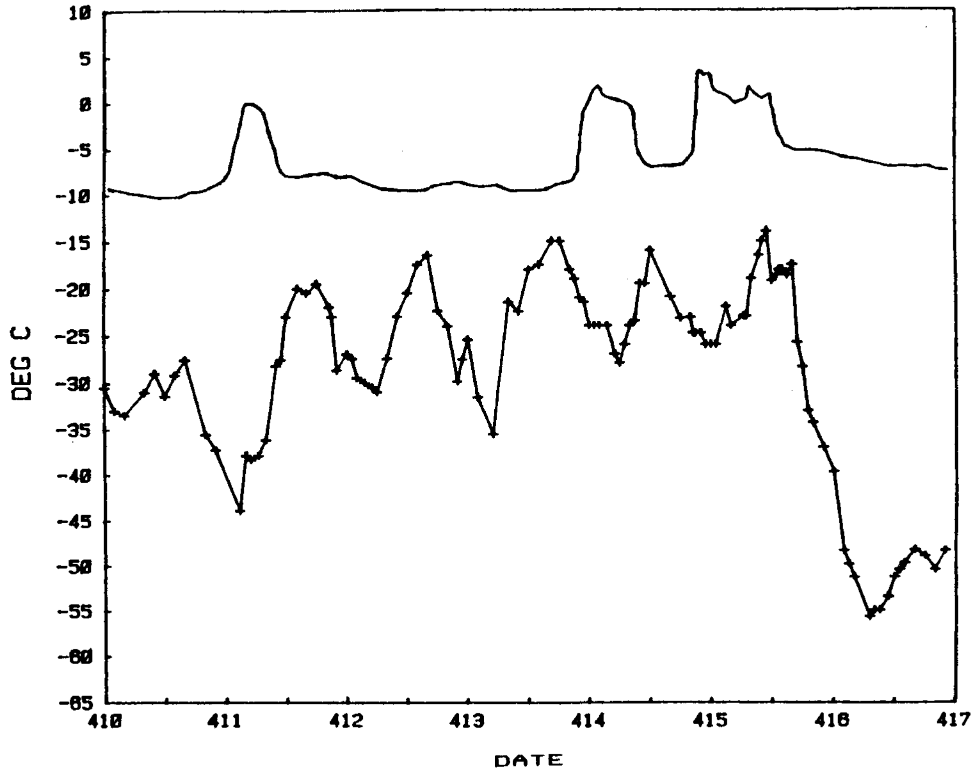

Figure 26.–Internal (solid line) and outside (line with crosses) air temperatures (corrected for windchill effect) at lair 84C095 between 10 and 17 April 1984.

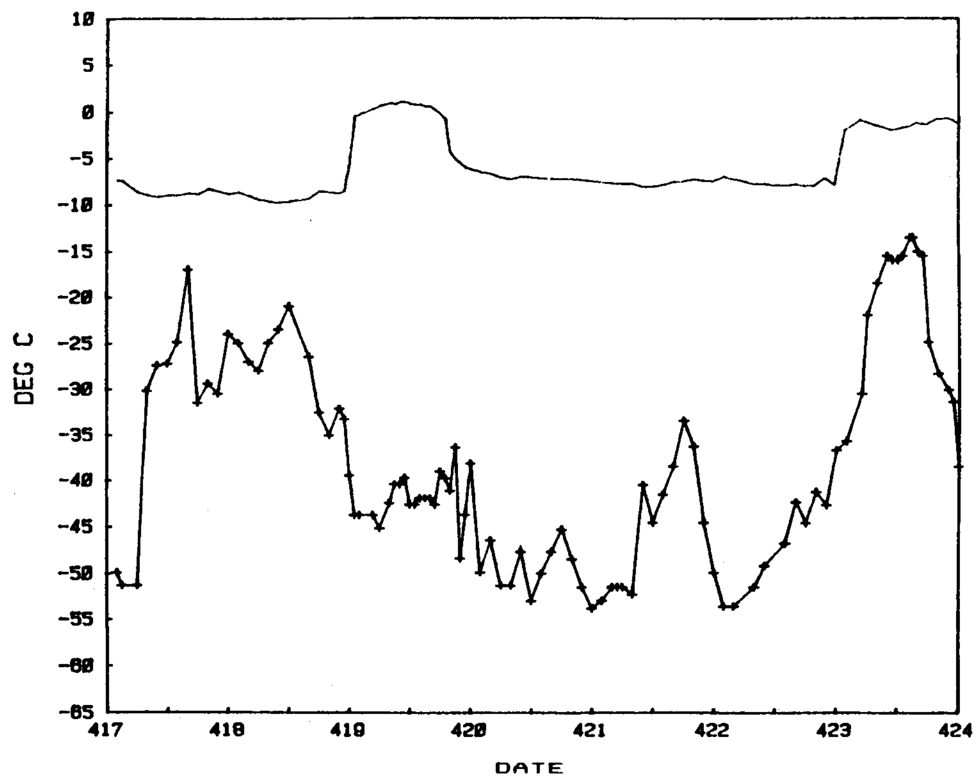

Figure 27.–Internal (solid line) and outside (line with crosses) air temperatures (corrected for windchill effect) at lair 84C095 between 17 and 24 April 1984.

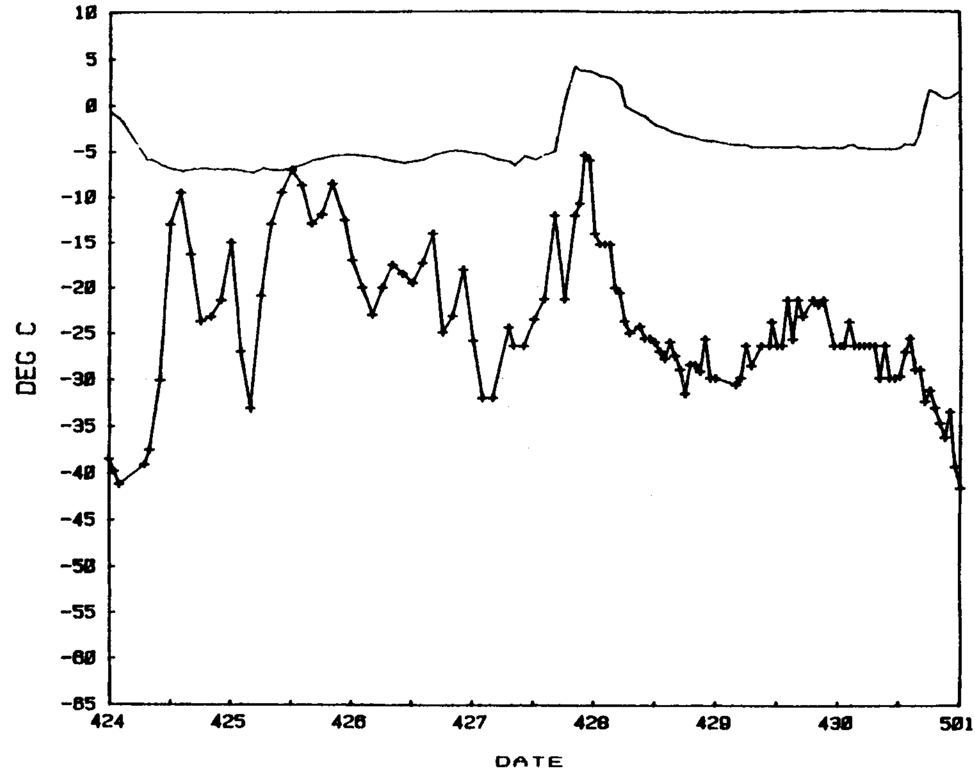

Figure 28.–Internal (solid line) and outside (line with crosses) air temperatures (corrected for windchill effect) at lair 84C095 between 24 April and 1 May 1984.

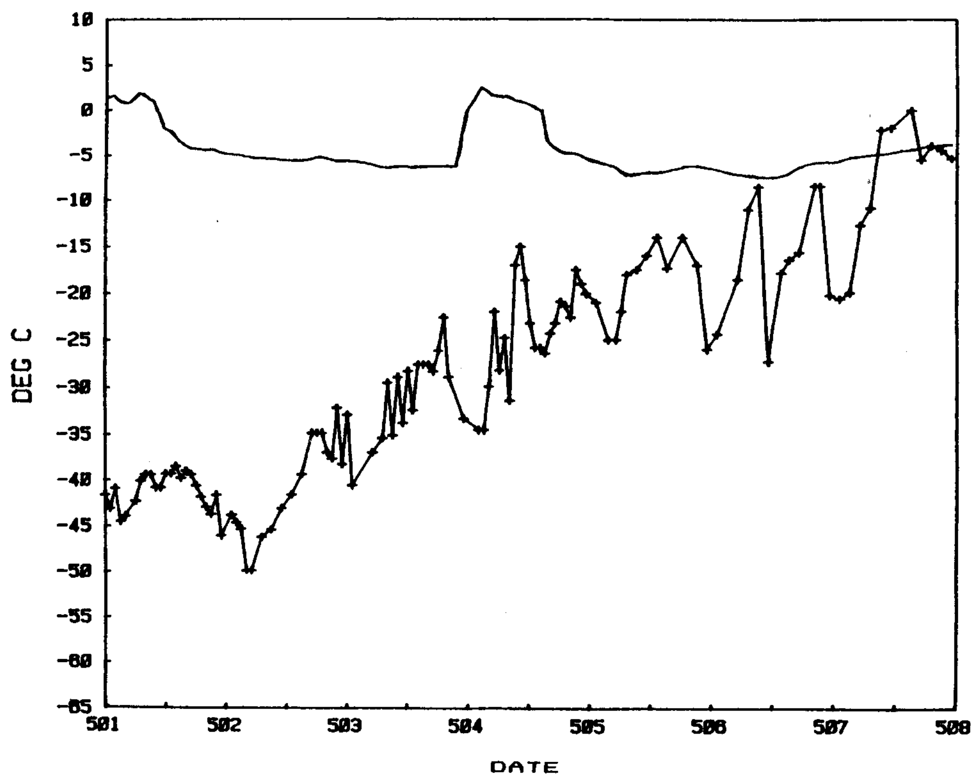

Figure 29.–Internal (solid line) and outside (line with crosses) air temperatures (corrected for windchill effect) at lair 84C095 between 1 and 8 May 1984.

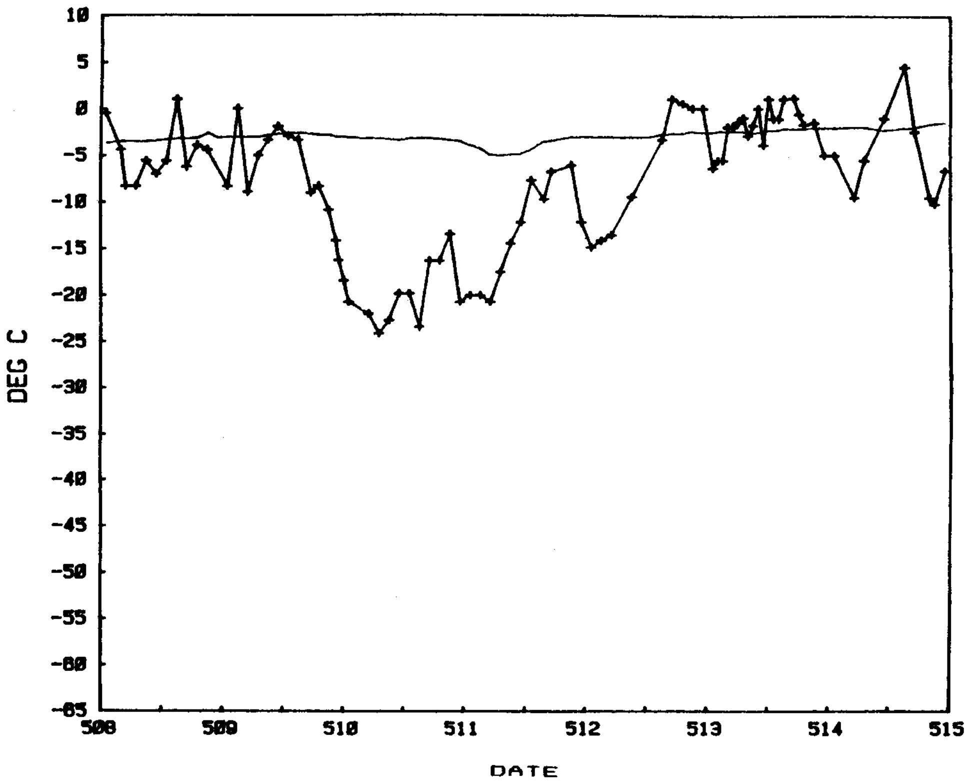

Figure 30.–Internal (solid line) and outside (line with crosses) air temperatures (corrected for windchill effect) at lair 84C095 between 8 and 15 May 1984.

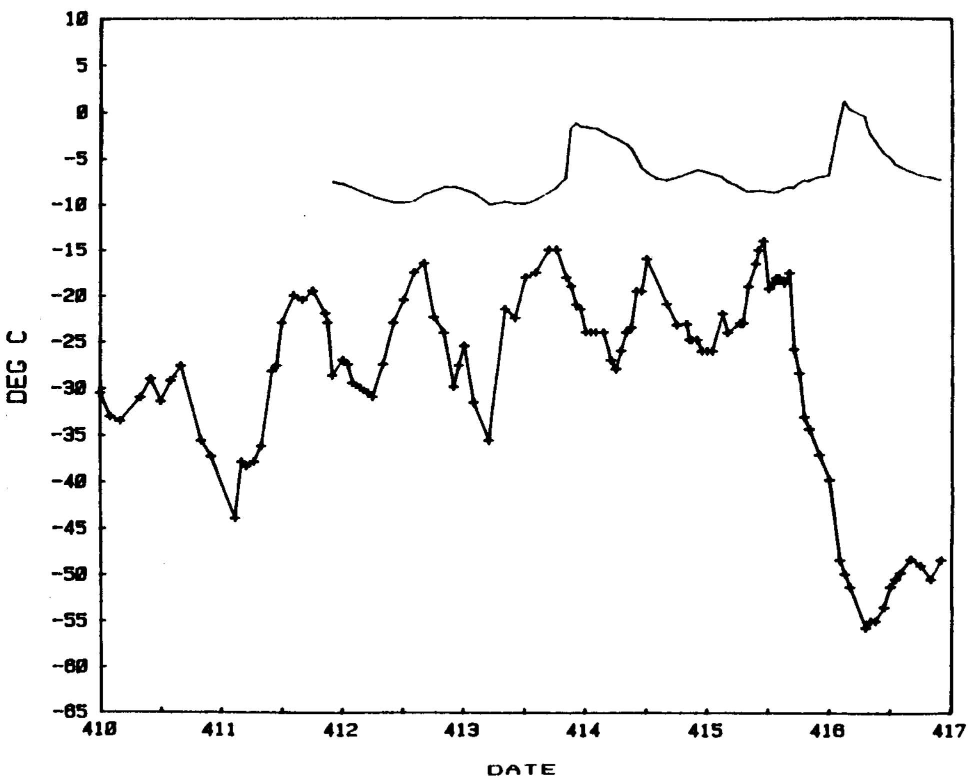

Figure 31.–Internal (solid line) and outside (line with crosses) air temperatures (corrected for windchill effect) at lair 84H113 between 10 and 17 April 1984.

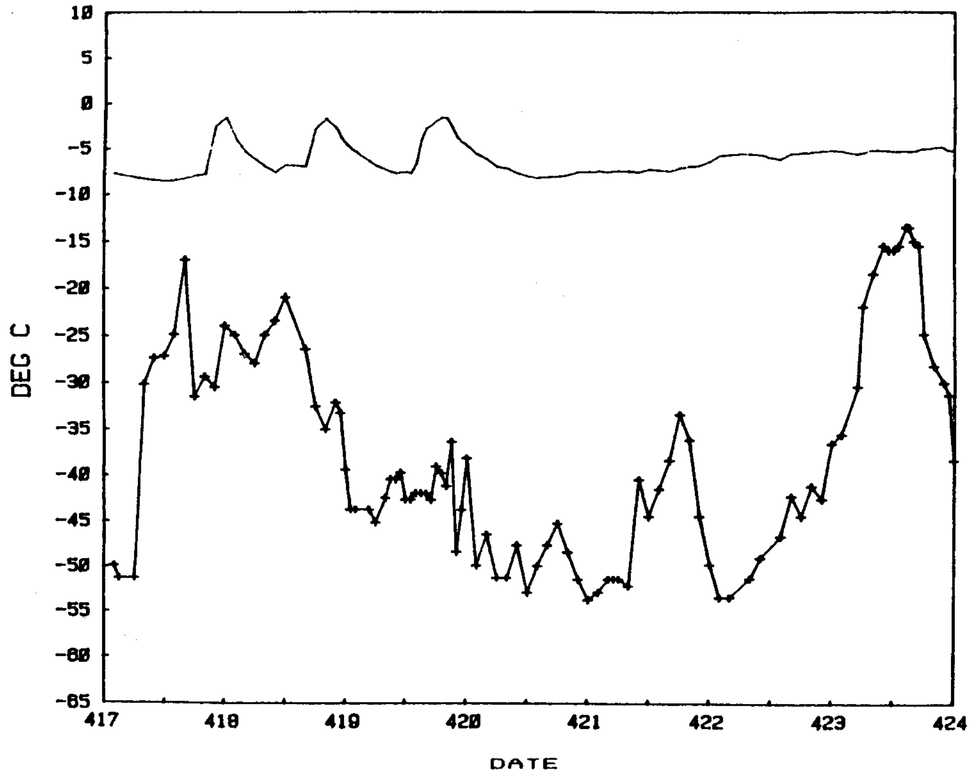

Figure 32.–Internal (solid line) and outside (line with crosses) air temperatures (corrected for windchill effect) at lair 84H113 between 17 and 24 April 1984.

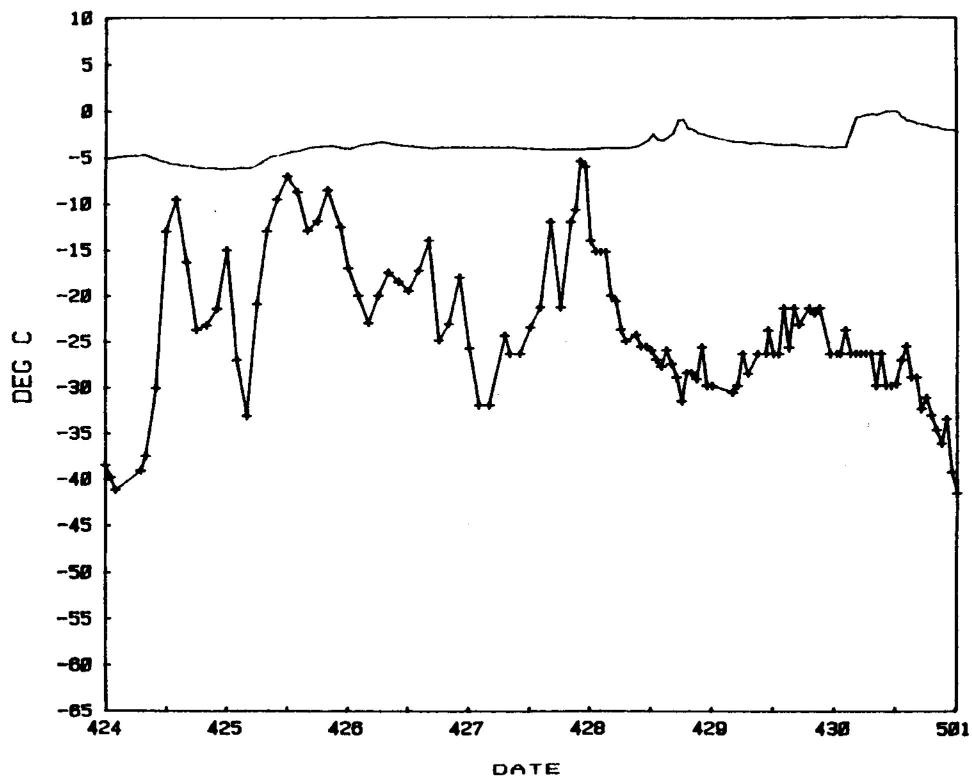

Figure 33.–Internal (solid line) and outside (line with crosses) air temperatures (corrected for windchill effect) at lair 84H113 between 24 April and 1 May 1984.

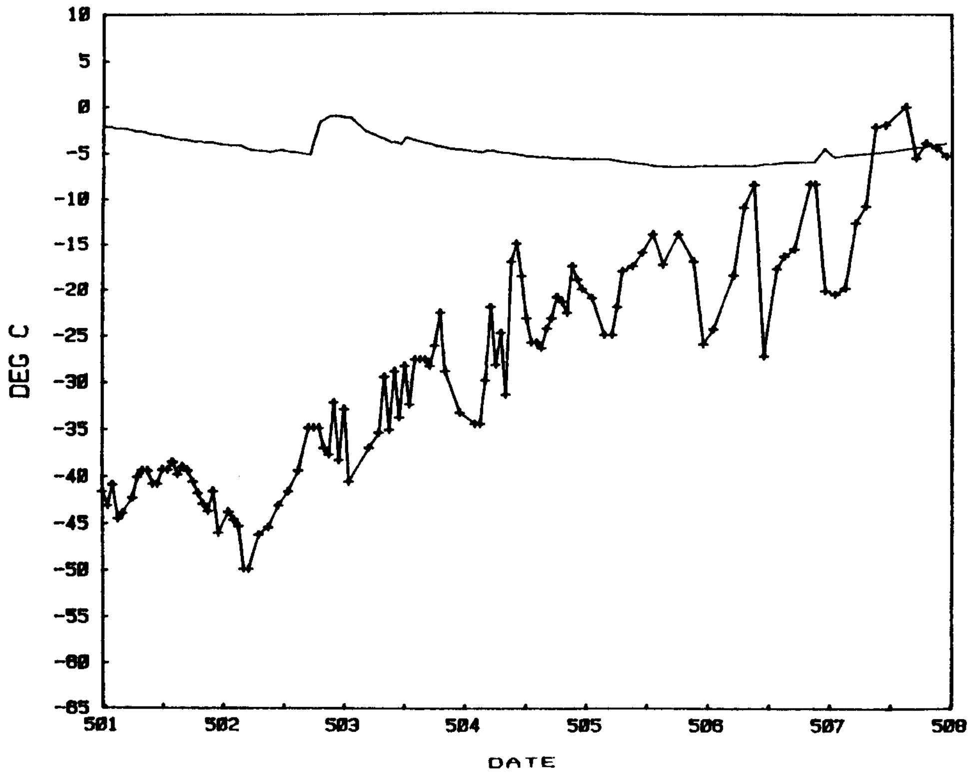

Figure 34.–Internal (solid line) and outside (line with crosses) air temperature (corrected for windchill effect) at lair 84H113 between 1 and 8 May 1984.

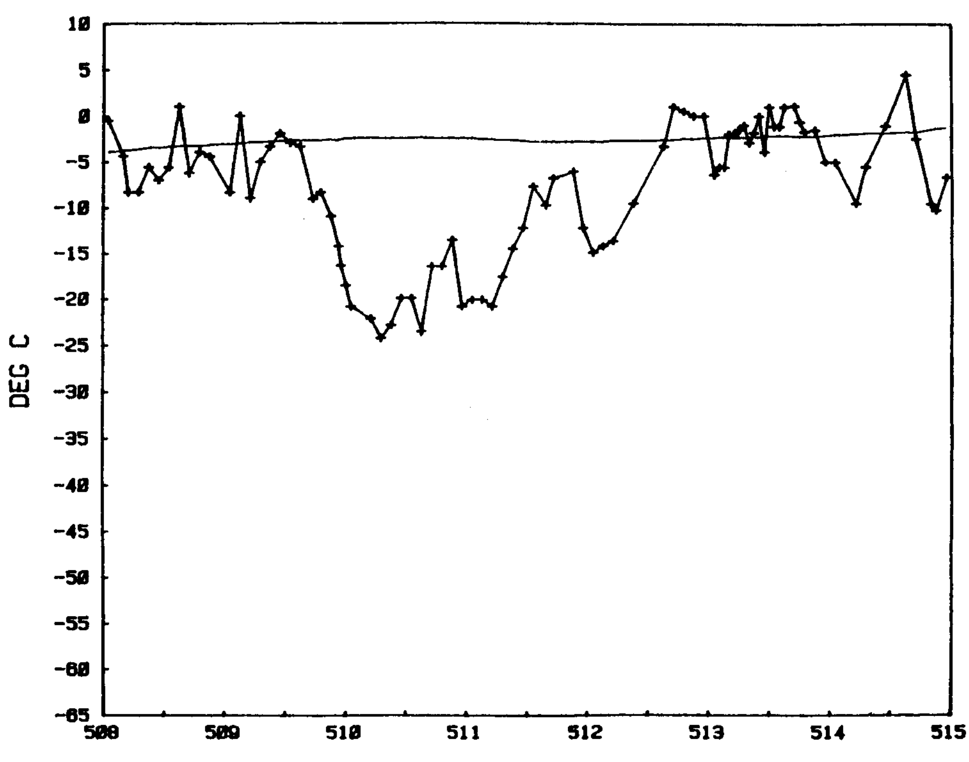

Figure 35.–Internal (solid line) and outside (line with crosses) air temperature (corrected for windchill effect) at lair 84H113 between 8 and 15 May 1984.

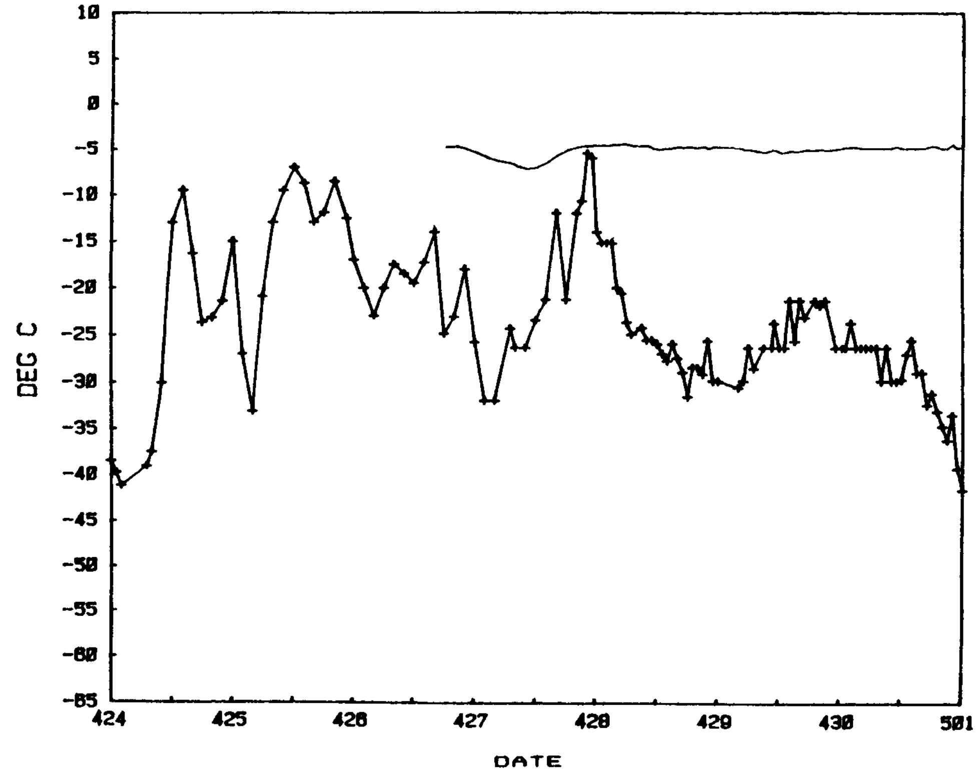

Figure 36.–Internal (solid line) and outside (line with crosses) air temperature (corrected for windchill effect) at lair 84H023 between 24 April and 1 May 1984.

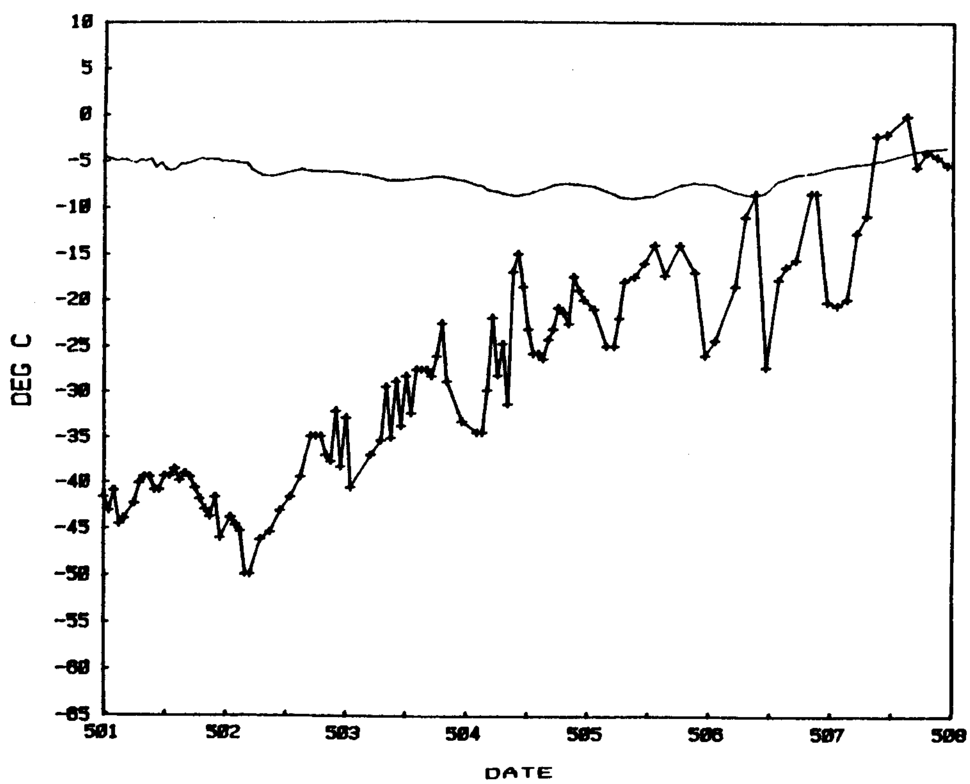

Figure 37.–Internal (solid line) and outside (line with crosses) air temperature (corrected for windchill effect) at lair 84H023 between 1 and 8 May 1984.

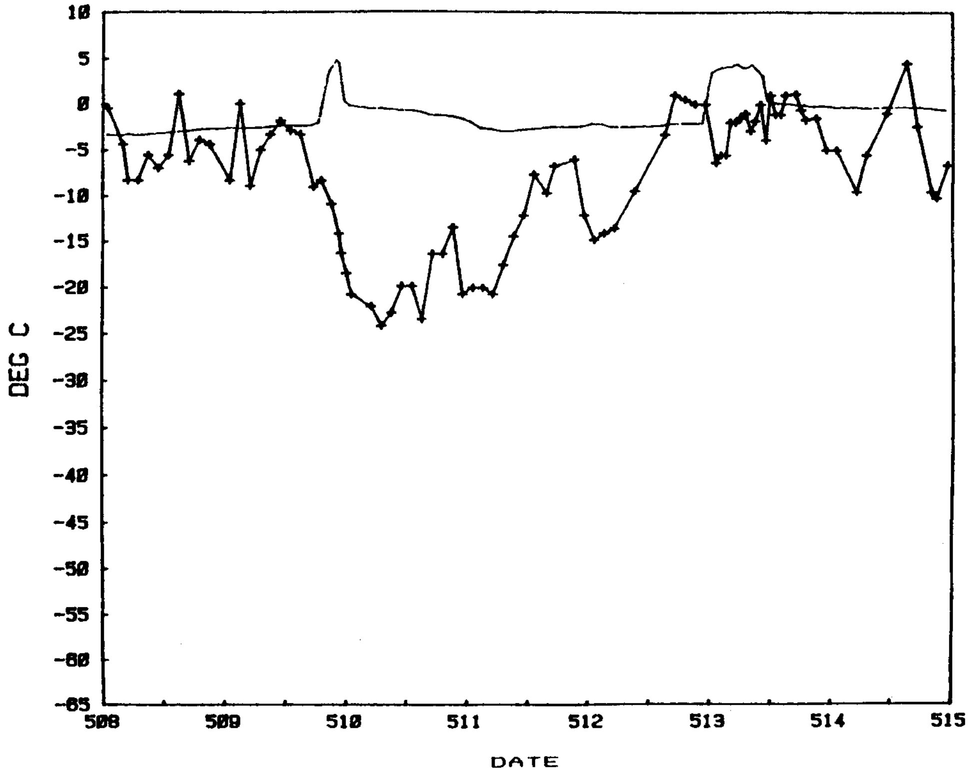

Figure 38.–Internal (solid line) and outside (line with crosses) air temperature (corrected for windchill effect) at lair 84H023 between 8 and 15 May 1984.

The temperature in lair 84H023 increased 7.2°C in 3 hours on 9 - 10 May and 6.0°C in 3 hours on 13 May (Figures 36 - 38). No signals were received from radio-tagged seals during those warming events. LU-84 used lair 84H023 before the last signal from her transmitter was recorded on 24 April, and she may have continued to use it in May without a transmitter or with a failed transmitter. On the other hand, another seal might have been using the lair in the absence of LU-84.

The longest, most continuous record of internal air temperature was obtained from lair 84C095 (Table 15). Air temperature in that lair averaged 27.0°C warmer than outside windchill temperatures in March, 26.2°C warmer in April, and 16.4°C warmer in May. By the second week of May, ambient windchill temperatures were frequently higher than internal air temperature (Figure 30).

Reactions of Seals to Noise Disturbances

The three seals radio-tagged in 1982 were captured at breathing holes and maintained lairs within an extensive grid of seismic lines (Figure 2). Those seals were tagged after the seismic surveys had been completed, so we do not know whether they changed their haulout behavior in response to the seismic surveys. It is clear, however, that they did not permanently abandon their established lairs. Table 17 details the structures used by those seals and the distance to the nearest seismic survey line.

Table 17.–Subnivean seal structures utilized by radio-tagged ringed seals in 1982 and their distances from seismic survey lines.

Seal no.	Subnivean structure	Nearest seismic line (m)
BA-82	82B040	129
BA-82	82H160	400
SA-82	82B045	37
SA-82	82H161	700
BE-82	82B036	19
BE-82	82H162	250

Three of the five seals radio-tagged in 1983 occupied lairs in the vicinity of seismic survey lines (Figure 2). TI-83 and GI-83 were tagged before the simulated seismic surveys; LR-83 was tagged afterward.

Not only during the seismic surveying, but throughout April, TI-83 tended to haul out mostly at night (Figure 7a). His signal was never received during the daytime when the seismic convoy was operating, but he did haul out most evenings during that period. Two exceptions were 26 and 27 April (third and final days of seismic convoy operations), when he did not haul out at all during the 24-hour cycle. A typical evening haulout was recorded again on 28 April.

GI-83 tended to haul out in the midday more than did TI-83 (Figure 11). During late March and early April, he commonly spent periods as long or longer than 20 hours in his lair. On 21 April, he began a haulout at 0550 hours, approximately 1.5 hours before the seismic convoy entered the study area. That haulout ended at 1701 hours when the advancing convoy was 644 m from his lair (83H024). The Vibroseis was idling between sweeps when GI-83 dove. Holliday *et al.* (1984) estimated noise levels received at GI-83's lair at that time were: 136 dB re 1 micro Pa (underwater); 69 dB re 20 micro Pa (airborne); 40 dB re 10^{-8} m/s (vertical vibration). No signal was received from GI-83 the next day and only a brief, weak signal, (not from lair 83H024) was received on 23 April. Five additional haulouts by GI-83 were recorded thereafter, at least two of them from lair 83H024. The last was a brief bout (1555 to 1645 hours) on 26 April. On 17 May, we excavated lair 83H024 and found signs of its continuing use as a haulout site. We were unable to ascertain whether GI-83 or some other seal was using the lair at that time.

LR-83 was radio-tagged after the simulated seismic survey was completed. Her haulout sites were between seismic lines A and C (Figure 2), and her birth lair probably was in use prior to the seismic survey. She continued to use that lair as late as 4 June, more than one month after the seismic survey.

In addition to the seals' responses to the seismic survey convoy and related activities, we recorded responses to noise generated by helicopters (Table 18), snow machines and other equipment operating on the ice (Table 19), and people walking and skiing on the ice (Table 20). In those cases where the seals' response is shown as "departed," we judged that they did so in response to human activity. In some cases their departures may have been coincidental with, but not in response to, human activities.

Responses to helicopter noise tended to vary with altitude of the machine and its lateral distance from the haulout site. Seals did not leave their haulout sites in response to helicopter flights at or above an altitude of 457 m. Departures were observed in 8 of 15 (53%) instances when helicopters were at altitudes of 305 m or less. Seals departed in six of nine (67%) instances at that altitude when helicopters were within 2 km (lateral distance) of the haulout site. At distances greater than 2 km, helicopters at or below 305 m caused two of six (33%) seals to depart their haulout sites.

The responses to machinery operating on the ice also varied considerably. Snow machines operating as far as 2.8 km from a haulout site, at times caused a seal to depart (Table 19). At other times, snow machines within 0.5 km did not cause a departure.

People moving on the ice caused seals to depart haulout sites from as far as 600 m but generally not until within 200 m (Table 20). Seals departed in 8 of 17 (47%) episodes of people walking at distances of 0.2 to 1.0 km from the lairs. Skiers at the same ranges resulted in 4 departures in 26 (15%) episodes. The difference in the frequency of departures in response to people walking versus skiing is significant ($Z = 2.27$, $p < 0.05$).

Of 30 haulout bouts that were disrupted by human activities (helicopters, snow machines, heavy equipment, foot traffic) the mean length of the disturbed haulout bouts was 5.0 hours (S.D. = 3.77), not significantly different from the mean length (5.4 hours) of undisturbed haulout bouts ($t_s = 0.512$, df = 58). Periods of non-haulout subsequent to those disturbances averaged longer (30.4 hours) than non-haulout episodes not preceded by disturbance (18.9 hours) but the difference was not statistically significant ($t_s = 1.51$, df = 58).

DISCUSSION

Ringed seals use thick claws on their pectoral limbs to create and maintain the breathing holes which allow them to survive in areas of complete ice cover. They also use their pectoral limbs to excavate subnivean lairs in which haulout is confined during the coldest weather. The ability to occupy areas of unbroken ice allows ringed seals to take advantage of food sources denied to species that must seasonally migrate to areas of less extensive ice cover. Occupation of areas of unbroken ice and dependence on breathing holes and lairs also makes ringed seals more vulnerable to predation by polar bears, Arctic foxes, and man. Increasingly,

Table 18.–Responses of hauled-out seals to helicopter noise. Durations given are of haulout bouts during which seals were exposed to helicopter noise and of subsequent non-haulout bouts in those cases when seals departed (went into the water) when exposed to helicopter noise.

Date	Time	Seal no.	Helicopter altitude (m)	Approximate distance to lair (km)	Seal's response	Bout durations (hours) Haulout/non-haulout
4/24/82	1020	BA-82	Landing	1.0	Departed	? / ?
4/29/82	1140	BA-82	Landing	3.0	Departed	1 / ?
4/30/82	1800	SA-82	Landing	2.5	Remained	12 / –
5/23/82	1030	BA-82	Landing	3.0	Remained	? / –
5/23/82	1036	BE-82	Landing	4.0	Remained	? / –
5/23/82	1430	BA-82	Takeoff	3.0	Remained	? / –
4/24/83	1349	GI-83	61	1.9	Remained	23 / –
5/17/83	1300	DQ-83	122	0.6	Remained	10 / –
5/17/83	1300	TI-83	122	1.9	Remained	10 / –
5/18/83	1930	JO-83	122	1.0	Departed	10 / 36
4/26/82	1330	BE-82	152	0	Departed	1 / 2
3/30/83	1151	GI-83	152	5.0	Departed	4 / 4
4/18/83	1205	GI-83	198	0.8	Departed	13 / 2
4/30/82	0945	SA-82	305	0	Departed	? / 3
4/12/84	1315	LK-84	305	0.6	Remained	12 / –
5/28/82	1045	SA-82	457	4.0	Remained	? / –
5/28/82	1045	BE-82	457	4.5	Remained	? / –
4/11/83	1640	DQ-83	762	0	Remained	? / –
5/04/83	1345	JO-83	914	0	Remained	7 / –
5/04/83	1345	DQ-83	914	0	Remained	16 / –

Table 19.–Responses of hauled-out seals to machinery on the ice. Durations given are of haulout bouts during which seals were exposed to machinery noise and of subsequent non-haulout bouts in those cases when seals departed (went into the water) when exposed to machinery noise.

Date	Time	Seal no.	Machinery	Approximate distance to lair (km)	Seal's response	Bout durations (hours) Haulout/non-haulout
4/21/83	1701	GI-83	Vibroseis convoy	0.6	Departed	11 / 42
4/30/82	1500	SA-82	Hovercraft	2.5	Remained	12 / –
4/30/82	1700	SA-82	Two snow machines	0.5	Remained	12 / –
5/18/82	1530	SA-82	Snow machine	0.5	Remained	10 / –
3/29/83	1015	GI-83	Snow machine	0.5	Departed	1 / 22
3/25/84	1437	LK-84	Snow machine	0.5	Departed	10 / 2
4/01/85	1530	LK-84	Snow machine	0.6	Departed	14 / 19
3/07/84	1457	? basking	Snow machine	1.2	Departed	? / ?
4/08/84	2030	LK-84	Snow machine	1.6	Departed	7 / 1
4/11/84	1830	LK-84	Snow machine	2.2	Departed	10 / 6
4/14/84	2146	LU-84	Snow machine	2.8	Departed	0.6 / 46

Table 20.–Responses of hauled-out seals to noises of people and dogs moving on the ice. Durations given are of haulout bouts during which seals were exposed to noises of people or dogs moving on the ice and of subsequent non-haulout bouts in those cases when the seal departed (went into the water) when exposed to the noise.

Date	Time	Seal no.	Noise	Approximate distance to lair (km)	Seal's response	Bout durations (hours) Haulout/non-haulout
4/19/82	1530	BA-82	Two walkers	0.1	Departed	? / ?
5/06/82	1740	SA-82	One walker	0.1	Departed	0.6 / 0.3
5/07/82	0741	BE-82	One walker	0.1	Departed	3 / 8
5/09/83	1159	LR-83	One walker	0.1	Departed	3 / 35
4/21/82	0815	BA-82	One walker	0.2	Remained	4 / –
4/30/83	1750	TI-83	Two walkers	0.2	Remained	5 / –
5/04/83	1220	TI-83	Two walkers	0.2	Remained	5 / –
5/07/83	1540	DQ-83	One walker	0.2	Departed	7 / 18
3/21/84	2200	HU-84	One walker	0.2	Remained	11 / –
5/14/82	1823	SA-82	One walker	0.4	Departed	4 / 38
4/11/83	2030	DQ-83	Two walkers	0.4	Departed	4 / 46
5/06/83	1655	DQ-83	One walker	0.4	Departed	6 / 16
3/25/84	1100	LK-84	One walker	0.4	Remained	10 / –
3/27/84	1200	LK-84	One walker	0.4	Remained	8 / –
3/31/84	1200	LK-84	One walker	0.4	Remained	6 / –
5/28/82	1415	SA-82	Two walkers	0.5	Departed	2 / ?
3/24/83	1530	GI-83	Two walkers	>0.5	Departed	1 / 17

Table 20 (Continued).

Date	Time	Seal no.	Noise	Approximate distance to lair (km)	Seal's response	Bout durations (hours) Haulout/non-haulout
5/12/83	1600	DQ-83	One walker	0.5	Remained	6 / –
4/22/83	0034	TI-83	Two walkers	0.6	Departed	2 / 23
3/26/84	2123	HU-84	One walker	0.6	Departed	6 / 124
4/18/84	1945	LU-84	One walker	1.0	Remained	17 / –
3/25/84	1830	LU-84	One walker	?	Remained	4 / –
3/26/84	2200	LU-84	One walker	?	Remained	7 / –
4/17/84	2253	NA-84	One walker	?	Departed	3 / 22
4/19/84	2200	NA-84	One walker	?	Remained	2 / 2
4/24/83	2000	TI-83	Skier	0.2	Remained	6 / –
5/27/83	0100	LR-83	Skier	0.2	Remained	9 / –
5/28/83	1300	LR-83	Skier	0.2	Remained	7 / –
3/08/84	1400	HU-84	Skier	0.2	Remained	11 / –
3/31/84	1926	LU-84	Skier	0.2	Departed	2 / 204
4/03/84	2130	ZO-84	Skier	0.2	Remained	9 / –
4/23/83	0000	TI-83	Skier	0.3	Remained	3 / –
5/29/83	1416	TI-83	Skier	0.3	Departed	7 / 19
4/24/83	1300	GI-83	Skier	0.4	Remained	23 / –
4/28/83	2000	TI-83	Skier	0.4	Remained	5 / –
5/18/83	1300	TI-83	Skier	0.4	Remained	12 / –

Table 20 (Continued).

Date	Time	Seal no.	Noise	Approximate distance to lair (km)	Seal's response	Bout durations (hours) Haulout/non-haulout
5/26/83	2000	TI-83	Skier	0.4	Remained	12 / –
3/26/84	1130	LK-84	Skier	0.4	Remained	12 / –
4/01/84	1300	LK-84	Skier	0.4	Remained	13 / –
4/02/84	1300	LK-84	Skier	0.4	Remained	7 / –
4/03/84	1300	LK-84	Two skiers	0.4	Remained	8 / –
4/04/84	1400	LK-84	Skier	0.4	Remained	7 / –
4/08/84	1600	LK-84	Skier	0.4	Remained	7 / –
4/10/84	1200	LK-84	Skier	0.4	Remained	4 / –
4/11/84	1330	LK-84	Skier	0.4	Remained	10 / –
4/18/84	1130	LK-84	Skier	0.4	Remained	11 / –
5/23/83	1600	LR-83	Skier	0.4	Departed	6 / 24
4/09/84	2200	ZO-84	Skier	0.4	Departed	2 / 22
3/07/84	1630	LU-84	Skier	0.5	Remained	7 / –
3/17/84	2000	HU-84	Skier	0.6	Remained	13 / –
3/10/84	1300	HU-84	Skier	1.0	Remained	14 / –
4/15/84	1310	ZO-84 basking	Skier	1.5	Departed	5 / 50
4/15/83	1250	GI-83	Dog running	0.05	Departed	4 / 58

human activities on the ice (especially stable, unbroken ice), extend beyond hunting and include industrial development. Noise associated with that development may adversely affect ringed seals and assessment of such effects requires detailed information about ringed seal ecology. Ecological concerns relevant to potential noise impacts include: (1) the areal distribution of subnivean seal structures, (2) the temporal distribution of those structures, (3) the temporal patterns of haulout on the ice, (4) the numbers of seals utilizing individual subnivean structures and the number of structures utilized by individual seals, and (5) the nature of the seals' dependency on subnivean structures.

Areal Distribution of Subnivean Seal Structures

The pupping habitat of ringed seals was believed to be confined generally to shorefast ice (McLaren 1958; Burns 1970; Smith 1973*a*), areas important for seismic profiling and gravel island construction. Recent evidence suggests that the drifting pack ice also may be important pupping habitat for ringed seals (Lentfer 1972; Finley *et al.* 1983; Burns unpubl. data), hence icebreaking ships also may create additional sources of disturbance to ringed seals during the critical periods of pupping and nursing.

The distribution of ringed seal lairs is influenced by the depth of snow on the ice; a minimum of 20 cm is required for lair construction (McLaren 1958; Smith and Stirling 1975; Burns and Kelly 1982). Shallow drifts limit the amount of insulation to the lair. Insufficient insulation can result in the lair being abandoned, as we observed in central Kotzebue Sound in 1984, or freezing of the newborn pup (Lukin and Potelov 1978). We think that the relatively low ratio of lairs to breathing holes in Kotzebue Sound in 1984 resulted from low snow depths and that it probably contributed to the low productivity of seals. Ice deformation of sufficient relief to promote deep drifts also can limit lair distribution. Areas of flat ice often contain breathing holes but cannot accommodate lairs. Even given adequate snowfall and ice deformation, suitably deep snow drifts still may not form if wind direction is erratic. Frequent changes in wind direction result in small, unstable drifts with few lairs, as we saw in northern Kotzebue Sound in 1984.

Breathing holes do not have the same requirement for insulating snow cover as do lairs and can be found in areas of essentially no snow cover and no deformation. Our aerial surveys indicated reduced frequencies of seals in areas of greater than 40% ice deformation, perhaps because seals are less likely to be ambushed by polar bears on the flatter ice (Burns *et al.* 1981*b*). Comparisons of seal densities in rough and flat ice are confounded, however, by the fact that seals are more difficult to see when they are hauled out in the rougher ice.

Water depth was comparatively uniform in both of our study areas, and hence could not have influenced the distribution of seal holes there. Several breathing holes and lairs were found in locations where water depth under the ice was less than 2 m. Aerial surveys in the eastern Beaufort Sea have suggested a slight preference by basking seals (June) for water depths from 50 to 100 m (Stirling *et al.* 1982).

Smith and Stirling (1975) gave the mean distance between breathing holes in one area as 233 m (S.D. = 163) and between lairs as 124 m (S.D. = 105). Those distances probably exhibit great variation from place to place, depending on the density of seals in the area, the snow cover, and the ice conditions. They also described "lair complexes," which were clusters of lairs around pupping lairs and within 3 to 65 meters of one another. Such complexes were thought to provide alternative haulout sites for pups and thus some protection from predators. We found adult males as well as females (including those with pups) using more than one lair, although generally separated by greater distances (up to 4 km) than described by Smith and Stirling (1975). Smith and Hammill (1981) suggested that female ringed seals maintain under-ice territories around birth lair complexes, and that several of those territories are contained within a larger territory maintained by a male. We found some support for that idea in the distribution of breathing holes and lairs used by radio-tagged seals. Distances between structures used by individual males averaged almost three times as great as distances between structures used by individual females. We have no direct evidence of territorial behavior, but the abandonment of lair 84C095 by a subadult male, HU-84, may have been the result of displacement by another seal. His occupation of that lair decreased in April, when another seal began occupying it more frequently.

Temporal Distribution of Subnivean Seal Structures

Ringed seals begin to maintain breathing holes through the ice when it first forms in the autumn. Excavation of lairs must await the accumulation of sufficient snow depth, which usually occurs by late February. Lairs with "pup tunnels" are first evident shortly after the onset of pupping in late March. By then, seal holes frequently are found in ice two or more meters thick, indicating that those holes must have been maintained for several months as the ice thickened. The distribution of seal holes, however, does not remain static throughout the winter. We have observed several instances in which seals opened new holes when cracks formed late in the winter, even in the relatively stable ice of southern Kotzebue Sound. Over the course of several days in April, a lair, eventually occupied by a female and pup, was excavated in the snow above a breathing hole that was opened in a new crack. Breathing holes remain important until ice breakup, but lairs are abandoned when the snow begins to soften, generally in late May or early June along the coast of Alaska.

Frequency and Duration of Haulout Bouts

From March to early June, ringed seals tend to spend increasingly longer periods hauled out. At the same time, there is a shift from generally arrhythmic to a rhythmic pattern, with a strong peak in the midday period. These longer periods out of the water may be necessitated by the onset of new hair growth, which can span three months (Ashwell-Erickson *et al.* 1986). Growth of new hair apparently requires sustained epidermal temperatures above those which can be attained in the water (Feltz and Fay 1966). Molting (shedding) of the old hair begins while lairs are still being used and continues through the basking season (pers.

obs.). During the molt, seals are more subject to stress (Ronald *et al.* 1970; Geraci and Smith 1976) and thus may be more sensitive to noise disturbances.

Females caring for pups especially increased the frequency and length of haulout bouts after parturition. Post-parturient females and their pups spent more time in lairs than did males or nonlactating females, confirming that they are especially vulnerable to disturbance during the nursing period. On-ice industrial activities thus are likely to have negative effects on ringed seals during midday from late March to late May.

The radio-tagged seals generally spent 80% or more of their time in the water, but we can do little more than speculate on their activities under the ice. The under-ice range of ringed seals remains unknown and probably varies with prey availability, breeding status, and access to air. Female seals may range beyond the vicinity of their lairs prior to pupping and after the pup is weaned, but care of the young may restrict them during the nursing period. Similarly, males may range more extensively before and after the breeding season than during it, when they presumably maintain under-ice territories. Prey distributions may be patchy in time and space, which would favor extended underwater ranging, although little is known about the distribution and abundance of ringed seal prey in winter. Access to air may limit under-ice movements in areas of extensive, flat ice cover but may not be a problem where the ice is highly deformed or leads are numerous. The long periods of non-haulout by radio-tagged seals in Kotzebue Sound and the high density of breathing holes there suggested that those seals may have been unrestricted in under-ice range.

Relationship Between the Number of Seals and the Number of Holes

Our data have shown that, in most instances, each ringed seal maintains more than one lair and that two or more seals may share maintenance of several breathing holes. Preventing breathing holes from freezing over requires frequent abrading of the ice, and to share that cost with other seals is energetically efficient. We consider the average number of lairs (2.85) used by radio-tagged seals in this study to be conservative, since many haulouts could not be ground-truthed to document the haulout site. Seals that abandon lairs in response to the activities of predators, human beings, or other seals are likely to have one or more alternative haulout sites and may not be greatly disadvantaged. Alternative haulout sites used by females (and their pups), however, are restricted to smaller areas than are those used by males. Local disturbances thus are more likely to drive females and dependent young from their normal home range. The fate of seals displaced from their home range and deprived of their regular alternate lairs is unknown.

Our data suggest that, generally, only one seal occupies a particular lair. Inuit hunters of the shorefast ice recognize certain large lairs as being used by more than one seal (Smith and Stirling 1975) and at least one large lair (84C095) in our study was used by two or more seals. As stated previously, we think that seal may have been displaced by another, but we cannot discount the possibility that the two seals simply shared the lair. The extent to which more than one seal uses a lair remains unknown but could be investigated by further studies of radio-tagged seals and by equipping lairs with thermistors and microphones to detect the presence of seals. The ratio of lairs to seals would provide the basis for accurate estimates of seal numbers per unit area. The ratio could be applied to counts of lairs using trained dogs (Smith and Stirling 1978; Burns and Kelly 1982; Hammill *et al.* 1985) to yield an accurate estimate of seal density. Surveys of lairs are inexpensive relative to aerial surveys and can cover large areas. At present, however, lair surveys provide only relative indices of abundance, rather than accurate estimates of seal density.

Advantages of Subnivean Lair Occupation

The mean duration (5.4 hours) of haulout bouts by ringed seals in lairs is close to the time required for clearance of the digestive tract (6 to 8 hours: Parsons 1977), suggesting that haulout in lairs may be related, in part, to digestion between foraging bouts. Lair occupation also may provide protection from predators and from cold.

Predators of ringed seals other than man include gulls, ravens, wolverines, wolves, dogs, killer whales, walruses, red foxes, Arctic foxes, and polar bears (Fay 1960; McLaren 1962; Burns 1970; Stirling and Calvert 1979), but only the last two are of real significance in the fast ice.

By giving birth to her pup inside of a lair, the female seal presumably protects the helpless pup to some degree from predators. Lairs help protect seals by making them invisible during haulout and by offering a barrier through which the predator must penetrate to gain access to the prey. Nonetheless, they are not completely protected, as Arctic foxes (*Alopex lagopus*) and polar bears (*Ursus maritimus*) can detect them in the lair by smell and then penetrate the lair by digging or, in the case of polar bears, sometimes by jumping on and collapsing the lair (Smith 1976, 1980).

Despite repeated examinations of many of the lairs in the Beaufort Sea study area, we found only 13.6% to have been entered by Arctic foxes, in contrast to 30.5% found by Smith (1976) in eastern Amundsen Gulf. Smith found the average annual predation rate by foxes to vary from 4.4% to as much as 57.7% (26.1% overall) of pup production. We examined 11 pupping lairs and found that three (27.3%) pups had been taken by foxes. Fox predation clearly varies widely from year to year and with the status of local fox populations. Foxes and pupping lairs are less numerous in the western than eastern Beaufort Sea and foxes probably have less influence on ringed seal numbers there, as well.

Arctic foxes are not known to take ringed seals older than pups, but polar bears prey on seals of all ages and most heavily on those under 2 years old (Stirling and Smith 1977; Stirling and Archibald 1977). In many regions, the bears are most successful preying on ringed seals in the moving pack ice (Stirling *et al.* 1975; Stirling and Archibald 1977). In some areas, however, bears are successful hunters of seals also in the stable shorefast ice where they catch seals both at breathing holes and in lairs (Smith 1980). Bear depredation of lairs in the shorefast ice of the Canadian Arctic varied regionally from 1.6 to 20.3% or more, with the success rate varying between 17 and 33% of the depredated lairs. Taugbøl (1982) reported that polar bears opened 62.2% of 193 lairs that he examined in Kongsfjorden, Svalbard, and that the bears were successful in 5.8% of the lairs, apparently obtaining just pups. Polar bears rarely are seen in Kotzebue Sound, and we saw no evidence of their presence in 1984. In the Beaufort Sea, however, we saw evidence of bears in our study area both in 1982 and 1983, but found no evidence of predation. A sow with two cubs passed through our study area in 1983 and, just outside of that area, opened 10 lairs, killing at least four seals (S. Amstrup pers. commun.). The use of multiple lairs by individual seals probably lessens the likelihood of successful bear predation, as suggested by Smith (1980). He also suggested that many lairs in close proximity, but randomly distributed, further decreased the success rate of the bears' attempts at predation.

In order to exploit arctic waters successfully throughout the year, ringed seals must be able not only to maintain holes through the ice but also to maintain their deep body temperature of approximately 37°C. As with other pinnipeds, core temperature is preserved chiefly by means of the insulating blubber layer and the heterothermism of superficial tissues (Irving and Hart 1957; Fay and Ray 1968; Ray and Smith 1968; Taugbøl 1982). Because subcutaneous fat, not the hair, is the effective insulator in the water, adult seals must circulate significant amounts of blood to the periphery to avoid freezing the skin. Healthy adult ringed seals appear to be thermally neutral in seawater near freezing and, probably, at much lower air temperatures. Taugbøl (1982) gave the lower critical temperature in air as -10°C, but that seems high considering that ringed seals are thermally neutral in water below 0°C. Windchill temperatures considerably lower than -10°C occur in much of the ringed seals' range during winter. Our data indicate, however, that temperatures inside subnivean lairs remain above -10°C even when ambient windchill temperatures are as low as -61°C.

At birth, ringed seals have little or no blubber and rely on a woolly coat, the lanugo, for insulation. The lanugo is an excellent insulator in air but offers almost no protection from cold when wet (Ray and Smith 1968). The blubber layer is deposited during the nursing period and the lanugo is replaced by an adult-like pelage, at about the time of weaning. Before the blubber layer is deposited, ringed seal pups have little tolerance for extreme cold, especially if they are wet. The lower critical air temperature for dry pups in lanugo is close to -25°C (Taugbøl 1982), considerably above common ambient temperatures during the pupping season but much lower than the coldest temperatures we recorded inside lairs. Taugbøl (1982) has presented evidence that pups in lanugo do escape predators by moving, or being moved, through the water to alternate lairs and that they thereafter can dry and regain thermal neutrality. The relatively great depth of snow drifts in which birth lairs are excavated may serve to provide extra insulation for the thermally vulnerable pups.

The seasonal timing of whelping may be an evolutionary compromise between warmer air temperatures later in the spring and cooler temperatures that favor the integrity of the snow covering lairs earlier in the spring. In late spring, the lairs begin to collapse from excessive warming. Whelping at that time would result in pups being exposed to relatively mild air temperatures but significant windchill and moisture. The net result probably would be greater heat loss than is experienced by pups born earlier in lairs when outside air temperatures are still quite low.

On several occasions we recorded air temperatures of occupied lairs considerably above freezing. That such high temperatures are common in lairs is evident from our frequent observations of lair interiors showing signs of considerable melting and refreezing of the snow walls and ceiling. Contrary to the observations of Irving (1968), we often have noted signs of melting where seals have lain on the ice. In most lairs, a seal-shaped depression was evident on the floor, and in some instances, large icicles hung down from the ceiling above that same depression. Frequently, a thin layer of the ceiling had partially thawed and refrozen as dense ice. That hard layer gives additional strength to the lair (making it harder to penetrate by predators) but, presumably, limits gas exchange with the outside. Lukin and Potelov (1978) suggested that the network of peripheral tunnels excavated by pups might function to increase gas exchange. The large amount of heat given off by seals in lairs indicates that they are perfusing their peripheral tissues with blood, warming the skin to comparatively high temperatures. This supports the idea that such haulout periods are important for growth and regeneration of peripheral tissues (Fay and Ray 1968). As discussed previously, haulout inside of lairs probably is important for new hair growth, which can begin even when outside temperatures, as well as water temperatures, would prohibit epidermal regeneration.

Proportion of Seals On the Ice During the Basking Season

Aerial surveys have been used extensively to count ringed seals basking on the ice during the molt in June (Burns and Harbo 1972; Smith 1973*a*, 1973*b*; Stirling *et al.* 1977; Smith *et al.* 1978; Finley 1979; Burns *et al.* 1981*a*; Kingsley *et al.* 1985). The greatest numbers of seals generally are visible in the midday period, and surveys usually are flown at that time. Although an unknown proportion of the local population remains unseen and uncounted under the ice, it is thought to be insignificant (McLaren 1966), less than 20% (Fedoseev 1971), less than 30% (Finley 1979), or as high as 50% (Smith 1973*a*). The counts, however, have been assumed to be reliable as indices of relative abundance when flown in the same midday period, under similar weather conditions.

The proportion of a radio-tagged sample on the ice during an aerial survey would yield an estimate of the proportion of the population that was visible. Such an estimate could be used to correct for the under-ice proportion, hence allowing an estimate of the total population. The variation in proportions of tagged samples on the ice throughout the survey period should be measured to test the assumption that the same relative proportions of local populations are basking in different areas or in the same area in different years. There may well be significant variation in that proportion even under seemingly comparable survey conditions, and estimates of the proportion of seals basking during each survey will be necessary if the area-to-area or year-to-year comparisons are to be reliable.

The timing of the molt, hence of the basking season, undoubtedly varies among individuals, depending on their sex, age, reproductive condition, general health, stability of the ice, and latitude. Harbor seal (*Phoca vitulina*) adults generally molt one month or more after yearlings (Kelly 1981), and a similar lag probably applies to ringed seals. The dates adult seals begin basking vary by as much as one month, as we observed in both the Beaufort Sea and Kotzebue Sound.

Estimates of ringed seal numbers have been made from surveys flown during the empirical peak in haulout numbers (midday in early to mid-June). Nonetheless, the variance in the proportions of all seals basking may be lowest at a time when some lesser proportion of the population is basking. Estimates of numbers from surveys conducted at those times may be more reliable. The efficacy of aerial surveys as a method of counting basking ringed seals, thus, would be greatly improved by monitoring a sample of radio-tagged seals throughout the entire basking period.

Aircraft support was not available through the basking seasons of 1982, 1983, or 1984. We were able to collect some data on the proportion of seals basking in early June of 1982, but sample sizes were too small in that limited effort to warrant any general conclusions. We examined the effect of the sample size of radio-tagged seals on the variance of a population estimate, based on aerial surveys corrected for the proportion of seals not basking. The variance of that estimate can be approximated using a Taylor series (Mood *et al.* 1974) to combine the variance of observed densities and the binomial variance of the proportion of seals visible. The covariance can be assumed to be zero since the two variance terms are logically independent. In a computer simulation, we found that, for tagged samples of 5 to 10 seals, the combined variance term is smallest when p, the proportion of tagged animals visible, is 0.60 or greater. For $p > 0.60$, the variance is improved little by increasing the number of tagged animals beyond eight. Thus, haulout data from 8 to 10 radio-tagged seals would be adequate for correcting density estimates from aerial surveys.

Reactions of Ringed Seals to Noise Disturbance

Sound levels of sufficient energy to cause physical harm to seals are extreme (Rausch 1973; Geraci and St. Aubin 1980) and unlikely to result from current methods of petroleum exploration and development. Noise levels of sufficient energy and duration to cause ringed seals to abandon breathing holes and lairs at greater than normal rates can result from seismic profiling with Vibroseis equipment (Burns and Kelly 1982) and probably from other on-ice industrial activities. Assessing the significance of that increased rate of abandonment requires information about the degree of dependency that ringed seals have on subnivean structures and the degree of geographical overlap between ringed seal populations and the activities causing abandonment.

Judging from the relative rates of abandonment of seal structures near and at various distances from human activities, we found that ringed seals have highly variable reactions to noise disturbances. Similar variability in response to human disturbances has been reported in harbor seals (Pitcher and Calkins 1979) and walruses (Fay *et al.* 1984). Some ringed seals' structures remained in active use despite close proximity to seismic survey lines, snow machine trails, gravel island construction, and flight paths of helicopters and small planes. Other structures were abandoned quickly when exposed to noises at greater distances. Part of the variation in the response of individuals to noise may have been due to differing levels of ambient background noise. The seals' sensitivity to potentially disturbing sounds may lessen when background noise, such as from wind-driven snow or ice strain, is high. Because individual responses to noise disturbance are so variable, critical distances for various activities are difficult to define. Although we found fewer active seal structures within 150 m of seismic lines than beyond that distance, we cannot say how the rate of abandonment changes within that range, which was chosen on the basis of sample size, rather than distance per se.

The frequency of occurrence of disturbances may have more influence on abandonment of structures than does the specific source of disturbance. Of the radio-tagged seals within the simulated seismic survey area in 1983, only one seemed to abandon a lair. GI-83 apparently abandoned his lair after human disturbances caused him to flee into the water at least six times, more than any other seal in the study (mean = 2.3). We cannot be certain that the lack of signals from his transmitter after 26 April resulted from him abandoning his lair, but the very high retention rate of transmitters on other seals is evidence against the possibility of his transmitter having failed or been lost.

The radio-tagged seals spent the majority of time in the water. Little is known about their activities under the ice, although much of it presumably involves feeding and, perhaps, territorial defense. Sound is readily conducted through the sea ice, into the water, and the effects of noise disturbance on seals under the ice remains unknown. The smaller proportion of time that seals spend in subnivean lairs, nonetheless, appears to be essential to the seals' well-being, and the dependence on the lairs is especially great for pups. Disturbances that cause them to leave the lair can affect them adversely in several ways. If a pup in lanugo is forced to flee into the water, it may not survive the resultant heat loss. Pups that do survive swimming through the water to an alternate lair will have to expend significant amounts of energy reserves in order to maintain core temperature while drying (Taugbøl 1982). Such pups will be easier prey for polar bears and Arctic foxes and will be less able to withstand other stresses. Lair occupation becomes increasingly frequent for older seals throughout the spring months, apparently due to the need to maintain higher epidermal temperatures for new hair growth. Ringed seals are likely to be most negatively affected by noise disturbances when they are most dependent on hauling out – from late March through June.

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