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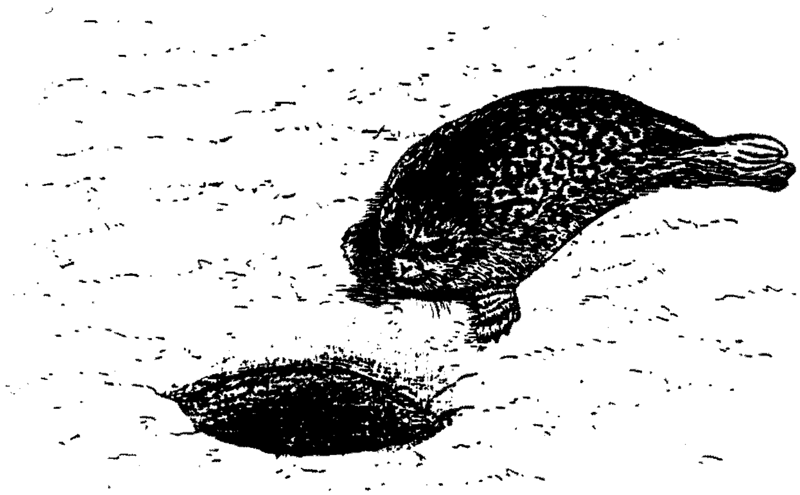
Ringed Seal Monitoring: Relationships of Distribution and Abundance to Habitat Attributes and Industrial Activities

Principal Investigators

Kathryn J. Frost and Lloyd F. Lowry
Alaska Department of Fish and Game
1300 College Road
Fairbanks, AK 99701

Assisted by

James Gilbert, Susan Hills, and Dawn Hughes



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I. Summary

Results of aerial surveys of ringed seals on the shorefast ice of the eastern Chukchi Sea and Beaufort Sea in May-June 1986 are reported and compared with results of similar surveys conducted in 1985.

The selected data base in 1986 included 3,598 nm of trackline and 1,766 nm^2 of area actually surveyed. In the Chukchi Sea, between (and including) Kotzebue Sound and Barrow, 19% of all fast ice was surveyed; in the Beaufort Sea we surveyed 11% of all fast ice between Barrow and Barter Island. Coverage was similar to that in 1985.

The density of seals on the fast ice in 1986 was highest in the Chukchi Sea from Kotzebue Sound to Point Lay; mean density was 5.4 seals/nm^2. Densities in the northern Chukchi and Beaufort seas were considerably lower (2.9 and 3.3 seals/nm^2). Within the Beaufort Sea, the observed density of seals was lowest between Barrow and Lonely (2.1 seals/nm^2), and almost 75% higher in the central region between Lonely and Flaxman Island (3.6-4.0 seals/nm^2).

In all sectors except sector B1 between Barrow and Lonely, where densities remained similar, the density of seals at holes and of total seals on the fast ice was significantly higher in 1986 than in 1985. For the Chukchi Sea as a whole, densities were 1.6 times higher in 1986; an estimated 24,000-30,000 seals were hauled out on 5,800 nm^2 of fast ice in 1986 compared to 12,000-16,000 seals on 4,900 nm^2 of fast ice in 1985. In the Beaufort Sea, the increase in observed densities was much smaller; the extrapolated estimates of total seals on all fast ice were similar (19,000-25,000 on 7,700 nm^2 in 1985; 21,000-29,000 on 6,500 nm^2 in 1986).

In 1986, industrial activity in the Beaufort Sea was greatly reduced from previous years. The only obvious nearshore activity was associated with 3 artificial islands northwest of Prudhoe Bay. Comparisons of seal density around those islands with adjacent "control" areas indicated no detectable negative effect on ringed seal distribution or abundance. As in 1985, densities were higher in the industrial block than in adjacent control areas.

In 1986, replicate surveys were flown in 4 sectors. Surveys conducted 3-4 days apart under similar ice conditions yielded statistically similar estimates of density. Surveys flown 7-14 days apart, interrupted by a storm which caused major changes in ice conditions, resulted in significantly higher density estimates for all post-storm surveys. We think that these increases, from 3 to almost 8 seals/nm^2 were caused by an influx of seals from other areas; data regarding the proportion of seals at cracks, changes in average group size, and the distribution of seals relative to the fast ice edge support this hypothesis.

In future monitoring efforts it will be necessary to screen all data used in year-to-year comparisons to ensure that only surveys flown before break-up begins and under similar environmental conditions, specifically, similar ice conditions are included. In 1987, this project will emphasize the development of numerical criteria which can be used to screen such data.

II. Introduction

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) as follows: "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 U.S., U.S.S.R., and Canada (Lowry et al. 1982; Davis et al. 1980).

Ringed seals are the major prey of polar bears (Ursus maritimus) (Smith 1980; ADF&G unpublished), 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 sea birds, 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 waters of northern Alaska.

Factors limiting the abundance of ringed seals are poorly known. 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 mediating 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 their ecological importance 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, 1981a, b; Lowry and Frost 1981), distribution, characteristics, and utilization of ringed seal lairs (Burns and Kelly 1982; Kelly et al. 1986), and distribution and abundance of seals hauled out during the molt (Burns and Eley 1978; Burns et al. 1981a; Burns and Kelly 1982). These studies have also, to some extent, addressed the issue of possible effects of Outer Continental Shelf exploration and development activities on the distribution, density, and behavior of ringed seals (Burns et al. 1981a; Burns and Kelly 1982; Kelly et al. 1986).

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. That contract was awarded to the Alaska Department of Fish and Game (ADF&G). Work on this project began on 1 January 1985. In February 1985, a research protocol was developed by ADF&G and finalized in consultation with NOAA and MMS. During the period from January to June 1985, ringed seal aerial survey data collected by ADF&G during 1970-1984 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. 1985a).

Ringed seal aerial surveys based upon the design specified by the research protocol were flown from 20 May through 15 June 1985. The surveys were satisfactorily completed and the data analyzed to determine regional and temporal patterns of seal abundance, and the effects of habitat attributes and industrial activities on seal density (Frost et al. 1985b). Results indicated that observed densities of ringed seals are quite dynamic, with year-to-year fluctuations in abundance in several areas. In 1985 high seal densities occurred in the pack ice, which received relatively little survey effort. On the shorefast ice, density was related to ice type and to distance from shore and from the edge of landfast ice. Seal density was high in the "industrial" area in the central Beaufort Sea. An analysis of density in relation to distance from artificial islands indicated the possibility of some localized displacement of seals within 2 nm of the islands.

Ringed seal aerial surveys based on the 1985 research protocol, with minor modifications, were again flown from 20 May through 16 June 1986. This interim report describes results of the second year of the monitoring program.

Background

The distribution of ringed seals in Alaskan waters is strongly correlated to that of sea ice (Burns 1970; Fay 1974). In the Bering, Chukchi, and Beaufort seas, these seals are most abundant in association with seasonal ice, although they range north in multi-year ice at least as far as 85°N latitude (Burns and Eley 1978). The seasonal expansion and contraction of the sea ice habitat requires that a significant proportion of the population is "migratory" while, during the same annual cycle, other animals may be relatively sedentary or undertake only short seasonal movements. Marking studies undertaken in the eastern Beaufort Sea have demonstrated both short- and long-distance movements (Smith and Stirling 1978; T. G. Smith, pers. commun.).

During summer and early autumn ringed seals are abundant in nearshore ice remnants in the Beaufort Sea and in the pack ice of the Chukchi and Beaufort seas (Burns et al. 1981b). 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 near Bering Strait and in Norton Sound throughout autumn and early winter. In mid-winter 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. 1981b). Few ringed seals are found in the ice front and fringe zones at the southern extent of seasonal sea ice in the Bering Sea (Burns et al. 1981b).

Northward movement, mainly by subadults, begins in April and is well underway by May. Adults migrate as the fast ice breaks up, pups remain in the ice remnants or move into the adjacent pack, and immatures 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 and southern Chukchi seas during summer, but most move farther north with the receding ice (Burns et al. 1981b; Lowry et al. 1982).

Although some consideration has been given to 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; Kingsley et al. 1985). Since ringed seal surveys are flown in late spring, aspects of the biology 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 in areas covered by shorefast ice, seals are basically dependent on breathing holes for access to air from about November to June. These holes may be initially formed by breaking through thin ice with the head or nose, but as the ice thickens they are kept open by abrading with front flipper claws. Since many seals may surface in cracks and leads whenever they occur, the pattern of freeze-up may greatly influence the ultimate distribution pattern of seals on the shorefast ice (see Smith et al. 1978, 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 to 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).

Lairs are of 2 basic types--haulout lairs which are simple structures usually more or less oval in shape; and pupping lairs which are more complex structures, usually with 1 or more side tunnels or chambers. Lairs are used for resting as well as social functions such as the birth and care of pups. Characteristics and dimensions of lairs have been well described by Smith and Stirling (1975).

As day length and temperature increase in the spring, increasing numbers of ringed seals appear hauled out near breathing holes or lairs. This hauling-out is associated with the annual molt which occurs in May-July (McLaren 1958). The numbers of seals seen hauled out in particular fast ice areas varies with the normal chronology of hauling out of resident seals, as well as possible influxes of seals from adjacent areas. McLaren (1961) first recognized that timing of the haulout period varies with latitude with the peak 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. Burns and Harbo (1972) state that off the north coast of Alaska maximum numbers of seals are 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 observed patterns, is essential to understanding ecological processes and interactions in waters of northern Alaska. This research project was designed to address those questions. Specific objectives are 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;

4. refine monitoring protocol for long-term studies on abundance of ringed seals in Alaskan coastal waters.

III. Methods

A. Study area

In 1986 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 to Barter Island. The study area was divided into 11 sample units that corresponded to sectors used in previous surveys and reports (Burns and Harbo 1972; Burns and Eley 1978; Frost et al. 1985b). Sector boundaries corresponded to easily identifiable landmarks such as capes, points, villages, or radar installations (Figure 1).

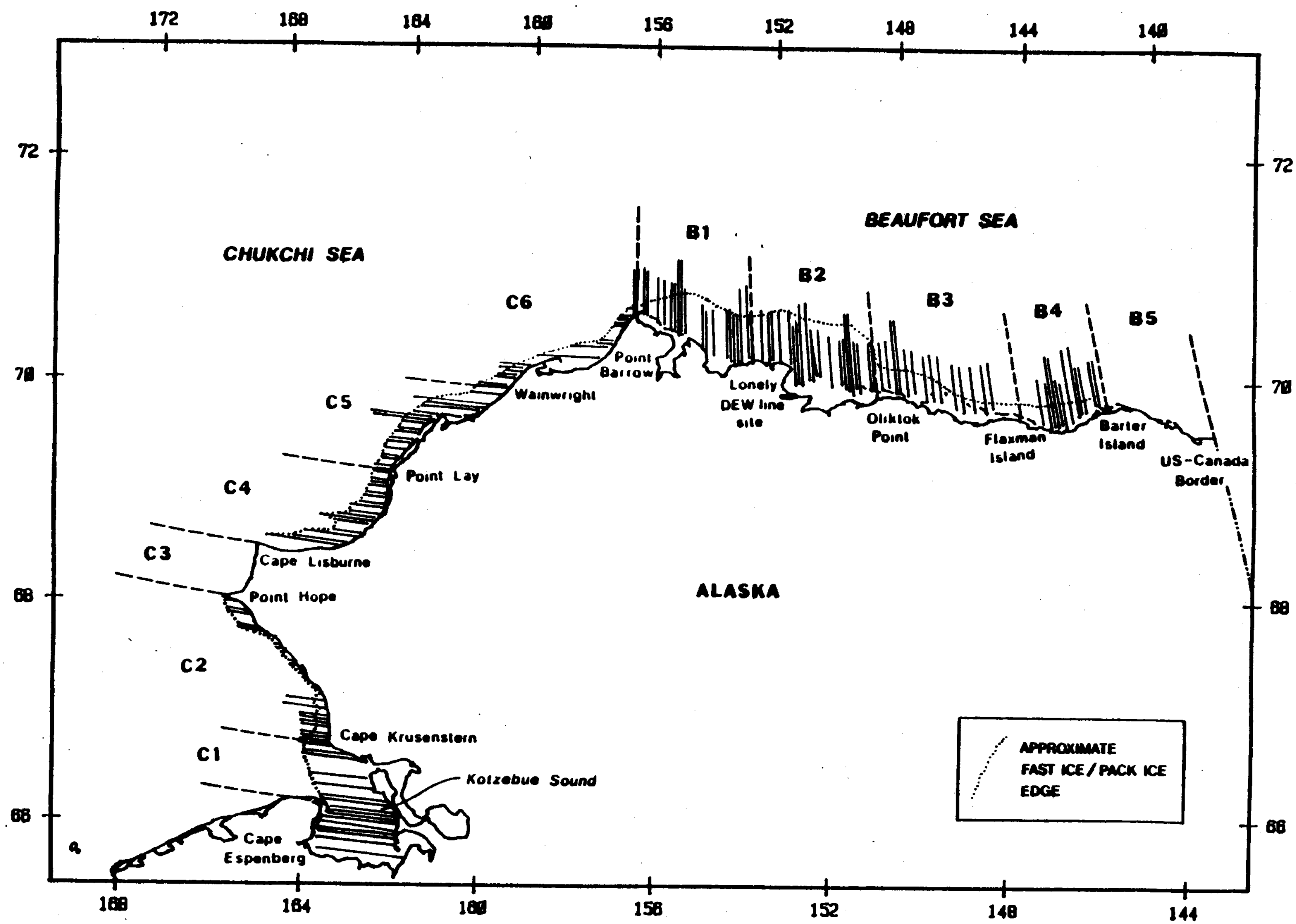

Figure 1. Map of northern Alaska showing sectors and selected 1986 survey lines used in the analysis of ringed seal aerial surveys.

B. Aerial survey design

Surveys of 9 sectors (all those shown in Figure 1 except C3 and B5) were flown between 20 May and 16 June 1986, beginning with the southernmost sector in Kotzebue Sound and proceeding north and east. Surveys in the Chukchi Sea occurred from 20-30 May and in the Beaufort Sea from 31 May-16 June.

Surveys were conducted between 1000 and 1600 hrs true local time to coincide with the time of day when maximal numbers of seals haul out (Burns and Harbo 1972; Smith 1975; Finley 1979; Smith and Hammill 1981). This diel pattern follows daily fluctuations in temperature and incident radiation (Finley 1979). On a few days when survey conditions were considered excellent, the survey window was extended to 1700 to allow completion of a sector.

The aircraft used was a fixed-wing Twin Otter equipped with bubble windows, 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, latitude, and longitude at beginning and end points of each transect and 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 all sectors were surveyed at 500 ft altitude; in the Beaufort Sea, low cloud ceilings necessitated a survey altitude of 300 ft. Two sectors, C6 and B1, 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 sat in the co-pilot's seat and recorded weather, ice conditions, and navigational information, and 2 observers stationed on either side of the aircraft just forward of the wings. During the first 10 days, a fourth person served as a back-up 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 nm out from the centerline and extended out to 0.5 nm for an effective width of 0.375 nm (2,250 ft). At 300 ft, the inclinometer angles remained the same and the effective track width was reduced to 0.225 nm (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 15 nm 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 nm wide, many transects were, in fact, considerably shorter than 15 nm. In the Beaufort Sea, transect length was 25 nm. In most sectors (except those with extensive open water) 4 transects were extended to 40 nm 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

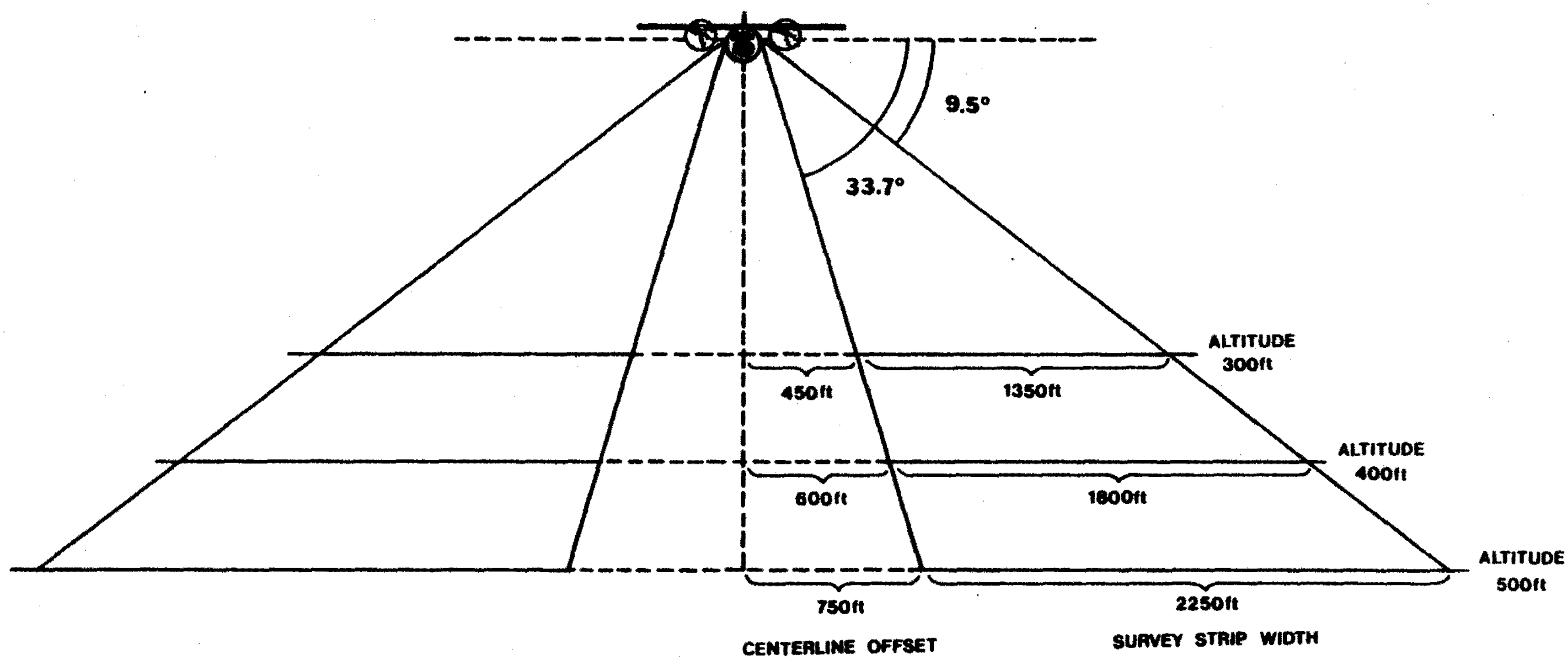

Figure 2. Diagram showing inclinometer angles, centerline offsets, and survey strip widths for ringed seal surveys.

identifiable. In those instances when it was not, the edge was determined based on satellite photographs taken during the same time period and the data were coded accordingly.

The survey was flown according to a stratified random strip transect design. Transect lines were spaced approximately 2 nm between centerlines (2 minutes of latitude, 6 minutes of longitude); within each sector, 60% of the possible transects were randomly selected and flown. In the sector of the Beaufort Sea where on-ice industrial activity is greatest (B3, Oliktok to Flaxman Island) coverage was intended to be 90%. In addition, replicate surveys of sector B3 were flown on 3 different days.

All data were recorded by 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, most polar bear tracks, belukhas (Delphinapterus leucas), and bowhead whales were recorded, as was the presence or absence of cracks in the fast ice and any evidence of on-ice human activity (e.g., seismic lines, artificial islands, drill ships).

Four ice parameters 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 percent 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. Parameters 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 conditions off shore 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 precluded the inference of surface winds from indicators such as white caps or blowing snow.

Table 1. Environmental data recorded during aerial surveys.

Parameter	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	nm	Distance from aircraft that observers can see at survey altitude.

C. Data analysis

Counts of seals at cracks and 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 x interval x strip width. Each minute interval therefore had assigned to it latitude and longitude (of the beginning point), area (nm^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/pack 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). Sample unit was a survey leg or portion thereof (e.g., minute interval) that conformed to requirements of the analysis.

IV. Results

A. Survey effort

During spring 1986 aerial surveys, approximately 84 hours of flight time were expended in the successfully completed sectors. The aircraft flew an estimated 10,080 nm during survey flights, of which approximately 6,100 nm were on survey trackline (Table 2). Coverage was greatest in sectors B1 and B3 where replicate flights were made to compare results at different altitudes, or to investigate day-to-day variability in counts. In sectors C2 through B2, 59%-65% of the possible transect lines were completed; in C1 and B4, 60% of the lines were flown but the data from several could not be used due to sun glare and poor visibility. Intended coverage of sector B3, the most heavily industrialized area, was 90% of the possible transect lines. Although 90% coverage was obtained, only 15 of the 34 lines flown were used in density calculations. The remaining 19 lines were flown 7-10 days after the first 15. During this period a major storm occurred and the density of seals at cracks increased so substantially that the samples were no longer statistically similar. Most lines in sectors C6 and B1 were surveyed more than once, at 300 ft and 500 ft altitudes. In C6, all selected lines (e.g., for 60% coverage) were flown 3 times, twice at one altitude and once at the other. In sector B1, 12 lines were flown at both 300 ft and 500 ft, and 13 lines were flown twice at 300 ft, several days apart. In sector B3, 20 lines were flown twice, 2-10 days apart, at the same altitude.

After all data were screened to eliminate transects flown under less than optimal conditions (e.g., poor light), and in C6 and B1 using only the

Table 2. Dates, number of legs, miles on track, and total area surveyed for each sector during ringed seal aerial surveys conducted by ADF&G 20 May-16 June 1986. Table includes all raw data.

Sector	Sector boundaries	Date	Number of legs	Altitude	Miles (nm) on track	Area (nm²) surveyed Fast	Pack
C1	Cape Espenberg-Cape Krusenstern	21 May	12	500	487	365	-
		23 May	6	500	172	126	3
C2	Cape Krusenstern-Point Hope	23 May	22	500	237	101	77
C3	Did not fly-poor ice	-	-		-	-	-
C4	Cape Lisburne-Point Lay	24 May	6	500	160	120	0
		25 May	10	500	122	92	0
C5	Point Lay-Wainwright	25 May	14	500	240	152	28
		26 May	3	500	77	52	6
C6	Wainwright-Barrow	26 May	4	500	112	45	39
		26 May	3	300	73	12	20
		27 May	4	500	91	18	51
		27 May	4	300	96	14	29
		30 May	15	500	168	114	13
		30 May	15	300	164	69	5
B1	Barrow-Lonely (total of 6 lines)	27 May	4	500	74	32	24
		27 May	4	300	74	17	16
		31 May	8	500	200	128	22
		31 May	14	300	377	103	67
		1 June	6	300	189	71	14
		14 June	9	300	237	105	2
B2	Lonely-Oliktok	4 June	18	300	534	232	8
		6 June	3	300	115	47	4
		13 June	2	300	52	24	0
		14 June	6	300	166	75	0
B3	Oliktok-Flaxman	6 June	15	300	415	183	4
		12 June	3	300	78	5	30
		13 June	16	300	444	71	129
		15 June	10	300	249	29	83
		16 June	10	300	258	57	59
B4	Flaxman-Barter	12 June	16	300	473	70	143
B5	Did not fly	-	-	-	-	-	-

preferred altitude, the selected data set from which density calculations for the fast ice were made contained 155 transect lines and an area of 1,766 nm^2 (Table 3, Figure 1). This represented 57% of the total number of possible lines at 2-nm intervals, and coverage by area of 19% of all fast ice in the Chukchi Sea and 11% of all fast ice in the Beaufort Sea between Point Barrow and Barter Island.

B. Factors affecting survey counts

1. Observer comparisons

During most surveys, a single trained observer counted seals on each side of the aircraft. Right- and left-side observers remained the same throughout the survey period. From 23-31 May at least 1 and sometimes 2 back-up observers participated in the survey 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.

Differences were greatest on 23 and 31 May when the back-up observers were not experienced at flying aerial surveys or counting seals. On the other days, differences between primary and secondary observers were not statistically significant.

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 7 of 29 flights (Table 5). On four of those, seals at cracks accounted for most of the difference between sides. When seals at cracks were excluded from comparisons only four were significantly different. There was no obvious explanation for the differences between left and right side counts on those flights.

Total counts of the numbers of seals seen by left and right observers for all days were compared. Although the left observer saw 8% more seals than the right observer (7,229 vs 6,688), the difference was not significant ($t=0.316$, $df=56$, $p>0.7$).

2. Altitude

In the Chukchi Sea, all sectors were surveyed at 500 ft altitude. In the Beaufort Sea, survey altitude was 300 ft due to the regular occurrence of low cloud ceilings and/or fog.

Sectors C6 and B1 were surveyed at both 300 ft and 500 ft to determine comparability of counts and the magnitude of differences at the 2 altitudes. Two methods were tested: (1) alternate pairs of lines were flown at 300 ft and 500 ft to ensure that time of day or light conditions did not differentially affect the data sets, (2) all selected lines in a sector were flown consecutively at one altitude and then, on the return flight, at the other. The first method was the least preferred since observers found it disruptive to continually switch between altitudes, with the concurrent change in search image size. Differences of a few hours in time of day and in lighting were considered to have a negligible effect when the second method was used.

Table 3. Number and percent of lines surveyed, miles on track, and area surveyed by sector for selected data only, 1986. Only these data were used in density calculations.

Sector	Number of lines	% of lines in sector	Miles on track (nm)	Area surveyed (nm^2) fast	Area surveyed (nm^2) pack
C1	16	52	595	443	3
C2	23	62	237	101	77
C4	16	62	282	212	0
C5	17	65	317	203	35
C6	15	63	168	114	13
B1	20	59	566	173	82
B2	21	62	650	280	13
B3	15	39	415	183	4
B4	12	50	368	57	109
Total	155	57	3,598	1,766	336

Table 4. Comparative counts of ringed seals made by primary and secondary observers, May 1986.

Date	Number of legs	1° Observer number of seals	1° Observer $\bar{x}$ seals/leg	1° Observer S.D.	2° Observer number of seals	2° Observer $\bar{x}$ seals/leg	2° Observer S.D.	Student's t-test
Inexperienced 2° observers								
23 May	15	644	42.9	35.0	523	34.9	30.7	t=1.53, df=14, p>0.10 n.s.
31 May	22	227	10.3	6.6	132	6.0	3.9	t=3.76, df=21, p<0.01
Experienced 2° observers								
24 May	6	339	56.5	33.9	347	57.8	33.8	t=-1.51, df= 5, p>0.10 n.s.
	6	312	52.0	37.4	293	48.8	29.4	t= 0.64, df= 5, p>0.50 n.s.
25 May	27	489	18.1	12.0	458	17.0	13.2	t= 1.69, df=26, p>0.10 n.s.
26 May	5	84	16.8	3.7	78	15.6	7.3	t= 0.48, df= 4, p>0.60 n.s.
27 May	14	88	6.3	7.7	93	6.6	10.9	t=-0.22, df=13, p>0.80 n.s.
	8	42	5.3	3.8	58	7.3	8.0	t=-0.93, df= 7, p>0.30 n.s.

Table 5. Results of chi-square analyses of the differences in counts between left and right observers for 1986 ADF&G surveys.

Survey date	Number of seals: left	right	expected	x^2	p[1]
21 May	1,009	933	971	2.97	ns
23 May	556	432	494	15.56	$p<0.005$
23 May	233	303	268	9.14	$p<0.005$
24 May	312	339	326	1.12	ns
25 May	235	214	225	0.98	ns
25 May	182	155	169	2.16	ns
26 May	125	116	121	0.34	ns
26 May	31	43	37	1.95	ns
26 May	80	60	70	2.86	ns
27 May	15	29	22	4.45	$p<0.005$
27 May	27	41	34	2.88	ns
30 May	164	221	193	8.44	$p<0.005$
30 May	128	115	122	0.70	ns
27 May	13	12	13	0.04	ns
27 May	15	10	13	1.00	ns
31 May	111	115	113	0.07	ns
31 May	117	103	110	0.89	ns
1 June	82	65	74	1.97	ns
4 June	413	432	423	0.43	ns
6 June	104	76	90	4.36	$p<0.005$
6 June	384	363	374	0.59	ns
12 June	496	454	475	1.86	ns
12 June	75	68	72	0.34	ns
13 June	680	650	665	0.68	ns
13 June	163	182	173	1.05	ns
14 June	293	249	271	3.57	ns
14 June	314	247	281	8.00	$p<0.005$
15 June	239	260	250	0.88	ns
16 June	633	401	517	52.05	$p<0.005$

[1] ns = not significant

For all 1986 altitude comparisons, regardless of method, densities of seals at holes based on counts at 500 ft were 50%-90% of those at 300 ft; 4 of 5 comparisons were statistically significant (Table 6). For all 5 flights combined, the 500-ft density was 73% of that determined at 300 ft, or conversely, 1.36 times as many seals/nm^2 were counted at 300 ft as at 500 ft. These comparisons were "block comparisons" based on adjacent but not always the same lines within a sector (e.g., the densities for May 26 were based on lines 1, 5, and 6 at 300 ft and lines 3, 4, 7, and 10 at 500 ft). For May 30 and 31, we compared only lines flown at both altitudes on the same day. On those days the combined density of seals at holes for 23 lines flown at 500 ft was 77% of those at 300 ft.

We also examined possible interactive effects of altitude and ice deformation through an analysis of variance for sectors B1 and C6. Each 1-minute interval was treated as a separate and independent observation. In sector B1, both altitude and ice deformation significantly influenced the observed density of seals, with ice the more significant (Table 7). The interaction of altitude and ice deformation was also significant, which we interpreted as meaning that the observed densities at each ice deformation class were influenced by both altitude and habitat selection by the seals. Findings were similar for sector C6 (Table 8), but the level of significance was not as high.

When ice deformation categories were grouped as 0-20 ("flat") and 20-40 ("rough") it appeared, for no known reason, that observed densities on flatter ice were considerably higher at 300 ft than at 500 ft (Table 9). For both sectors combined, the density in 0%-20% deformation, based on surveys at 300 ft, was 1.6 times that at 500 ft. In rougher ice, the ratio of densities at 300 ft and 500 ft was close to unity.

3. Weather

In 1986, we did not survey on days when we considered conditions were poor for seals to haul out, e.g., when wind velocity was greater than 20 knots. In most instances, wind velocities were less than 15 knots. We performed a multiple regression analysis of the effect of wind and temperature on the density of seals at holes in the fast ice. The data were analyzed using each survey leg as an observation, with the wind and temperature recorded at the beginning of the leg as the independent variable (Table 10). Only wind velocity was correlated with seal density. Air temperature was not correlated with either seal density, or seal density adjusted by wind velocity. Although the R-square value was very small in this analysis, we think it is probably due to the lack of survey effort at high winds or extreme temperatures.

C. Habitat factors affecting abundance

1. Ice deformation

The proportion 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.

Table 6. Comparison of densities of ringed seals at holes derived from surveys flown at 300 ft and 500 ft altitudes in sectors C6 and B1 during May 1986, fast ice only.

Sector		300 ft				500 ft				Student's t-test
		# of legs	area nm^2	seals/ nm^2	sd	# of legs	area nm^2	seals/ nm^2	sd	
C6	5/26	3	12.4	3.79	0.84	4	44.6	1.86	0.39	$t=3.67$ $df=5$ $p<0.02$
	5/27	4	13.8	2.68	0.38	4	17.8	2.42	1.12	$t=0.44$ $df=6$ $p>0.7$
	5/30	15	68.6	2.93	0.41	15	113.7	2.35	0.40	$t=3.90$ $df=28$ $p<0.001$
B1	5/27	4	17.4	1.27	0.25	4	31.8	0.79	0.20	$t=3.01$ $df=6$ $p<0.05$
	5/31	8	77.0	2.38	0.25	8	128.4	1.71	0.22	$t=5.62$ $df=14$ $p<0.001$

Table 7. Analysis of variance of effect of ice deformation class and altitude on density of ringed seals at holes in the fast ice, sector B1, 27 May-1 June 1986.

	Sum of squares	df	Mean square	F	Sig.
Total	1,411.941	310	4.555		
Altitude	17.475	1	17.475	4.338	0.038
Ice deformation	119.452	4	29.863	7.414	<0.001
Alt x Ice deformation interaction	65.459	4	16.365	4.063	0.003
Residual	1,212.411	301	4.028		

Table 8. Analysis of variance of effect of ice deformation class and altitude on density of ringed seals at holes in the fast ice, sector C6, 26-31 May 1986.

	Sum of squares	df	Mean square	F	Sig.
Total	2,204.827	212	10.400		
Altitude	37.215	1	37.215	3.768	0.054
Ice deformation	57.471	3	19.157	11.940	0.124
Alt x deformation interaction	77.466	3	25.822	2.615	0.052
Residual	2,024.529	205	9.876		

Table 9. Comparison of the effect of ice deformation on seal density at 300' and 500' altitude.

Sector	Percent ice deformation	300 ft area	300 ft seals	300 ft seals/nm^2	500 ft area	500 ft seals	500 ft seals/nm^2	density 300' / density 500'
C6	0-20	40.8	164	4.0	74.9	164	2.2	1.84
	20-40	49.7	115	2.3	95.2	193	2.0	1.14
B1	0-20	97.8	233	2.4	83.0	117	1.4	1.69
	20-40	87.7	138	1.6	74.2	127	1.7	0.92
C6 + B1	0-20	138.6	397	2.9	157.9	281	1.8	1.61
	20-40	137.4	253	1.8	169.4	320	1.9	0.97

Table 10. Regression of the density of ringed seals at holes on wind, using each line as an independent observation.

	Sum of squares	df	Mean square	F
Regression	21.065	1	21.065	7.932
Residual	1,274.658	480	2.656	

R Square = 0.016

Equation: Seal density = 2.761 - 0.040 * wind velocity (kts)

In the Chukchi Sea, 99% of all fast ice was less than 40% deformed, and 91% was less than 30%. The density of seals was highest in the 0%-10% category (5.6 seals/nm^2) and decreased steadily with increasing deformation. The densities in 0%-5% and 5%-10% ice were similar. The percent of total seals in each category was generally in proportion to the percent of total fast ice made up by that category, except for areas of 0%-10% deformation, where 60% of the seals occurred in 50% of the area (Table 11). Seal density in 0%-10% areas was over 1 seal/nm^2 greater than in the next deformation category. Cracks, and therefore seals at cracks, were not abundant in the Chukchi Sea, and there was no detectable pattern in the abundance of seals at cracks relative to ice deformation.

In the Beaufort Sea, the pattern of seal density in relation to ice deformation was similar to the Chukchi Sea; 97% of all fast ice was less than 40% deformed, with 90% less than 30% deformed. The density of seals was greatest in the 0%-10% category, where 48% of the seals occurred in 37% of the ice (Table 12). As in the Chukchi Sea, the density of seals in 0%-10% ice was over 1 seal/nm^2 greater than in 10%-20% ice.

The density of seals at cracks in the Beaufort was greatest in 0%-10% deformation (0.86/nm^2) and within that category in 0%-5% ice (1.13 seals/nm^2). It decreased steadily to 0.5 in 10%-20% ice, 0.1-0.2 in 20%-30% and 30%-40% ice, and to zero in greater than 40% deformation. Cracks are most often present and visible in large expanses of flat ice.

2. Distance from shore and/or the fast ice edge

The effect of distance from shore and from the fast ice edge on the density of hauled out seals was examined by several methods.

A multiple regression analysis was done for the density of seals at holes relative to distance from the ice edge and land. In the Beaufort Sea (sectors B1-B4 combined) in 1986, there was no relationship between either variable, or both variables jointly, and the density of seals at holes. In the Chukchi Sea, both distance to land and distance to edge were significant (Table 13). The density of seals increased with distance away from the edge of either land or shorefast ice. However, only 5% of the variability in densities was explained by these distances.

Since ice conditions and/or coastal topography were quite variable, a comparison by individual sector was also made of the density of seals with distance from shore by 2-nm increments. In all but one comparison, seals at holes were least abundant 0-2 nm from shore (Tables 14 and 15). The single exception was the early (pre-storm) B-3 data, where seals very near shore were as or more abundant than those farther off shore. This may be related to the presence of numerous barrier islands throughout the sector, some of which are almost 10 nm from the mainland. In our analyses distance from shore is measured as distance to any land whether an island or the mainland.

A similar analysis of density with distance from the fast ice edge indicated that in the Chukchi Sea the density of seals at holes was similar

Table 11. Ringed seal density (total seals) in relation to ice deformation in the Chukchi Sea in 1986, fast ice only.

Deformation (percent)	Area surveyed nm²		Seals number		Density seals/nm²
	nm²	percent	number	percent	
0-5	286.8	26.7	1,620	32.3	5.65
5-10	247.0	23.0	1,367	27.3	5.53
0-10(combined)	533.7	49.7	2,987	59.6	5.60
10-20	284.0	26.5	1,192	23.8	4.20
20-30	156.6	14.6	605	12.1	3.86
30-40	86.4	8.1	211	4.2	2.44
>40	12.0	1.1	21	0.4	1.75
Total	1072.7		5,016		

Table 12. Ringed seal density (total seals) in relation to ice deformation in the Beaufort Sea in 1986, fast ice only.

Deformation (percent)	Area surveyed		Seals		Density seals/nm²
	nm²	percent	number	percent	
0-5	111.9	16.2	533	20.2	4.76
5-10	142.8	20.6	744	28.2	5.21
0-10(combined)	254.7	36.8	1,277	48.4	5.01
10-20	205.7	29.7	807	30.6	3.92
20-30	158.9	23.0	410	15.5	2.58
30-40	51.9	7.5	105	4.0	2.02
>40	20.7	3.0	39	1.5	1.88
Total	691.9		2,638		

Table 13. Regression analysis of density of seals at holes related to distance from land and distance from fast ice edge in the Chukchi Sea in 1986.

	Sum of squares	df	Mean square	F
Regression	314.97	2	157.49	12.36**
Residual	5,463.46	429	12.74	
Multiple R	0.23347			
R. square	0.05451			

Equation: seal density = 1.350 + 0.285 * distance from land
+ 0.174 * distance from ice edge

Table 14. Density of ringed seals at holes on shorefast ice of the Chukchi Sea in relation to distance from shore, May-June 1986.

Distance from shore (nm)	Sector density (seals/nm²)				
	C1	C2	C4	C5	C6
0-2	3.47	2.16	4.24	1.88	1.66
2-4	4.11	3.56	4.85	3.09	2.22
4-6	4.18	4.42	5.02	2.74	2.37
6-8	6.69		6.62	2.69	2.71
8-10	6.61		4.55	1.81	

Table 15. Density of ringed seals at holes on thé shorefast ice of the Beaufort Sea in relation to distance from shore, May-June 1986.

Distance from shore (nm)	Sector density (seals/nm^2)				
	B1	B2	B3-early	B3-late	B4
0-2	1.89	2.55	4.80	3.06	1.11
2-4	2.66	3.92	3.82	4.53	3.19
4-6	2.80	3.52	5.39	6.03	5.92
6-8	2.49	3.94	3.10	7.79	5.85
8-10	1.52	3.89	3.62	6.39	4.20

from 0 to 10 nm in from the edge. Inter-sector variability was considerable (Table 16). There was no particular pattern relative to seals at cracks; their distribution was highly variable among sectors.

In the sectors B1-B3 in the Beaufort Sea, the overall density of seals on fast ice was lowest 0-2 nm from the edge, somewhat higher 2-4 nm in, and higher still 4-10 nm from the edge, with some inter-sector variability (Table 17).

We also examined density with distance from the fast ice edge for post-storm data from sector B3. Unlike pre-storm data, which suggested that seals were less abundant near the edge, the post-storm data showed both seals at holes and at cracks to be far more abundant close to the edge. This was true of seals shoreward of the edge on fast ice and of those seaward of the edge on pack ice (Table 18). On the fast ice, seals at cracks accounted for just over half of the total seals within 0-2 nm of the edge and from 0%-43% nearer to shore. On pack ice, seals at cracks made up 74%-87% of total seals across the entire 10-nm band adjacent to the edge.

In light of our findings regarding density relative to distance from shore and from the fast ice edge, we decided to compare different subsamples of the nearshore ice in order to determine whether one area was less variable than another. We chose the Beaufort Sea where the fast ice is quite extensive and compared density values for selected pre-storm data for all fast ice, any ice within 10 nm of shore, and any ice within 20 nm of shore (Table 19). We found that the densities were generally similar in all 3 samples. The "all fast ice" samples had the lowest variance, and consequently the narrowest confidence interval, probably because sample size was greatest. For sectors B1-B3, the ratio of 1.96 standard deviations to mean density of total seals in 1986 was 0.11 for all fast ice; 0.13 for 0-20 nm from shore; and 0.14 for 0-10 nm from shore. Sector B4, which was far more variable than the other sectors in 1986, showed the same pattern, with 1.96 standard deviation:mean density ratios ranging from 0.12 for all fast ice to 0.18 for the 0-10-nm band closest to shore.

3. Pack ice

In an attempt to expand coverage of the pack ice, survey design in 1986 included four 40-nm-long lines in each sector. In the Chukchi Sea, some of those lines were not flown because the lead at the outer edge of the shorefast ice was extremely wide, sometimes in excess of 50 nm. Consequently, total pack ice coverage there in 1986 was 127 nm^2, mostly in sectors C2 and C5. The combined Chukchi Sea density of total seals on pack ice was 1.2 seals/nm^2 (Table 20). Only 2% of those were seals at cracks.

The total pre-storm density of seals on pack ice in the Beaufort Sea (sectors B1-B3) was 0.4 seals/nm^2. Unlike the Chukchi Sea, over half (51%) were seals at cracks. In sector B4, flown after the storm, the total density in pack ice was 1.5 seals/nm^2 with two-thirds of those at cracks. Post-storm replicates of sector B3 (302 nm^2) indicated a total pack ice density of 5.5 seals/nm^2, of which 78% were seals at cracks.

Table 16. Density of ringed seals at holes on shorefast ice of the Chukchi Sea in relation to distance from the fast ice edge, May-June 1986.

Distance from fast ice edge (nm)	Sector density (seals/nm²)				
	C2	C4	C5	C6	Total
0-2	3.25	6.01	3.04	2.15	3.81
2-4	3.54	6.07	2.06	2.51	3.52
4-6	3.36	4.60	2.70	2.73	3.45
6-8	3.27	4.93	2.47	1.89	3.47
8-10	1.70	4.78	3.20	1.92	3.67

Table 17. Density of ringed seals at holes on shorefast ice of the Beaufort Sea in relation to distance from the fast ice edge, May-June 1986.

Distance from fast ice edge (nm)	Sector density (seals/nm²)			
	B1	B2	B3	B1-B3
0-2	1.17	2.14	1.11	1.52
2-4	1.84	2.21	1.86	1.98
4-6	2.71	2.71	2.78	2.72
6-8	1.10	3.07	2.89	2.23
8-10	1.28	3.08	2.75	2.36

Table 18. Density of ringed seals on shorefast and pack ice of sector B3 in relation to distance from the fast ice edge, 12-16 June 1986.

Distance from fast ice edge (nm)	Density (seals/nm²)					
	Fast ice			Pack ice		
	holes	cracks	total	holes	cracks	total
0-2	6.85	7.16	14.01	2.49	10.43	12.92
2-4	6.17	3.93	10.11	1.82	5.55	7.37
4-6	4.29	1.83	6.12	0.86	3.57	4.44
6-8	4.48	0	4.48	0.72	4.74	5.46
8-10	5.80	0.29	6.09	0.87	2.43	3.30

Table 19. Comparisons of densities obtained in sectors B1-B3 combined for all fast ice, any ice from shore to 10 nm seaward, and any ice from shore to 20 nm seaward, 1985-1986.

	1985 density (seals/nm²)			1986 density (seals/nm²)			1.96 std dev:density (total seals)	
	holes	cracks	total	holes	cracks	total	1985	1986
All fast ice	1.83	1.12	2.95	3.21	0.10	3.31	0.16	0.11
0-10 nm offshore	1.95	0.34	2.29	3.25	0.06	3.31	0.19	0.14
0-20 nm offshore	1.87	1.07	2.94	3.04	0.10	3.14	0.19	0.13

Table 20. Density of ringed seals on shorefast ice and pack ice in the Chukchi and Beaufort seas, May-June 1986.

	Fast ice				Pack ice			
		Seals/nm²				Seals/nm²		
Sector	nm²	holes	cracks	total	nm²	holes	cracks	total
Chukchi								
C1	443	5.52	0.25	5.77	3	2.12	0	2.12
C2	101	3.38	0.92	4.30	77	1.30	0.03	1.33
C4	212	5.03	0.17	5.20	0	-	-	-
C5	203	2.69	0.04	2.73	35	0.69	0	0.69
C6	114	2.35	0.90	3.25	13	1.27	0	1.27
ALL	1073	4.35	0.32	4.67	127	1.15	0.02	1.17
Beaufort								
B1	173	2.07	0.0	2.07	82	0.18	0.01	0.20
B2	280	3.60	0.03	3.63	13	0.32	0.32	0.63
B3	183	3.70	0.29	3.99	4	0	4.45	4.45
B4	56	4.21	5.24	9.44	109	0.58	0.94	1.52
B1-B3	635	3.21	0.10	3.31	98	0.19	0.21	0.41
B1-B4	692	3.30	0.52	3.81	208	0.39	0.60	0.99
B3 (late)	161	5.37	2.94	8.31	302	1.22	4.31	5.53

D. Temporal and spatial trends in abundance

1. Abundance by sector, 1986

In the Chukchi Sea, densities of total seals in the 1986 surveys were greatest south of Point Lay (sectors C2 and C4) and in Kotzebue Sound (C1) and were considerably lower to the north. The mean density for the 3 southernmost sectors combined (C1-C4) was 5.4 seals/nm² (range 4.3-5.8), compared to 2.9 seals/nm² for the more northern sectors C5 and C6 (Table 21). The combined density for C5 and C6 was more similar to the overall Beaufort Sea density (3.3 seals/nm² for sectors B1-B3) than to the southern Chukchi Sea sectors. Most of the seals counted in the Chukchi Sea were seen at holes. Seals at cracks accounted for 7% of the total seals in sectors C1-C6 combined (range 1%-28%).

In the Beaufort Sea, sector densities were lowest in the west between Barrow and Lonely (2.1 seals/nm²), almost twice as high in the central Beaufort region between Lonely and Flaxman Island (3.8 seals/nm²), and 4 times as high between Flaxman and Barter Island (9.4 seals/nm²). However, we do not consider the B4 data to be comparable to that from other Beaufort Sea sectors. A storm occurred part way through our survey, lasting from 7-11 June, during which the position of the ice edge and the abundance of cracks, and seals along cracks, changed dramatically. Sector B4 was surveyed only once, after the storm. In sectors B2 and B3, which were surveyed both before and after the storm, the densities of total seals increased from a mean of 3.8 seals/nm² before the storm to 8.1 afterward. We assume that sector B4 showed a similar increase in density after the storm, and that the 9.4 seals/nm² value should not be used in year-to-year or area-to-area comparisons. Seals at cracks accounted for 3% (range 0%-7%) of the total seals in sectors B1-B3, compared to 55% in B4.

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 1986 by multiplying the density in each sector by the area of fast ice coverage (Table 21). Determination of the area of fast ice in each sector was based on field notations of the position of the ice edge, or on satellite photographs of the ice taken during the survey period. Calculations indicated 24,200-30,100 seals hauled out on fast ice in the Chukchi Sea, and 20,800-29,000 in the Beaufort Sea. These estimates do not account for seals that were in the water at the time of the surveys, or for seals on the pack ice. The Beaufort Sea estimate includes sector B4 with its much higher (post-storm) density, but relatively small area of fast ice.

2. Daily variability

During 1986 surveys, portions of several sectors were flown more than once to test variability from day to day or from one week to the next. In the northern Chukchi Sea (sector C6), 2 sets of lines were flown twice, 3-4 days apart. There was no significant difference in the density of seals at holes in either comparison. The density of seals at cracks did differ, however, with significantly higher densities on the later date (Table 22).

Table 21. 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 1986.

Sector	Density - seals/nm² (±95% confidence interval)	Fast ice area - nm²	Estimated number of hauled-out seals
B1	2.07 (±0.32)	1,300	2,275 - 3,107
B2	3.63 (±0.43)	2,175	6,960 - 8,831
B3	3.99 (±0.37)	2,625	9,503 - 11,445
B4	9.44 (±3.28)*	435	2,678 - 5,533
Beaufort Total	3.81 (±0.63)	6,535	20,781 - 29,015
C1	5.77 (±0.78)	2,515	12,550 - 16,473
C2	4.30 (±1.52)	650	1,807 - 3,783
C4	5.20 (±0.75)	990	4,406 - 5,891
C5	2.73 (±0.78)	905	1,765 - 3,177
C6	3.25 (±1.73)	740	1,125 - 3,685
Chukchi Total	4.68 (±0.51)	5,800	24,186 - 30,102
Grand Total		12,335	44,967 - 59,117

* Density after storm - not for comparison

Table 22. 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)	# legs	Replicate 1 date	Replicate 1 density (seals/nm²) holes	Replicate 1 density (seals/nm²) cracks	Replicate 1 density (seals/nm²) total	Replicate 2 date	Replicate 2 density (seals/nm²) holes	Replicate 2 density (seals/nm²) cracks	Replicate 2 density (seals/nm²) total	Student's t-test
C6 (300')	7	26/27 May	3.20	0.0	3.20	30 May	3.49	1.38	4.87	holes t= 0.99, df=12, n.s. cracks t= 3.65, df=12, p<0.01 total t= 2.65, df=12, p<0.05
C6 (500')	8	26/27 May	2.02	0.0	2.02	30 May	2.01	0.41	2.41	holes t= 0.05, df=14, n.s. cracks t= 5.99, df=14, p<0.001 total t= 1.78, df=14, n.s.
B1 (300')	9	31 May - 1 June	2.18	0.0	2.18	14 June	4.62	0.50	5.12	holes t= 13.23, df=16, p<0.001 cracks t= 5.68, df=16, p<0.001 total t = 14.12, df=16, p<0.001
B2 (300')	5	4-6 June	4.09	0.12	4.21	13-14 June	3.14	4.92	8.06	holes t= 2.67, df=8, p<0.05 cracks t= 2.70, df=8, p<0.05 total t= 2.09, df=8, n.s.
B3 (300')	12	12-13 June	5.69	1.80	7.48	15-16 June	5.84	3.00	8.85	holes t= 0.36, df=22, n.s. cracks t= 4.27, df=22, p<0.001 total t= 2.77, df=22, p<0.02
B3 (300')	8	6 June	3.72	0.44	4.16	15-16 June	4.94	3.73	8.68	holes t= 3.90, df=14, p<0.01 cracks t= 7.57, df=14, p<0.001 total t= 6.82, df=14, p<0.001

In the Beaufort Sea, 4 replicate data sets were compared. One pair of surveys (sector B3, 12-13 June and 15-16 June) was flown 3-4 days apart under similar ice conditions. The density of seals at holes did not differ significantly in that comparison. Three pairs of surveys occurred 7-14 days apart with a major storm event in the interim. The position of the fast ice edge and the occurrence of cracks were markedly different before and after the storm. In all 3 of those replicate pairs (pre- and post-storm), the density of seals at holes did differ significantly. In B1 and B3, the density of seals at holes increased significantly. In B2, although total density doubled, the density of seals at holes decreased by 23%.

In B1 and B2 pre- and post-storm comparisons, only densities for seals hauled out on fast ice were used; the position of the ice edge did not change markedly during the storm and the survey areas were comparable for the 2 samples. In B3, the ice edge changed substantially during the storm, reducing the total fast ice area by approximately two-thirds. Thus, the B3 density comparisons between June 6th and the 15th and 16th (Table 22) were for noncomparable areas (102 nm^2 vs 38 nm^2). We therefore also compared the densities for all ice combined, both fast and pack (which 1 week earlier had been classified as fast), to ensure coverage of a similar area. In this comparison, as in sector B2, although total density on June 15th and 16th was almost double what it was on the 6th (7.2 vs 4.2, $t=9.33$, $df=14$, $p<0.001$), the density of seals at holes was significantly less (2.63 vs 3.59, $t=4.43$, $df=14$, $p<0.001$).

Comparisons of seals at cracks in all replicate samples indicated that these densities are much less consistent from day to day than are those for seals at holes. All replicate comparisons, including surveys flown only a few days apart, indicated a significant difference in the density of seals hauled out at cracks. In every case, the density was greatest on the later date.

We also calculated average group size (the number of seals hauled out at a single hole) and the density of groups for pre- and post-storm surveys. In all sectors (B1-B3), the average group size was significantly greater for the post-storm surveys (Table 23). Average group size in early June was 1.3-1.4; in mid-June after the storm it had increased to 1.6-1.8. The density of groups also increased in 2 of 3 sectors (B1 and B3). In sector B2, the density of groups decreased (Table 24).

E. Density of seals in relation to industrial activities

The only industrial activity noted within the study area in 1986 was artificial islands. We saw little or no evidence of on-ice seismic surveys or ice roads other than those leading to artificial islands.

During 1986 aerial surveys, there were 3 artificial islands located in the study area in the region between Oliktok and Prudhoe (Figure 3). They were: 1) Seal Island, located 10 nm west of Prudhoe Bay, which was inactive all winter, 2) Northstar Island, located 4 nm west-northwest of Seal Island, which was operational until early April, and 3) Sandpiper Island, located 5.5 nm west-northwest of Northstar Island, which was operational all winter.

Table 23. Comparison of average group size for seals at holes (fast ice only) in early and mid-June 1986 in the Beaufort Sea.

	Pre-storm (31 May-6 June)		Post-storm (12-16 June)		
Sector	average #/group	s.d.	average #/group	s.d.	Student's t-test
B1	1.26	0.63	1.59	1.10	t=4.54, df=593, p<0.001
B2	1.27	0.67	1.78	1.38	t=5.21, df=1,004, p<0.001
B3	1.35	0.82	1.74	1.34	t=5.53, df=997, p<0.001

Table 24. Comparison of the density of groups for seals at holes (fast ice only) in early and mid-June 1986 in the Beaufort Sea.

	Pre-storm (31 May-6 June)		Post-storm (12-16 June)		
Sector	groups/nm^2	s.d.	groups/nm^2	s.d.	Student's t-test
B1	1.80	0.12	2.92	0.28	t=11.02, df=16, p<0.001
B2	3.17	0.52	1.85	0.19	t=5.28, df=8, p<0.001
B3	2.71	0.31	3.16	0.44	t=2.37, df=14, p<0.05

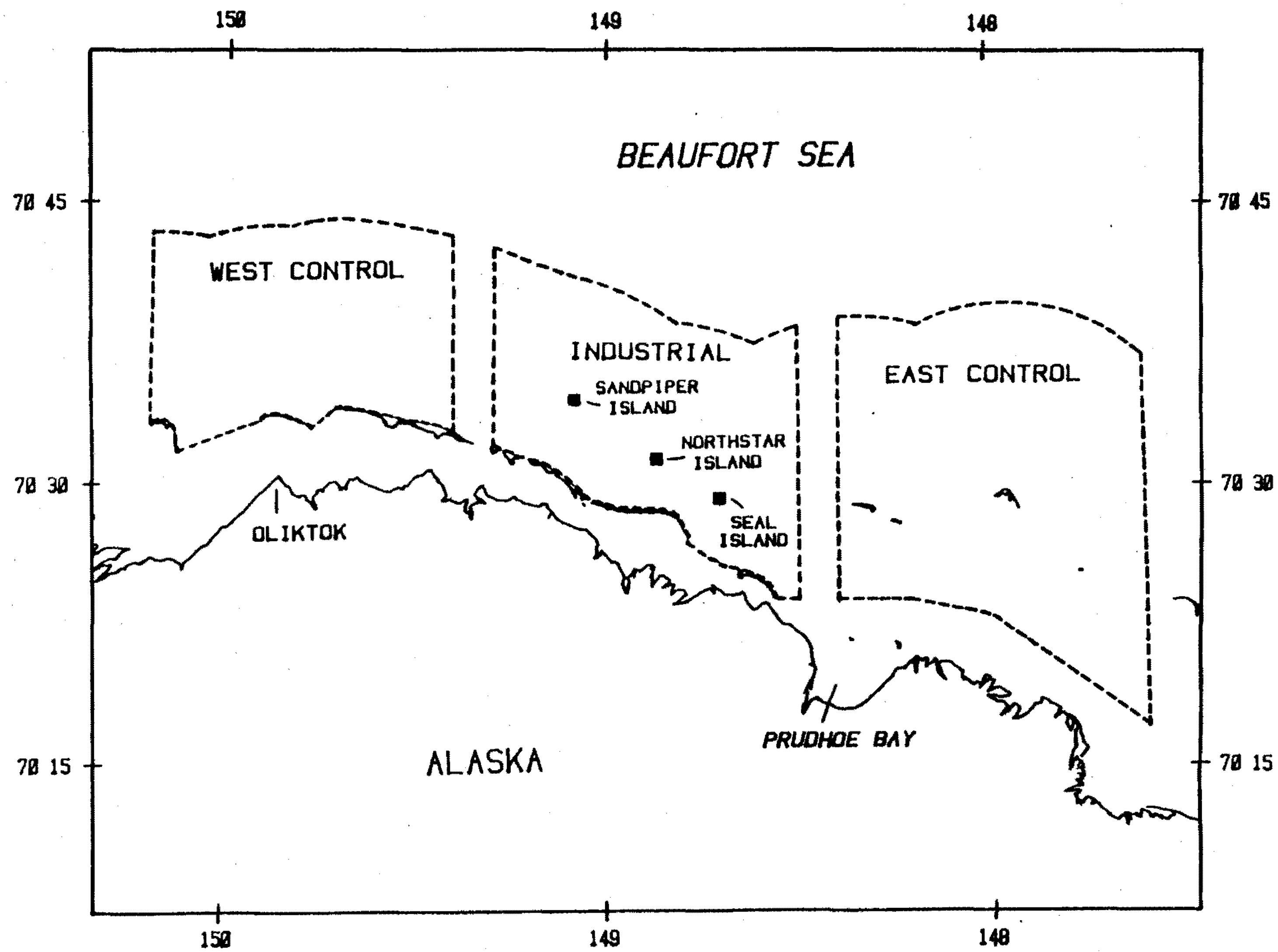

Figure 3. Map showing locations of artificial islands in sector B3 of the Beaufort Sea, 1986, and industrial and control blocks.

Surveys were conducted in the vicinity of all 3 islands on 6 June. Densities were calculated for a series of 2-nm concentric circles centered at each artificial island. Also, since the islands were close together and interactive effects were possible, a density in relation to distance from all islands was calculated using for each sighting the minimum distance from any of the 3 islands.

Results show no clear trend in seal density that can be related to distance from the artificial islands (Table 25). At Seal and Sandpiper islands the highest density was observed in the 0-2 nm distance interval. When all 3 islands were considered in aggregate the density in the 0-2 nm distance interval was a high as at any other distance. There was no indication that seal density was negatively affected by the operational status of a particular island. In fact, the highest density of all was recorded within 2 nm of Sandpiper Island which was operational during the survey and had been working all winter.

As a further test of possible cumulative effects of activities on and near artificial islands, seal densities were calculated for an "industrial" block and 2 adjacent "control" blocks (Figure 3). All sightings from the selected data which were within 10 nm of land were used in this comparison, and densities were compared using t-tests. Data collected on 4-6 June prior to the storm was treated separately from that collected from 12-16 June (Table 26).

In both comparisons, the density was highest in the industrial block. In comparisons based on 4-6 June surveys the industrial block had a significantly higher density of seals at holes and of total seals than either control block. Data collected from 12-16 June also showed a significantly higher density of seals at holes in the industrial block. Other comparisons between the west control and the industrial block were not significant. In the east control block, seals at cracks had a significantly higher density, but the total density was lower.

V. Discussion and Conclusions

A. Aerial survey methodology and effectiveness

As in 1985, comparisons between experienced primary and secondary or left and right observers indicated no overall significant differences in observers. Although the left observer counted 8% more total seals, leg-to-leg variability was considerable. Differences in strip width estimation or light conditions may have been responsible for this relatively small difference. As one might expect, fewer seals were seen by inexperienced observers; whereas experienced back-up observers counted an average of 98% as many seals as did primary observers, the average for inexperienced observers was 75%. This difference was probably due to a variety of factors, including inconsistent strip width estimation, incomplete search pattern, underestimation of group size, and undeveloped search image. We believe it is essential that all observers in a monitoring program are adequately trained in conducting ringed seal surveys in order to ensure both high quality data and comparability with historical data. New observers should be trained by experienced individuals and should fly as back-up observers until consistently comparable counts are achieved.

Table 25. Ringed seal density in relation to distance from artificial islands, June 1986.

Distance (nm)	Seal Island area (nm^2)	Seal Island density ($seals/nm^2$)	Northstar Island area (nm^2)	Northstar Island density ($seals/nm^2$)	Sandpiper Island area (nm^2)	Sandpiper Island density ($seals/nm^2$)	Any Island area (nm^2)	Any Island density ($seals/nm^2$)
0-2	0.8	6.05	1.8	4.98	1.8	8.33	4.4	6.54
2-4	1.7	5.78	3.5	5.20	5.4	3.34	7.1	3.93
4-6	2.6	4.56	3.5	6.80	5.4	6.47	4.4	6.55
6-8	6.2	2.27	6.1	4.23	7.9	3.17	10.6	1.98
8-10	5.3	5.09	6.2	2.10	7.0	3.58	7.1	3.66

Table 26. Densities of ringed seals ($seals/nm^2$) within 10 nm of land in "industrial" and "control" blocks in the Beaufort Sea, June 1986. Standard deviations are given in parentheses.

Block	#legs n	Seals at holes density (s.d.)	Seals at cracks density (s.d.)	Total seals density (s.d.)
Test 1 - June 4-6				
Industrial	4	4.95 (0.77)	0.00 (0.0)	4.95 (0.77)
Control West	5	3.28 (0.41)	0.22 (0.20)	3.51 (0.45)
Control East	4	3.37 (0.73)	0.03 (0.03)	3.41 (0.76)
Test 2 - June 12-16				
Industrial	11	6.39 (0.83)	1.24 (0.61)	7.63 (1.00)
Control West	6	5.02 (0.94)	1.54 (1.02)	6.56 (1.01)
Control East	8	4.04 (0.87)	2.08 (0.69)	6.12 (1.09)

Under good survey conditions when ice is relatively flat, clean, and white with little or no dirty surface meltwater or river runoff, and when cloud ceilings permit, a survey altitude of 500 ft is optimum for detecting seals and maximizing survey coverage. Such conditions generally prevail in the Chukchi Sea. In the Beaufort Sea, however, cloud ceilings and/or fog are usually below 500 ft, and in some years meltwater and dirty ice are widespread. Because of such variable conditions in 1985, we recommended that all surveys in the Beaufort Sea be conducted at 300 ft. At that time, we noted that observed densities at 300 ft survey altitude appeared to be somewhat greater than densities obtained for the same area at 500 ft, and proposed in 1986 to systematically compare results obtained at the 2 altitudes.

Altitude tests were conducted in 2 sectors in 1986. For all comparisons in aggregate, 1.36 times as many seals/nm² were counted at 300 ft as at 500 ft. Separate analysis of "flat" (0%-20% deformation) ice and "rough" (20%-40% deformation) ice indicated that, for those data used in altitude comparisons, estimates of the density of seals at holes in flat ice were substantially different at 300 ft and 500 ft altitude, while densities at 300 ft and 500 ft in rough ice were similar (1.8 vs 1.9 seals/nm², see Table 9). The observed density in flat ice was 1.6 times greater at 300 ft than at 500 ft. This difference existed for both observers, and could have been because of overestimation at 300 ft or underestimation at 500 ft. In a similar comparison using 1985 data from sector B1, the observed densities in both flat and rough ice were greater at 300 ft. Interpretation is complicated, however, because the 300 ft survey occurred 2 weeks later than the survey at 500 ft.

Other survey data from 1981-1986 were also re-examined. Within-year altitude comparisons were not possible for pre-1985 data since all surveys were conducted at 300 ft in 1981 and 500 ft in 1982, so we decided to look for year-to-year consistency in the relationship between densities of total seals in 0%-20% and 20%-40% deformed ice. For 1982, 1985, and 1986, the observed density based on surveys at 500 ft was 1.4 to 1.6 times greater in flat ice than in rough. The only 500 ft surveys for which this was not true were the 1986 altitude comparisons in sectors C6 and B1, where observed densities in flat and rough ice were similar (1.8 vs 1.9 seals/nm²). The ratio was slightly smaller for 1982 surveys when strip width was 0.25 nm on either side of the aircraft than for those in 1985 and 1986 when strip width was 0.375 nm (density in flat and in rough = 1.8 vs 1.3 in 1982 (Beaufort); 2.7 vs 1.7 in 1985 (Chukchi); and 5.1 vs 3.4 in 1986 (Chukchi)). In contrast, for surveys flown at 300 ft in 1981 and 1985 (Beaufort Sea), the densities of seals in flat ice and seals in rough ice were similar; (1.6 seals/nm² in both in 1981; 3.3 in flat vs 3.1 in rough in 1985). This was not, however, the case for 300 ft surveys in 1986, when the observed density for all Beaufort Sea flat ice was 1.6 times greater than for rough ice (3.9 seals/nm² vs 2.4 seals/nm²); this ratio was similar to the ratio observed in all years at 500 ft.

In aggregate, these analyses suggest that, for some reason, the counts made during altitude tests were not representative of other data regarding the proportions of seals in flat and rough ice. By comparison to all other 500 ft data, counts made at 500 ft during altitude tests either over-estimated seals in rough ice or underestimated seals in flat ice, resulting in similar density estimates for both categories of ice. Conversely, at 300 ft, counts during altitude tests showed a greater difference between densities in flat and rough ice than were detected during previous 1981 and 1985 surveys. These differences may be a result of switching back and forth between 2 survey altitudes during tests, with observers either over- or undercompensating for the changes, or perhaps they could be an artifact of differences in the way ice is classified at the 2 altitudes. During 1987, we plan to conduct additional altitude comparisons to help in interpretation of 1986 results.

Previous studies have shown that date, time of day, and weather affect the haul-out behavior, and thus the observed densities of ringed seals (Burns and Harbo 1972; Finley 1979; Smith and Hammill 1981). Our survey methodology incorporates the findings of those studies and, consequently, further tests of such effects have been largely precluded. Date and time of day have been standardized so that all surveys are flown in late May (Chukchi) or early June (Beaufort) between 1000 and 1600 hours (sun time) when maximum numbers of seals are known to be hauled out.

No surveys in 1986 were intentionally flown at wind speeds greater than 20 knots; most were flown in 5- to 10-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. Since less than 2% of the sample variability was attributable to wind, we believe that the 0- to 20-knot-wind "weather window" is satisfactory.

In 1986, our basic aerial survey design provided for 60% random selection of all possible transect lines within each sector. This was based on an analysis of the relationship between the error variance and sampling intensity calculated using a set of transects from 1981 ringed seal aerial survey data, and re-evaluated using 1985 survey data (see Frost et al. 1985b).

We did a similar analysis using the 1986 data base. The relationship between variance and the number of transects selected was calculated using selected pre-storm data for sectors C1 and B2 and B3 combined (Figure 4). As sampling intensity increases, the variance drops quite rapidly. Mean variances at 60%, 90%, and 100% of all legs flown (or 30%, 45% and 50% of all possible lines) (only seals at holes) were 0.044, 0.028, and 0.027 in sectors B2 and B3, and 0.081, 0.037, and 0.033 in sector C1. The inclusion of seals at cracks results in somewhat more variability, especially in sector C1.

Sampling intensity, measured as the proportion of total possible lines which were flown, was between 50% and 60% in both 1985 and 1986. Actual area of fast ice surveyed was also similar, differing by less than 50 nm². To ensure that this coverage produced satisfactory confidence limits on density estimates, we calculated the ratio between 1.96 standard deviations and the mean density for each sector. This ratio measures the confidence interval around the mean such that a value of 0.10 would indicate that the 95% confidence limits are equal to the mean, plus or minus 10%. When only seals at holes were considered, values ranged from 0.09 in sector C1 (52% of lines surveyed) to 0.33 in sector C6 (63% of lines surveyed) (Table 27).

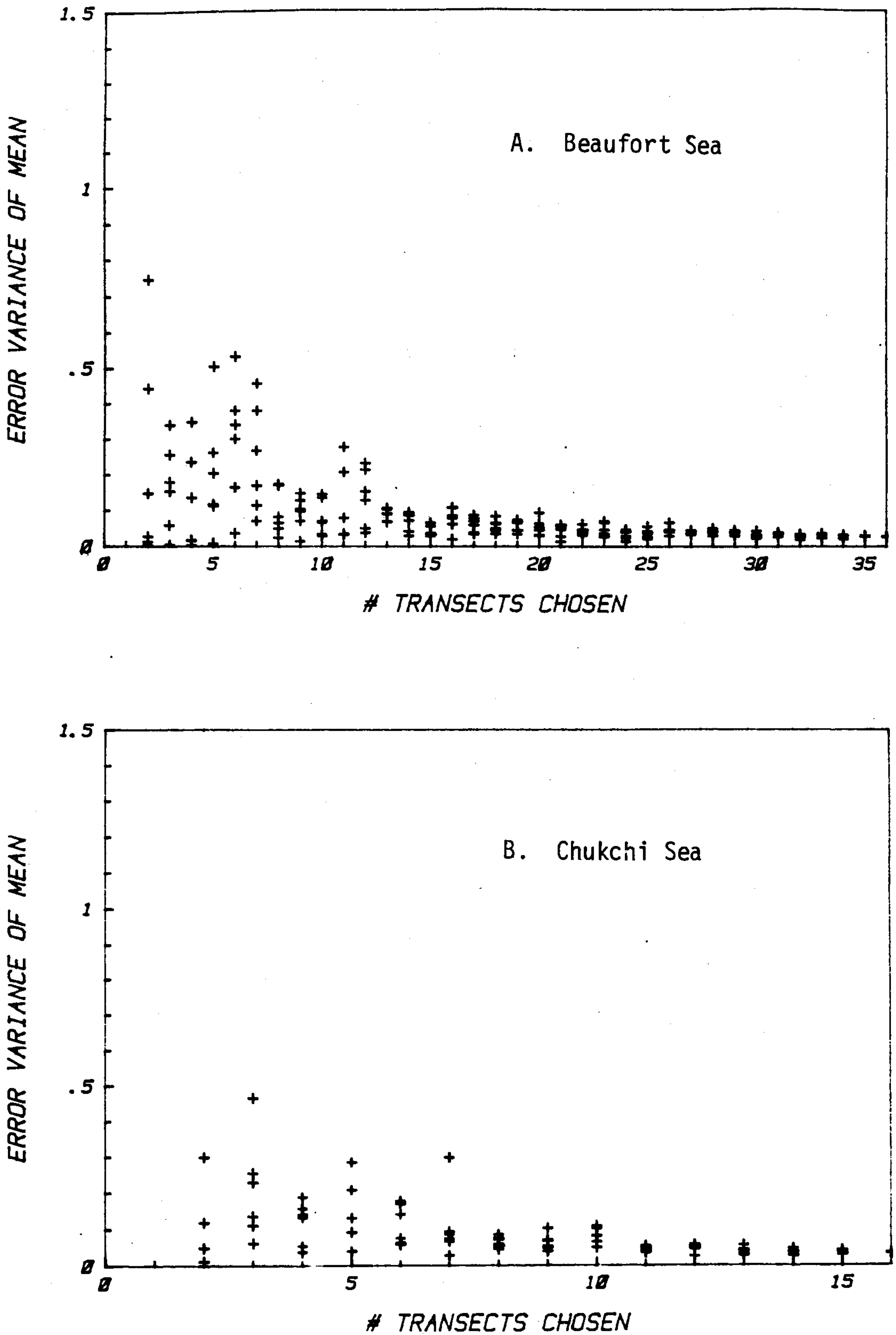

Figure 4. Relationship between error variance and sampling intensity for seals at holes based on 1986 survey data. A. Beaufort Sea. B. Chukchi Sea.

Table 27. Comparison of the 95% confidence limits on ringed seal density estimates (1.96 standard deviations divided by density of seals) for 11 sectors surveyed in May-June 1985 and 1986.

	95% confidence interval			
	seals at holes		total seals	
Sector	1985	1986	1985	1986
C1	0.10	0.09	0.19	0.14
C2	0.49	0.30	0.43	0.36
C4	0.22	0.16	0.24	0.14
C5	0.39	0.27	0.39	0.29
C6	0.30	0.33	0.30	0.53
All Chukchi	0.10	0.09	0.12	0.11
B1	0.20	0.15	0.24	0.15
B2	0.26	0.11	0.26	0.12
B3	0.14	0.15	0.23	0.18
B4	0.15	0.30	0.16	0.35
All Beaufort	0.10	0.10	0.14	0.16
B1-B3	0.11	0.10	0.16	0.11

The ratio for sector B3, where sampling intensity was least (due to weather), was 0.15. When seals at cracks were added to the data base, the variability generally increased and ranged from 0.12 in sector B2 to 0.53 in sector C6. When all Chukchi and Beaufort sectors were combined, the 95% confidence interval was ±10% in the Chukchi Sea and ±11% in the Beaufort Sea.

A comparison of 1985 and 1986 surveys indicated that in most sectors the confidence intervals were smaller in 1986 than in 1985. The 2 exceptions were sector C6, which had a far larger proportion of seals at cracks in 1986 (28% vs 0%), and B4, which was surveyed after the storm and not considered comparable to the rest of the survey. The confidence intervals in those sectors approximately doubled with no significant difference in sampling effort.

B. Factors affecting abundance of seals

The density of seals on the fast ice appears to be related to ice deformation and to the distance from shore and from the edge of landfast ice. In 1986, the highest densities of seals occurred in ice of 0%-10% deformation in both the Chukchi and Beaufort seas, with progressively lower densities as deformation increased. Approximately 3 times as many seals/nm² were seen in ice of 0%-10% deformation as in >40% deformation. This is consistent with 1985 results and with those of previous surveys (Burns and Kelly 1982).

Seals were slightly less abundant within 2 nm of land throughout the study area in both 1985 and 1986. The difference was significant by an analysis of variance only for the Chukchi Sea in 1986. Even in that comparison, only 4% of the variance was attributable to distance from land.

In the Chukchi Sea in 1986, as in 1985, there was no clear overall pattern of density relative to distance from the fast ice edge. In some sectors, seals were more abundant within 2 nm of the edge, while in others the reverse was true. In the Beaufort Sea in both years, seals were slightly less abundant within 2 nm of the edge than they were farther away. Most noteworthy, however, was the reversal of this pattern after the storm when the density of total seals was 1.5 to 2.0 times greater within 2 nm of the edge than it was on the remainder of either fast or pack ice. 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. Whereas the density of seals at holes 4-10 nm from the fast ice edge of sector B3 increased 1.7 times after the storm (from 2.8 seals/nm² to 4.7 seals/nm²), the density near the edge increased 4-fold (from 1.6 seals/nm² to 6.5 seals/nm²).

Although it was our intent to expand coverage of the pack ice in 1986, we were unsuccessful in doing so. The lead between fast and pack ice in the Chukchi Sea was over 50 nm wide in most places and in order to conserve aircraft time we chose to terminate our survey lines at the fast ice edge. In the Beaufort Sea, total pack ice coverage was over 500 nm² in 1986 compared to about 100 nm² in 1985, but over 400 nm² of that was for the post-storm period. Overall, densities in the pack ice in both the Chukchi and the (pre-storm) Beaufort seas were lower in 1986 than in 1985.

In general, coverage of the pack ice in these and earlier aerial surveys dating back to 1970 has not been extensive in any year and has not included every sector every year (Table 28). From this limited coverage, it appears that densities in the pack ice vary greatly from year to year. While densities of seals on fast ice (in areas where pack ice was also surveyed) differed by 150%-350% among years, differences on pack ice were as much as 600%. The most noticeable change was in sector C2 where we counted 8.0 seals/nm^2 on the pack ice in 1985 and 1.3 seals/nm^2 in 1986.

C. Ringed seal abundance in the Beaufort and Chukchi seas

Aerial surveys for ringed seals conducted in 1985 and 1986 were the most extensive and systematic ever flown in Alaska, and the first for which between-year statistical comparison was possible. In all sectors of the Chukchi Sea, the density of seals at holes and of total seals on the fast ice was significantly greater in 1986 than in 1985 (Table 29). In both years, the density of seals at cracks was quite low, 7%-8% of total seals, and there was no consistent pattern in abundance by sector from one year to the next. In the central Beaufort Sea (B2, B3), the density of seals at holes and of total seals was also significantly greater in 1986. In the western Beaufort (B1) the density of seals at holes was similar in both years with a slightly lower total density in 1986 due to the absence of seals at cracks. In 1985, seals at cracks made up 36% of the total seals counted on the Beaufort Sea fast ice; in 1986 they made up just 3% in sectors B1-B3 and 14% if post-storm data from sector B4 are included.

The between-year increase in ringed seal density was much greater in the Chukchi Sea than in the Beaufort. In the Chukchi Sea, the ratio of 1986:1985 densities for total seals ranged from 1.3 in sector C5 (Point Lay to Wainwright) to 1.9 in sector C1 (Kotzebue Sound), for an overall average of 1.6 times more seals in 1986 than in 1985 (Table 30). Most of this difference was attributable to seals at holes. In the Beaufort Sea, the annual differences in density were less pronounced, with 1986:1985 ratios ranging from 0.9 to 1.3 in sectors B1-B3 for an overall ratio of 1.1. Since B4 was surveyed after a major storm event, the very high density for that sector (9.4 seals/nm^2) was not included in comparisons. Despite the increases in density of seals, the relative ranking of sectors remained similar from one year to the next. In the Chukchi Sea in both 1985 and 1986, the sectors south of Point Lay (C1-C4) had the highest densities, with C1 and C4 the two highest. Within the Beaufort Sea, the relative ranking of sectors B1-B3 remained the same between years; the density of total hauled-out seals in sector B3 was over 1.5 times that in B1 in both years, with sector B2 somewhat intermediate.

Although the increase in the density of seals from 1985 to 1986 was statistically significant for both the Chukchi and Beaufort seas, the difference in total estimated numbers of seals was not. Comparison of 1985 and 1986 results indicates a large between-year increase in the estimated total number of seals in the Chukchi Sea but not in the Beaufort (Table 31). In the Chukchi Sea, this difference was due to increases in 1986 in both total density (4.7 vs 2.9 seals/nm^2) and in area of fast ice coverage (5,800 nm^2 vs 4,900 nm^2). The resultant 1986 estimate of the total number of hauled-out seals was about 1.5 times the 1985 estimate; the 95% confidence intervals on the estimates did not overlap for any sector or for all sectors combined.

Table 28. Densities of ringed seals on pack ice and shorefast ice in the Chukchi and Beaufort seas, 1970-1986.

		Fast ice		Pack ice	
		nm² surveyed	total density	nm² surveyed	total density
CHUKCHI SEA					
sectors	year				
C2	1986	101	4.30	77	1.33
	1985	52	2.89	127	8.01
	1984	122	2.87	36	1.78
C5,C6	1986	317	2.91	47	0.85
	1976	342	4.96	164	0.27
	1970	215	6.14	38	1.48
BEAUFORT SEA					
sectors	year				
B1,B2	1986	452	3.04	95	0.25
	1976	318	1.34	68	0.16
B3	1985	414	3.33	51	2.07
	1981	554	1.50	17	0.00
	1975	202	0.96	19	2.16
B4	1986	56	9.44	109	1.52

Table 29. Comparison of the densities of ringed seals hauled out on the fast ice in the Chukchi Sea, 1985 and 1986.

Sector	Seals at holes			Seals at cracks			Total		
	density (s.d.) 1985	density (s.d.) 1986	test value	density (s.d.) 1985	density (s.d.) 1986	test value	density (s.d.) 1985	density (s.d.) 1986	test value
C1	2.79 (0.14) n=19	5.52 (0.26) n=16	t=37.25 df=33 p<0.001	0.29 (0.26) n=19	0.25 (0.19) n=16	t=0.53 df=33 N.S.	3.08 (0.30) n=19	5.77 (0.40) n=16	t=22.16 df=33 p<0.001
C2	2.49 (0.62) n=17	3.38 (0.51) n=22	t=4.77 df=37 p<0.001	0.40 (0.15) n=17	0.92 (0.35) n=22	t=6.29 df=37 p<0.001	2.89 (0.63) n=17	4.30 (0.78) n=22	t=6.26 df=37 p<0.001
C4	3.31 (0.37) n=16	5.03 (0.41) n=16	t=12.59 df=30 p<0.001	0.26 (0.18) n=16	0.17 (0.08) n=16	t=1.81 df=30 N.S.	3.57 (0.43) n=16	5.20 (0.38) n=16	t=11.35 df=30 p<0.001
C5	2.04 (0.41) n=10	2.69 (0.37) n=17	t=4.15 df=25 p<0.001	0.0 (0.0) n=10	0.04 (0.04) n=17	t=4.14 df=25 p<0.001	2.04 (0.41) n=10	2.73 (0.40) n=17	t=4.29 df=25 p<0.001
C6	1.85 (0.28) n=14	2.35 (0.40) n=15	t=3.91 df=27 p<0.001	0.0 (0.0) n=14	0.90 (0.52) n=15	t=6.71 df=27 p<0.001	1.85 (0.28) n=14	3.25 (0.88) n=15	t=5.84 df=27 p<0.001
All Chukchi	2.68 (0.14) n=76	4.35 (0.21) n=86	t=60.72 df=160 p<0.001	0.23 (0.10) n=76	0.32 (0.11) n=86	t=5.46 df=160 p<0.001	2.91 (0.18) n=76	4.68 (0.26) n=86	t=51.32 df=160 p<0.001
B1	2.04 0.21 n=20	2.07 (0.16) n=20	t=0.50 df=38 N.S.	0.18 (0.09) n=20	0.00 0.00 n=20	t=8.58 df=38 p<0.001	2.22 (0.27) n=20	2.07 (0.16) n=20	t=2.13 df=38 p<0.05
B2	2.15 (0.29) n=14	3.60 (0.21) n=21	t=16.15 df=33 p<0.001	0.59 (0.22) n=14	0.03 (0.03) n=21	t=9.57 df=33 p<0.001	2.74 (0.37) n=14	3.63 (0.22) n=21	t=8.13 df=33 p<0.001
B3	1.62 (0.11) n=35	3.70 (0.28) n=15	t=27.95 df=48 p<0.001	1.72 (0.35) n=35	0.29 (0.20) n=15	t=18.26 df=48 p<0.001	3.33 (0.39) n=35	3.99 (0.37) n=15	t=5.72 df=48 p<0.001
B4	1.65 (0.12) n=14	4.21 (0.65) n=12	t=13.39 df=24 p<0.001	0.37 (0.12) n=14	5.24 (2.04) n=12	t=8.27 df=24 p<0.001	2.01 (0.16) n=14	9.44 (1.67) n=12	t=15.34 df=24 p<0.001
B1-B3	1.83 (0.10) n=69	3.21 (0.16) n=56	t=56.84 df=123 p<0.001	1.12 (0.21) n=69	0.10 (0.06) n=56	t=38.72 df=123 p<0.001	2.95 (0.24) n=69	3.31 (0.18) n=56	t=9.74 df=123 p<0.001
All Beaufort	1.79 (0.09) n=88	3.30 (0.16) n=68	t=70.44 df=154 p<0.001	1.01 (0.18) n=88	0.52 (0.30) n=68	t=12.10 df=154 p<0.001	2.80 (0.20) n=88	3.81 (0.32) n=68	t=22.76 df=154 p<0.001

Table 30. Comparison of ringed seal densities (total seals/nm^2) on the shorefast ice of the Chukchi to Beaufort seas based on surveys conducted in 1985 and 1986.

Sector	1985		1986		Ratio
	density	rank	density	rank	1986/1985
C1	3.08	2	5.77	1	1.87
C2	2.89	3	4.30	3	1.49
C4	3.57	1	5.20	2	1.46
C5	2.04	4	2.73	5	1.34
C6	1.85	5	3.25	4	1.76
C1-C6	2.91		4.68		1.61
B1	2.22	3	2.07	3	0.93
B2	2.74	2	3.63	2	1.32
B3	3.33	1	3.99	1	1.20
B4	2.01	4	9.44	*	4.70
B1-B3	2.95		3.31		1.12
B1-B4	2.80		3.81		1.36

* Not ranked because it was flown after a storm which resulted in major changes in distribution and abundance of seals.

Table 31. Comparison of the estimated numbers (95% confidence limits) of ringed seals (total seals) hauled out on fast ice of the Beaufort and Chukchi seas during aerial surveys conducted in May-June 1985 and 1986.

	1985		1986	
Sector	fast ice area-nm^2	estimated number of hauled-out seals	fast ice area nm^2	estimated number of hauled-out seals
B1	1,255	2,100-3,400	1,300	2,300-3,100
B2	2,415	4,900-8,400	2,175	7,000-8,800
B3	2,565	6,600-10,500	2,625	9,500-11,400
B4	1,510	2,600-3,500	435	2,700-5,500
Beaufort Total	7,745	18,600-24,700	6,535	20,800-29,000
C1	2,590	6,500-9,500	2,515	12,600-16,500
C2	370	600-1,500	650	1,800-3,800
C4	845	2,300-3,700	990	4,400-5,900
C5	610	800-1,700	905	1,800-3,200
C6	475	600-1,100	740	1,100-3,700
Chukchi Total	4,890	12,500-15,900	5,800	24,200-30,100
Grand Total	12,635	31,100-40,600	12,335	45,000-59,100

By contrast, in the Beaufort Sea, the 95% confidence intervals of the total estimates of hauled-out seals for the 2 years almost entirely overlapped. The population estimates did not differ, either with or without inclusion of sector B4. This was, in part, because the observed increase in density in 1986 (3.8 seals/nm^2 in 1986 vs 2.8 seals/nm^2 in 1985) was offset by a decrease in area of fast ice (6,535 nm^2 vs 7,745 nm^2).

An analysis of pre-1986 aerial survey data which was included in our 1985 annual report (Frost et al. 1985b) indicated a steady decline in the density of ringed seals in the northern Chukchi Sea from 1970 through 1985. A comparison of 1986 results with those historical data suggests that the decline has halted and may be on the upswing. However, 1 or more additional years of data are required to confirm the apparent reversal. Although densities in the northern Chukchi Sea had increased in 1986, they were still markedly lower than densities south of Point Lay.

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. For example, in many years, ice in the Beaufort Sea remains white 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 7-11 June, caused major changes in ice conditions. The chronology of breakup may substantially affect 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 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) decreased by almost 2,000 nm^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 has little effect on our surveys of the fast ice, since surveys are conducted prior to significant break-up of the fast ice sheet. Pack ice conditions, however, are more variable from year to year and more difficult to interpret. While we are relatively confident that the observed increase in density of seals on fast ice of the southern Chukchi Sea in 1986 was real, we are less certain how to interpret the decrease in observed density on the pack ice. It could be due to a real decrease in "resident" overwintering seals; to a difference in the timing of breakup in more southern regions, with a later onset of northward migration in 1986 than in 1985; or to different ice conditions.

In the Beaufort Sea, major changes in fast ice conditions with concurrent changes in seal distribution, are more likely to occur during the survey period. This happened in 1986 when 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.

However, data from surveys flown 1-2 weeks apart, separated by the period of high winds, were significantly different. Both the observed density of total seals and the proportion of seals at cracks increased greatly after the storm when ice conditions indicated the beginning of breakup. This increase could have been due to several factors: (a) more "resident" seals hauling out as the season progressed, (b) more hauled-out seals becoming visible as snow melted and haul-out lairs collapsed, (c) 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, (d) 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/or (e) seal pups increasing in size and molting to adult pelage which made them more visible to observers. Any or all of the above factors may have been operative 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 prior to the storm, the density of seals at holes was lower within 0-2 nm of the edge than it was elsewhere. Very few seals at cracks were observed. After the storm, this pattern changed: near the edge (0-2 nm) seals at holes increased from 1.1 seals/nm^2 to 6.9/nm^2; seals at cracks increased from zero to 7.2/nm^2 (sector B3). The average group size of seals at holes also increased during this period, from 1.35 to 1.74 seals/group ($t=5.53$, $df=997$, $p<0.001$); the greatest difference occurred near the edge. Whereas only about 40% of the seals at holes were in groups of 2 or more early in June, over 60% were in such groups by mid-June. Some, but probably not all, of this increase may have been due to the maturation and increased visibility of pups.

In combination, we think these observed changes suggest that at least in sector B3 there was a substantial influx of ringed seals as breakup began. 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 storm, the density of seals at holes was actually slightly lower. 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; ice conditions there changed very little during the 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, density of groups of seals as well as of seals increased. 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 newcomers might 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, and/or a higher proportion visible due to the collapse of lair ceilings as the snow melted. Studies in Kotzebue Sound and the Beaufort Sea have shown that the duration of haul-out bouts 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 haul-out duration continues to increase after that time.

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 the density for all fast ice with that for fast ice within 6 nm of land. Whereas pre- and post-storm comparisons for all fast ice (Table 22) indicated differences of greater than 1 seal/nm^2 (25% to over 100% increases or decreases), the change near shore was much less. Within 6 nm of land (sectors B1-B3 combined), the density of seals at holes increased only 9%, from 3.5 to 3.8 seals/nm^2. Although the difference was significant ($t=3.656$, $df=34$, $p<0.001$), there was considerable overlap in the 95% confidence interval of the estimated number of seals (5,133 ± 742 vs 5,539 ± 1,108, area = 1,450 nm^2).

We think that in future surveys, if for unavoidable reasons surveys must take place after breakup begins and cracks are widespread, that it may be possible to utilize the nearshore portion of such data for annual comparisons. Future studies should address this question.

D. Density of seals in relation to industrial activities

Data collected in 1985 indicated the possibility of a local reduction in seal density within 2 nm of artificial islands. This did not occur in 1986 and, in fact, seal density was very high within 2 nm of Sandpiper Island which was operational all winter.

In 1985, industrial activity was fairly widespread and involved both artificial islands and seismic exploration. Comparisons of density of seals in the industrial versus control blocks showed a higher density of seals in the industrial block. In 1986, industrial activities that we could identify were limited to 3 artificial islands northwest of Prudhoe Bay. The industrial and control blocks we delineated were much smaller and, in fact, all were contained within what was designated as the industrial block in 1985. Seal density was again higher in the industrial block.

We conclude that industrial activities of the types that occurred in the central Beaufort Sea during spring 1986 had no detectable negative effect on ringed seal distribution or abundance.

E. Implications of survey results to monitoring program

Analyses of 1985 and 1986 survey data have identified several areas of potential concern regarding methodology for aerial surveys intended to monitor changes in the distribution and abundance of ringed seals.

1. It is apparent from comparison of experienced and inexperienced observers that survey personnel must be adequately trained to count ringed seals before serving as primary observers. Training should

include flying as back-up for an experienced observer until comparable counts are repeatedly obtained in a variety of ice conditions.

2. Surveys within the same sector or geographic region should be conducted at the same altitude to avoid the possibility of obtaining non-comparable counts. When 2 areas are to be surveyed at different altitudes (such as sector C6 in the Chukchi Sea and B1 in the Beaufort Sea), the surveys should be flown on different days, rather than changing altitude midflight on the same day.

3. An analysis of the variance around density estimates for areas 0-10 and 0-20 nm from land, and for all fast ice, indicated that in the Beaufort Sea, the narrowest confidence interval was obtained by surveying across the entire fast ice where sample size was largest. We recommend, when possible, that survey lines extend to at least 20 nm from land, or to the edge of the fast ice.

4. The greatest potential problem identified in 1986 was the rapidity with which the onset of breakup can occur, and the magnitude of resultant changes in seal distribution and density. Surveys flown only 7 days apart, well within the survey window but under very different ice conditions, produced statistically noncomparable density estimates which differed by a factor of 2 or more. Some of this change was probably due to more seals hauling out or being visible as their lairs collapsed, but we believe a large part was caused by an influx or redistribution of seals from other areas. Knowing that these sorts of changes can occur, it is important that monitoring surveys be conducted before the fast ice begins to break up and such influxes take place. It is extremely difficult, however, to determine precisely when this change occurs. In most areas, we think the best indicators are frequently occurring cracks within the fast ice and a high proportion of seals at cracks relative to total seals. Larger average group size of seals at holes may also be a reliable indicator. For selected data in 1985 and 1986, average group size was 1.3-1.4, in contrast to 1986 post-storm data in which average group size was 1.6-1.8.

   With few exceptions, seals at cracks made up less than 30% of total seals, and usually less than 20%, for all sectors surveyed in 1985 and 1986. The exceptions were sectors flown after the storm in 1986 and sector B3 in 1985. We have already concluded that 1986 post-storm data, in which 30%-50% of the observed seals were at cracks, were not comparable to other data selected for annual comparisons. Sector B3 data from 1985, in which 52% of total seals were at cracks, was included in the 1985 selected data set, and consequently also in 1985-1986 comparisons. In retrospect, this sector should possibly have been excluded from comparisons.

   Further investigations are necessary in order to develop strict criteria for including or excluding data from the data base used in year-to-year or area-to-area comparisons.

VI. Recommendations for Future Studies

A. Conduct additional altitude comparisons to (1) address questions raised in 1986 regarding the different proportions of seals observed in flat and rough ice at 300 ft and 500 ft survey altitudes and (2) determine whether the one-third higher densities observed at 300 ft were due to a general ability to see better at the lower altitude where seals appear larger and the area to be searched is much smaller, or to some other factor.

B. Conduct radio-tagging studies to gather data on haul-out patterns of ringed seals. As pointed out in both this study and Kelly et al. (1986), we are lacking data on the proportion of the population that is visible during aerial surveys and on how that proportion varies from day to day throughout the survey period.

C. Conduct replicate surveys of a sector over a 1- to 2-week period to test daily variability in the density of hauled-out seals.

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