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

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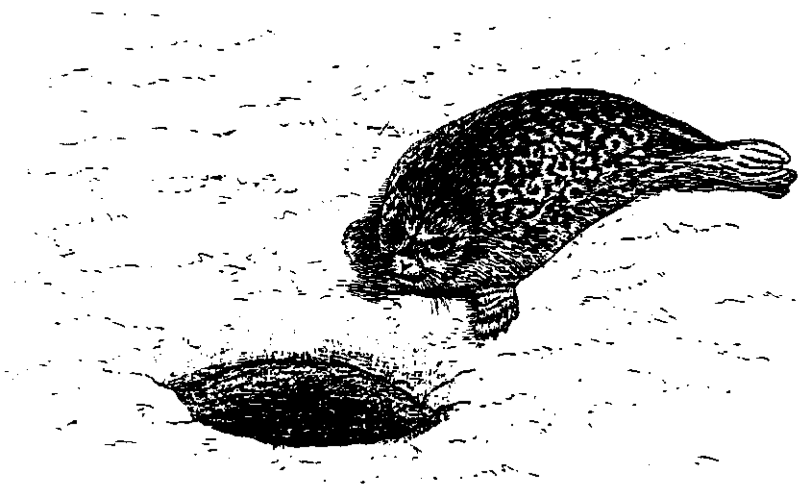

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I. Summary

This is the final report of a 3-year study intended to develop a program of monitoring abundance of ringed seals in Alaska through aerial surveys. In this report, results of aerial surveys of ringed seals on the shorefast ice of the eastern Chukchi Sea and Beaufort Sea in May-June 1987 are reported and compared with results of similar surveys conducted in 1985 and 1986.

Surveys were flown at approximately 130 knots in a Twin Otter aircraft equipped with bubble windows, GNS-500 navigation system and a radar altimeter. Counts of hauled-out seals were made during late May and early June along a series of transects oriented east-west (Chukchi Sea) or north-south (Beaufort Sea). Observers (usually 2) each counted seals in a strip transect either 1,350 ft (300 ft altitude) or 2,250 ft (500 ft altitude) wide.

The selected data base in 1987 included 4,317 nm of trackline and 2,166 nm^2 of area (both fast and pack ice) actually surveyed. In the Chukchi Sea, between Kotzebue Sound and Point Barrow, 16% of all fast ice was surveyed; in the Beaufort Sea we surveyed 14% of all fast ice between Point Barrow and the U.S.-Canada Demarcation line. Coverage was similar to that in 1985 and 1986.

The density of seals on the fast ice in 1987 was highest in the Chukchi Sea from Kotzebue Sound to Point Lay; mean density was 4.0 seals/nm^2. Density in the northern Chukchi Sea was considerably lower (2.6 seals/nm^2). In the Beaufort Sea, the observed density of seals was lowest between Barrow and

Lonely (3.1 seals/nm^2), much higher between Lonely and Flaxman Island (8.1 seals/nm^2) and between Barter Island and the U.S.-Canada Demarcation line (7.7/nm^2), and highest between Flaxman Island and Barter Island (12.0 seals/nm^2).

Replicate surveys were conducted at 300 ft and 500 ft altitudes in 1986 and 1987 to determine whether density estimates at different altitudes were comparable. For 5 systematic altitude comparisons, the 500-ft density of seals at holes was 76% of that determined at 300 ft, or conversely, 1.32 times more seals were counted at 300 ft. Based on these data, all density estimates for seals at holes which were made from counts conducted at 500 ft were multiplied by a correction factor of 1.32. Only corrected data were used in inter-annual and geographic comparisons.

Comparisons of experienced and inexperienced observers indicated that counts by inexperienced observers were usually 5%-42% lower. Counts of different experienced observers were comparable. Tests using 2 experienced observers counting a single strip suggested that a single, trained observer sees about 82% of the seals hauled out on the ice. This is a relatively high proportion compared to estimates for other species in different environments, but nonetheless means that density estimates for hauled-out seals based on aerial surveys by experienced observers are probably low by at least 18%. This does not include seals that are in the water and cannot be counted.

Analysis of the relationship between the error variance of the mean and the number of transects selected demonstrated that the error variance dropped rapidly until approximately 50% of all possible transects were selected from the data base, after which the variance declined gradually. Analysis of the combined Chukchi-Beaufort data base indicated that coverage of 60% of all possible transects reduced variance in data sets to reasonable levels, but that coverage of 90% resulted in considerably greater precision. The error variance was lowest for seals at holes.

For 1985-1987, the smallest 95% confidence limits for density of seals at holes occurred in sectors C1, B1, and B3 (±9%-23%). Confidence limits for the Beaufort Sea as a whole were ±9%-10% for seals at holes and ±14%-33% for all seals; comparable values for the Chukchi Sea were ±9%-13% and ±11%-13%.

The relationship between ice deformation and seal distribution and density was quite consistent from year to year; seals were less abundant in rougher ice (>20% deformation). Even after data were adjusted to express density in relation to area of flat ice only, seals were more abundant in areas of lower deformation. This indicates that areas of flat ice were preferred.

Ringed seals were generally less abundant within 2 nm of the coast than they were farther from shore, particularly in the Chukchi Sea where the coastline is simple with no offshore barrier islands. In the Chukchi Sea there was no clear overall pattern in density relative to distance from the fast ice edge for 1985-1987. In the Beaufort Sea prior to the beginning of breakup, seals were less abundant near the edge. After the ice began to crack, densities within 4 nm of the edge were as high as 12 seals/nm^2, with most seals occurring along cracks, and decreased rapidly both toward shore and seaward. We believe this increase in density is due to an influx of seals from other areas into the highly fractured boundary zone between fast and pack ice, rather than a redistribution of seals from immediately adjacent areas.

Inter-annual variations in densities recorded for pack ice were large. Much of the pack ice surveyed was near the fast ice edge, where distribution changes markedly as breakup begins, and probably was not typical of the pack ice as a whole. In the Beaufort Sea, density in pack ice decreased with distance from the edge, and the density of seals at holes appeared to stabilize about 10 nm from the edge at about 1 seal/nm^2.

In all sectors of the Chukchi Sea, the density of total seals in the fast ice was 1.6-1.7 times greater in 1986 than in either 1985 or 1987. The total estimated number of seals and 95% confidence limits in the Chukchi Sea ranged from 18,400 ± 1,700 in 1985 to 35,000 ± 3,000 in 1986. The 1987 estimate of 20,200 ± 2,300 was similar to 1985. Densities were consistently higher south of Point Lay than to the north.

In the Beaufort Sea, annual and geographic variations in density were less regular. Survey timing relative to breakup differed among years; 1986 surveys occurred before breakup, 1987 surveys occurred after beginning of breakup, and 1985 surveys were mixed. The densities in all sectors except B1 were higher in 1986 than in 1985. For the area between Barrow and Flaxman Island, the density of total seals increased from 2.7 to 3.5 seals/nm^2 from 1985 to 1986, and the estimated number of seals within the 20-m depth contour from 9,800 ± 1,800 to 13,000 ± 1,600. In 1987, the density and the estimated number of seals for that area were considerably higher, 5.24 seals/nm^2 and 19,400 ± 3,700 seals, but this probably included seals that had moved in from other areas as ice began to break up.

Observed changes in group size, the percent of seals at cracks, and distribution relative to the fast ice edge in 1985-1987, in combination, suggested that a substantial influx of ringed seals into the Beaufort Sea occurred as the ice began to crack and break up. Before breakup, group size was about 1.3 seals/group, increasing to 1.6 or more seals/group later on. Similarly, during breakup the percentage of seals at cracks increased from less than 20%-30% of total seals to often more than 50%.

Industrial activity in the Beaufort Sea from 1985-1987 consisted mostly of construction and operation of artificial islands. There was a steady decline in activity from 1985, when both seismic exploration and artificial island activity were underway, to 1987 when there was little or no offshore activity in the study area. Our data indicate that in 1985-1986 there were no apparent broad-scale effects of industrial activity that could be measured by aerial surveys. However, while aerial surveys are useful in monitoring long-term trends in abundance over large areas, they are not well-suited to detecting small-scale differences in geographically restricted areas. The 1985-1987 aerial survey data do not eliminate the possibility that local effects may occur which would more appropriately be detected by other techniques, or that regional effects could occur at greater levels of industrial activity.

II. Introduction

A. Study rationale

Ringed seals (Phoca hispida) are a major ecological component of the arctic and subarctic marine fauna. Their importance to northern peoples living on the shores of ice-covered seas has been well described by Smith (1973:118) 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; Burns and Frost 1988; 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 (OCS) exploration and development activities on the distribution, density, and behavior of ringed seals (Burns et al. 1981a; Burns and Kelly 1982; Burns and Frost 1988; Frost and Lowry in press; Kelly et al. 1986; Kelly et al. in press).

In 1984, the National Oceanic and Atmospheric Administration (NOAA) and the Minerals Management Service (MMS) requested the submission of proposals to begin a program of monitoring the ringed seal population off Alaska with particular attention to possible effects of OCS activities. The contract was awarded to the Alaska Department of Fish and Game (ADF&G), and work began on 1 January 1985. In February 1985, a research protocol was developed by ADF&G and finalized in consultation with NOAA and MMS. 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, and have been incorporated, as appropriate, in geographical and temporal comparisons of ringed seal distribution and abundance in this report (Frost et al. 1985a). Because these earlier surveys were conducted using different methodology and less accurate navigation, and in the Chukchi Sea were flown on much later dates and therefore in different ice conditions, their utility was limited to very general comparisons.

Ringed seal aerial surveys based upon the design specified by the research protocol were flown during May and June of 1985, 1986, and 1987. The surveys were satisfactorily completed and the data have been analyzed to determine factors affecting survey counts, regional and temporal trends in ringed seal abundance, habitat factors affecting distribution and abundance, and the effects of industrial activities on seal density. Results of 1985 and 1986 aerial surveys were presented in Frost et al. (1985b, 1987). The results of 1987 surveys, as well as comprehensive analyses of the three years of surveys combined, are presented in this final report.

B. Background on ringed seal biology

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, ringed seals are most abundant in association with seasonal ice, although they occur in multi-year ice in the far north polar region. The seasonal expansion and contraction of the sea ice habitat requires that a significant proportion of the population is "migratory" while, during the same annual cycle, other animals may be relatively sedentary or undertake only short seasonal movements. The dynamics of these seasonal movements are poorly known. Marking studies undertaken in the Canadian Beaufort Sea have demonstrated both local and long-distance (e.g., to Alaska and Siberia) movements (Smith and Stirling 1978; T. G. Smith, pers. commun.).

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; Frost and Lowry 1981). They also occur in ice-free waters of the Beaufort Sea and in open water close to the ice edge in the Chukchi Sea. With the onset of freeze-up, many ringed seals move southward and are common in grease and slush ice in areas south of the advancing pack. They become increasingly abundant in the coastal zone throughout autumn and early winter. In 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 immature animals are most numerous in the pack. Many ringed seals pass through Bering Strait in May and June. A small proportion of the population, mainly juveniles, may remain in ice-free areas of the Bering 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 and 1981a and b; 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 until May or 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 in 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; Burns and Frost 1988).

Lairs are of 2 basic types--haulout lairs which are single-chambered structures usually more or less oval in shape; and pupping lairs which are more complex structures, usually with several chambers and 1 or more side tunnels. 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) and Burns and Frost (1988).

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, and that the peak of haulout occurs progressively later in more northerly areas. Smith and Hammill (1981) working at Popham Bay (64°17'N) recorded seals hauled out as early as 9 May, with peak densities reached on 1 June in part of the study area. In another portion of their study area peak densities were not reached until 21 June, possibly due to an immigration of seals. Finley (1979) watched seals at Freemans Cove (75°06'N) and Aston Bay (73°43'N). The haulout began in this region in early June, with the maximum number of basking seals counted on 22 June in Freemans Cove and 29 June in Aston Bay. He thought the late June peak at Aston Bay, which occurred on the last day of the study, was due to an influx of seals from unstable ice areas. Off the north coast of Alaska, Burns and Harbo (1972) found that the maximum numbers of seals were hauled out in the second and third weeks of June.

III. 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 were to:

1. identify temporal and spatial trends in ringed seal abundance and relate these to current and historic population status;

2. identify habitat attributes that affect the distribution and abundance of ringed seals;

3. compare the distribution and abundance of ringed seals in areas subjected to industrial activities and in appropriate control areas; where appropriate, make recommendations for mitigating any adverse environmental effects;

4. develop, implement, and refine a monitoring protocol for long-term studies on the distribution and abundance of ringed seals in Alaskan coastal waters.

IV. Methods

A. Study area

In 1985-1987 aerial surveys were conducted over the shorefast ice and some areas of adjacent pack ice of the Chukchi and Beaufort seas from southern Kotzebue Sound north and east to the U.S.-Canada border. The study area was divided into 11 sectors that corresponded to those used in previous surveys and reports (Burns and Harbo 1972; Burns and Eley 1978). Sector boundaries corresponded to easily identifiable landmarks such as capes, points, villages, or radar installations (Figure 1). The only sector boundary that has changed since the first surveys in 1970 is the one

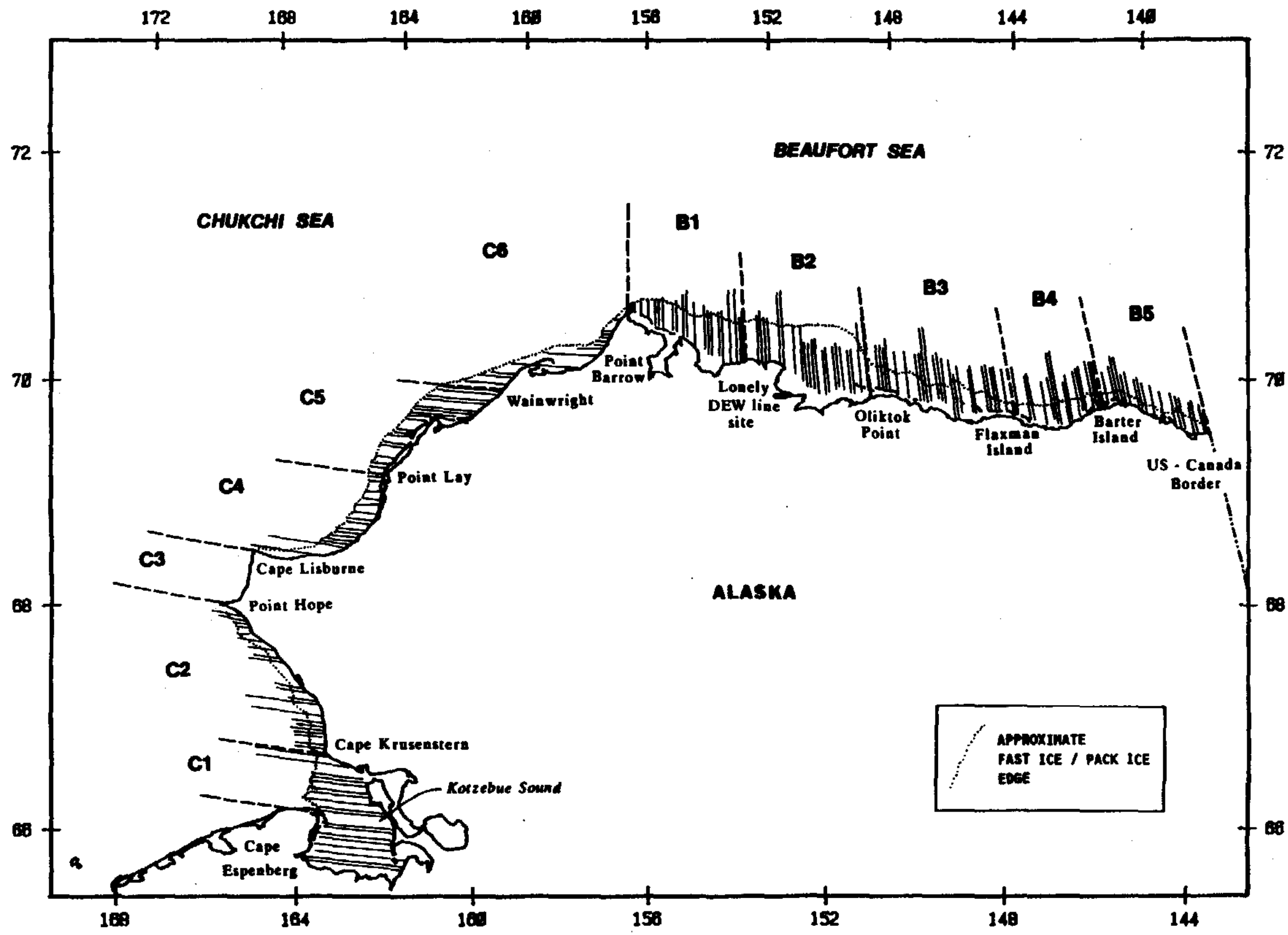


Figure 1. Map of the Chukchi and Beaufort seas showing sectors referred to in this report, and selected transect lines used in analysis of 1987 ringed seal survey data.

between sectors B3 (Oliktok to Flaxman) and B4 (Flaxman to Barter Island). That line was moved from Bullen Point to mid-Flaxman Island during the analysis of data from the early 1980's because of confusion between Flaxman Island and Flaxman Airforce Base, a name used on some older charts for Bullen Point (Burns et al. 1981a; Burns and Kelly 1982). The mid-Flaxman boundary was used in analysis of 1985-1987 data and was also incorporated in any re-analysis of historical data.

Shorefast ice begins to form along the coast in October or November as day length shortens and air and water temperatures cool. In some years, when weather is cold and calm, freezeup may occur quite rapidly, resulting in extensive areas of flat, shorefast ice. In other years when storms occur during freezeup or temperatures fluctuate greatly, freezeup may occur over a more extended period and result in shorefast ice containing rubble fields, hummocks, and pressure ridges. These areas accumulate snow and are suitable for the excavation of ringed seal lairs.

Freezeup commences earliest in most northerly areas, occurring as soon as early October in the Beaufort Sea, and progressively later to the south. In northern Bering Sea, freezing of the shorefast ice may not occur until mid- to late November. Conversely, breakup occurs earliest to the south and progresses northward. In large embayments, like Kotzebue Sound, shorefast ice may remain until June, melting and rotting in place. Along the open Chukchi Sea coast, cracking and breaking of the shorefast ice usually begins in mid- to late May, compared to early to mid-June along the Beaufort Sea coast. There is considerable annual variability in the progression of freezeup and breakup.

The shorefast ice grows in thickness and extent throughout the winter, until about April or May, depending on latitude. Its seaward extent depends on coastal topography, bathymetry, and weather as they affect the ridging, grounding, and, therefore, stability of the ice, but generally coincides roughly with the 20-m contour (Stringer 1982). Near major promontories, such as Cape Lisburne, the shorefast ice may extend only a mile or two, in contrast to the central Beaufort Sea where it extends tens of miles.

Contact between the shorefast ice and the drifting ice is marked by a well-defined shear line (Reimnitz and Barnes 1974) or less distinct shear zone (Burns 1970; Shapiro and Burns 1975). In the Chukchi Sea by mid-May, the interface between shorefast and pack ice is well defined by the open water of the Chukchi polynya (Stringer 1982). In the Beaufort Sea at the time of our surveys in June, the seaward extent of the shorefast ice is less obvious, consisting of a fairly broad zone of large pressure ridges created when the pack ice impinged on the edge of shorefast ice. There are often large expanses of attached ice seaward of this zone of ridges, which form a temporary extension of the shorefast ice (Shapiro and Barry 1978).

As the ice begins to break up in June, the attached fast ice is the first to break off, followed by sequential cracking and breaking at ridge systems progressively closer to shore. Thus, what is part of the "attached" shorefast ice one day may be detached and part of the drifting pack ice just a few days later.

B. Aerial survey design

Surveys of 10 sectors (all those shown in Figure 1 except C3) were flown between 21 May and 16 June during the 3 years 1985-1987, beginning with the southernmost sector in Kotzebue Sound and proceeding north and east. Surveys in the Chukchi Sea generally occurred during late May and those in the Beaufort Sea during early June.

Surveys were conducted between 1000 and 1600 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 Twin Otter equipped with over-sized, custom, bubble windows, auxiliary internal fuel tank, radar altimeter, and GNS-500 navigation system. An on-board data recording system, which was linked to the GNS-500 and radar altimeter, was used to mark time, altitude, and latitude and longitude at beginning and end points of each transect, as well as other positions of interest. The aircraft and data-recording system were provided by NOAA. All surveys were flown at an indicated airspeed of approximately 120 knots, and true ground speed of 110-130 knots. In the Chukchi Sea, most surveys were flown at 500 ft altitude in 1985 and 1986. In 1987, sector C1 was surveyed at 500 ft. All other sectors in the Chukchi Sea (C2-C6) were flown at 300 ft because of extensive surface meltwater which made seals difficult to see at 500 ft. In the Beaufort Sea, low cloud ceilings and persistent fog necessitated a survey altitude of 300 ft in all years. In some sectors (C1, C6, and B1), some lines were flown at altitudes of both 300 ft and 500 ft to enable an assessment of the effect of altitude on survey results.

Three scientific personnel participated in each survey: a navigator who recorded weather, ice conditions, and navigational information, and 2 observers stationed on either side of the aircraft just forward of the wings. On some days, the navigator or a fourth person served as a 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 strip 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 16 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 16 nm. In the Beaufort Sea, transect length was 24-26 nm. In most sectors (except

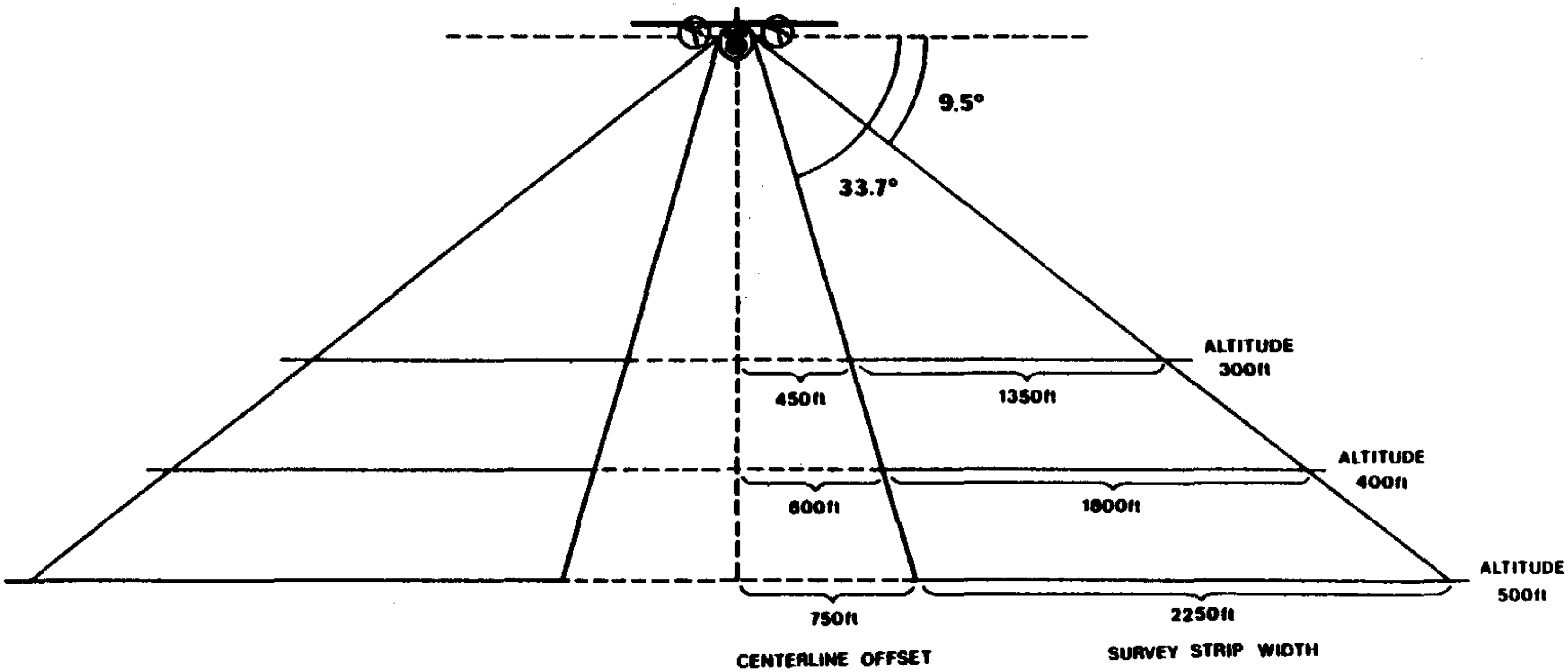


Figure 2. Diagram showing inclinometer angels, centerline offsets, and survey strip widths for ringed seal aerial surveys.

those with extensive open water) several 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 identifiable. In those instances when it was not, the edge was determined based on satellite photographs taken during the same time period. The data were coded accordingly.

The survey was flown according to a stratified random strip transect design. Transect lines were spaced approximately 2 nm between centerlines (2 minutes of latitude, 6 minutes of longitude); within each sector, approximately 60% of the possible transects were randomly selected and flown. Replicate surveys were flown in some sectors on one or more days.

All data were recorded by 1-minute intervals. When the aircraft came on transect, the navigator called a mark to observers; all three simultaneously started digital stopwatches. Each observer recorded sightings or other observations, by minute, on data sheets. The ending time of each transect was noted to the nearest second.

All seals hauled out on the ice were identified to species (either ringed or bearded (Erignathus barbatus) seals), counted, and noted as being by holes or cracks. Seals at different holes were counted as separate groups, while those around a single hole were considered as part of the same group. When seals were seen spaced out along cracks, the total number within the transect was recorded rather than a listing of individuals. In addition to seals, all polar bears, polar bear tracks, belukhas (Delphinapterus leucas), and bowhead whales were recorded, as was any evidence of on-ice human activity such as artificial islands, seismic trails, ice roads, and drill ships.

Four ice variables were recorded; type, cover, deformation, and meltwater (Table 1). Type was classified as either fast ice or pack ice. Cover was recorded in octas (eighths) and was in almost all instances 8 octas. Deformation and meltwater were estimated by 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. Variables recorded included air temperature, wind speed and direction, visibility, and cloud cover (Table 1). Notations were also made by survey personnel regarding local visibility and cloud cover at the beginning and ending points of each line. In addition, wind and temperature readings were obtained by the aircraft at survey altitude.

Coastal winds and temperatures were sometimes substantially different from 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 usually precluded the inference of surface winds from indicators such as white caps or blowing snow.

Table 1. Environmental data recorded during aerial surveys.

Variable	Value(s)	Definition
Ice type	Fast	Shorefast, anchored to the beach, solid cover with or without occasional cracks, pressure ridges, and shear lines.
	Pack	Ice drifting and separated from the fast ice by a lead approximately parallel to the shore, and/or a major shear zone.
Ice cover	0-8	Ice cover in octas (eighths). Ice of 8/8 coverage may have cracks and/or small leads in it.
Ice deformation	0-9	Proportion of the ice surface that is deformed by broken ice, ice jumbles, pressure ridges, snow drifts; 0=0%-5% deformed; 1=5%-10%; 2=10%-20%; 3=20%-30%, etc.
Meltwater	0-9	Proportion of the ice surface covered by water, including river runoff or standing meltwater. Categories the same as for ice deformation.
Wind speed/ direction		From nearest weather station or calculated by aircraft GNS. Direction to nearest degree true. Speed recorded as 0-5, 6-10, 11-15, 16-20, and >20 knots.
Cloud cover	0-9	Cloud cover in octas (1-8) with 9 representing an obscured sky, and 0 a clear sky.
Temperature	°C	Air temperature determined at nearest weather station or by aircraft at survey altitude.
Visibility	nm	Distance from aircraft that observers can see at survey altitude.

C. Data analysis

Counts of seals at cracks and at holes were added separately for each 1-minute interval. Ending times of transects were recorded to the nearest second but rounded up or down to the nearest whole minute for analysis. The lengths of transect lines were calculated from beginning and ending GNS positions and divided by total elapsed time to obtain ground speed. The area surveyed per minute interval was calculated by multiplying speed 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 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.

For each year, a selected data base was created for each sector, to be used in geographic and inter-annual comparisons. The selected data were screened to eliminate duplicate lines and all transects flown in less than optimal survey conditions (e.g., wind speed $\geq$20 knots, excessive sun glare, fog or snow that reduced visibility). For 1986, when some surveys were conducted both before and after the beginning of breakup, only those occurring before breakup were included in the selected data base. Other non-selected data were used to assess the effects of parameters such as altitude or date of survey on survey results.

Non-selected data included transects flown in poor weather or at alternate altitudes, replicate surveys of the same lines, and surveys occurring after breakup had begun.

V. Results of 1987 Aerial Surveys

A. Survey effort

During aerial surveys in May-June 1987, we expended approximately 84 hours of flight time in the successfully completed sectors, divided almost equally between the Beaufort and Chukchi seas. The aircraft flew an estimated 10,080 nm during survey flights, of which approximately 6,000 nm were on survey trackline (Table 2). In the Chukchi Sea, coverage was greatest in sector C1, which had the greatest area of fast ice. In the Beaufort Sea, coverage was greatest in sectors B1 and B3, where replicate flights were made to compare results at different altitudes, and to investigate day-to-day variability in counts. In sectors C1 and C2,

Table 2. Dates, number of legs, miles on track, and total area surveyed for each sector during ringed seal aerial surveys conducted 20 May-16 June 1987. Table includes all data collected.

Sector	Sector boundaries	Date	Number of legs	Altitude (ft)	Miles (nm) on track	Area (nm^2) surveyed Fast	Pack
C1	Cape Espenberg-Cape Krusenstern	21 May	8	500	365	274	0
		22 May	10	500	381	233	53
			4	300	130	59	0
		24 May	6	500	63	47	0
			6	300	63	28	0
C2	Cape Krusenstern-Point Hope	23 May	21	300	360	63	99
			6	300	99	18	27
		24 May	8	300	164	16	58
C4	Cape Lisburne-Point Lay	28 May	19	300	370	117	50
C5	Point Lay-Wainwright	29 May	12	300	143	64	0
		31 May	6	300	203	92	0
C6	Wainwright-Barrow	31 May	12	300	168	76	0
		4 June	13	300	176	79	0
B1	Barrow-Lonely	31 May	7	300	66	30	0
		2 June	6	500	124	62	31
			21	300	430	161	32
		5 June	8	300	141	55	8
		13 June	8	300	163	49	25
B2	Lonely-Oliktok	3 June	17	300	463	183	25
		5 June	4	300	128	44	13
		11 June	4	300	63	28	0
B3	Oliktok-Flaxman	6 June	20	300	530	105	133
		7 June	3	300	73	7	26
		11 June	24	300	382	102	70
B4	Flaxman-Barter	7 June	15	300	396	53	125
B5	Barter-Demarcation	12 June	18	300	307	45	93

several sets of replicate lines were flown to test the effects of altitude and of different sun angles on observer counts. In sector C6, all lines except one were flown twice at the same altitude, several days apart. In sector B1, one set of 7 lines was flown twice at 300 ft altitude, 2 days apart, and another set of 8 lines was flown once at 500 ft and 3 times at 300 ft, over a period of 11 days. Much of sector B3 was surveyed twice at 300 ft, 5 days apart. Sector B5 was surveyed completely for the first time in 1987. In previous years, either time constraints or ice conditions precluded its completion.

The selected data set from which density calculations for the fast ice were made contained 186 transect lines and an area of 1,517 nm^2 (Table 3, Figure 1). This represented 62% of the total number of possible lines at 2-nm intervals, and coverage by area of 16% of all fast ice in the Chukchi Sea and 14% of all fast ice in the Beaufort Sea study areas.

B. Factors affecting survey counts

1. Observer comparisons

During most surveys, a single experienced observer counted seals on each side of the aircraft. Right- and left-side observers remained the same throughout the survey period. From 22-24 May, several inexperienced back-up observers participated in the surveys and provided comparative counts. Rear observation posts did not have bubble windows but visibility was otherwise satisfactory. Results of comparisons of primary and secondary observers are presented in Table 4. In all comparisons combined,

Table 3. Number and percent of lines surveyed, miles on track, and area surveyed by sector for selected data only, 1987. Only these data were used in density calculations.

Sector	Number of lines	% of lines in sector	Miles on track (nm)	Area surveyed (nm^2) fast	pack
C1	18	58	746	507	53
C2	21	57	360	63	99
C4	19	73	370	117	50
C5	18	69	346	156	0
C6	12	50	168	76	0
B1	21	62	430	161	32
B2	21	62	591	227	38
B3	23	61	603	112	159
B4	15	63	396	53	125
B5	18	67	307	45	93
Total	186	62	4,317	1,517	649

Table 4. Comparative counts of ringed seals made by primary and inexperienced secondary observers, May-June 1987.

		Primary Observer		Secondary Observer		
Date	# legs	number of seals	$\bar{x}$ seals/ leg	number of seals	$\bar{x}$ seals/ leg	Paired t-test
22 May	6	213	35.5	144	24.0	t=5.02 df=5 p<0.01
23 May	22	382	17.4	309	14.0	t=2.67 df=21 p<0.02
	6	149	24.8	125	20.8	t=4.00 df=5 p<0.02
24 May	20	175	8.8	142	7.1	t=2.26 df=19 p<0.04

inexperienced back-up observers counted 78% as many seals as did experienced observers, with a range of 67% to 85% on individual flights.

Counts of left and right observers were compared for each survey flight. Left and right sides were significantly different ($p<0.05$), as measured by a chi-square test, on 10 of 29 flights (Table 5). Some of the differences were attributable to large numbers of seals at cracks, and for others there was no obvious explanation. Overall, when all flights on all days were combined, there was less than a 1% difference in the total counts of seals made by left and right observers (6,553 vs 6,595); the difference was not significant by either paired t or Wilcoxon signed rank tests (paired $t=0.13$, $df=28$, $p>0.8$; $z=1.157$, $p>0.2$, ns).

2. Altitude

Prior to 1987, all sectors in the Chukchi Sea were surveyed at 500 ft altitude and those in the Beaufort Sea at 300 ft. In 1987, due to advanced melt conditions in the Chukchi Sea, all Chukchi sectors except C1 were flown at 300 ft. As in previous years, all Beaufort Sea sectors were flown at 300 ft due to the regular occurrence of low cloud ceilings and/or fog.

Portions of sectors C1 and B1 were surveyed at both 300 ft and 500 ft to determine comparability of counts at the 2 altitudes. Test lines were flown consecutively at one altitude and then, on the return flight, at the other. Small differences in time of day and in lighting were considered to have a negligible effect on results.

Table 5. Results of chi-square analyses of the differences in counts between left and right observers for 1987 ringed seal surveys.

Survey date	Number of seals left	right	expected	X^2 (df=1)	P[1]
21 May	360	374	367	0.27	ns
22 May	251	305	278	5.24	<0.025
	151	186	168.5	3.64	ns
	59	92	75.5	7.21	<0.01
23 May	16	12	14	0.57	ns
	366	374	370	0.09	ns
	149	181	165	3.10	ns
24 May	20	13	16.5	1.48	ns
	16	12	14	0.57	ns
	139	183	161	6.01	<0.025
28 May	167	217	192	6.51	<0.025
	152	88	120	17.07	<0.005
29 May	71	77	74	0.24	ns
31 May	106	149	127.5	7.25	<0.01
	93	112	102.5	1.76	ns
	33	46	39.5	2.14	ns
2 June	269	276	272.5	0.09	ns
	83	63	73	2.74	ns
3 June	392	462	427	5.74	<0.025
4 June	99	102	100.5	0.04	ns
5 June	108	101	104.5	0.23	ns
	107	112	109.5	0.11	ns
6 June	575	605	590	0.76	ns
7 June	210	176	193	2.99	ns
	553	499	526	2.77	ns
11 June	1,142	910	1,026	26.23	<0.005
	69	62	65.5	0.37	ns
12 June	609	517	563	7.52	<0.01
13 June	188	289	238.5	21.39	<0.005
Total	6,553	6,595	6,574	0.13	ns

[1] ns = not significant

For all 1987 altitude comparisons, densities of seals at holes based on counts at 500 ft were 71%-76% of those at 300 ft; all comparisons were statistically significant (Table 6). For the 3 flights combined, the 500-ft density was 75% of that determined at 300 ft or, conversely, 1.33 times as many seals/nm^2 were counted at 300 ft as at 500 ft.

3. Meltwater

In 1987, spring weather had already begun melting snow on the surface of the fast ice by the time our surveys began. Unlike the 2 previous years when little or no surface melt was present, in late May 1987 there were extensive areas of dirty ice and meltwater. Because of this, survey altitude in the Chukchi Sea was reduced from 500 ft to 300 ft for all sectors except C1.

In Sector C1, which was flown at 500 ft, 26% of the ice was classified as having greater than 30% meltwater. The density of seals in 0%-30% meltwater was 3.57/nm^2, compared to 2.27/nm^2 in greater than 30% meltwater. In sectors C2-C4 combined, flown at 300 ft, the density in 0%-30% meltwater was 4.95/nm^2, and in greater than 30% meltwater it was 2.79/nm^2. Thus, 1.6 to 1.8 times as many seals were counted in areas without extensive surface meltwater. It is unknown whether the lower densities were due to fewer seals on the ice or to difficulty in seeing seals in areas with disruptive coloring caused by meltwater.

Table 6. Comparison of densities of ringed seals at holes derived from surveys flown at 300 ft and 500 ft altitudes in sectors C1 and B1 during May-June 1987, fast ice only.

Sector		300 ft				500 ft				Student's t-test
		# of legs	area nm^2	seals/ nm^2	sd	# of legs	area nm^2	seals/ nm^2	sd	
C1	5/22	4	59	2.58	0.19	4	120	1.91	0.35	t=3.365 df=6 p<0.02
	5/24	6	28	0.98	0.24	6	47	0.70	0.09	t=2.676 df=10 p<0.05
B1	6/2	6	39	2.94	0.47	6	62	2.23	0.28	t=3.19 df=10 p<0.01

C. Habitat factors affecting distribution and abundance

1. Ice deformation

The percentage of the ice surface that was deformed by pressure ridges, ice jumbles, or snow drifts was recorded by 10% increments for each minute of all survey transects. The 0%-10% category was further subdivided as 0%-5% or 5%-10% deformation.

In the Chukchi Sea in 1987, 99% of all fast ice was less than 40% deformed, and 79% was less than 10%. The density of seals was highest (4.6 seals/nm^2) in the 0%-5% category, where 67% of the number of seals occurred on 56% of the fast ice area, and decreased steadily with increasing deformation (Table 7). Seal density in 0%-10% areas was over 1 seal/nm^2 greater than in the next deformation category. Ice in Kotzebue Sound was considerably flatter than in more northern Chukchi Sea sectors. Ninety-eight percent of all fast ice in sector C1 was less than 10% deformed, compared to 62% in sectors C2-C6. Cracks, and therefore seals at cracks, were not abundant in the Chukchi Sea. However, virtually all seals at cracks occurred in ice of 0%-5% deformation.

In the Beaufort Sea, the pattern of seal density in relation to ice deformation was similar to the Chukchi Sea, with more seals occurring in flat ice than in rougher ice. Ninety-nine percent of all fast ice was less than 40% deformed, but, unlike the Chukchi Sea, only 41% was less than 10% deformed. The density of seals was greatest in the 0%-10% category, where

Table 7. Ringed seal density (total seals) in relation to ice deformation in the Chukchi Sea in 1987, fast ice only.

Deformation (percent)	Area surveyed		Seals		Density
	nm^2	percent	number	percent	$seals/nm^2$
0-5	435.5	56.4	2,013	67.2	4.62
5-10	171.5	22.2	572	19.1	3.34
0-10(combined)	607.0	78.6	2,585	86.3	4.26
10-20	124.0	16.1	324	10.8	2.61
20-30	31.5	4.1	73	2.4	2.32
30-40	6.4	0.8	7	0.2	1.09
>40	2.9	0.4	6	0.2	2.07
Total	771.8		2,995		

Table 8. Ringed seal density (total seals) in relation to ice deformation in the Beaufort Sea (sectors B1-B4) in 1987, fast ice only.

Deformation (percent)	Area surveyed		Seals		Density
	nm^2	percent	number	percent	$seals/nm^2$
0-5	100.7	18	693	23	6.88
5-10	125.7	23	758	25	6.03
0-10(combined)	226.4	41	1,451	48	6.41
10-20	170.3	31	904	30	5.31
20-30	117.4	21	548	18	4.67
30-40	34.2	6	82	3	4.09
>40	5.4	1	10	<1	1.85
Total	553.7		2,995		

48% of the seals occurred on 41% of the fast ice area (Table 8). As in the Chukchi Sea, the density of seals in 0%-10% ice was over 1 seal/nm² greater than in 10%-20% ice.

Cracks were more numerous and more broadly distributed in the Beaufort Sea than in the Chukchi Sea. The density of seals at cracks in the Beaufort was greatest in 0%-5% deformation (3.48/nm²) and considerably less in other deformation categories (1.27-2.25/nm²). Cracks are most often present and visible in large expanses of flat ice.

2. Distance from shore and fast ice edge

The effect of distance from shore and from the fast ice edge on the density of hauled-out seals was examined for each sector by comparing the density of seals by 2-nm increments. In all comparisons in both the Chukchi and Beaufort seas, seals at holes were less abundant 0-2 nm from shore than they were 2-4 nm off shore (Tables 9 and 10). In most sectors, the density within 2 nm of shore was the lowest on any part of the fast ice.

A similar analysis of density with distance from the fast ice edge indicated that in the Chukchi Sea, seals were generally more numerous within 0-4 nm of the fast ice edge than farther away (Table 11). The exception was sector C5, from Point Lay to Wainwright, were seals were half as abundant within 2 nm of the edge as elsewhere. Seals at cracks were present in substantial numbers only in sector C4, and density was greatest near the edge. For all Chukchi Sea sectors combined, the density of seals at holes on the fast ice was 28% higher within 2 nm of the edge than 2-4 nm

Table 9. Density of ringed seals at holes on shorefast ice of the Chukchi Sea in relation to distance from shore, May-June 1987.

Distance from shore (nm)	Sector density (seals/nm²)				
	C1	C2	C4	C5	C6
0-2	1.53	2.43	2.79	2.44	1.84
2-4	3.86	3.03	4.80	2.60	2.70
4-6	3.91	3.63	3.25	2.92	5.33
6-8	3.38	8.98	4.03	2.88	2.55
8-10	5.40		3.87	2.05	2.87

Table 10. Density of ringed seals at holes on the shorefast ice of the Beaufort Sea in relation to distance from shore, May-June 1987.

Distance from shore (nm)	Sector density (seals/nm²)				
	B1	B2	B3	B4	B5
0-2	1.40	1.91	2.75	3.08	5.66
2-4	2.10	3.00	2.89	3.55	5.47
4-6	2.57	3.99	5.37	4.23	7.75
6-8	3.21	5.84	3.53	1.90	16.90
8-10	3.59	5.80	3.08	3.95	

Table 11. Density of ringed seals at holes on shorefast ice of the Chukchi Sea in relation to distance from the fast ice edge, May-June 1987.

Distance from fast ice edge (nm)	Sector density (seals/nm²)				
	C2	C4	C5	C6	Total
0-2	8.82	4.33	1.29	3.35	4.20
2-4	3.68	4.13	2.56	3.54	3.48
4-6	2.41	3.46	2.62	2.11	2.66
6-8	2.13	3.10	2.47	2.02	2.55
8-10		2.57	2.22	1.82	2.24

Table 12. Density of ringed seals at holes on shorefast ice of the Beaufort Sea in relation to distance from the fast ice edge, June 1987.

Distance from fast ice edge (nm)	Sector density (seals/nm²)				
	B1	B2	B3	B4	B1-4
0-2	3.60	2.66	4.07	3.62	3.65
2-4	3.59	4.24	4.40	3.63	3.97
4-6	3.58	3.11	4.22	3.96	3.82
6-8	2.34	3.10	2.28	3.36	2.67
8-10	1.94	3.08	3.43	3.14	2.70

away (Figure 3A). This analysis excluded sector C1, where distance from the edge was not applicable for most lines since all of Kotzebue Sound was fast ice.

In the Beaufort Sea (sectors B1-B4), the density of seals at holes on fast ice was highest within 0-6 nm of the edge, and was similar across that entire region (Table 12). Seals at cracks were abundant only in sectors B3 and B4, but they, too, were most numerous within 6 nm of the edge. In the pack ice, densities were lower and seals at cracks were more broadly distributed, but the density of both seals at holes and those at cracks was highest within 2 nm of the edge (Figure 3B).

3. Pack ice

Total coverage of the pack ice in the Chukchi Sea in 1987 was 176 nm^2, all in sectors C1-C4. The combined Chukchi Sea density of total seals on pack ice was 3.67 seals/nm^2. Most of those were seals at holes.

In the Beaufort Sea, total coverage of pack ice in sectors B1-B4 was 355 nm^2. An additional 93 nm^2 was surveyed 1 week later in sector B5. The density of total seals in pack ice in sectors B1-B4 combined was 3.32 seals/nm^2. In marked contrast to the Chukchi Sea, 62% of those (2.05/nm^2) were seals at cracks. Densities of seals at holes were similar in sectors B1-B4 (range 1.1-1.5 seals/nm^2). However, seals at cracks ranged from less than 0.5/nm^2 in sectors B1 and B2, to over 2 seals/nm^2 in sectors B3 and B4. Sector B5 was flown about a week later than the other sectors and the density in pack ice (8.3 seals/nm^2) was about 2.5 times higher than in sectors B1-B4 combined.

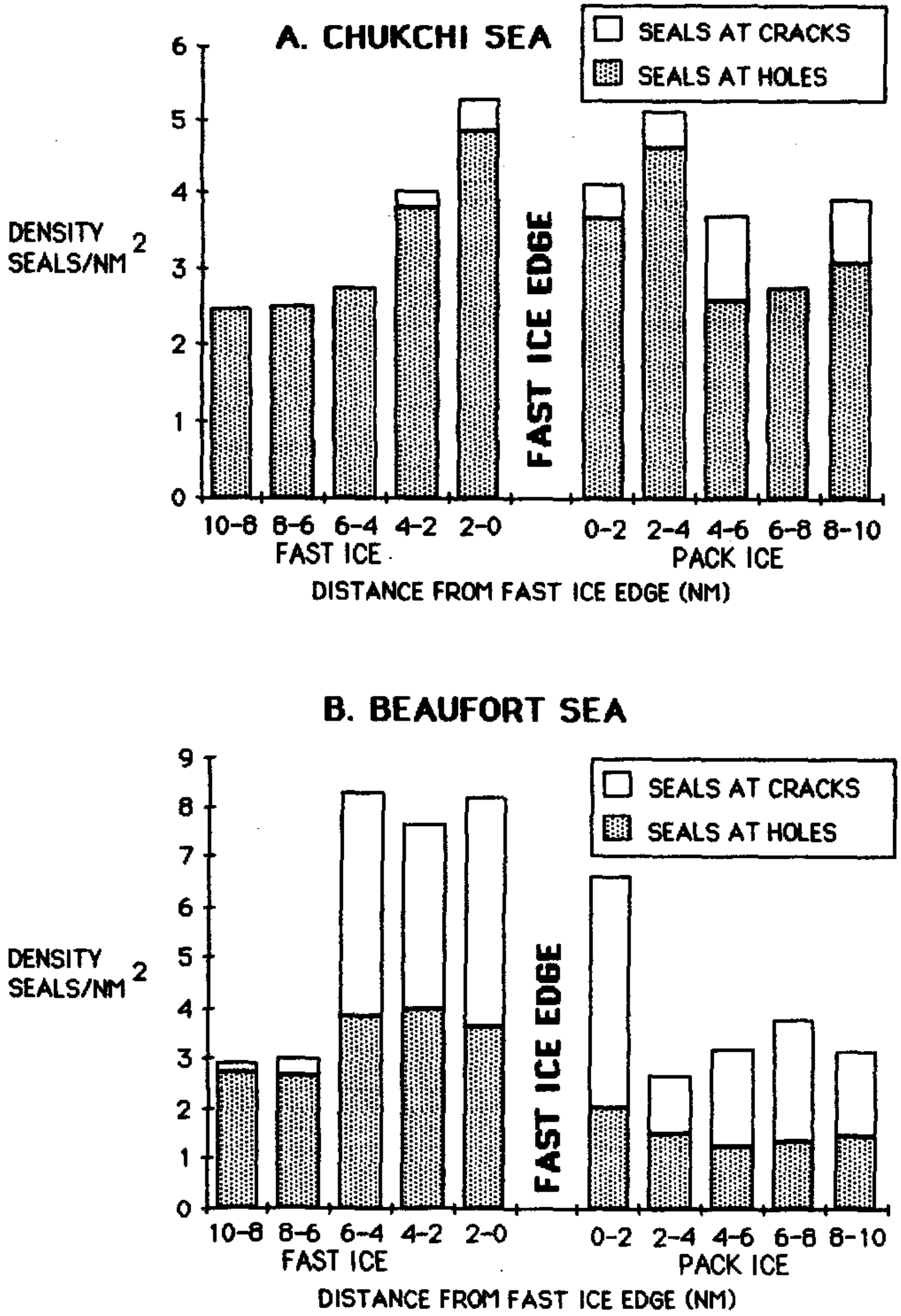


Figure 3. Relationship between seal density (seals/nm^2) and distance from the fast ice edge in 1987. A - Chukchi Sea, not including sector C1, B - Beaufort Sea, sectors B1-B4.

The trend in density on the pack ice relative to the fast ice edge was similar to that on fast ice: more seals were seen close to the edge (Figure 3). For both seals at holes and seals at cracks in the Beaufort Sea, the density was highest within 2 nm of the edge, intermediate 2-10 nm from the edge, and lowest 10-20 nm distant. The density of total seals nearest the edge was $6.6/nm^2$, compared to $3.2/nm^2$ between 2 and 10 nm, and $2.3/nm^2$ seaward of 10 nm. Less area of pack ice was surveyed in the Chukchi Sea, but the trend was similar, with 4.4 $seals/nm^2$ within 4 nm of the edge, $3.2/nm^2$ between 4 and 10 nm, and 2.2 beyond 10 nm.

D. Temporal and Spatial Patterns in Abundance

1. Regional patterns

Densities of total seals on the fast ice of the Chukchi Sea in 1987 were greatest south of Point Lay (sectors C1-C4) and were considerably lower to the north (Table 13). The mean density of total seals for the 3 southernmost sectors combined (C1-C4) was 4.0 $seals/nm^2$, compared to 2.6 $seals/nm^2$ for the more northern sectors C5 and C6. Most of the seals counted in the Chukchi Sea were seen at holes. Seals at cracks accounted for 1% of the total seals in sectors C1-C6 combined (range 0%-6%).

In the Beaufort Sea, densities were lowest in the west between Barrow and Lonely (3.1 $seals/nm^2$), over twice as high in the central Beaufort region between Lonely and Flaxman Island (8.1 $seals/nm^2$) and the eastern Beaufort between Barter Island and Demarcation Point ($7.7/nm^2$), and 4 times as high between Flaxman and Barter Island (12.0 $seals/nm^2$). However, the sector

Table 13. Density of ringed seals on shorefast ice and pack ice in the Chukchi and Beaufort seas, May-June 1987.

	Fast ice				Pack ice			
		Seals/nm²				Seals/nm²		
Sector	nm²	holes	cracks	total	nm²	holes	cracks	total
Chukchi[1]								
C1	506	3.92	0.01	3.92	53	2.76	0.15	2.91
C2	63	4.53	0.03	4.56	99	3.82	0.74	4.57
C4	92	3.57	0.23	3.80	23	1.57	0.00	1.57
C5	156	2.59	0.00	2.59	0	-	-	-
C6	76	2.65	0.05	2.70	0	-	-	-
ALL	892	3.58	0.03	3.62	176	3.20	0.47	3.67
Beaufort								
B1	161	3.00	0.11	3.10	32	1.14	0.25	1.39
B2	227	4.35	0.08	4.44	39	1.17	0.49	1.66
B3	112	3.57	4.51	8.08	159	1.48	2.65	4.13
B4	53	3.52	8.53	12.05	125	1.09	2.23	3.31
B5	45	6.69	1.02	7.71	93	2.70	5.65	8.35
B1-B3	501	3.74	1.08	4.82	230	1.38	1.95	3.33
B1-B4	554	3.72	1.79	5.51	355	1.28	2.05	3.32
B1-B5	599	3.94	1.74	5.68	449	1.57	2.80	4.37

[1] In 1987, snow melt occurred much earlier than in the previous 2 survey years. Sector C1 was surveyed at 500 ft, but observers subsequently decided that the remaining Chukchi Sea sectors should be flown at 300 ft due to extensive meltwater and poor sightability of seals at 500 ft. All densities of seals at holes in C1 have been multiplied by the correction factor 1.32 to make them comparable to data from other sectors that were surveyed at 300 ft.

B3-B5 data may not be comparable to that from sectors B1 and B2. Breakup was apparently well advanced by the time we flew sectors B3-B5, despite the relatively early date.

Observed densities of seals were extrapolated to estimate the total number of ringed seals hauled out on the shorefast ice of the Chukchi and Beaufort seas in May-June 1987 by multiplying the density in each sector by the area of fast ice coverage (Table 14). Calculations indicated means and 95% confidence intervals of 20,200 ± 2,300 total seals hauled out on fast ice in the Chukchi Sea, and 24,100 ± 6,800 in the Beaufort Sea. These estimates do not account for seals that were in the water at the time of the surveys, seals that were missed by observers, or seals in the pack ice. The Beaufort Sea estimate includes very high numbers of seals at cracks in sectors B3-B5.

2. Temporal variability

During 1987 surveys, portions of several sectors were flown more than once to test for temporal variability. In the Chukchi Sea (sectors C2 and C6), 2 sets of lines were flown twice, up to 4 days apart. There was no significant difference in the density of seals at holes or total seals in either comparison (Table 15).

In the Beaufort Sea, 5 replicate data sets were compared. Two sets of lines in sector B1 were flown 2-3 days apart under similar ice conditions. There was no significant difference in the density of total seals in either

Table 14. Density and estimated numbers (95% confidence limits) of total ringed seals hauled out on the fast ice in the study area during aerial surveys conducted in May-June 1987.

Sector	Density - seals/nm^2 (±95% confidence interval)	Fast ice area - nm^2	Estimated number of hauled-out seals
B1	3.10 (±0.37)	1,050	3,260 ± 390
B2	4.44 (±0.53)	1,770	7,860 ± 940
B3	8.08 (±2.96)	780	6,300 ± 2,310
B4	12.05 (±11.94)	410	4,940 ± 4,900
B5	7.71 (±2.45)	240	1,850 ± 590
Beaufort Total	5.68 (±1.61)	4,250	24,140 ± 6,840
C1	3.92 (±0.69)	2,390	9,370 ± 1,650
C2	4.56 (±1.74)	655	2,990 ± 1,140
C4	3.80 (±1.20)	715	2,720 ± 860
C5	2.59 (±0.31)	995	2,580 ± 310
C6	2.70 (±1.27)	830	2,240 ± 1,070
Chukchi Total	3.62 (±0.41)	5,585	20,220 ± 2,290
Grand Total		9,835	44,360 ± 9,130

Table 15. Comparison of ringed seal densities derived from replicate surveys of the same lines flown on different days. Only seals on shorefast ice are included.

Sector (altitude)	# legs	Replicate 1 date	Replicate 1 density (seals/nm²) holes	cracks	total	Replicate 2 date	Replicate 2 density (seals/nm²) holes	cracks	total	Student's t-test
C2	6	23 May	6.32	0.0	6.32	23 May	6.10	0.06	6.16	holes t=0.170, df=10, n.s. total t=0.124, df=10, n.s.
C6	12	31 May	2.65	0.05	2.70	4 June	2.60	0.0	2.60	holes t=0.231, df=22, n.s. total t=0.468, df=22, n.s.
B1	7	31 May	2.64	0.0	2.64	2 June	2.52	0.22	2.74	holes t=0.459, df=12, n.s. total t=0.374, df=12, n.s.
B1	8	2 June	3.06	0.15	3.21	5 June	3.70	0.0	3.70	holes t=2.70, df=14, p<0.02 total t=2.07, df=14, n.s.
B1	8	5 June	3.70	0.0	3.70	13 June	8.06	0.51	8.58	holes t=8.89, df=14, p<0.001 total t=10.25, df=14, p<0.001
B1	8	2 June	3.06	0.15	3.21	13 June	8.06	0.51	8.58	holes t=10.77, df=14, p<0.001 cracks t=3.01, df=14, p<0.01 total t=11.97, df=14, p<0.001
B3	15	6 June	3.71	2.51	6.23	11 June	5.11	6.08	11.19	holes t=7.07, df=28, p<0.001 cracks t=4.61, df=28, p<0.001 total t=5.83, df=28, p<0.001

comparison. Three pairs of surveys (sectors B1 and B3) occurred 5-11 days apart. In all 3, the density of seals at holes and of total seals was significantly greater on the later date.

In sector B1, the position of the ice edge, and therefore the area of fast ice surveyed, remained similar throughout our surveys. In sector B3, the ice edge was breaking up quite rapidly, and the total fast ice area was reduced by approximately 23% between the 6 June and 11 June surveys. To ensure that density comparisons for sector B3 were made between comparable areas, we compared (a) only the area within 6 nm of land and (b) all ice, both fast and pack. In both comparisons, significantly more seals were hauled out on the later date (4.90 vs 11.75 seals/nm^2 within 6 nm of land and 4.91 vs 11.38 seals/nm^2 for fast and pack ice combined). The increase was greatest for seals at cracks.

We also calculated average group size (the number of seals hauled out at a single hole) and the density of groups for early and mid-June surveys in the Beaufort Sea (Table 16). In sector B3, the average group size was significantly greater for the later surveys (1.5 vs 1.8, $t=2.311$, $p<0.05$). In B1, the difference was not significant (1.3 vs 1.4, $t=1.518$, $p>0.1$). The density of groups increased in both sectors, with the greatest increase in B1. Group size was also comparatively large in sectors B4 and B5 which were surveyed late in the study period.

E. Density of seals in relation to industrial activities

In spring of 1987 there was little industrial activity in the study area. We saw no evidence of on-ice seismic surveys, or ice roads other than those leading to artificial islands.

Table 16. Comparison of average group size and density of groups for seals at holes in the fast ice, in the Beaufort Sea, June 1987 .

Sector	Date	Seals/nm^2	Groups/nm^2	Group size
B1	2 June	3.06	2.32	1.25
	13 June	8.06	5.81	1.39
B2	3,5 June	4.35	3.27	1.33
B3	6,7 June	3.71	2.41	1.53
	11 June	5.11	3.10	1.78
B4	7 June	3.52	1.80	1.96
B5	12 June	6.69	3.14	2.13

During 1987 aerial surveys, as in the 2 previous years, there were 3 artificial islands located in the study area in the region between Oliktok and Prudhoe Bay (Figure 4). They were: (1) Seal Island, located 10 nm west of Prudhoe Bay, (2) Northstar Island, located 4 nm west-northwest of Seal Island, and (3) Sandpiper Island, located 5.5 nm west-northwest of Northstar Island. All 3 islands were inactive during winter and spring of 1986-87.

Surveys were conducted in the vicinity of the 3 islands twice in 1987, on 6 and 11 June. The shortest straight-line distances from artificial islands to each minute sighting block were determined by comparing positions for each interval to positions for the islands. Densities were then calculated for 2-nm concentric circles centered at the artificial islands, out to a distance of 10 nm. Since the islands were less than 10 nm apart and interactive effects were possible, a density in relation to all islands were also calculated using the minimum distance from any of the 3 islands for each 1-minute sighting block.

There was no consistent trend in seal density with distance from the 3 non-operational islands (Table 17). Seals were more numerous near Seal Island, less numerous near Northstar, and differed between the 2 surveys at Sandpiper. At Seal Island, where the density was very high near the island, there was a large crack in the ice running perpendicular to the shore, both to the north and to the south. This crack, which appeared to be caused by the island, may have provided an avenue along which seals penetrated into the nearshore fast ice.

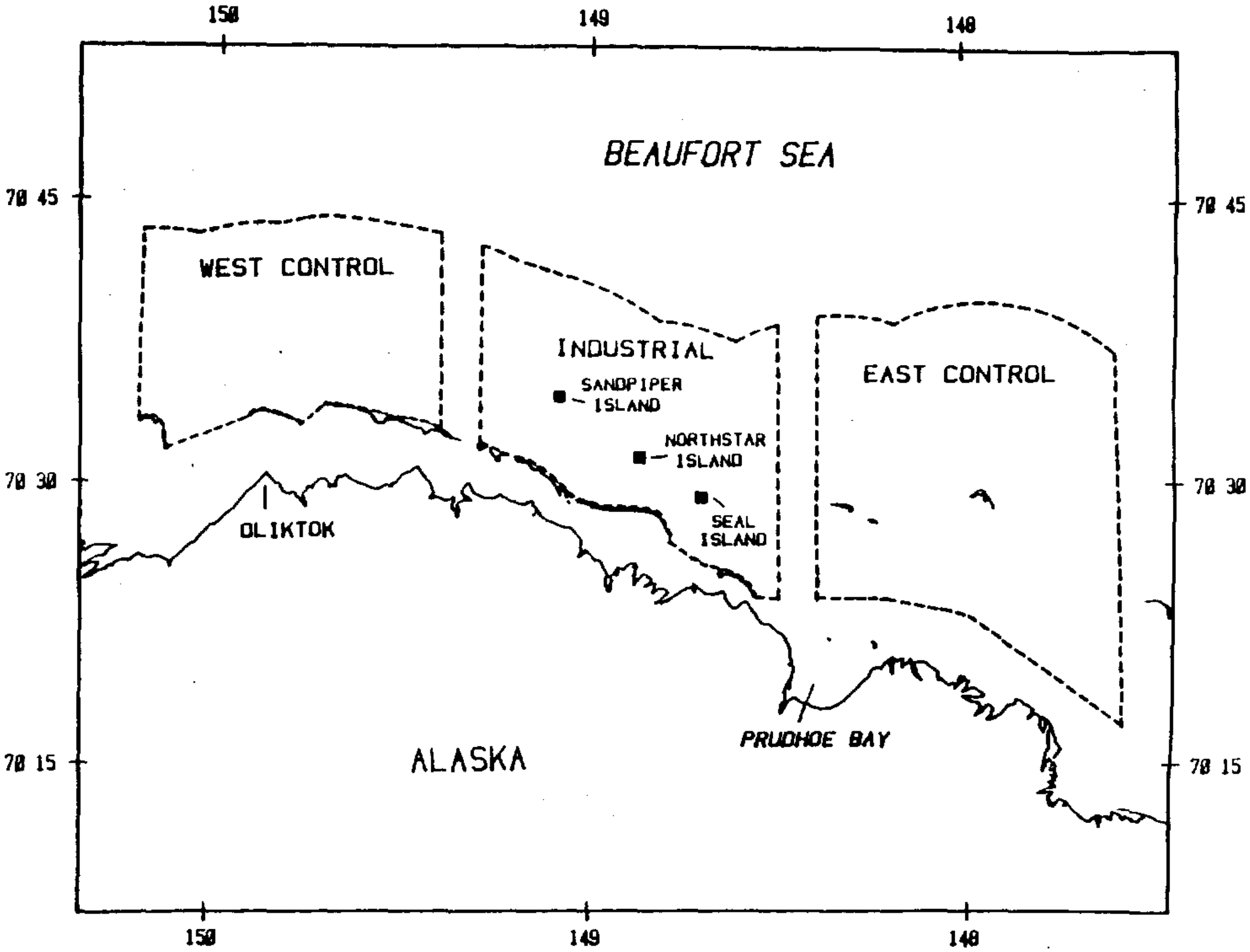


Figure 4. Map of the Central Beaufort Sea showing locations of artificial islands and industrial and control blocks used in 1986 and 1987 data analyses.

Table 17. Density of ringed seals at holes in relation to distance from 3 artificial islands in the Beaufort Sea, June 1987.

Island	Survey	nm^2 surveyed	Distance (nm) 0-2	2-4	4-6	6-8	8-10
Seal	87-1	26	-	1.1	2.9	2.7	5.5
	87-2	32	14.4	9.5	10.4	5.9	4.8
Northstar	87-1	23	1.1	3.3	5.6	4.1	5.2
	87-2	34	3.8	8.4	14.2	6.3	6.1
Sandpiper	87-1	27	7.1	7.6	2.2	4.2	3.9
	87-2	34	6.8	5.5	6.6	5.2	11.9
Any Island	87-1	45	4.7	6.7	2.4	4.1	4.0
	87-2	50	7.1	8.1	9.5	5.8	5.4

When all 3 islands were considered in aggregate, the densities in the 0-2 nm distance interval were 12%-30% lower than those in the 2-4 nm interval. The density differences between these 2 intervals were not significant on either day (t-tests, $p>0.05$). Sample sizes were very small in the distance intervals closest to the island: 5 minutes and 4.5 nm^2 in the 0-2 nm and 2-4 nm intervals combined on 6 June and 10-14 minutes and 9.0-12.5 nm^2 in those intervals on 11 June.

Data from the 1987 surveys were also analyzed according to the 1986 industrial and control blocks (Figure 4) even though there was little or no offshore industrial activity. In the absence of industrial activity, density of total seals in the "industrial" block was significantly higher ($p<0.02$), than in either control area for both surveys (Table 18).

The industrial block was an area in which some type of industrial activity (such as seismic surveys or artificial islands) had occurred in 1986, and included the ice within 10 nm of land. Control blocks were located to the east and west of the industrial block and were areas with no obvious industrial activity. Although they were "controls" in the sense that there was no industrial activity there in 1986, they may or may not have been environmentally comparable in terms of bathymetry, ice conditions, prey availability, etc.

Table 18. Densities of ringed seals (seals/nm^2) within 10 nm of land in "industrial" and "control" blocks in the Beaufort Sea, June 1987. Standard deviations are given in parentheses.

Block	#legs	Seals at holes density (SD)	Seals at cracks density (SD)	Total seals density (SD)
Test 1 - 5-6 June				
Industrial	4	3.80 (1.05)	3.38 (1.11)	7.17 (1.55)
Control West	5	3.84 (0.57)	0.61 (0.37)	4.45 (0.77)
Control East	7	2.04 (0.56)	1.51 (0.55)	3.55 (0.70)
Test 2 - 11 June				
Industrial	9	8.10 (1.41)	6.73 (4.51)	14.83 (5.23)
Control West	9	5.90 (0.40)	2.36 (2.23)	8.25 (2.34)
Control East	9	3.36 (0.55)	3.33 (2.43)	6.69 (2.43)

VI. Discussion and Conclusions

A. Survey effort

The total amount of survey effort, in terms of area surveyed of fast ice and pack ice, is summarized for each sector in Table 19. The total area surveyed was 3,409 nm^2 (92% fast ice) in 1985, 3,405 nm^2 (74% fast ice) in 1986, and 2,958 nm^2 (71% fast ice) in 1987. Variations in total and proportional coverage were due mostly to intentional adjustments to in survey design. The reduced fast ice coverage in the Beaufort Sea in 1986 and 1987 was due largely to the decision not to attempt 90% coverage of all lines in sectors B2 and B3. Also, the intensive grid around artificial islands (lines spaced 1 nm apart) was flown only in 1985. Survey design in 1986 and 1987 included, where possible, 2-4 lines per sector extending 40 nm off shore in order to provide coverage of pack ice. There was no systematic attempt to obtain pack ice coverage in 1985. Overall, there was considerable variability in pack ice coverage due to annual variations in the location of the fast ice edge and the relationship between timing of surveys and the beginning of breakup.

Although we initially intended to gather data on seal density for all portions of the Chukchi and Beaufort sea coasts, it was impossible to do so. In all 3 years, the shorefast ice from Point Hope to Cape Lisburne (sector C3) consisted of a very narrow band, seaward of which was a lead of variable width and a very extensive shear zone. These conditions made aerial strip transect surveys impractical. Furthermore, steep cliffs south of Cape Lisburne cause severe downdrafts near shore and make flying over

Table 19. Total area surveyed (nm^2) in fast and pack ice during ringed seal aerial surveys conducted in May-June 1985-1987. All data collected are included.

Sector	Sector boundaries	1985 fast	1985 pack	1986 fast	1986 pack	1987 fast	1987 pack
C1	Cape Espenberg - Cape Krusenstern	542	20	491	3	641	53
C2	Cape Krusenstern - Point Hope	58	136	101	77	97	184
C3	Point Hope - Cape Lisburne	0	0	0	0	0	0
C4	Cape Lisburne - Point Lay	167	0	212	0	117	50
C5	Point Lay - Wainwright	134	0	204	34	156	0
C6	Wainwright - Barrow	115	0	272	157	155	0
	Total Chukchi Sea	1,016	156	1,280	271	1,166	287
B1	Barrow - Lonely	382	7	456	145	357	96
B2	Lonely - Oliktok	820	0	378	12	255	38
B3	Oliktok - Flaxman	631	63	345	305	214	229
B4	Flaxman - Barter	279	11	70	143	53	125
B5	Barter - Demarcation	13	31	0	0	45	93
	Total Beaufort Sea	2,125	112	1,249	605	924	581
	Total	3,141	268	2,529	876	2,090	868

the narrow band of fast ice difficult and unsafe. Also, while seals do occur in such habitats, this is not the type of region which supports large numbers of resident animals. We also did not obtain adequate coverage in the Beaufort Sea east of Barter Island (sector B5). Reasons for this include limited extent of shorefast ice, early and complex patterns of breakup, and limitations on the number of survey hours available. A concerted effort to get data for this region in 1987 resulted in only 45 nm^2 of fast ice surveyed.

The amount of fast ice area surveyed, expressed as a percent of total fast ice area in relation to survey area in the selected data base was quite consistent (Table 20). The difference between the Chukchi Sea and Beaufort Sea in 1985 and 1986 is due to the fact that in those years all Chukchi Sea sectors were surveyed at 500 ft (strip width 2,250 ft) and all Beaufort Sea sectors were surveyed at 300 ft (strip width 1,350 ft). In 1987, all sectors except C1 were surveyed at 300 ft and the difference in coverage was much less. When data for the Chukchi and Beaufort seas are combined, effort as reflected in the selected data base was virtually identical among years: 14.3% coverage in 1985, 14.3% coverage in 1986, and 15.0% coverage in 1987.

The total area of fast ice surveyed (Table 19) can be compared to the area included in the selected data base (Table 20) as a partial evaluation of survey performance. In 1985, 58% of all data collected was used in the selected data base; this value increased to 70% in 1986 and 73% in 1987. This increase reflects both the results of analysis of 1985 data that refined our definition of the survey window (Frost et al. 1985b), and an increased ability of survey personnel to anticipate appropriate survey conditions.

Table 20. Aerial survey coverage during ringed seal aerial surveys conducted in May-June 1985-1987, selected data only.

Year	Region	Area of fast ice	Area of fast ice surveyed	Percent coverage	Area of pack ice surveyed
1985	Chukchi	4,890	946	19	128
	Beaufort	7,745	861	11	97
1986	Chukchi	5,800	1,073	19	128
	Beaufort	6,535	693	11	208
1987	Chukchi	5,858	919	16	202
	Beaufort	4,250	598	14	447

B. Aerial survey methodology

1. Influence of weather

Previous studies have shown that weather affects 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 incorporated the findings of those studies, which largely precluded further tests of weather effects since we did not survey during extreme conditions that might have markedly affected observed densities. Analysis of weather effects is further complicated by the fact that weather reports were available only from a limited number of coastal stations and may not have accurately represented conditions in the survey areas on the ice surface.

The data collected in 1985 contained some legs flown at wind speeds of 21-25 and 26-30 knots, and air temperatures of -6° to -10°C. Analysis of the data indicated a significantly lower density of seals on transects flown at wind speeds of greater than 25 knots (Frost et al. 1985*b*). Temperatures below -5°C and wind chills below -20°C also produced lower density estimates but those comparisons were considered inconclusive because of small sample sizes. It was recommended that whenever possible future surveys should be flown at wind speeds $\leq$15 knots.

No surveys in 1986 or 1987 were intentionally flown at wind speeds greater than 20 knots; most were flown in 5- to 15-knot winds but some legs were flown with 16-20 knot winds. A multiple regression analysis of the effect of wind and temperature on the density of seals at holes indicated that wind speed, but not temperature, was correlated with seal density (Frost et al. 1987). Since less than 2% of the sample variability was attributable to wind, we believe that all data collected at wind speeds of $\leq$ 20 knots can be considered comparable.

2. Altitude effects

Previous aerial surveys of ringed seals have generally been flown at altitudes of 300 ft to 500 ft. The preferred altitude has usually been 500 ft, with 300 ft considered an acceptable alternative when necessitated by low cloud ceilings and/or fog (Stirling et al. 1977 and 1981a, b; Kingsley et al. 1982 and 1985; Burns et al. 1981; Burns and Kelly 1982). Density estimates derived at the 2 altitudes have been compared or combined without the use of correction factors. When the protocol for our surveys was developed, we proposed a standard survey altitude of 500 ft unless conditions required otherwise.

In 1985, the ice in the Chukchi Sea was flat and clean, low cloud ceilings were not a problem, and all sectors were therefore flown at 500 ft. Some of the Beaufort Sea sectors were initially flown at 500 ft, until it became apparent to observers that greater ice deformation, dirtier ice, and sometimes extensive meltwater made it difficult to detect seals at that altitude. Furthermore, cloud ceilings and/or fog were often below 500 ft. In response, all sectors, or parts of sectors, were also surveyed at 300 ft. The observed mean densities at the 300 ft survey altitude were from 23% to almost 300% greater than those at 500 ft (Frost et al. 1985b).

Although these comparisons were not made on identical data sets and were not necessarily under the same weather and ice conditions, the difference was large enough to warrant further investigation.

Altitude comparisons were conducted in 2 sectors (C6 and B1) in 1986 (Frost et al. 1987) and in 2 sectors (C1 and B1) in 1987. For all comparisons in which the same lines were flown on the same day at both altitudes, the densities of seals at holes based on counts at 500 ft were 71%-80% of those at 300 ft (Table 21). All comparisons were statistically significant ($p<0.05$). For the 5 systematic altitude comparisons combined, the 500-ft density of seals at holes was 76% of that determined at 300 ft, or, conversely, 1.32 times as many seals/nm^2 were counted at 300 ft as at 500 ft ($p<0.001$).

In 1986, we conducted separate analyses of "flat" (0%-20% deformation) ice and "rough" (20%-40% deformation) ice for the data sets used in altitude comparisons (Frost et al. 1987). These comparisons suggested that ice deformation might have an interactive effect with survey altitude, and that the differential counts at 300 ft and 500 ft occurred primarily in flat ice. However, when ratios of seals in flat or rough ice were compared for the entire 1986 data base, that did not appear to be the case. Data from 1987 surveys were also analyzed as flat or rough ice and have been included in comparisons using all suitable ringed seal survey data (Table 22). Based on data sets from 5 years, altitude has no apparent effect on the observed ratio of densities (D) of seals in flat and rough ice. At 300 ft altitude, the ratio of $D_{flat}:D_{rough}$ ranged from 1.0-1.8, and at 500 ft from 0.9-1.7. The ratios of densities in flat ice or rough ice at the 2

Table 21. Comparison of densities of ringed seals at holes derived from surveys flown at 300 ft and 500 ft altitudes in sectors C1, C6, and B1 during May-June 1986-1987, fast ice only.

		300 ft				500 ft			
Sector	Date	# of legs	area nm^2	seals/ nm^2	sd	area nm^2	seals/ nm^2	sd	Student's t-test
C1	5/22/87	4	59	2.58	0.19	120	1.91	0.35	t=3.365 df=6 p<0.02
	5/24/87	6	28	0.98	0.24	47	0.70	0.09	t=2.676 df=10 p<0.05
	5/30/86	15	68.6	2.93	0.41	113.7	2.35	0.40	t=3.90 df=28 p<0.001
B1	5/31/86	8	77.0	2.38	0.25	128.4	1.71	0.22	t=5.62 df=14 p<0.001
	6/2/87	6	39	2.94	0.47	62	2.23	0.28	t=3.19 df=10 p<0.01
All		39	271	2.49	0.18	471	1.88	0.16	t=15.61 df=76 p<0.001

Table 22. Densities of total ringed seals (seals/nm²) in flat and rough ice for surveys conducted at 300 ft and 500 ft, 1981-1987. Data from 1985-1987 are from this study. Data from 1981 and 1982 were collected by ADF&G as part of RU #232 and re-analyzed as part of this study.

		300 ft ice deformation			500 ft ice deformation		
Year	Area	0%-20% "flat"	20%-40% "rough"	D flat / D rough	0%-20% "flat"	20%-40% "rough"	D flat / D rough
1981	Beaufort	1.6	1.6	1.0			
1982	Beaufort				1.8	1.3	1.4
1985	Beaufort	3.3	3.1	1.1	2.7	1.7	1.6
1986	Beaufort	5.1	3.4	1.5	3.9	2.4	1.7
	Altitude test only	2.9	1.8	1.6	1.8	1.9	0.9
1987	Beaufort	5.9	4.5	1.3			
	Chukchi	3.7	2.1	1.8			
	Altitude test only	2.6	2.7	1.0	1.8	1.7	1.1

altitudes were also similar, and generally approximated the 1.32 correction factor developed for altitude based on 1986 and 1987 data sets ($D_{flat\ 300}:D_{flat\ 500} = 1.2\text{-}1.6$; $D_{rough\ 300}:D_{rough\ 500} = 0.9\text{-}1.8$).

Other investigators have discussed the factors affecting sightability of animals from the air. Caughley (1974) stated that the 3 most important factors are probably ground speed, strip width, and altitude, and that sightability declines with increases in all three. Data examined for sightability biases by Caughley (1974) and Caughley et al. (1976) indicated that for elephants a 50% reduction in survey altitude resulted in a 25% increase in the number counted. Their analyses of wildebeest surveys indicated that more variability was associated with strip width than with altitude, and that doubling strip width (from 200 m to 400 m) resulted in about a 50% reduction in estimated density. Survey speed was also found to affect density estimates.

In all 1985-1987 surveys of ringed seals, air speed was held constant. However, altitude and strip width varied between areas and among years. Our survey protocol specified that inclinometer angles defining strip width would remain constant, regardless of altitude, to minimize disruption and recalibration by observers during changes in altitude. However, this meant that changes in strip width always occurred concurrently with changes in altitude, and the biases associated with the 2 variables could not be tested independently. Thus, we could not determine whether the lower densities observed at 500 ft vs 300 ft were attributable to increased altitude, increased strip width, or both.

Data collected in 1981 and 1982, however, utilized a 0.5-nm survey strip that was subdivided into inner and outer 0.25-nm bands for which counts were kept separately. We compared densities for inner and outer strips and those for inner strips and total strips for 1981 surveys conducted at 300 ft and 1982 surveys conducted at 500 ft. In both years, the densities calculated for the inner 0.25-nm strips exceeded those for the outer strips and for the total 0.5-nm strips, implying that fewer seals were missed closer to the aircraft (Table 23). Inner strip densities exceeded the total strip densities by 10% to 18%. Such comparisons indicate that the actual distance between observer and animal, as well as increased strip width, affect density estimates.

3. Observer comparisons

During most of the ADF&G aerial surveys for ringed seals in 1985-1987, a single trained observer counted seals on each side of the aircraft. The right-side observer (Frost) was the same in all 3 years. The left-side observer was Gilbert in May 1985 and all of 1986 and Golden in June 1985 and all of 1987. Total counts of the numbers of seals seen by left and right observers for all survey days in a given year were compared through paired t and Wilcoxon signed rank tests (Table 24). In no year was the difference between left and right observers significant by either test. Total counts of the left observer ranged from 7% less to 8% more than the right observer.

Other investigators conducting aerial surveys of ringed seals have also investigated the effects of observer bias by comparing counts of seals on

Table 23. Density of ringed seals in inner and outer 0.25-nm survey strips based on aerial surveys conducted by ADF&G in May-June 1981 and 1982. Inner and outer strips for 1981 extend from 750 ft to 2,250 ft and 2,250 ft to 3,750 ft from the aircraft, and in 1982 from 0-1,500 ft and 1,500-3,000 ft.

			Seals/nm²			Ratio	
Year	Sector	nm²	inner	outer	total	inner/outer	inner/total
1981 (300 ft)	B1	70	1.62	1.77	1.69	0.92	0.96
	B2	592	1.43	1.06	1.24	1.35	1.15
	B3	516	1.49	1.07	1.28	1.39	1.16
	B4	130	1.67	1.93	1.76	0.87	0.95
	All	1,308	1.48	1.19	1.34	1.24	1.10
1982 (500 ft)	B1	106	1.31	0.67	0.99	1.96	1.32
	B2	94	1.68	1.23	1.45	1.37	1.16
	B3	243	1.85	1.32	1.58	1.40	1.17
	B4	47	1.11	1.00	1.05	1.11	1.06
	All	490	1.63	1.13	1.38	1.44	1.18

Table 24. Comparison of the number of seals counted by left and right observers for ringed seal aerial surveys, May-June 1985-1987.

Date	n	# seals left	# seals right	Paired t-test	Wilcoxon signed rank
May 1985	10	2,272	2,478	t=1.409, df=9 p>0.1, ns	z=-0.459, p>0.6, ns
June 1985	13	1,751	1,859	t=0.996, df=12 p>0.3, ns	z=-0.943, p>0.3, ns
May-June 1986	29	7,229	6,688	t=1.79, df=28 p>0.05, ns	z=-1.774, p>0.05, ns
May-June 1987	29	6,553	6,595	t=0.13, df=28 p>0.9, ns	z=-1.157, p>0.2, ns

the left and right sides of the aircraft during simultaneous transects. Stirling et al. (1977) found no significant differences in 8 comparisons of ringed seal counts made in 1974 and 1975. Stirling et al. (1981a and b) reported differences of 2% to 25% in surveys conducted during 1974-79 in the eastern Beaufort Sea and Canadian High Arctic, but none of the differences were significant. Tests of potential observer bias must be made on relatively large samples, such as data from entire survey days, rather than on a transect-by-transect basis since habitat variability and clumped distribution of seals can cause substantial within-transect differences. Ice conditions on the left and right sides of the aircraft may be considerably different, and although one expects this to average out as more lines are surveyed, it is still possible for a few very large groups of seals, or a few areas (such as newly refrozen leads) where seals are very abundant, to result in large differences in counts between the 2 sides of the aircraft.

During 1985-1987 aerial surveys for ringed seals, back-up observers participated and provided comparative counts on 13 occasions (Table 25). Rear observation posts did not have bubble windows but visibility was otherwise satisfactory. Seals occasionally dove into the water before they came into view of the second observer, which, depending on the search pattern of the back-up observer, may have resulted in some seals being missed. Participants agreed that this generally was not a major problem.

Of the 13 comparisons, 7 were between an experienced primary observer and an inexperienced back-up observer. In 5 of those comparisons, the experienced observer counted significantly more seals ($p<0.05$). In 6

Table 25. Comparison of counts of ringed seals made by experienced and inexperienced observers during aerial surveys conducted during May-June, 1985-1987.

Date	# legs	Primary observer: number of seals	Primary observer: $\bar{x}$ seals/leg	Back-up observer: number of seals	Back-up observer: $\bar{x}$ seals/leg	Paired t-test
Back-up Inexperienced						
22 May 1985	14	442	31.6	420	30.0	t=0.598, df=13, p>0.5, ns
22 May 1985	14	393	28.1	436	31.1	t=1.74, df=13, p>0.1, ns
23 May 1986	14	564	40.3	427	30.5	t=2.386, df=13, p<0.04
31 May 1986	22	227	10.3	132	6.0	t=3.762, df=21, p<0.001
22 May 1987	6	213	35.5	144	24.0	t=5.019, df=5, p<0.01
23 May 1987	28	531	18.9	434	15.5	t=3.485, df=27, p<0.002
24 May 1987	20	175	8.8	142	7.1	t=2.260, df=19, p<0.04
Back-up Experienced						
30 May 1985	28	320	11.4	306	10.9	t=1.077, df=27, p>0.2, ns
24 May 1986	6	339	56.5	347	57.8	t=1.512, df=5, p>0.1, ns
25 May 1986	27	489	18.1	458	17.0	t=1.686, df=26, p>0.1, ns
26 May 1986	5	84	16.8	78	15.6	t=0.48, df=4, p>0.6, ns
27 May 1986	14	88	6.3	93	6.6	t=0.219, df=13, p>0.8, ns
27 May 1986	8	42	5.3	58	7.3	t=0.928, df=7, p>0.3, ns

comparisons between experienced observers, or with a novice observer who had received some training, differences were not significant ($p>0.1$). Inexperienced observers undercounted by 5%-42% in all but one comparison. In contrast, when both observers were experienced, there was no pattern to which observer had the highest count.

Using the counts of primary and experienced back-up observers, calculations were made to estimate the proportion of total seals present that were seen by a single observer. Calculations were made using the formula from Caughley (1974) in which, based on the differential counts of 2 observers, he determined the probability that a group of elephants was seen by one observer (p), seen by both observers (p^2), seen by one or the other ($2p(1-p)$), or missed by both ($(1-p)^2$). The probability p can be estimated from the relationship:

$$2p(1-p)/p^2=S/B$$

from which

$$p=2B/(2B+S)$$

where S is the number of groups seen by a single observer only and B is the number seen by both. The number missed is represented by $M=S^2/4B$. Based on 4 comparisons (Table 26), $p=0.83$ for groups (range=0.79-0.86) and 0.82 for individual seals (range=0.74-0.86). In other words, the counts suggest that a single observer sees about 83% of the groups and 82% of the seals hauled out on the ice. This is a relatively high proportion compared to the estimated 40% determined by Caughley for elephants in wooded areas of Uganda.

Table 26. Number of groups of seals and numbers of seals seen by one or both observers during comparative counts by primary and experienced back-up observers. P = probability that a given seal is seen by a given observer. S_A = number seen only by observer A. S_B = number seen only by observer B. B = number seen by both observers. M = number missed. See text for formulas and explanation

Date		S_A	S_B	B	M	Estimated total #	P
30 May 1985	groups	33	26	174	5	238	0.86
	number						0.85
24 May 1986	groups	40	23	142	7	212	0.82
	number						0.78
16 June 1986	groups	10	10	38	3	61	0.79
	number						0.86
28 May 1987	groups	9	12	40	3	64	0.79
	number						0.74
Combined samples	groups	92	71	394	17	574	0.83
	number						0.82

Using these data, the probability that seals were seen by both observers was 0.7, and that they were seen by only one or the other was 0.3. It is evident that, while the numbers of seals counted by experienced primary and back-up observers were not statistically different, neither observer saw all of the seals present, nor did the 2 observers see all of the same seals. Individual observers missed, on the average, 18% of the seals in the survey strip. This indicates that, at a minimum (i.e., not taking into account the proportion of seals that are in the water and thus not able to be counted) the density estimates resulting from these aerial surveys are low by about 18%.

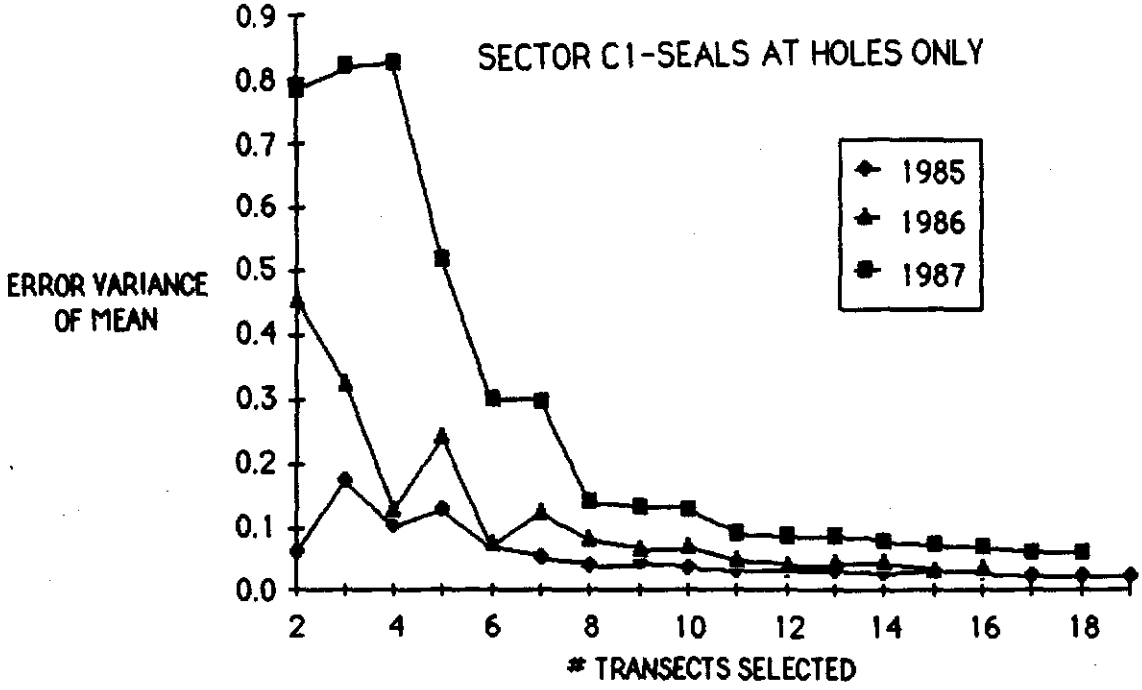
4. Survey coverage

In order to arrive at a sampling plan for our initial 1985 surveys, we analyzed the relationship between variance and sampling intensity using a set of transects from 1981 ringed seal aerial surveys in the Beaufort Sea. That analysis indicated that the variance (square of the standard deviation) of the mean density estimate dropped rapidly until about 50% of all possible transects were selected from the data base, with a slower, steady decrease as additional transects were incorporated. Based on that, sampling intensity was set at 60% of all possible lines within each sector, except for sectors B2 and B3 where coverage was 90% of all lines.

This relationship was reanalyzed using data collected in sectors B2 and B3 in 1985 and the same pattern was found (Frost et al. 1985b). In addition, we analyzed and plotted the ratio between 1.96 standard deviations of the mean and the mean density for each sector. This ratio measures the confidence interval around the mean density such that a value of 0.10 would indicate that the 95% confidence limits are equal to the mean plus or minus 10%. A test of the regression line indicated that there was no significant difference in the size of the confidence interval with sampling intensities ranging from 38%-92%. With a sampling intensity of 60%, density estimates should have 95% confidence intervals of ±5%-15%.

For 1986 surveys, we attempted to obtain 90% coverage in sector B3 and 60% coverage in other areas. However, due to a storm that occurred during the survey period, adequate data were obtained from only 15 of 38 lines in sector B3 (39.5% coverage). We analyzed the relationship between the number of transects selected from the 1986 data base and the variance of the mean for sectors C1 and B2/B3 combined, and examined the ratio between 1.96 standard deviations and mean density for each sector in 1985 and 1986. Sampling intensity of 50%-60% of all possible lines was judged adequate, and 95% confidence intervals for all Chukchi and all Beaufort sea data were equal to the mean plus or minus 9%-10% (Frost et al. 1987).

The relationship between the number of transects selected from the data base and the variance of the mean is shown by year for 4 sectors or sector combinations in Figures 5-8. Each point represents the mean of 6 separate calculations which randomly selected the indicated number of transects from the data base. Several patterns are evident from these figures. In all cases, the variance dropped rapidly up until approximately 50% of all possible transects were selected from the data base, after which the variance declined gradually. Variance was very erratic when only a few transects were selected. In all cases, the variance was much lower when



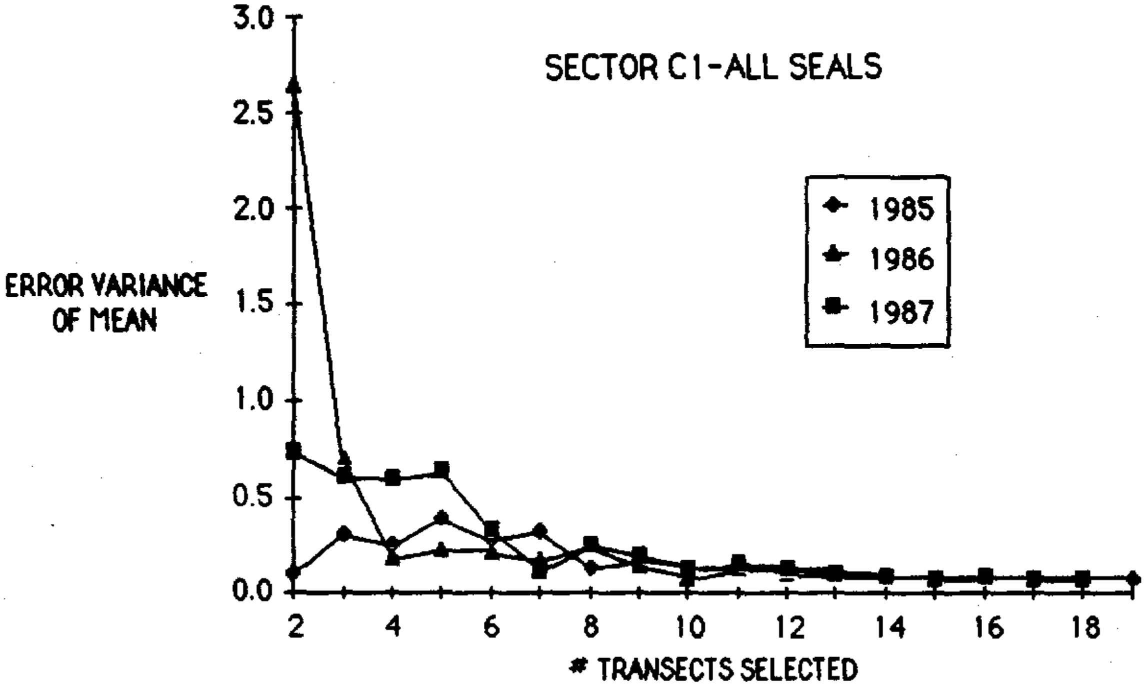
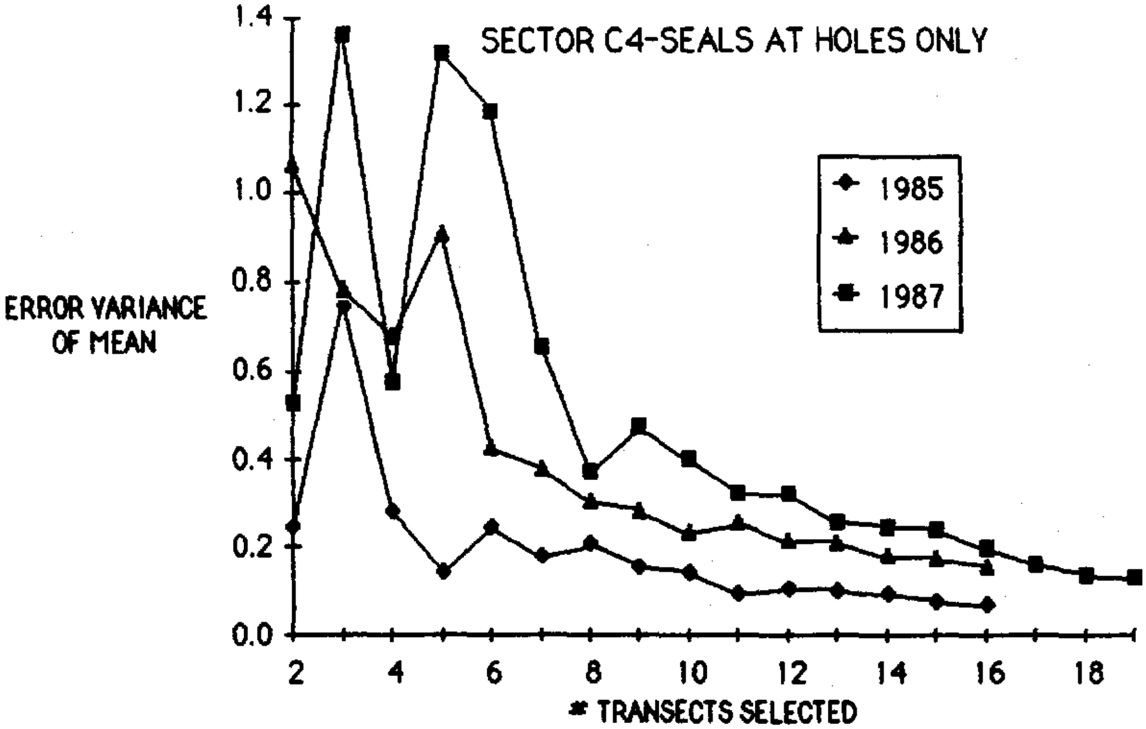


Figure 5. Relationship between the number of transects selected from the data base and the variance (σ^2) of the mean density estimate for sector C1. Each point represents the mean of 6 separate calculations.



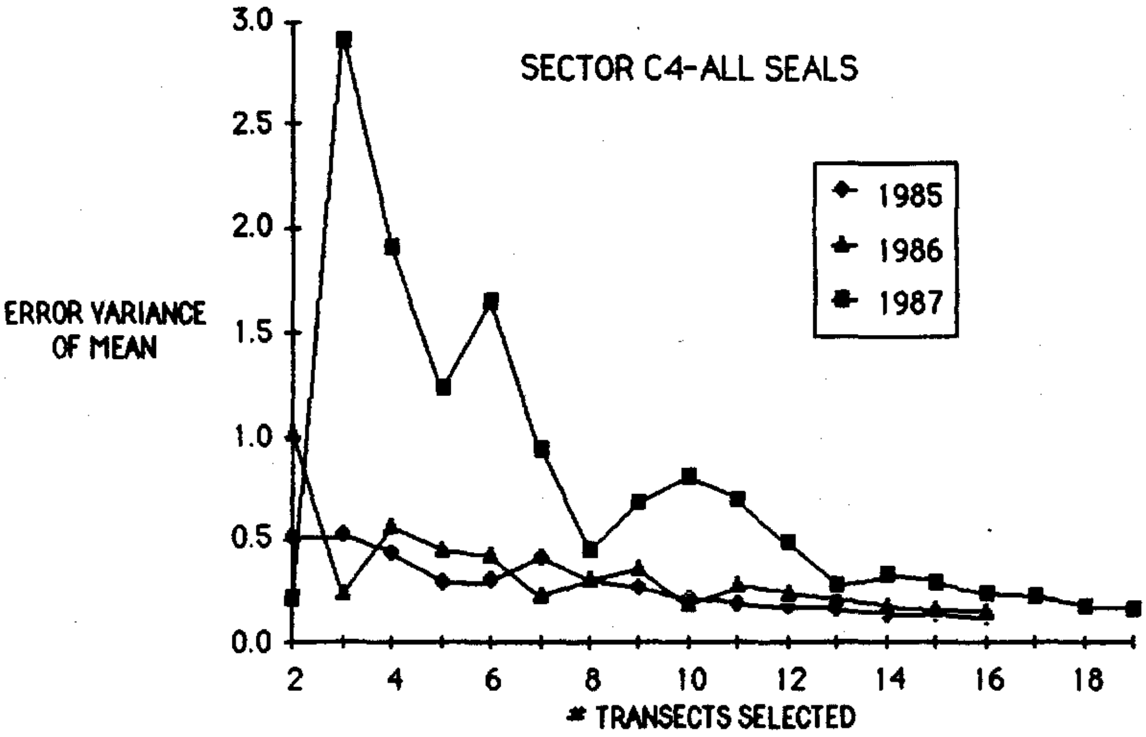
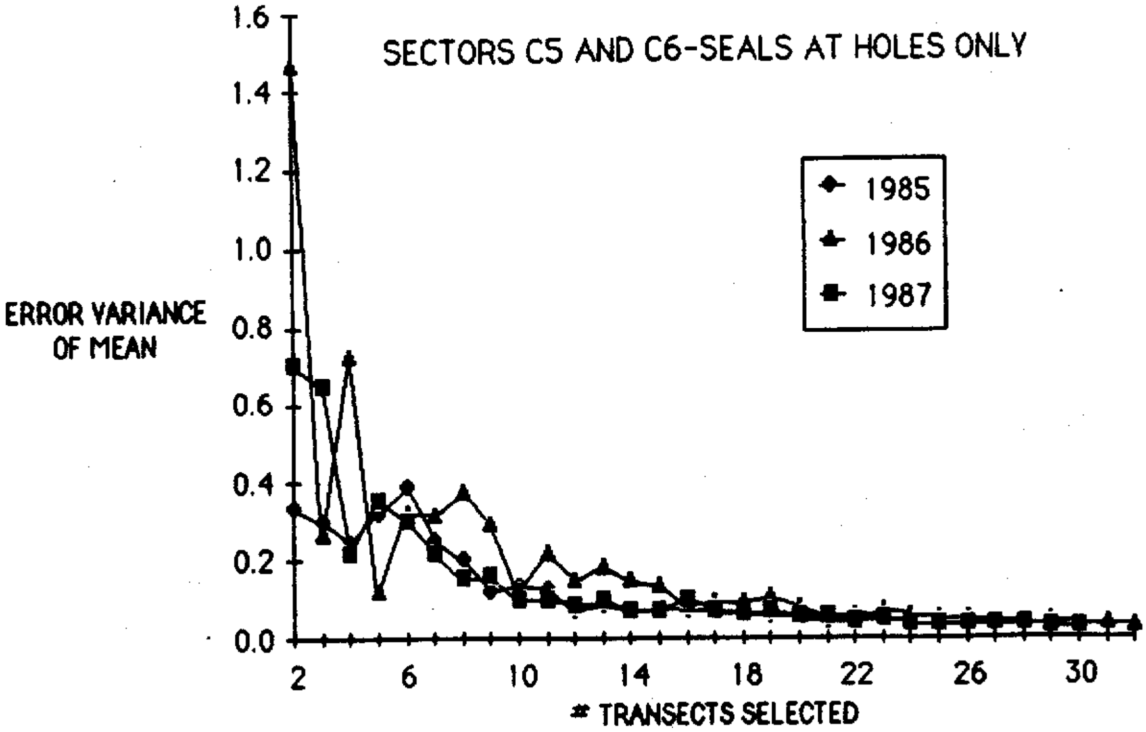


Figure 6. Relationship between the number of transects selected from the data base and the variance (σ^2) of the mean density estimate for sector C4. Each point represents the mean of 6 separate calculations.



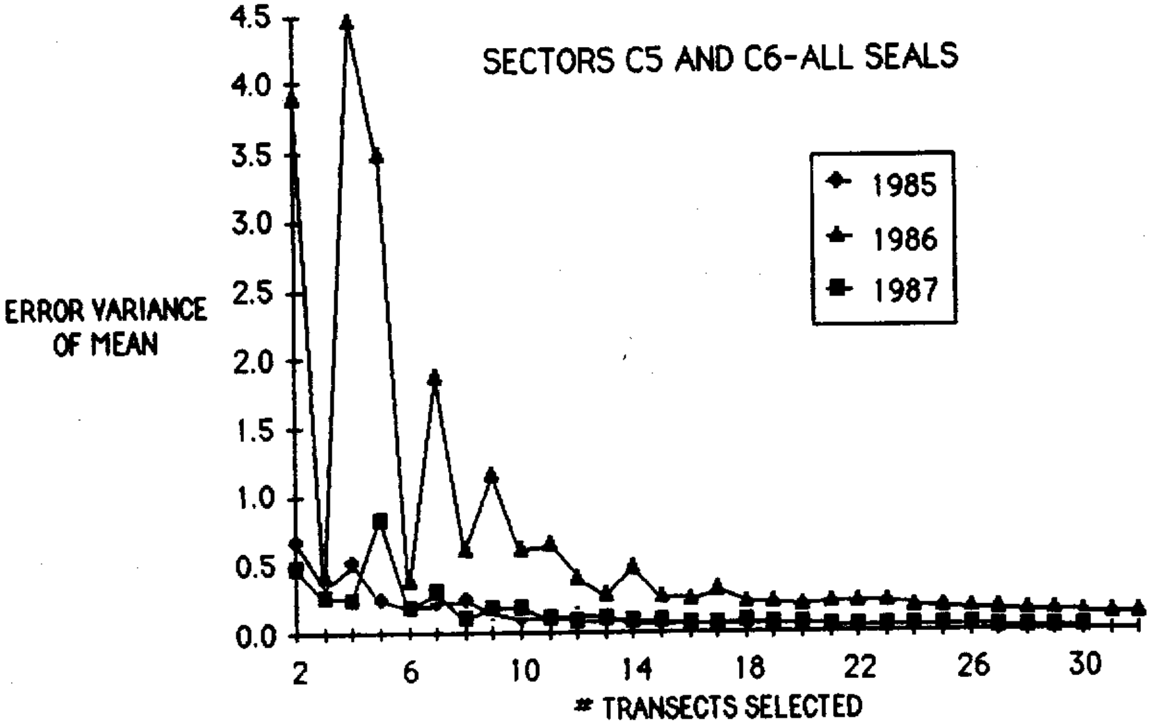
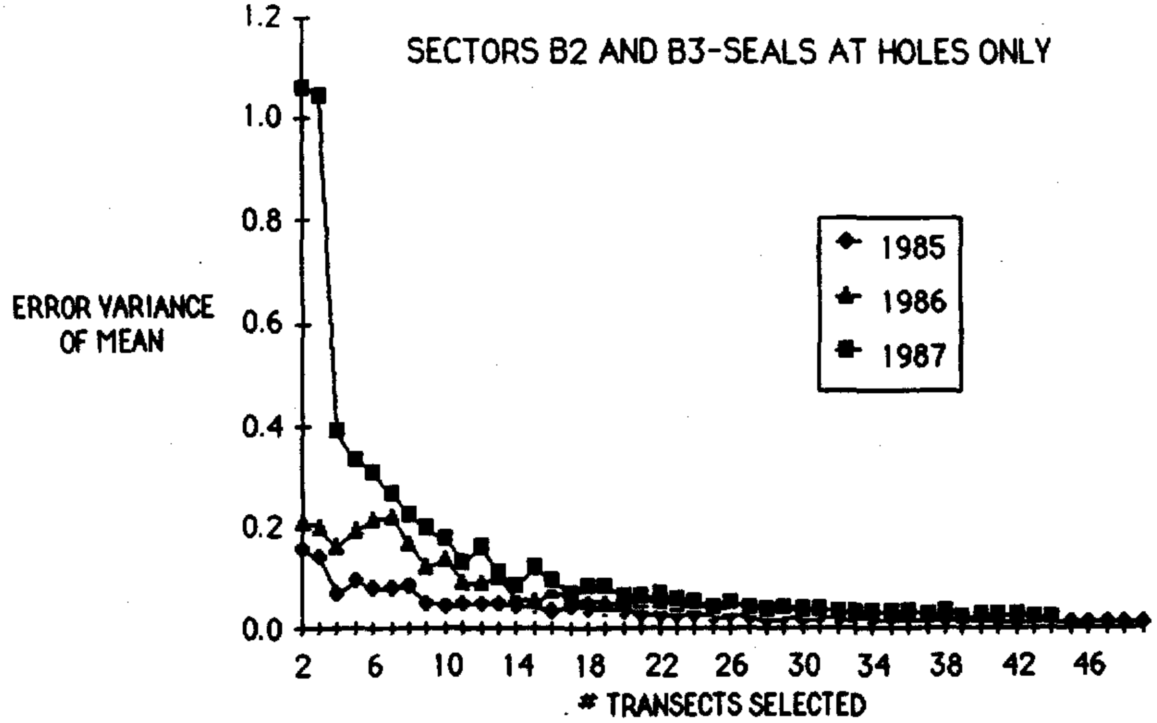


Figure 7. Relationship between the number of transects selected from the data base and the variance (σ^2) of the mean density estimate for sectors C5 and C6 combined. Each point represents the mean of 6 separate calculations.



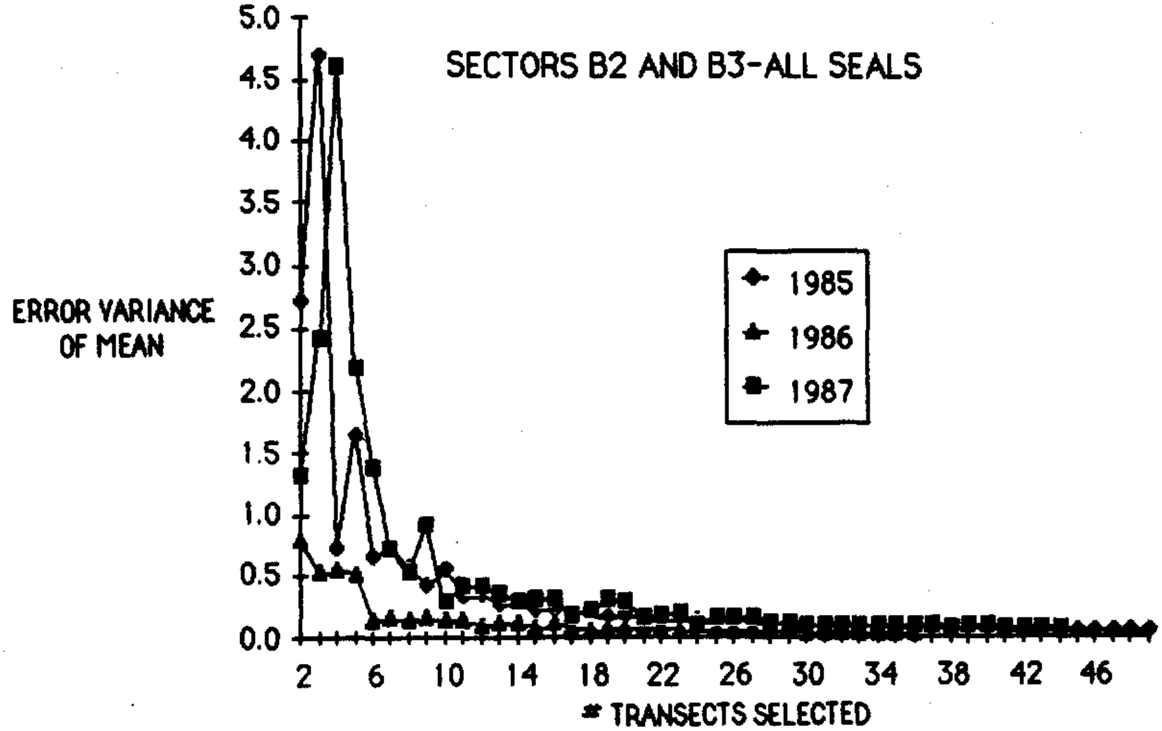


Figure 8. Relationship between the number of transects selected from the data base and the variance (σ^2) of the mean density estimate for sectors B2 and B3 combined. Each point represents the mean of 6 separate calculations.

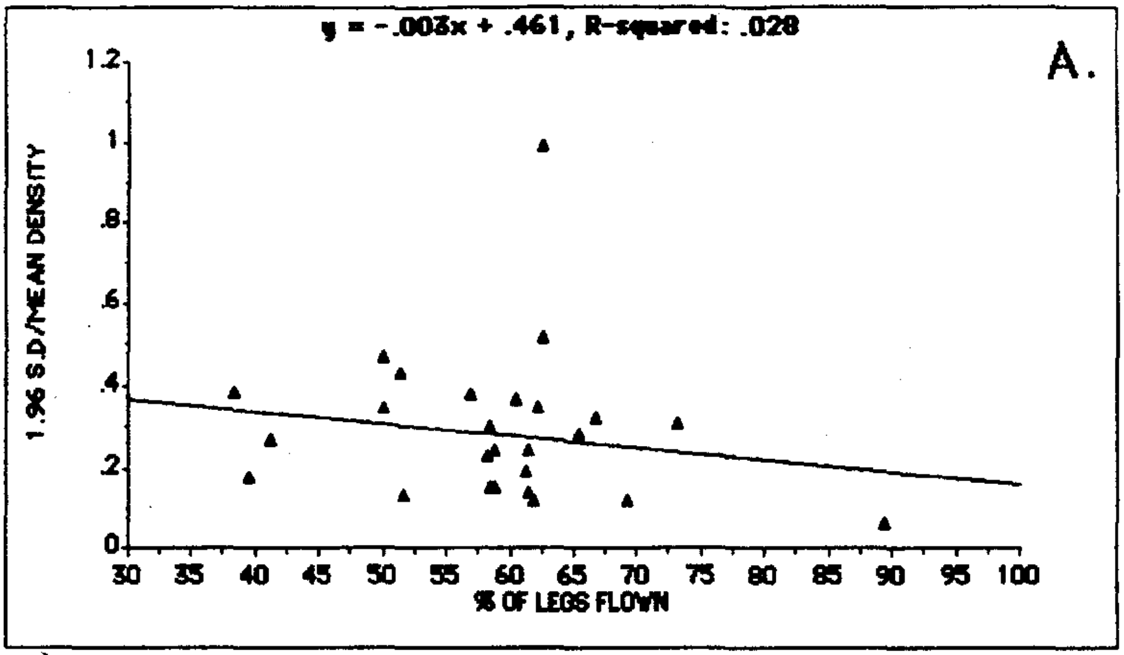
only seals at holes were included in the data. There was some evidence of year-to-year differences in variability in data sets: data for sectors C1, C4, and B2/B3 combined were most variable in 1987, while data for sectors C5/C6 combined were most variable in 1986.

The information shown in Figures 5-8 is summarized in Table 27. Again, it is evident that data sets that include only seals at holes are less variable than those that include all seals. Also, the variability becomes less as data sets include more legs. If the variance indicated by including all legs surveyed in the data base represents the realistic minimum for a given area, these figures can be used to indicate how much greater the variance is when only 60% or 90% of possible lines are flown. If 60% of possible lines are flown variance is predicted to be 1.24-3.35 times greater for seals at holes and 1.09-4.19 times greater for all seals. If 90% of all possible lines are flown, variance would be 1.0-1.36 times greater for seals at holes and 1.05-1.34 times greater for all seals. In aggregate, these analyses indicate that while coverage of 60% of all possible legs reduces variance in data sets to reasonable levels, coverage of 90% results in considerably greater precision.

Although we attempted to obtain 60% coverage in all sectors in all years, for various reasons the actual percent of all possible transects in the selected data ranged from 38% to 90%. We divided the value for 1.96 standard deviations by the mean density estimate for all seals in each sector for each year, and plotted that value against the percent of all possible legs flown (Figure 9A). Although there was a slight trend evident (i.e., the greatest coverage (90%) had the lowest value (0.06)), the

Table 27. Relationship between variance of the mean (σ^2) and the percent of all possible transects selected for selected sectors, 1985-1987.

			Percent of transects selected					
			seals at holes only			all seals		
Sector	Year	# Legs	60%	90%	100%	60%	90%	100%
C1	1985	19	0.031	0.024	0.025	0.125	0.074	0.068
	1986	16	0.069	0.042	0.034	0.072	0.080	0.066
	1987	18	0.091	0.069	0.060	0.145	0.075	0.060
C4	1985	16	0.144	0.090	0.066	0.207	0.139	0.115
	1986	16	0.230	0.178	0.156	0.191	0.176	0.145
	1987	19	0.324	0.159	0.130	0.696	0.222	0.166
C5 & C6	1985	24	0.071	0.047	0.043	0.065	0.045	0.043
	1986	32	0.104	0.040	0.031	0.218	0.145	0.118
	1987	30	0.063	0.036	0.030	0.076	0.034	0.030
B2 & B3	1985	49	0.021	0.013	0.011	0.086	0.057	0.049
	1986	36	0.054	0.031	0.027	0.070	0.037	0.032
	1987	44	0.055	0.025	0.023	0.147	0.087	0.069



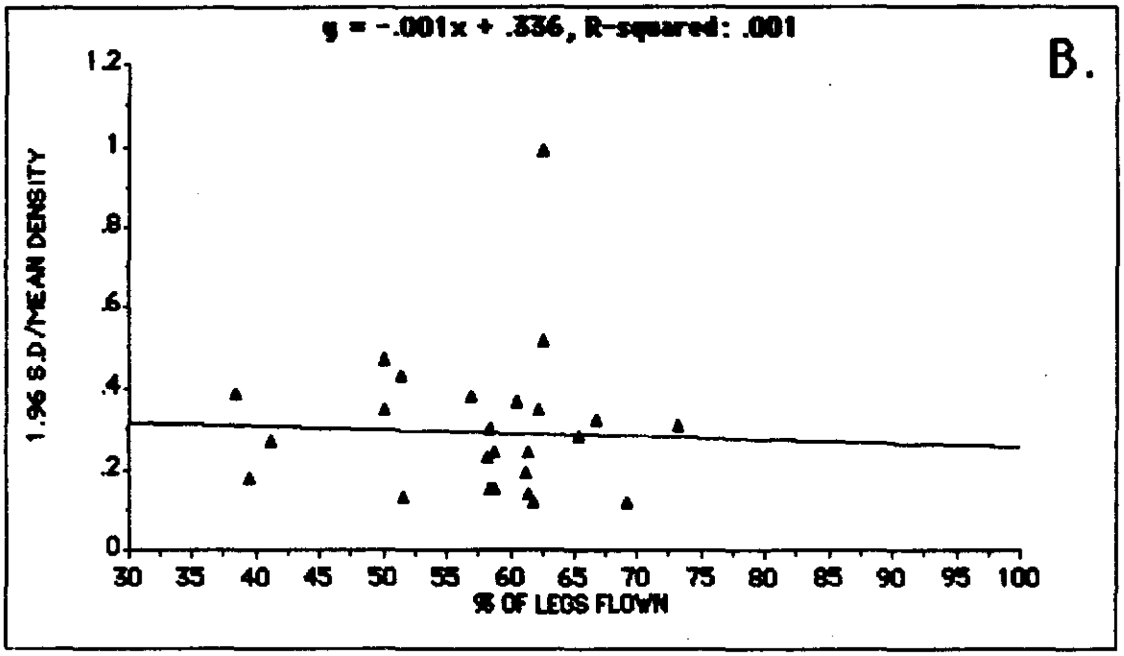


Figure 9. Relationship between 1.96 standard deviations divided by the mean density of all seals and percent of all possible legs flown for each sector 1985-1987. A. all sectors included. B. data from sector B3 in 1985 (89.5% coverage) deleted.

relationship was not statistically significant (R=0.167, p>0.39). If the sector with 90% coverage is deleted (Figure 9B), there is virtually no trend (R=0.036, p>0.85). This indicates that the amount of variability was quite constant over the range of sampling intensities accomplished during this study.

Since this calculated value (1.96 standard deviations/mean density) is an index of the size of the 95% confidence limits around mean density estimates, it can be used to compare the variability of density estimates among sectors and years (Table 28). The individual sectors with the smallest confidence limits for density of seals at holes were C1 (±9%-23%), B1 (±12%-20%), and B3 (±14%-19%). Confidence limits for total seals were somewhat greater, especially where cracks were numerous as occurred in sectors B3 and B4 in 1987. Variability was greatly reduced when several sectors were combined to make larger data sets. Confidence limits for the Beaufort Sea as a whole were ±9%-10% for seals at holes and ±14%-33% for all seals; comparable values for the Chukchi Sea were ±9%-13% and ±11%-13%. Obviously, seals along cracks had a much greater influence on variability in density estimates in the Beaufort Sea than in the Chukchi Sea.

C. Factors affecting abundance of seals

1. Ice deformation

The results of our 1985-1987 surveys in the Chukchi and Beaufort seas indicate that the relationship between ice deformation and seal distribution and density was quite consistent from year to year (Table 29).

Table 28. Comparison of the 95% confidence limits on ringed seal density estimates (1.96 standard deviations divided by mean density of seals) for sectors surveyed in May-June, 1985-1987.

	95% confidence interval					
	seals at holes			total seals		
Sector	1985	1986	1987	1985	1986	1987
C1	0.10	0.09	0.23	0.19	0.14	0.23
C2	0.49	0.30	0.38	0.43	0.36	0.38
C4	0.22	0.16	0.26	0.24	0.14	0.31
C5	0.39	0.27	0.12	0.39	0.29	0.12
C6	0.30	0.33	0.49	0.30	0.53	0.47
All Chukchi	0.10	0.09	0.13	0.12	0.11	0.13
B1	0.20	0.15	0.12	0.24	0.15	0.12
B2	0.26	0.11	0.12	0.26	0.12	0.12
B3	0.14	0.15	0.19	0.23	0.18	0.37
B4	0.15	0.30	0.24	0.16	0.35	0.99
All Beaufort	0.10	0.10	0.09	0.14	0.16	0.33
B1-B3	0.11	0.10	0.08	0.16	0.11	0.20

Table 29. Density of ringed seals (total seals/nm^2) in relation to ice deformation in the Beaufort and Chukchi seas, 1985-1987.

	Seals/nm^2					
	Chukchi			Beaufort		
Deformation (percent)	1985	1986	1987	1985	1986	1987
0-10	3.2	5.6	4.3	2.1	5.0	6.4
10-20	2.5	4.2	2.6	3.7	3.9	5.3
20-30	2.4	3.9	2.3	3.4	2.6	4.7
30-40	1.5	2.4	1.1	2.9	2.0	4.1
>40	-	1.8	2.1	2.2	1.9	1.9

Seals were less abundant in rougher ice. The greatest difference was for ice of 0%-20% deformation, where densities were generally 1.5 to 2 times higher than in ice of greater deformation.

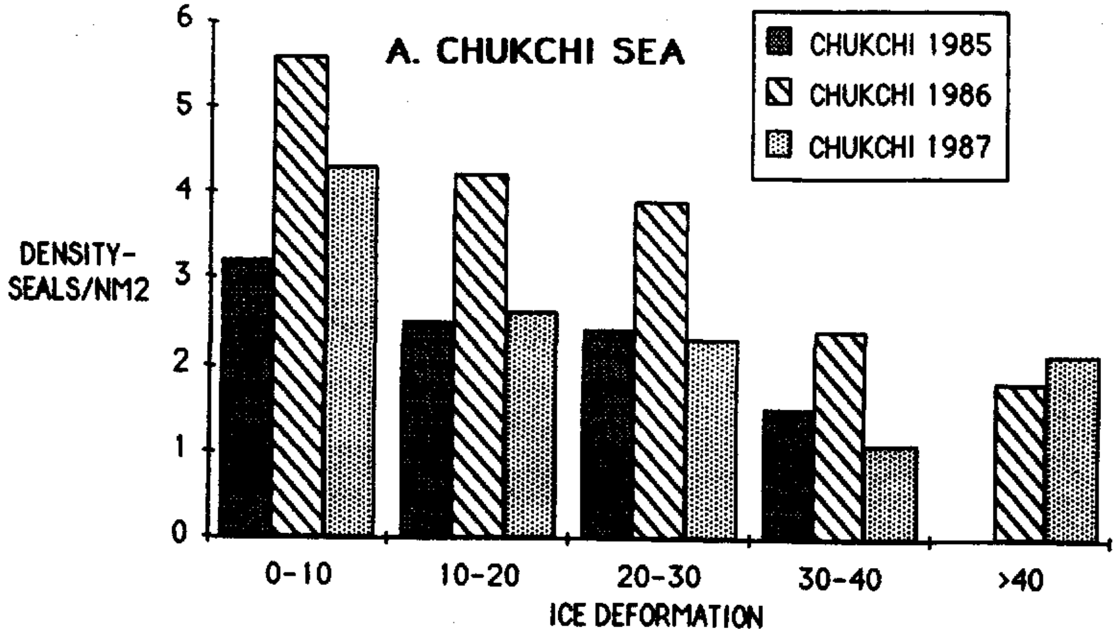
Numerous investigators have noted that ice conditions affect the distribution of ringed seals and, in particular, that stable shorefast ice is their preferred breeding habitat (McLaren 1958; Burns 1970; Smith 1973). Studies conducted in the Canadian Arctic have addressed the effects of ice conditions in terms of percent coverage (from unbroken fast to broken open pack), or relative to the degree of cracking (solid, cracking, or rotten) (Kingsley et al. 1985; Stirling et al. 1981b). These studies found that seals preferred areas with little open water, and seemed to avoid areas of rotten, flooded ice. Ice conditions in Alaska at the time of our surveys were quite different than those experienced during surveys in Canada. Surveys were flown over mostly unbroken fast ice and not in areas where significant amounts of open water were present. Our surveys were intended to occur before substantial cracking and melting of the fast ice occurred. Although in some years breakup commenced earlier than usual, and such conditions were present during our surveys, the variables used in Canadian studies have not been relevant to our data.

Burns et al. (1981a) first reported on ringed seal distribution relative to the percent of ice surface that was deformed by hummocks and pressure ridges. They found that ringed seals showed a significant preference for less deformed fast ice, with the density in ice of 0%-30% deformation about 1.3 times higher than in ice of 30%-50% deformation, and 2 times higher than in >50% deformation. Burns and Kelly (1982) reported similar results from data collected in 1982.

The results of 1985-1987 surveys in the Chukchi and Beaufort seas corroborate these earlier studies (Figure 10). In all years, regardless of whether annual densities were high or low, hauled-out seals were less abundant in rough ice.

To assess whether seals actually preferred large, flat areas for hauling out, or whether lower abundance in rough ice was related to the absolute availability of flat areas on which to lie, we examined whether the reduced densities in rough ice were proportional to the reductions in available flat areas.

Results of a linear regression of density on ice deformation for all years combined (Figure 11A) indicated that density was highly correlated with deformation ($R=0.98$, $p<0.01$). To determine whether the lower densities in rougher ice were simply proportional to the availability of flat ice areas, we corrected all densities as density per area of flat ice: for example, in an area of 30%-40% deformation, total area in that category was multiplied by 0.65 and a corrected density calculated based on that corrected area (Table 30). Corrected density was then regressed against percent deformation (Figure 11B). This relationship was also significant ($R=0.86$, $p<0.05$), indicating that the relationship between flatness and higher density is not simply due to the availability of flat ice to haul out on, but that areas with large amounts of rougher ice are less desirable and that flat ice areas are preferred. The slope of the line was less in the comparison using corrected densities, indicating that absolute availability of flat ice areas is of some importance. The reasons why ringed seals prefer flatter ice are unknown, but may have to do with their ability to detect approaching predators in more open areas.



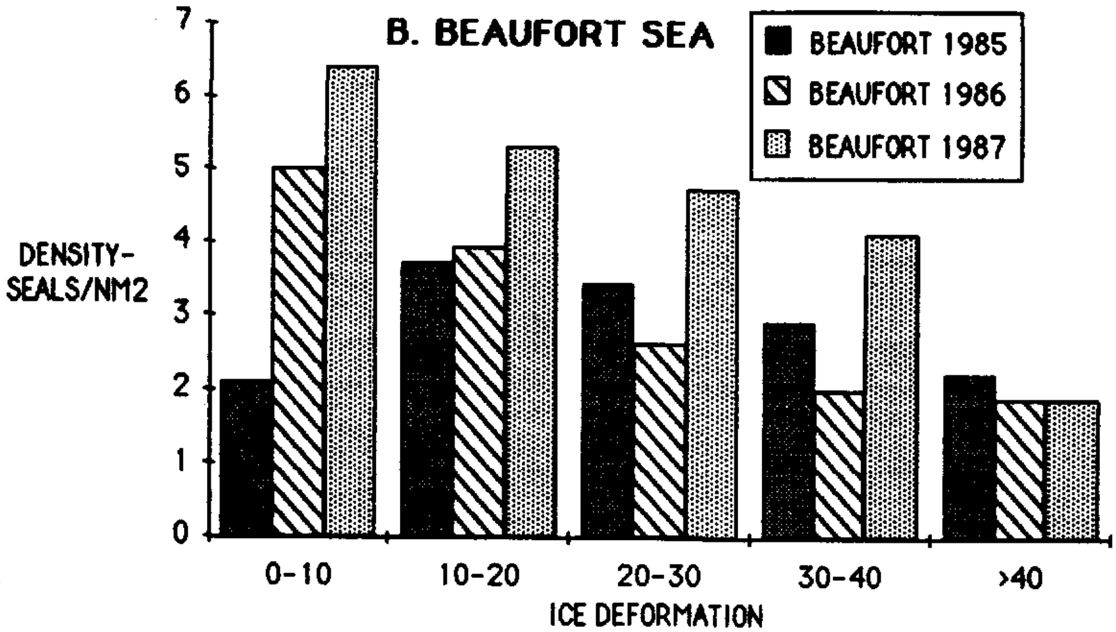


Figure 10. Ringed seal density (total seals/nm^2) in relation to ice deformation in the Chukchi and Beaufort seas, 1985-1987. A - Chukchi Sea, B - Beaufort Sea.

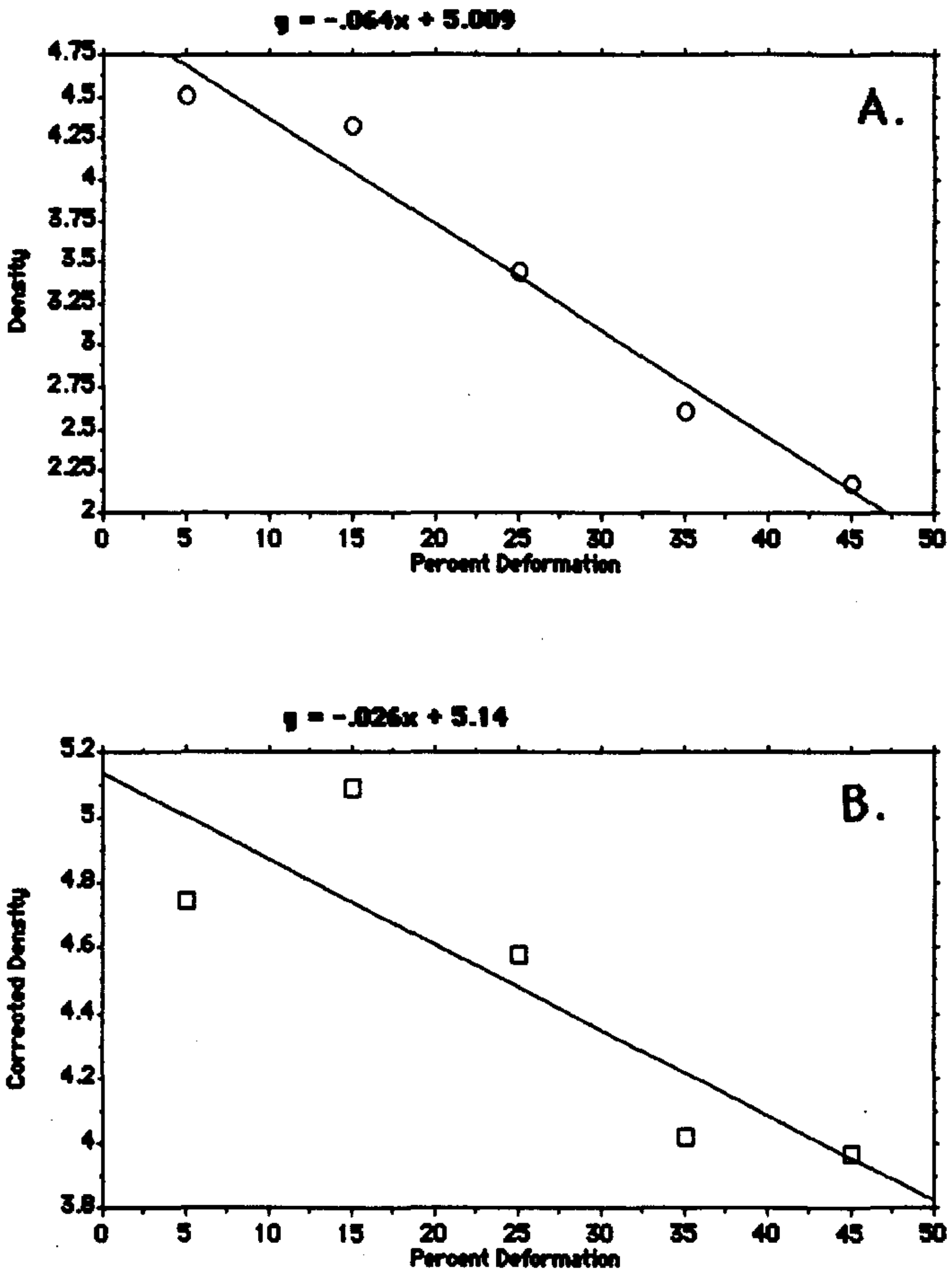


Figure 11. Relationship between seal density (total seals/nm^2) and ice deformation for Chukchi Sea and Beaufort Sea data, 1985-1987 combined. A - uncorrected density, B - density corrected for flat ice areas only. See text for explanation.

Table 30. Combined densities (1985-1987) of ringed seals (total seals/nm^2) in relation to ice deformation in the Beaufort Sea.

Deformation (percent)	Area	Area of flat ice	# seals	Density	
				all ice	flat ice only
0-10	712	676	3,209	4.51	4.75
10-20	516	439	2,233	4.33	5.09
20-30	476	357	1,636	3.44	4.58
30-40	246	160	643	2.61	4.02
>40	142	78	310	2.18	3.97

The preference by ringed seals for flatter ice was evident for all surveys flown during early June, before breakup began. However, when 1986-87 data from later surveys were analyzed, results indicated that once the ice had begun to crack and break up, there was no longer an apparent correlation between density and deformation (1986 - R=0.47, p>0.5; 1987 - R=0.88, p>0.1). Densities were as high or higher in rougher ice as they were in flat ice areas (Table 31).

2. Distance from the fast ice edge

In the Chukchi Sea there was no clear overall pattern in density relative to distance from the fast ice edge for 1985-1987 (Figure 12). In some sectors, seals were more abundant within 0-4 nm of the edge while in others the reverse was true, and within sectors differences were not consistent between years. For example, in sector C6, seals were least abundant near the edge in 1985, most abundant near the edge in 1987 and showed no clear trend in 1986. By themselves, the 1987 data (Figure 3) suggest a relationship between the fast ice edge and seal density, but when all 3 years are considered, no firm conclusions can be drawn.

In the Beaufort Sea, analysis of density relative to distance from the fast ice edge was complicated by difficulties in determining the exact location of the "edge." The delineation between fast ice and pack was usually abrupt in the Chukchi Sea, and was often marked by an open lead. In the western Beaufort Sea (sector B1) this was also usually the case. However, in the central and eastern Beaufort Sea, particularly sectors B2 and B3, identifying the edge from the survey aircraft was often difficult. Here

Table 31. Density of ringed seals (total seals/nm^2) in relation to ice deformation in early and mid-June 1986-87, Beaufort Sea.

Ice deformation	June 1986		June 1987	
	early	middle	early	middle
0-10	5.0	7.6	6.4	9.3
10-20	3.9	9.8	5.3	8.5
20-30	2.6	6.4	4.7	11.3
30-40	2.0	6.9	4.1	15.0
>40	1.9		1.9	

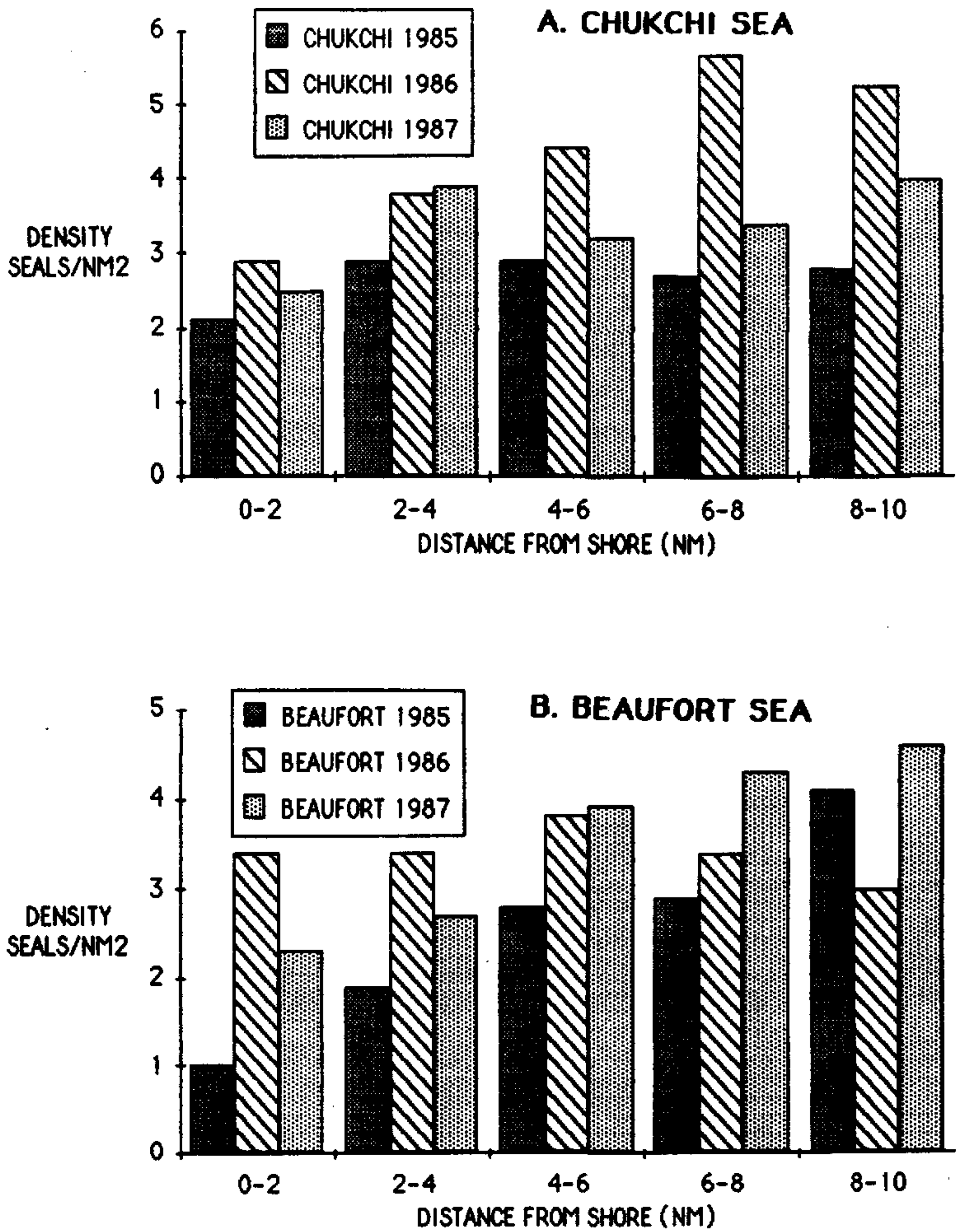


Figure 12. Relationship of seal density with distance from shore. Data for Beaufort Sea 1987 is seals at holes only, all other data are total seals (see text for explanation). A - Chukchi Sea, B - Beaufort Sea.

the edge was not a sharp break to obviously different ice, but rather a transition zone of pressure ridges, shear lines, and refrozen leads. Identification of the edge was further complicated by the fact that, in the Beaufort Sea, large expanses of "attached fast ice" (Stringer 1982) form seaward of the true fast ice zone. Early in the survey period this attached fast ice is contiguous with stable shorefast ice and the two are extremely difficult to differentiate during surveys. As breakup begins, the attached fast ice sheet begins to fracture along ridge and shear lines, approximately parallel to shore, and the area of "fast ice" may decrease substantially in only a few days. It is usually possible to determine the location of the fast ice edge from satellite photographs. However, because of the large scale of these photos, the accuracy of ice edge positions is probably plus or minus 2-4 nm.

These factors cause problems in determining patterns in seal abundance relative to the fast ice edge. Nonetheless, based on 1985-1987 data, there was a fairly clear relationship in the Beaufort Sea between seal abundance and distance from the edge (Figure 13). When surveys were conducted prior to the beginning of breakup, seals were less abundant near the edge. For all sectors combined in the pre-breakup 1986 data set, density within 4 nm of the edge was 1.8 total seals/nm^2, compared to 2.5/nm^2 beyond 4 nm.

In 1986, additional surveys were flown a week later after a storm and after the attached fast ice had started to break up (Frost et al. 1987). In these post-storm surveys, the density of seals in sector B3 was approximately 12/nm^2 within 4 nm of the edge, with about half of those occurring at cracks. Densities beyond 4 nm from the edge were about 50%

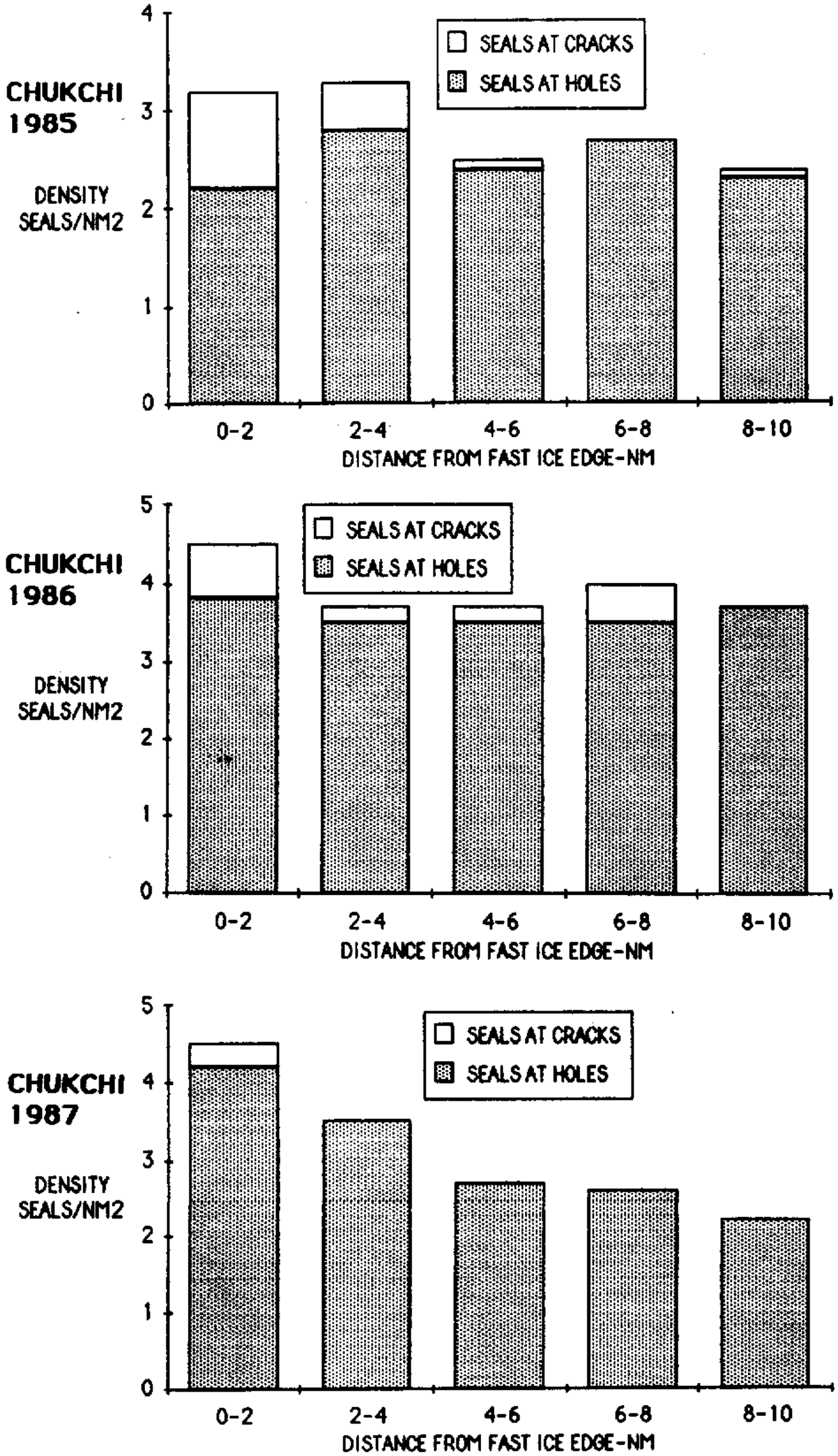


Figure 13. Relationship between density of ringed seals on the fast ice and distance from the fast ice edge for the Chukchi Sea, 1985-1987.

lower. In 1987, all surveys were flown after the ice had begun to break up under conditions similar to those during 1986 post-storm surveys. As in the 1986 post-storm data, 1987 densities near the edge were also higher: 7.6 total seals/nm^2 within 0-4 nm of the edge compared to 3.3/nm^2 from 4-10 nm away (Figure 13). In sector B3, there were over 12 seals/nm^2 within 4 nm of the edge, and about two-thirds of them were at cracks.

Analysis of 1985 data was more complicated. Preliminary analyses of density with distance to the ice edge presented in Frost et al. (1985) indicated that densities were low near the edge and higher farther away. However, re-examination of the 1985 satellite ice photos indicated that in sector B3 the actual fast ice edge was much closer to shore than we placed it in the 1985 report, and that the "edge" referred to then was the seaward extent of the attached fast ice. It is now obvious, after additional experience in the area, that an early breakup was underway in sector B3, and that in terms of seal distribution patterns the fast ice edge was better approximated by the 20-m depth contour than by the apparent "edge determined in 1985. Therefore, 1985 data were reanalyzed as distance from the 20-m depth contour. That analysis, as in 1986 and 1987 under breakup conditions, indicated that density in mid-June was highest near the edge: 3.6 seals/nm^2 within 4 nm of the "edge" compared to 2.5 beyond 4 nm. Early June data, before breakup began, showed similar densities within and beyond 4 nm of the edge (1.6 vs 1.5/nm^2).

In aggregate, these data suggest that the distribution and abundance of ringed seals in the Beaufort Sea relative to the ice edge changes as breakup begins. The distribution shifts from one where seals are relatively widely distributed at holes away from the unstable fast ice edge, to one where large numbers of seals occur near the edge, especially along newly formed narrow cracks. We believe this increase in density is due to an influx of seals from other areas into the highly fractured boundary zone between fast and pack ice, rather than simply a redistribution of seals from immediately adjacent areas or a change in haul-out behavior. Whereas the density of seals at holes 4-10 nm from the fast ice edge of sector B3 in 1986 increased 1.7 times after the ice began to break up (from 2.8 seals/nm^2 to 4.7 seals/nm^2), the density near the edge increased 4-fold (from 1.6 seals/nm^2 to 6.5 seals/nm^2). Comparisons of early and late surveys in sector B1 in 1985 and 1987 also indicated an increase in density between the two that occurred mostly near the fast ice edge. In 1985, the increase within 4 nm of the edge was almost 400%, from 0.8 to 3.1 seals/nm^2, compared to a 24% increase at 4-10 nm from the edge. In 1987, density within 4 nm of the edge increased from 3.9 to 14.5 seals/nm^2, and beyond 4 nm, from 2.6 to 6.9 seals/nm^2.

Canadian investigators also found that ringed seals occurred in highest densities in cracking ice, rather than on unbroken fast or rotten, melting ice (Stirling et al. 1981a and b and Kingsley et al. 1985). They suggested that these cracking conditions occur near or behind the edge and that the associated high densities of seals represented either a collapse in the winter underwater social structure and the opportunity for more animals to haul out at newly available sites, or an influx of seals from other areas. Smith (1973) also believed that the increase in seals in his study area near Home Bay after 15 June was due to an influx from other areas.

3. Distance from shore

Based on results of all 3 years of surveys, ringed seals were generally less abundant within 2 nm of the coast than they were farther off shore (Table 32, Figure 14). This tendency was the most consistent and pronounced in the Chukchi Sea ($R=0.906$, $p<0.05$) where the coastline is simple with no offshore barrier islands, and where depth increases quite rapidly with distance from shore. In the Beaufort Sea, coastal topography differs greatly among sectors, there are numerous barrier islands and several large, very shallow embayments (Harrison Bay, Camden Bay, and Smith Bay), and the width of the fast ice is quite variable. Sectors B1 and B2, with relatively simple coast line and extensive fast ice, showed the same pattern as the Chukchi Sea, with densities within 2 nm of land consistently lower than farther off shore. Sectors B3 and B4 were less consistent, probably because the fast ice edge was much closer to shore, extensive barrier islands occur in these sectors, and in 1987 breakup was underway during our surveys and there had already been a large influx of seals at cracks. When seals at cracks were omitted from the 1987 data (there were very few seals at cracks in the selected data base for other years), the trend of increasing density with distance from shore for 1985-1987 combined was significant for sectors B1-B3 ($R=0.96$, $p<0.01$, Figure 14B).

In their 1970 surveys, Burns and Harbo (1972) also found a tendency for density to increase with increasing distance from shore in sector B2 (their sector IV). In Hudson Bay, Smith (1975) found no clear relationship of density relative to distance from shore. In Home Bay (Baffin Island) Smith (1973) found that seals were much less abundant beyond 18 miles from shore.

Table 32. Density of ringed seals (total seals) in relation to distance from shore in the Chukchi and Beaufort seas, 1985-1987.

Sector	Year	Distance from shore (nm)				
		0-2	2-4	4-6	6-8	8-10
C1	1985	2.6	2.6	2.8	3.1	2.9
	1986	3.6	4.7	4.8	7.7	6.7
	1987	1.5	3.9	3.9	3.4	5.4
C2	1985	3.1	2.6	2.7		
	1986	3.0	3.6	6.8	6.8	
	1987	2.5	3.0	3.6	9.0	
C4	1985	1.2	3.6	4.2	2.5	3.4
	1986	4.5	4.9	5.2	6.9	4.7
	1987	2.8	5.7	3.3	4.0	3.9
C5	1985	1.3	3.3	2.1	1.8	1.3
	1986	1.9	3.1	2.7	2.7	2.1
	1987	2.4	2.6	2.9	2.9	2.1
C6	1985	1.3	2.3	2.2	2.3	1.3
	1986	1.7	2.2	3.0	3.7	2.6
	1987	1.8	2.9	5.3	2.6	2.9
B1	1985	1.3	1.8	3.1	2.8	2.2
	1986	1.9	2.7	2.8	2.5	1.5
	1987	1.4	2.2	2.6	3.6	3.6
B2	1985	0.2	2.0	1.9	2.0	2.0
	1986	2.6	3.9	3.5	3.9	3.9
	1987	1.9	3.0	4.1	5.8	5.8
B3	1985	1.3	2.1	3.3	4.1	6.8
	1986	4.8	3.8	5.5	3.5	4.1
	1987	6.2	5.0	13.3	7.3	7.3
B4	1986	0.2	1.8	2.2	2.8	2.5
	1986	4.5	5.4	19.9	10.3	6.9
	1987	26.9	30.0	5.2	4.7	4.0

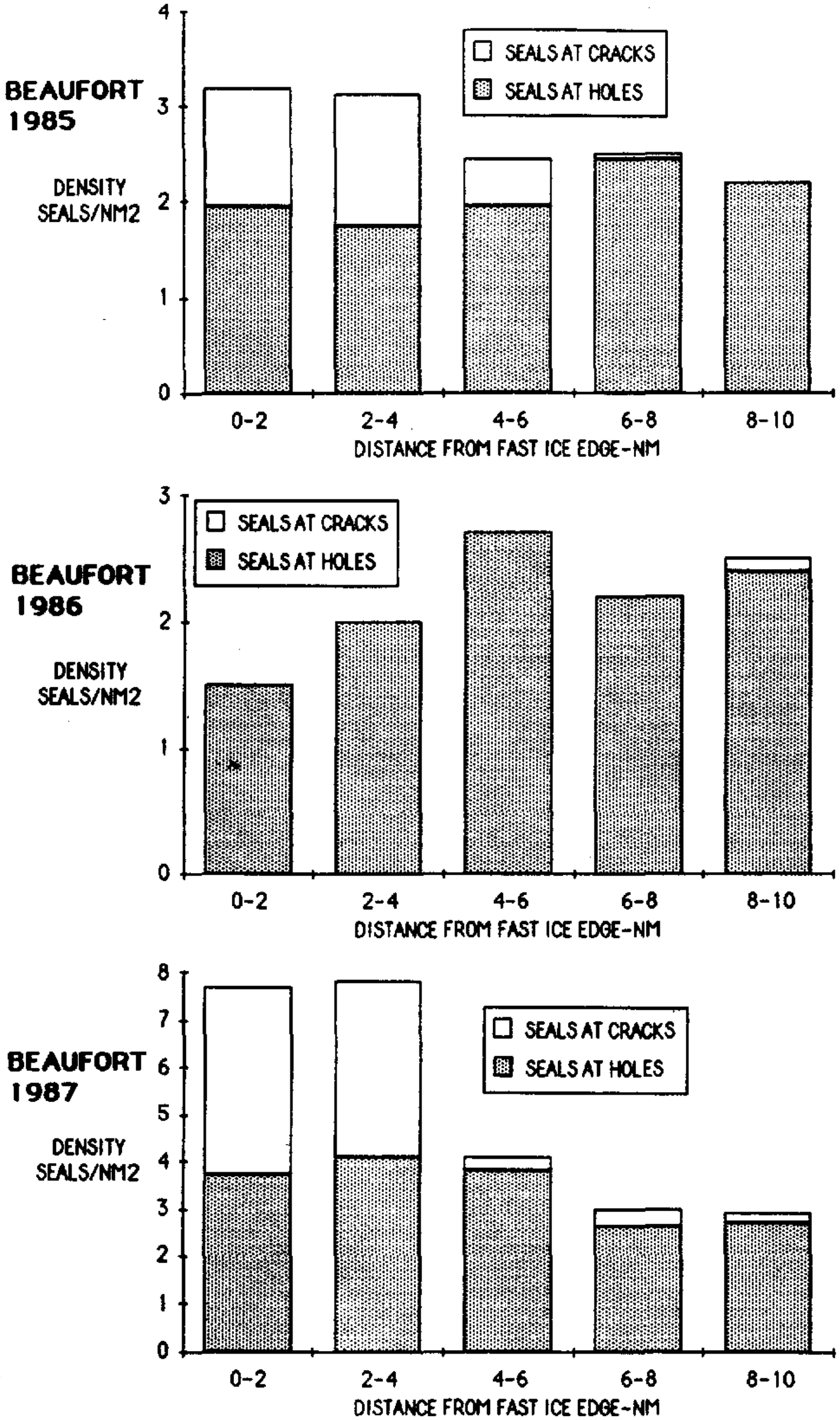


Figure 14. Relationship between density of ringed seals on the fast ice and distance from the fast ice edge for the Beaufort Sea, 1985-1987.

The factors contributing to onshore-offshore abundance patterns are poorly understood, but may include such things as depth, ice topography, proximity to active ice areas, and prey availability. In the very nearshore region, ice may freeze all the way to the bottom, entirely excluding seals.

4. Pack Ice

Although the primary objective of our surveys was to determine the distribution and abundance of ringed seals on the shorefast ice, some survey lines extended into the pack ice. In general, coverage of the pack ice in these and earlier aerial surveys has not been extensive in any year, and has not included every sector every year.

Inter-annual variations in densities recorded for pack ice were large, with values for the same sector differing by as much as a factor of 8 or 9 between years. For example, in sector C2 we counted 8.0 seals/nm^2 on pack ice in 1985 compared to 1.3 seals/nm^2 in 1986 and 4.6/nm^2 in 1987. Whereas densities in fast ice since 1970 have fluctuated from about 50% below to 40% above the mean, densities in pack ice have fluctuated by over 100%. Part of this may be because much of the pack ice surveyed was near the fast ice edge, which is an area where distribution changes markedly as breakup begins. Surveys conducted in the same calendar week may reflect vastly different ice conditions or breakup chronology from one year to the next.

In the Beaufort Sea, density in the pack ice generally decreased with distance from the fast ice edge. Regressions of seal density on distance from the edge out to 20 nm were significant for seals at holes and total seals in all 3 years (Table 33). In 1985 and 1987, years when the ice was beginning to crack and break up during some of our surveys, the density of seals at cracks was significantly higher within a few miles of the edge, and lower but generally similar in the pack ice farther off shore. In the early June 1986 surveys, seals at cracks were not more abundant near the edge; there was no significant trend in density with distance from the edge ($R=0.429$, $p>0.2$). However, 1 week later after breakup had begun, distribution of seals at cracks was similar to that in 1985 and 1987: seals at cracks were much more abundant near the edge ($R=0.845$, $p<0.002$).

Pack ice densities based on surveys conducted very near the edge should not be used to estimate the number of seals in offshore areas. This is particularly true if there is any indication that breakup and aggregation of seals near the edge was underway at the time of the surveys. The data for 1985-1987 suggest that, for all surveys, densities of seals at holes stabilize about 10 miles from the fast ice edge at just under 1 seal/nm^2 (Table 34). The density of seals at cracks was more variable, but the range (0.4-2.1/nm^2) was considerably less farther offshore than nearer the edge (0.3-5.5/nm^2).

D. Ringed seal abundance

1. Chukchi Sea

Aerial surveys for ringed seals conducted in 1985-1987 were the most extensive and systematic ever flown in the Chukchi Sea, and the first for which between-year statistical comparisons were possible. In all sectors

Table 33. Density of ringed seals in the pack ice relative to distance from the fast ice edge, Beaufort Sea, 1985-1987.

Distance	Seals at holes/nm² (total seals) 1985	1986 early	1986 late	1987
0-2	1.7 (3.9)	2.6 (2.7)	2.5 (12.9)	2.0 (6.6)
2-4	1.8 (3.9)	1.7 (1.9)	1.8 (7.4)	1.5 (2.7)
4-6	1.6 (3.8)	2.0 (2.1)	0.9 (4.4)	1.3 (3.2)
6-8	1.7 (3.6)	1.7 (1.8)	0.7 (5.5)	1.3 (3.8)
8-10	1.5 (2.6)	0.9 (2.0)	0.9 (3.3)	1.4 (3.2)
10-12	0.9 (2.0)	1.1 (1.7)	0.7 (3.2)	0.6 (2.1)
12-14	1.1 (2.1)	0.7 (0.9)	0.4 (3.5)	0.8 (1.6)
14-16	1.0 (1.8)	0.4 (0.4)	0.9 (3.1)	0.9 (2.7)
16-18	0.6 (1.7)	1.1 (1.4)	0.9 (2.0)	1.7 (3.1)
18-20	0.1 (1.9)	0 (1.2)	0.5 (1.4)	0.3 (0.3)

Table 34. Density of ringed seals (seals/nm^2) in the pack ice from 0-10 and 10-20 nm from the fast ice edge, Beaufort Sea, 1985-1987. Values without parentheses are for seals at holes only; values in parentheses are for total seals.

	0-10 nm		10-20 nm	
Year	mean	standard deviation	mean	standard deviation
1985	1.6 (3.6)	0.16 (0.35)	0.9 (2.0)	0.16 (0.28)
1986 Early	1.8 (2.1)	0.21 (0.22)	0.8 (1.2)	0.19 (0.23)
Late	1.4 (6.9)	0.22 (0.66)	0.6 (2.7)	0.09 (0.46)
1987	1.9 (5.1)	0.22 (0.59)	0.9 (2.6)	0.13 (0.59)

of the Chukchi Sea, the density of total seals on the fast ice was significantly greater in 1986 than in either 1985 or 1987 (Table 35). The combined Chukchi Sea density of total seals in 1986 was 1.6 times the 1985 density and 1.7 times the 1987 density. Seals at holes were also more abundant in 1986 in every sector except C2 where 1986 and 1987 densities were similar. In all 3 years for all sectors combined, the density of seals at cracks was quite low, equalling only 1%-6% of total seals. Sector C2 in 1985 and 1986 (11% and 17%) and C6 in 1986 (22%) were the only sectors where more than 10% of the total seals were located along cracks.

Based on 1985-1987 data, densities in the Chukchi Sea south of Point Lay (sectors C1-C4) were consistently higher than densities to the north in sectors C5 and C6 (Table 36). This was not the case in data reported by Burns and Eley (1978) for June 1976, when sector C1, Kotzebue Sound, had the lowest density in the entire Chukchi Sea (0.93/nm^2) and sector C6 had the second highest (4.96/nm^2) (Frost et al. 1985b). However, 1976 surveys were flown during the second week in June, almost 3 weeks later than our surveys. We think the low density in Kotzebue Sound, and probably the high density in C6, reflects the different timing of the surveys rather than a lower density of seals. In 1986 and 1987 when we returned to Kotzebue Sound in mid-June to conduct belukha whale surveys, we saw very few ringed seals hauled out on the ice. Although the fast ice was still in place, the ice was rotten and melting and conditions were very poor for hauling out. Since we observed considerably higher densities of seals in the Beaufort Sea in mid-June than in early June it is reasonable to think that the northern Chukchi Sea experiences a similar increase.

Table 35. Comparison of the densities (seals/nm²) of ringed seals hauled out on the fast ice in the Chukchi and Beaufort seas, 1985-1987. All data from surveys flown at 500 ft have been corrected to make results comparable to data collected at 300 ft.

	Mean density (SD)								
	Seals at holes			Seals at cracks			Total		
Sector	1985	1986	1987	1985	1986	1987	1985	1986	1987
C1	3.68 (0.14)	7.29 (0.26)	3.92 (0.35)	0.29 (0.26)	0.25 (0.19)	0.01 (0.00)	3.97 (0.30) n=19	7.54 (0.40) n=16	3.92 (0.35) n=18
C2	3.29 (0.62)	4.46 (0.51)	4.53 (0.89)	0.40 (0.15)	0.92 (0.35)	0.03 (0.02)	3.69 (0.63) n=17	5.38 (0.78) n=22	4.56 (0.89) n=21
C4	4.37 (0.37)	6.64 (0.41)	3.57 (0.47)	0.26 (0.18)	0.17 (0.08)	0.23 (0.17)	4.63 (0.43) n=16	6.81 (0.38) n=16	3.80 (0.61) n=16
C5	2.69 (0.41)	3.55 (0.37)	2.59 (0.16)	0.00 (0.00)	0.04 (0.04	0.00 (0.00)	2.69 (0.41) n=16	3.59 (0.40) n=17	2.59 (0.16) n=18
C6	2.44 (0.28)	3.10 (0.40)	2.65 (0.66)	0.00 (0.00)	0.90 (0.52)	0.05 (0.08)	2.44 (0.28) n=14	4.00 (0.88) n=15	2.70 (0.65) n=12
All Chukchi	3.54 (0.14)	5.74 (0.21)	3.58 (0.20)	0.23 (0.10)	0.32 (0.11)	0.03 (0.03)	3.77 (0.18) n=76	6.06 (0.26) n=86	3.62 (0.21) n=85
B1	2.32 (0.21)	2.07 (0.16)	3.00 (0.19)	0.18 (0.09)	0.06 (0.00)	0.11 (0.06)	2.50 (0.27) n=20	2.07 (0.16) n=20	3.10 (0.19) n=21
B2	2.15 (0.29)	3.60 (0.21)	4.35 (0.27)	0.59 (0.22)	0.03 (0.03)	0.08 (0.04)	2.74 (0.37) n=14	3.63 (0.22) n=21	4.44 (0.27) n=21
B3	1.61 (0.11)	3.70 (0.28)	3.57 (0.35)	1.72 (0.35)	0.29 (0.20)	4.51 (1.46)	3.33 (0.39) n=35	3.99 (0.37) n=15	8.08 (1.51) n=23
B4	1.65 (0.12)	4.21 (0.65)	3.52 (0.44)	0.37 (0.12)	5.24 (2.04)	8.53 (6.01)	2.01 (0.16) n=14	9.44 (1.67) n=12	12.05 (6.09) n=15
B1-B3	1.89 (0.12)	3.21 (0.16)	3.74 (0.17)	1.12 (0.24)	0.10 (0.06)	1.08 (0.47)	3.01 (0.24) n=69	3.31 (0.18) n=56	4.82 (0.49) n=65
All B1-B4	1.87 (0.10)	3.30 (0.16)	3.72 (0.16)	1.03 (0.18)	0.20 (0.30)	1.79 (0.91)	2.90 (0.23) n=88	3.81 (0.32) n=68	5.51 (0.93) n=80

Table 36. Comparison of ringed seal densities (total seals/nm^2) on the shorefast ice of the Chukchi Sea based on surveys conducted in 1985-1987. All data from surveys flown at 500 ft have been corrected to make results comparable to data collected at 300 ft.

	1985		1986		1987	
Sector	density	rank	density	rank	density	rank
C1	3.97	2	7.54	1	3.92	2
C2	3.69	3	5.38	3	4.56	1
C4	4.63	1	6.81	2	3.80	3
C5	2.69	4	3.59	5	2.59	5
C6	2.44	5	4.00	4	2.70	4
C1-C6	2.77		6.06		3.62	

The analysis of pre-1986 northern Chukchi Sea aerial survey data presented in Frost et al. (1985b) indicated a steady decline in the density of ringed seals in the northern Chukchi Sea from 1970 through 1985. When 1986 and 1987 data are added to that analysis, it appears that the 1985-1987 densities, although variable from year to year, are consistently lower than those reported for the 1970's (Figure 15). The difference in densities is, in actuality, probably greater than Figure 14 indicates, since some of the earlier surveys were flown at 500 ft, which results in estimates lower than those obtained at 300 ft. It is unclear whether this apparent recent decrease in densities between Point Lay and Wainwright is a real reflection of changing seal abundance, or is an artifact of survey methodology. Surveys conducted in the 1970's consisted of lines flown parallel to instead of perpendicular to the coast, and thus, depending on the location of lines relative to the fast ice edge, could reflect higher densities found near the edge. In 2 of our 3 recent survey years, densities within 0-4 nm of the edge in sector C6 were 1.6-1.7 times greater than densities away from the edge. The 1970's surveys were also conducted as much as 2 weeks later than 1985-1987 surveys, which means that they may reflect a seasonal increase of hauled-out seals similar to what we found in the Beaufort Sea. We conclude that recent surveys cannot be considered comparable to those conducted in the 1970's, which were flown using different survey methodology and at a later date.

Sector densities were multiplied by total area of fast ice to estimate the number of seals hauled out on fast ice of the Chukchi Sea in 1985-1987 (Table 37). The total estimated number of seals in sectors C1-C6 ranged from 18,400 ± 1,700 in 1985 to 35,100 ± 3,000 in 1986. The 1987 estimate,

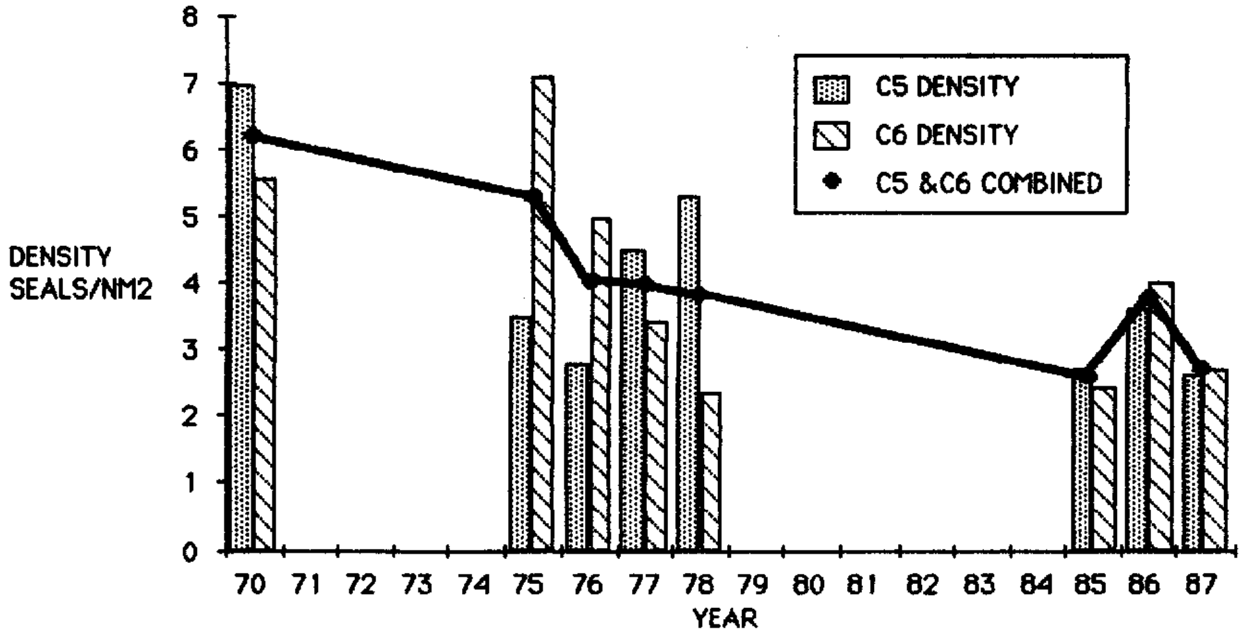


Figure 15. Densities of ringed seals in sectors C5 and C6, Point Lay to Point Barrow, for 8 years between 1970 and 1987.

Table 37. Density and estimated numbers (95% confidence limits) of total seals hauled out on fast ice of the Chukchi Sea during aerial surveys conducted in May-June 1985-1987. Densities based on counts made at 500 ft have been multiplied by 1.32 to make them comparable to densities obtained at 300 ft.

	1985			1986			1987		
Sector	fast ice area-nm²	density	estimated number of hauled-out seals	fast ice area nm²	density	estimated number of hauled-out seals	fast ice area nm²	density	estimated number of hauled-out seals
C1	2,590	3.97 (±0.59)	8,800-11,800	2,515	7.54 (±0.78)	17,000-20,900	2,390	3.92 (±0.69)	7,800-11,000
C2	370	3.69 (±1.23)	900-1,800	650	5.38 (±1.53)	2,500-4,500	655	4.56 (±1.74)	1,800-4,100
C4	845	4.63 (±0.84)	3,200-4,600	990	6.81 (±0.74)	6,000-7,500	715	3.80 (±1.20)	1,900-3,600
C5	610	2.69 (±0.80)	1,200-2,100	905	3.59 (±0.78)	2,500-4,000	995	2.59 (±0.31)	2,300-2,900
C6	475	2.44 (±0.55)	900-1,400	740	4.00 (±1.72)	1,700-4,200	830	2.70 (±1.27)	1,200-3,300
Chukchi Total	4,890	3.77 (±0.35)	16,700-20,100	5,800	6.06 (±0.51)	32,200-38,100	5,585	3.62 (±0.41)	17,900-22,500

20,200 ± 2,300, was similar to 1985. The area of fast ice was variable from year to year. In some areas, both density and area increased or decreased from one year to the next, causing large differences in the estimated number of seals. In other areas, changes in density were partially masked by opposite changes in density and in the area of fast ice.

2. Beaufort Sea

Annual and geographic variations in density were less regular in the Beaufort Sea than in the Chukchi Sea (Table 35). In 1985, the density of seals at holes was highest in sector B1 and lowest in B3, but because of substantial numbers of seals at cracks, the density of total seals was highest in sector B3. In 1986, densities of seals at holes and total seals were significantly greater than in 1985 in all sectors except B1, where the density was significantly lower. In sectors B1 and B2 in 1987, all densities were significantly greater than in the 2 previous years. In sector B3, the density of seals at holes was similar to 1986, but seals at cracks were far more numerous (4.5 vs 0.3/nm^2). In both 1986 and 1987, the densities of all types of seals were very high in sector B4, primarily because of the large numbers of seals at cracks (4.5-8.5/nm^2). Breakup was clearly underway in this sector when it was surveyed, with extensive fracturing and cracking of the fast ice, suggesting that the densities were probably not indicative of overwintering seal abundance. No pre-breakup surveys were available for sector B4 in 1986 for comparison, so changes in distribution and abundance could not be assessed as they could be in the central Beaufort Sea where both pre- and post-breakup surveys were conducted.

In the central Beaufort, the density of total seals was lowest in 1985, intermediate in 1986, and highest in 1987, but densities for 1986 and 1987 do not reflect the same ice conditions relative to breakup. Annual variability in the arrival of "spring" and the onset of breakup makes it difficult to conduct surveys under exactly the same conditions from year to year. Although the timing of surveys relative to calendar date can be held constant from year to year, the timing relative to breakup is more difficult to assess and control. For example, in some years, ice in the Beaufort Sea remains white, unbroken, and relatively free of meltwater until the second week in June. In 1985, several days of warm, sunny weather produced "mid-June" conditions by June 2. In 1986, a storm from 7-11 June caused major changes in ice conditions. In 1987, by the time we surveyed the central Beaufort Sea on 3-7 June, breakup was underway. The chronology of breakup substantially affects the total area of fast ice coverage and, consequently, estimates of the total number of seals on the fast ice. In some areas, the ice breaks up at such a rapid rate that what is classified as fast ice one day may be called pack ice several days later. This was true in the Beaufort Sea in 1986 when the area of fast ice in sector B3 (Oliktok to Flaxman Island) decreased by almost 2,000 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 had little effect on our surveys of the fast ice, since surveys were conducted prior to significant break-up of the fast ice sheet. In the Beaufort Sea, however, major changes in fast ice conditions with concurrent changes in seal distribution, have occurred during the survey period. In 1986, a 5-day period of high winds caused major changes in the position of the ice edge and in the incidence of cracks. Replicate flights conducted 3-4 days apart, either before or after the storm and under similar ice conditions, produced statistically comparable results, but data from surveys before and after the period of high winds were significantly different. Both the observed density of total seals and the proportions of seals at cracks increased greatly after the storm when ice conditions indicated the beginning of breakup. This increase could have been due to one or more of several factors: (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 (e) seal pups increasing in size and molting to adult pelage, thus making them more visible to observers. Any of 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 1985 and 1986, prior to the onset of breakup, the density of seals at holes was similar (1985) or lower (1986) within 0-4 nm of the edge than it was elsewhere. Very few seals at cracks were observed. Later in June in 1986, distribution changed: near the edge (0-2 nm) seals at holes increased from 1.1 seals/nm^2 to 6.9/nm^2, and seals at cracks increased from zero to 7.2/nm^2 (in sector B3). In 1987, when all surveys were flown after the beginning of breakup, densities near the edge were also very high: over 12 seals/nm^2 occurred within 4 nm of the edge in B3, and over 7 seals/nm^2 for all Beaufort Sea sectors combined. Most of the seals were at cracks.

The average group size of seals at holes tended to increase with date, as did the percent of total seals found at cracks. Between early and mid-June surveys in 1986, group size in sectors B1-B3 increased from about 1.3 seals/group to over 1.6 seals/group. In other years, the differences were less pronounced, but the tendency was the same (Table 38). The percent of seals at cracks also generally increased with date, particularly in the central Beaufort Sea (Table 39). In sector B4, seals at cracks made up 18% of total seals in 1985 and over 50% in 1986 and 1987. In contrast, in sector B1 seals at cracks never made up more than 10% of the total seals. In sectors B2 and B3, year-to-year differences were substantial, ranging from less than 10% to over 50%.

In combination, we think these observed changes in group size and in percent of seals at cracks suggest that a substantial influx of ringed seals occurs in the Beaufort Sea as breakup begins. Before breakup beings, group size is about 1.3 seals/group, seals at cracks make up less than 20%-30% of total seals, and densities are not particularly high near the

Table 38. Average group size of ringed seals on fast ice of the Beaufort Sea, 1985-1987.

Sector	Average number of seals/group					
	June 1985		June 1986		June 1987	
	early	middle	early	middle	early	middle
B1	1.29	1.30	1.26	1.59	1.25	1.39
B2	1.36	1.55	1.27	1.78	1.33	-
B3	1.45	1.37	1.35	1.74	1.53	1.78
B4	1.12	1.22	-	1.87	1.96	-

Table 39. Percent of total ringed seals seen at cracks in the fast ice, Beaufort Sea, 1985-1987.

Sector	Percent of seals at cracks					
	June 1985		June 1986		June 1987	
	early	middle	early	middle	early	middle
B1	0.0	7.2	2.9	9.7	3.6	6.4
B2	12.8	21.5	0.8	47.2	1.8	-
B3	23.2	51.6	7.3	54.8	55.8	49.3
B4	-	18.4	-	55.5	70.8	-

fast ice edge. After breakup begins and new seals move into the area, distribution changes considerably. In 1986, when surveys occurred both before and after the beginning of breakup in sector B3, we were able to compare areas under both conditions. These comparisons indicated that most of the incoming seals were found near the fast ice/pack ice boundary zone. Comparable increases in observed density did not occur near shore; although seals at cracks were more abundant after the ice began to break up, the density of seals at holes was actually slightly lower. In 1986, a similar influx of seals probably also occurred in sectors B2 and B4, as suggested by both the high proportion and high absolute density of seals at cracks in those areas.

The dynamics in sector B1 were considerably different. Cracks, and seals at cracks, were not common in any year in either early or mid-June surveys, probably because of the effect Point Barrow has on stabilizing the fast ice in that area. Ice conditions in sector B1 changed very little during the 1986 storm and the proportion and density of seals at cracks were similar in early and mid-June surveys. Unlike sectors B2 and B3 where the density of groups actually decreased slightly in later surveys, in sector B1, the density of groups of seals as well as of seals increased (Frost et al. 1987). As in the other sectors, this could have been due to an influx of nonresident seals which, in the absence of cracks, hauled out at other seals' holes or lairs. Kelly et al. (1986) found that in most instances, a seal maintains more than 1 lair. We think it is possible that the nonresidents use these "empty" lairs before cracks form. Alternately, the concurrent increases in sightings and density may have reflected a higher proportion of seals hauled out on the later date, 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 events doubles from March to June and that the onset of basking (hauling out on the surface of the ice instead of inside a lair) varies considerably among individuals (Kelly et al. 1986). Since those studies terminated in early June, it is unknown whether or not haul-out duration continues to increase after that time.

Other investigators have reported similar increases in density and/or changes in distribution as the spring season advances. Helle (1980) documented a 10-fold increase in density of hauled-out ringed seals in the Baltic Sea between mid-April and late May and concluded that mid-April was too early for surveys. Smith (1973) found that counts in Home Bay were approximately stable from 26 May until 5 or 6 June, increased and fluctuated around a higher peak from 5-15 June, and increased again after 15 June. He suggested that increases after mid-June were probably due to an influx of seals from another area.

Finley (1979) found that in some areas of the Canadian Arctic, densities of ringed seals remained relatively stable from early June into July, whereas in others there were great increases in density. He, like Smith, attributed such increases to influxes of seals from other areas. As density increased in these areas, Finley noted that seals aggregated in larger numbers at holes and in very large groups along cracks. In Aston Bay, the ratio of seals to holes increased from 0.33:1 to 2.63:1 as the season progressed, with as many as 19 seals found around a single hole. Finley suggested that social structure may break down as areas receive influxes of seals from areas of unstable ice, resulting in the larger groups seen later in the season. He proposed, as we have, that large groups of seals at holes and the presence of many seals at cracks may be indicative of seals that are non-resident, whereas small group size and few seals at cracks represent relative stability in the local population.

In a further attempt to determine the cause and geographic extent of the apparent influx of nonresident seals, and to determine whether there was any portion of the fast ice where densities remained more constant, we compared 1986 densities for all fast ice with that for fast ice within 6 nm of land. Whereas pre- and post-storm comparisons for all fast ice 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 6%, from 3.5 to 3.7 seals/nm^2. Although the difference was significant ($t=4.763$, $p<0.001$), there was considerable overlap in the 95% confidence interval of the estimated number of seals (5,017 ± 739 vs 5,380 ± 767, area = 1,450 nm^2).

We suggested (Frost et al. 1987) that if for unavoidable reasons future surveys must take place after breakup has begun and cracks are widespread, it might be possible to utilize the nearshore portion of transects for annual comparisons. However, a closer analysis of the 1986 data showed that, although the combined sector B1-B3 densities of seals at holes were similar within 6 nm of shore for the 2 survey periods, the individual sector densities were not (Table 40). The density of seals at holes increased 26% between surveys in sector B1, and decreased 17% in sector B3.

Table 40. Density of seals within 6 nm of shore in early and mid-June, 1986-1987.

Year		B1-B3 combined		B1		B3	
		early	middle	early	middle	early	middle
1986	Hole	3.46	3.71	2.38	3.00	4.56	3.79
	Crack	0.01	2.66	0.0	0.86	0.02	3.04
	Total	3.47	6.37	2.38	3.85	4.58	6.84
1987	Hole	2.91	4.53	1.93	3.53	3.19	4.86
	Crack	2.19	4.28	0.04	0.78	2.04	5.78
	Total	5.10	8.81	1.97	4.31	5.23	10.64

Although all of our surveys in 1987 occurred after the beginning of breakup, we did have replicate surveys in sectors B1 and B3, flown about a week apart. The density of seals at holes within 6 nm of shore increased 83% during that period in sector B1, and increased 52% in sector B3. In combination, the figures in Table 40 indicate that the area within 6 nm of shore is not any more suitable for inter-annual comparisons of data collected under different ice conditions than is the entire fast ice zone.

We conclude that in order for meaningful comparisons to be made between years, surveys must be conducted prior to the onset of breakup and before seals have started to move in from other areas and aggregate in large groups near the fast ice edge. In some years, such as 1987, this may occur in early June, while in other years the ice may be suitable for surveys until mid-June. The best indications of whether or not conditions are suitable are the percentage of seals at cracks relative to total seals, group size, the presence of numerous cracks, and whether the attached fast ice in the central Beaufort Sea has begun to crack and break off from the actual shore fast ice. If this process is well advanced it can be determined from satellite photos of the ice. Early in the process, reconnaissance flights at low altitude are necessary.

Early in the season when ice conditions are most suitable for surveys it is also most difficult to determine the location of the fast ice edge. In some sectors the problem is more acute than others. In sector B1, the edge is usually well-defined. However, in sectors B2 and B3, it is very difficult at low altitude to differentiate fast ice from pack ice. We therefore analyzed our data in several different ways to see if there was a fixed parameter that could be used to determine ending coordinates of transect lines before the surveys, and which would produce densities that compare favorably with those for fast ice as a whole. Using data from sectors B2 and B3, where distinguishing the ice edge is most problematic, we compared densities for all fast ice (edge usually determined by matching satellite photographs with field notations) with those for ice within 10 and 20 nm of shore and for all ice within the 20-m depth contour, which, according to Reimnitz and Kempema (1984) and Stringer (1982), approximately delimits the seaward edge of fast ice (Table 41). According to Reimnitz and Kempema (1984) there is a band of shoals in the central and western Beaufort Sea that lies approximately along the 18- to 20-m depth contour. These shoals cause pack ice to ground and form a protective zone of ridges which protects and stabilizes the fast ice. For seals at holes and total seals, density within the 20-nm contour most closely approximates density on the fast ice (Figure 16). Whereas the 20-m depth contour correlates with position of the fast ice edge, the 10-nm and 20-nm bounds are arbitrary and may fall in very different places relative to the fast ice edge in different sectors. We therefore suggest that future surveys use the 20-m depth contour to delimit the seaward end of survey lines, and inter-annual comparisons be made only for ice within the 20-m contour. By so doing, a comparable area is included in the data from year to year. Also, this is the area most likely to be impacted by human activities.

The total number of seals within the 20-m depth contour in the Beaufort Sea was estimated by multiplying the density of seals by the area of all ice between shore and the 20-m depth contour. Shallow areas (<3 m) of large embayments (Harrison and Smith bays) were excluded from the analyses

Table 41. Densities (seals/nm²) of ringed seals on different portions of the ice in sectors B2 and B3, 1985-1987.

Year	Zone	nm	Holes density	Holes sd	Total density	Total sd
1985	<20 m	322	1.98	0.14	2.80	0.14
	fast	564	1.76	0.12	3.17	0.30
	10 nm	246	1.87	0.17	2.36	0.31
	20 nm	477	1.82	0.12	3.22	0.37
1986	<20 m	320	3.99	0.21	4.15	0.24
	fast	463	3.64	0.17	3.77	0.20
	10 nm	163	3.93	0.26	4.02	0.27
	20 nm	346	3.82	0.18	3.98	0.21
1987	<10 m	354	4.15	0.23	6.16	0.69
	fast	340	4.09	0.22	5.64	0.69
	10 nm	226	3.44	0.28	6.19	0.81
	20 nm	442	3.35	0.25	5.39	0.45

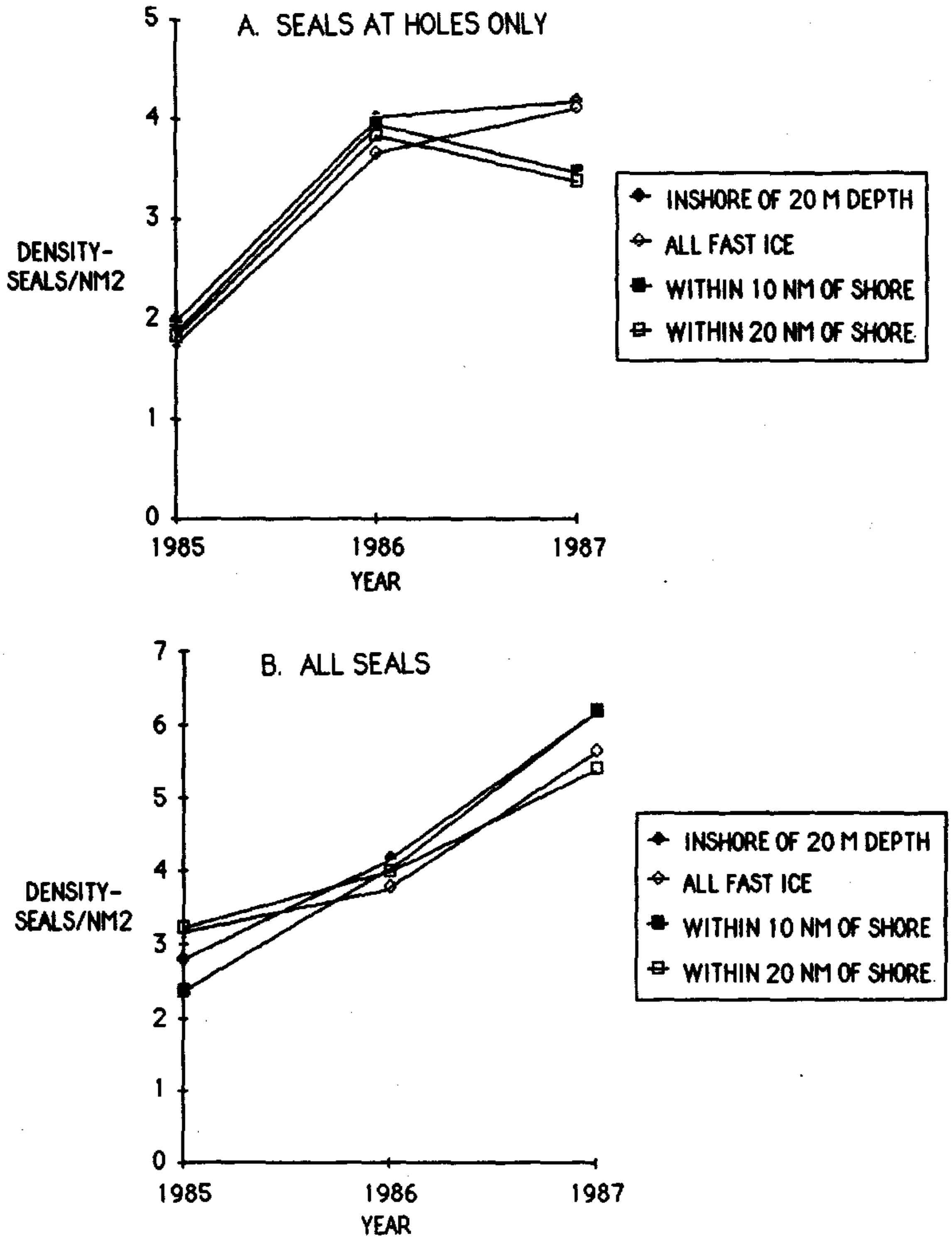


Figure 16. Densities of ringed seals in sectors B2 and B3, Lonely to Flaxman Island, 1985-1987.

because they freeze to the bottom. The estimated numbers of seals at holes and total seals within the 20-m depth contour were higher in sectors B2-B4 in 1986 than in 1985, with no overlap of 95% confidence limits. Although the density in sector B1 was significantly lower in 1986, the 95% confidence limits overlapped considerably (Table 42).

Comparisons between early June 1986 surveys and 1987 surveys indicate that substantially more total seals were hauled out on ice within the 20-m contour in 1987. The number of seals at holes was more variable, with more seals in some sectors and less or similar numbers in others. As pointed out in earlier discussions, the 1986 and 1987 surveys, although occurring on approximately the same dates, represented different ice conditions. The mid-June 1986 surveys in sector B3, conducted after breakup had begun, are more comparable to 1987 surveys. Estimates of the numbers of seals for those surveys are similar to the 1987 estimates: 7,200 ± 900 for mid-June 1986 and 6,700 ± 2,200 for 1987.

Historical data also indicate substantial year-to-year variability in the occupancy of nearshore areas by ringed seals. Data are available for the Alaskan Beaufort Sea since 1970 (Burns and Harbo 1970; Burns and Eley 1978; Burns et al. 1981a; Burns and Kelly 1982, reanalyzed in Frost et al. 1985). During that period, the density of ringed seals on the fast ice of the Beaufort Sea as a whole, dropped from a high of 3.3 seals/nm^2 in 1975, to a low of 1.1 seals/nm^2 in 1977, and subsequently steadily increased to 3.5 seals/nm^2 by 1986 (Figure 17). The density in any particular year ranged from 50% below to 40% above the mean density for 8 years of surveys (1987 was not included because breakup had already begun).

Table 42. Density and estimated numbers (95% confidence limits) of ringed seals hauled out on ice within the 20-m depth contour during aerial surveys conducted in the Beaufort Sea, June 1985-1987.

Sector	nm² within 20-m contour	1985		1986		1987	
		density	number	density	number	density	number
A. Seals at Holes							
B1	1,100	2.28 (±0.40)	2,100-2,900	2.08 (±0.41)	1,800-2,700	2.98 (±0.37)	2,900-3,700
B2	1,800	2.06 (±0.49)	2,800-4,600	3.73 (±0.45)	5,900-7,500	4.57 (±0.53)	7,300-9,200
B3	800	1.93 (±0.34)	1,300-1,800	4.57 (±0.79)	3,000-4,300	3.51 (±0.68)	2,300-3,400
B4	450	1.77 (±0.43)	600-1,000	4.08 (±1.25)	1,300-2,400	3.16 (±0.84)	1,000-1,800
B1-B3	3,700	2.09 (±0.23)	6,900-8,600	3.40 (±0.38)	11,200-14,000	3.80 (±0.35)	12,800-15,400
B. All Seals							
B1	1,100	2.40 (±0.46)	2,200-3,200	2.08 (±0.41)	1,800-2,700	3.10 (±0.38)	3,000-3,800
B2	1,800	2.31 (±0.54)	3,200-5,100	3.77 (±0.46)	6,000-7,600	4.75 (±0.56)	7,500-9,600
B3	800	3.12 (±0.98)	1,700-3,300	5.01 (±0.90)	3,300-4,700	8.33 (±2.72)	4,500-8,800
B4	450	1.99 (±0.38)	700-1,100	9.12 (±3.75)	2,400-5,800	10.90 (±11.34)	0-10,000
B1-B3	3,700	2.66 (±0.49)	8,000-11,700	3.51 (±0.42)	11,400-14,500	5.24 (±1.00)	15,700-23,100

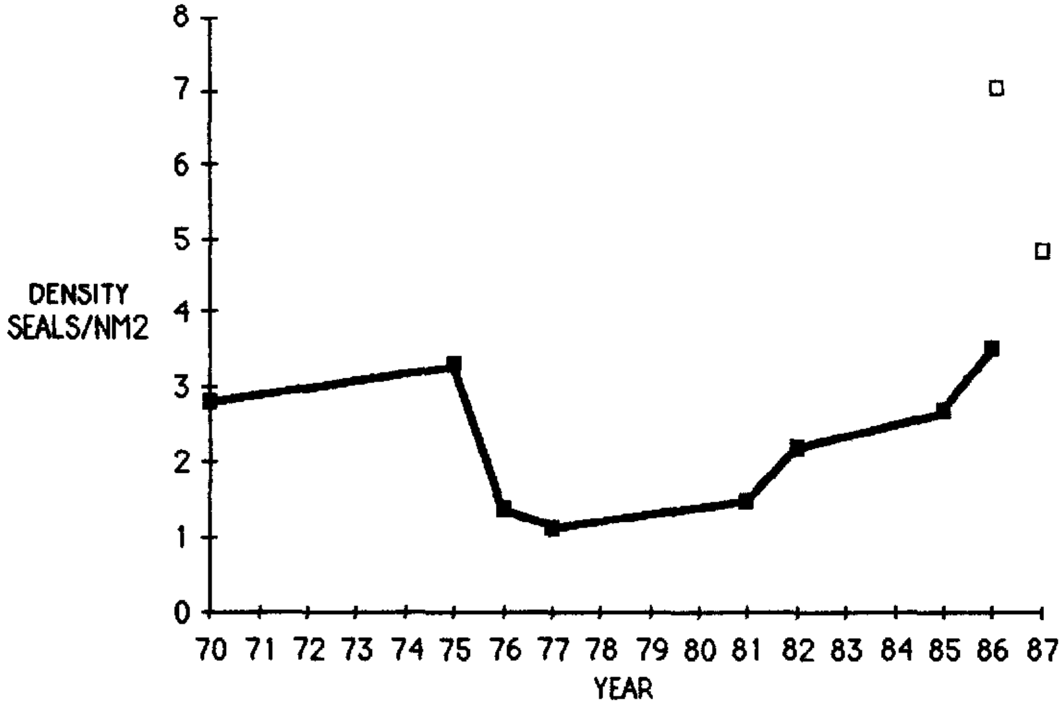


Figure 17. Density of ringed seals (total seals/nm^2) in the Beaufort Sea (sectors B1-B4) 1970-1987. Open squares indicate post-breakup values for 1986 and 1987. Densities for 1985-1987 are for total seals within the 20-m depth contour.

E. Density of seals in relation to industrial activities

Construction and operation of artificial islands were the principal industrial activities in our study area during 1985-1987. Data were obtained for 3 artificial islands: Seal, Northstar, and Sandpiper, for all 3 years of the survey (Table 43). In 1985, all 3 of the islands were active: Seal was engaged in drilling operations and Northstar and Sandpiper were under construction. For all comparisons, the density of seals at holes was 20%-80% lower within 2 nm of the islands than it was 2-4 nm away.

During the 1986 surveys Seal Island was inactive and had been so all winter; Northstar was inactive at the time of survey but had been in operation through April; and Sandpiper was currently active. The area was surveyed before break-up on 6 June, and after break-up had commenced on 13-16 June. Unlike 1985, densities were not consistently lower within 2 nm of the islands than they were elsewhere; results for individual islands were contradictory. Near Northstar (active until April) the density for both surveys was slightly lower (3%-15%) within 2 nm of the island than 2-4 nm away. Near Sandpiper the density was higher within 2 nm of the island on one survey, and lower on the other.

During winter and spring of 1986-87, all 3 artificial islands were inactive. Neither construction nor drilling operations occurred. As in previous years, the islands were surveyed twice in 1987, on 6 and 11 June. There was no consistent difference in seal density with distance from the 3 non-operational islands. Seals were more numerous near Seal Island, less numerous near Northstar, and differed between the 2 surveys at Sandpiper.

Table 43. The density of ringed seals at holes in relation to distance from 3 artificial islands in the Beaufort Sea, June 1985-1987.

1985

Island	Survey	Distance from any island (nm) 0-2	2-4	4-6	6-8	8-10
Seal	85-1	0.7	1.2	1.1	1.7	1.3
	85-2	-	1.9	1.0	3.3	2.2
Northstar	85-1	0.8	1.6	2.2	1.4	0.9
	85-2	0.8	1.0	5.8	1.5	1.5
Sandpiper	85-1	0.6	3.1	1.0	1.0	1.1
	85-2	2.6	4.4	1.8	1.9	1.6

1986

Island	Survey	Distance from any island (nm) 0-2	2-4	4-6	6-8	8-10
Seal	86-1	6.1	5.8	4.6	2.3	5.1
	86-2	-	4.6	6.5	5.0	5.6
Northstar	86-1	5.0	5.2	6.8	4.2	2.1
	86-2	5.0	5.9	5.7	8.8	5.3
Sandpiper	86-1	8.3	3.3	6.5	3.2	3.6
	86-2	5.2	6.2	6.8	9.1	9.1

1987

Island	Survey	Distance from any island (nm) 0-2	2-4	4-6	6-8	8-10
Seal	87-1	-	1.1	2.9	2.7	5.5
	87-2	14.4	9.5	10.4	5.9	4.8
Northstar	87-1	1.1	3.3	5.6	4.1	5.2
	87-2	3.8	8.4	14.2	6.3	6.1
Sandpiper	87-1	7.1	7.6	2.2	4.2	3.9
	87-2	6.8	5.5	6.6	5.2	11.9

Interpretation of the data regarding differences in density around individual islands was complicated, and the utility of such data limited, by several factors: sample sizes were small (17-80 nm^2 total per survey), particularly within 2 nm of the islands where the sample for a survey usually consisted of 1-3 minutes (1-6 nm^2) of data; the islands were close enough together (particularly Seal and Northstar islands which were only 4 nm apart) for interactive effects to occur; and not all islands were in similar operational status either within or between years. Consequently, the data set shown in Table 43 could not be treated as 18 replicate tests of the effect of an artificial island on seal density.

To address the first two of these problems we determined the minimum distance from any island in the data set from each survey (Table 44). In 5 of the 6 comparisons, the density of seals at holes was 12%-72% lower within 2 nm of any island than it was 2-4 nm away. Inspection of the raw data indicated that for the single exception (survey 86-1) the higher density at 0-2 nm was probably an artifact of the way position was assigned to the minute survey interval. Although the density of seals was lower near the islands in both 1985 when all islands were active and 1987 when none were active, the magnitude of the difference was much greater during activity (50%-70%) than in its absence (12%-30%).

A block comparison of industrial and adjacent control areas was also done for all 3 years. In 1985, industrial activity, including seismic lines, ice roads, and islands, was widespread, resulting in an industrial block approximately 60 nm across. In 1986, the only obvious activities were the artificial islands and associated ice roads, resulting in an industrial

Table 44. The density of ringed seals at holes in relation to distance from any of 3 artificial islands in the Beaufort Sea, June 1985-1987.

Survey	nm^2	Distance from any island (nm)				
		0-2	2-4	4-6	6-8	8-10
85-1	103	0.7	2.5	1.0	1.8	1.2
85-2	67	1.5	3.2	2.0	1.9	1.4
86-1	34	6.5	3.9	6.6	2.0	3.7
86-2	75	5.1	6.3	5.4	11.4	6.4
87-1	45	4.7	6.7	2.4	4.1	4.0
87-2	50	7.1	8.1	9.5	5.8	5.4

block which was only 16 nm across. During 1987 surveys there was no offshore industrial activity; however, data were analyzed according to the 1986 industrial and control blocks for comparative purposes.

In both 1985 and 1986 the density of total seals was significantly higher in the industrial block than in the control blocks (Figure 18). In 1987, in the absence of any offshore industrial activity, density in the "industrial" block was also higher than either control, suggesting that some characteristics other than the presence or absence of activity were responsible for the difference.

Annual and long-term variability in the occupancy of nearshore areas by ringed seals make it necessary to conduct regular and relatively extensive surveys of areas in which smaller-scale comparisons are to be made. For example, the density of ringed seals in the central Beaufort Sea (sectors B2 and B3) decreased in the mid- to late 1970's and subsequently increased in the mid-1980's. This could be attributed to changes in industrial activity, which intensified in the late 1970's and early 1980's, then gradually decreased. However, the western Beaufort Sea (sector B1), which experienced little or no seismic or other industry activity, showed the same fluctuations in density during this time period. Furthermore, the major decline in density which occurred in the study area between 1975 and 1977 also occurred in the Canadian Beaufort Sea (Stirling et al. 1981a).

While aerial surveys are useful in monitoring long-term trends in abundance over large areas, they are not well-suited to detecting small-scale differences in geographically restricted areas. In this study, aerial

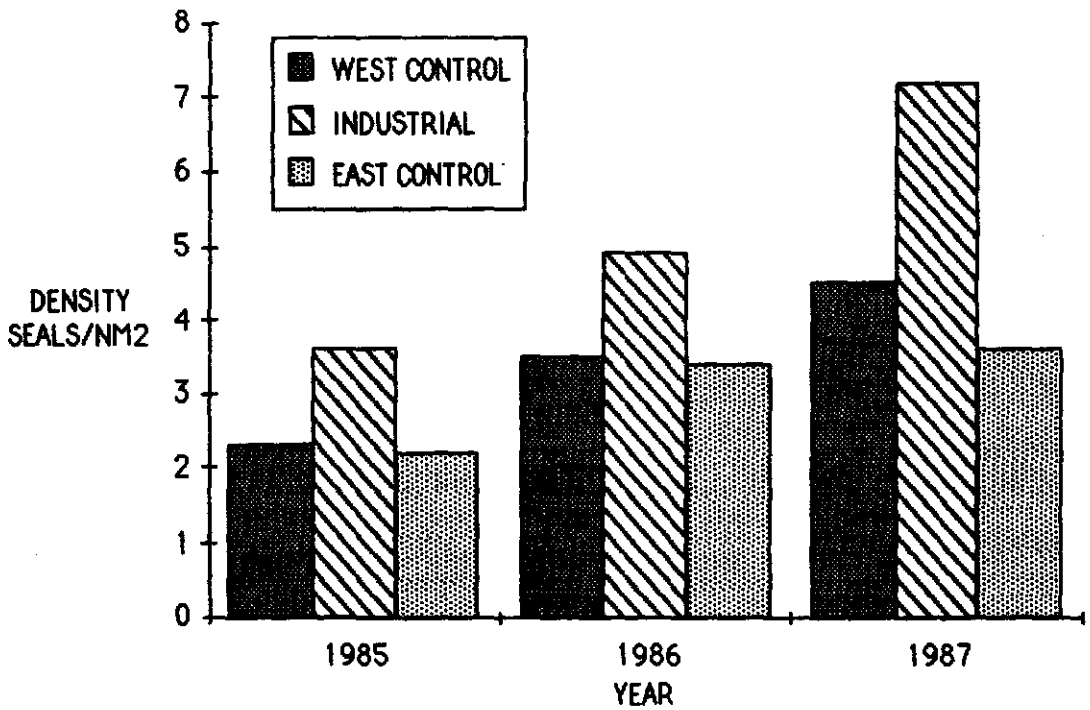


Figure 18. Seal density (total seals/nm^2) in industrial and control blocks in the central Beaufort Sea, 1985-1987.

survey data indicated a possible local effect of artificial islands on the density of ringed seals. However, interpretation was complicated by the fact that the minimum sighting unit was 1 minute or 2 nm; land and the edge of shorefast ice, which may both affect seal densities, were variable distances from the 3 islands; and the precision of navigational equipment sometimes varied by ± 1 nm. In analyses of industrial and control blocks, the greatest difficulties were in obtaining an accurate measure of industrial activity and in designating comparable control blocks. There is considerable east-west variability in the Beaufort Sea in ice topography, extent of shorefast ice, and bathymetry. Control and industrial blocks were not necessarily comparable simply because they were adjacent, as is indicated by higher densities in the "industrial" blocks with or without industrial activity.

In aggregate, analyses of historical and recent aerial survey data emphasize the importance of matching research technique to the question at hand. Our data indicate that in 1985-1986 there were no apparent broad-scale effects of industrial activity on the density of ringed seals as measured by aerial surveys. Burns and Frost (1988) reached the same conclusion for aerial surveys conducted in 1981-1982 in areas with and without on-ice seismic exploration, but they also concluded that aerial surveys are not well-suited to detecting small-scale differences in geographically restricted areas. The aerial survey data do not eliminate the possibility of local effects which would be more appropriately detected by other techniques, or the possibility that regional effects could occur at different levels of industrial activity. Most aerial surveys conducted during peak years of industrial activity in the central Beaufort Sea did not have sampling effort or design suitable for statistical analyses of differences between relatively small areas. By conducting on-ice studies, Burns and Kelly (1982) found that although aerial surveys showed no significant difference in densities along seismic and control lines, the rate of alteration or refreezing of lairs and breathing holes within 150 m of seismic lines was approximately double the rate at distances greater than 150 m. Kelly et al. (1986, in press) also reported results of on-ice studies which indicated that ringed seals do respond to anthropogenic disturbance. Burns and Frost (1988) found that seal structures were abandoned at 3 times the rate in disturbed areas (31% of all structures) as they were in areas free of human-caused disturbance (10% of all structures).

F. Implications of survey results to monitoring program

Analyses of 1985-1987 survey data have identified several areas of potential concern regarding methodology for aerial surveys to monitor changes in the distribution and abundance of ringed seals.

1. Comparisons of experienced and inexperienced observers indicate that novice observers see significantly fewer seals than do experienced observers. Survey personnel must be adequately trained to count ringed seals and classify ice conditons 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 survey conditions.

2. Surveys flown at 500 ft result in density estimates which are significantly lower than those for surveys of the same area conducted at 300 ft. We recommend that all surveys be conducted at 300 ft. When surveys that were conducted at different altitudes are compared, densities must first be corrected to make the results comparable. Densities of seals at holes for surveys at 500 ft should be multiplied by 1.32 to make them equivalent to surveys at 300 ft. Estimates of seals at cracks were not significantly different, perhaps because seals aggregated along linear features are easier to see, and need not be corrected.

3. Surveys within the same sector or geographic region should be conducted under similar ice conditions within and between years. Although calendar date provides a rough guideline for assuring similar conditions, there is considerable annual variability in the onset of breakup. Counts of seals on fast ice that are made after breakup begins are likely to include large influxes of seals from other areas, and should not be considered representative of the overwintering, resident population. Factors such as the amount of cracking, the distribution of seals relative to the edge, and the abundance of seals at cracks must be used to interpret data and assess whether or not significant changes in seal distribution have begun to occur.

4. In the Chukchi Sea, survey lines should extend from shore to the edge of fast ice, which is easily recognizable at survey altitude. In the Beaufort Sea, where the edge of fast ice is often difficult to locate without the use of satellite photographs, survey lines should extend

from shore to the 20-m contour line, which coincides approximately with the edge of fast ice. In large, very shallow embayments such as Smith Bay and Harrison Bay, transect lines should begin at the 3-m depth curve.

VII. Recommendations For Future Studies

A. Future aerial monitoring surveys

We recommend that MMS continue a program of monitoring the abundance of ringed seals on the shorefast ice of the Chukchi and Beaufort seas. Surveys conducted during 1985-1987 have allowed a substantial refinement of survey protocol and have provided a large amount of "baseline" data on ringed seal distribution and abundance during May and June. During 1985-1987 oil and gas activity in the OCS region was minimal in the Beaufort Sea and non-existent in the Chukchi Sea. We were therefore not able to measure or monitor possible effects of OCS industrial activities on ringed distribution and abundance.

Although it is impossible to accurately predict the probable timing and magnitude of OCS activities, recent sales in the Beaufort Sea (sale 97) and Chukchi Sea (sale 109) suggest that activity will increase within the next few years. We therefore recommend that a 3-year series of ringed seal monitoring surveys be conducted in 1991-1993. Those surveys should follow the protocol developed in this study and should incorporate the following:

1. surveys should include and emphasize areas leased in sale 97 (sectors B1-B4) and sale 109 (C4-C6);

2. surveys should be conducted before breakup in order to ensure that data are comparable;

3. survey coverage should extend from shore to the 20-m depth contour in the Beaufort Sea, and from shore to the fast ice edge in the Chukchi Sea.

B. Effects of disturbance on ringed seals

Aerial surveys provide the best means to look at large-scale patterns and changes in ringed seal distribution and abundance. Results of aerial surveys indicate that industrial activities (primarily on-ice seismic profiling) to date have not caused large-scale changes in seal distribution (Frost and Lowry, in press). However, other studies (Kelly et al., in press) indicate that seismic surveys and other activities can cause localized changes in seal distribution and behavior. Further studies are required if the possible magnitude and significance of disturbance on ringed seals are to be assessed. Such studies should examine fine-scale distribution (using trained dogs to locate lairs and breathing holes) and behavior (using telemetry) near realistic and representative sources of disturbance, such as artificial islands, active drilling rigs, seismic shot lines, and ice roads or air strips.

C. Factors affecting ringed seal abundance

It is clear from this and other studies that the density of seals during the spring haul-out period varies geographically and temporally. Causes of these variations are poorly known, but both physical factors (e.g., ice characteristics, weather, and oceanography) and biological processes (e.g., food availability, predation, and territoriality) are likely to be involved. Research into all possible factors that could control ringed seal distribution and abundance is needed in order to understand natural variability, and to better interpret results of the monitoring program.

D. Other aspects of ringed seal distribution

Ringed seals are widely distributed year-round in waters of northern Alaska, but there is very little information on their distribution and abundance except for on the shorefast ice in spring. This study has supplemented previously available data on abundance of ringed seals in the flaw zone and nearshore areas of pack ice during May-June. Substantial numbers of seals inhabit these areas, and their interaction with seal density on the fast ice during breakup is significant and warrants further study. In order to produce a valid estimate of the total size of the ringed seal population off Alaska, more information is needed on densities in the offshore pack ice. Ringed seal distribution and abundance during the open-water season should be investigated in order to evaluate important habitats and processes, and potential effects of OCS activities that occur during July-November.

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