MONITORING DISTRIBUTION AND ABUNDANCE OF RINGED SEALS IN NORTHERN ALASKA

Final Report

Prepared by

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PROJECT ORGANIZATION

This report includes data from two sets of aerial surveys for ringed seals in the Alaska Beaufort Sea conducted in 1985-1987 and 1996-1999. The 1985-1987 surveys were done under NOAA contract 84-ABC-00210 to the Alaska Department of Fish and Game (ADF&G). Those studies were funded by Minerals Management Service (MMS), Department of the Interior, through an Interagency Agreement with the National Oceanic and Atmospheric Administration, as part of the Alaska Outer Continental Shelf Environmental Assessment Program. The 1990s surveys were funded through Cooperative Agreement 14-35-0001-30810 between MMS and ADF&G.

This cooperative effort involved the MMS Alaska Region Environmental Studies Section, ADF&G, the National Marine Fisheries Service (NMFS), the University of Alaska, and the North Slope Borough. ADF&G had primary responsibility for project management and coordination, conduct of surveys, data analysis, and reporting. The NMFS National Marine Mammal Laboratory assisted in the conduct of surveys, data analysis, and reporting. The University of Alaska Fairbanks assisted with conduct of surveys and reporting. A University of Alaska Anchorage graduate student worked on this project as part of a Master of Science thesis in biology. A University of Alaska Fairbanks graduate student assisted with data analysis as part of a Research Assistantship. The North Slope Borough Department of Wildlife Management assisted other cooperators in communicating information to people residing in the study area. All cooperators had input into project design, and have access to, and will be able to make use of, all data collected.

Kathryn J. Frost (ADF&G, now retired and affiliated with University of Alaska Fairbanks) was one of the Principal Investigators for this project. She participated in all aspects of the study including logistics arrangements, design of aerial surveys, conduct of surveys as a primary observer during 1985-1987 and 1996-1999, quality control of data, budget preparation and tracking, data analysis, and report preparation.

Lloyd F. Lowry (ADF&G, now retired and affiliated with University of Alaska Fairbanks) was one of the Principal Investigators for this project. He participated in the study design, was a primary observer for aerial surveys during 1996-1999, assisted with quality control of data, and participated in data analysis and report preparation.

Grey Pendleton, ADF&G, was a data recorder for aerial surveys during 1996-1999. He participated in quality control of data, data analysis, and report preparation. In addition, he had primary responsibility for statistical design of surveys, multivariate statistical analysis of the survey data, reanalysis of data from previous surveys conducted in 1985-1987, and for design of the power analysis to evaluate the ability of surveys to detect trends in abundance.

Helen Nute, University of Alaska Fairbanks, had primary responsibility for univariate analyses of the surveys. This included reanalysis of data from 1985-1987 as well as analysis of data collected during the 1996-1999 survey effort. Ms. Nute did extensive quality control of datasets and analytical procedures.

Douglas DeMaster, NMFS National Marine Mammal Laboratory, participated in the design of aerial surveys, acted as either a primary observer or data recorder during surveys, and had primary responsibility for analysis of line transect data collected during 1996-1997 and reported in annual reports.

Casey Hessinger, University of Alaska Anchorage, was a data recorder for aerial surveys conducted during 1996-1999. She assisted with data analysis and report preparation. She prepared an extensive annotated ringed seal bibliography, which has been submitted to MMS as a product of this study. Ms. Hessinger participated in this study as part of her thesis project for a Master of Science degree at UAA.

Susan Hills, University of Alaska Fairbanks, participated in conduct of aerial surveys during 1985-1987 and 1996-1999 as a data recorder and as a primary recorder of ice conditions. She assisted with interpretation of ice conditions and reconciliation of field observations of the fast ice edge with available satellite imagery. She also prepared a summary report describing industrial monitoring programs for ringed seals in the central Beaufort Sea that was submitted to MMS as an appendix to the 1998 annual report for this project.

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EXECUTIVE SUMMARY

This report describes results of aerial surveys conducted to determine the distribution and abundance of ringed seals (*Phoca hispida*) in the central Beaufort Sea off Alaska. This was a cooperative project funded by the U.S. Department of the Interior, Minerals Management Service, with additional support contributed by the Alaska Department of Fish and Game, the National Marine Fisheries Service, the University of Alaska, and the North Slope Borough. Specific objectives were to: 1) review and refine protocols for monitoring ringed seals by aerial surveys; 2) estimate relative abundance and density of ringed seals on fast ice in the Beaufort Sea during 1996-1999 and compare with data collected during 1985-1987; and 3) correlate observed ringed seal densities on fast ice with environmental parameters.

Data from two sets of aerial surveys for ringed seals in the Alaska Beaufort Sea are analyzed in this report. The 1985-1987 surveys were conducted under NOAA Contract 84-ABC-00210 to the Alaska Department of Fish and Game as part of the Alaska Outer Continental Shelf Environmental Assessment Program. The 1996-1999 surveys were funded through Cooperative Agreement 14-35-0001-30810 between the Minerals Management Service and the Alaska Department of Fish and Game.

Ringed seals are a widespread, circumpolar species, that in Alaskan waters occur in the Beaufort, Chukchi, and Bering seas, usually in association with sea ice. Although they also occur in pack ice, ringed seals are the only species of seal in Alaska that commonly lives on and under the extensive, largely unbroken, shorefast ice. They make and maintain breathing holes in the ice from freeze-up until breakup. As day length and temperature increase in the spring, increasing numbers of ringed seals haul out on the surface of the ice near breathing holes or lairs. This hauling-out or basking is associated with the annual molt, which occurs in May-July. It is during this time that seals are most readily observed and counted.

The shorefast ice also provides a reasonably safe and convenient surface on which various human activities are conducted. Coastal residents have traditionally used the fast ice to hunt for seals and other marine mammals. More recently the oil and gas industry has used the fast ice for conducting certain phases of petroleum exploration and development. Currently, a warming climate trend is causing changes in the characteristics of sea ice which may affect both ringed seals and humans, and the ice they live on and use. Because such human activities may impact seal populations, and because climate change may affect ringed seal habitat, it is important to monitor changes in distribution and abundance over both short and long term time scales.

We conducted aerial surveys during late May and early June 1996-1999 in the Beaufort Sea between Point Barrow and Kaktovik (156° 36'W to 143°42'W), an east-west extent of approximately 500 km. Two experienced primary observers counted seals using the strip transect protocols established during 1985-1987 surveys. Surveys transects were laid out along lines of longitude, and extended from approximately the 3 m depth contour to 40+ km offshore. Survey altitude was 91 m, and strip width was 0.41 km on each side of the aircraft. The survey aircraft had oversized bubble windows, radar altimeter, and an onboard navigation system linked to computers operated by data recorders. Three ice variables were recorded: ice type (fast or pack), percent ice deformation, and percent of the ice surface covered by melt water. Weather conditions were recorded at the beginning of each transect and whenever conditions changed.

A subset of the data collected and reported in 1985-1987 was reanalyzed and incorporated in this report. Data used in the reanalysis included surveys conducted at 91 m altitude in sectors B1-B4. During the 1990s survey effort, complete coverage of the Alaskan Beaufort Sea (sectors

B1-B4) was obtained for 1997 and 1999. During 1996 and 1998 only sectors B3 and B4 were surveyed. Only data within 40 km of shore in sectors B3 and B4 were included in the final analysis of all years.

We calculated simple or "raw" densities of observed ringed seals by dividing the number of seals counted within the strata of interest by the area of that strata. Univariate analyses of the effects of habitat, weather, and time of day were done using chi-square goodness-of-fit tests. We also used Poisson regression to model the relationship of seal counts to covariates. Although date has a strong effect on seal counts, our 1996-1999 surveys did not include enough temporal coverage to include date as an explanatory variable.

The dataset for 1985-1987 included 71-80 transect lines each year. We counted 2,189 seals on 2,271 km^2 of ice habitat in 1985, 2,605 seals on 2,361 km^2 in 1986 and 3,867 seals on 2,524 km^2 of ice in 1987. Total survey effort during 1996-1999 included 40-139 transect lines per year. We counted 1,612 seals on 1,961 km^2 in 1996, 3,429 seals on 4,288 km^2 in 1997, 1,111 seals on 1,198 km^2 in 1998 and 3,796 seals on 3,697 km^2 in 1999. Ringed seals were broadly distributed throughout the study area in all years. Observed densities for fast ice and pack ice combined in the 1980s ranged from 1.01 seals/km^2 in 1985 to 1.85 seals/km^2 in 1987. Observed densities for the 1990s were similar to 1985 and somewhat lower than in 1986 and 1987, ranging from 0.81 seals/km^2 in 1996 to 1.17 seals/km^2 in 1999. The range in density estimates from the Poisson regression model was somewhat greater. There was a threefold difference between the modeled densities for 1985 (2.25 seals/km^2) and 1999 (0.64 seals/km^2).

The habitat-related variables water depth, location relative to the fast ice edge, and ice deformation had substantial and consistent effects on the distribution and abundance of seals in the study area. The highest seal densities occurred between >5 m and 25 m depths. Similar depth preferences have been found in other ringed seal studies done in comparable habitats. Seals were most numerous near the shorefast ice edge, with densities declining both shoreward and seaward of the edge. Substantial variability may have been introduced into the analysis of density relative to distance from the edge because of the subjectivity and difficulty of visually determining the position of the fast ice edge. It is unclear what makes the ice edge so attractive to ringed seals and results in higher densities at this fast ice-pack ice interface. Seals feed at a reduced rate at this time of year when they are entering the molt. Higher densities near the edge could reflect diminished territoriality of seals breeding on shorefast ice, and/or an influx of seals from other regions as the ice begins to crack and break and the molt approaches .

We found a strong and consistent relationship between seal densities and the degree of ice deformation in all years and for all years combined, with more seals found in flatter, less deformed ice. We think this difference is related to seal behavior and not to observer bias in highly deformed ice. Ringed seals are a primary prey of polar bears, and the constant threat of predation has shaped their behavior on the ice. Seals haul out to bask in areas where they can see and smell approaching predators, and where they can escape down holes or cracks too small for a polar bear to follow. Thus, it is not surprising that observed densities of basking ringed seals are higher in flat ice than in rough, ridged ice where polar bears hunt most commonly.

Univariate analysis of our data from 1985-1999 suggested that observed densities of seals were generally highest between about 1100 and 1400 hrs local time (solar noon is about 1300 hrs). In contrast, Poisson regression models predicted that densities would be highest at 1000 or 1100 hrs and decline steadily throughout the day. Results of the Poisson analysis were inconsistent with behavioral data from tagged seals, which indicate that more seals haul out in mid day.

Analyses of the effects of weather factors on seal counts were inconclusive. This was likely at least partially due to the fact that temperature and wind speed were measured at the survey altitude of 91 m rather than on the surface of the ice. Furthermore, surveys were conducted in weather considered suitable for hauling out, and the survey window excluded very windy or stormy weather. Other investigators have also concluded that multivariate regression using wide-area survey data is ineffective for determining the effects of weather.

It was our hope at the beginning of this project that we might be able to use Poisson regression to model the effects of covariates and to "correct" the data collected in different years to standard conditions, thus making our estimated index of ringed seal density more accurate and our interpretation of trend more reliable. However, the results of our analyses demonstrated difficulties with such an approach. For several habitat-related covariates (ice deformation, distance from the fast ice edge, water depth), results of univariate and multivariate analyses indicated similar relationships. For others (e.g., weather), neither analysis was particularly informative.

Despite attempts to standardize survey methodology, substantial intra- and interannual variability in survey conditions and ice characteristics is unavoidable. This makes it difficult to identify trends in abundance. Interannual comparisons of seal abundance may reflect the overall status of the population, annual differences in distribution caused by variation in habitat characteristics, differences in the proportion hauled out, or a combination thereof. Our surveys were not designed to quantify date effects on seal behavior. We had hoped that by narrowing the survey window and conducting surveys before breakup and melting occurred we could minimize the effect of date. However, recent information from radiotagged seals indicates the change from hauling out in lairs to basking in the open is rapid and annually variable, and such behavior may significantly affect the number of seals counted even over a narrow period of time. Future efforts to improve our estimates of trend should include quantification of the effects of within and between-year temporal variation on survey counts.

We also conducted power analysis to evaluate our ability to detect changes in ringed seal abundance and as a means of evaluating whether Poisson regression models improved out ability to detect trend. Power analysis was based on simulations for two levels of effort, two time periods, and positive or negative annual trend changes of 0%-20% . Power to detect trend was low for all combinations of sample size, years, and population change. Almost no additional power was gained by adding 30% more lines to the survey coverage. However, power increased markedly when the survey period was increased from 5 years to 10 years. With 5 years of surveys, the power to detect a 20% annual decline was only 0.23 (P=0.05) for the raw data and 0.51 for Poisson modeled data. With 10 years of surveys, power increased to 0.53 and 0.73 for raw and modeled counts. Our analysis indicated almost no power (8%-32%) to detect an annual trend of 5%, a more realistic rate of change for a ringed seal population. This suggests that current methods of collecting and analyzing aerial survey need to be improved if the data are to be useful for detecting trends in abundance.

Both observed and modeled densities of ringed seals in the central Beaufort Sea indicated considerable annual variability on both fast ice and pack ice. The lowest observed annual density during the 1980s was similar to densities in 1998 and 1999 and about 25% higher than the lowest density during the 1990s. The highest annual density during the 1980s survey period, however, was more than double the highest density for the 1990s. The range in density estimates from the Poisson regression model was somewhat greater, with a threefold difference between the modeled densities for 1985 and 1999. Trend analysis based on an ANOVA comparison of observed density estimates suggested a marginally significant (p=0.09) but substantial decline of

31% from the 1980s to the 1990s. The Poisson regression model indicated highly significant ($p<0.001$) declines of 72% on fast ice and 43% on pack ice over the 15-year period. However, the apparent decline between the 1980s and the 1990s may be due to a difference in the timing of surveys rather than an actual decline in abundance. The 1980s surveys were conducted substantially later (June 6-12) than surveys in the 1990s (May 27-June 4). If the phenology of seal basking was comparably earlier in the 1990s than in the 1980s then the decline in seal numbers may well be real. However if such a change in seal basking did not occur, then the 1990s surveys were flown at a time when a relatively small proportion of seals were visible and the apparent decline could be an artifact.

Regardless of whether or not the differences in ringed seal densities described above are real, there are several reasons to think that ringed seal abundance in the Beaufort Sea either has changed or is likely to change in the future. Beaufort Sea populations of polar bears, which prey on ringed seals, and bowhead whales, which compete with them for food, have increased since the 1970s. Furthermore, as climate warms, impacts on ringed seal distribution, abundance, and productivity will likely result from the combined effects of changes in physical habitats, changes in prey populations, and changes in inter-species interactions.

ACKNOWLEDGEMENTS

This project was funded primarily by the U.S. Department of the Interior, Minerals Management Service, Alaska Region Environmental Studies Section. Additional support and in-kind services were contributed by the Alaska Department of Fish and Game, the National Marine Fisheries Service, the University of Alaska Fairbanks, and the North Slope Borough. Cleve Cowles, Jane Carlson, Valerie Elliott, and Warren Horowitz assisted with implementation of the cooperative agreement.

We thank Tom Blaesing, Commander Northwest, for providing the aircraft used for 1996 - 1999 surveys and for his expert piloting. These surveys would not have been so safe or efficient without Tom's extensive experience on the North Slope and his commitment to providing the best survey aircraft possible. Doug DeMaster, Casey Hessinger, Sue Hills, Debbie Blaesing, Grey Pendleton, John Bengtson, and Janice Waite served as observers and data recorders on the surveys.

Rob DeLong developed computer programs for manipulating aerial survey data. Casey Hessinger prepared the ringed seal bibliography, assisted with organization of historical data files, and developed a pilot project for GIS analysis to examine ringed seal distribution and density relative to habitat variables. Jeff Laake provided advice on study design and data analysis.

INTRODUCTION

Ringed seals (*Phoca hispida*) are a widespread, circumpolar species, that in Alaskan waters occur in the Beaufort, Chukchi, and Bering seas, usually in association with sea ice (Burns 1970). They are small phocid seals, with adult animals in Alaska averaging 115 cm in nose-tail length and 49 kg in weight (Frost and Lowry 1981).

Although they also occur in pack ice, ringed seals are the only species of seal in Alaska that commonly lives in and under the extensive, largely unbroken, shorefast ice (Burns 1970). Shorefast ice begins to form in October-November, and persists until May-July, depending on location. At its maximum extent the shorefast ice extends seaward to about the 20 m isobath, which may be 40 km or more offshore (Stringer *et al.* 1980). Using strong claws on their front flippers, ringed seals make breathing holes in the newly formed ice and maintain the holes as the ice thickens (Smith and Stirling 1975, Smith and Hammill 1981). Later in the season some holes are enlarged to provide access to the ice surface on which seals excavate lairs in the accumulated snow. Pregnant females give birth to and nurture their single pup in the lairs during March-May (Smith and Stirling 1975).

As day length and temperature increase in the spring, increasing numbers of ringed seals haul out on the surface of the ice near breathing holes or lairs. This hauling-out or basking is associated with the annual molt, which occurs in May-July (McLaren 1958) when increased skin temperatures are needed to promote epidermal growth (Feltz and Fay 1966). It is during this time that seals are most readily observed and counted. Seasonal shifts in distribution occur due to changes in sea ice characteristics, but the dynamics of those movements are poorly known.

In addition to being an important habitat for ringed seals, the shorefast ice also provides a reasonably safe and convenient surface on which various human activities may be conducted. Coastal residents have traditionally used the shorefast ice to hunt for seals and polar bears (*Ursus maritimus*), trap for arctic foxes (*Alopex lagopus*), and to travel between villages and camps. More recently the oil and gas industry has used the shorefast ice for conducting certain phases of petroleum exploration and development. Activities that might affect ringed seals and their habitat include principally seismic profiling, exploratory drilling, and oil production, which require deployment of camps and heavy equipment, and construction of gravel or ice islands, ice roads, and airstrips.

Over the last several decades, there has been a warming trend in much of the Arctic, resulting in a thinning of the sea ice and changes in the annual extent of sea ice coverage (Vinnikov *et al*. 1999). Such changes may affect both ringed seals and humans who rely on sea ice for various activities (Huntington 2000). For this reason, it is important to monitor changes in distribution and abundance of ringed seals over both short and long term time scales.

STUDY RATIONALE AND OBJECTIVES

The Minerals Management Service (MMS) supports environmental studies needed to provide the information required for planning outer continental shelf (OCS) lease sales and monitoring the impacts of oil and gas industry-related activities on marine resources. Due to the possible impacts of OCS activities on ringed seals, especially possible conflicts on the shorefast ice, MMS has supported a variety of studies on them (e.g., Kelly *et al.* 1986, Frost and Burns 1989). In 1985-1987, MMS contracted with the Alaska Department of Fish and Game (ADF&G) to conduct a series of aerial surveys for ringed seals in the Chukchi and Beaufort seas, one of the objectives of which was to develop and initiate a program for monitoring seal distribution and abundance (Frost *et al.* 1988). In 1996, MMS and ADF&G entered into a cooperative agreement to repeat the aerial surveys of ringed seals in the Beaufort Sea.

Results of the surveys conducted in 1996-1999 are reported here and compared to surveys conducted in 1985-1987. In addition, because both on-ice studies and previous aerial survey analyses have described effects of various habitat, weather, and temporal factors on survey results, we have included analyses of the effects of such factors on monitoring of seal distribution and abundance in the central Beaufort Sea.

Specific objectives of this project identified in the Cooperative Agreement and addressed by this report are as follows:

1. Review and refine the established protocol for monitoring ringed seal distribution and abundance by aerial surveys.

2. Estimate relative abundance and density of molting ringed seals on fast ice in the Beaufort Sea during 1996-1999 and compare with data collected during 1985-1987.

3. Correlate ringed seal densities on shorefast ice with environmental variables.

METHODS

Collection of Survey Data

Aerial surveys were flown during late May and early June 1985-1987 and 1996-1999 in the Beaufort Sea between Point Barrow (longitude 156° 36'W) and Kaktovik (longitude 143°42'W), an east-west extent of approximately 500 km (Figure 1). The study area was divided into four sectors (designated B1-B4) to facilitate comparisons with previous ringed seal surveys done in this region.

Surveys were flown at groundspeeds of approximately 222 km/hr (120 knots) and a survey altitude of 91 m. Most were conducted between 1100 and 1700 hrs local time (solar noon is at approximately 1300 hrs at Prudhoe Bay) to coincide with the time of day when maximal numbers of seals haul out and bask on the ice (Burns and Harbo 1972; Smith 1975; Finley 1979; Smith and Hammill 1981). A few transects were surveyed slightly before 1100 hrs or after 1700 hrs.

Surveys were flown north-south along lines of longitude, and were therefore generally oriented perpendicular to the coast. Possible transect lines were spaced at 3.6 km between centerlines (6 minutes of longitude). A subset of these was lines surveyed each year. In parts of some sectors in 1996, 1997 and 1999, lines were spaced at 1.8 km intervals (3 minutes of longitude). Transect lines extended from approximately the 3 m depth contour to 40+ km offshore. Only data collected within 40 km of the shoreward end of the transect were used in the final analyses.

Survey strip width was 0.41 km on each side of the aircraft, with a 134 m offset from the transect centerline. Observers maintained the appropriate strip width by using inclinometers to mark survey angles (9.5° and 34° below the horizon) on the window with a grease pencil and periodically checking the angles throughout the day.

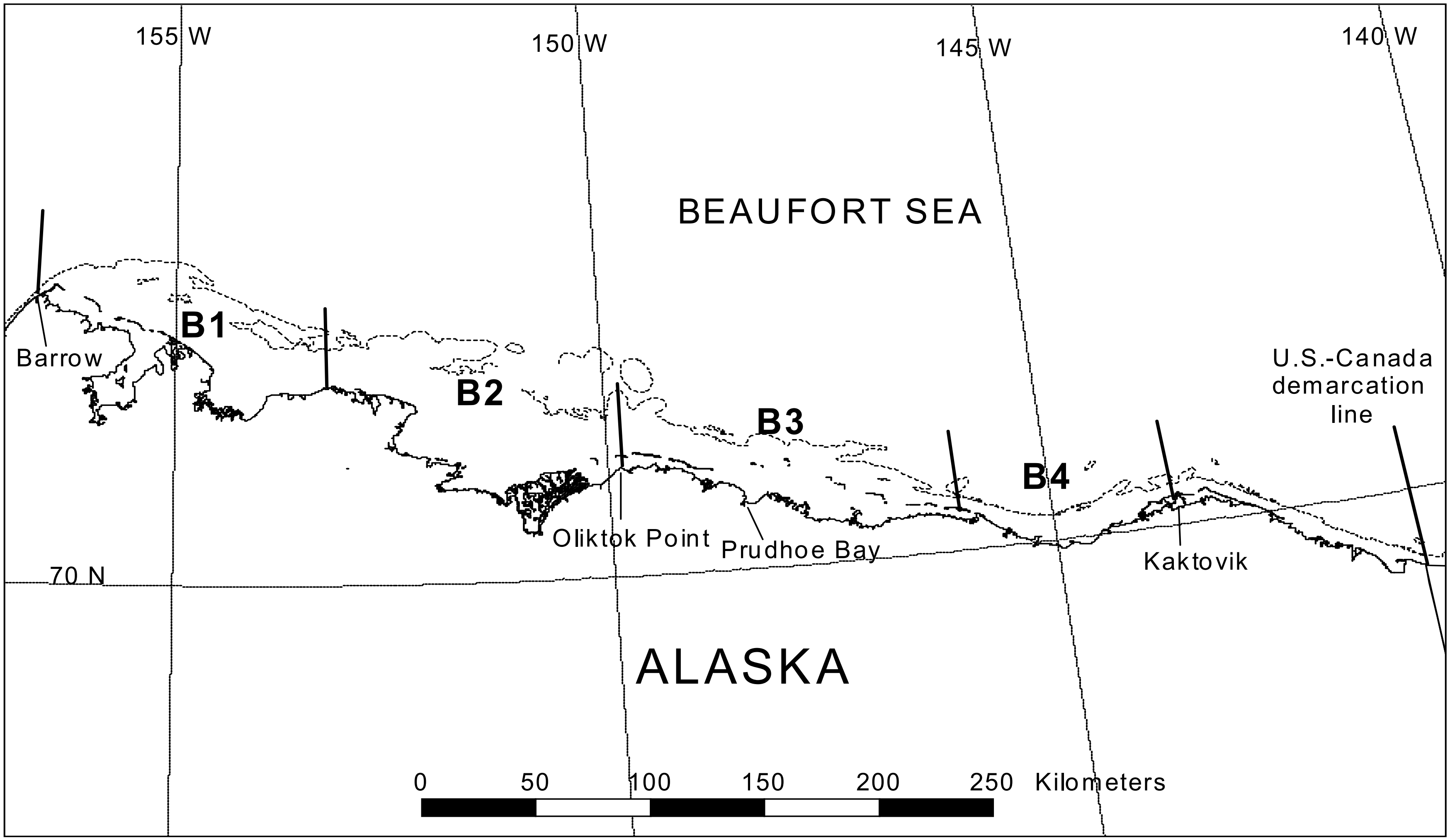


Figure 1. Map of the Beaufort Sea study area showing sectors used in analysis of ringed seal survey data. Dashed line is the 20 m depth contour.

All seals hauled out on the ice within the survey strip were identified to species (either ringed or bearded (*Erignathus barbatus*) seals), the number in each group was counted, and each was noted as being at a hole or by a crack. 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 spaced along cracks, the total number along a single crack (and within the survey strip) was recorded as a single group. Sightings of polar bears and polar bear tracks were noted as was any evidence of on-ice human activity such as ice roads or artificial islands.

Three ice variables were recorded: ice type (fast or pack), ice deformation (percent of the ice surface within the survey strip that was deformed by pressure ridges, ice jumbles, and snow drifts in 10% increments), and melt water (percent of the ice surface covered by standing water due to melting snow or river runoff in 10% increments). The delineation between fast and pack ice was indicated by a variety of features, including: a shear zone or large pressure ridge; the presence of open leads, broken ice and open water spots in the ice; or a large refrozen lead. In some areas the delineation between fast and pack ice was not clear from the aircraft, and the location of the edge was assigned later by examining NOAA ice maps made from satellite images taken during the same time period.

Weather conditions (cloud cover, air temperature, and wind speed) were recorded at the beginning of each transect and whenever conditions changed. Because there were no on-ice weather stations and available weather reports were based on conditions over land, we based our weather information on conditions measured at survey altitude. The absence of open water in fast ice and the melted condition of the snow precluded the inference of surface winds from indicators such as white caps or blowing snow. Surveys were not conducted, or were discontinued, if wind speed exceeded 36 km/hr for more than a short time, or if the ceiling was below the survey altitude of 91 m.

Surveys methods were generally similar in all years (see Frost *et al.* 1988, 1997, 1998, 1999b). Primary differences were the type of aircraft used, the type of navigation system, and the manner in which ice conditions and seal sightings were recorded.

The survey aircraft for 1985-1987 surveys was a Twin Otter equipped with oversized bubble windows, radar altimeter, and a Global Navigation System (GNS-500). A laptop computer was linked to the GNS-500 and radar altimeter, and was used to mark time, altitude, and latitude and longitude at the beginning and ending points of each transect, as well as at other points of interest.

In 1985-1987, three scientific personnel participated in each survey. A navigator recorded weather, ice conditions (averaged for survey strips on both sides of the aircraft), and navigation information directly into the computer. Observers on each side of the aircraft counted and recorded seals on paper datasheets. All data were recorded by 1-minute intervals. Count data were later entered into the computer database.

The survey aircraft for the 1996-1999 surveys was a twin-engine Aero Commander equipped with large bubble windows at all observation positions. On all flights two experienced primary observers counted seals using the strip transect protocols established during the 1985-1987 surveys. An additional observer seated behind the right primary observer counted using either strip transect protocols or line transect methods. Each observer was paired with a data recorder who entered all sightings directly into a laptop computer. Data recorders also entered information on ice and weather conditions, evidence of on-ice industrial activity, and sightings of other animals. For the 1990s surveys, ice characteristics were recorded independently on each side of the aircraft.

During the 1996-1999 surveys each recorder/observer pair had direct intercom communication, but was isolated from other observer/recorder pairs. A Global Positioning System unit interfaced with all three computers such that positions were recorded at start and end points of survey lines, each minute along a survey line, at each seal sighting, and at all changes in ice or weather conditions. All entries were checked and edited as necessary each evening following the survey flights. The approximate edge of the fast ice was reconciled by left and right side observers to ensure consistent coding of data.

Data Analysis

Data Sources

Results of the 1985-1987 surveys were reported in a final report for that project by Frost *et al.* (1988). A subset of the data collected and reported in 1985-1987 was reanalyzed and incorporated in this report. Data incorporated into the reanalysis included surveys conducted within 40 km of shore between Point Barrow and Kaktovik. We used only data from surveys flown at 91 m altitude in suitable weather conditions and before breakup of the shorefast ice had obviously begun. A single survey of each line was included in the dataset; temporal replicates to examine the effects of breakup were not included. These data were the same as the "selected" datasets that were used for density calculations in Frost *et al.* (1988).

In the 1990s survey effort, complete coverage of the Alaskan Beaufort Sea was obtained in 1997 and 1999, while in 1996 and 1998 only two of the four possible sectors (B3 and B4) were surveyed. All data collected during the 1990s surveys were used in the final analyses.

Bathymetry data from the National Ocean Service “Coastal Bathymetry of the Bering, Chukchi, and Beaufort Seas” were used to analyze seal density relative to water depth. The bathymetric contours began at 5 m and were then in 10 meter intervals out to 200 m.

Strip Transect Densities

The simple or “raw” density of observed ringed seals was calculated by dividing the number of seals counted within the strata of interest (sector or several sectors combined) by the area of that strata. To determine standard errors (SE) and confidence intervals (CI), we used a modified ratio estimator that considered seal counts and areas separately for each survey line. The area surveyed was computed from the latitude and longitude of the first and last survey points on each line. Areas were computed separately for each side of the plane, although these were very close in all cases. Mean density (R) and standard error ($S(R)^2$) were then computed for each sector using the Jackknife procedure (Manly 1991), and as shown below:

$$\hat{R} = \frac{\sum y_i}{\sum x_i}$$

$$S(\hat{R})^2 = \frac{\left[\sum\left(\frac{(y_i^2)}{x_i}\right) - \hat{R}\sum y_i\right]}{(n-1)\left(\sum x_i\right)}$$

where y_i = number of seals in line *i*, x_i = area of line *i*, and n = the number of lines used to compute the density.

Approximate 95% confidence intervals were computed as the mean density plus or minus the standard error multiplied by the appropriate t-statistic with n-1 degrees of freedom, where n is the number of survey lines in a sector.

Ringed seal density estimates were computed for all combinations of ice types (fast ice, pack ice, and all ice) and seals (seals at holes, seals at cracks, and all seals). For the fast and pack ice estimates, density within the portion of the strip covered by each of the two ice types was computed for each line.

Univariate Analyses

We tested the significance of observed differences in ringed seal densities relative to habitat, weather, and time of day using chi-square (χ^2) goodness-of-fit tests. Analyses included all seals (seals at holes and at cracks) on any ice (fast and pack) within 40 km of shore in sectors B3 and B4. Chi-square tests were conducted for each variable relative to the number of individual seals as well as to the number of seal groups (sightings) for every year and for all years combined.

Bonferroni-adjusted 95% confidence intervals were calculated by stratum for each variable for proportion of occurrence (the observed proportion of seals within a strata relative to total seals in all strata) and for observed seals as:

$100\ (1-\alpha/I)\%$,

where α=.05

I = number of strata (categories)

If the expected proportion for a stratum (based on survey area) was outside the confidence interval for the observed proportion, the difference was considered significant (Manly *et al.* 1993).

The Pearson statistic was used to test the null hypothesis that selection of strata (categories) was random for a particular variable. Rejection of the null hypothesis (large χ_P^2 compared to percentage points of the chi-square distribution) indicates that selection is not random, and that there is an association between the variable and strata selection.

Covariate Analysis (Poisson Regression)

Survey counts are indicators of the actual population of animals using a particular habitat, area, or site. The observed count is less than or equal to the true population and can be expressed as follows:

$C = N * p$

where C is the observed count, N is the population of interest, and p is the probability that an animal in N is included in C ($p \leq 1$). The inclusion probability, p, can take on a variety of forms including constants, probability functions (*e.g*., binomial), and functions of covariates such as date, time of day, or weather conditions. Excluding the unlikely event that p is a constant (a constant fraction of the population is counted on all occasions and under all circumstances), analyses involving C as a surrogate for N will be imprecise and often biased (Barker and Sauer 1992, 1995).

We used Poisson regression (McCullagh and Nelder 1989) to model the relationship between seal counts and environmental covariates. Poisson regression is appropriate for these analyses because the Poisson distribution is a positive discrete distribution in which only positive integers are acceptable values. This is more suitable for count data, especially where there are zero counts, than the normal distribution where non-integers and negative values also are permissible. This approach is very similar to that of Manly *et al.* (1993) except that they use logistic regression to predict the probability that an animal is present rather than predicting the number of animals present. We modeled habitat variables that might affect the distribution and local abundance of seals (*e.g*., ice deformation, water depth, distance from the fast ice edge and longitude) simultaneously with factors that likely affect only the availability of seals for counting (*e.g*., weather or time of day).

To model the effects of covariates, we used only data from sectors B3 and B4 within 40 km of the shoreward end of transects. These were the only sectors surveyed in all seven survey years. Only data from surveys conducted at the standard survey altitude of 91 m were included in the dataset. Replicate counts of transects conducted to examine date- or altitude-related differences in seal density were not included in the final dataset.

Data from the left and right sides of the aircraft were used as independent observations in the regression analyses. The transects were divided into segments based on each unique combination of survey variables. During the 1980s surveys, all habitat factors were determined for the entire survey strip (left and right combined) and only at 1-minute internals. Thus, for example, ice deformation was averaged for the left and right sides for an entire minute to produce an ice deformation value that was assigned to seal sightings from both observers. segments.

During the 1990s surveys, observations of ice deformation were recorded separately for left and right observers as they occurred instead of at 1-minute intervals. Changes in other variables were also noted as they occurred and location of all such changes were assigned through a direct computer link with the aircraft GPS. Thus, each survey transect was divided in segments based on ice type (pack or fast), ice deformation, air temperature, wind speed, and cloud cover. When any of these variables changed, a new segment was defined such that each segment was uniform with respect to the explanatory variables. Data from the left and right side observers were treated as separate transects since ice conditions differed between left and right sides. This resulted in segments of differing sizes on the left and right sides. For both the 1980s and 1990s, water depth (starting with depths <5 m then in 10 m intervals) and distance from the fast ice edge (in 2 km intervals) were added to the datasets prior to creating segments. Because the original data in the 1980s was summarized at 1 minute intervals (although changes in depth and distance from the fast ice edge did not always match these intervals), there were generally fewer segments per transect in the 1980s than the 1990s. The number of seals observed and the area surveyed (segment length in km multiplied by strip width of 0.41 km) were determined for each segment.

The response variable in the regression analysis was the number of seals in a segment. The explanatory variables were year, ice type (pack or fast), percent ice deformation, distance from the fast ice edge, water depth, longitude, time of day, temperature, wind speed, and percent cloud cover. Water depth, longitude, and distance from the fast ice edge were included to account for large-scale patterns of seal abundance that were independent of local ice or weather conditions. Time was included to examine temporal changes in visibility. Year*longitude and year*distance-from-ice-edge interactions were included to account for annual large-scale changes in seal sightings that were unrelated to the other habitat variables in the model. These changes in sighting distributions could be due to changes among years in the distribution of the population or changes in the distribution of sighting conditions.

Although date has a strong effect on seal counts (see Frost *et al.* 1988), our 1996-1999 surveys did not include temporal replicates that are required to investigate this question, and date was therefore not included as an explanatory variable. We also chose not to include distance from shore in our analysis. We used depth in lieu of distance from shore because it is likely to influence factors affecting ringed seals such as prey availability and ice characteristics. Distance from shore, except as a reflection of water depth, is less likely to directly affect seal density. Using both in the same analysis caused problems with collinearity.

The ln (area) of each segment was included in the regressions as an offset variable (Agresti 1990) to account for the fact that, all other variables being equal, larger segments have more seals than smaller segments (adjusts analyses to a density basis). Quadratic terms and interactions were included for some variables or combinations of variables when we believed that relationships were not linear (on the log scale).

Based on preliminary analyses, the assumption of a Poisson distribution did not 'fit' the data well. We made two adjustments to the analyses to adjust for this lack of fit . First we omitted segments <0.01 km^2. These tiny segments were artifacts of combining the survey data with depth and distance-from-fast-ice-edge bands that were not part of the original data. When any seals were in these segments, very high densities resulted that had undue influence on the regression results. To account for remaining lack of fit, probably due to the presence of large groups of seals which would be unexpected with the small mean densities we observed, we adjusted tests and standard errors using the Pearson chi-square statistic as an overdispersion parameter (*i.e.*, quasi-likelihood approach, Agresti 1990). This results in somewhat larger standard errors and *P*-values than those computed without the adjustment.

To account for possible spatial correlation in the data (*i.e.*, residuals from the regression for segments close together were more similar than for residuals from segments far apart), we included a spatial component in the variance structure. We used a spatial exponential function with a nugget effect to model the dependency in the residuals based on the distance between segments within a survey line (Littell *et al.* 1996). Survey lines were treated as a random effect. We assumed independence for data from separate survey lines and years.

All variables (including selected quadratic terms and interactions) were included in an initial model. Final regression models were then determined using a backward selection process. Terms were dropped from consideration one at-a-time based on the *P*-values from the Wald *F* statistics; those with the largest *P*-values were dropped first. This continued until all variables had *P*-values $<\sim 0.05$. Continuous variables with *P*-values >0.05 were retained in the model if they were contained in a continuous by categorical interaction (*e.g.*, longitude*year) that had a small *P*-value.

Power Analysis

We estimated statistical power for detecting change in the size of the ringed seal population using simulation. Power is the probability of rejecting the null hypothesis of a statistical test. In this case, the null hypothesis was that the linear year effect from the Poisson regression of the ringed seal counts differed from zero. We used simulations to account for the effect of other variables that affected ringed seal counts (see results of the Poisson regression analysis). We estimated power for two levels of effort (50 or 65 survey lines), 5 or 10 years of surveys, and various rates of population change (-0.2, -0.15, -0.1, -0.05, 0.1, 0.15, 0.2). Simulations for the power analysis are based on the results of a regression using data from 1996-1999 for sectors B3 and B4 and included only seals counted on fast ice.

To account for varying conditions in each simulated year of data, we retained the data structure, except for the counts, for the original four years of data (1996-1999). For each year of simulated data, we selected one of the original years at random (with replacement). We then randomly selected transects, with replacement, from that year's data. For the selected transects, we retained the original segments and covariates, including segment area, except that we randomly assigned longitude within the range for the study area and we systematically added the year effect (*i.e.*, trend) at a rate as defined previously. This procedure retained in the simulated data the interrelationships among the covariates and the year to year variation in conditions of the original data. Based on the covariates and size of each transect segment, we used the estimated regression coefficients and overdispersion factor from our original Poisson regression to obtain a mean and variance for generating a gamma random variable, which was then used as the mean count for that segment. The simulated 'count' for each segment was then generated using a Poisson random number generator with associated gamma mean for that segment. Gamma distributions are positive and continuous, unlike Poisson variables that only take on integer values. Because they are continuous and positive, gamma random variables are useful for modeling the means of count data (although counts are integers, the means need not be). When the means are small, such as with our data, gamma distributions are asymmetric with most values near zero, but having a long tail to the right. This mimics the situation in the original data. Data were generated independently for each segment with no spatial correlation other than that induced by nearby segments often having similar values of covariates.

When the desired number of years of simulated data were generated, we estimated trend, and hence power, in two ways, one using the Poisson model and the other using simple linear regression to regress the natural log of the yearly total count of seals against year. In the Poisson case, we estimated the regression coefficients using the final Poisson regression model we obtained from the analysis of our original data (the model we used to generate the data). Even though there was little evidence of spatial correlation in the original regression, we included estimation of spatial correlation in the regressions for the simulated data to maintain consistency with the original analysis. For each regression method, we tallied whether the year effect was significant ($P<0.05$) and whether the estimate was positive or negative. This procedure was repeated 201 times. The estimated power is the proportion of these 201 replicates with significant year effects. In some cases a significant trend is estimated when the true trend has the opposite sign (*e.g.*, significant negative trend estimate when the true trend is positive). Because of this, we graphed the power separately for significant estimated positive and negative trends so that all power estimates are one tailed.

RESULTS

Survey Effort

During the 1985-1987 surveys all four sectors of the Beaufort Sea study area (Figure 1) were surveyed in every year. The dataset selected for this analysis included 223 transect lines that covered 7,156 km^2 of ice habitat (Table 1). Annually, we surveyed 71-80 transects covering 2,271-2,524 km^2. Total annual ringed seal counts were 2,189 in 1985, 2,605 in 1986 and 3,867 in 1987 (Appendices A and B). The proportion of the total survey area comprised by fast ice varied from 98% (1985) to 68% (1987).

Table 1. Area surveyed and number of seals counted on fast and pack ice within 40 km of shore during aerial surveys conducted in the Alaskan Beaufort Sea, 1985-1987 and 1996-1999.

Year/Sector	Fast Ice		Pack Ice		All Ice	
(# transects)	Area (km^2)	# Seals	Area (km^2)	# Seals	Area (km^2)	# Seals
1985						
B1 (n=10)	303.2	252	3.0	1	306.2	253
B2 (n=14)	447.9	399	-	-	447.9	399
B3 (n=34)	1117.2	1299	1.6	0	1118.8	1299
B4 (n=14)	359.0	214	39.5	24	398.5	238
All sectors	2227.3	2164	44.1	25	2271.4	2189
1986						
B1 (n=20)	549.4	348	114.4	9	663.8	357
B2 (n=21)	696.2	820	-	-	696.2	820
B3 (n=18)	519.9	668	80.6	105	600.5	773
B4 (n=12)	197.7	534	202.5	121	400.2	655
All sectors	1963.2	2370	397.5	235	2360.7	2605
1987						
B1 (n=21)	510.5	497	40.2	33	550.6	530
B2 (n=21)	649.8	920	53.4	61	703.2	981
B3 (n=23)	377.6	909	388.9	571	766.5	1480
B4 (n=15)	176.1	528	327.5	348	503.6	876
All sectors	1714.0	2854	810.0	1013	2524.0	3867
1996						
B1 (n=0)	-	-	-	-	-	-
B2 (n=3)	67.5	51	25.1	51	92.6	102
B3 (n=43)	655.2	355	658.4	560	1313.6	915
B4 (n=18)	131.4	91	423.3	504	554.7	595
All sectors	854.1	497	1106.8	1115	1960.9	1612
1997						
B1 (n=30)	809.2	313	136.6	9	945.9	322
B2 (n=21)	640.9	388	-	-	640.9	388
B3 (n=57)	1, 491.2	1152	259.2	250	1, 750.5	1402
B4 (n=31)	582.3	732	368.2	585	950.5	1317
All sectors	3523.6	2585	764.1	844	4287.8	3429
1998						
B1 (n=0)	-	-	-	-	-	-
B2 (n=0)	-	-	-	-	-	-
B3 (n=28)	276.5	209	552.7	465	829.2	674
B4 (n=12)	131.6	179	236.8	258	368.4	437
All sectors	408.1	388	789.5	723	1197.6	1111
1999						
B1 (n= 15)	253.6	194	175.9	72	429.5	266
B2 (n=20)	338.5	234	281.3	191	619.8	425
B3 (n=57)	918.7	803	833.7	886	1752.4	1689
B4 (n=31)	313.5	604	581.5	812	895.0	1416
All sectors	1824.3	1835	1872.4	1961	3696.7	3796

The 1990s surveys were originally planned to include abbreviated first-year (1996) coverage from Oliktok to Kaktovik, followed by two years (1997 and 1998) of broader surveys extending from Barrow to Kaktovik. Due to early breakup and poor ice conditions, the 1998 survey included only the Oliktok-Kaktovik region, and an additional year of surveys extending from Barrow to Kaktovik was added in 1999 (Appendices A and B). The dataset for the 1996-1999 surveys included 366 transects and 11,144 km^2 of ice habitat (Table 1). Annually, we surveyed 40-139 transects covering 1,198-4,288 km^2. Total annual ringed seal counts were: 1996 - 1,612 per 1,961 km^2; 1997 - 3,429 per 4,288 km^2; 1998 - 1,111 per 1,198 km^2; and 1998 - 3,796 per 3,697 km^2. Fast ice made up 34%-82% of the total survey area.

Ringed Seal Distribution and Abundance

Observed Densities and Group Sizes

Only sectors B3 and B4, which were surveyed in all seven years, were included in the complete data analyses. However, observed density estimates and standard errors for all sectors and all years are provided in Appendix A, and maps showing all transect lines and ringed seal sightings are provided in Appendix B.

Ringed seals were broadly distributed throughout the central Beaufort Sea study area in all years (Figures 2-8). Observed densities for fast ice and pack ice combined in the 1980s ranged from 1.01 seals/km^2 in 1985 to 1.85 seals/km^2 in 1987 (Table 2). Observed densities for the 1990s were similar to 1985 and somewhat lower than in 1986 and 1987, ranging from 0.81 seals/km^2 in 1996 to 1.17 seals/km^2 in 1999. Total estimated densities were substantially higher on fast ice than pack ice during the 1980s surveys. The differences between pack and fast ice were not consistent for the 1990s surveys. In two years, pack ice densities were much greater than fast ice densities, and in the other two years the densities were similar. Except for 1987, more seals were seen at holes than at cracks on fast ice (Figure 9). On pack ice the relative proportions of seals at holes and cracks was more variable.

The average group size of seals counted at holes was quite consistent across all survey years, ranging from 1.34-1.67 seals/group for all ice combined (Table 3). Average group size for seals at cracks was generally double or triple the average group size at holes, and was considerably more variable (3.38-5.71 seals/group). For most years, average group size was largest for seals along cracks in fast ice.

Factors Affecting Seal Densities

Univariate chi-square analyses were done to examine the relationship between ringed seal density and water depth, distance from the fast ice edge, ice deformation, and longitude, for each year and for all years combined (Table 4 and Appendix C).

Poisson regression models were separately constructed from ringed seal survey data for 1985-1987, 1996-1999, and for all years combined (Table 5). Regression coefficients for variables that were retained in the final models are shown in Table 6.

Depth - Univariate analysis indicated that water depth had a significant effect on observed ringed seal densities in each survey year, and for all years combined ($P<0.001$). In the 1980s, observed densities were lowest in water $\leq$ 5 m deep (0.30-0.93 seals/km^2) and >35 m deep (0.42-0.48 seals/km^2) and highest in >5-25 m water depths (1.13-2.79 seals/km^2; Figure 10a).

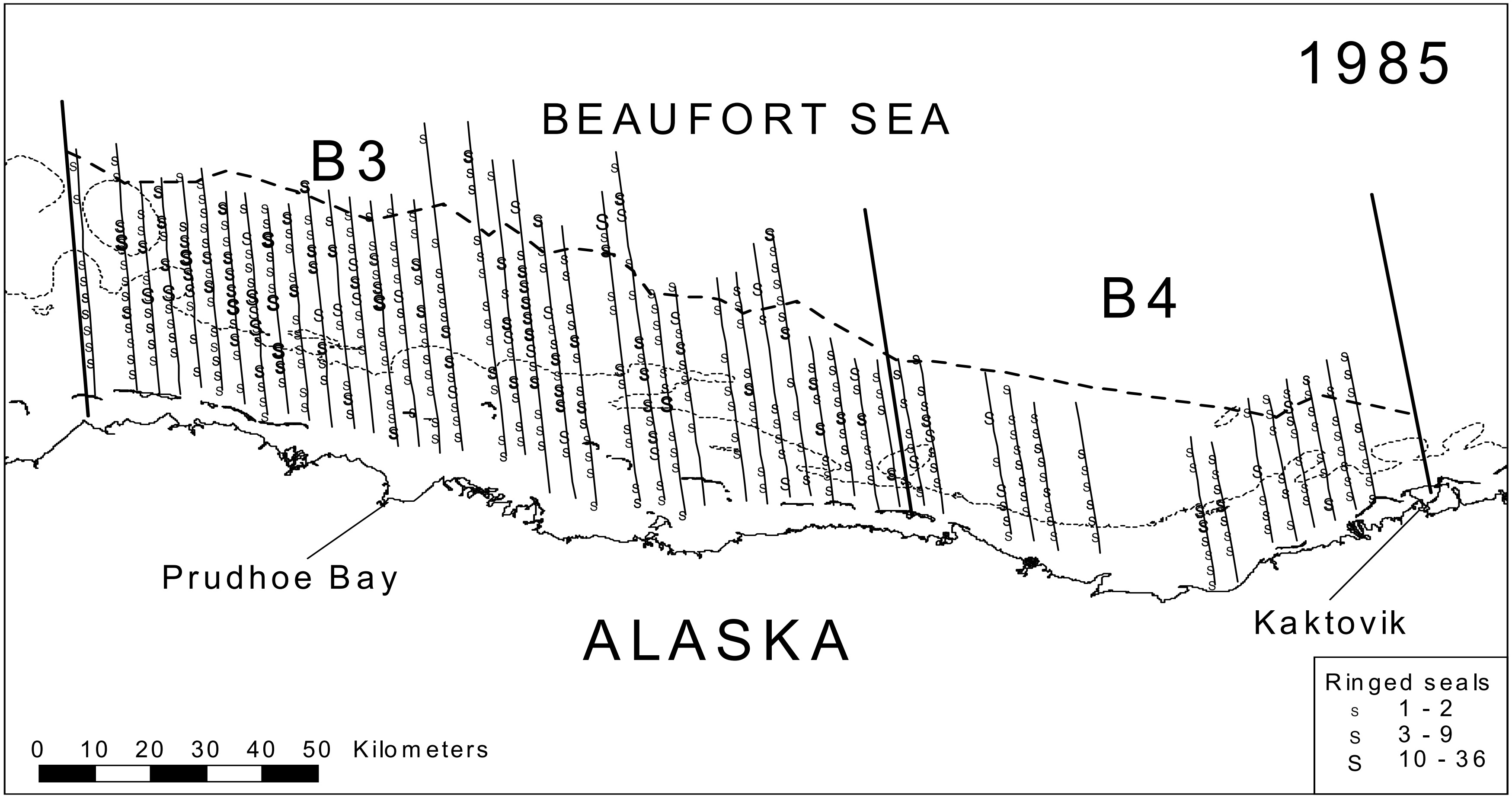


Figure 2. Map of the Beaufort Sea study area showing sightings of ringed seals made during 9-12 June 1985. Thick dashed line is the approximate edge of shorefast ice. Thin dashed line is the 20m depth contour.

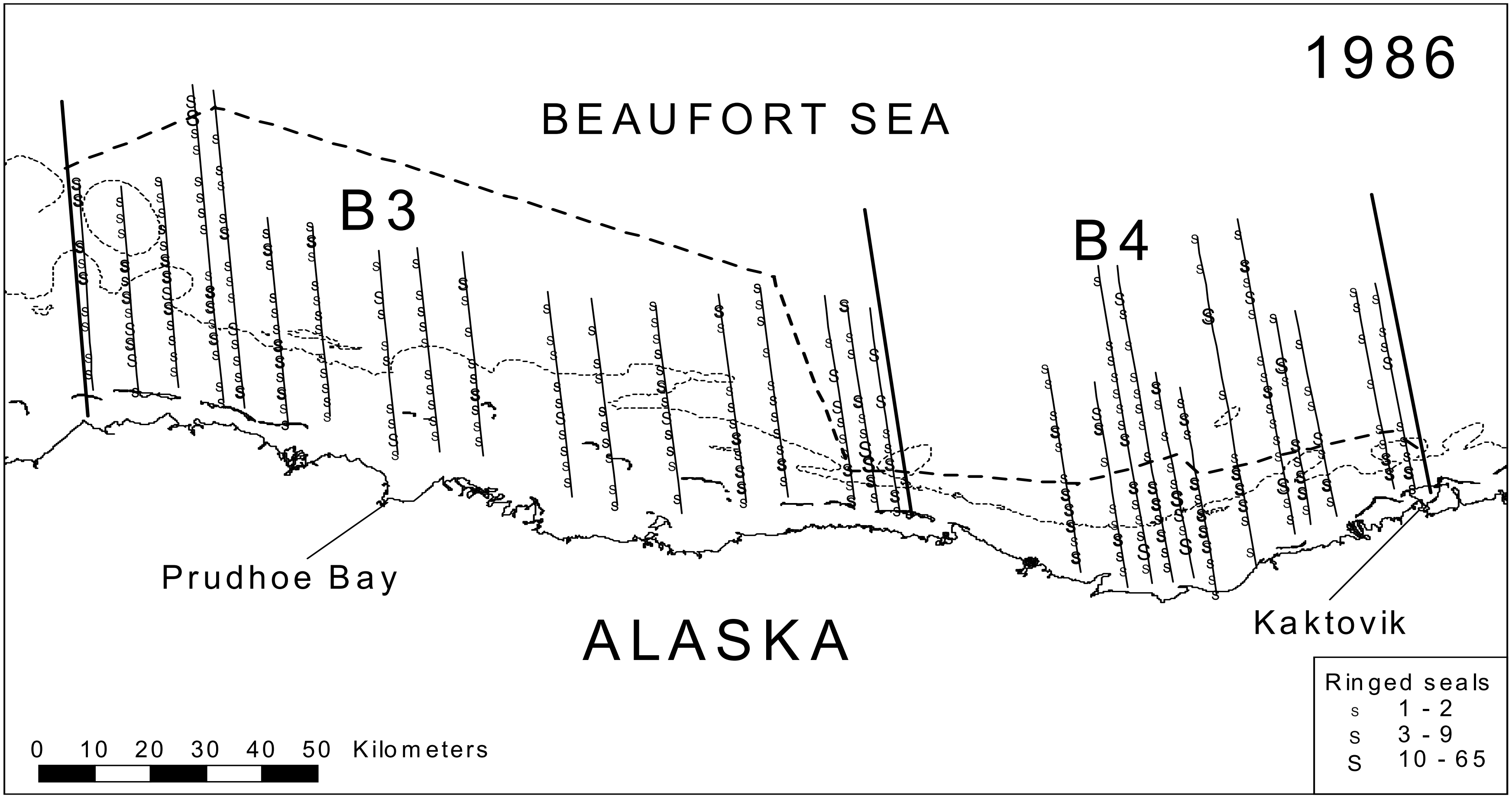


Figure 3. Map of the Beaufort Sea study area showing sightings of ringed seals made during 31 May-12 June 1986. Thick dashed line is the approximate edge of shorefast ice. Thin dashed line is the 20m depth contour.

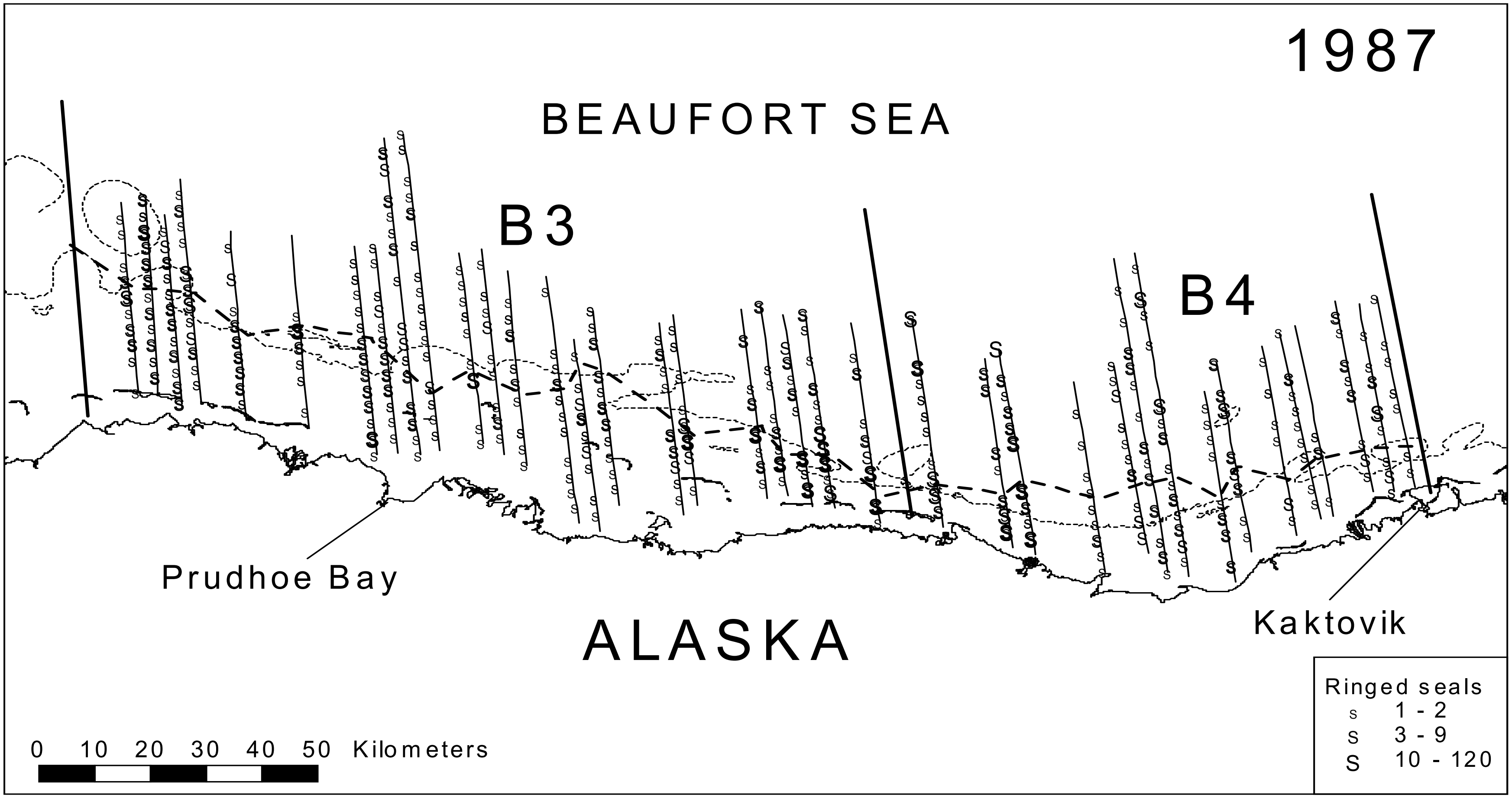


Figure 4. Map of the Beaufort Sea study area showing sightings of ringed seals made during 6-7 June 1987. Thick dashed line is the approximate edge of shorefast ice. Thin dashed line is the 20m depth contour.

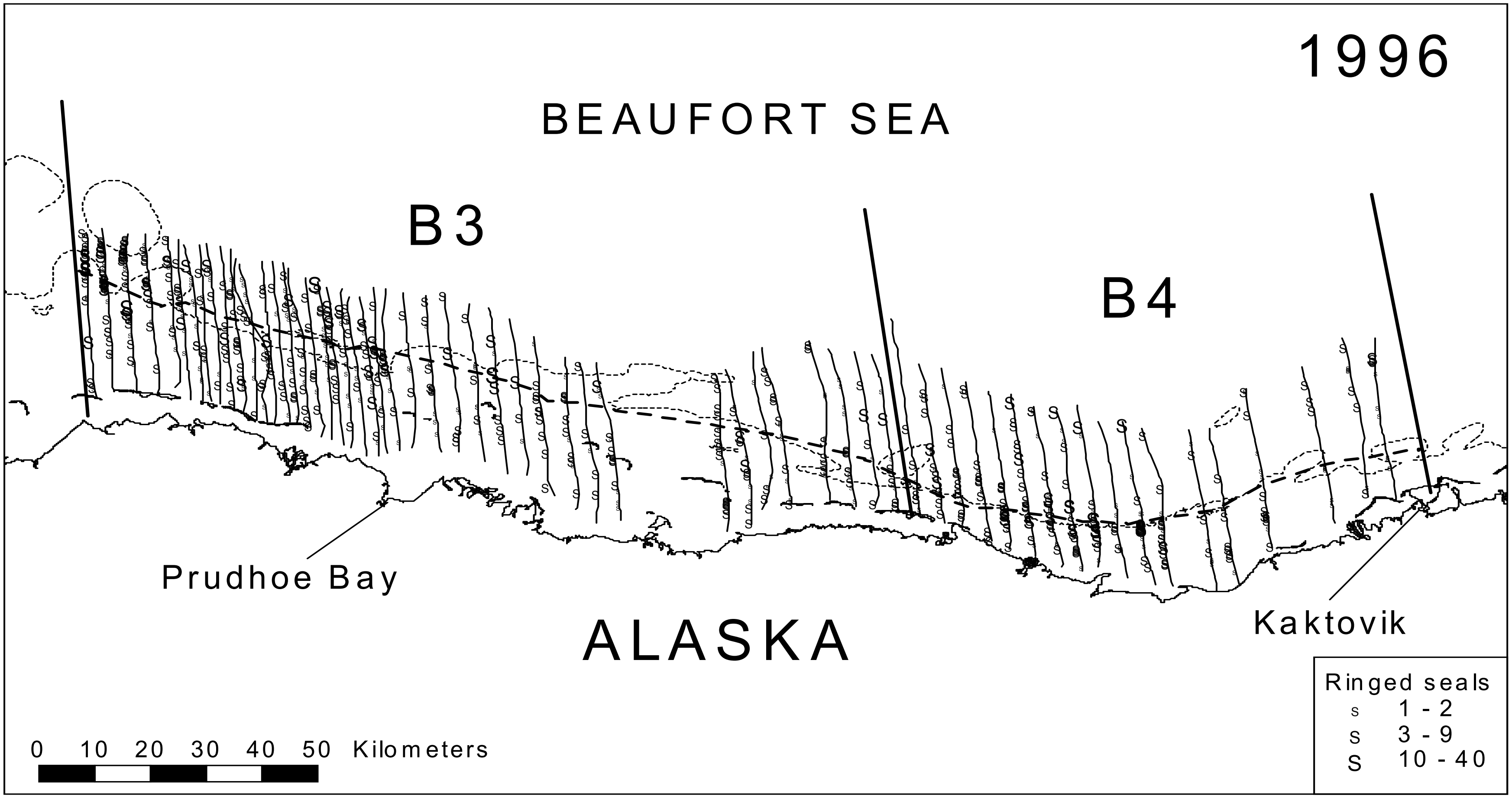


Figure 5. Map of the Beaufort Sea study area showing sightings of ringed seals made during 29-31 May 1996. Thick dashed line is the approximate edge of shorefast ice. Thin dashed line is the 20m depth contour.

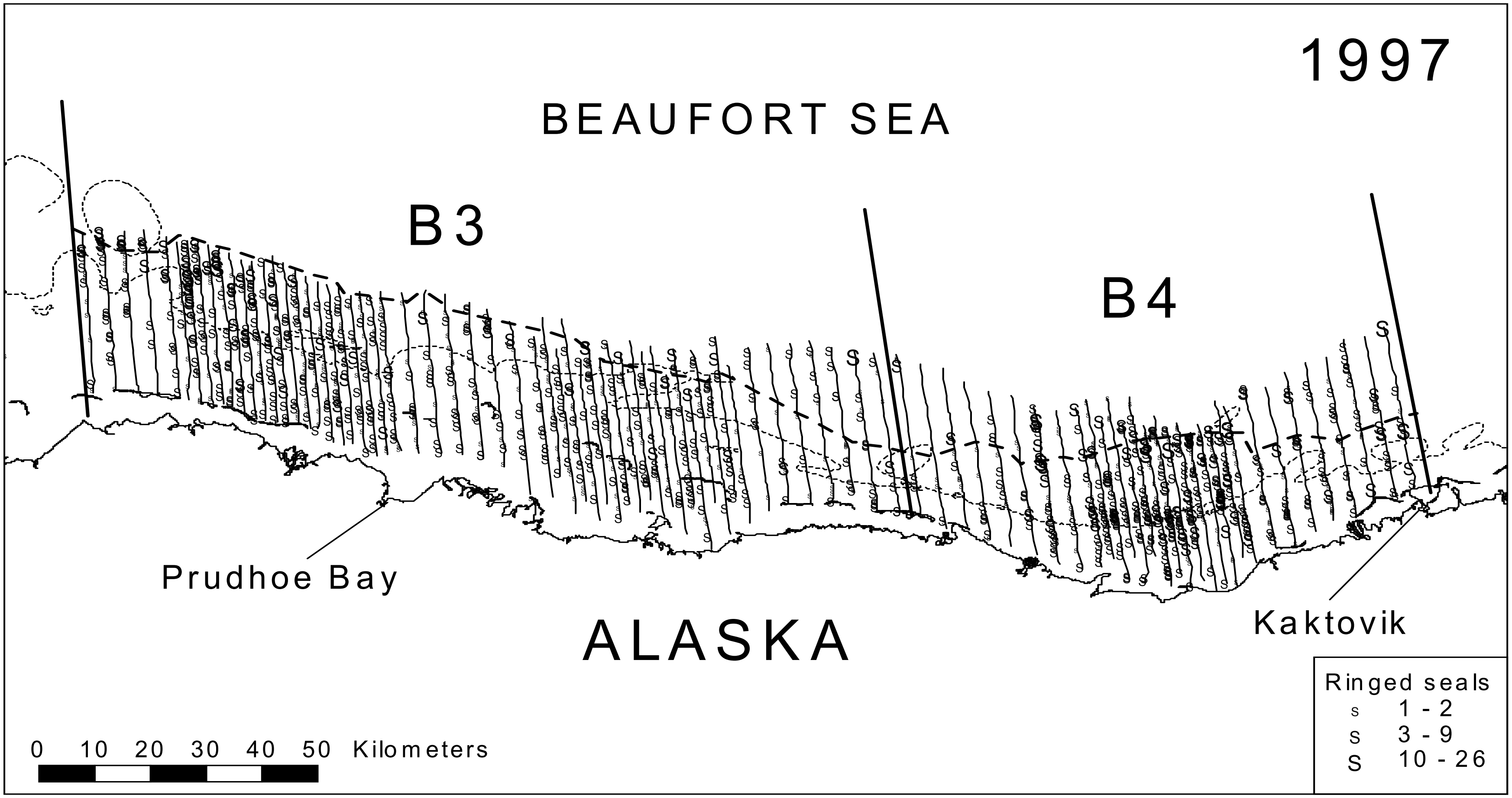


Figure 6. Map of the Beaufort Sea study area showing sightings of ringed seals made during 27 May-1 June 1997. Thick dashed line is the approximate edge of shorefast ice. Thin dashed line is the 20m depth contour.

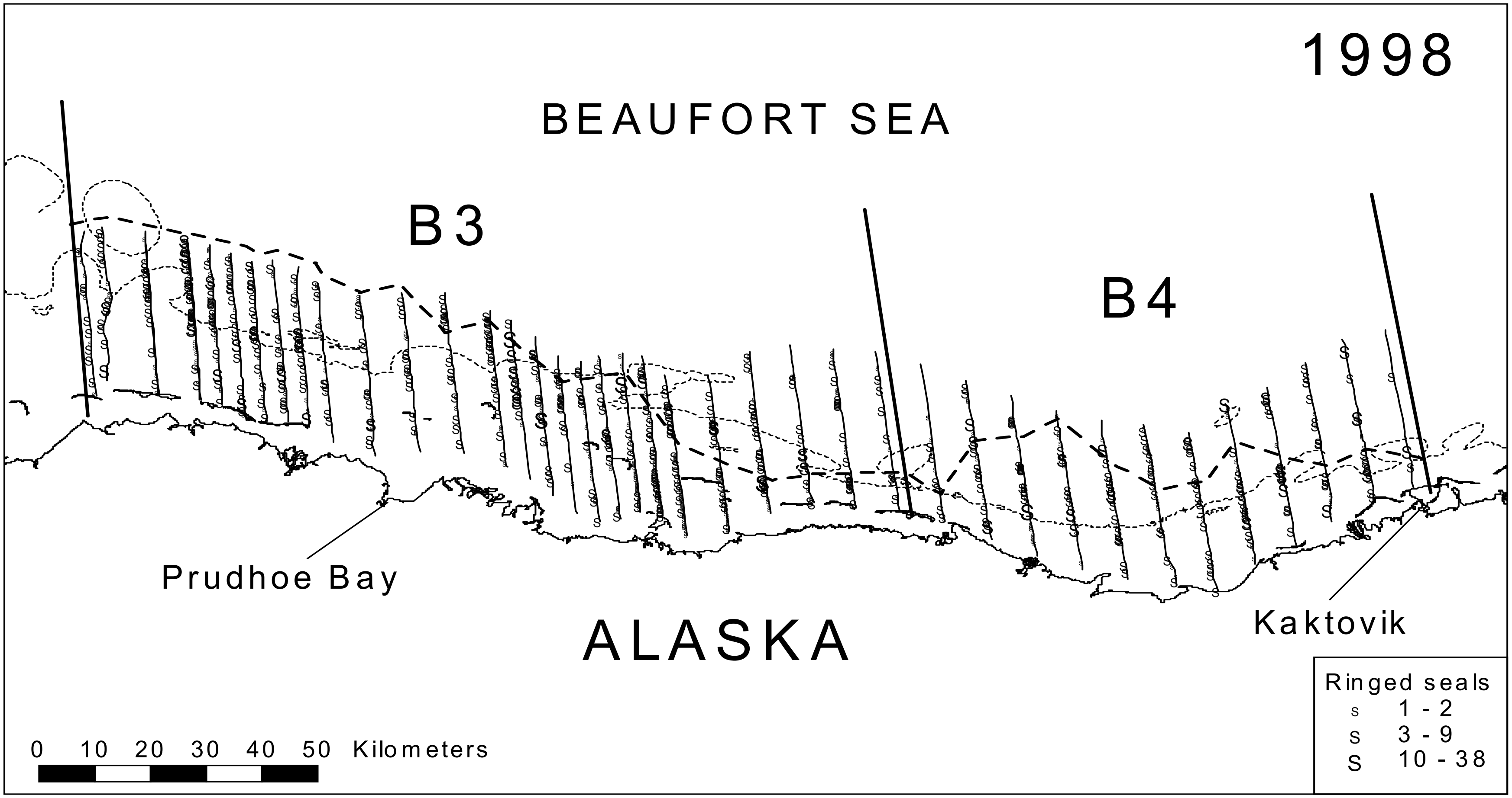


Figure 7. Map of the Beaufort Sea study area showing sightings of ringed seals made during 27-28 May 1998. Thick dashed line is the approximate edge of shorefast ice. Thin dashed line is the 20m depth contour.

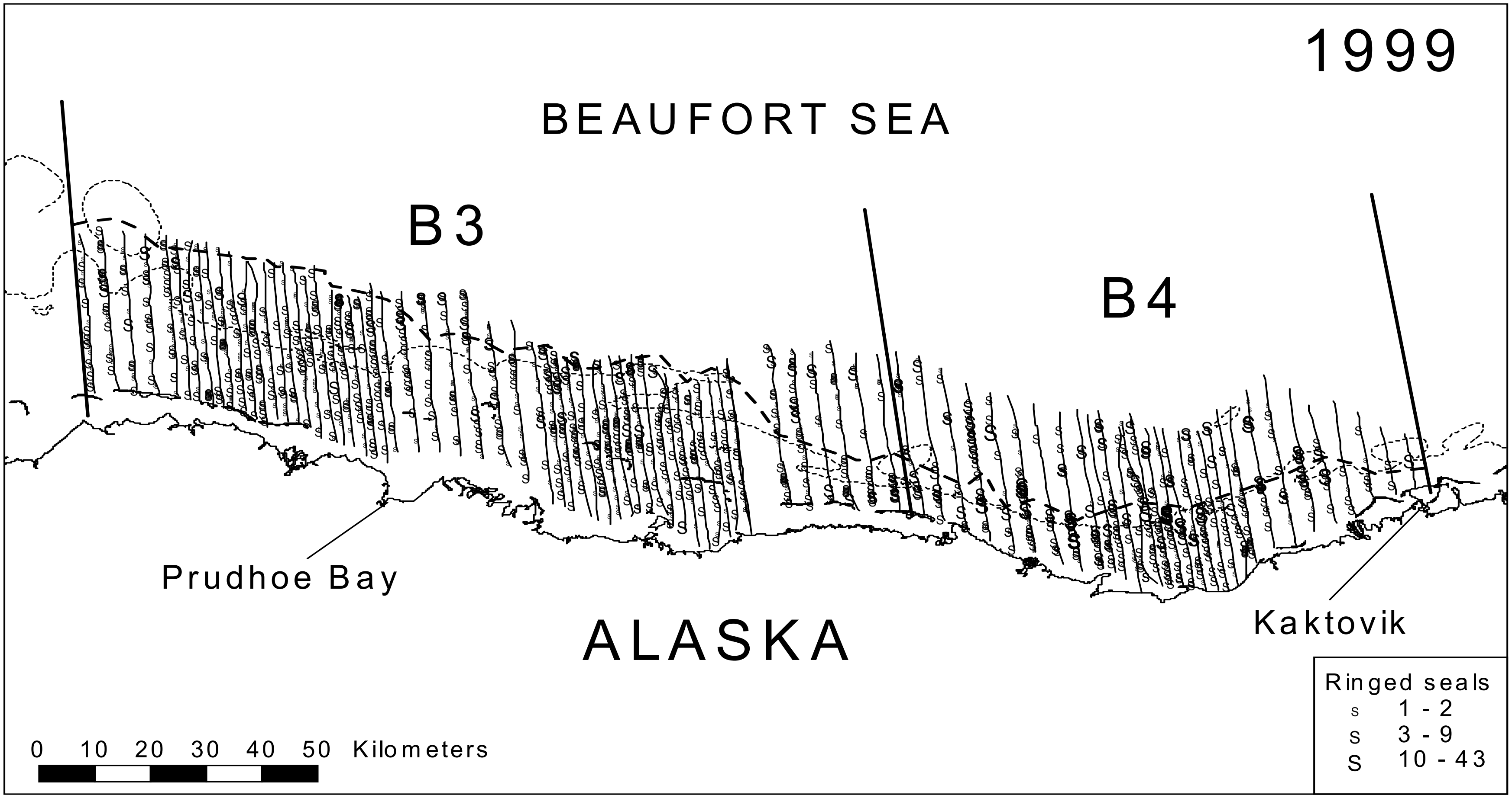


Figure 8. Map of the Beaufort Sea study area showing sightings of ringed seals made during 29 May-4 June 1999. Thick dashed line is the approximate edge of shorefast ice. Thin dashed line is the 20m depth contour.

Table 2. Densities of ringed seals at holes and at cracks on fast ice, pack ice, and all ice combined within 40 km of shore in the central Beaufort Sea of Alaska (149º50’ W to 143º40’ W), based on aerial surveys conducted in 1985-1987 and 1996-1999.

		Fast Ice			Pack Ice			All Ice Combined		
		At Holes	At Cracks	All Seals	At Holes	At Cracks	All Seals	At Holes	At Cracks	All Seals
1985	Seals/ km^2	0.54	0.49	1.02	0.44	0.15	0.58	0.54	0.48	1.01
	SE	0.03	0.10	0.11	0.10	0.05	0.14	0.03	0.10	0.11
	LCL	0.48	0.32	0.84	0.23	0.04	0.30	0.48	0.32	0.83
	UCL	0.59	0.65	1.21	0.65	0.25	0.87	0.59	0.64	1.20
1986	Seals/ km^2	1.19	0.49	1.67	0.22	0.58	0.80	0.91	0.51	1.43
	SE	0.08	0.22	0.20	0.03	0.14	0.14	0.08	0.16	0.14
	LCL	1.04	0.12	1.33	0.16	0.33	0.55	0.78	0.25	1.19
	UCL	1.33	0.86	2.02	0.28	0.83	1.05	1.05	0.78	1.66
1987	Seals/ km^2	1.06	1.53	2.60	0.44	0.85	1.28	0.71	1.15	1.85
	SE	0.08	0.52	0.53	0.06	0.14	0.18	0.06	0.23	0.24
	LCL	0.92	0.66	1.69	0.33	0.61	0.98	0.60	0.76	1.45
	UCL	1.20	2.41	3.50	0.54	1.09	1.58	0.82	1.54	2.26
1996	Seals/ km^2	0.51	0.06	0.57	0.60	0.38	0.98	0.56	0.24	0.81
	SE	0.04	0.03	0.05	0.11	0.06	0.13	0.06	0.05	0.08
	LCL	0.44	0.01	0.48	0.42	0.27	0.76	0.46	0.17	0.67
	UCL	0.58	0.10	0.65	0.79	0.48	1.21	0.67	0.32	0.95
1997	Seals/ km^2	0.89	0.02	0.91	0.47	0.86	1.33	0.79	0.21	1.01
	SE	0.06	0.01	0.06	0.08	0.18	0.22	0.06	0.04	0.08
	LCL	0.79	0.00	0.80	0.33	0.57	0.96	0.70	0.14	0.88
	UCL	0.99	0.03	1.01	0.61	1.15	1.70	0.89	0.28	1.14
1998	Seals/ km^2	0.65	0.30	0.95	0.53	0.38	0.92	0.58	0.35	0.93
	SE	0.08	0.19	0.21	0.06	0.06	0.08	0.05	0.07	0.09
	LCL	0.52	-0.03	0.60	0.43	0.28	0.78	0.49	0.24	0.78
	UCL	0.78	0.62	1.30	0.64	0.48	1.05	0.66	0.47	1.07
1999	Seals/ km^2	0.92	0.23	1.14	0.69	0.51	1.20	0.80	0.38	1.17
	SE	0.07	0.08	0.11	0.06	0.06	0.09	0.05	0.05	0.07
	LCL	0.80	0.09	0.96	0.60	0.40	1.05	0.72	0.29	1.05
	UCL	1.03	0.36	1.32	0.79	0.61	1.35	0.87	0.46	1.30

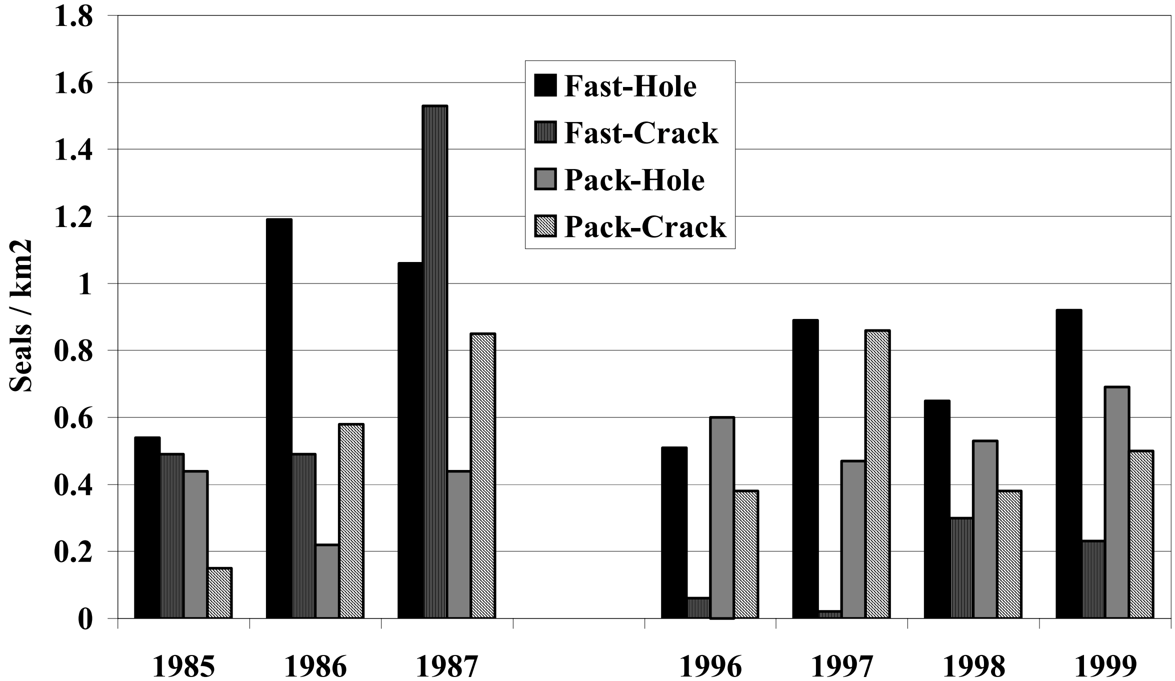


Figure 9. Estimated densities of ringed seals at holes and cracks on fast and pack ice within 40 km of shore based on aerial surveys in the central Beaufort Sea, 1985-1987 and 1996-1999.

Table 3. Number of groups and average group size of observed ringed seals based on aerial surveys in the central Beaufort Sea of Alaska (149º50' W to 143º40' W) conducted in 1985-1987 and 1996-1999.

	Fast Ice			Pack Ice			All Ice		
	Hole	Crack	All	Hole	Crack	All	Hole	Crack	All
1985									
Number of seals	796	717	1513	18	6	24	814	723	1537
Number of groups	591	199	790	18	6	24	609	205	814
Average group size	1.35	3.60	1.92	1.00	1.00	1.00	1.34	3.53	1.89
1986									
Number of seals	852	350	1202	62	164	226	914	514	1428
Number of groups	577	52	629	45	38	83	622	90	712
Average group size	1.48	6.73	1.91	1.38	4.32	2.72	1.47	5.71	2.01
1987									
Number of seals	588	849	1437	313	606	919	901	1455	2356
Number of groups	358	115	473	220	158	378	578	273	851
Average group size	1.64	7.38	3.04	1.42	3.84	2.43	1.56	5.33	2.77
1996									
Number of seals	401	45	446	654	410	1064	1055	455	1510
Number of groups	285	22	307	347	112	459	632	134	766
Average group size	1.41	2.05	1.45	1.88	3.66	2.32	1.67	3.40	1.97
1997									
Number of seals	1847	37	1884	297	538	835	2144	575	2719
Number of groups	1241	7	1248	184	125	309	1425	132	1557
Average group size	1.49	5.29	1.51	1.61	4.30	2.70	1.50	4.36	1.75
1998									
Number of seals	267	121	388	422	301	723	689	422	1111
Number of groups	179	17	196	275	108	383	454	125	579
Average group size	1.49	7.12	1.98	1.53	2.79	1.89	1.52	3.38	1.92
1999									
Number of seals	1129	278	1407	980	718	1698	2109	996	3105
Number of groups	842	45	887	661	178	839	1503	223	1726
Average group size	1.34	6.18	1.59	1.48	4.03	2.02	1.40	4.47	1.80

Table 4. Summary of chi-square analyses of observed ringed seal density relative to habitat variables affecting distribution and abundance in the central Beaufort Sea of Alaska.

Variable	Chi-square	*df*	*P*-value	Combined
Water Depth				
1985	140.56	4	<0.001	
1986	263.92	6	<0.001	
1987	631.11	6	<0.001	
1996	154.10	4	<0.001	
1997	917.10	5	<0.001	
1998	72.01	5	<0.001	
1999	110.77	4	<0.001	
All	730.97	6		<0.001
Distance from Fast Ice Edge				
1985	143.41	12	<0.001	
1986	405.12	15	<0.001	
1987	807.68	15	<0.001	
1996	416.17	13	<0.001	
1997	294.83	13	<0.001	
1998	81.02	11	<0.001	
1999	409.32	13	<0.001	
All-Fast	814.21	15		<0.001
Ice deformation				
1985	247.03	5	<0.001	
1986	212.59	5	<0.001	
1987	333.09	5	<0.001	
1996	69.27	5	<0.001	
1997	195.34	5	<0.001	
1998	15.03	5	0.01	
1999	108.58	5	<0.001	
All	469.38	5		<0.001
Longitude				
1985	216.58	6	<0.001	
1986	73.42	6	<0.001	
1987	769.48	6	<0.001	
1996	183.21	6	<0.001	
1997	464.61	6	<0.001	
1998	73.27	6	<0.001	
1999	266.80	6	<0.001	
All	584.47	6		<0.001

Table 5. Terms initially included in regression models of ringed seal densities in the central Beaufort Sea of Alaska. Those with *P*-values < ~0.05 were retained in the final model as were lower order terms that were included in higher order categorical interactions (e.g., dist*yr). Ice type and year were retained in all models. Entries in bold type were retained in the final model. Sample size (n) is the number of transect segments used in the analysis.

	1980s (n=6,286)			1990s (n=16,553)			All (n=23,839)		
Variable	F	num df	*P*	F	num df	*P*	F	num df	*P*
ice type	**13.89**	**2**	**<0.001**	**5.16**	**2**	**0.006**	**8.08**	**2**	**<0.001**
year	**7.41**	**1**	**0.007**	**0.72**	**1**	**0.397**	**41.18**	**1**	**<0.001**
year*icetype	0.00	1	0.952	**9.96**	**1**	**0.002**	**4.31**	**1**	**0.038**
dist-ice edge	0.87	1	0.351	0.83	1	0.370	**13.91**	**1**	**<0.001**
$dist^2$	**11.14**	**1**	**0.001**	**26.08**	**1**	**<0.001**	**25.20**	**1**	**<0.001**
dist*yr	1.08	2	0.339	1.00	3	0.392	**2.14**	**6**	**0.046**
$dist^2$*yr	**5.04**	**2**	**0.007**	**4.74**	**3**	**0.003**	**3.68**	**6**	**0.001**
longitude	**0.14**	**1**	**0.713**	**17.86**	**1**	**<0.001**	**11.06**	**1**	**0.001**
$long^2$	**7.80**	**1**	**0.005**	3.59	1	0.058	**0.77**	**1**	**0.380**
long*yr	**5.30**	**2**	**0.005**	1.63	3	0.180	**5.11**	**6**	**<0.001**
$long^2$*yr	**3.53**	**2**	**0.029**	2.05	3	0.127	**4.01**	**6**	**0.001**
icedef	**17.19**	**1**	**<0001**	**52.51**	**1**	**<0.001**	**93.74**	**1**	**<0.001**
$icedef^2$	0.01	1	0.937	0.01	1	0.931	0.00	1	0.957
time	0.43	1	0.513	1.47	1	0.226	**6.29**	**1**	**0.012**
$time^2$	**26.44**	**1**	**<0.001**	1.46	1	0.227	**4.87**	**1**	**0.027**
depth	**10.70**	**1**	**0.001**	**20.76**	**1**	**<0.001**	**21.54**	**1**	**<0.001**
$depth^2$	**11.41**	**1**	**0.001**	**16.36**	**1**	**<0.001**	**29.47**	**1**	**<0.001**
wind	0.57	1	0.449	2.36	1	0.125	0.97	1	0.325
$wind^2$	0.41	1	0.522	1.37	1	0.241	2.17	1	0.140
temperature	1.61	1	0.205	0.62	1	0.430	1.17	1	0.280
$temp^2$	1.52	1	0.217	**4.22**	**1**	**0.040**	**11.72**	**1**	**0.001**
cloud	0.08	1	0.780	0.30	1	0.583	0.54	1	0.461

Table 6. Poisson regression coefficients from final ringed seal regression models for the 1980s, 1990s, and all years.

	1985-1987				1996-1999				All			
Variable	Est.	SE	t	*P*	Est.	SE	t	*P*	Est.	SE	t	*P*
intercept (pack)	1.4961	0.5459	2.74	0.006	-0.0760	0.2180	-0.35	0.727	6.0059	1.9196	3.13	0.002
intercept (fast)	1.9511	0.4723	4.13	<0.001	-0.3119	0.1903	-1.64	0.101	6.4925	1.9128	3.39	0.001
year (pack)	0.4355	0.1600	2.72	0.009	-0.1413	0.0536	-2.64	0.009	-0.0478	0.0165	-2.90	0.004
year (fast)	0.4355	0.1600	2.72	0.009	0.0643	0.0581	1.11	0.269	-0.0917	0.0137	-6.71	<0.001
dist–edge85									0.0298	0.0145	2.05	0.041
dist-edge86									0.0119	0.0100	1.18	0.238
dist-edge87									0.0147	0.0098	1.49	0.136
dist-edge96									0.0416	0.0117	3.56	<0.001
dist-edge97									0.0258	0.0083	3.10	0.002
dist-edge98									0.0185	0.0138	1.34	0.180
dist-edge99									0.0069	0.0080	0.86	0.388
$dist^2$ 85	-0.0005	0.0001	-3.35	0.040					-0.0002	0.0003	-0.77	0.440
$dist^2$ 86	-0.0005	0.0001	-3.35	0.040					-0.0002	0.0002	-1.01	0.311
$dist^2$ 87	-0.0005	0.0001	-3.35	0.040					-0.0012	0.0004	-2.70	0.007
$dist^2$ 96					-0.0023	0.0006	-4.02	<0.001	-0.0032	0.0007	-4.59	<0.001
$dist^2$ 97					-0.0004	0.0002	-1.56	0.120	-0.0002	0.0003	-0.49	0.622
$dist^2$ 98					-0.0012	0.0004	-2.71	0.007	-0.0011	0.0007	-1.67	0.096
$dist^2$ 99					-0.0009	0.0004	-2.50	0.012	-0.0009	0.0004	-2.55	0.011
longitude85	-0.1602	0.0688	-2.33	0.020					-0.1599	0.0580	-2.76	0.006
longitude86	0.0960	0.0756	1.27	0.204					0.0243	0.0600	0.40	0.686
longitude87	0.1073	0.0556	1.93	0.054					0.0802	0.0460	1.74	0.082
longitude96					0.0958	0.0227	4.23	<0.001	0.0765	0.0418	1.83	0.067
longitude97					0.0958	0.0227	4.23	<0.001	0.0524	0.0377	1.39	0.165
longitude98					0.0958	0.0227	4.23	<0.001	0.2122	0.0597	3.55	<0.001
longitude99					0.0958	0.0227	4.23	<0.001	0.1711	0.0345	4.96	<0.001

Table 6. Continued.

	1980's				1990's				All			
Variable	Est.	SE	t	*P*	Est.	SE	t	*P*	Est.	SE	t	*P*
$long^2$ 85	0.0202	0.0425	0.48	0.635					-0.0253	0.0301	-0.84	0.402
$long^2$ 86	-0.0991	0.0345	-2.87	0.004					-0.0729	0.0273	-2.67	0.008
$long^2$ 87	-0.1164	0.0348	-3.34	0.001					-0.0479	0.0250	-1.92	0.055
$long^2$ 96									0.0349	0.0224	1.56	0.119
$long^2$ 97									0.0557	0.0176	3.16	0.002
$long^2$ 98									-0.0025	0.0274	-0.09	0.928
$long^2$ 99									-0.0085	0.0201	-0.42	0.672
icedef	-0.0228	0.0055	-4.15	<0.001	-0.0277	0.0038	-7.26	<0.001	-0.0284	0.0029	-9.68	<0.001
$icedef^2$												
time									-0.6856	0.2734	-2.51	0.012
$time^2$	-0.0073	0.0014	-5.14	<0.001					0.0214	0.0097	2.21	0.027
depth	-0.0959	0.0293	-3.27	0.001	-0.0776	0.0170	-4.55	<0.001	-0.0707	0.0152	-4.64	<0.001
$depth^2$	-0.0022	0.0007	-3.38	0.001	-0.0015	0.0004	-4.04	<0.001	-0.0018	0.0003	-5.43	<0.001
wind												
$wind^2$												
temperature												
$temp^2$					-0.0031	0.0015	-2.05	0.040	-0.0058	0.0017	-3.42	0.001
cloud												

In the 1990s, densities were also lowest in water $\leq$ 5 m deep (0.35-0.73 seals/km^2) and deeper than 35 m (0-0.77 seals/km^2), and were highest in water depths of >5-35 m (1.00-1.33 seals/km^2; Figure 10b). Seals were more broadly distributed relative to depth in the 1990s surveys than in the 1980s. For all years combined, the highest densities occurred in 5-15 m (1.27 seals/km^2) and 15-25m (1.18 seals/km^2) water depths (Figure 10c).

The Poisson regression model also indicated that seal densities were lowest in water <5 m and >35 m deep and highest in water 15-25 m deep (Figure 11). Model results were similar for the 1980s, the 1990s, and for all years combined, and were significant for depth and depth^2 at P<0.001.

Fast ice edge - For all years, univariate analysis indicated that the position of the shorefast ice edge had a significant effect on ringed seal densities (P<0.001). In 1986, peak density was 15-20 km from the edge (3.16 seals/km^2), and in 1987 it was 0-15 km from the edge (2.36-3.68 seals/km^2; Figure 12a). Densities relative to the ice edge showed less of a pattern in 1985. The relationship between seal density and distance from the fast ice edge was quite consistent for the 1990s surveys with peak densities (1.29-1.90 seals/km^2) occurring within 5 km of the edge, either on fast or pack ice (Figure 12b). For all years combined, observed densities were highest within 5 km of the fast ice edge (Figure 12c).

The Poisson regression model also indicated a significant, non-linear effect of distance from the fast ice edge on seal densities (distance^2, $P\leq$0.001). Relative densities were highest near the fast ice edge, and decreased both shoreward and seaward of the edge for both the 1980s and 1990s (Figures 13 a,b). The model for all years combined also indicated that densities were highest near and just beyond the edge (Figure 13c). However, in the combined analysis analysis, the modeled densities for 1985, 1986 and 1997 did not show a peak near the ice edge. This is in contrast to the 1980s-only and 1990s-only analyses, and also to the results of the univariate analyses.

Ice deformation - Ice deformation had a significant effect on seal densities for each individual survey year, and for all years combined in the univariate analyses (P<0.001 except P=0.01 for 1998). Seal densities in all years were highest in smoother ice (0%-10% and 10%-20% deformation categories). In the 1980s, densities in different ice deformation categories ranged from 0.24-2.87 seals/km^2 (Figure 14a). Peak densities in 1986 and 1987 were in ice that was <10% deformed (1.93 and 2.87 seals/km^2). In contrast, observed densities on 0%-10% deformation ice in 1985 were low (0.57 seals/km^2). During 1996-1998 surveys, the range in densities across deformation categories was 0.27-1.45 seals/km^2 (Figure 14b). As in the 1980s, densities in 1996-1998 were highest on smooth ice. In 1999, densities were highest in 10%-20% deformation ice (1.45 seals/km^2). In the combined analysis for all years, densities were highest in 0%-20% ice deformation with gradually declining densities in rougher ice categories (Figure 14c).

The Poisson regression model for ice deformation indicated significant relationships between ice deformation and observed seal densities for all data sets (P<0.001). Modeled densities were highest in the flattest ice, and lowest in the most highly deformed ice (Figure 15).

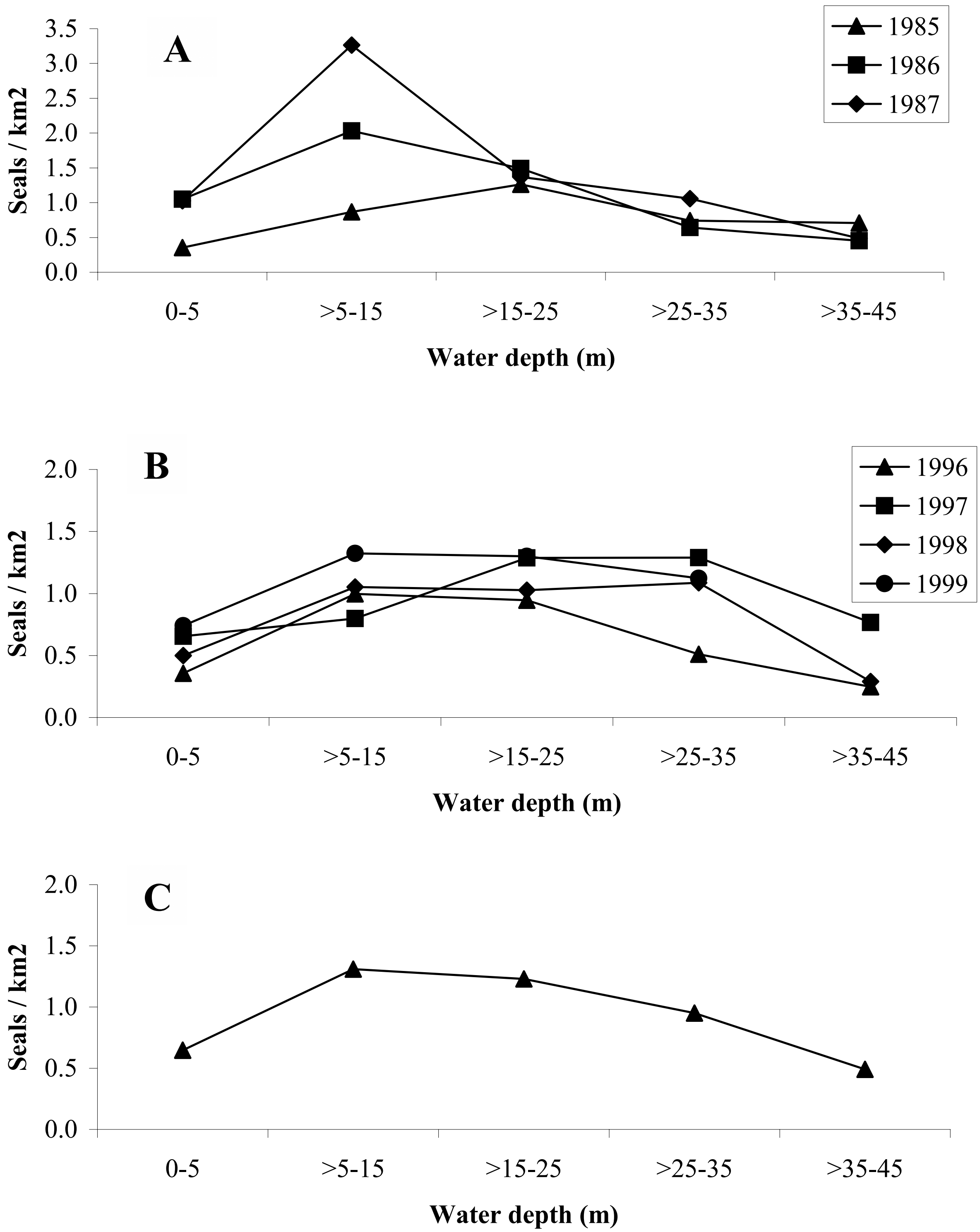


Figure 10. Observed densities of ringed seals by water depth in the central Beaufort Sea for a) 1985-1987, b) 1996-1999 and c) all years combined.

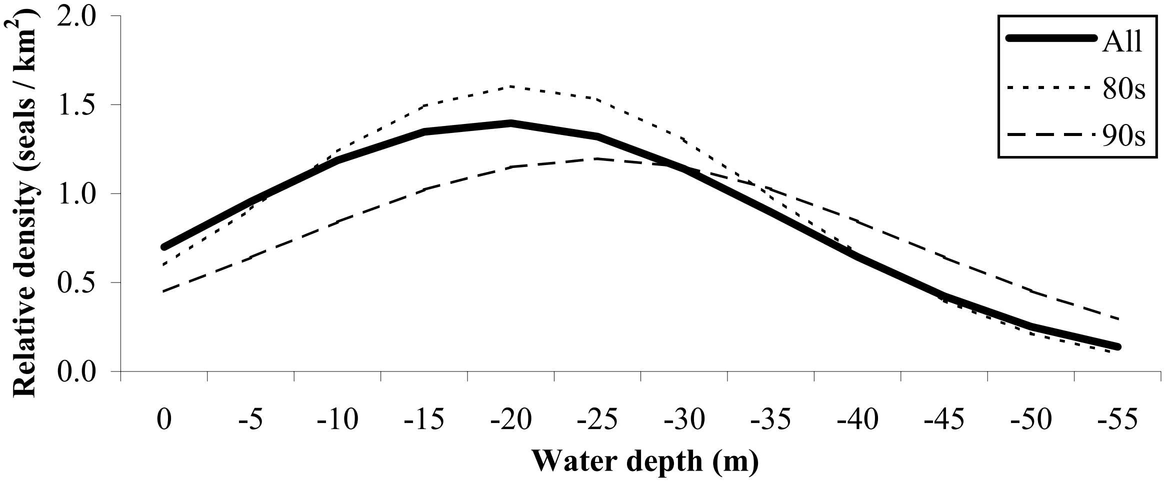


Figure 11. Modeled estimates of ringed seal densities relative to water depth in the central Beaufort Sea based on aerial surveys conducted in 1985-1987 and 1996-1999.

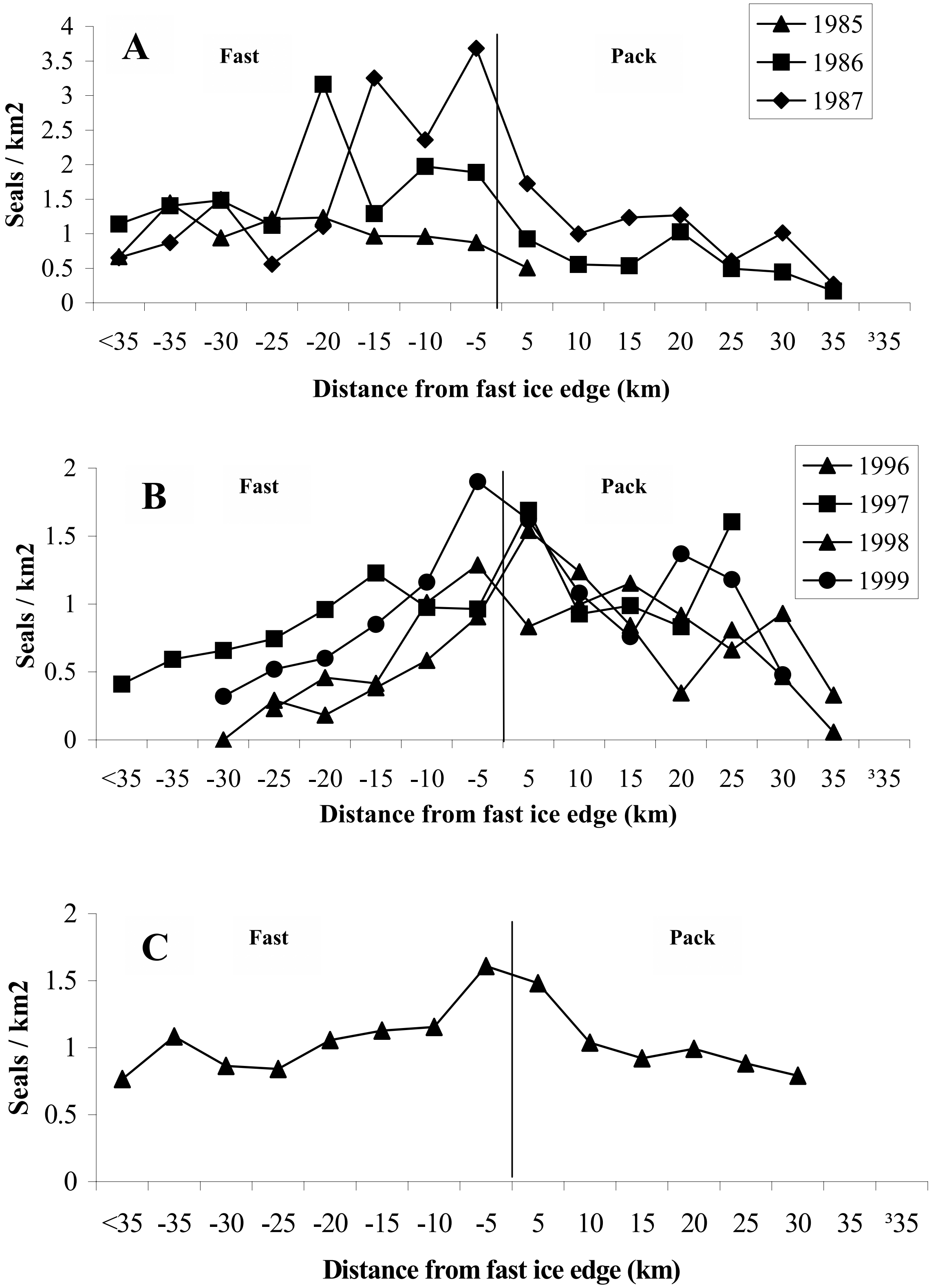


Figure 12. Observed densities of ringed seals by distance from the fast ice edge in the central Beaufort Sea for a) 1985-1987, b) 1996-1999 and c) all years combined.

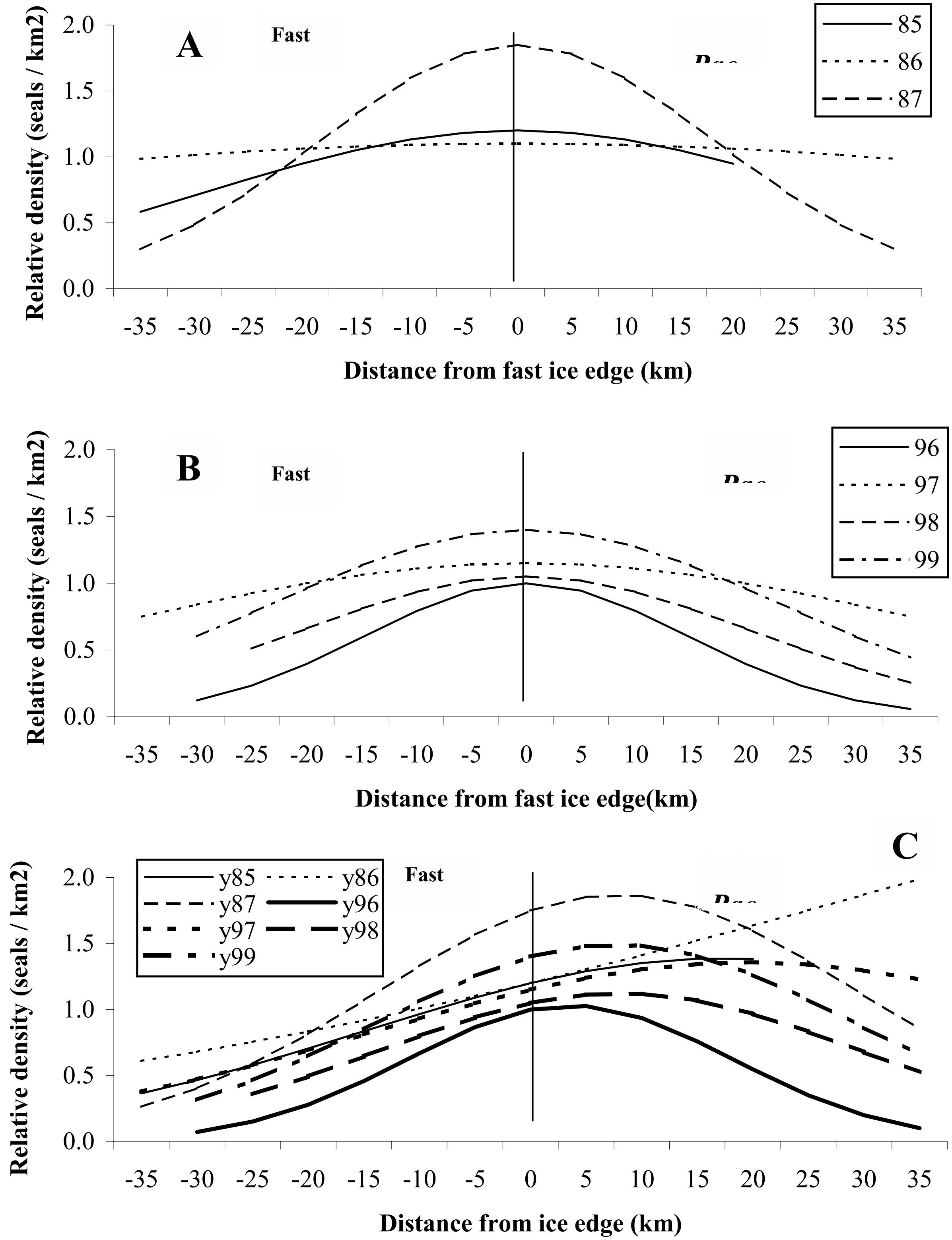


Figure 13. Modeled estimates of ringed seal densities relative to distance from the fast ice edge based on aerial surveys in the central Beaufort Sea for a) 1985-1987, b) 1996-1999 and c) all years combined.

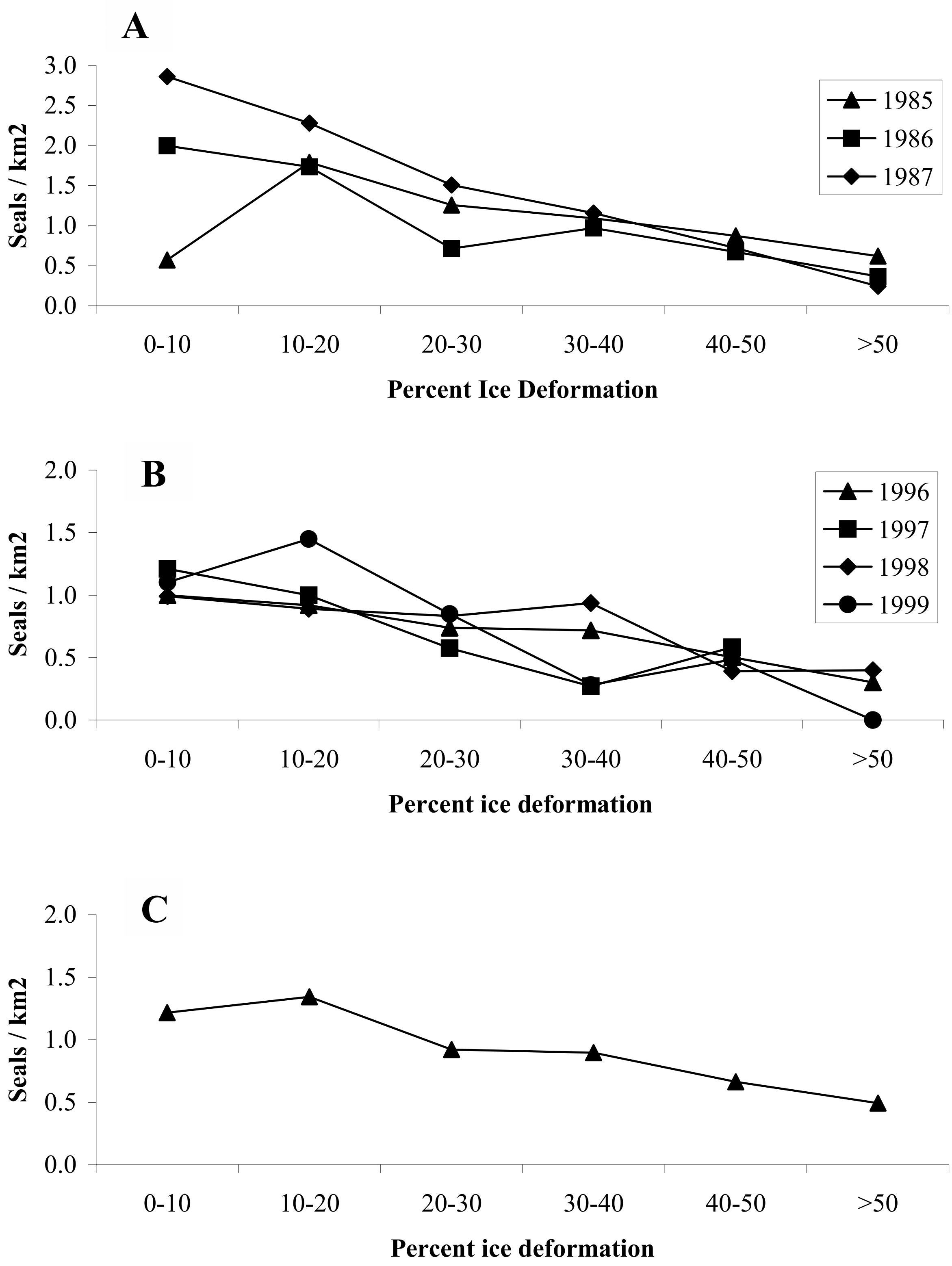


Figure 14. Observed densities of ringed seals relative to ice deformation in the central Beaufort Sea for a) 1985-1987, b) 1996-1999 and c) all years combined.

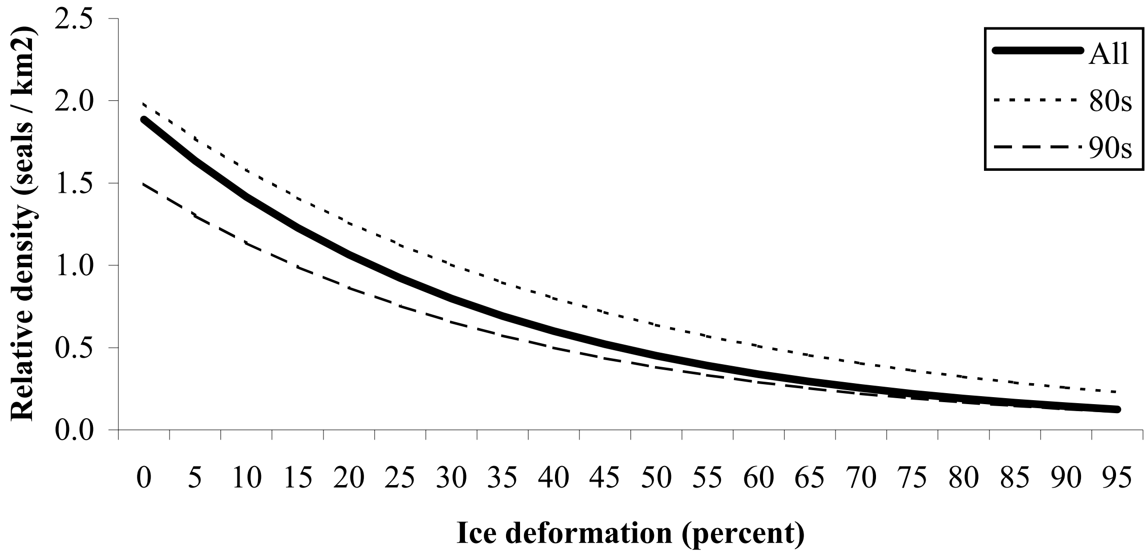


Figure 15. Modeled estimates of ringed seal densities relative to percent ice deformation in the central Beaufort Sea based on aerial surveys during 1985-1987 and 1996-1999.

Longitude **-** Univariate analysis indicated that longitude had a significant effect on seal densities in all years and for all years combined (*P*<0.001). However, the influence of longitude varied by year and was not consistent either within or across survey periods (Figure 16). In 1987 and in the1990s, the highest densities generally occurred at about 144° and 145° W. For all years combined, the highest density occurred at 145°, from approximately Brownlow Point to Flaxman Island.

In the Poisson model, the influence of longitude was marginally significant in the 1980s. Some of the longitude terms were significant for the 1990s and for all years combined. Modeled densities were generally highest in the central part of the study area for the 1980s, and at the eastern end in the 1990s (Figures 17 a, b). Although there were significant within-year trends in density relative to longitude, it was clear from the combined year model that there was no consistent trend across all years (Figure 17c).

Factors Affecting the Proportion of Seals Hauled out

We also analyzed the observed density of ringed seals relative to time of day, the presence of melt water, cloud cover, temperature, and wind speed. Those are variables that we thought could affect either the proportion of seals hauled out and available for counting, or our ability to see and count them. Results of univariate chi-square analyses for each of these variables are presented in Table 7 and Appendix C. With the exception of melt water, the same variables were included in the multivariate Poisson regression analysis, and results are shown in Tables 5 and 6.

Time of day - Univariate analyses of seal density versus time of day were significant for each survey year and for all years combined (*P*<0.001). In most years, densities increased somewhat until 1200 or 1300 hrs, then gradually decreased through the afternoon. However, the relationship between time of day and estimated densities was inconsistent. In 1985, for example, the estimated densities at 1000-1059 hrs and 1100-1159 hrs were over double the estimated densities later in the day (Figure 18a). In 1999, another atypical year, observed densities increased steadily through the day, and were highest after 1700 hrs (Figure 18b). When the data for all years are combined they show only a weak relationship between seal density and time of day (Figure 18c).

The Poisson model for time of day indicated significant relationships (*P*<0.001) for the 1980s and for all years combined, but not for the 1990s (*P*=0.226). The modeled data for the 1980s indicated a substantial decline in seal densities during the day. However, the effect of time of day was smaller when the analysis included all survey years (Figure 19).

Melt water - Univariate analyses of melt water were significant only in some cases (from *P*<0.001 to *P*=0.37). Little or no melt water was present in 1986, 1987, 1997, and 1999. Significant effects occurred in 1985, 1996, and 1998, when melt water was quite common. Densities tended to be somewhat higher in intermediate melt categories of 20%-40% than elsewhere (Figure 20).

We did not include melt water in the Poisson regression analysis due to the nearly complete absence of melt water in four of seven years.

Weather - Univariate analysis indicated significant effects of cloud cover, temperature and wind in most years and for all years combined. However, the effects were inconsistent for all three variables. Observed density was highest when skies were clear in 1999, but in 1996-1998 densities were lowest when skies were clear (Figure 21a). Overall there seemed to be little pattern in the relationship between seal densities and cloud cover (Figure 21b).

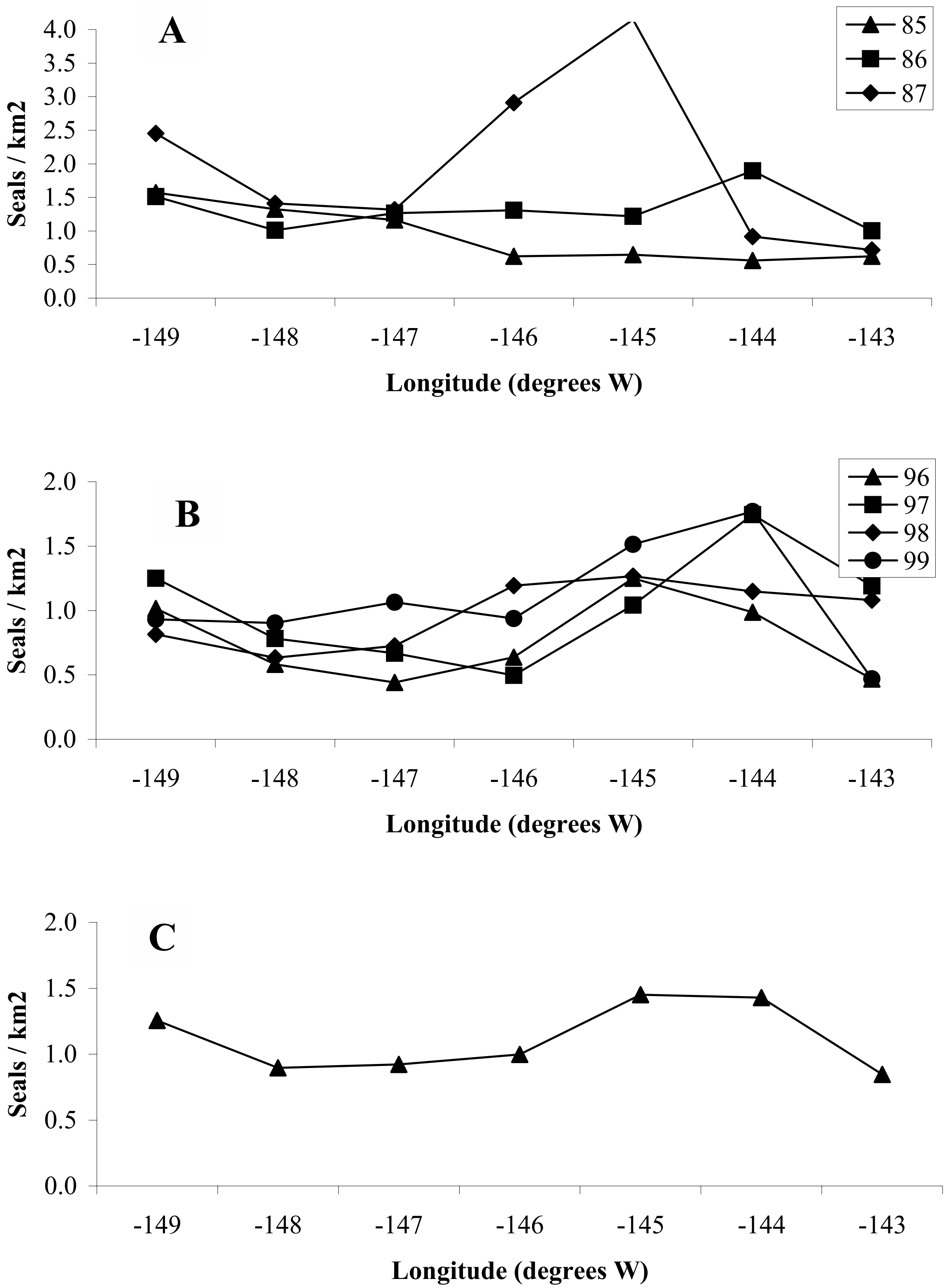


Figure 16. Observed densities of ringed seals relative to longitude in the central Beaufort Sea for a) 1985-1987, b) 1996-1999 and c) all years combined.

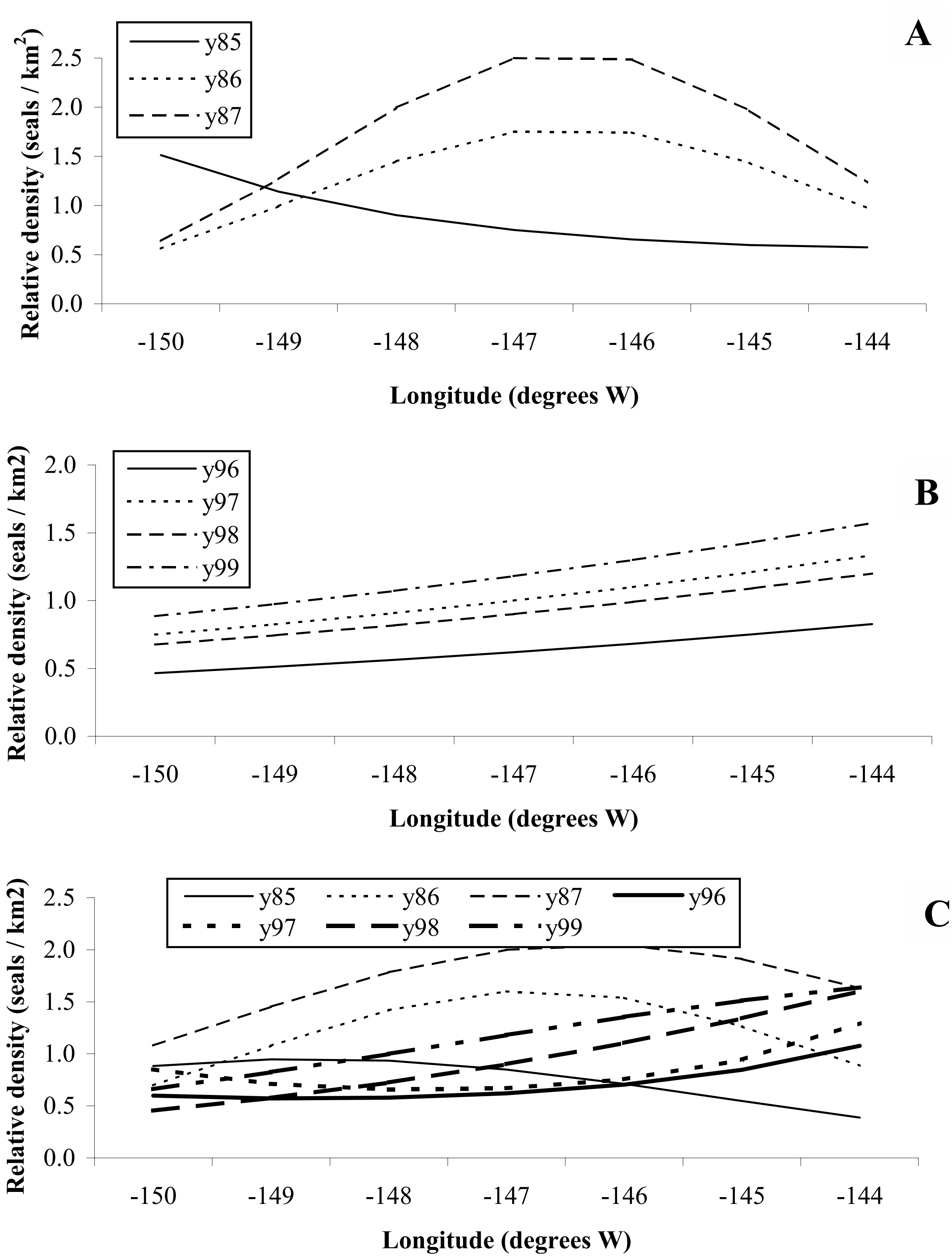


Figure 17. Modeled estimates of ringed seal densities relative to longitude based on aerial surveys in the central Beaufort Sea for a) 1985-1987, b) 1996-1999 and c) all years combined.

Table 7. Summary of chi-square analyses of observed ringed seal density relative to habitat variables affecting distribution and abundance in the central Beaufort Sea of Alaska.

Variable	Chi-square	*df*	*P*-value	Combined
Time of Day				
1985	147.30	6	<0.001	
1986	98.07	6	<0.001	
1987	723.45	6	<0.001	
1996	256.52	6	<0.001	
1997	159.31	6	<0.001	
1998	51.81	6	<0.001	
1999	116.70	7	<0.001	
All	403.98	7		<0.001
Melt Water				
1985	134.41	5	<0.001	
1986	252.45	3	<0.001	
1987	0	0	-	
1996	58.07	5	<0.001	
1997	5.41	5	0.368	
1998	102.15	5	<0.001	
1999	12.89	2	0.002	
All	131.69	5		<0.001
Cloud Cover				
1985	240.22	2	<0.001	
1986	0	0	-	
1987	0	0	-	
1996	44.72	3	<0.001	
1997	282.36	6	<0.001	
1998	57.71	5	<0.001	
1999	41.59	6	<0.001	
All	396.13	10		<0.001
Temperature				
1985	104.69	1	<0.001	
1986	1.66	2	0.440	
1987	52.36	1	<0.001	
1996	93.85	2	<0.001	
1997	110.91	4	<0.001	
1998	14.54	3	0.002	
1999	244.48	1	<0.001	
All	370.03	6		<0.001
Wind Speed				
1985	95.25	2	<0.001	
1986	47.00	4	<0.001	
1987	373.93	3	<0.001	
1996	44.15	3	<0.001	
1997	131.24	4	<0.001	
1998	38.19	3	<0.001	
1999	61.52	5	<0.001	
All	333.51	5		<0.001

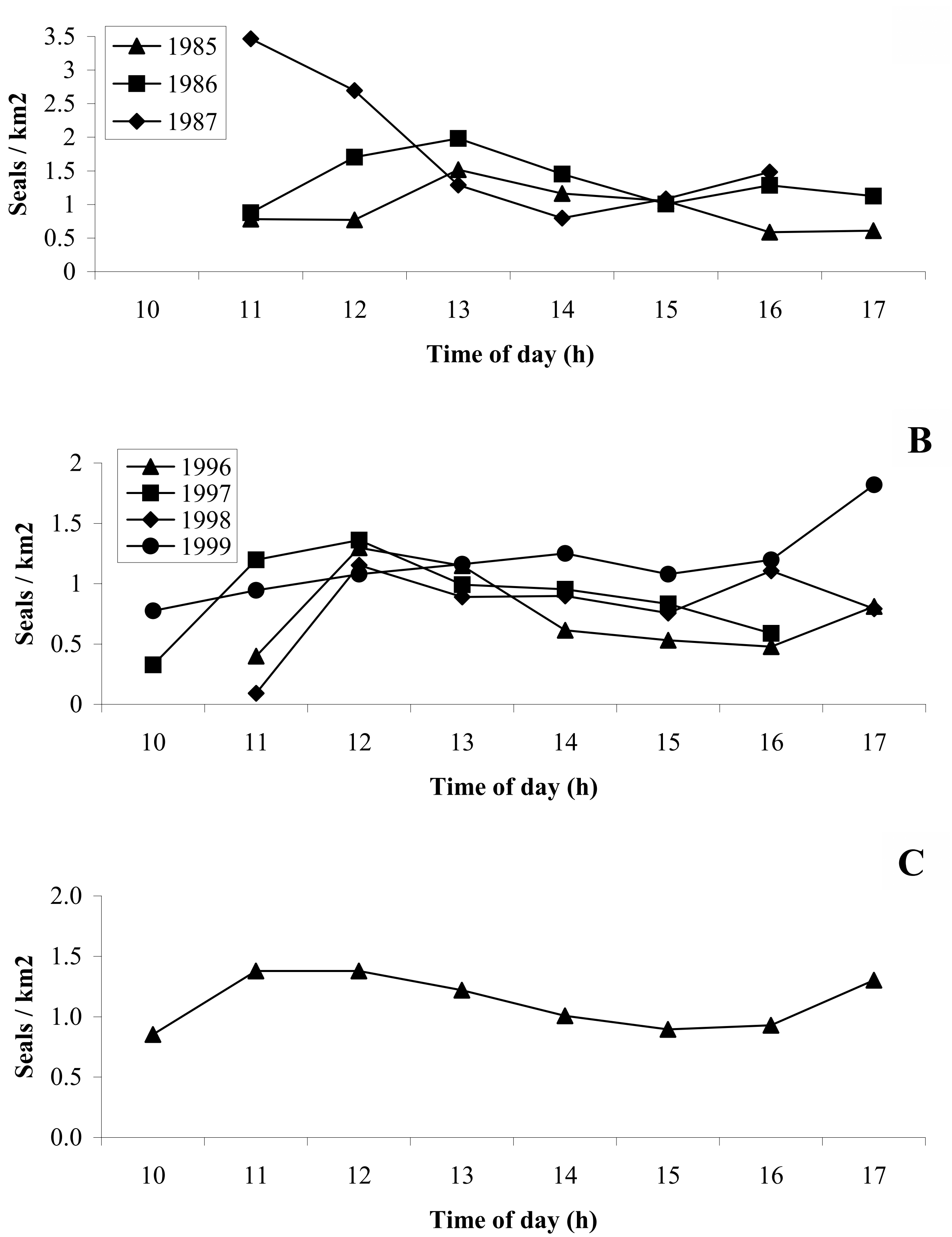


Figure 18. Observed densities of ringed seals relative time of day (h) in the central Beaufort Sea for a) 1985-1987, b) 1996-1999 and c) all years combined.

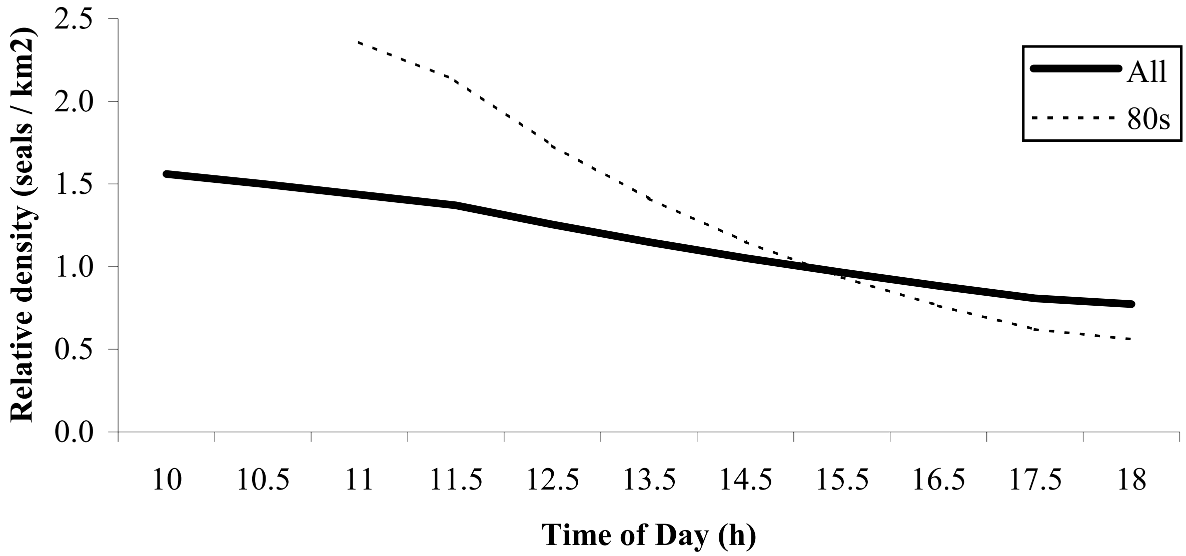
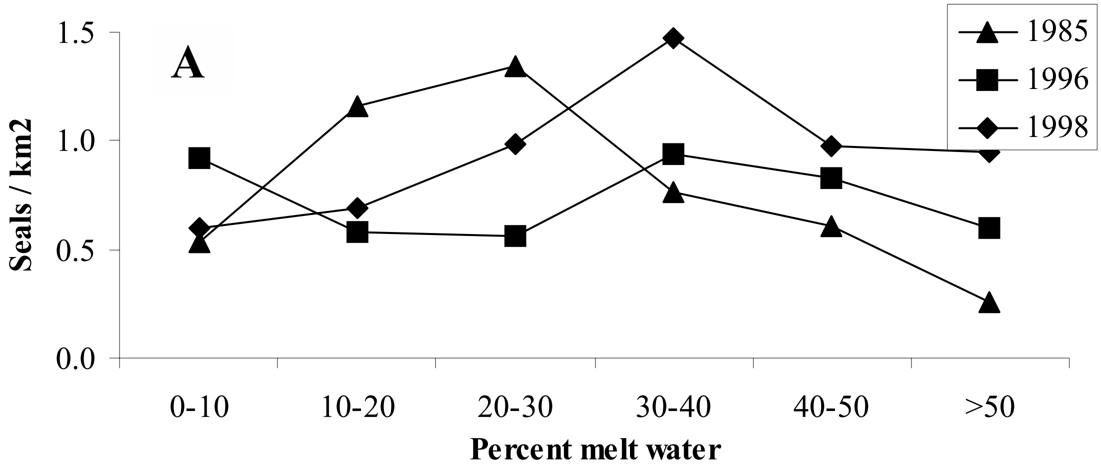


Figure 19. Modeled estimates of ringed seal densities relative to time of day in the central Beaufort Sea based on aerial surveys during 1985-1987 and 1996-1999. Regressions for the 1990s alone were not significant.



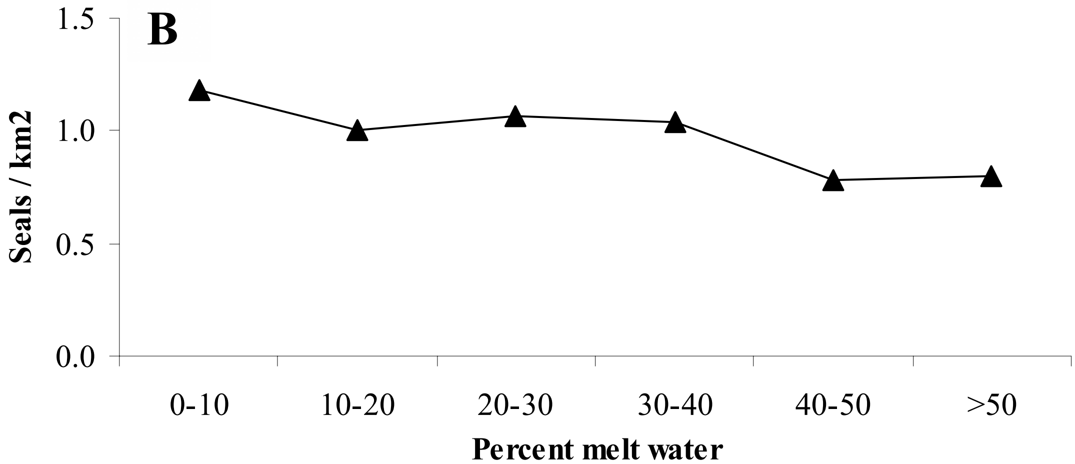


Figure 20. Observed densities of ringed seals relative to percent melt water coverage in the central Beaufort Sea a) 1985, 1996 and 1998 and b) all years combined.

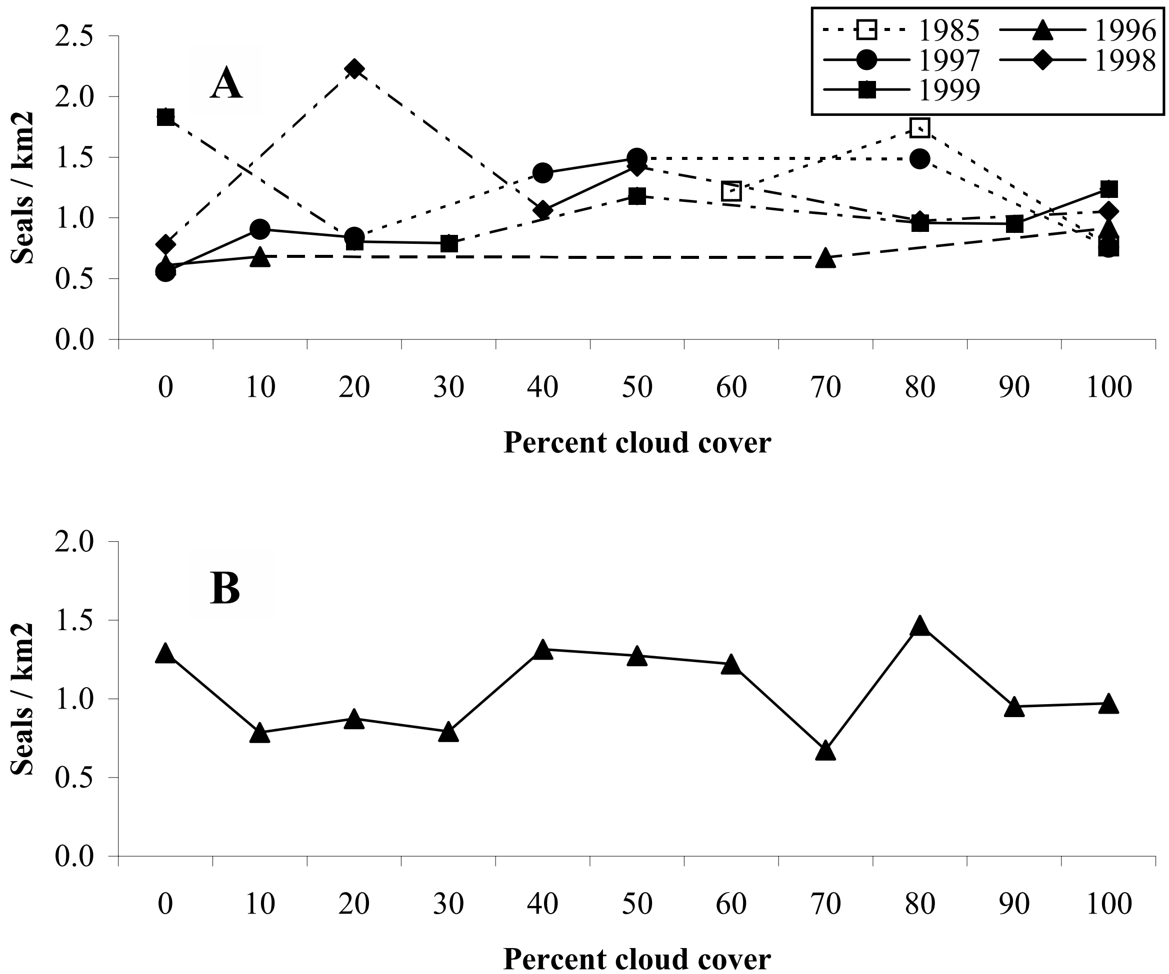


Figure 21. Observed densities of ringed seals relative to percent cloud coverage in the central Beaufort Sea for a) 1985 and 1996-1999 and b) all years combined.

Some years had higher densities with higher temperatures (Figure 22a,b) and/or wind speeds (Figure 23a,b), and for others the reverse was true. For the combined univariate analyses, density decreased with increasing temperature and increased with increasing wind speed, although neither temperature or wind demonstrated a strong pattern (Figures 22c and 23c).

The Poisson regression model indicated no significant relationship between cloud cover or wind speed and seal densities. There was a significant non-linear relationship between air temperature and seal densities for the 1990s and for all data combined, but not for the 1980s. Seal densities were slightly higher around 0° C than when it was warmer or colder (Figure 24).

Power Analysis

Power Based on Observed Density Estimates

For raw (observed) densities, the power to detect population declines (*i.e.*, negative annual change) was greater than the power to detect increases (*i.e.*, positive annual change) for all combinations of sample size and years surveyed (Figure 25). With five years of data (both 50 and 65 lines/yr), power was low, even for extreme declines (power = 0.23 – 0.28 for -20%/yr change). In addition, detection of 'false' trends was high. When there was no trend (0%/yr change), approximately 10% of the simulations indicated significant (P<0.05) increases and 10% indicated significant declines. This is twice the expected rejection rate when there is no trend. In addition, 'false' trends occurred, where there were significant positive trend estimates for a true negative trend and significant negative trend estimates for true positive trends. It is expected that the occurrence of these types of 'false' trends should decline to zero as the true trend gets larger. This was not the case with the five year simulations where 'incorrect sign false' trends occurred about 10% of the time for both positive and negative trends irrespective of the magnitude of the trend. The number of lines surveyed (50 or 65) did not consistently affect power with five years of data.

With 10 years of survey effort, performance was considerably improved. Power for declines of –20%/yr was 0.51- 0.52. For a comparable increase, power was 0.26-0.32 (Figure 25). The 'false' trends when there was no true trend were at about the expected rate of 5% and 'false' trends declined as true trends increased, as expected. Power was slightly higher for 65 survey lines than for 50 lines for detecting population declines but was similar for the two sample sizes for detecting population increases.

Based on our simulations, trend estimates were biased toward 0 for both negative and positive true change. Median estimates of trend were 25%-30% smaller than true trends; this pattern was relatively unaffected by sample size or number of survey years (Figure 26).

Power Based on Modeled Densities

We also examined power for modeled densities from the Poisson regression analysis. For the Poisson model, increasing the number of survey lines from 50 to 65 resulted in modest increases in power for most combinations of trend and number of years (Figure 27). Doubling the number of years from 5 to 10 dramatically increased power, especially for smaller trends (*i.e.*, <10%/yr).

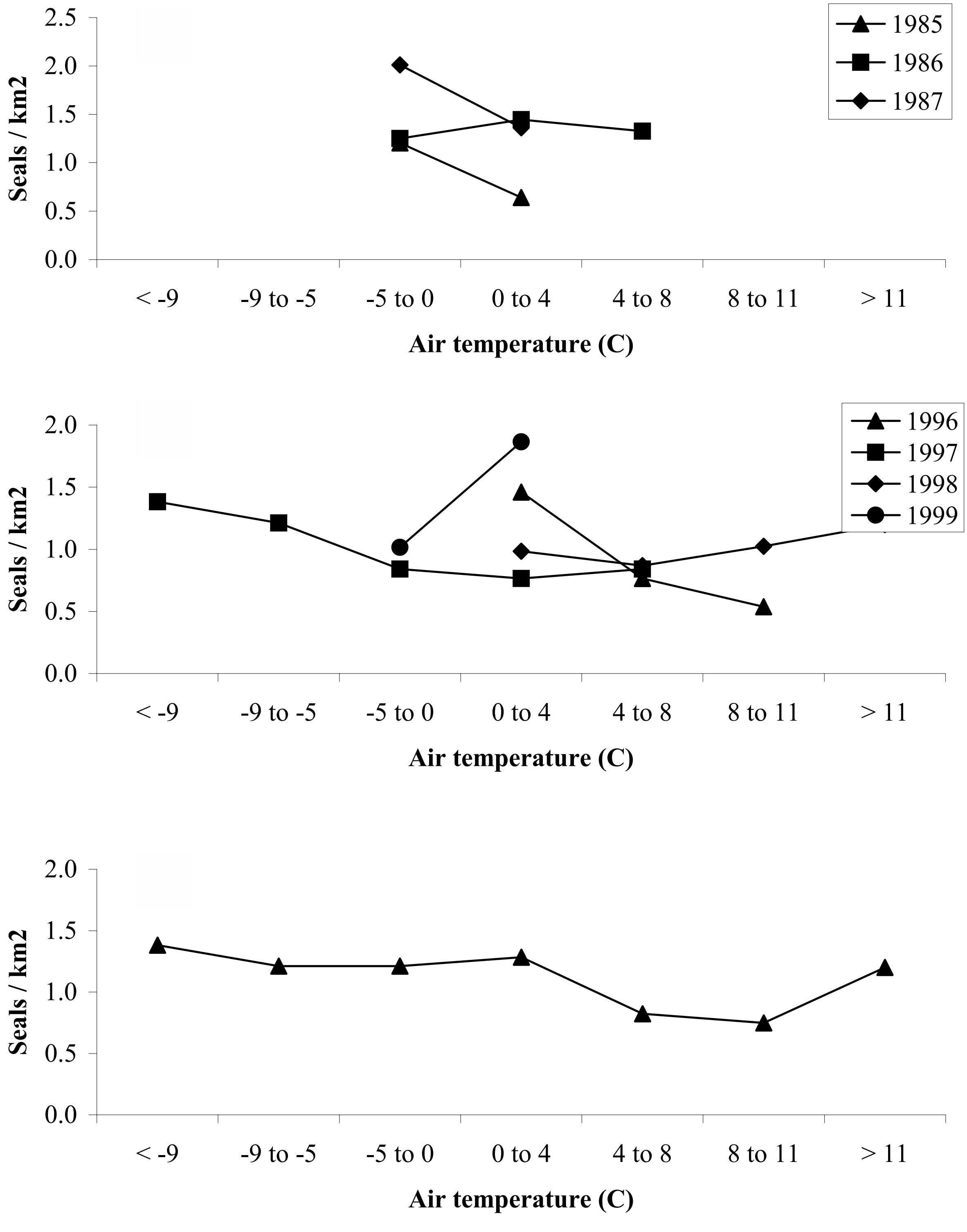


Figure 22. Observed densities of ringed seals relative to air temperature (C) in the central Beaufort Sea for a) 1985-1987, b) 1996-1999 and c) all years combined. Air temperatures were measured at survey altitude of 91 m.

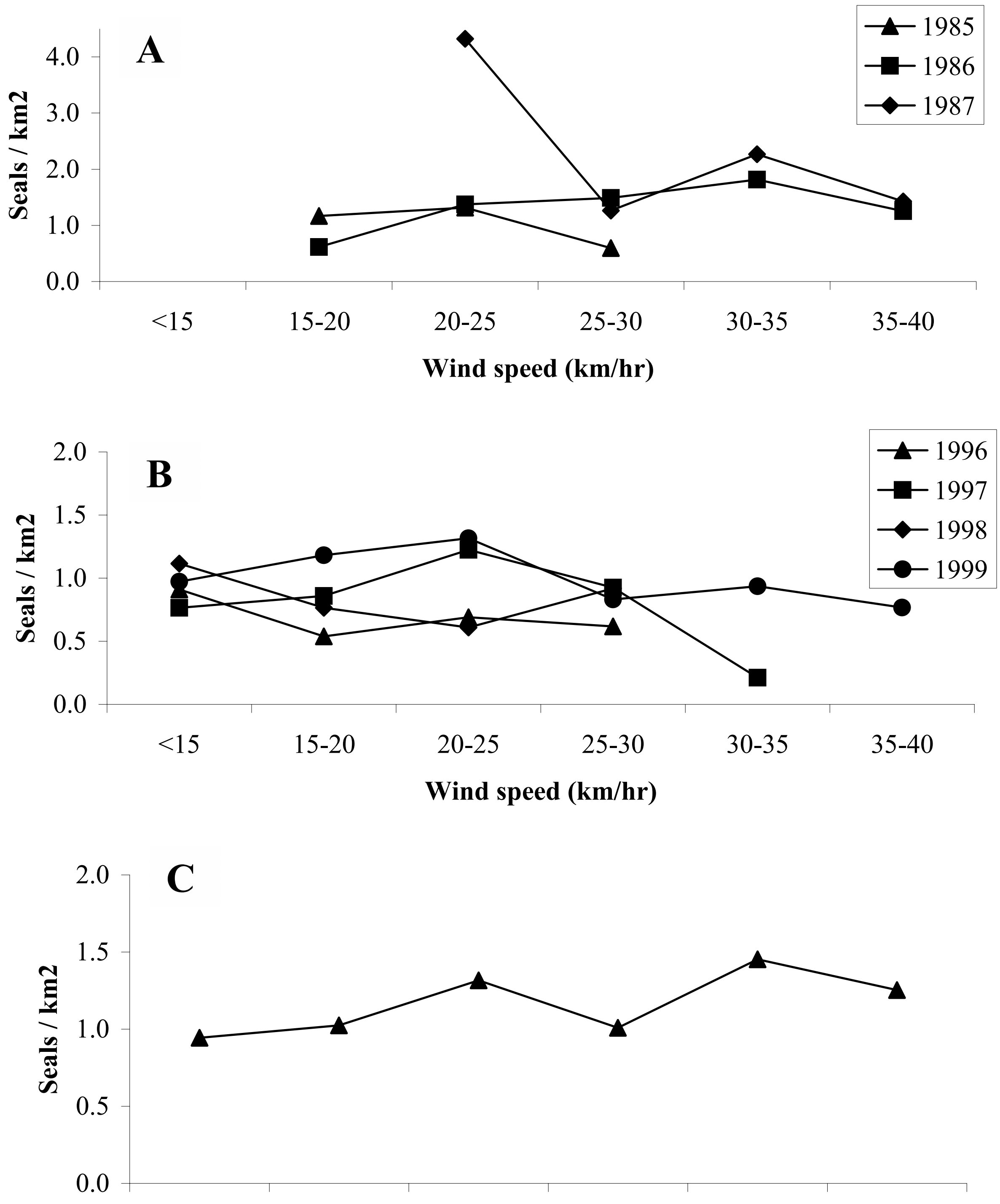


Figure 23. Observed densities of ringed seals relative wind speed (km/hr) in the central Beaufort Sea for a) 1985-1987, b) 1996-1999 and c) all years combined. Wind speed was measured at survey altitude of 91m.

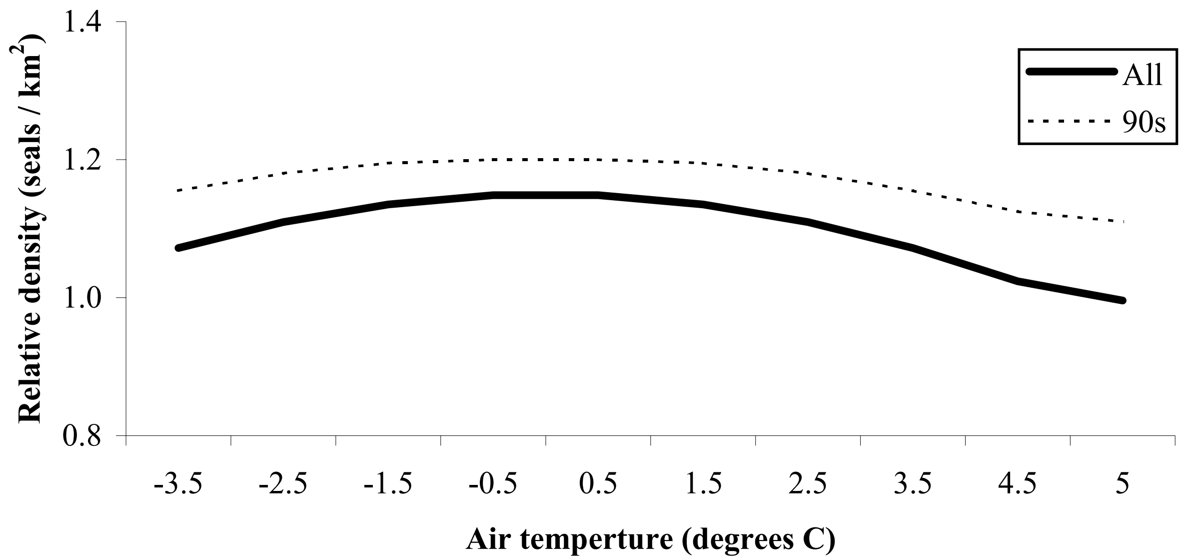


Figure 24. Modeled estimates of ringed seal densities relative to air temperature in the central Beaufort Sea based on aerial surveys during 1985-1987 and 1996-1999. Regression models for air temperature in the 1980s were not significant.

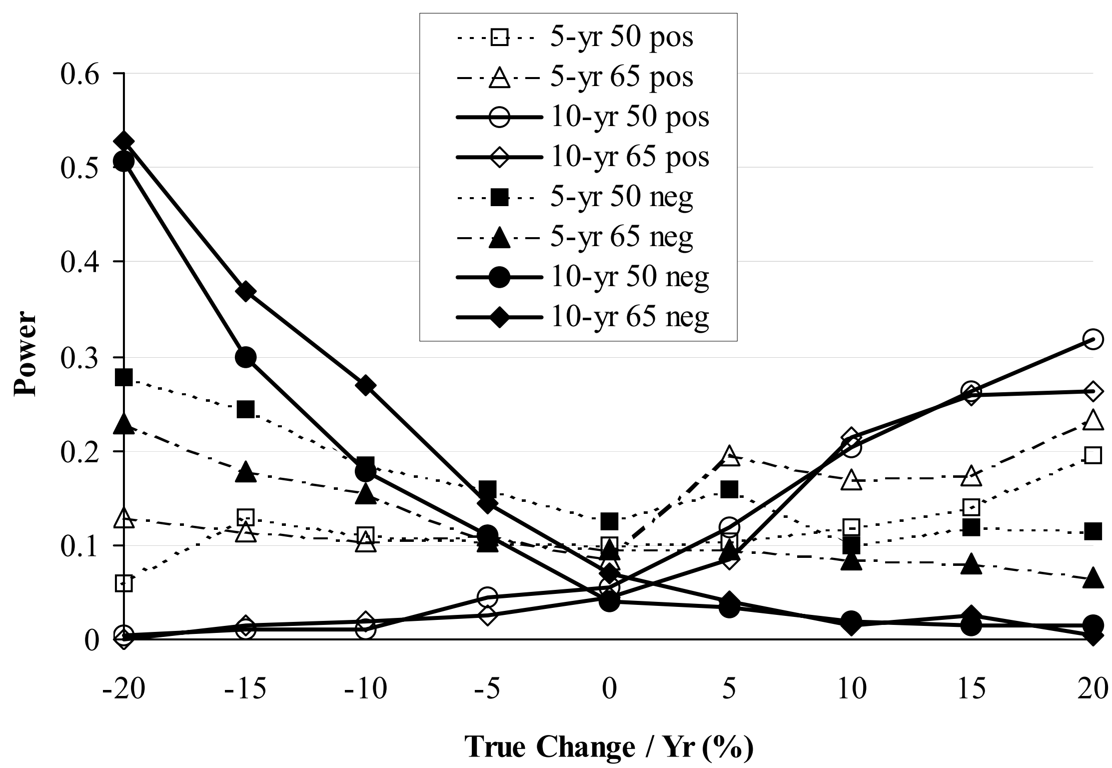


Figure 25. Comparison of estimated power of raw density estimates for ringed seal aerial surveys conducted in the central Beaufort Sea, 1996-1999. Power curves are based on 50 or 65 transect lines surveyed for either 5 or 10 years. Power is based on 1-tailed tests for all rates of change not equal to zero.

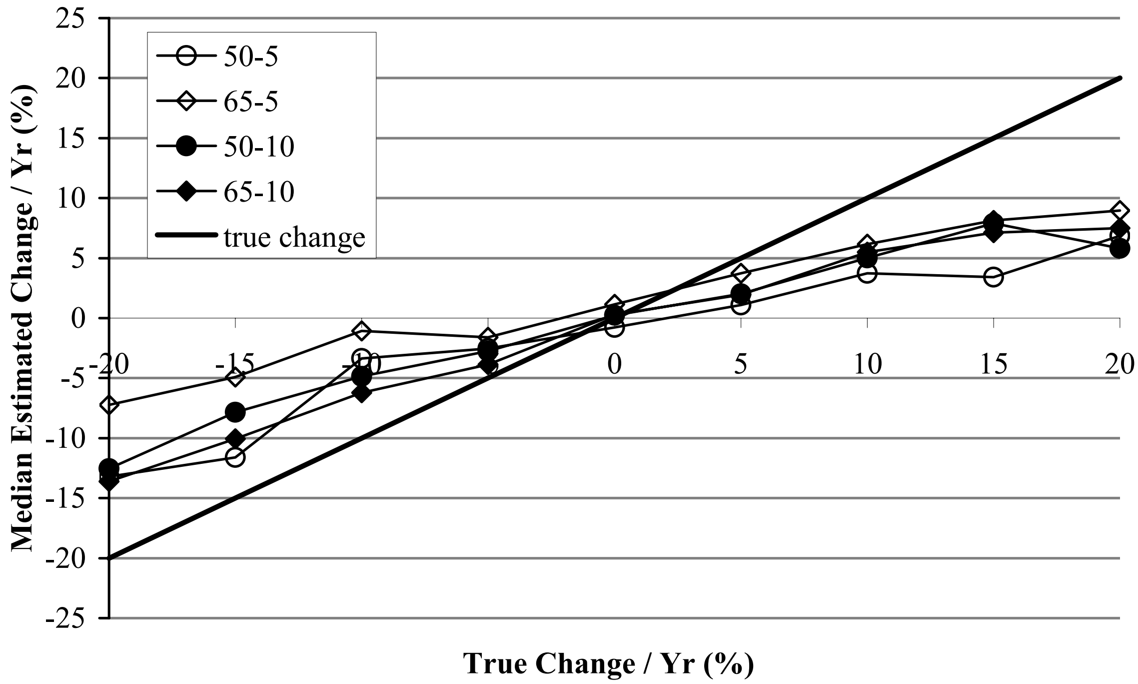


Figure 26. Comparison of true change and estimated change based on raw density estimates for ringed seal aerial surveys conducted in the central Beaufort Sea, 1996-1999. Power curves are based on 50 or 65 transect lines surveyed for either 5 or 10 years.

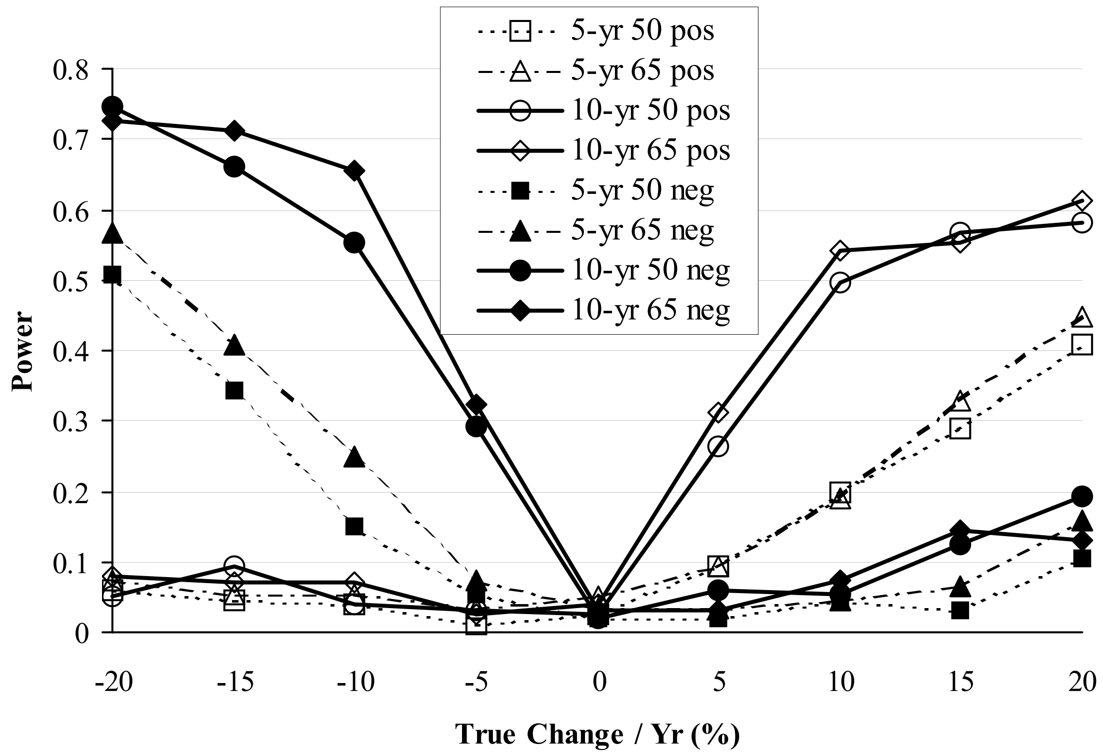


Figure 27. Estimated power to detect trend based on modeled estimates of ringed seal density from Poisson regression. Power curves are based on 50 and 65 transect lines surveyed for either 5 or 10 years. Power is based on 1-tailed tests for all rates of change not equal to zero.

Even with 10 years of surveys, the 'false' rejection rate for the Poisson model did not approach zero as trend increased. For declines of 10% and greater, the 'false' rejection rate did not fall below 5%-10% (Figure 28). For population increases, the 'false' rejection rate increased with increasing trend. Median estimates of trend were biased toward 0 for the Poisson model; number of years of data and survey lines had relatively little effect on this bias.

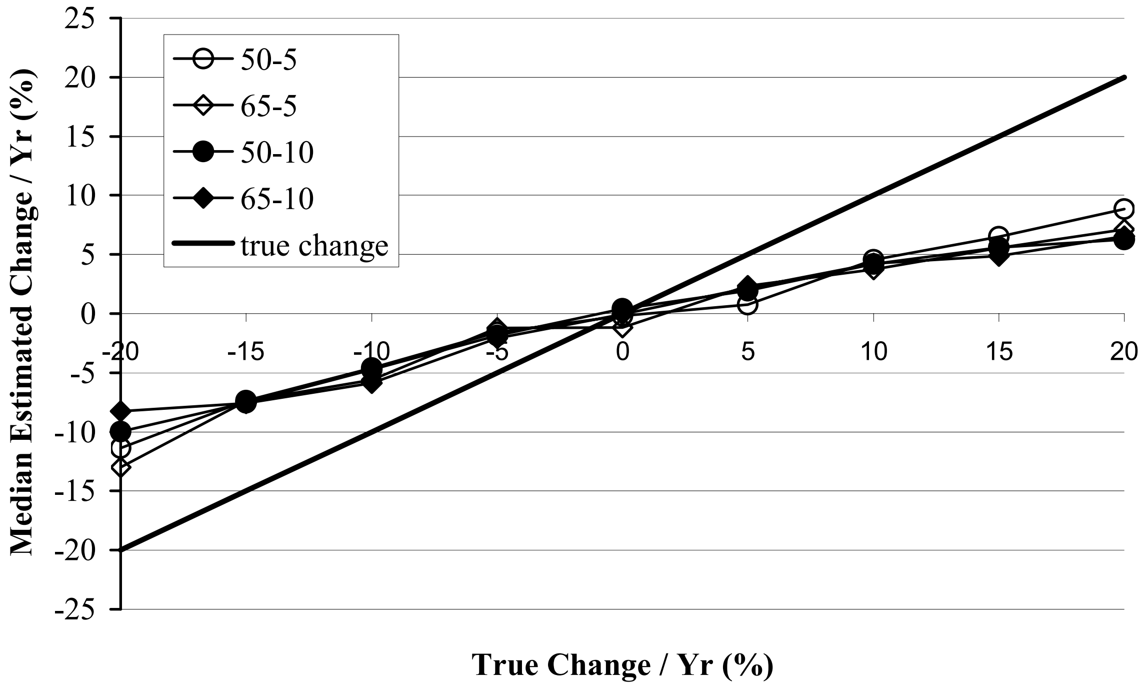


Figure 28. Comparison of true change and estimated change based on Poisson regression modeled density estimates for ringed seal aerial surveys conducted in the central Beaufort Sea, 1996-1999. Power curves are based on 50 or 65 transect lines surveyed for either 5 or 10 years.

Trends in Abundance

We used linear regressions to test whether there was a significant change in the observed density of ringed seals over the years when surveys were conducted (see Figure 29). Regressions were done for fast ice, pack ice, and all ice types using the same dataset used in the univariate and Poisson analyses. Regressions for both ice types and for all ice combined indicated no statistically significant trends, increasing or decreasing, in the density of ringed seals (fast ice - $F_{0.95(1,5)}$=2.60, P=0.17; pack ice - $F_{0.95\,(1,5)}$=1.69, P=0.25; all ice combined - $F_{0.95\,(1,5)}$=2.37, P=0.18).

We also conducted an analysis of variance (ANOVA) to examine whether there was a significant difference in observed density of ringed seals for surveys conducted in the 1980s versus the 1990s. The years 1985-1987 were grouped as time period 1 and the years 1996-1999 as time period 2. At significance level alpha=0.05, there was no significant difference between time periods for either fast ice, pack ice, or all ice combined. However, if the measure of significance is set at alpha= 0.10, the density of total seals on fast ice and all ice combined was significantly lower in the 1990s than in the 1980s (Table 8). The average density on all ice types combined for the 1990s, was 31% lower than the average density for the 1980s, and the average density on fast ice was 50% lower.

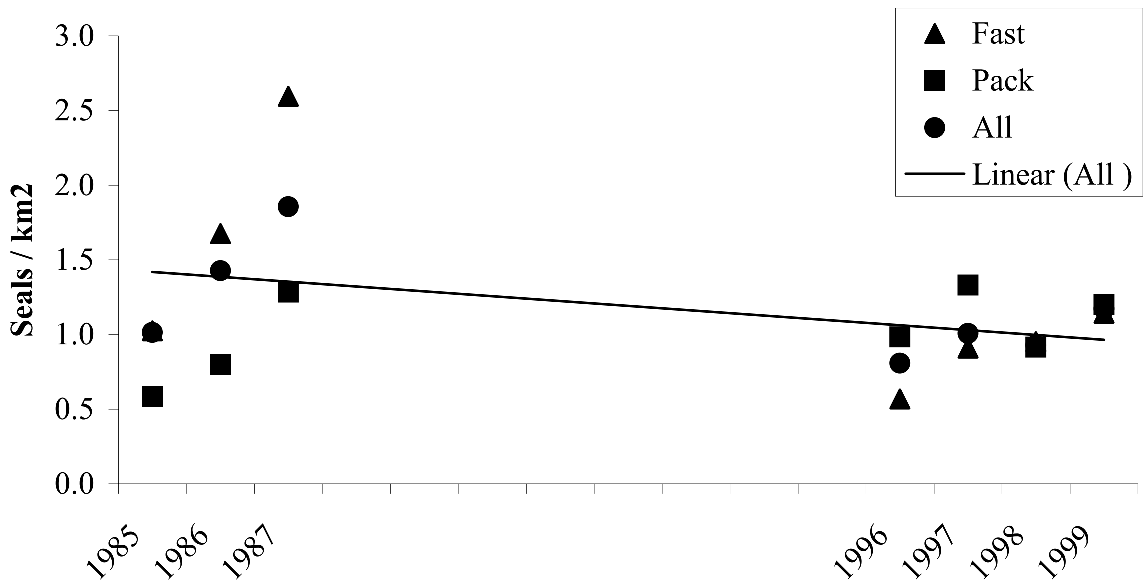


Figure 29. Observed densities of ringed seals on fast ice and pack ice in the central Beaufort Sea based on aerial surveys conducted in 1985-1987 and 1996-1999.

Table 8. Analysis of variance statistics for a comparison of observed ringed seal densities on fast, pack and all ice combined based on aerial surveys flown in the 1980s (time period 1) the 1990s (time period 2).

Ice type	Time period	Average density/km^2	F statistic	*P*-value
Fast	1	1.77	$F_{.95(1,5)}=4.61$	0.08
	2	0.89		
Pack	1	0.89	$F_{.95(1,5)}=1.13$	0.34
	2	1.11		
All	1	1.43	$F_{.95(1,5)}=4.23$	0.09
	2	0.98		

Examination of ice type and year effects (trend) using Poisson regression models indicated significant differences between fast ice and pack ice for all analyses (Table 5). Modeled densities were higher on fast ice in the 1980s and for all years combined, and higher on pack ice in the 1990s. There was a clear and significant increasing trend in modeled densities during 1985-1987 for both fast and pack ice; the model indicated an increase of 55% per year (Table 9). For 1996-1999, there was no significant overall directional trend, with the model predicting a significantly increasing trend for fast ice but a decreasing trend for pack ice.

Table 9. Trend estimates (percent change/year) from Poisson regression models for ringed seal density on the central Beaufort Sea based on aerial surveys conducted in 1985-1987 and 1996-1999.

	1980s	1990s	All Years
Fast Ice		6.6 (-4.8 – 19.5)	-8.6 (-6.5 – -10.6)
Pack Ice		-13.2 (-3.6 – -21.8)	-4.0 (-6.7 – -1.3)
All Ice	54.6 (13.0 - 111.5)		

When both survey periods were considered in a combined analysis, modeled densities demonstrated a marked decline (Figure 30, Table 9). From 1985-1999, the density on fast ice declined at a rate of 8.6%/year (72% decline overall), compared to a 4%/year decline on pack ice.

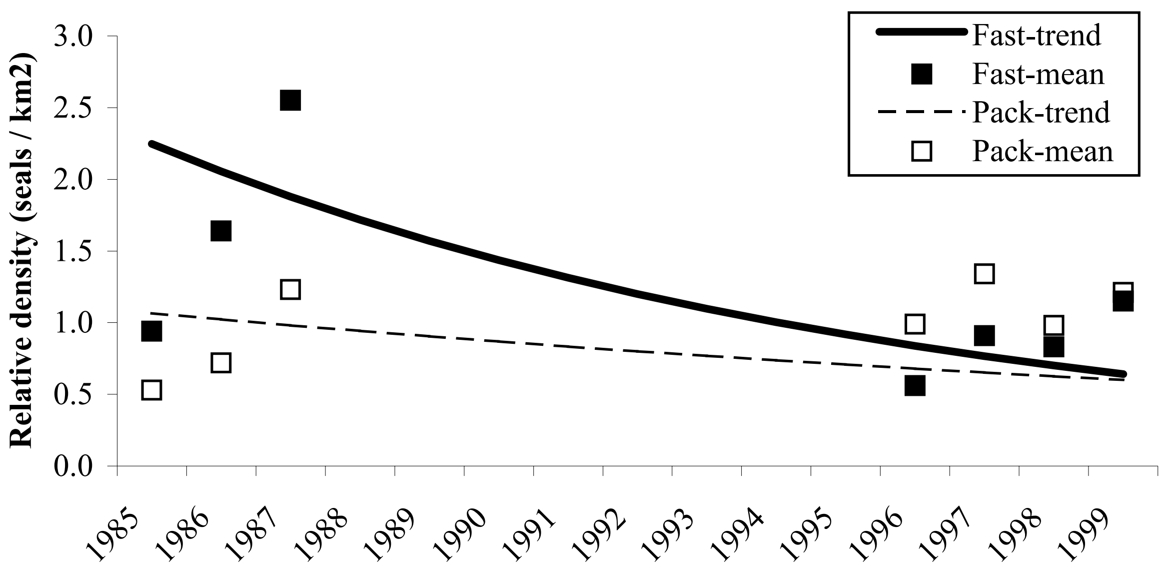


Figure 30. Modeled estimates of ringed seal densities for all ice combined within 40 km of shore based on aerial surveys of the central Beaufort Sea in 1985-1987 and 1996-1999.

DISCUSSION

Factors Affecting Aerial Survey Counts

Since the earliest aerial surveys for ringed seals were conducted, observers have been aware that habitat characteristics, weather, and temporal factors affect the distribution and abundance of seals and the proportion available to be counted during surveys, and therefore introduce variability into counts and estimates of density (Burns and Harbo 1972, Smith 1973, Finley 1979, Smith and Hammill 1981). This is true not only for ringed seals but for other pinnipeds as well (Smith 1965, Olesiuk 1990, Thompson and Harwood 1990, Frost *et al.* 1999a). To improve the reliability of counts and density estimates, and thus improve the ability to detect spatial or temporal patterns in abundance, both survey methods and analytical procedures have been developed to either minimize, or quantify and account for, such variability. Better understanding of such factors (covariates) has made it possible to improve survey results and interpretation by either conducting surveys in a narrow range of "optimal" conditions (Burns and Harbo 1972, Huber *et al.* 2001), or by modeling effects of covariates and then adjusting the data to account for variability (Frost *et al.* 1999a, Boveng *et al.* in press).

In this study, we examined the effects of two types of covariates on observed counts of ringed seals: those that we expected would affect the actual distribution and abundance of seals (habitat-related variables) and those that could affect our ability to count the seals that were present (temporal and weather-related factors).

Habitat Factors

Estimated densities of seals in our central Beaufort Sea study area were lowest in water shallower than 5 m and deeper than 35 m. This was true for the 1980s as well as for the 1990s, although distribution relative to depth was somewhat broader in the 1990s. LGL Limited conducted ringed seal surveys in a subset of our study area (the western half of sector B3, from approximately 147º to 149º W) during 1997-2001 using methods similar to ours (Miller *et al.* 1998, Link *et al.* 1999, Moulton *et al.* 2000, and Moulton *et al.* 2001). For the area they surveyed, the highest seal densities were generally in water 5-15 m deep. Seals were more common in somewhat deeper water in 1999 compared to other years (Moulton *et al.* 2000). Other investigators have also found differences in densities of ringed seals relative to water depth. In the East Siberian Sea, Ognetov (1993) found higher densities of seals in water 10-30 m deep (0.12-0.39 seals/km^2) than in water shallower than 10 m (0.10 seals/km^2) or deeper than 30-40 m (0.01 seals/km^2). In contrast, in the eastern Canadian Beaufort Sea and the Canadian High Arctic, ringed seal densities were generally higher in deeper water (50-100 m or 50-150 m) (Stirling *et al.* 1982, Kingsley 1990). The differences in distribution relative to depth between the Alaskan and East Siberian coasts on one hand and the eastern Beaufort Sea and Canadian High Arctic on the other may be related to coastal topography and the effects it has on both bathymetry and sea ice. Both the central Beaufort and East Siberian Sea coastlines are relatively linear features, with water depths generally getting deeper as one moves north and off shore. In those areas, fast ice occurs as a linear band along the coast. In the eastern Beaufort Sea and the Canadian Arctic, fast ice is much more extensive and extends over much deeper water because it is protected on all sides by land. The stable habitat offered by fast ice can be found farther offshore in deeper water.

Univariate and Poisson regression analyses indicated that observed as well as modeled densities of ringed seals in the central Beaufort Sea were highest near the fast ice edge, and decreased both shoreward and seaward of the edge. Univariate analyses, which did not take into account the interactive effects of other factors, indicated somewhat more annual variability, particularly for the 1980s. However, when data were modeled in combination with other covariates, it was clear that densities were highest near the ice edge. Covariate analysis by Moulton *et al.* (2000) also indicated that during 1997-1999 ringed seals densities in their study area decreased with increasing distance from the fast ice edge.

Some variability may have been introduced into the analysis of density relative to distance from the fast ice edge because of the difficulty of visually determining the position of the edge. Cues to observers for locating the outer edge of the fast ice included the presence of a large pressure ridge or shear area (often on the seaward side of a wide refrozen lead), or the presence of broken ice and open cracks (indicating pack ice). It was sometimes difficult to identify this boundary when a delineating pressure ridge was not visible, when there was a series of such ridges, and/or when no open water was present in the pack ice. Furthermore, early in the season there may be a substantial amount of "attached fast ice" beyond the actual edge (Stringer *et al*. 1980). Until pack ice movement at the onset of breakup begins to fracture the attached fast ice, it is rarely possible to distinguish it from true fast ice. The effects of this problem can be seen in the assigned locations of the fast ice edge by survey personnel in 1985-1987 and 1996-1999 (Figures 2-8). In 1985 and 1986, observers located the fast ice edge well seaward of the 20-m contour, particularly in sector B3. In 1987 and 1996, the assigned location of the fast ice edge closely approximated the 20-m contour, while in 1998 and 1999 it was positioned somewhat offshore. In fact, the "true" fast ice zone in the central Beaufort Sea is usually delineated by a series of offshore shoals at about the 20 m depth contour (Reimnitz and Kempema 1984). Those shoals cause the formation of grounded ice ridges and hummocks that protect the ice between there and shore from pack ice forces, and create the relatively immobile and flat fast ice zone that persists well into June.

It is unclear what makes the fast ice edge so attractive to ringed seals and results in higher densities in that region. Seals feed at a reduced rate, as indicated by stomach contents and body condition, during late spring when they are entering the molt (Lowry *et al.* 1980, Frost and Lowry 1984). However, seal distribution and density in late May and early June, prior to breakup, are thought to reflect distribution patterns established earlier in the year. Higher abundance of seals in an area could indicate greater availability of prey during fall and winter when seals are actively feeding and when breathing holes are established. Alternatively, higher densities near the edge at the time of our surveys could be due to an influx of seals from other regions. During late winter and spring, ringed seals are thought to partition their habitat based on age, sex, and reproductive status, with adults predominating in and near the fast ice, subadults in the flaw (or edge) zone, and both occurring in drifting pack ice (McLaren 1958, Smith 1973). Until territoriality breaks down at the end of the breeding season, most seals seen on fast ice are single seals at holes. As the season progresses, average group size increases and it is much more common to see multiple seals at the same hole, or many seals along a crack in the ice (Smith and Hammill 1981, Finley *et al.* 1983, Frost *et al.* 1988). Subadults wintering outside the fast ice habitat may move into the fast ice to molt, resulting in high local densities just shoreward of the edge (Finley 1979). Seals may also move into a region as breakup progresses in other areas (Kingsley *et al*. 1985, Smith and Harwood 2001). A seal tagged at Little Diomede Island, Alaska, in May 2001 moved >700 km north and east into the Chukchi Sea before its tag ceased to transmit in June (Sheffield and Menadelook 2001). It is possible that ringed seals prefer to haul out and molt on fast ice rather than pack ice because they are less vulnerable to polar bear predation in fast ice areas.

We found a strong and consistent relationship between seal densities and the degree of ice deformation in all years and for all years combined, with more seals found in flatter, less deformed ice. Similarly, Frost *et al*. (1988) reported that observed ringed seal densities during early June were higher in flat ice than in rough ice throughout both the Chukchi and Beaufort seas. However, once the ice began to crack and break up, they found that the correlation between ice deformation and observed seal density disappeared. Investigators in the eastern Beaufort Sea and the Canadian Arctic have also reported that during the molting season ringed seals bask in flat, open areas (Smith and Stirling 1975, Stirling *et al*. 1977, Smith 1980). Moulton *et al*. (2000) speculated that densities might be lower in rough ice because seals were harder to see. While that possibility cannot be entirely dismissed, the absence of a correlation between density and ice deformation after the beginning of breakup reported by Frost *et al*. (1988) suggests that the difference is related to seal distribution and not observer bias.

Ringed seals are a primary prey of polar bears in most parts of their range, and the constant threat of predation has shaped their behavior on the ice (Smith 1980, Kingsley and Stirling 1991, Stirling and Øritsland 1995). Bears hunt mostly along pressure ridges, in hummocky ice, and at the edges of rough ice areas, but seldom in flat open areas. Seals in turn haul out to bask in areas where they can see and smell approaching predators, and where they can escape down holes or cracks too small for a polar bear to follow (Kingsley and Stirling 1991). It is not surprising that densities of basking ringed seals are higher in flat ice than in rough, ridged ice where polar bears hunt more commonly.

We tested the effect of longitude on the distribution and abundance of seals because we thought it possible that there might be some east-west habitat gradient that was not reflected in the other variables incorporated in our analyses. While both univariate analysis and Poisson regression models indicated significant longitudinal gradients in some years, the trends were not the same in all years. This is not surprising, since factors that might be responsible for a latitudinal gradient may differ from one year to the next. For example, prey distribution and abundance might vary annually, as might the dynamics of freeze up and the subsequent development of fast ice.

Factors Affecting Proportion Hauled Out

The proportion of ringed seals hauled out at any particular time during late spring when surveys are conducted can be highly variable, ranging from 23% to 90% or more (Finley 1979, Smith and Hammill 1981, Kelly and Quakenbush 1990, Lydersen 1991, Born *et al.* 2002). This variability has important implications for interpretation of aerial survey results. Annual differences in survey conditions that affect the proportion hauled out can make comparisons of density estimates to determine trend more difficult. Standardizing conditions under which surveys are flown is one way to reduce variability in counts, and that has been a common procedure. For example, since the early 1970s most ringed seal surveys have been flown during midday, in June, at wind speeds less than 40 km/hr (Burns and Harbo 1972, Smith 1975, Finley 1979, Smith and Hammill 1981). Nonetheless, even with such restricted survey windows, there may still be considerable variability in the proportion of seals hauled out.

Univariate analysis of the data we collected from 1985 to 1999 suggested that observed densities of hauled out seals were generally highest between about 1100 and 1400 hrs local time (solar noon is about 1300 hrs). Some years, most notably 1999, did not follow this pattern. In contrast, Poisson regression models for density relative to time of day for the 1980s and all data combined predicted that densities would be highest at 1000 or 1100 hrs and decline steadily throughout the day. There was no significant relationship between time of day and density for the 1990s. Moulton *et al*. (2000, 2001) found a similarly inconsistent relationship between the number of ringed seals hauled out and time of day. In contrast to inconclusive results from analyses of aerial survey data, the results of most tagging studies indicate a strong diurnal component to ringed seal hauling out behavior, with most seals hauled out between mid morning and late afternoon (Finley 1979, Smith and Hammill 1981, Lydersen 1991, Kelly and Quakenbush 1990, Kelly *et al.* 2000). However, seals tagged in northwest Greenland showed no diel pattern in hauling out between June and August (Born *et al*. 2002). It may not be surprising that regression analysis did not appear to accurately predict diel seal behavior, since our surveys occurred only within the peak hauling out period. Kingsley *et al*. (1985) reported that time of day was not a significant factor in multiple regression analysis of ringed seal densities in the Canadian High Arctic. They noted there was good evidence of diurnal behavior from other studies and suggested that the lack of a significant correlation was probably because surveys were conducted during the middle of the day when seals were most likely to be hauled out.

Although more ringed seals generally are seen basking on warm, sunny days with relatively light winds, it is difficult to statistically quantify this relationship. Any analysis of the effects of weather on seal counts is complicated by the lack of local, on-site information about weather conditions. Temperature and wind speed recorded from the survey aircraft at survey altitude or from weather stations on land may not accurately reflect conditions on the ice. It is not surprising, therefore, that our analyses of these factors relative to seal counts were inconsistent and inconclusive. Furthermore surveys are generally not conducted in weather considered unsuitable for hauling out (Lunn *et al*. 1997, Kingsley *et al*. 1985). In addition, cloud cover may affect seal counts in contradictory ways, thus obfuscating any relationship that may exist. For example, seals may prefer to haul out on warm clear days, but such conditions can also result in sun glare that impairs observers' ability to count. Conversely, cloudy days might be less optimal for hauling out but better for detecting seals. Attempts by other investigators to quantify the effects of weather on aerial survey results have also been inconsistent and inconclusive, with multivariate regression analysis often producing results that either contradict other studies, vary across years or survey replicates, or conflict with what is known about seal behavior (Finley 1979, Kingsley *et al*. 1985). In fact, Kingsley *et al*. (1985) concluded that multivariate regression using wide-area survey data was ineffective for determining the effects of weather, and they did not use weather variables in their multivariate analysis.

Notwithstanding the above, some investigators have been able to demonstrate effects of weather variables such as wind speed and temperature on the hauling out behavior of ringed seals as well as other as seal species. Densities were negatively correlated with wind speed for ringed seals in the Canadian Arctic (Smith and Hammill 1981, Stirling *et al*. 1982) and Weddell seals (*Leptonychotes weddelli*) in the Antarctic (Wartzok 1991). For ringed seals, as well as other ice associated seals, temperature seems to have the greatest influence when it is too warm and may exceed the animals' thermal tolerance. Densities decrease when conditions are too warm and calm (Burns and Harbo 1972, Finley 1979, Harrison and Kooyman 1968). Watts (1996) suggested that temperature appears to be less significant in models that take time of day and date into account, since to some degree they measure the same thing.

Aerial Survey Design

Methods for conducting aerial surveys of ringed seals have been similar for the last 30 years or more, and have generally been standardized to exclude very windy or stormy weather and to minimize the effects of diurnal haulout patterns by flying in the middle of the day (Stirling *et al.* 1977, Kingsley *et al.* 1985, Frost *et al.* 1988, Lunn *et al.* 1977). Nonetheless, investigators have documented substantial within and between year variability in both survey conditions and the characteristics of sea ice, and have recognized that it may be difficult to identify abundance trends in light of such variability. Interannual comparisons of seal densities within an area may show the true status of the population, or may instead reflect annual differences in counting conditions or the proportion hauled out.

For many pinniped species, the physical attributes of habitat that influence distribution and abundance remain similar over time. For example, physical characteristics of the rocks and sandbars on which hauled out harbor seals are counted change little from year to year. Counts may change due to factors such as weather, time, or tide, but not because of changes in the haulout itself. This makes it possible to model the effects of factors responsible for variation in counts, and thus make more realistic estimates of both abundance and trend (see Frost *et al*. 1999a, Boveng *et al.* in press, Ver Hoef and Frost in press).

In contrast, the dynamic sea ice habitat used by ringed seals is temporally variable on short (days and weeks) as well as long (annual and decadal) time scales. A particular geographic location may have suitable ice conditions one year but not the next. Weather at the time of freeze-up and throughout the winter affects ice roughness and snow cover, which in turn determine the suitability of ice as seal habitat. Even within the same season, snow and ice conditions may change dramatically within just a few days, particularly around the time of breakup (Frost *et al*. 1988). Not only do ice conditions change dramatically during break-up, but there is substantial annual variation in when break-up occurs. This type of variability makes the timing of surveys and between-year comparisons very difficult.

Measuring and Incorporating Covariate Effects

One of the primary reasons for conducting ringed seal surveys is to detect changes in seal abundance over time and to quantify those changes with some degree of statistical certainty. Detection of trend is complicated when there is substantial within or between survey variability in density that is unrelated to true abundance. When some or all of the factors responsible for variation are known, it may be possible to adjust survey methods to minimize the effects of such factors, *i.e.* to use a relatively narrow and standard “survey window” in an attempt to hold the covariates constant (Burns and Harbo 1972, Stirling *et al.* 1977, Frost *et al.* 1988, Thompson and Harwood 1990, Watts 1996, Lunn *et al.* 1997, Frost *et al*. 1999a). Nonetheless, complete standardization is impractical, and some covariate effects are likely to remain. In an attempt to deal with this problem, Kingsley *et al.* (1985) did multivariate regression analyses of data from aerial surveys of ringed seals in the Canadian High Arctic. They then used the information from the regression analysis to determine optimum habitat and survey conditions, and selected a subset of the complete dataset for use in calculating stratum densities.

Some investigators have used correction factors to account for certain measurable covariate effects. Olesiuk *et al.* (1990) used a correction factor to adjust for the effects of date on harbor seal (*Phoca vitulina*) counts during the pupping season. Beaufort sea state and cloud cover had substantial effects on counts of harbor porpoises (*Phocoena phocoena*), and Forney *et al.* (1991) used those factors as covariates in their trend analysis. Similarly, DeMaster *et al*. (2001) considered effects of Beaufort state when developing correction factors for aerial surveys of beluga whales (*Delphinapterus leucas*). Garrott *et al.* (1995) modeled the effects of survey conditions and air and water temperature on counts of Florida manatees (*Trichechus manatus latirostris*), and found that about 50% of the variation in counts was explained by those factors. After that variation was accounted for, they were able to detect a significant increase in the number of manatees counted along the Florida coast in 1982-1992. Frost *et al.* (1999a) considered tide, time of day and date as covariates in their analysis of harbor seal aerial survey counts in Prince William Sound, Alaska. If they ignored the effects of covariates, a negative trend in seal counts during 1990-1997 was not significant. However, when covariates were used to “normalize” the data to standard conditions, the decline became highly significant.

It was our hope at the beginning of this project that we might be able to use Poisson regression models to develop parameter estimates for the different covariates and use them to "correct" the data to standard conditions, thus making our estimated index of ringed seal density more accurate and our interpretation of trend more reliable. However, the results of our analysis of survey data collected over seven years using similar methods and frequently the same observers revealed problems with that approach. For several habitat-related covariates (ice deformation, distance from the fast ice edge, water depth), results of univariate and multivariate analysis indicated similar relationships. For others, such as weather related variables and time of day, neither analysis was particularly informative. The relationship between weather and time variables tended to be inconsistent for univariate analyses, and not surprisingly, were often not significant in Poisson regression models (Table 10). This may have been in part because the survey "window" had already been standardized to optimize the conditions under which surveys were flown.

Table 10. Summary of univariate and multivariate analyses of ringed seal densities in the central Beaufort Sea relative to environmental and temporal variables, based on aerial surveys conducted in 1985-1987 and 1996-1999 ("+" = significant effect. "ns" = not significant).

	Univariate			Multivariate		
Variable	1980s	1990s	All Yrs	1980s	1990s	All Yrs
Habitat						
Water depth	+	+	+	+	+	+
Distance from fast ice edge	+	+	+	+	+	+
Ice deformation	+	+	+	+	+	+
Longitude	+	+	+	+	+	+
Temporal						
Time of day	+	+	+	+	ns	+
Weather						
Cloud	+	+	+	ns	ns	ns
Temperature	mixed	+	+	ns	+	+
Wind speed	+	+	+	ns	ns	ns
Other						
Melt water	+	mixed	+		not included	

We included a spatial component in the Poisson regression to account for possible spatial correlation in the data, with survey line treated as a random effect. The variance structure of the model showed little evidence of spatial correlation among residuals within a survey line (Table 11). However, there was substantial variation among lines, particularly for the 1980s when among-line variance was 39% of the total error variance.

Effects of Survey Date on Seal Counts

Kelly *et al.* (2000) monitored the hauling out behavior of 18 ringed seals tagged in the central Beaufort Sea in 1999 and 2000. They found that early in spring seals hauled out exclusively in snow covered lairs where they could not be seen by observers. As the season progressed, seals gradually began to haul out on the surface of the ice where they could be counted during surveys. Once seals began to bask, they did not return to their lairs. Field measurements indicated that most seals were basking when the snow temperature near the snow-ice interface had warmed to 0º C, and that snow temperature might be a good predictor of peak haulout and therefore of the best time to conduct surveys. However, even though a snow temperature of 0º C predicted basking and May 31st was the day on which 50% of tagged seals were basking in both 1999 and 2000, there was a substantial between-year difference in the length of the transition period from resting in lairs to hauling out on the surface. In 1999, only seven days lapsed between the time the first tagged seal basked outside of its lair and when 75% of the tagged seals were basking. In contrast, the transition period lasted 24 days in 2000. Kelly *et al.* estimated that only 12% of the seals present in their study area were hauled out on 29 May 1999 compared to 40% just six days later. Thus our 1999 surveys, which were flown during 29 May-4 June, very likely counted a rapidly changing proportion of the population. Born *et al*. (2002) also found that the proportion of time ringed seals spent hauled out changed rapidly in spring. It is unknown how much geographical variation there may be in the onset of basking within a region such as the Beaufort Sea.

Table 11. Variance components associated with Poisson regressions of seal counts on year and covariates.

Covariance parameter	Parameter estimate	Proportion of total error variance
1980s		
Line*yr variance	5.084	0.391
Sill-Nugget (autocorrelation)	0	0
Residual variance	7.931	0.609
Total error variance	13.016	1.000
1990s		
Line*yr variance	0.811	0.102
Sill-Nugget (autocorrelation)	0.012	0
Residual variance	7.123	0.896
Total error variance	7.946	1.000
All years		
Line*yr variance	1.807	0.188
Sill-Nugget (autocorrelation)	0.003	0
Residual variance	7.797	0.812
Total error variance	9.607	1.000

While it is useful to know when most seals are on the surface basking, that unfortunately does not resolve other survey-related problems. Even if snow temperatures do reliably predict basking, and if, as suggested by Kelly *et al.* (2000), a proxy can be found for actual on-ice snow temperatures, it is still not certain that counts from surveys will reflect only seals resident in the survey area. Concurrent with the increased visibility of resident seals later in the spring may be an influx of seals from the pack ice as well as from other geographic regions (Finley 1979, Smith and Harwood 2001). Whether or not this occurs, and to what degree, has not been documented in the Alaskan Beaufort Sea. The chronology of breakup, both within the survey area as well as in areas far removed, may affect what seals are present during the survey period. Also, resident seals may not always bask in the same location as where their winter lairs were located (Kelly and Quakenbush 1990, Kelly *et al.* 2001).

In addition to the biological factors described above, annual variability in weather conditions may also affect timing of surveys. From the perspective of observers, the optimal timing for ringed seal surveys is before sea ice break up begins and when water on the ice surface from melt and overflow of rivers is not yet extensive (Burns and Harbo 1972, Frost and Lowry unpubl. obs.). In the central Beaufort Sea, such conditions generally occur in late May to early June, but that is not always the case. In our surveys, melt water covered <2% of the ice we surveyed in four years, and 38%-94% in the other three years. In 1998, 80%-90% of the ice near shore was covered by melt water when surveys were flown in 27-28 May, resulting in poor conditions for counting seals. Thus, conditions in 1998 had deteriorated before the usual scheduled date for surveys to begin, and may have been unsuitable for surveys before the date that most seals were basking. Prudhoe Bay temperature records show that weather was extraordinarily warm in April-May 1998 (Table 12).

Table 12. Temperature and heating degree day data for Prudhoe Bay, 1985-1989 and 1996-1999, and dates when aerial surveys were conducted in the central Beaufort Sea.

Year	April mean temperature (°C)	May mean temperature (°C)	April heating degree days[1]	May heating degree days[1]	Survey dates
1985					9-12 June
1986	-22.2	-7.5	2,192	1,435	31May-12 June
1987	-22.3	-6.4	2,199	1,377	6-7 June
1996	-19.1	-2.8	2,019	1,173	29-31 May
1997	-16.7	-5.1	1,890	1,297	27 May-1 June
1998	-9.2	-2.0	1,484	1,130	27-28 May
1999	-19.3	-3.9	2,035	1,234	29 May-4 June

[1] Calculated as the daily average temperature in degrees Fahrenheit subtracted from 65 and summed for all days in the month. Larger values indicate colder weather.

In our survey design we tried to minimize the effect of date as much as possible by narrowing the survey window and conducting surveys before breakup and melting occurred. As a result surveys in the 1990s were flown several days earlier than those in the 1980s. A cursory examination of temperature records confirms that the weather in the study area in April and May was consistently much warmer in the 1990s (Table 12). Mean April air temperatures at Prudhoe Bay were 3-13°C warmer in the 1990s, while May temperatures were 2-5°C warmer. Heating degree days data suggest that an equivalent amount of warming occurred 5-10 days earlier in the 1990s than in the 1980s, which is similar to the difference in our survey dates.

Our surveys were not designed to quantify effects of date on seal behavior. Because surveys flown in the 1990s were done over relatively short periods of 2-7 days, it was not possible to model the effect of date in the covariate analysis. While surveys in the 1980s occurred over a broader date range and it was clear that there was a strong date effect (Frost *et al.* 1988), there was almost no overlap in survey dates between the 1980s and the 1990s that would allow us to distinguish date-related influences from long-term trends in abundance. While Poisson regression analysis enabled us to quantify and model the effects of some covariates, the final model did not account for a substantial proportion of the variation in seal counts. We think that this may be largely due to the effects of temporal variation in the proportion of seals hauling out.

Efforts to improve our estimates of trend must include quantification of the effects of within and between-year temporal variation on survey counts.

Use of Power Analysis

We conducted power analysis to evaluate our ability to detect changes in ringed seal abundance and also as a means of evaluating whether Poisson regression models, which incorporated the effects of environmental, weather and temporal covariates, improved our ability to detect trend. Results indicated that power was low for all combinations of sample size, years, and population change. The low power is the result of the large variation in counts (mostly 0 or small counts but occasional large counts >10), the large effect of other variables on the counts such as ice deformation and geographic position, and the large variation in conditions from year to year. Such factors make detection of temporal changes in the ringed seal population difficult even for long term studies with intensive surveys.

In general, power characteristics of the Poisson model were better than those of the log-linear regression on raw counts. Power was approximately twice as high with the Poisson models for most combinations of years, sample size, and trend compared with the raw count regressions (Figure 31). For very large declines and 10 years of data, the power of Poisson model was about 35% higher. As for the raw count regressions, power under the Poisson model was higher for detecting population declines than for detecting increases of the same magnitude. In contrast with the 5-year raw count regression results, the performance of the Poisson model when there was no trend was good for both 5 and 10 years of data with rejection rates less than or equal to the expected rate of 5%. The one aspect of power where the raw count regression (10 years only) was superior to the Poisson model was with 'false' rejections (e.g., significant estimated negative trend when the true trend is positive) when there was a trend. Under the raw count model with 10 years of data, the 'false' rejection rate declined to 0 as trend increased. This did not occur under the Poisson model. If the Poisson model is used for estimating trend from future survey data, this undesirable property of 'false' trends will need to be balanced against the highly desirable trait of increased power.

Regardless of whether we used observed or Poisson modeled densities, almost no additional power was gained by adding more lines to the survey coverage. Power increased markedly when the survey period was increased from 5 years to 10 years. With five years of simulated data, the regression of yearly total "raw" counts against years had poor characteristics in terms of both low power to detect change and high rates of 'false' trends. With 10 years of simulated data, there was moderate power to detect large changes in population (20% annually) with good (*i.e.*, low) rates of 'false' trends. However, an annual population change of 20% is not likely for long-lived, slow-reproducing mammals such as ringed seals. Our analysis indicated almost no power to detect an annual trend of 5%, suggesting that current survey methods must be modified if surveys are to be useful for detecting trends in abundance.

Power analysis and other methods of assessing sampling adequacy or desirable sample sizes are difficult in complex problems such as our ringed seal surveys. For simple statistical situations involving only a single parameter (e.g., t-tests, 2x2 contingency tables, simple linear regression) exact power curves for a range of effects are easily calculated (Thomas 1997). But in complex multi-parameter analyses of population change based on incomplete counts, covariates, and possible spatial correlation, such as our survey, the number of alternative hypotheses that need to be considered rapidly becomes too large for exact computation. In these cases power must be approximated using simulation. In our power simulations, we attempted to maintain the inter-relationships among the covariates and natural variability in the data, while investigating how the Poisson regression model detected systematic changes in our main variable of interest, trend. However, to reduce these simulations to a tractable problem required a number of assumptions. We assumed that the relationships of the covariates to the counts were known (*i.e.*, we used the estimated coefficients from our 1990s, fast ice analysis as known constants). We also assumed the estimated overdispersion parameter was known. The use of a gamma-Poisson mixture model to simulate a long-tailed distribution of counts (*i.e.*, many 0 counts but a few large counts as well) gave a pattern similar to our observed data, but undoubtedly not exactly the same. Because of these necessary assumptions and simplifications, the estimates of power we present should be interpreted as rough approximations to power useful for planning future survey efforts.

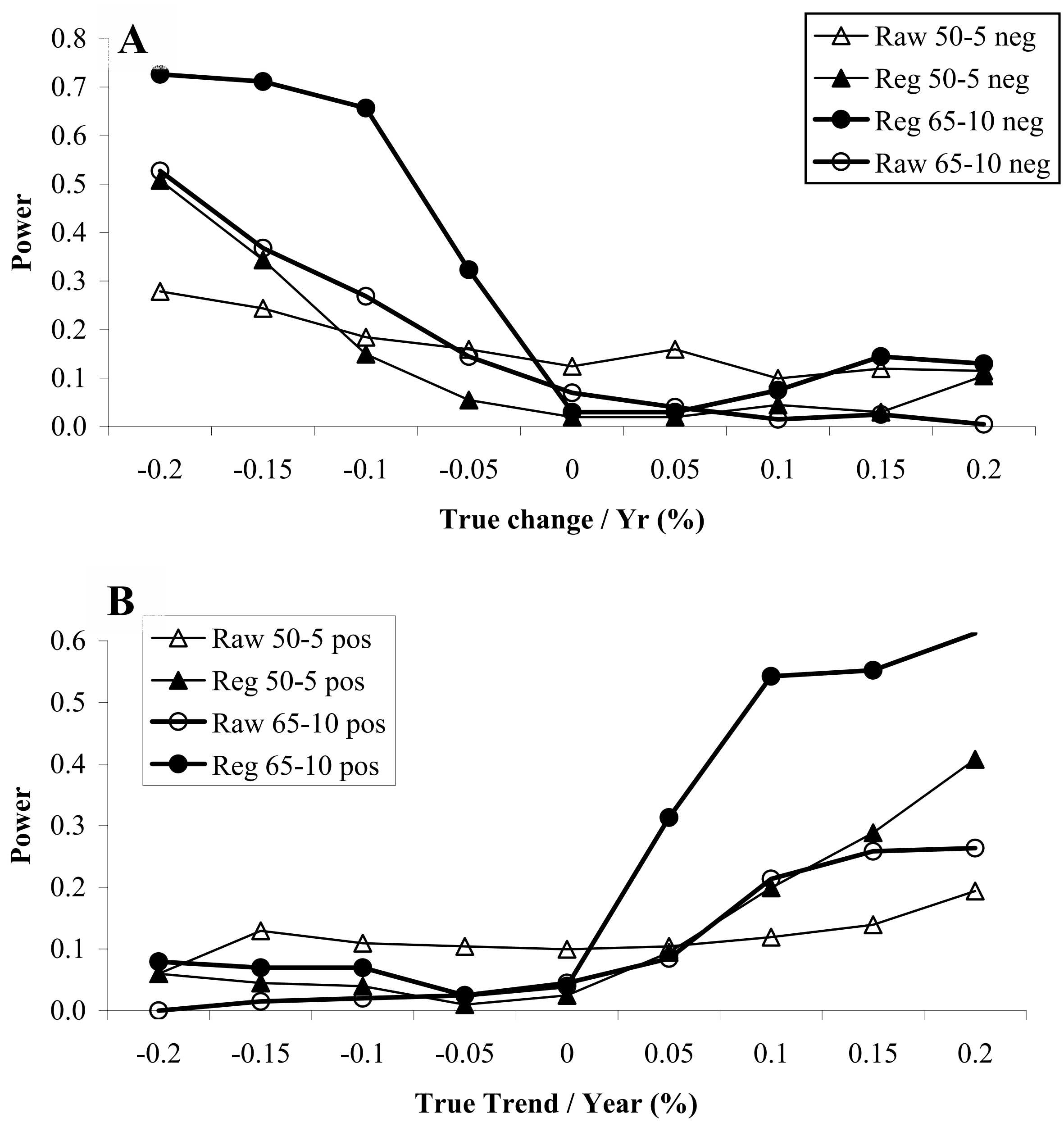


Figure 31. Comparison of estimated power to detect trend for raw and modeled densities. Power is based on 1-tailed tests for rates of change not equal to zero: a) negative trends and b) positive trends.

Variability and Trends in Ringed Seal Densities

Both observed and modeled densities of ringed seals in the central Beaufort Sea indicated considerable annual variability on both fast ice and pack ice. The lowest observed annual density during the 1980s was similar to densities in 1998 and 1999 and about 25% higher than the lowest density during the 1990s. The highest annual density during the 1980s survey period, however, was more than double the highest density for the 1990s. The range in density estimates from the Poisson regression model was somewhat greater, with a threefold difference between the modeled densities for 1985 and 1999.

Densities reported by Moulton *et al*. (2000) for the western part of our study area were substantially lower than those calculated from our surveys (1997 – 0.43 seals/km^2 vs. 0.77 seals/km^2 in our sector B3; 1998 – 0.39 seals/km^2 vs. 0.76 seals/km^2 in B3; 1999 – 0.63 seals/km^2 vs. 0.87 seals/km^2 in B3; see Appendix A). Those differences may be explained by a longitudinal gradient in density because the Moulton *et al.* surveys encompassed only the western portion of sector B3 while our Poisson regression analysis showed significantly higher densities occurring to the east.

Densities reported for our surveys are generally within or somewhat higher than the ranges reported for other areas where ringed seals have been surveyed. In the eastern Beaufort Sea in the 1970s, ringed seal densities ranged from about 0.1-0.5 seals/km^2 (Stirling *et al*. 1977). In the Canadian High Arctic, densities in the early 1980s were between 0.06-1.16 seals/km^2, depending on the area and year. Densities in northwestern Baffin Bay in the early 1980s (1.3-1.7 seals/km^2; Finley *et al*. 1983) and Hudson Bay during the early 1990s (0.38-1.93 seals/km^2; Lunn *et al.* 1997) were comparable to results of this study. In some areas, densities as high as 7-14 seals/km^2 have been reported (Smith and Hammill 1981). Marked between-year variations in density estimates are common for ringed seal surveys. Two- to four-fold annual differences have been reported in this and other studies. Such differences have variously been attributed to actual changes in seal abundance or to differences in the proportion hauled out due the timing of surveys relative to ice conditions and timing of the annual molt (Stirling *et al.* 1982, Frost *et al.* 1988, Lunn *et al.* 1997).

Trend analysis based on an ANOVA comparison of observed seal densities in the central Beaufort Sea suggested a marginally significant but substantial decline of 31% from the 1980s to the 1990s. The Poisson regression model indicated highly significant declines of 72% on fast ice and 43% on pack ice over the 15-year period. However, the apparent decline between the 1980s and the 1990s may be due to a difference in the timing of surveys rather than an actual decline in abundance. The 1990s surveys were conducted several days earlier than surveys in the 1980s due to warmer weather (see Table 12) and its anticipated effect on ice conditions. If the phenology of seal basking was comparably earlier in the 1990s than in the 1980s then the decline in seal numbers may well be real. However if such a change in seal basking did not occur, then the 1990s surveys were flown at a time when a relatively small proportion of seals were visible and the apparent decline could be an artifact. Because of problems such as this, Stirling *et al.* (1977) pointed out the value of having other evidence (reproductive rates, lair surveys, evidence of polar bear predation) to corroborate survey results. Unfortunately no such corroborative information is available for ringed seals in the central Beaufort Sea.

Regardless of whether or not the differences in ringed seal densities described above are real, there are several reasons to think that ringed seal abundance in the Beaufort Sea either has changed or is likely to change in the future. Ringed seals are the primary prey of polar bears (Smith 1980), and a detailed analysis by Stirling and Øritsland (1995) suggests that in many regions ringed seal populations may be limited by polar bear predation. There is evidence that the southern Beaufort Sea polar bear population increased considerably during the 1970s and 1980s (Amstrup *et al*. 2001), and increased predation could have reduced ringed seal abundance. Ringed seals are part of a relatively simple food web in the Beaufort Sea (Frost and Lowry 1984) where they feed primarily on crustaceans and arctic cod (*Boreogadus saida*). The population of bowhead whales, which feed in the Beaufort Sea and may compete for food with both ringed seals and arctic cod (Lowry 1993), has been increasing and is now much larger than it was in the 1970s (Zeh *et al*. 1993). Perhaps most importantly, because of their strong dependence on sea ice ringed seals are very likely to be affected by climate change, which is predicted to result in considerable warming and loss of sea ice in the Beaufort Sea region (Vinnikov *et al*. 1999). As climate warms, impacts on ringed seal distribution, abundance, and productivity will likely result from the combined effects of changes in physical habitats, changes in prey populations, and changes in inter-species interactions (Lowry 2000). There is little information that can be used to predict how the Beaufort Sea ringed seal population will respond to climatic warming, but at least one study has shown how variation in the stability of shorefast ice or the timing of breakup can reduce ringed seal productivity (Smith and Harwood 2001).

CONCLUSIONS AND RECOMMENDATIONS

1) The apparent decline in observed and modeled ringed seal densities between the 1980s and the 1990s may be due to a difference in the timing of surveys rather than an actual decline in abundance. Surveys in the 1990s were conducted a week or more earlier than surveys in the 1980s, and may have occurred before the maximum number of seals were hauling out to bask. If the phenology of seal basking was comparably earlier in the 1990s than in the 1980s then the decline in seal numbers may well be real. However if such a change in seal basking did not occur, then the 1990s surveys were flown at a time when a relatively small proportion of seals were visible and the apparent decline could be an artifact.

2) Univariate and Poisson regression analyses both indicated that habitat-related factors including ice deformation, water depth, and distance from the fast ice edge significantly affected the distribution and abundance of seals. Densities decreased as ice deformation increased and with increasing distance from the fast ice edge. Seal densities were highest in water >5-35 m deep. The effects of longitude were not consistent across years or between analyses.

3) Analyses of the effects of weather-related variables, time of day, and melt water were inconsistent across years and between analytical methods. Poisson regression analysis did not contribute significantly to our understanding of the effects of these variables, perhaps because the survey “window” had already been standardized to optimize the conditions under which surveys were flown.

4) Date was not included as a covariate in our analyses because a representative date range was not surveyed in all years. An unknown proportion of annual variation in density estimates is likely due to the unquantified effects of date. For this reason, future efforts to improve estimates of trend should include quantification of the effects of within and between-year temporal variation on survey counts.

5) It is apparent from these and previous surveys that the observed distribution and abundance of ringed seals may change not only between years but also during a selected survey period. It is unclear whether and to what degree such changes represent a change in hauling out

behavior, immigration from the pack ice or other areas as breakup begins, or a combination of these factors. In order to conduct future surveys at the appropriate time and to better interpret results and facilitate trend analysis, it is essential to better understand temporal changes in distribution and haulout behavior. While progress has been made in identifying behavioral changes at the onset of basking, virtually nothing is known about distributional changes at this time of year.

6) Based on our simulations (including their inherent weaknesses), accounting for the effect of covariates to the extent possible when estimating population trend should be done; this was especially the case for short time series. However, even with improved power from the more complex analyses, the ability to detect changes of the sizes expected (5% per year or less) was poor. In addition, both regression approaches seemingly result in conservatively biased trend estimates (*i.e.*, true trends are more extreme than estimated trends). Because of the dynamic nature of the seals and their environment, changes in survey protocols are likely necessary to improve the sensitivity of monitoring programs. These changes might include the use of radio-marked animals and/or repeated surveys over smaller areas.

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APPENDIX A

APPENDIX A

Densities of ringed seals

The tables present the lines flown and the unadjusted densities of observed ringed seals by sector for fast ice, pack ice, and all ice combined for aerial surveys conducted in the Alaska Beaufort Sea during 1985-1987 and 1996-1999.

Table A.1. Dates and lines surveyed for aerial surveys conducted in May-June 1985-1987 and 1996-1999. All surveys were flown at an altitude of 91 m with a strip width of 0.41 km on each side of the aircraft.

Date Sector (Lines flown)

1985
6/9/85 **B3** (18,20,21,22,23,24,26,27,28,29,31,32,33,34)
6/11/85 **B3** (1,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17) **B2** (27,29,30,31,32,33)
6/12/85 **B3** (35,36,37,38) **B4** (1,2,5,6,7,9,14,15,17,18,19,20,21,22)
6/13/85 **B2** (2,4,5,8,10,11,12,13) **B1** (18,19,20,24,26,27,28,29,33,34)

1986
5/31/86 **B1** (1,2,4,5,8,10,12,13,14,15,16,21,22,24)
6/1/86 **B1** (28,29,30,31,32,34)
6/4/86 **B2** (1,4,6,7,9,12,13,14,15,17,18,19,20,23,26,27,30,31)
6/6/86 **B2** (28,29,34) **B3** (1,3,5,7,8,10,12,15,17,19,23,25,28,31,33)
6/12/86 **B3** (38,37,36) **B4** (8,10,11,12,13,14,16,18,1111119,20,23,24)

1987
6/2/87 **B1** (2,3,5,7,9,10,11,14,15,17,18,20,23,24,25,27,28,30,32,33,34)
6/3/87 **B2** (4,5,6,7,10,11,14,16,17,18,19,20,22,23,25,26,27)
6/5/87 **B2** (29,30,32,34)
6/6/87 **B3** (3,4,5,6,8,11,14,15,16,17,19,20,21,23,24,25,28,29,32,33)
6/7/87 **B3** (34,35,37) **B4** (2,5,6,9,11,12, 13,15,16,18,19,20,22,23,24)

1996
29 May **B2** (33) **B3** (4, 5, 6, 6.5, 8.5, 12, 14, 14.5,15, 23, 25, 30, 31, 32, 33, 35,36 ,37 ,38)
30 May **B2** (32, 34) **B3** (1, 2, 3, 5.5, 7, 7.5, 8, 9, 9.5, 10, 10.5, 11, 11.5, 12.5, 13, 13.5, 16, 20, 21, 24, 30)
31 May **B3** (17, 18, 19, 22) **B4** (1, 2, 3, 4, 5, 6, 7, 8, 9, 10,11,12,14,15,17,20,22,23)

1997
25 May **B1** (1, 3, 5, 6, 7, 9, 11, 12, 13, 15, 17, 19, 21, 22, 23, 25, 27, 28, 29)
26 May **B1** (31, 33) **B2** (1, 3, 4, 5, 7, 8, 9, 11, 13, 15, 17, 18, 19, 21, 23, 25, 27)
27 May **B3** (5.5, 6.5, 7.5, 8.5, 9.5, 10.5, 11.5, 12.5, 13.5, 14.5, 22.5, 23.5, 24.5, 25.5, 26.5, 27.5, 28.5, 29.5, 30.5)
28 May **B3** (17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 28, 30, 31, 32)
29 May **B2** (28, 29, 31, 33) **B3** (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16)
31 May **B4** (5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24) **B3** (27, 29)
1 June **B4** (1, 2, 3, 4, 9.5, 10.5, 11.5, 12.5, 13.5, 14.5, 15.5) **B3** (33, 34, 35, 36, 37, 38)
2 June **B1** (15, 17, 19, 21, 22, 23, 25, 27, 28, 29)

1998
27 May **B3** (1, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38) **B4** (2)
28 May **B3** (4, 6, 7, 9, 11, 21, 23, 25, 27) **B4** (4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24)

1999
29 May **B2** (7, 8, 9, 11, 13, 15, 17, 18, 19, 21, 23, 25, 27, 28, 29, 31, 33) **B3** (1, 2, 3)
30 May **B3** (4, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 22, 24, 26, 27, 28, 29, 30, 31)
31 May **B3** (5, 5.5, 6.5, 7, 7.5, 8.5, 9.5, 10.5, 11.5, 12.5, 13.5, 14.5, 19, 21, 22.5, 23, 23.5, 24.5, 25, 25.5, 26.5, 27.5, 28.5, 29.5)
1 June **B1** (7, 11, 12, 13, 15, 17, 19, 21, 23, 27, 29, 33) **B2** (1, 3, 5)
3 June **B1** (25, 28, 29, 31) B4 (4, 6, 8, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24)
4 June **B3** (30.5, 31, 33, 34, 35, 36, 37, 38) **B4** (2, 3, 5, 7, 9, 9.5, 10.5, 11.5, 12.5, 13.5, 14.5, 15.5)

Table A.2. Unadjusted densities of observed ringed seals, by sector, for fast ice, pack ice, and all ice combined within 40 km of shore based on May-June 1985 aerial surveys.

1985	Fast Ice			Pack Ice			All Ice		
	Hole	Crack	All	Hole	Crack	All	Hole	Crack	All
B1 (n=10)									
density	0.73	0.11	0.83	0.34	0	0.34	0.72	0.10	0.83
SE	0.10	0.05	0.13	0.36	0	0.36	0.09	0.05	0.13
LCL	0.55	0.01	0.60	0	0	-1.91	0.55	0.01	0.59
UCL	0.90	0.20	1.07	2.58	0	2.58	0.90	0.20	1.06
B2 (n=14)									
density	0.69	0.20	0.89	-	-	-	0.69	0.20	0.89
SE	0.09	0.07	0.11	-	-	-	0.09	0.07	0.11
LCL	0.54	0.08	0.70	-	-	-	0.54	0.08	0.70
UCL	0.85	0.32	1.08	-	-	-	0.85	0.32	1.08
B3 (n=34)									
density	0.56	0.61	1.16	-	-	-	0.56	0.61	1.16
SE	0.04	0.13	0.14	-	-	-	0.04	0.13	0.14
LCL	0.48	0.39	0.92	-	-	-	0.48	0.39	0.92
UCL	0.63	0.82	1.40	-	-	-	0.63	0.82	1.40
B4 (n=14)									
density	0.49	0.11	0.60	0.46	0.15	0.61	0.48	0.11	0.60
SE	0.04	0.04	0.05	0.11	0.06	0.15	0.04	0.03	0.05
LCL	0.42	0.04	0.51	0.22	0.03	0.29	0.42	0.05	0.51
UCL	0.55	0.17	0.68	0.69	0.27	0.93	0.55	0.17	0.69

Table A.3. Unadjusted densities of observed ringed seals, by sector, for fast ice, pack ice, and all ice combined within 40 km of shore based on May-June 1986 aerial surveys.

1986	Fast Ice			Pack Ice			All Ice		
	Hole	Crack	All	Hole	Crack	All	Hole	Crack	All
B1 (n=20)									
density	0.63	0	0.63	0.07	0.01	0.08	0.54	0	0.54
SE	0.06	0	0.06	0.04	0.01	0.04	0.07	0	0.07
LCL	0.54	0	0.54	0	0	0	0.42	0	0.42
UCL	0.73	0	0.73	0.15	0.02	0.16	0.65	0	0.65
B2 (n=21)									
density	1.17	0.01	1.18	-	-	-	1.17	0.01	1.18
SE	0.07	0.01	0.07	-	-	-	0.07	0.01	0.07
LCL	1.05	0	1.05	-	-	-	1.05	0	1.05
UCL	1.28	0.03	1.30	-	-	-	1.28	0.03	1.30
B3 (n=18)									
density	1.18	0.10	1.28	0.20	1.10	1.30	1.05	0.24	1.29
SE	0.08	0.06	0.11	0.05	0.39	0.43	0.10	0.10	0.12
LCL	1.04	0	1.09	0.04	0	0.03	0.88	0.06	1.08
UCL	1.33	0.21	1.48	0.35	2.24	2.57	1.22	0.42	1.49
B4 (n=12)									
density	1.20	1.50	2.70	0.23	0.37	0.60	0.71	0.93	1.64
SE	0.20	0.56	0.45	0.04	0.10	0.10	0.11	0.33	0.29
LCL	0.85	0.49	1.89	0.15	0.19	0.42	0.52	0.33	1.11
UCL	1.56	2.50	3.51	0.30	0.55	0.78	0.90	1.52	2.16

Table A.4. Unadjusted densities of observed ringed seals, by sector, for fast ice, pack ice, and all ice combined within 40 km of shore based on May-June 1987 aerial surveys.

1987	Fast Ice			Pack Ice			All Ice		
	Hole	Crack	All	Hole	Crack	All	Hole	Crack	All
B1 (n=21)									
density	0.94	0.03	0.97	0.62	0.20	0.82	0.92	0.04	0.96
SE	0.06	0.02	0.06	0.14	0.16	0.19	0.05	0.02	0.06
LCL	0.84	0.00	0.87	0.35	-0.11	0.45	0.82	0.01	0.86
UCL	1.04	0.06	1.08	0.90	0.51	1.19	1.01	0.08	1.06
B2 (n=21)									
density	1.41	0.01	1.42	0.86	0.21	1.07	1.37	0.02	1.39
SE	0.08	0.01	0.08	0.44	0.22	0.66	0.09	0.02	0.10
LCL	1.26	0	1.27	0.01	0	0	1.21	0	1.22
UCL	1.55	0.02	1.56	1.71	0.64	2.35	1.53	0.06	1.56
B3 (n=47)									
density	1.06	1.34	2.41	0.49	0.98	1.47	0.77	1.16	1.93
SE	0.10	0.43	0.45	0.10	0.20	0.26	0.09	0.22	0.23
LCL	0.89	0.60	1.64	0.31	0.64	1.02	0.62	0.78	1.54
UCL	1.24	2.09	3.18	0.66	1.32	1.91	0.92	1.54	2.32
B4 (n=15)									
density	1.06	1.94	3.00	0.38	0.69	1.06	0.61	1.13	1.74
SE	0.15	1.26	1.29	0.07	0.20	0.23	0.08	0.49	0.51
LCL	0.80	0	0.72	0.25	0.33	0.66	0.46	0.27	0.85
UCL	1.31	4.17	5.28	0.50	1.04	1.47	0.76	1.99	2.63

Table A.5. Unadjusted densities of observed ringed seals, by sector, for fast ice, pack ice, and all ice combined within 40 km of shore based on 28-31 May 1996 aerial surveys.

1996	Fast Ice			Pack Ice			All Ice		
	Hole	Crack	All	Hole	Crack	All	Hole	Crack	All
B2 (n=3)									
Density/km^2	0.73	0.03	0.76	2.03	0	2.03	1.08	0.02	1.10
SE	0.13	0.03	0.15	0.33	0	0.33	0.09	0.02	0.08
LCL	0.34	0	0.31	1.08	0	1.08	0.82	0	0.87
UCL	1.11	0.11	1.20	2.98	0	2.98	1.34	0.08	1.34
B3 (n=43)									
Density/km^2	0.48	0.06	0.54	0.66	0.19	0.85	0.57	0.13	0.70
SE	0.05	0.04	0.06	0.16	0.04	0.16	0.08	0.03	0.09
LCL	0.40	0	0.44	0.39	0.12	0.58	0.44	0.08	0.55
UCL	0.57	0.12	0.65	0.92	0.26	1.12	0.70	0.17	0.84
B4 (n=18)									
Density/km^2	0.64	0.05	0.69	0.52	0.67	1.19	0.55	0.52	1.07
SE	0.10	0.03	0.10	0.13	0.15	0.24	0.10	0.12	0.18
LCL	0.47	0	0.53	0.30	0.41	0.77	0.38	0.32	0.75
UCL	0.81	0.11	0.86	0.75	0.92	1.61	0.72	0.73	1.39

Table A.6. Densities of ringed seals, by sector, for fast ice, pack ice, and all ice combined within 40 km of shore based on May/June 1997 aerial surveys. (This table uses 2 June data for lines in B1, where it is available and 31 May data for the remaining lines in B1.)

1997	Fast Ice			Pack Ice			All Ice		
	Hole	Crack	All	Hole	Crack	All	Hole	Crack	All
B1 (n=30)									
Density/km^2	0.39	0	0.39	0.05	0.01	0.07	0.34	0	0.34
SE	0.04	0	0.04	0.03	0.01	0.03	0.04	0	0.04
LCL	0.32	0	0.32	0	0.00	0.02	0.26	0	0.26
UCL	0.46	0	0.46	0.10	0.03	0.11	0.42	0.01	0.42
B2 (n=21)									
Density/km^2	0.61	0	0.61	--	--	--	0.61	0	0.61
SE	0.06	0	0.06	--	--	--	0.06	0	0.06
LCL	0.50	0	0.50	--	--	--	0.50	0	0.50
UCL	0.71	0	0.71	--	--	--	0.71	0	0.71
-B3 (n=57)									
Density/km^2	0.76	0.01	0.77	0.54	0.42	0.96	0.73	0.07	0.80
SE	0.07	0.01	0.07	0.12	0.08	0.15	0.06	0.02	0.06
LCL	0.65	0	0.66	0.35	0.28	0.72	0.62	0.04	0.69
UCL	0.87	0.03	0.89	0.74	0.56	1.21	0.83	0.11	0.91
B4 (n=31)									
Density/km^2	1.23	0.03	1.26	0.42	1.17	1.59	0.92	0.47	1.39
SE	0.10	0.02	0.11	0.12	0.35	0.44	0.10	0.10	0.17
LCL	1.05	0	1.07	0.21	0.57	0.84	0.74	0.30	1.09
UCL	1.40	0.06	1.44	0.63	1.76	2.34	1.09	0.64	1.68

Table A.7. Unadjusted density estimates of ringed seals, by sector, for fast ice, pack ice, and all ice combined within 40 km of shore based on May 1998 aerial surveys.

1998	Fast Ice			Pack Ice			All Ice		
	Hole	Crack	All	Hole	Crack	All	Hole	Crack	All
B3 (n=28)									
Density/km^2	0.53	0.22	0.76	0.49	0.35	0.84	0.51	0.31	0.81
SE	0.06	0.21	0.23	0.06	0.07	0.08	0.04	0.08	0.08
LCL	0.43	0	0.37	0.39	0.24	0.70	0.43	0.17	0.67
UCL	0.63	0.59	1.14	0.59	0.46	0.98	0.58	0.44	0.96
B4 (n=12)									
Density/km^2	0.91	0.45	1.36	0.63	0.46	1.09	0.73	0.46	1.19
SE	0.20	0.41	0.41	0.15	0.14	0.18	0.12	0.13	0.19
LCL	0.56	0	0.62	0.36	0.22	0.76	0.52	0.22	0.85
UCL	1.26	1.19	2.10	0.90	0.71	1.42	0.94	0.69	1.52

Table A.8. Unadjusted densities of observed ringed seals, by sector, for fast ice, pack ice, and all ice combined within 40 km of shore based on May-June 1999 aerial surveys.

1999	Fast Ice			Pack Ice			All Ice		
	Hole	Crack	All	Hole	Crack	All	Hole	Crack	All
B1 (n=15)									
density	0.77	0	0.77	0.36	0.05	0.41	0.60	0.02	0.62
SE	0.08	0	0.08	0.07	0.03	0.07	0.07	0.01	0.07
LCL	0.62	0	0.62	0.24	0	0.28	0.48	0	0.50
UCL	0.91	0	0.91	0.49	0.09	0.54	0.72	0.04	0.73
B2 (n=20)									
density	0.69	0	0.69	0.67	0.01	0.68	0.68	0	0.69
SE	0.06	0	0.06	0.08	0.01	0.08	0.06	0	0.06
LCL	0.58	0	0.58	0.53	0	0.54	0.57	0	0.57
UCL	0.80	0	0.80	0.82	0.02	0.82	0.79	0.01	0.80
B3 (n=57)									
density	0.77	0.11	0.87	0.69	0.37	1.06	0.73	0.23	0.96
SE	0.04	0.04	0.06	0.05	0.06	0.09	0.03	0.03	0.05
LCL	0.70	0.05	0.77	0.61	0.28	0.92	0.68	0.18	0.88
UCL	0.83	0.17	0.98	0.78	0.46	1.21	0.79	0.28	1.05
B4 (n=31)									
density	1.36	0.57	1.93	0.69	0.71	1.40	0.92	0.66	1.58
SE	0.20	0.24	0.29	0.13	0.14	0.19	0.11	0.13	0.17
LCL	1.02	0.16	1.43	0.47	0.48	1.08	0.73	0.44	1.29
UCL	1.69	0.98	2.42	0.91	0.94	1.72	1.11	0.88	1.87

APPENDIX B

APPENDIX B

Maps of Beaufort Sea study area showing sightings of ringed seals during 1985-1987 and 1996-1999.

These figures show sightings of seals in all sectors (B1-B4) surveyed during 1985-1987 and 1996-1999. Only lines included in the selected dataset are included. Temporal replicates and lines flown at altitudes greater than 91 m are not included.

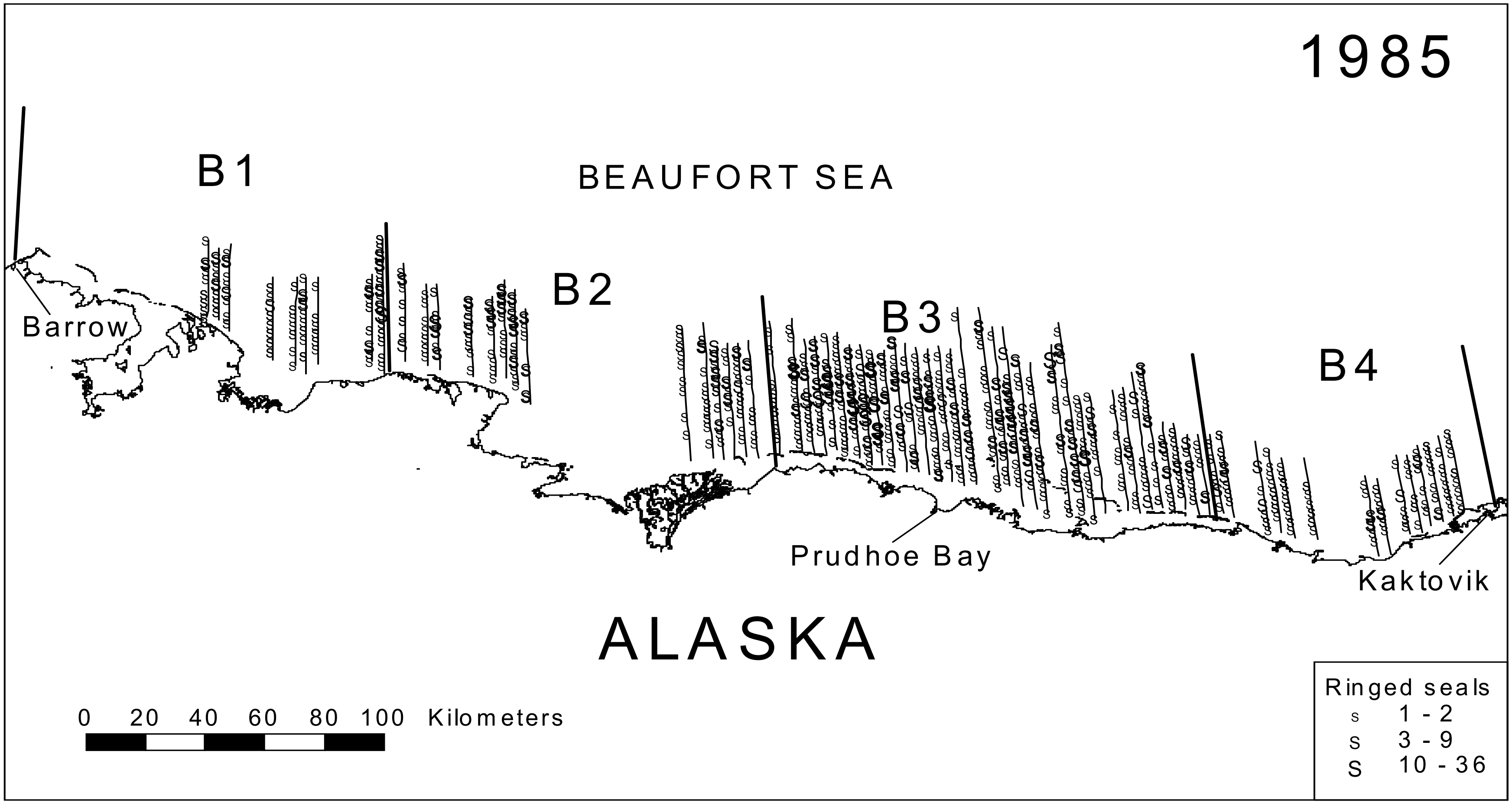

Figure B.1. Map of the Beaufort Sea study area showing sightings of ringed seals made during 9-13 June 1985.

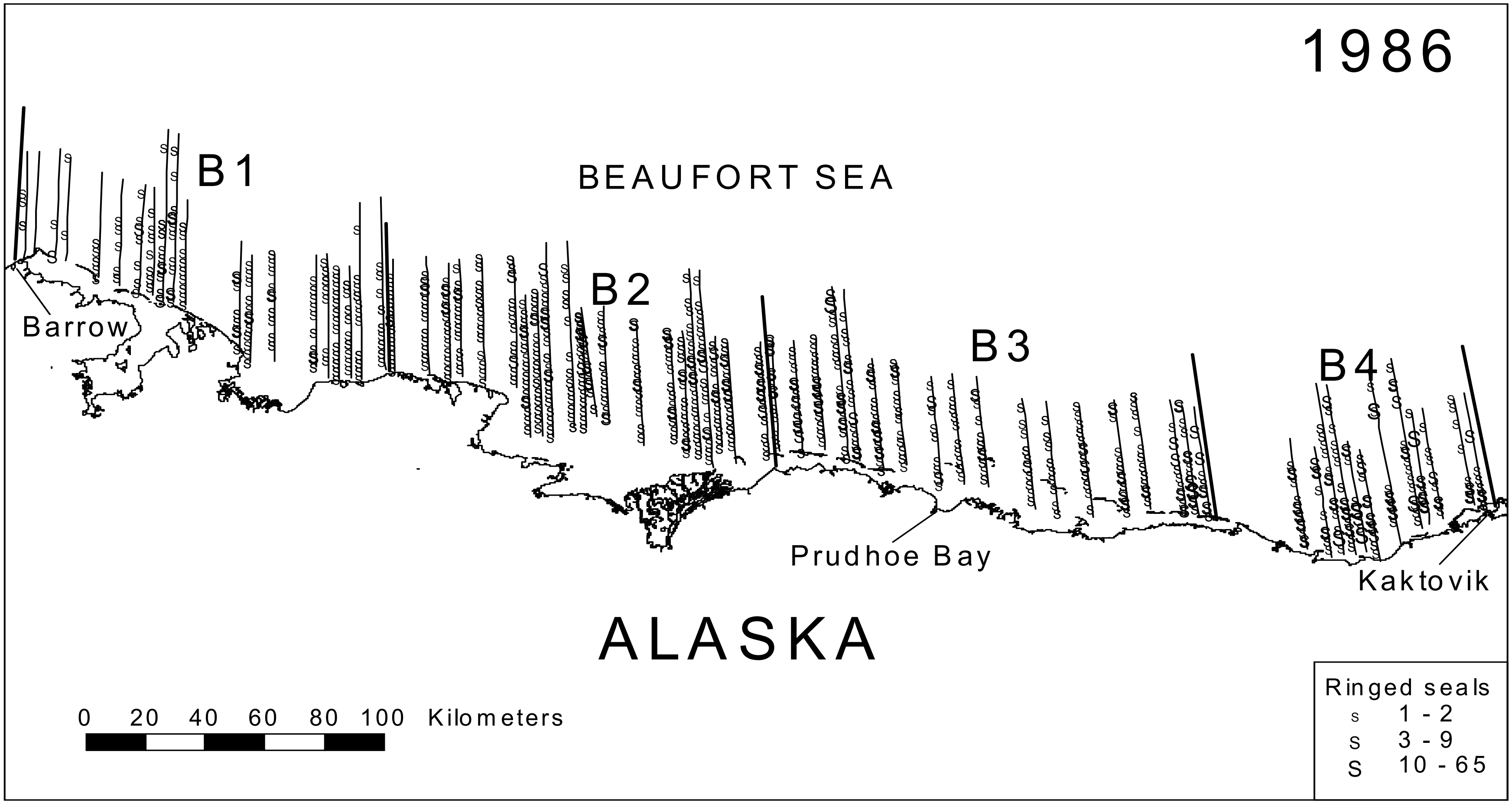

Figure B.2. Map of the Beaufort Sea study area showing sightings of ringed seals made during 31 May-12 June 1986.

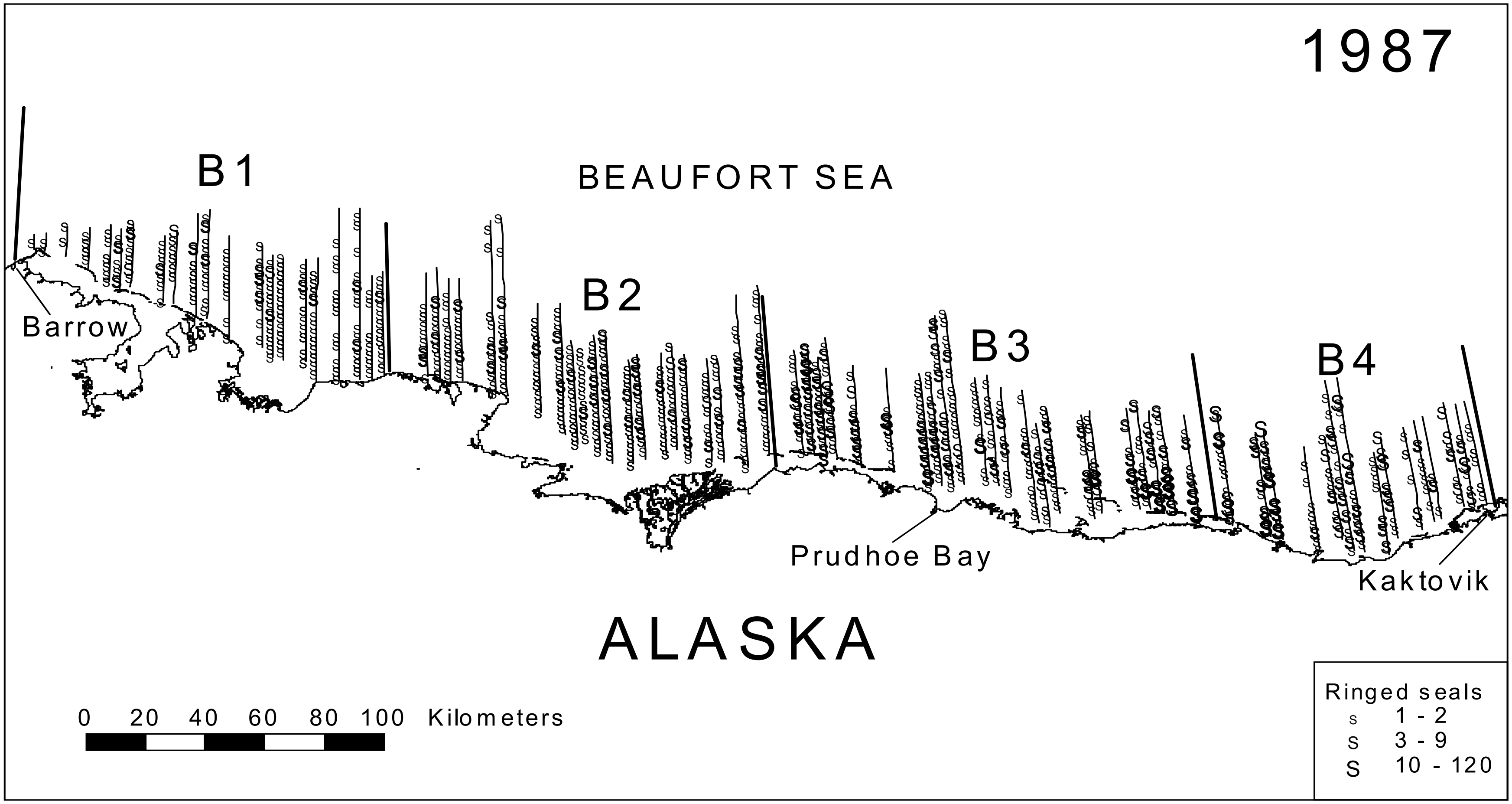

Figure B.3. Map of the Beaufort Sea study area showing sightings of ringed seals made during 2-7 June 1987.

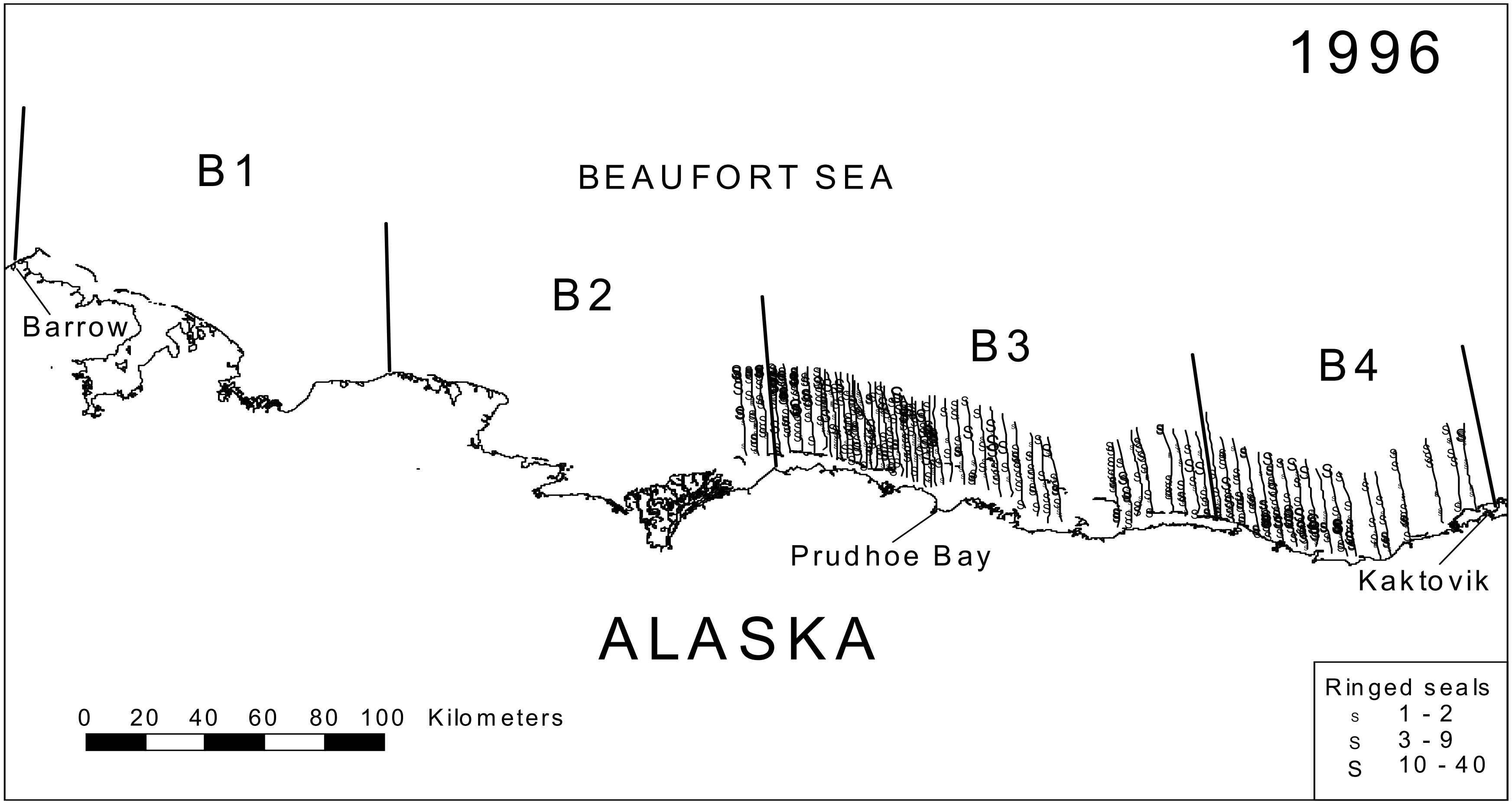

Figure B.4. Map of the Beaufort Sea study area showing sightings of ringed seals made during 29-31 May 1996.

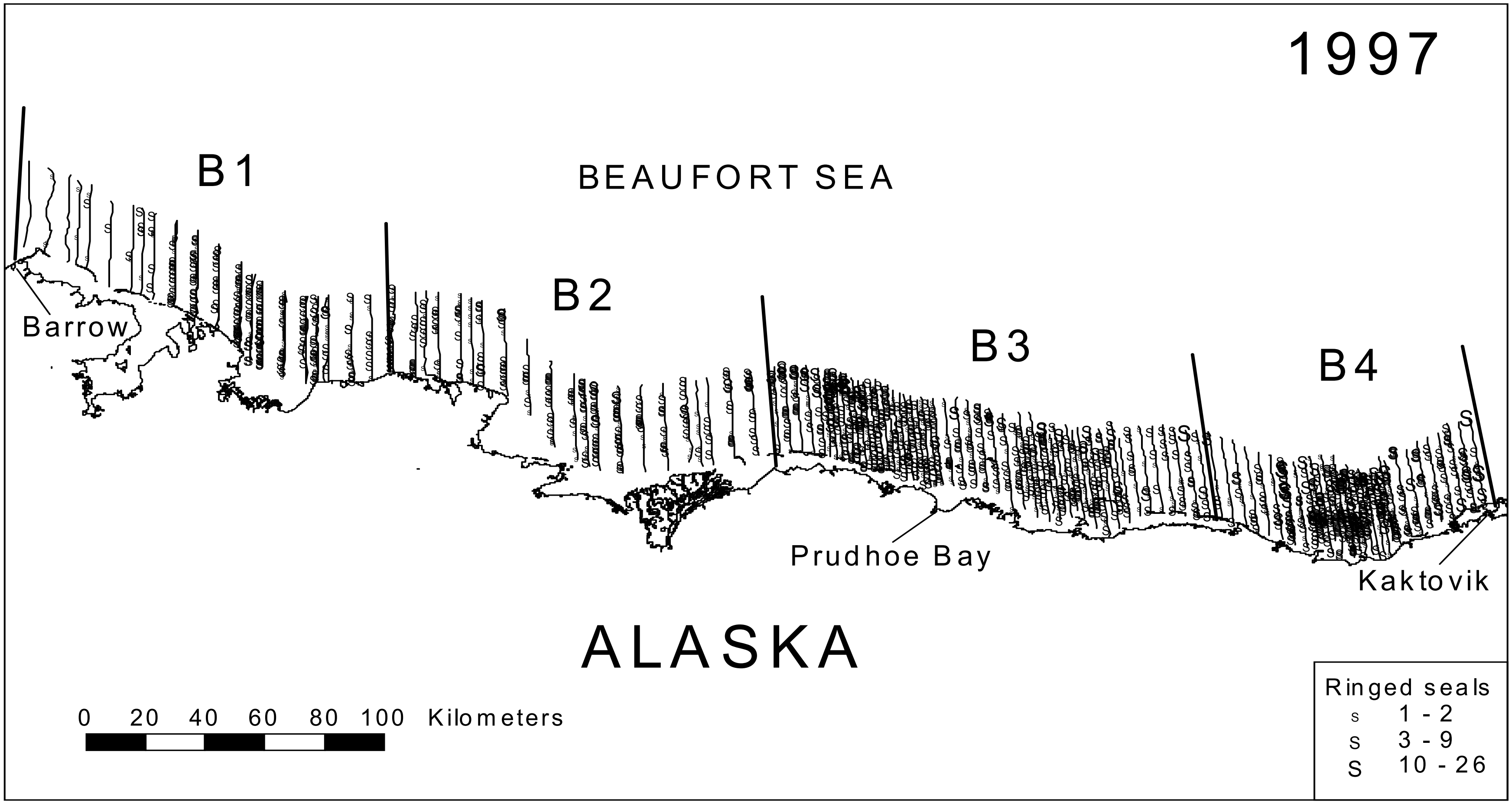

Figure B.5. Map of the Beaufort Sea study area showing sightings of ringed seals made during 25 May-2 June 1997.

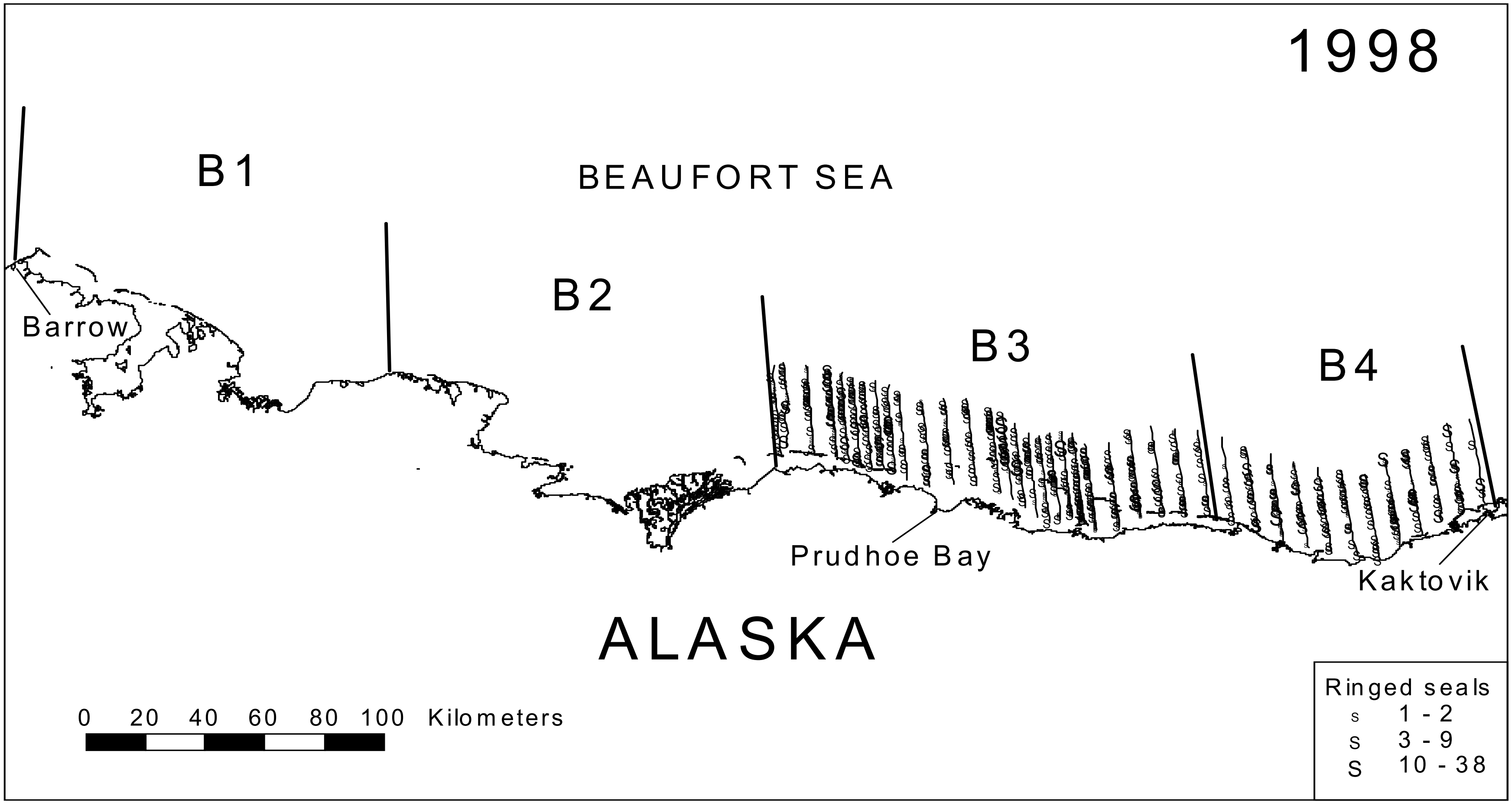

Figure B.6. Map of the Beaufort Sea study area showing sightings of ringed seals made during 27-28 May 1998.

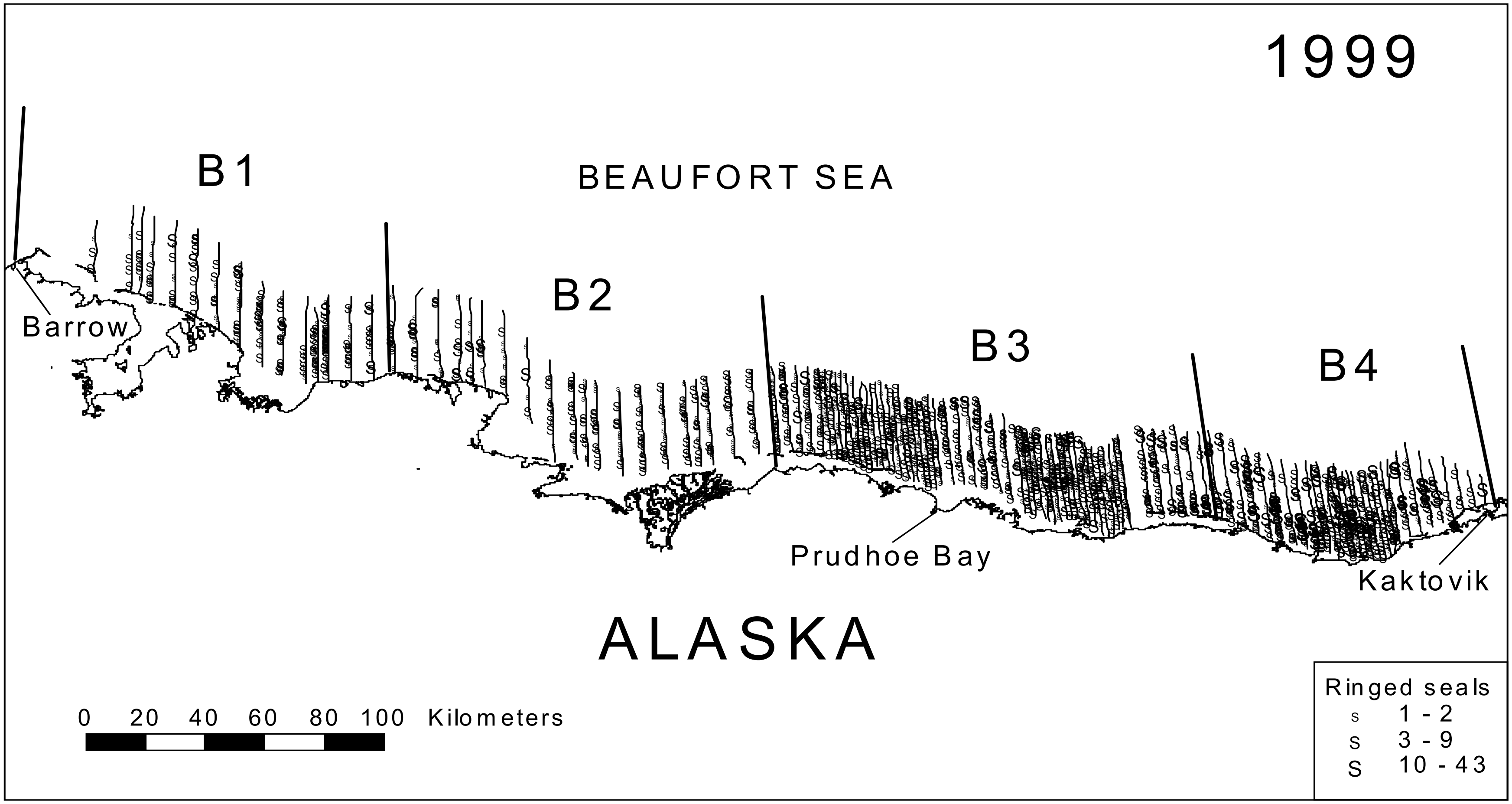

Figure B.7. Map of the Beaufort Sea study area showing sightings of ringed seals made during 29 May-4 June 1999.

APPENDIX C

APPENDIX C

Statistical tables for aerial surveys of ringed seals

The tables present the results of chi-square goodness-of-fit tests and Bonferroni-corrected 95% confidence intervals used to assess the significance of observed differences in ringed seal densities in relation to water depth, distance from the ice edge, ice deformation, longitude, time of day, melt water, cloud cover, temperature, and wind speed. Statistics are shown for sightings of individual seals.

Table C.1. Water depth versus observed and expected numbers of ringed seals counted during aerial surveys in the central Beaufort Sea, 1985-1987 and 1996-1999.

Year	Depth (meters)	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. per Interval	95% Bonferroni Confidence Limits on Prop. of Occur. Lower	95% Bonferroni Confidence Limits on Prop. of Occur. Upper	95% Bonferroni Confidence Limits on Observed Seals Lower	95% Bonferroni Confidence Limits on Observed Seals Upper	Observed Proportion Relative to CI	Observed Density of Seals/km^2
1985	5	166.31	0.11	59	153.81	0.04	0.03	0.05	39.62	78.38	<exp	0.35
	15	534.76	0.34	464	494.55	0.32	0.29	0.35	418.20	509.80	within	0.87
	25	548.46	0.35	693	507.22	0.48	0.44	0.51	643.91	742.09	>exp	1.26
	35	292.37	0.19	217	270.39	0.15	0.13	0.17	182.00	252.00	<exp	0.74
	45	32.48	0.02	23	30.04	0.02	0.01	0.02	10.74	35.26	within	0.71
1986	5	111.32	0.11	117	150.66	0.08	0.06	0.10	89.12	144.88	<exp	1.05
	15	335.83	0.32	682	454.52	0.48	0.44	0.51	631.22	732.78	>exp	2.03
	25	303.04	0.29	452	410.14	0.32	0.28	0.35	404.72	499.28	within	1.49
	35	233.38	0.22	150	315.87	0.11	0.08	0.13	118.83	181.17	<exp	0.64
	45	53.21	0.05	24	72.01	0.02	0.01	0.03	10.93	37.07	<exp	0.45
	55	13.43	0.01	2	18.17	0.00	0.00	0.00	-1.80	5.80	<exp	0.15
	>55	4.90	0.00	1	6.63	0.00	0.00	0.00	-1.69	3.69	<exp	0.20
1987	5	176.88	0.13	182	311.50	0.08	0.06	0.09	147.14	216.86	<exp	1.03
	15	406.16	0.30	1325	715.29	0.56	0.54	0.59	1260.24	1389.76	>exp	3.26
	25	372.85	0.28	510	656.62	0.22	0.19	0.24	456.23	563.77	<exp	1.37
	35	282.31	0.21	299	497.17	0.13	0.11	0.15	255.54	342.46	<exp	1.06
	45	73.92	0.06	36	130.19	0.02	0.01	0.02	19.98	52.02	<exp	0.49
	55	19.96	0.01	3	35.16	0.00	0.00	0.00	-1.66	7.66	<exp	0.15
	>55	5.16	0.00	0	9.08	0.00	0.00	0.00	0.00	0.00	<exp	0.00
1996	5	282.53	0.15	101	227.95	0.07	0.05	0.08	75.99	126.01	<exp	0.36
	15	654.12	0.35	652	527.76	0.43	0.40	0.46	602.43	701.57	>exp	1.00
	25	662.46	0.35	626	534.49	0.41	0.38	0.45	576.70	675.30	>exp	0.94
	35	238.88	0.13	122	192.73	0.08	0.06	0.10	94.72	149.28	<exp	0.51
	45	32.31	0.02	8	26.07	0.01	0.00	0.01	0.73	15.27	<exp	0.25

Table C.1. Depth continued.

Year	Depth (meters)	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. Per Interval	95% Bonferroni Confidence Limits on Prop. of Occur.		95% Bonferroni Confidence Limits on Observed Seals		Observed Proportion Relative to CI	Observed Density of Seals/km^2
							Lower	Upper	Lower	Upper		
1997	5	433.52	0.16	284	436.66	0.10	0.09	0.12	241.93	326.07	<exp	0.66
	15	965.20	0.36	770	972.18	0.28	0.26	0.31	708.02	831.98	<exp	0.80
	25	861.33	0.32	1109	867.56	0.41	0.38	0.43	1041.39	1176.61	>exp	1.29
	35	381.54	0.14	492	384.30	0.18	0.16	0.20	439.04	544.96	>exp	1.29
	45	57.36	0.02	44	57.78	0.02	0.01	0.02	26.64	61.36	within	0.77
	55	0.52	0.00	20	0.53	0.01	0.00	0.01	8.24	31.76	>exp	38.30
1998	5	218.36	0.18	109	202.59	0.10	0.07	0.12	82.84	135.16	<exp	0.50
	15	434.14	0.36	457	402.79	0.41	0.37	0.45	413.74	500.26	>exp	1.05
	25	367.30	0.31	377	340.78	0.34	0.30	0.38	335.37	418.63	within	1.03
	35	145.32	0.12	158	134.83	0.14	0.11	0.17	127.29	188.71	within	1.09
	45	31.08	0.03	9	28.84	0.01	0.00	0.02	1.12	16.88	<exp	0.29
	55	0.19	0.00	0	0.17	0.00	0.00	0.00	0.00	0.00	<exp	0.00
1999	5	504.47	0.19	374	591.64	0.12	0.10	0.13	327.28	420.72	<exp	0.74
	15	949.52	0.36	1256	1113.59	0.41	0.38	0.43	1185.56	1326.44	>exp	1.32
	25	841.75	0.32	1095	987.20	0.35	0.33	0.38	1026.42	1163.58	>exp	1.30
	35	338.45	0.13	380	396.93	0.12	0.11	0.14	332.96	427.04	within	1.12
	45	13.33	0.01	0	15.64	0.00	-	-	-	-	<exp	0.00
All	5	1893.38	0.15	1226	2092.44	0.09	0.08	0.10	1136.13	1315.87	<exp	0.65
	15	4279.73	0.35	5606	4729.67	0.41	0.40	0.42	5451.25	5760.75	>exp	1.31
	25	3957.19	0.32	4862	4373.22	0.36	0.34	0.37	4711.40	5012.60	>exp	1.23
	35	1912.25	0.15	1818	2113.29	0.13	0.13	0.14	1711.19	1924.81	<exp	0.95
	45	293.70	0.02	144	324.58	0.01	0.01	0.01	111.89	176.11	<exp	0.49
	55	34.10	0.00	25	37.68	0.00	0.00	0.00	11.56	38.44	within	0.73
	>55	10.06	0.00	1	11.11	0.00	0.00	0.00	-1.69	3.69	<exp	0.10

Table C.2. Distance from fast ice edge versus observed and expected numbers of ringed seals counted during aerial surveys in the central Beaufort Sea, 1985-1987 and 1996-1999.

Year	Distance from ice edge (km)	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. per Interval	95% Bonferroni Confidence Limits on Prop. of Occur.		95% Bonferroni Confidence Limits on Observed Seals		Observed Proportion Relative to CI	Observed Density of Seals/km^2
							Lower	Upper	Lower	Upper		
1985	<-35	656.61	0.42	438	607.24	0.30	0.27	0.34	387.42	488.58	<exp	0.67
	-35	168.62	0.11	244	155.94	0.17	0.14	0.20	202.81	285.19	>exp	1.45
	-30	187.17	0.12	176	173.09	0.12	0.10	0.15	140.05	211.95	within	0.94
	-25	155.01	0.10	188	143.35	0.13	0.10	0.15	151.01	224.99	>exp	1.21
	-20	150.78	0.10	186	139.44	0.13	0.10	0.15	149.18	222.82	>exp	1.23
	-15	96.21	0.06	93	88.98	0.06	0.05	0.08	66.03	119.97	within	0.97
	-10	63.45	0.04	61	58.68	0.04	0.03	0.06	38.90	83.10	within	0.96
	-5	50.47	0.03	44	46.67	0.03	0.02	0.04	25.12	62.88	within	0.87
	5	27.61	0.02	14	25.54	0.01	0.00	0.02	3.24	24.76	<exp	0.51
	10	8.65	0.01	1	8.00	0.00	0.00	0.00	-1.89	3.89	<exp	0.12
	15	4.25	0.00	6	3.93	0.00	0.00	0.01	-1.07	13.07	within	1.41
	20	4.94	0.00	3	4.57	0.00	0.00	0.01	-2.00	8.00	within	0.61
	25	0.61	0.00	2	0.57	0.00	0.00	0.00	-2.08	6.08	within	3.26
1986	<-35	196.59	0.19	224	266.08	0.16	0.13	0.19	183.39	264.61	<exp	1.14
	-35	52.69	0.05	74	71.31	0.05	0.03	0.07	49.25	98.75	within	1.40
	-30	72.86	0.07	108	98.62	0.08	0.05	0.10	78.47	137.53	within	1.48
	-25	70.58	0.07	79	95.53	0.06	0.04	0.07	53.47	104.53	within	1.12
	-20	94.26	0.09	298	127.58	0.21	0.18	0.24	252.62	343.38	>exp	3.16
	-15	82.17	0.08	106	111.21	0.07	0.05	0.09	76.73	135.27	within	1.29
	-10	92.72	0.09	183	125.49	0.13	0.10	0.15	145.67	220.33	>exp	1.97
	-5	75.33	0.07	142	101.96	0.10	0.08	0.12	108.58	175.42	>exp	1.88
	5	68.10	0.06	63	92.17	0.04	0.03	0.06	40.07	85.93	<exp	0.93
	10	54.14	0.05	30	73.27	0.02	0.01	0.03	13.98	46.02	<exp	0.55
	15	54.31	0.05	29	73.50	0.02	0.01	0.03	13.25	44.75	<exp	0.53
	20	57.50	0.05	59	77.83	0.04	0.03	0.06	36.77	81.23	within	1.03
	25	34.26	0.03	17	46.37	0.01	0.00	0.02	4.89	29.11	<exp	0.50
	30	29.17	0.03	13	39.48	0.01	0.00	0.02	2.39	23.61	<exp	0.45
	35	17.69	0.02	3	23.94	0.00	0.00	0.01	-2.11	8.11	<exp	0.17
	>35	2.71	0.00	0	3.66	0.00	0.00	0.00	0.00	0.00	<exp	0.00

Table C.2. Distance from edge continued.

Year	Distance from ice edge (km)	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. per Interval	95% Bonferroni Confidence Limits on Prop. of Occur.		95% Bonferroni Confidence Limits on Observed Seals		Observed Proportion Relative to CI	Observed Density of Seals/km^2
							Lower	Upper	Lower	Upper		
1987	<-35	9.18	0.01	6	16.17	0.00	0.00	0.01	-1.23	13.23	<exp	0.65
	-35	3.44	0.00	3	6.07	0.00	0.00	0.00	-2.12	8.12	within	0.87
	-30	20.07	0.02	30	35.35	0.01	0.01	0.02	13.92	46.08	within	1.49
	-25	34.05	0.03	19	59.97	0.01	0.00	0.01	6.17	31.83	<exp	0.56
	-20	84.14	0.06	93	148.17	0.04	0.03	0.05	65.07	120.93	<exp	1.11
	-15	107.90	0.08	351	190.01	0.15	0.13	0.17	299.93	402.07	>exp	3.25
	-10	118.71	0.09	280	209.06	0.12	0.10	0.14	233.58	326.42	>exp	2.36
	-5	177.01	0.13	652	311.72	0.28	0.25	0.30	587.83	716.17	>exp	3.68
	5	176.23	0.13	304	310.35	0.13	0.11	0.15	255.92	352.08	within	1.73
	10	131.46	0.10	131	231.51	0.06	0.04	0.07	98.13	163.87	<exp	1.00
	15	127.32	0.10	157	224.23	0.07	0.05	0.08	121.23	192.77	<exp	1.23
	20	152.41	0.11	193	268.41	0.08	0.07	0.10	153.66	232.34	<exp	1.27
	25	87.59	0.07	53	154.25	0.02	0.01	0.03	31.73	74.27	<exp	0.61
	30	70.20	0.05	71	123.63	0.03	0.02	0.04	46.48	95.52	<exp	1.01
	35	29.93	0.02	8	52.71	0.00	0.00	0.01	-0.34	16.34	<exp	0.27
	>35	7.60	0.01	4	13.38	0.00	0.00	0.00	-1.91	9.91	<exp	0.53
1996	-30	1.67	0.00	0	1.35	-	-	-	-	-	<exp	
	-25	20.62	0.01	6	16.63	0.00	0.00	0.01	-1.12	13.12	<exp	0.29
	-20	125.84	0.07	23	101.51	0.02	0.01	0.02	9.13	36.87	<exp	0.18
	-15	175.03	0.09	67	141.19	0.04	0.03	0.06	43.69	90.31	<exp	0.38
	-10	214.02	0.11	125	172.64	0.08	0.06	0.10	93.80	156.20	<exp	0.58
	-5	244.12	0.13	221	196.92	0.15	0.12	0.17	180.98	261.02	within	0.91
	5	254.18	0.14	392	205.04	0.26	0.23	0.29	342.37	441.63	>exp	1.54
	10	249.84	0.13	309	201.54	0.20	0.17	0.24	263.33	354.67	>exp	1.24
	15	247.12	0.13	208	199.35	0.14	0.11	0.16	168.98	247.02	within	0.84
	20	170.86	0.09	59	137.82	0.04	0.02	0.05	37.06	80.94	<exp	0.35

Table C.2. Distance from edge continued.

Year	Distance from ice edge (km)	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. per Interval	95% Bonferroni Confidence Limits on Prop. of Occur.		95% Bonferroni Confidence Limits on Observed Seals		Observed Proportion Relative to CI	Observed Density of Seals/km^2
							Lower	Upper	Lower	Upper		
96 cont	25	89.03	0.05	72	71.82	0.05	0.03	0.06	47.87	96.13	within	0.81
	30	55.85	0.03	26	45.05	0.02	0.01	0.03	11.27	40.73	<exp	0.47
	35	17.63	0.01	1	14.22	0.00	0.00	0.00	-1.91	3.91	<exp	0.06
1997	<-35	21.94	0.01	9	22.10	0.00	0.00	0.01	0.27	17.73	<exp	0.41
	-35	150.41	0.06	89	151.48	0.03	0.02	0.04	61.97	116.03	<exp	0.59
	-30	230.80	0.09	152	232.45	0.06	0.04	0.07	117.10	186.90	<exp	0.66
	-25	272.89	0.10	203	274.83	0.07	0.06	0.09	163.07	242.93	<exp	0.74
	-20	320.44	0.12	307	322.73	0.11	0.10	0.13	258.92	355.08	within	0.96
	-15	343.13	0.13	421	345.57	0.15	0.13	0.18	366.04	475.96	>exp	1.23
	-10	366.55	0.14	357	369.16	0.13	0.11	0.15	305.69	408.31	within	0.97
	-5	359.16	0.13	346	361.72	0.13	0.11	0.15	295.37	396.63	within	0.96
	5	276.54	0.10	467	278.51	0.17	0.15	0.19	409.70	524.30	>exp	1.69
	10	161.85	0.06	150	163.01	0.06	0.04	0.07	115.31	184.69	within	0.93
	15	106.23	0.04	105	106.98	0.04	0.03	0.05	75.73	134.27	within	0.99
	20	57.72	0.02	48	58.13	0.02	0.01	0.03	27.99	68.01	within	0.83
	25	27.42	0.01	44	27.62	0.02	0.01	0.02	24.83	63.17	within	1.60
	30	4.68	0.00	21	4.72	0.01	0.00	0.01	7.70	34.30	>exp	4.49
1998	-25	4.35	0.00	1	4.03	0.00	0.00	0.00	-1.86	3.86	<exp	0.23
	-20	34.97	0.03	16	32.44	0.01	0.00	0.02	4.62	27.38	<exp	0.46
	-15	86.70	0.07	36	80.43	0.03	0.02	0.05	19.09	52.91	<exp	0.42
	-10	124.71	0.10	126	115.69	0.11	0.09	0.14	95.72	156.28	within	1.01
	-5	156.30	0.13	201	145.00	0.18	0.15	0.21	164.24	237.76	>exp	1.29
	5	158.70	0.13	132	147.23	0.12	0.09	0.15	101.10	162.90	within	0.83
	10	162.76	0.14	162	151.00	0.15	0.12	0.18	128.30	195.70	within	1.00
	15	161.40	0.13	186	149.73	0.17	0.14	0.20	150.35	221.65	>exp	1.15
	20	140.61	0.12	129	130.44	0.12	0.09	0.14	98.41	159.59	within	0.92
	25	96.88	0.08	64	89.87	0.06	0.04	0.08	41.75	86.25	<exp	0.66
	30	57.00	0.05	53	52.88	0.05	0.03	0.07	32.64	73.36	within	0.93
	35	12.14	0.01	4	11.27	0.00	0.00	0.01	-1.72	9.72	<exp	0.33

Table C.2. Distance from edge continued.

Year	Distance from ice edge (km)	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. per Interval	95% Bonferroni Confidence Limits on Prop. of Occur. Lower	Upper	95% Bonferroni Confidence Limits on Observed Seals Lower	Upper	Observed Proportion Relative to CI	Observed Density of Seals/km^2
1999	-35	3.07	0.00	0	3.63	-	-	-	-	-	<exp	
	-30	43.38	0.02	14	51.27	0.00	0.00	0.01	3.12	24.88	<exp	0.32
	-25	85.76	0.03	45	101.35	0.01	0.01	0.02	25.60	64.40	<exp	0.52
	-20	147.87	0.06	89	174.75	0.03	0.02	0.04	61.91	116.09	<exp	0.60
	-15	246.76	0.09	209	291.62	0.07	0.05	0.08	168.33	249.67	<exp	0.85
	-10	329.53	0.13	381	389.44	0.12	0.11	0.14	327.75	434.25	within	1.16
	-5	351.45	0.13	669	415.35	0.22	0.19	0.24	602.29	735.71	>exp	1.90
	5	362.86	0.14	589	428.83	0.19	0.17	0.21	525.38	652.62	>exp	1.62
	10	333.06	0.13	360	393.61	0.12	0.10	0.13	308.04	411.96	within	1.08
	15	283.88	0.11	215	335.49	0.07	0.06	0.08	173.79	256.21	<exp	0.76
	20	231.67	0.09	318	273.78	0.10	0.09	0.12	268.79	367.21	within	1.37
	25	149.86	0.06	177	177.10	0.06	0.05	0.07	139.36	214.64	within	1.18
	30	39.90	0.02	19	47.16	0.01	0.00	0.01	6.34	31.66	<exp	0.48
	35	5.60	0.00	5	6.62	0.00	0.00	0.00	-1.51	11.51	within	0.89
All	<-35	884.32	0.07	677	978.76	0.05	0.04	0.06	602.04	751.96	<exp	0.77
	-35	378.23	0.03	410	418.62	0.03	0.03	0.03	351.07	468.93	within	1.08
	-30	555.95	0.05	480	615.32	0.04	0.03	0.04	416.40	543.60	<exp	0.86
	-25	643.26	0.05	541	711.96	0.04	0.03	0.04	473.64	608.36	<exp	0.84
	-20	958.3	0.08	1012	1060.64	0.07	0.07	0.08	921.54	1102.46	within	1.06
	-15	1137.9	0.09	1283	1259.42	0.09	0.09	0.10	1182.24	1383.76	within	1.13
	-10	1309.69	0.11	1513	1449.55	0.11	0.10	0.12	1404.60	1621.40	within	1.16
	-5	1413.84	0.11	2275	1564.83	0.17	0.16	0.18	2146.31	2403.69	>exp	1.61
	5	1324.22	0.11	1961	1465.64	0.14	0.13	0.15	1839.89	2082.11	>exp	1.48
	10	1101.76	0.09	1143	1219.42	0.08	0.08	0.09	1047.36	1238.64	within	1.04
	15	984.51	0.08	906	1089.65	0.07	0.06	0.07	820.05	991.95	<exp	0.92
	20	815.7	0.07	809	902.81	0.06	0.05	0.07	727.47	890.53	<exp	0.99
	25	485.65	0.04	429	537.51	0.03	0.03	0.04	368.76	489.24	<exp	0.88
	30	256.8	0.02	203	284.22	0.01	0.01	0.02	161.21	244.79	<exp	0.79
	35	82.99	0.01	21	91.85	0.00	0.00	0.00	7.47	34.53	<exp	0.25
	>35	15.18	0.00	4	16.80	0.00	0.00	0.00	-1.91	9.91	<exp	0.26

Table C.3. Ice deformation versus observed and expected numbers of ringed seals counted during aerial surveys in the central Beaufort Sea, 1985-1987 and 1996-1999.

Year	% Ice-deformation	Area Surveyed (km2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. /Interval	95% Bonferroni Confidence Limits on Prop. of Occur.		95% Bonferroni Confidence Limits on Observed Seals		Observed Proportion Relative to CI	Observed Density of Seals/km^2
							Lower	Upper	Lower	Upper		
1985	10	407.60	0.27	233	415.57	0.15	0.13	0.17	195.89	270.12	<exp	0.57
	20	208.00	0.14	372	212.06	0.24	0.21	0.27	327.65	416.35	>exp	1.79
	30	335.78	0.22	422	342.34	0.27	0.24	0.30	375.78	468.22	>exp	1.26
	40	291.99	0.19	319	297.70	0.21	0.18	0.23	277.02	360.98	within	1.09
	50	122.72	0.08	107	125.11	0.07	0.05	0.09	80.67	133.33	within	0.87
	>50	151.27	0.10	94	154.22	0.06	0.04	0.08	69.21	118.79	<exp	0.62
1986	10	322.17	0.32	643	459.73	0.45	0.42	0.49	593.40	692.60	>exp	2.00
	20	261.76	0.26	454	373.53	0.32	0.29	0.35	407.57	500.43	>exp	1.73
	30	244.04	0.24	174	348.24	0.12	0.10	0.14	141.39	206.61	<exp	0.71
	40	141.97	0.14	138	202.59	0.10	0.08	0.12	108.54	167.46	<exp	0.97
	50	25.30	0.03	17	36.11	0.01	0.00	0.02	6.19	27.81	<exp	0.67
	>50	5.47	0.01	2	7.81	0.00	0.00	0.00	-1.73	5.73	<exp	0.37
1987	10	268.51	0.21	768	498.06	0.33	0.30	0.35	707.98	828.03	>exp	2.86
	20	309.76	0.24	706	574.58	0.30	0.27	0.32	647.34	764.66	>exp	2.28
	30	348.18	0.27	525	645.84	0.22	0.20	0.25	471.71	578.29	<exp	1.51
	40	269.15	0.21	311	499.25	0.13	0.11	0.15	267.65	354.35	<exp	1.16
	50	58.22	0.05	42	107.99	0.02	0.01	0.03	25.06	58.95	<exp	0.72
	>50	16.33	0.01	4	30.28	0.00	0.00	0.00	-1.27	9.27	<exp	0.25
1996	10	451.42	0.24	451	364.14	0.30	0.27	0.33	404.09	497.91	>exp	1.00
	20	420.42	0.22	386	339.14	0.26	0.23	0.29	341.28	430.72	>exp	0.92
	30	533.71	0.29	394	430.53	0.26	0.23	0.29	348.98	439.02	within	0.74
	40	270.32	0.14	194	218.06	0.13	0.11	0.15	159.70	228.30	within	0.72
	50	125.05	0.07	63	100.87	0.04	0.03	0.06	42.50	83.50	<exp	0.50
	>50	69.75	0.04	21	56.26	0.01	0.01	0.02	8.99	33.01	<exp	0.30

Table C.3. Ice deformation continued.

Year	% Ice-deformation	Area Surveyed (km2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. /Interval	95% Bonferroni Confidence Limits on Prop. of Occur.		95% Bonferroni Confidence Limits on Observed Seals		Observed Proportion Relative to CI	Observed Density of Seals/km^2
							Lower	Upper	Lower	Upper		
1997	10	1358.14	0.50	1641	1367.82	0.60	0.58	0.63	1573.71	1708.29	>exp	1.21
	20	812.22	0.30	810	818.01	0.30	0.27	0.32	747.08	872.92	within	1.00
	30	387.71	0.14	223	390.47	0.08	0.07	0.10	185.25	260.75	<exp	0.58
	40	121.71	0.05	33	122.57	0.01	0.01	0.02	17.94	48.06	<exp	0.27
	50	18.93	0.01	11	19.06	0.00	0.00	0.01	2.27	19.73	within	0.58
	>50	1.06	0.00	1	1.07	0.00	0.00	0.00	-1.64	3.64	within	0.94
1998	10	663.01	0.55	657	615.07	0.59	0.55	0.63	613.80	700.20	within	0.99
	20	255.29	0.21	227	236.84	0.20	0.17	0.24	191.55	262.45	within	0.89
	30	158.61	0.13	132	147.14	0.12	0.09	0.14	103.55	160.45	within	0.83
	40	86.51	0.07	81	80.26	0.07	0.05	0.09	58.14	103.86	within	0.94
	50	23.06	0.02	9	21.39	0.01	0.00	0.02	1.12	16.88	<exp	0.39
	>50	10.02	0.01	4	9.30	0.00	0.00	0.01	-1.27	9.27	<exp	0.40
1999	10	1500.11	0.57	1651	1759.23	0.53	0.51	0.56	1577.64	1724.36	<exp	1.10
	20	832.32	0.31	1207	976.08	0.39	0.37	0.41	1135.34	1278.66	>exp	1.45
	30	276.39	0.10	235	324.14	0.08	0.06	0.09	196.12	273.88	<exp	0.85
	40	28.63	0.01	8	33.57	0.00	0.00	0.00	0.55	15.45	<exp	0.28
	50	8.22	0.00	4	9.64	0.00	0.00	0.00	-1.27	9.27	<exp	0.49
	>50	1.99	0.00	0	2.33						<exp	0.00
All Years	10	4970.96	0.41	6044	5611.00	0.44	0.43	0.45	5890.35	6197.65	>exp	1.22
	20	3099.77	0.25	4162	3498.88	0.30	0.29	0.31	4019.82	4304.18	>exp	1.34
	30	2284.42	0.19	2105	2578.55	0.15	0.14	0.16	1993.59	2216.41	<exp	0.92
	40	1210.28	0.10	1084	1366.11	0.08	0.07	0.08	1000.63	1167.37	<exp	0.90
	50	381.5	0.03	253	430.62	0.02	0.02	0.02	211.42	294.58	<exp	0.66
	>50	255.89	0.02	126	288.84	0.01	0.01	0.01	96.52	155.48	<exp	0.49

Table C.4. Longitude speed versus observed and expected numbers of ringed seals counted during aerial surveys in the central Beaufort Sea, 1985-1987 and 1996-1999.

Year	Longitude (degrees)	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. in Interval	95% Bonferroni Confidence Limits on Prop. of Occur.		95% Bonferroni Confidence Limits on Observed Seals		Observed Proportion Relative to CI	Observed Density of Seals/km^2
							Lower	Upper	Lower	Upper		
1985	-149	235.37	0.16	370	239.97	0.24	0.21	0.27	324.87	415.14	>exp	1.57
	-148	330.90	0.22	438	337.37	0.28	0.25	0.31	390.33	485.67	>exp	1.32
	-147	285.72	0.19	333	291.31	0.22	0.19	0.24	289.51	376.49	within	1.17
	-146	269.68	0.18	168	274.95	0.11	0.09	0.13	135.08	200.92	<exp	0.62
	-145	173.20	0.11	112	176.58	0.07	0.05	0.09	84.58	139.42	<exp	0.65
	-144	195.14	0.13	109	198.96	0.07	0.05	0.09	81.92	136.08	<exp	0.56
	-143	27.34	0.02	17	27.87	0.01	0.00	0.02	5.97	28.03	within	0.62
1986	-149	165.87	0.17	251	236.70	0.18	0.15	0.20	212.31	289.69	within	1.51
	-148	138.51	0.14	140	197.65	0.10	0.08	0.12	109.77	170.23	<exp	1.01
	-147	128.84	0.13	163	183.85	0.11	0.09	0.14	130.68	195.33	within	1.27
	-146	167.32	0.17	219	238.76	0.15	0.13	0.18	182.37	255.63	within	1.31
	-145	66.43	0.07	81	94.80	0.06	0.04	0.07	57.49	104.51	within	1.22
	-144	267.86	0.27	508	382.23	0.36	0.32	0.39	459.33	556.67	>exp	1.90
	-143	65.89	0.07	66	94.02	0.05	0.03	0.06	44.66	87.34	<exp	1.00
1987	-149	165.25	0.13	405	306.52	0.17	0.15	0.19	355.74	454.27	>exp	2.45
	-148	184.87	0.15	261	342.92	0.11	0.09	0.13	220.02	301.98	<exp	1.41
	-147	249.39	0.20	328	462.61	0.14	0.12	0.16	282.80	373.20	<exp	1.32
	-146	167.04	0.13	486	309.84	0.21	0.18	0.23	433.17	538.84	>exp	2.91
	-145	134.55	0.11	558	249.58	0.24	0.21	0.26	502.49	613.51	>exp	4.15
	-144	267.37	0.21	245	495.96	0.10	0.09	0.12	205.14	284.86	<exp	0.92
	-143	101.66	0.08	73	188.57	0.03	0.02	0.04	50.38	95.63	<exp	0.72

Table C.4. Longitude continued.

Year	Longitude (degrees W)	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. per Interval	95% Bonferroni Confidence Limits on Prop. of Occur.		95% Bonferroni Confidence Limits on Observed Seals		Observed Proportion Relative to CI	Observed Density of Seals/km^2
							Lower	Upper	Lower	Upper		
1996	-149	388.09	0.21	394	312.93	0.26	0.23	0.29	348.09	439.91	>exp	1.02
	-148	479.35	0.26	279	386.51	0.18	0.16	0.21	238.43	319.57	<exp	0.58
	-147	204.04	0.11	90	164.53	0.06	0.04	0.08	65.25	114.75	<exp	0.44
	-146	259.00	0.14	165	208.84	0.11	0.09	0.13	132.39	197.61	<exp	0.64
	-145	299.02	0.16	374	241.11	0.25	0.22	0.28	328.88	419.12	>exp	1.25
	-144	181.32	0.10	179	146.20	0.12	0.10	0.14	145.21	212.79	within	0.99
	-143	61.85	0.03	29	49.88	0.02	0.01	0.03	14.65	43.35	<exp	0.47
1997	-149	385.64	0.14	482	387.91	0.18	0.16	0.20	428.43	535.57	>exp	1.25
	-148	489.29	0.18	383	492.16	0.14	0.12	0.16	334.20	431.80	<exp	0.78
	-147	531.35	0.20	355	534.47	0.13	0.11	0.15	307.74	402.26	<exp	0.67
	-146	370.20	0.14	184	372.38	0.07	0.05	0.08	148.77	219.23	<exp	0.50
	-145	351.07	0.13	366	353.13	0.13	0.12	0.15	318.12	413.88	within	1.04
	-144	476.44	0.18	831	479.24	0.31	0.28	0.33	766.38	895.62	>exp	1.74
	-143	99.12	0.04	118	99.70	0.04	0.03	0.05	89.42	146.58	within	1.19
	Total	2703.12	1	2719	2719	1						1.01
1998	-149	209.77	0.18	171	194.61	0.15	0.12	0.18	138.64	203.36	within	0.82
	-148	191.26	0.16	121	177.43	0.11	0.08	0.13	93.07	148.93	<exp	0.63
	-147	275.77	0.23	200	255.83	0.18	0.15	0.21	165.55	234.45	<exp	0.73
	-146	152.43	0.13	182	141.41	0.16	0.13	0.19	148.81	215.19	>exp	1.19
	-145	153.09	0.13	194	142.02	0.17	0.14	0.21	159.96	228.04	>exp	1.27
	-144	154.23	0.13	177	143.07	0.16	0.13	0.19	144.18	209.82	>exp	1.15
	-143	61.04	0.05	66	56.63	0.06	0.04	0.08	44.80	87.20	within	1.08

Table C.4. Longitude continued.

Year	Longitude (degrees W)	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. per Interval	95% Bonferroni Confidence Limits on Prop. of Occur.		95% Bonferroni Confidence Limits on Observed Seals		Observed Proportion Relative to CI	Observed Density of Seals/km^2
							Lower	Upper	Lower	Upper		
1999	-149	393.74	0.15	367	461.80	0.12	0.10	0.13	318.61	415.39	<exp	0.93
	-148	495.84	0.19	448	581.55	0.14	0.13	0.16	395.33	500.67	<exp	0.90
	-147	523.53	0.20	557	614.03	0.18	0.16	0.20	499.49	614.51	within	1.06
	-146	362.64	0.14	340	425.33	0.11	0.09	0.12	293.19	386.81	<exp	0.94
	-145	366.43	0.14	555	429.77	0.18	0.16	0.20	497.57	612.43	>exp	1.51
	-144	462.61	0.17	818	542.57	0.26	0.24	0.28	751.97	884.03	>exp	1.77
	-143	42.58	0.02	20	49.94	0.01	0.00	0.01	8.01	31.99	<exp	0.47
All Years	-149	1943.73	0.16	2440	2193.22	0.18	0.17	0.19	2319.46	2560.54	>exp	1.26
	-148	2310.01	0.19	2070	2606.51	0.15	0.14	0.16	1957.18	2182.82	<exp	0.90
	-147	2198.65	0.18	2026	2480.86	0.15	0.14	0.16	1914.17	2137.83	<exp	0.92
	-146	1748.32	0.14	1744	1972.72	0.13	0.12	0.13	1639.01	1848.99	<exp	1.00
	-145	1543.79	0.13	2240	1741.94	0.16	0.15	0.17	2123.49	2356.51	>exp	1.45
	-144	2004.97	0.16	2867	2262.32	0.21	0.20	0.22	2738.82	2995.18	>exp	1.43
	-143	459.47	0.04	389	518.45	0.03	0.02	0.03	336.70	441.30	<exp	0.85

Table C.5. Time of day versus observed and expected numbers of ringed seals counted during aerial surveys in the central Beaufort Sea, 1985-1987 and 1996-1999.

Year	Time of Day (hour)	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. Per Interval	95% Bonferroni Confidence Limits on Prop. of Occur.		95% Bonferroni Confidence Limits on Observed Seals		Observed Proportion Relative to CI	Observed Density of Seals/km^2
							Lower	Upper	Lower	Upper		
1985	11	239.62	0.16	187	244.30	0.12	0.10	0.14	152.51	221.49	<exp	0.78
	12	268.02	0.18	206	273.26	0.13	0.11	0.16	170.05	241.95	<exp	0.77
	13	311.76	0.21	473	317.85	0.31	0.27	0.34	424.25	521.75	>exp	1.52
	14	331.67	0.22	386	338.16	0.25	0.22	0.28	340.21	431.79	>exp	1.16
	15	167.40	0.11	176	170.67	0.11	0.09	0.14	142.40	209.60	within	1.05
	16	100.32	0.07	59	102.29	0.04	0.03	0.05	38.74	79.27	<exp	0.59
	17	98.56	0.06	60	100.49	0.04	0.03	0.05	39.57	80.43	<exp	0.61
1986	11	99.35	0.10	87	141.78	0.06	0.04	0.08	62.69	111.32	<exp	0.88
	12	90.95	0.09	155	129.79	0.11	0.09	0.13	123.38	186.62	within	1.70
	13	227.36	0.23	451	324.43	0.32	0.28	0.35	403.75	498.25	>exp	1.98
	14	186.78	0.19	271	266.54	0.19	0.16	0.22	231.14	310.86	within	1.45
	15	128.11	0.13	129	182.80	0.09	0.07	0.11	99.86	158.14	<exp	1.01
	16	210.42	0.21	270	300.27	0.19	0.16	0.22	230.20	309.81	within	1.28
	17	57.74	0.06	65	82.40	0.05	0.03	0.06	43.81	86.19	within	1.13
1987	10	9.16	0.01	40	16.99	0.02	0.01	0.02	23.13	56.87	>exp	4.37
	11	245.06	0.19	849	454.56	0.36	0.33	0.39	786.31	911.69	>exp	3.46
	12	217.87	0.17	587	404.13	0.25	0.23	0.27	530.52	643.48	>exp	2.69
	13	194.11	0.15	250	360.05	0.11	0.09	0.12	209.79	290.21	<exp	1.29
	14	232.49	0.18	185	431.26	0.08	0.06	0.09	149.88	220.12	<exp	0.80
	15	264.25	0.21	286	490.16	0.12	0.10	0.14	243.36	328.64	<exp	1.08
	16	107.20	0.08	159	198.84	0.07	0.05	0.08	126.24	191.76	<exp	1.48

Table C.5. Time of day continued.

Year	Time of Day (hour)	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. Per Interval	95% Bonferroni Confidence Limits on Prop. of Occur.		95% Bonferroni Confidence Limits on Observed Seals		Observed Proportion Relative to CI	Observed Density of Seals/km^2
							Lower	Upper	Lower	Upper		
1996	11	37.59	0.02	15	30.32	0.01	0.00	0.02	4.63	25.37	<exp	0.40
	12	306.13	0.16	397	246.94	0.26	0.23	0.29	350.99	443.01	>exp	1.30
	13	426.25	0.23	490	343.84	0.32	0.29	0.36	441.07	538.93	>exp	1.15
	14	384.38	0.21	236	310.06	0.16	0.13	0.18	198.04	273.96	<exp	0.61
	15	373.35	0.20	198	301.17	0.13	0.11	0.15	162.72	233.28	<exp	0.53
	16	314.59	0.17	150	253.76	0.10	0.08	0.12	118.73	181.27	<exp	0.48
	17	28.39	0.02	23	22.90	0.02	0.01	0.02	10.20	35.80	within	0.81
1997	10	52.11	0.02	17	52.49	0.01	0.00	0.01	5.94	28.06	<exp	0.33
	11	379.01	0.14	454	381.71	0.17	0.15	0.19	401.68	506.32	>exp	1.20
	12	501.17	0.19	682	504.74	0.25	0.23	0.27	621.19	742.81	>exp	1.36
	13	625.74	0.23	620	630.20	0.23	0.21	0.25	561.15	678.85	within	0.99
	14	501.27	0.19	478	504.84	0.18	0.16	0.20	424.61	531.39	within	0.95
	15	375.04	0.14	312	377.72	0.11	0.10	0.13	267.29	356.71	<exp	0.83
	16	265.42	0.10	156	267.31	0.06	0.05	0.07	123.38	188.62	<exp	0.59
1998	11	32.72	0.03	3	30.36	0.00	0.00	0.01	-1.65	7.65	<exp	0.09
	12	183.85	0.15	212	170.56	0.19	0.16	0.22	176.77	247.23	>exp	1.15
	13	262.76	0.22	234	243.76	0.21	0.18	0.24	197.44	270.56	within	0.89
	14	202.47	0.17	182	187.83	0.16	0.13	0.19	148.82	215.18	within	0.90
	15	211.87	0.18	160	196.55	0.14	0.12	0.17	128.52	191.48	<exp	0.76
	16	251.11	0.21	278	232.96	0.25	0.22	0.29	239.17	316.83	>exp	1.11
	17	51.73	0.04	41	47.99	0.04	0.02	0.05	24.10	57.90	within	0.79

Table C.5. Time of day continued.

Year	Time of Day (hour)	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. Per Interval	95% Bonferroni Confidence Limits on Prop. of Occur. Lower	95% Bonferroni Confidence Limits on Prop. of Occur. Upper	95% Bonferroni Confidence Limits on Observed Seals Lower	95% Bonferroni Confidence Limits on Observed Seals Upper	Observed Proportion Relative to CI	Observed Density of Seals/km^2
1999	10	63.18	0.02	49	74.09	0.02	0.01	0.02	30.01	67.99	<exp	0.78
	11	395.55	0.15	374	463.87	0.12	0.10	0.14	324.41	423.59	<exp	0.95
	12	259.45	0.10	280	304.26	0.09	0.08	0.10	236.36	323.64	within	1.08
	13	358.13	0.14	416	420.00	0.13	0.12	0.15	364.10	467.90	within	1.16
	14	483.37	0.18	604	566.87	0.19	0.18	0.21	543.69	664.31	within	1.25
	15	536.25	0.20	578	628.88	0.19	0.17	0.21	518.69	637.31	within	1.08
	16	322.08	0.12	386	377.71	0.12	0.11	0.14	335.73	436.27	within	1.20
	17	229.65	0.09	418	269.32	0.13	0.12	0.15	365.99	470.01	>exp	1.82
All Years	10	124.45	0.01	106	140.47	0.01	0.01	0.01	77.96	134.04	<exp	0.85
	11	1428.9	0.12	1969	1612.88	0.14	0.13	0.15	1856.67	2081.33	>exp	1.38
	12	1827.44	0.15	2519	2062.73	0.18	0.17	0.19	2394.95	2643.05	>exp	1.38
	13	2406.11	0.20	2934	2715.91	0.21	0.20	0.22	2802.61	3065.39	>exp	1.22
	14	2322.43	0.19	2342	2621.46	0.17	0.16	0.18	2221.45	2462.55	<exp	1.01
	15	2056.27	0.17	1839	2321.03	0.13	0.13	0.14	1729.85	1948.15	<exp	0.89
	16	1571.14	0.13	1458	1773.43	0.11	0.10	0.11	1359.27	1556.73	<exp	0.93
	17	466.07	0.04	607	526.08	0.04	0.04	0.05	541.13	672.87	>exp	1.30

Table C.6. Melt water versus observed and expected numbers of ringed seals counted during aerial surveys in the central Beaufort Sea, 1985-1987 and 1996-1999.

Year	% Melt Water	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion of Total Obs. per Interval	95% Bonferroni Confidence Limits on Prop. of Occur.		95% Bonferroni Confidence Limits on Observed Seals		Observed Proportion Relative to CI	Observed Density of Seals/km^2
							Lower	Upper	Lower	Upper		
1985	0-10	79.95	0.05	43	81.51	0.03	0.02	0.04	25.94	60.06	<exp	0.54
	11-20	678.71	0.45	788	691.97	0.51	0.48	0.54	736.13	839.87	>exp	1.16
	21-30	318.27	0.21	428	324.49	0.28	0.25	0.31	381.58	474.42	>exp	1.34
	31-40	261.83	0.17	200	266.95	0.13	0.11	0.15	165.18	234.82	<exp	0.76
	41-50	121.09	0.08	73	123.46	0.05	0.03	0.06	51.00	95.00	<exp	0.60
	>50	57.5	0.04	15	58.62	0.01	0.00	0.02	4.83	25.17	<exp	0.26
1986	0-10	979.34	0.98	1361	1397.49	0.95	0.94	0.97	1341.04	1380.96	<exp	1.39
	11-20	7.62	0.01	62	10.87	0.04	0.03	0.06	42.76	81.24	>exp	8.14
	21-30	10.68	0.01	3	15.24	0.00	0.00	0.01	-1.32	7.32	<exp	0.28
	31-40	3.08	0.00	2	4.40	0.00	0.00	0.00	-1.53	5.53	within	0.65
1987	0-10	1270.12	1.00	2356	2356.00	1.00	-	-	-	-	-	1.85
1996	0-10	1158.71	0.62	1063	934.69	0.70	0.67	0.74	1016.24	1109.76	>exp	0.92
	11-20	341.13	0.18	198	275.18	0.13	0.11	0.15	163.40	232.60	<exp	0.58
	21-30	132.63	0.07	75	106.99	0.05	0.03	0.06	52.73	97.27	<exp	0.57
	31-40	73.38	0.04	69	59.19	0.05	0.03	0.06	47.59	90.41	within	0.94
	41-50	22.87	0.01	19	18.45	0.01	0.01	0.02	7.57	30.43	within	0.83
	>50	141.95	0.08	85	114.51	0.06	0.04	0.07	61.37	108.63	<exp	0.60
1997	0-10	2683.95	0.99	2714	2703.08	1.00	1.00	1.00	2708.11	2719.89	>exp	1.01
	11-20	13.42	0.00	5	13.52	0.00	0.00	0.00	-0.89	10.89	<exp	0.37
	21-30	0.4	0.00	0	0.40	0.00	0.00	0.00	0.00	0.00	<exp	0.00
	31-40	0.3	0.00	0	0.30	0.00	0.00	0.00	0.00	0.00	<exp	0.00
	41-50	0.26	0.00	0	0.26	0.00	0.00	0.00	0.00	0.00	<exp	0.00
	>50	1.43	0.00	0	1.44	0.00	0.00	0.00	0.00	0.00	<exp	0.00

Table C.6. Melt water continued.

Year	% Melt Water	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion of Total Obs. per Interval	95% Bonferroni Confidence Limits on Prop. of Occur.		95% Bonferroni Confidence Limits on Observed Seals		Observed Proportion Relative to CI	Observed Density of Seals/km^2
							Lower	Upper	Lower	Upper		
1998	0-10	318.94	0.27	190	295.88	0.17	0.14	0.20	156.89	223.11	<exp	0.60
	11-20	65.46	0.05	45	60.73	0.04	0.02	0.06	27.66	62.34	within	0.69
	21-30	134.65	0.11	132	124.91	0.12	0.09	0.14	103.55	160.45	within	0.98
	31-40	185.38	0.15	273	171.98	0.25	0.21	0.28	235.15	310.85	>exp	1.47
	41-50	103.76	0.09	101	96.26	0.09	0.07	0.11	75.72	126.28	within	0.97
	>50	388.32	0.32	369	360.24	0.33	0.30	0.37	327.59	410.41	within	0.95
1999	0-10	2640.24	1.00	3089	3096.30	0.99	0.99	1.00	3079.45	3098.55	within	1.17
	11-20	5.72	0.00	16	6.71	0.01	0.00	0.01	6.45	25.55	within	2.80
	21-30	1.7	0.00	0	1.99	0.00	0.00	0.00	0.00	0.00	<exp	0.00
All Years	10	9131.25	0.75	10816	10306.97	0.79	0.78	0.79	10688.85	10943.15	>exp	1.18
	20	1112.06	0.09	1114	1255.25	0.08	0.07	0.09	1029.58	1198.42	<exp	1.00
	30	598.33	0.05	638	675.37	0.05	0.04	0.05	572.92	703.08	within	1.07
	40	523.97	0.04	544	591.44	0.04	0.04	0.04	483.69	604.31	within	1.04
	50	247.98	0.02	193	279.91	0.01	0.01	0.02	156.61	229.39	<exp	0.78
	>50	589.2	0.05	469	665.06	0.03	0.03	0.04	412.85	525.15	<exp	0.80

Table C.7. Cloud cover versus observed and expected numbers of ringed seals counted during aerial surveys in the central Beaufort Sea, 1985-1987 and 1996-1999.

Year	% Cloud Cover	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. per Interval	95% Bonferroni Confidence Limits on Prop. of Occur.		95% Bonferroni Confidence Limits on Observed Seals		Observed Proportion Relative to CI	Observed Density of Seals/km^2
							Lower	Upper	Lower	Upper		
1985	60	134.21	0.09	164	136.83	0.11	0.09	0.12	135.01	192.99	within	1.22
	80	332.42	0.22	578	338.92	0.37	0.34	0.40	532.45	623.55	>exp	1.74
	100	1050.71	0.69	805	1071.25	0.52	0.49	0.55	757.96	852.04	<exp	0.77
1986	0	1000.72	1.00	1428	1428.00	1.00	1.00	1.00	1573.00	1573.00	within	1.43
1987	0	1270.12	1	2356	2356	1	1.00	1.00	2508.00	2508.00	within	1.85
1996	0	484.68	0.26	296	390.97	0.20	0.17	0.22	257.47	334.53	<exp	0.61
	10	210.89	0.11	144	170.12	0.10	0.08	0.11	115.49	172.51	within	0.68
	70	31.10	0.02	21	25.08	0.01	0.01	0.02	9.63	32.37	within	0.68
	100	1144.01	0.61	1048	922.83	0.69	0.66	0.72	1003.31	1092.69	>exp	0.92
1997	0	243.07	0.09	136	244.80	0.05	0.04	0.06	105.42	166.58	<exp	0.56
	10	179.76	0.07	163	181.05	0.06	0.05	0.07	129.70	196.30	within	0.91
	20	369.08	0.14	310	371.71	0.11	0.10	0.13	265.42	354.58	<exp	0.84
	40	657.72	0.24	903	662.41	0.33	0.31	0.36	836.94	969.06	>exp	1.37
	50	182.91	0.07	272	184.22	0.10	0.08	0.12	229.91	314.09	>exp	1.49
	80	169.52	0.06	252	170.73	0.09	0.08	0.11	211.32	292.68	>exp	1.49
	100	897.69	0.33	683	904.09	0.25	0.23	0.27	622.16	743.84	<exp	0.76
1998	0	674.22	0.56	528	625.47	0.48	0.44	0.52	484.10	571.90	<exp	0.78
	20	10.32	0.01	23	9.58	0.02	0.01	0.03	10.48	35.52	>exp	2.23
	40	153.39	0.13	163	142.30	0.15	0.12	0.17	131.89	194.11	within	1.06
	50	61.73	0.05	88	57.26	0.08	0.06	0.10	64.25	111.75	>exp	1.43
	80	61.61	0.05	60	57.15	0.05	0.04	0.07	40.12	79.88	within	0.97
	100	235.25	0.20	248	218.24	0.22	0.19	0.26	211.39	284.61	within	1.05

Table C.7. Cloud cover continued.

Year	% Cloud Cover	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. per Interval	95% Bonferroni Confidence Limits on Prop. of Occur.		95% Bonferroni Confidence Limits on Observed Seals		Observed Proportion Relative to CI	Observed Density of Seals/km^2
							Lower	Upper	Lower	Upper		
1999	0	12.00	0.005	22	14.07	0.01	0.00	0.01	9.43	34.57	within	1.83
	20	16.11	0.01	13	18.89	0.00	0.00	0.01	3.32	22.68	within	0.81
	30	151.41	0.06	120	177.56	0.04	0.03	0.05	91.11	148.89	<exp	0.79
	50	513.89	0.19	606	602.66	0.20	0.18	0.21	546.59	665.41	within	1.18
	80	123.02	0.05	118	144.27	0.04	0.03	0.05	89.34	146.66	within	0.96
	90	138.78	0.05	132	162.76	0.04	0.03	0.05	101.76	162.24	<exp	0.95
	100	1692.45	0.64	2094	1984.79	0.67	0.65	0.70	2023.76	2164.24	>exp	1.24
All Years	0	3684.81	0.30	4766	4159.26	0.35	0.33	0.36	4607.58	4924.42	>exp	1.29
	10	390.65	0.03	307	440.95	0.02	0.02	0.03	257.84	356.16	<exp	0.79
	20	395.51	0.03	346	446.44	0.03	0.02	0.03	293.88	398.12	<exp	0.87
	30	151.41	0.01	120	170.91	0.01	0.01	0.01	89.05	150.95	<exp	0.79
	40	811.11	0.07	1066	915.55	0.08	0.07	0.08	977.01	1154.99	>exp	1.31
	50	758.53	0.06	966	856.20	0.07	0.06	0.08	880.95	1051.05	>exp	1.27
	60	134.21	0.01	164	151.49	0.01	0.01	0.01	127.88	200.12	within	1.22
	70	31.1	0.00	21	35.10	0.00	0.00	0.00	8.01	33.99	<exp	0.68
	80	686.57	0.06	1008	774.97	0.07	0.07	0.08	921.27	1094.73	>exp	1.47
	90	138.78	0.01	132	156.65	0.01	0.01	0.01	99.56	164.44	within	0.95
	100	5020.11	0.41	4878	5666.49	0.35	0.34	0.37	4718.73	5037.27	<exp	0.97

Table C.8. Air temperature versus observed and expected numbers of ringed seals counted during aerial surveys in the central Beaufort Sea, 1985-1987 and 1996-1999.

Year	Temperature (deg C)	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. per Interval	95% Bonferroni Confidence Limits on Prop. of Occur.		95% Bonferroni Confidence Limits on Observed Seals		Observed Proportion Relative to CI	Observed Density of Seals/km^2
							Lower	Upper	Lower	Upper		
1985	-5 to 0	1019.09	0.6716	1228	1039.01	0.79	0.77	0.82	1192.33	1263.67	>exp	1.20
	0 to 4	498.26	0.3284	319	507.99	0.21	0.18	0.23	283.33	354.67	<exp	0.64
1986	-5 to 0	33.57	0.0335	42	47.90	0.03	0.02	0.04	26.72	57.28	within	1.25
	0 to 4	866.81	0.8662	1253	1236.92	0.88	0.86	0.90	1223.33	1282.67	within	1.45
	4 to 8	100.34	0.1003	133	143.18	0.09	0.07	0.11	106.71	159.29	within	1.33
1987	-5 to 0	968.52	0.7625	1946	1796.55	0.83	0.81	0.84	1904.75	1987.25	>exp	2.01
	0 to 4	301.6	0.2375	410	559.45	0.17	0.16	0.19	368.75	451.25	<exp	1.36
1996	0 to 4	150.71	0.08	220	121.57	0.15	0.12	0.17	187.18	252.82	>exp	1.46
	4 to 8	1599.23	0.85	1224	1290.04	0.81	0.79	0.84	1187.60	1260.40	<exp	0.77
	8 to 11	120.74	0.06	65	97.39	0.04	0.03	0.06	46.12	83.88	<exp	0.54
1997	≤ -9	137.46	0.05	190	138.44	0.07	0.06	0.08	155.76	224.24	>exp	1.38
	-9 to -5	1055.03	0.39	1278	1062.55	0.47	0.45	0.49	1210.96	1345.04	>exp	1.21
	-5 to 0	924.96	0.34	778	931.55	0.29	0.26	0.31	717.30	838.70	<exp	0.84
	0 to 4	213.22	0.08	163	214.74	0.06	0.05	0.07	131.11	194.89	<exp	0.76
	4 to 8	369.08	0.14	310	371.71	0.11	0.10	0.13	267.31	352.69	<exp	0.84
1998	0 to 4	138.08	0.12	136	128.10	0.12	0.10	0.15	108.71	163.29	within	0.98
	4 to 8	843.41	0.70	732	782.43	0.66	0.62	0.69	692.57	771.43	<exp	0.87
	8 to 11	91.68	0.08	94	85.06	0.08	0.06	0.11	70.83	117.17	within	1.03
	> 11	123.33	0.10	148	114.41	0.13	0.11	0.16	119.71	176.29	>exp	1.20
1999	-5 to 0	2159.05	0.82	2194	2531.99	0.71	0.69	0.72	2137.13	2250.87	<exp	1.02
	0 to 4	488.61	0.18	911	573.01	0.29	0.28	0.31	854.13	967.87	>exp	1.86

Table C.8. Air temperature continued.

Year	Temperature (deg C)	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. per Interval	95% Bonferroni Confidence Limits on Prop. of Occur.		95% Bonferroni Confidence Limits on Observed Seals		Observed Proportion Relative to CI	Observed Density of Seals/km^2
							Lower	Upper	Lower	Upper		
All Years	≤ -9	137.46	0.01	190	155.16	0.01	0.01	0.02	153.18	226.82	within	1.38
	-9 to -5	1055.03	0.09	1278	1190.87	0.09	0.09	0.10	1186.40	1369.60	within	1.21
	-5 to 0	5105.19	0.42	6188	5762.53	0.45	0.44	0.46	6030.96	6345.04	>exp	1.21
	0 to 4	2657.29	0.22	3412	2999.44	0.25	0.24	0.26	3275.71	3548.29	>exp	1.28
	4 to 8	2912.06	0.24	2399	3287.01	0.17	0.17	0.18	2279.26	2518.74	<exp	0.82
	8 to 11	212.42	0.02	159	239.77	0.01	0.01	0.01	125.28	192.72	<exp	0.75
	> 11	123.33	0.01	148	139.21	0.01	0.01	0.01	115.45	180.55	within	1.20

Table C.9. Wind speed versus observed and expected numbers of ringed seals counted during aerial surveys in the central Beaufort Sea, 1985-1987 and 1996-1999.

Year	Windspeed (km/hr)	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. per Interval	95% Bonferroni Confidence Limits on Prop. of Occur.		95% Bonferroni Confidence Limits on Observed Seals		Observed Proportion Relative to CI	Observed Density of Seals/km^2
							Lower	Upper	Lower	Upper		
1985	15-20	1086.09	0.72	1266	1107.31	0.82	0.79	0.84	1229.70	1302.30	>exp	1.17
	20-25	32.73	0.02	43	33.37	0.03	0.02	0.04	27.52	58.48	within	1.31
	25-30	398.53	0.26	238	406.32	0.15	0.13	0.18	204.03	271.97	<exp	0.60
1986	15-20	66.93	0.07	41	95.51	0.03	0.02	0.04	24.75	57.25	<exp	0.61
	20-25	315.74	0.32	434	450.56	0.30	0.27	0.34	389.23	478.77	within	1.37
	25-30	457.75	0.46	681	653.19	0.48	0.44	0.51	632.38	729.62	within	1.49
	30-35	126.73	0.13	230	180.84	0.16	0.14	0.19	194.22	265.78	>exp	1.81
	35-40	33.57	0.03	42	47.90	0.03	0.02	0.04	25.55	58.45	within	1.25
1987	20-25	66.84	0.05	289	123.98	0.12	0.11	0.14	249.23	328.77	>exp	4.32
	25-30	434.91	0.34	549	806.74	0.23	0.21	0.25	497.75	600.25	<exp	1.26
	30-35	501.65	0.39	1137	930.54	0.48	0.46	0.51	1076.42	1197.58	>exp	2.27
	35-40	266.72	0.21	381	494.74	0.16	0.14	0.18	336.36	425.64	<exp	1.43
1996	<15	1175.11	0.63	1069	947.91	0.71	0.68	0.74	1024.90	1113.10	>exp	0.91
	15-20	120.74	0.06	65	97.39	0.04	0.03	0.06	45.30	84.70	<exp	0.54
	25-30	273.67	0.15	189	220.76	0.13	0.10	0.15	156.88	221.12	within	0.69
	30-35	301.16	0.16	186	242.93	0.12	0.10	0.14	154.10	217.90	<exp	0.62
1997	<15	213.22	0.08	163	214.74	0.06	0.05	0.07	131.11	194.89	<exp	0.76
	15-20	963.24	0.36	827	970.10	0.30	0.28	0.33	765.21	888.79	<exp	0.86
	20-25	1214.98	0.45	1488	1223.64	0.55	0.52	0.57	1421.14	1554.86	>exp	1.22
	25-30	246.59	0.09	228	248.35	0.08	0.07	0.10	190.77	265.23	within	0.92
	30-35	61.72	0.02	13	62.16	0.00	0.00	0.01	3.73	22.27	<exp	0.21
1998	<15	429.11	0.36	479	398.08	0.43	0.39	0.47	437.78	520.22	>exp	1.12
	15-20	171.18	0.14	131	158.80	0.12	0.09	0.14	104.15	157.85	<exp	0.77
	25-30	152.91	0.13	93	141.86	0.08	0.06	0.10	69.94	116.06	<exp	0.61
	30-35	443.31	0.37	407	411.26	0.37	0.33	0.40	366.90	447.10	within	0.92

Table C.9. Wind continued.

Year	Windspeed (km/hr)	Area Surveyed (km^2)	Proportion Total Area Surveyed	Observed Number of Seals	Expected Number of Seals	Proportion Total Obs. per Interval	95% Bonferroni Confidence Limits on Prop. of Occur. Lower	Upper	95% Bonferroni Confidence Limits on Observed Seals Lower	Upper	Observed Proportion Relative to CI	Observed Density of Seals/km^2
1999	<15	215.87	0.08	210	253.16	0.07	0.06	0.08	173.08	246.92	<exp	0.97
	15-20	872.82	0.33	1032	1023.58	0.33	0.31	0.35	962.75	1101.25	within	1.18
	20-25	1127.74	0.43	1485	1322.54	0.48	0.45	0.50	1411.56	1558.44	>exp	1.32
	25-30	92.64	0.03	77	108.64	0.02	0.02	0.03	54.14	99.86	<exp	0.83
	30-35	243.44	0.09	228	285.50	0.07	0.06	0.09	189.65	266.35	<exp	0.94
	35-40	95.16	0.04	73	111.59	0.02	0.02	0.03	50.73	95.27	<exp	0.77
All Years	<15	2033.31	0.17	1921	2295.11	0.14	0.13	0.15	1813.73	2028.27	<exp	0.94
	15-20	3280.99	0.27	3362	3703.44	0.24	0.23	0.25	3229.00	3495.00	<exp	1.02
	20-25	2910.94	0.24	3832	3285.75	0.28	0.27	0.29	3693.25	3970.75	>exp	1.32
	25-30	2347.4	0.19	2369	2649.65	0.17	0.16	0.18	2252.15	2485.85	<exp	1.01
	30-35	1234.71	0.10	1794	1393.69	0.13	0.12	0.14	1689.79	1898.21	>exp	1.45
	35-40	395.44	0.03	496	446.36	0.04	0.03	0.04	438.31	553.69	within	1.25