Ringed Seal Distribution and Abundance Near Potential Oil Development Sites in the Central Alaskan Beaufort Sea, Spring 1998

for

BP Exploration (Alaska) Inc.
900 East Benson Blvd. POB 196612
Anchorage, AK 99519-6612

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by

Michael R. Link
Tamara L. Olson
Michael T. Williams

LGL Alaska Research Associates, Inc.
4175 Tudor Centre Drive, Suite 202
Anchorage, Alaska
99508

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EXECUTIVE SUMMARY

This report describes the progress made in the second year of a study to examine the effects of nearshore oil production facilities in the central Alaskan Beaufort Sea on ringed seal (*Phoca hispida*) distribution and abundance during the winter/spring period. The developments proposed by BP Exploration (Alaska) Inc. are at Northstar, seaward of the barrier islands northwest of Prudhoe Bay, and Liberty, in the Stefannson Sound/Foggy Island Bay area east of Prudhoe Bay. Both Northstar and Liberty are within the landfast ice zone where ringed seals maintain breathing holes through the winter and spring.

The objectives of the study are to (1) conduct repeated surveys of the study area to obtain estimates of the relative abundance and observed density of ringed seals on the fast ice; (2) identify relationships between habitat, time and weather variables and observed ringed seal densities in the study area; (3) compare seal densities at varying distances from industrial sites in the absence of recent winter industrial activity; (4) attempt to establish whether any observed differences in seal densities at varying distances from industrial sites are likely related to natural factors or to differing exposure to industrial activities; and (5) review the adequacy of the survey approach in 1997 and 1998, and recommend any changes to the study design, methods or analyses that would improve the ability to assess industry effects (if any) on ringed seal abundance and distribution in the study area in future years.

Intensive, site-specific aerial surveys were conducted in the central Alaskan Beaufort Sea from 23 May to 30 May 1998 using standardized methods consistent with those applied in 1997. In 1998, we surveyed 6350 linear kilometers of transects during 7 survey days. During this period we conducted two complete coverages of 80 unique transects within a study area extending about 75 km east to west and 40 km north to south. The survey was actually conducted as two surveys of a grid of 40 transect, and two surveys of another grid of 40 transects spaced midway between the lines in the first grid. Thus, each part of the study area was surveyed on four different days.

A total of 1039 sightings of 1426 ringed seals were recorded on-transect in fast ice habitat during the four surveys. These four surveys covered a total of 4079 km^2 of fast ice habitat. Excluding waters <3 m deep where seals were rarely seen, there were 1015 sightings of 1402 on-transect seals during survey coverage of 3569 km^2. The observed density of ringed seals in areas $\geq$3 m deep was 0.34 seals/km^2 during the first complete coverage of the 80 transects, and 0.45 seals/km^2 during the second coverage. The overall observed density in areas $\geq$3 m deep was 0.39 seals/km^2.

Observed seal densities were compared in relation to various habitat, temporal and weather variables considered one at a time. Observed densities were found to vary significantly with water depth and to a lesser degree ice deformation. Densities in areas with water depths exceeding 3 m were notably higher than densities in areas with depths <3 m. The 1998 results are very similar to those from 1997. In 1997, densities also depended strongly on water depth ($P<0.001$), with much lower densities in the 0-3 m stratum than in deeper waters.

Seal density tended to decline with increasing ice deformation (ice roughness) during the first survey but there was no such trend during the second survey in 1998.

During 1997 surveys, there was a strong tendency ($P<0.001$) for decreasing seal density with increasing ice deformation when all data were combined (Miller et al. 1998).

The sighting rate for ringed seals also varied significantly with time of day, survey date, wind speed, air temperature, and windchill factor in 1998. In 1997, significant differences were not found with respect to time of day, temperature, and windchill. In 1997, there were also strong day-to-day differences in sighting rate, but the pattern was not the same as in 1998. The sighting rate did not vary significantly with respect to cloud cover in 1998. In 1997, sighting rates differed significantly in relation to cloud cover but no particular pattern was evident.

Observed seal densities were also examined in relation to distance from potential offshore oil development sites. At Northstar (Seal Island), an area where there have been no recent industrial activities during winter, we examined ringed seal densities within the area west of Reindeer Island and north of the barrier islands where water depth was 5-20 m. The observed seal densities in this area, based on 421 km^2 of on-transect survey coverage, was 0.35 and 0.68 seals/km^2. Within this area, observed seal densities did not vary significantly with distance from Seal Island in 1998 (or in 1997). At the Liberty (Tern Island) development site the observed seal density from each of the two survey coverages was 0.37 seals/km^2 (based on about 300 km^2 of survey coverage). Observed ringed seal densities in this area did not vary significantly with increasing distance from Tern Island. In 1997, there was a tendency (non-significant) for increasing seal densities with increasing distance from Tern Island.

The density of ringed seals differed significantly between an area of Vibroseis activity (318 km^2) at the eastern edge of the study area and an adjacent area to the west (363 km^2) where little industrial activity occurred in 1998. We included only 3 to 10 m depth strata for this comparative analysis. The observed seal density in the area where Vibroseis activity had occurred was 0.26 seals/km^2, as compared with 0.40 seals/km^2 in the adjacent area without Vibroseis activity and 0.36 seals/km^2 in the study area outside of the Vibroseis area. The lower densities in the Vibroseis area were observed during both replicate survey coverages in 1998. In 1997, the density in the "1998 Vibroseis area" was 0.46 seals/km^2 as compared with 0.47 seals/km^2 in both the adjacent area and the remainder of the study area (3 to 10 m depth). The differences in seal densities between the Vibroseis and no-Vibroseis areas in 1998 (and not in 1997) suggest that the Vibroseis activity in 1998 may have displaced seals from the area.

The study approach and design used in 1998 provided site-specific baseline information that will be valuable in assessing the effects of industrial development on ringed seal numbers and distribution in the Northstar/Seal Island and Liberty areas during future winter-spring seasons. The general study design incorporates the essential features of a Before-After Control-Impact (BACI) design, involving surveys close to and farther from the anticipated impact sites both before and (in subsequent years) after the onset of oil development. Industry effects on wintering ringed seals are expected to be localized and difficult to detect because of the confounding influences of various environmental factors on numbers of seals present and/or hauled out. For these reasons, within-season replication of surveys and close spacing of transects (as done in this study) are necessary to detect and quantify effects on seal distribution. There is also a need for a multivariate approach to the analysis of environmental and industry influences on seal density. Covariate data are being collected for use in future multi-variate analyses.

INTRODUCTION

BP Exploration (Alaska) Inc. (BP) is planning to develop two oilfields in nearshore waters of the central Alaskan Beaufort Sea. One oil production facility would be in the Northstar Unit, seaward of the barrier islands northwest of Prudhoe Bay (Fig. 1). The Northstar development would be the first offshore oil production facility north of the barrier islands in the Alaskan Beaufort Sea. BP is also planning to construct the Liberty oil production facility in the Stefansson Sound/Foggy Island Bay area, east of Prudhoe Bay (Fig. 1). Both Northstar and Liberty are within the landfast ice zone where ringed seals maintain breathing holes through the winter and spring.

Ringed Seal Status and Biology

Ringed seals occur in the Beaufort Sea year-around, and this species is the most abundant species of marine mammal resident in the Beaufort Sea region. The world-wide population of ringed seals is estimated at 6 to 7 million (Stirling and Calvert 1979), while the Alaska stock in the Bering-Chukchi-Beaufort area consists of 1 to 1.5 million seals (Kelly 1988). Frost and Lowry (1981) estimated 80,000 ringed seals are found in the Beaufort Sea during the summer and about 40,000 are resident there in the winter. A more recent (1987) population estimate for the ringed seals for the area from southern Kotzebue Sound (Chukchi Sea) to the U.S. – Canada Border (Beaufort Sea) was 44,360 ±9,130 (Frost et al. 1988; Hill et al. 1997).

During the winter and spring, the ringed seal occurs in landfast ice and offshore pack ice. Breathing holes are established in landfast ice as the ice forms in autumn and are maintained by the seals throughout the winter. As snow accumulates, ringed seals excavate lairs in the drifts. Pregnant females each give birth to a single pup in a birth lair from mid March through April. They nurse their pups for 4-6 weeks (Smith 1973; Smith and Stirling 1975; Kingsley 1990). Mating occurs in late April and May. From mid May through July, ringed seals frequently haul out in the open air at holes or on the edges of narrow cracks to bask in the sun and molt. Most quantitative surveys of ringed seal abundance and distribution are conducted during the late May - early June period when large numbers of seals haul out on the ice.

Observed Ringed Seal Densities in the Central Alaskan Beaufort

The Alaska Department of Fish and Game (ADF&G) began conducting studies of ringed seal distribution and abundance in the central Alaskan Beaufort Sea in the early 1970s (Burns and Harbo 1972; Frost and Lowry 1988; Frost et al. 1988, 1997). The most recent (mid 1980s to present) of these studies have been summarized by Frost et al. (1997), and the relevant density data quoted there are shown in Table 1.

These recent studies have included aerial surveys of both fast ice and pack ice habitats. The Northstar and Liberty sites are typically well within the landfast ice zone during late May and early June when aerial surveys are usually conducted. The study area for the present BP project is entirely within sector B3 as defined by ADF&G. Sector B3 extends from Oliktok Point (149°51'W) to Flaxman Island (146°03'W, Fig. 2). Considering only fast ice habitats in sector B3, observed ringed seal densities in 1985-87 and 1996-97 ranged from 0.57 to 2.94 seals/km^2. Thus, seal densities observed on

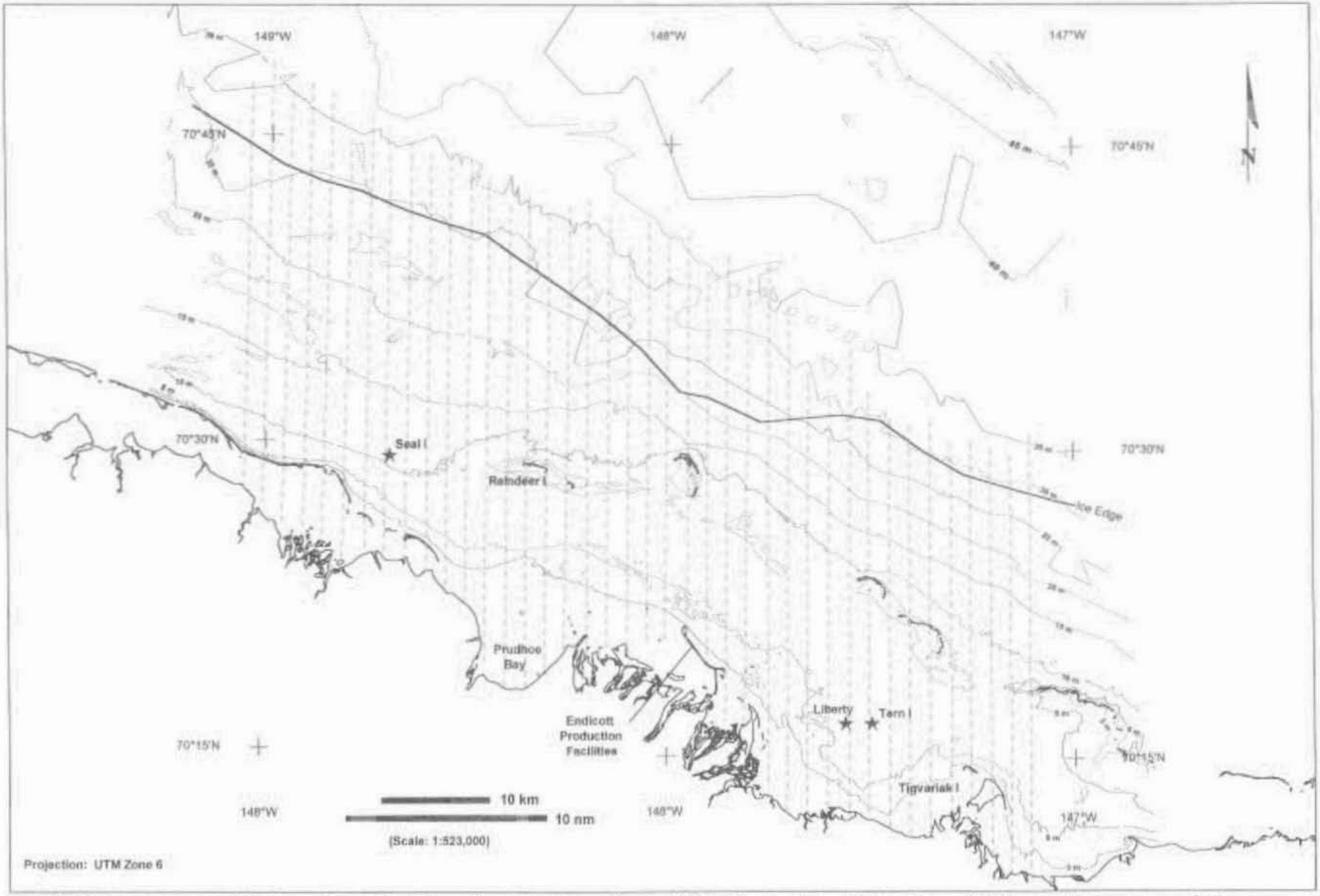

FIGURE 1. Central Alaskan Beaufort Sea showing locations of Northstar (Seal Island) and Liberty (Liberty and Tern Islands) in relation to aerial survey transects flown twice in 1998. A similar grid of 40 transects offset 0.5 n.mi. to the east was also flown twice.

Table 1. Observed seal densities (seals/km^2) in fast ice for ADF&G sectors B3 and B4 (from Frost et al. 1997 and K. Frost, ADF&G, pers. comm.).

	Sector B3			Sector B4
Year	Industrial Prospect	Non-Industrial	Total	Total
1985	1.44	0.81	1.01	0.59
1986	1.21	1.26	1.24	2.71
1987	2.48	3.11	2.94	3.99
1996			0.57	0.67
1997			0.74	1.17

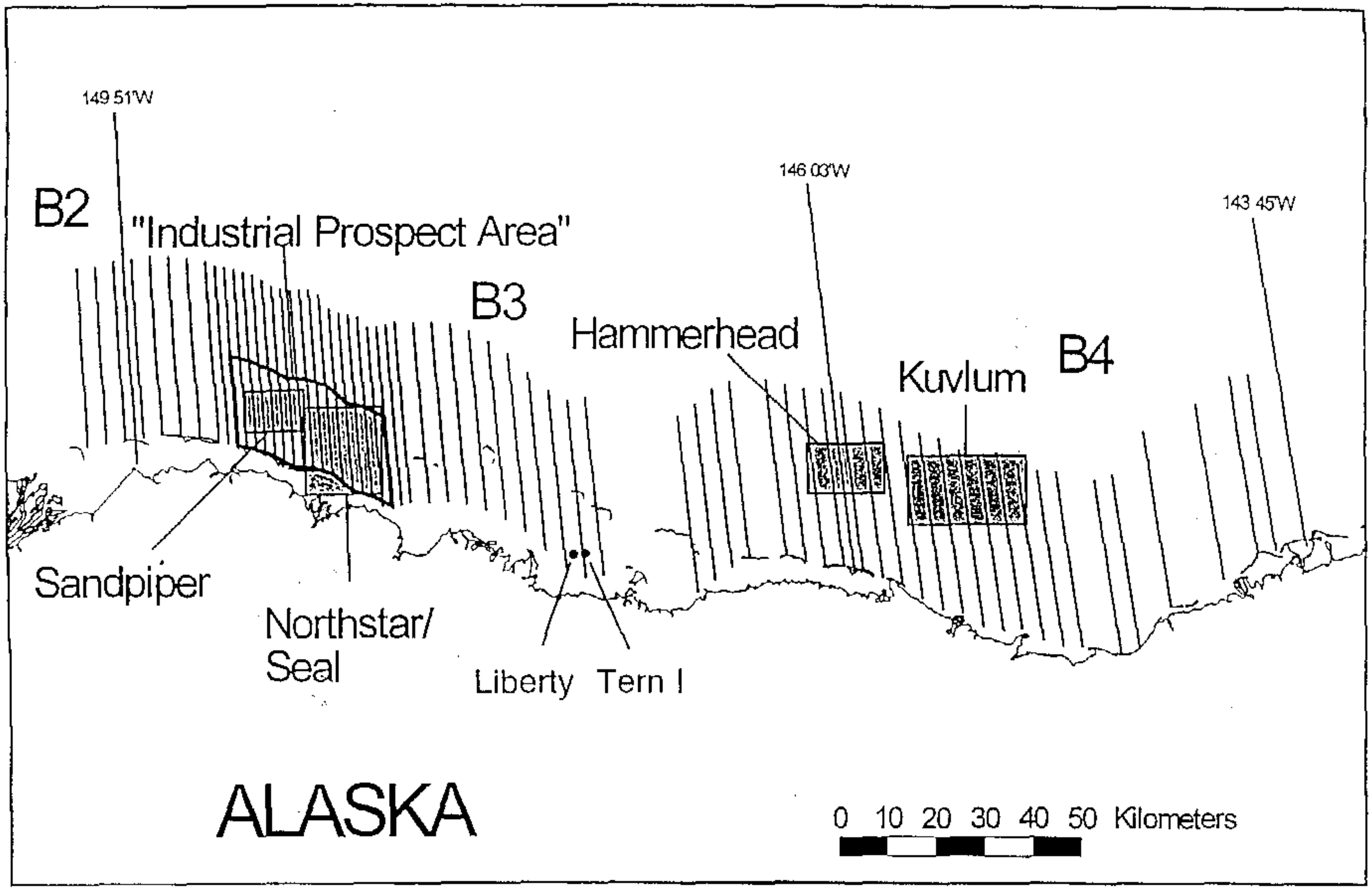

FIGURE 2. Map of the central Alaskan Beaufort Sea showing ADF&G sectors B3 (including the Industrial Prospect Area) and B4. The parallel N-S lines are the transects flown during ADF&G surveys on 29-31 May 1996 (adapted from Frost et al. 1997).

fast ice in this sector varied by about a factor of five among these five years of ADF&G surveys. These density estimates include seals both at holes and at cracks.

Sector B3 has been further sub-divided by ADF&G into an "industrial prospect area" and a "non-industrial area" (Fig. 2). The industrial prospect area includes the proposed Northstar development area but not the Liberty development area. Lower ringed seal densities were observed in the "industrial prospect" than in other fast ice areas within Sector B3 in 3 of 4 years for which data were presented (1986-87 and 1996 but not 1985; Table 1). Ringed seal densities in adjacent sector B4 (Flaxman Isl. to Barter Isl., Fig. 2) were generally higher than in Sector B3 in four of the five years for which data are available, ranging from 0.59 to 3.99 seals/km^2.

Green and Johnson (1983) found average seal densities of 0.74 seals/km^2 in their Seal Island (Northstar) study area in June 1982, following island-construction activities during February-April 1982. Densities in a control area centered about 23 km west of the Seal Island survey grid averaged 0.66 seals/ km^2. Both the industrial and control areas were in the landfast ice, and the density calculations excluded areas of predominantly rough ice, areas inside the barrier islands, and areas with water <5.5 m deep.

Miller et al. (1998) found that ringed seal densities varied significantly with water depth in fast ice of the central Alaska Beaufort Sea (Fig. 1; same survey coverage as presented here for 1998). Based on surveys conducted during late May – early June 1997, Miller et al. (1998) found observed seal densities in water < 3 m of 0.09 seals/km^2 compared with an overall average of 0.43 seals/km^2 in areas $\geq$ 3 m deep. The highest density was observed in the depths of 5 to10 m (0.51 seals/km^2).

Ringed seal densities in the pack ice are more variable from year to year than are those in the fast ice (Frost et al. 1988). In the Beaufort Sea, seal densities in pack ice generally decrease with increasing distance from the ice edge out to about 20 n.mi. (37 km) north of the ice edge. Pack ice habitat ≥10 n.mi. (18.5 km) beyond the fast ice edge typically supports observed seal densities of about 0.29 seals/km^2. During the four years for which ADF&G data are available (1985-87 and 1996-97), observed seal densities in the pack ice ranged from 0.43 to 1.23 seals/km^2 in sector B3, and from 0.48 to 2.37 seals/km^2 in sector B4 (Frost et al. 1997; K. Frost, pers. comm.).

There are few data on seal densities in lagoons such as the Stefansson Sound/ Foggy Island Bay area where the Liberty Development is planned. Surveys of seals on the ice in the central part of the Alaskan Beaufort Sea during spring have concentrated on the landfast ice zone seaward of the barrier islands. Some surveys have extended south to cover the more northerly parts of the lagoons, but previous surveys generally have not attempted to survey the shallower parts of the lagoons. In 1997, BP seal surveys found low densities of ringed seals in water <3 m deep (Miller et al. 1998). However, areas $\geq$3 m depth inside the lagoons had similar densities to those areas in the landfast ice seaward of the barrier islands. Therefore, suitable habitat and water depth for overwintering ringed seals is present in the Liberty area.

Factors Influencing Numbers of Seals Seen

Aerial surveys for ringed seals are usually flown in late May and June when ringed seals haul out on the ice to molt and are therefore most easily counted from the air. However, not all ringed seals haul out at the same time, and many factors influence the proportion of the population that hauls out at any given time. These factors may include date within the spring season, time of day, solar radiation, cloud cover, temperature, and wind speed. The effects and interactions of these variables are not fully understood. However, the proportion of the ringed seals hauled out and the observed seal densities are usually found to be negatively correlated with wind speed and wind chill factor. More ringed seals haul out during the mid-day period than at other times of day (Finley 1979; Frost et al. 1997).

Some of the effects of these variables on seal censuses can be minimized by standardizing aerial survey procedures, e.g., flying surveys at the same time of day and minimizing survey effort during extremely cold or windy conditions. However, even moderately different weather conditions on different days may result in different proportions of ringed seals hauling out on the ice. Thus, observed differences in ringed seal densities in areas surveyed on different days or at different times within a single day may represent differences in population size, but may also be related to differences in the proportions of the population hauling out.

Between-year comparisons can be confounded by variable ice conditions. Ringed seals often haul out along cracks in the ice. Some seals may move from pack ice into adjacent areas of landfast ice as cracks form in the landfast ice during spring breakup. Breakup occurs earlier in some years than in others as a result of storm events or mild temperatures. This can result in an early influx of ringed seals from pack ice areas into fast ice areas. Ringed seal densities observed during spring surveys, especially after the ice starts to deteriorate, may be biased upwards by the presence of seals that spent the winter elsewhere.

Observed densities of ringed seals are also affected by variation in the effectiveness of the observers, which can involve variable observer experience, fatigue, and sighting conditions. Many comparisons of seal counts by observers on each side of the survey aircraft have found no significant differences between counts (Frost et al. 1988; Stirling et al. 1977). However, in comparisons of seal counts by an experienced observer with those of an inexperienced backup observer at another seat on the same side of the aircraft, the inexperienced observer counted significantly fewer seals during five of the seven comparisons. Less than 100% of the seals on the ice along the flight track will be seen even by an attentive observer, and the proportion seen will vary with observer abilities and alertness, visibility, and glare. However, as compared with many other marine mammals, ringed seals hauled out on the ice are relatively easy to count. They are usually conspicuous and they usually occur either singly or in groups small enough to be counted accurately. Using simultaneous counts by primary and experienced backup observers, Frost et al. (1988) calculated that a single experienced observer sees 83% of the groups and 82% of the seals hauled out on the ice within the aerial survey coverage.

Effects of Industrial Activity on Ringed Seal Distribution

Several studies have attempted to measure the impacts of industrial activities on the distribution and densities of ringed seals in the Beaufort Sea. Reduced numbers of seals have been noticed within 3.7 km (2 n.mi.) of artificial islands during years with industrial activity (Frost and Lowry 1988; Frost et al. 1988). The effect was strongest near active islands: a 50-70% reduction in density was noted within 3.7 km as compared to 3.7-7.4 km away. Green and Johnson (1983) found that, based on densities of ringed seal breathing holes, ringed seals avoided the immediate area of Seal Island during the winter that the island was constructed. The radius of discernible effects was not precisely determined but it was apparently on the order of a few kilometers.

Over larger areas, no changes in ringed seal distribution or numbers have been seen with respect to industrial activities of any type, including on-ice seismic surveys as well as artificial islands (Frost and Lowry 1988; Kelly et al. 1988). Green and Johnson (1983) concluded that the overall effects of the construction of Seal Island in the winter of 1982 on seal distribution and densities were insignificant. A study of ringed seal numbers and distribution in the Canadian Beaufort Sea, Amundsen Gulf and Prince Albert Sound in 1984 found no correlation between ringed seal densities and proximity to industrial sites that had been active the previous year (Kingsley 1986).

In all of these studies, the survey coverage and number of sightings close to the industrial operations were small. This limited the ability to detect and quantify any avoidance effect that might exist.

Current MMS-Funded ADF&G Study of Ringed Seals

The Minerals Management Service (MMS) recently funded the Alaska Department of Fish and Game (ADF&G) to conduct a three-year (1996-98) study of ringed seal distribution and numbers in the Alaskan Beaufort Sea. Aerial surveys were conducted during late May and early June in 1996, 1997 and 1998 and will be conducted again in 1999. The survey effort by ADF&G in these recent surveys is similar to that obtained during previous ADF&G studies conducted in the mid to late 1980s (Frost et al. 1997; K. Frost, pers. comm.). In areas considered to be industrial areas, parallel north-south transects spaced as closely as 1 n.mi. apart are surveyed once each spring season. In other areas the ADF&G transects are 2 n.mi. apart and at least 60% of the transects are randomly selected to be flown.

The broad geographic coverage of the ADF&G surveys provides good information on relative numbers of ringed seals in different regions, plus minimum estimates of actual numbers of seals present. However, because most of this survey effort covers a given area only once per year, it will be difficult to determine the reasons for any observed differences in seal densities in different areas. Such differences might be attributable to spatial factors (such as the presence of industrial activities in certain areas), temporal factors (hour of the day; date in the season), or variations in weather. These effects could be difficult to distinguish in the absence of day-to-day replication. ADF&G is analyzing their data to allow for the effects of the confounding temporal and weather variables insofar as possible. Nonetheless, these broad-scale surveys may not provide sufficient site-specific data to detect or quantify past or future localized effects of specific industrial activities on seal distribution or density. However, combined with more intensive, site-specific survey data, the ADF&G data will be invaluable in providing additional replicate surveys and in documenting any region-wide changes in the distribution and abundance of ringed seals.

Objectives of BP Study on Ringed Seals

During 1997, we began a study designed to obtain additional site-specific data suitable for addressing questions about the potential effects of the Northstar and Liberty offshore oil developments on overwintering ringed seals (Miller et al. 1998). A 75 by 40 km study area was surveyed four times in the 26 May - 4 June 1997 period, with 40 transects being flown during each survey. In 1998, the study continued with four additional surveys of the same study area. There were two surveys of a grid of 40 transects, and two surveys of another grid of 40 transects spaced midway between the lines in the first grid. Thus, the data can be viewed as four surveys of the study area, or as two replicate coverages of a total of 80 different transects.

These 1997 and 1998 surveys were intended to supplement the broader scale MMS-funded ADF&G aerial surveys by obtaining repeated finer-scale coverage of a smaller study area that included both the Northstar and Liberty sites. The additional survey coverage provides baseline data concerning the numbers and distribution of ringed seals during the late spring of 1997 and 1998, before development began at Northstar and during the early stages of development at Liberty. During the winter/early spring of 1997, there were drilling and limited Vibroseis operations in the Liberty area. During the winter/early spring of 1998, there was Vibroseis activity in the eastern portion of the study area, east of Liberty. This allowed us to examine the possible effects of this activity on seal distribution and abundance.

If similar surveys are conducted during and/or after the construction of offshore oil industry facilities within the surveyed area, the baseline data from 1997 and 1998 (and any additional pre-construction years when surveys are done) should allow detection of any biologically significant change in seal densities that might occur. The data will allow comparison of seal densities near and far from the industrial site(s) before and after construction. Thus, the survey design incorporates the essential features of a BACI (Before-After Control-Impact) design. BACI designs are considered optimal for monitoring environmental impacts in the field (Green 1979).

To minimize the problems resulting from temporal variability in the proportion of the ringed seals hauling out, the study is designed to obtain repeated survey coverage of all parts of the study area within each year of surveys. This design will permit analyses of seal densities in relation to a variety of potentially influencing factors, natural as well as industrial. If marked day-to-day variation in ringed seal numbers/densities is apparent, it may be possible to restrict comparisons of densities in industrial and "control" areas to within-day comparisons rather than a single comparison of data from all (or different) days lumped together. Alternatively, survey date could be used as a blocking factor in an analysis incorporating data from all days, and/or weather and temporal variables could be used as covariates.

Throughout the surveys we have recorded (or obtained) data on weather conditions that are likely to affect the extent of haulout (e.g., cloud cover, wind speed and temperature). During the surveys, we also recorded sea ice conditions that may influence ringed seal distribution and densities (e.g., fast ice deformation). In addition, bathymetric (water depth) data for the study area have been obtained. Examination of observed ringed seal densities in relation to these variables will be important in determining whether differences in observed seal densities are related to temporal or weather-induced variation in haul out patterns, habitat effects, or industry effects. When data from additional years become available, more complex analyses incorporating the various environmental factors (and time of day) as covariates will be possible.

The specific objectives of the 1998 phase of the study were as follows:

1. Conduct repeated surveys of the study area during spring 1998 to obtain estimates of the relative abundance and observed density of ringed seals on the fast ice.

2. Compare weather, time, and habitat variables with observed ringed seal densities in the study area.

3. Compare seal densities at varying distances from industrial sites in the absence of recent winter industrial activity (Northstar and Liberty).

4. Based on the results of (2), establish whether observed differences in densities at varying distances from industrial sites are likely related to differing temporal or weather variables during aerial surveys, habitat differences, or differing exposure to industrial activities.

5. Based on the results of (4), review the adequacy of the approach of the study conducted in 1998, and recommend any changes or improvements to the study design, methods or analyses that would improve the assessment of industry effects (if any) on ringed seal abundance and distribution in the study area.

METHODS

Survey Design and Procedures

Two "grids" of aerial survey transects were flown between longitudes 147°06'W and 149°04.5'W. Each grid consisted of 40 north-south transects spaced 1 n.mi. (1.85 km) apart (Table A-1). Each transect extended from the Beaufort Sea shoreline to roughly 20 n.mi. (37 km) offshore (Fig. 1). One of the grids we surveyed includes some of the same transects flown by ADF&G during their wider-ranging ringed seal surveys. The second or alternate grid was offset from the first by 0.5 n.mi. (0.9 km) to the east. In this report, we define a *survey replicate* as a complete survey of the 80 unique transects. (Table A-2 provides definitions of terminology used in our analysis of the survey data.) In 1998, two complete survey replicates were completed. In total, 6,350 linear kilometers of surveys were flown by LGL during 7 days within the period 23-30 May 1998.

A 40-transect grid usually required two days to complete and a survey replicate took four days to complete. Typically, odd-numbered transect lines were flown on one day and even-numbered lines were flown on the next day. Thus, each day's flight usually sampled the entire area, rather than sampling the eastern portions one day and the western portions the next.

The northern ends of repeated transects varied somewhat from day to day. Northbound transects were usually terminated when we had flown at least 20 n.mi. (37 km) or when it was apparent that we had reached the northern edge of the fast ice. The fast ice edge was often easy to recognize because of large open leads in the ice.

The southern ends of transects were usually defined by the coastline. However, late in the season we sometimes avoided flying over narrow nearshore bands of deteriorated ice. Near the Endicott production facilities, we started or ended some transects 1-2 km north of Howe Island to avoid flying close to bird colonies located there.

The survey procedures used in these surveys generally followed those of Frost and Lowry (1988). We used strip transect methodology, which has been standard for previous aerial surveys of ringed seals in Alaska. The surveys were flown in a twin-engine Shrike Commander at an altitude of 300 ft (91 m) ASL and a ground speed of 120 knots (222 km/h). The aircraft was equipped with a GPS for accurate offshore navigation and a barometric altimeter. The aircraft had standard (not bubble) windows. The two observers occupied the front right (co-pilot's) seat and a rear seat on the left side of the aircraft, immediately behind the pilot. The surveys were usually flown between 8:00 and 16:00 h true local time (10:00-18:00 Alaska Daylight Time) when numbers of hauled out seals are expected to be highest.

We surveyed transect strips 411 m in width (1350 ft) on each side of the aircraft. These strips extended from 135 m to 546 m from the centerline. Strip boundaries were marked on the aircraft's windows with tape at the appropriate inclinometer angles, which were 9.5° and 34° below the horizontal for surveys at 91 m (300 ft) altitude. Sightings of seals inside 135 m or beyond 546 m were recorded as off-transect sightings. (Note: For consistency with previous ringed seal surveys, we have *not* attempted adjust the strip boundaries to take account of the "earth curvature" corrections described by Lerczak and Hobbs [1998].)

Data Recording Procedures

A GeoLink data logger automatically recorded time and aircraft position (latitude and longitude) at 1-s intervals throughout the flights. The GeoLink system consisted of a portable computer, Trimble GPS unit on a PCMCIA card, and GeoLink data logging software. At keystrokes initiated by the left rear observer, the time and position of the aircraft were automatically logged at the start and end of each transect.

The two observers recorded the time, visibility, percent ice cover, percent ice deformation, percent meltwater, sunglare, and overall sightability conditions onto audio tape at the end of each 1 minute (~3.7 km) time period. An electronic timer signaled the observers at 1-minute intervals.

Ice deformation was estimated by the aerial observers on each side of the aircraft. At the end of each 1-min interval, the observers estimated the percent of the on-transect ice surface surveyed during the preceding minute that was deformed rather than smooth ice. The ice deformation estimates were categorized by intervals of 10%. Cloud cover (in tenths) was estimated by the front seat aerial observer at the start of each transect.

For each seal sighting, the observer dictated into a portable audio tape recorder the species, number, habitat (hole or crack), and behavior (look, move, dive, or none) of the seal(s), and noted whether the sighting was on or off transect.

When polar bears were sighted, the observer recorded size/age/sex class when this was determinable, behavior and direction of movement. Polar bear sightings are reported in Appendix 2.

The observers also recorded the time of any sightings of industrial sites or activity, including ice roads, drill rigs, seismic lines or artificial islands.

Analysis Procedures

The location of each seal sighting was determined by matching the time of the sighting with the position recorded for that time in the GeoLink GPS logs. Each sighting was also linked to the environmental variables recorded for the corresponding one minute (3.7 km) time period.

Hourly (or more frequent) temperature and wind speed data for Deadhorse airport at Prudhoe Bay were obtained from the National Climatic Data Center (Asheville, NC) for the 8 day study period. Each one-minute time period was assigned a wind speed and temperature by interpolating from the values obtained from the nearest preceding and following weather reports. Windchill was determined for each weather reporting period based on the wind speed and temperature, and was assigned to each time period in the same manner as were the temperature and wind speed data. It should be recognized that temperature, wind speed, and windchill no doubt varied somewhat over the landfast ice relative to the values at Deadhorse.

The data on percent ice deformation collected at 1-min intervals were averaged across days and plotted at the midpoint of each 1-min time period. The averaging procedure involved comparing the midpoints of replicated time periods. If the midpoints were within 800 m of each other, the ice deformation data were averaged. If they were more than 800 m apart, they were treated as independent values. These data were contoured at 5% intervals using Vertical Mapper for MapInfo. The contoured data were used as a GIS layer showing ice deformation. MapInfo was used to compute the portions of the surveyed area that occurred within various ice deformation categories. Seal sightings were overlaid onto the ice deformation layer. The numbers of on-transect seal sightings/km^2 and individuals/km^2 were determined for each ice deformation category using MapInfo supplemented by specially written MapBASIC computer code.

In a similar manner depth contours were developed based on all available depth soundings. Sounding data, obtained on CD-ROMs from NOAA, included Hydrographic Survey Data, Vol. 1, vers. 3.1, and Marine Geophysical Data/Bathymetry, Magnetics, Gravity, vers. 3.2. The 3 m, 5 m, and additional contours by 5 m intervals out to 45 m were derived using Vertical Mapper for MapInfo. These depth contours were used as a GIS layer. MapInfo was used to calculate the surveyed areas within each contour interval. Seal sightings were overlaid onto the depth GIS layer, and densities for both on-transect sightings and individual seals were calculated. Ice deformation and water depth categories were sometimes combined with adjacent categories to obtain a smaller number of broader categories for analysis purposes.

Five kilometer "bins" of distance from the ice edge shoreward were also plotted and used as a GIS layer. The on-transect surveyed area in each bin was calculated. In the same manner as described above, seal sightings were overlaid onto this layer, and seal sightings/ km^2 and individuals/ km^2 were calculated for each 5-km interval.

Date, time-of-day, and weather effects were analyzed using the 1-minute time periods as the common unit of observation. For example, to compare ringed seal densities with respect to time-of-day, all 1-min time periods surveyed within a particular hour were combined in one bin. The number of on-transect seals was divided by the on-transect area surveyed to calculate the density for that hour.

Statistical Tests

We used the chi-square (χ^2) goodness-of-fit test to assess the significance of observed differences in ringed seal densities with respect to variables such as water depth, ice deformation, etc. When significant results were obtained with the χ^2 test, simultaneous Bonferonni-corrected 95% confidence intervals were calculated for the observed proportions by strata. An expected proportion (based on available survey area) falling outside the confidence interval for the observed proportion was considered significantly different for that stratum (Manley et al. 1993). All tests were done based on numbers of seal sightings (singletons or groups) rather than numbers of individual seals. We assumed that the different seals within a closely spaced group should not be considered statistically independent. The expected numbers of seal sightings in the various strata (if seal density were unrelated to the variable in question) were assumed proportional to the surveyed amounts of fast ice within those strata. Although the statistical tests were always conducted on the basis of seal sightings (total number of singletons or groups seen), we discuss the results in terms of observed seal densities (individuals/km^2).

Two complete survey replicates were conducted in 1998. All 80 transects were surveyed twice. For comparisons of seal densities with respect to water depth, ice deformation, distance from ice edge, and distance from potential development sites, we considered the two survey replicates to be non-independent. At any given location along each of those transects, the water depth, ice deformation, etc., would be the same during each survey, and some of the same seals may have been seen repeatedly. To avoid problems with statistical inference associated with the lack of independence of these "repeated measures", we examined each survey replicate (group of 80 unique transects) separately.

In analyzing the relationships of observed seal densities to date, time of day and weather, we treated each survey of a grid as at least partially independent from others with respect to these variables. We assumed that numbers of seal sightings at a given location would vary as a result of survey-to-survey variation in the temporal and environmental factors that affect the proportion of seals hauled out. However, there is still a concern about interdependence of results from the repeated surveys given the presumably fixed number of seals in each area and the close spacing of adjacent transects. Thus, the statistical tests on date, time of day, and weather effects should be considered with appropriate caveats.

As was the case with the 1997 analyses (Miller et al. 1998), the statistical treatment of the 1998 data in this report should be considered preliminary. The approach used here was intended, in part, to help refine future survey designs and to help identify analysis techniques to be applied after more than two years' data are available. The DISCUSSION section includes comments about more elaborate statistical approaches that may be applied in the future to assess the simultaneous effects of several natural and industry factors on observed numbers of ringed seals in different parts of the study area on different dates.

DESCRIPTION OF STUDY AREA

Water Depth

The study area is about 75 km wide and extends about 40 km offshore (Fig. 1). Within this area, maximum water depth reaches about 30 m near the north ends of the survey transects. Barrier islands occur across much of the study area (Fig. 1). West of Prudhoe Bay, these barrier islands are fairly close to shore (2-7 km). However, in the generally shallower waters near and east of Prudhoe Bay, the barrier islands tend to be farther offshore, with some being as much as 20 km from shore.

Waters inside the barrier islands are shallow. West of Prudhoe Bay maximum depths of about 4.5 m occur in the narrow lagoons formed by the barrier islands. In the broader areas inside the barrier islands east of Prudhoe Bay (e.g., Foggy Island Bay), water depths reach a maximum of about 9 m. The water depth is 12 m at the planned Northstar development site (Seal Isl.), and 6.4 m at the planned Liberty development site in Foggy Island Bay.

Ice Conditions

The study area in the spring of 1998 extended beyond the edge of the landfast ice. (Survey coverage of pack ice north of the landfast ice has been excluded from our analyses.) Thus, fast ice is the only habitat considered here. In late winter, first-year sea ice in the Beaufort Sea is generally about 2 m thick. From the shore out to a water depth of about 2 m the ice is frozen to the bottom, forming the bottom-fast ice zone. The remaining ice in the landfast ice zone floats on seawater, with occasional grounded ridges in deeper water.

Sea ice forms in September or October, typically starting along shore where water is less saline and where wave action is often reduced. Initially the water is covered with slush and pancake ice, which gradually thickens into ice sheets. If storms occur during the early stages of freeze-up, the smooth sheet of ice can be broken into blocks, forming a chaotic mass of ice. These storm events are less severe inside the barrier islands and the landfast ice there tends to be stable and is usually very smooth. Offshore of the barrier islands the ice is more subject to storm events and interactions with drifting pack ice during freeze up. These storm events result in the formation of rough, deformed ice with high (up to 10s of meters) ridges of ice rubble. Average ice deformation as recorded during our 1998 surveys is mapped in Figure 3. The ice was notably more deformed offshore of the barrier islands than inside the lagoons (Fig. 3).

Breakup of the sea ice usually occurs by June or July. By 23 May1998, the Kuparuk, Sagavanirktok, Kadleroshilik and Shaviovik rivers were all flowing and river floodwater extended over landfast ice. Ice along the shoreline was beginning to melt and crack in some areas, and the presence of refrozen meltwater indicated that temperatures had previously been warmer. By 26 May 1998, puddles of meltwater formed on the ice and by 28 May larger pools of meltwater and "marble ice" reduced the sightability of seals. (Marble ice is flooded ice that appears blue-green and contains

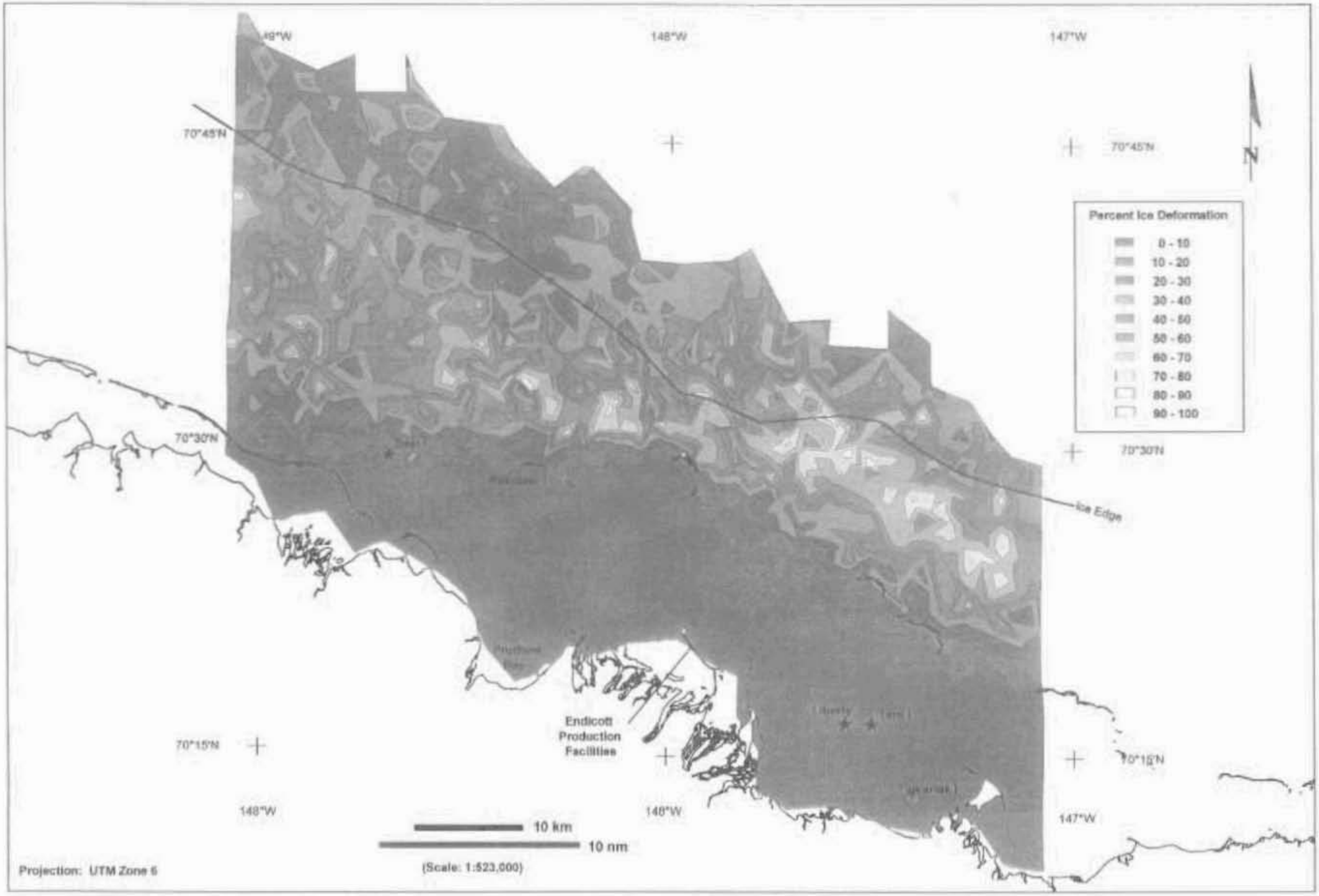

FIGURE 3. Location of the fast ice edge and percent ice deformation in the central Alaskan Beaufort Sea study area, 23-30 May 1998.

dark cracks and embedded pieces of dirty ice, resembling marble). Cracks in the fast ice were evident at the north ends of our transects, near the fast ice edge, and a few tidal cracks had formed near shore. Nearly all of the seals (90%) seen on the fast ice were at breathing holes rather than along cracks. No changes in the location of the fast ice edge were evident during our 1998 study period. However, the location of the fast ice edge was recognizable on most days when surveys were flown, as "closed" pack ice was present north of the landfast ice through 30 May.

Industrial Sites

Two offshore sites in the study area are expected to be developed by BP Exploration (Alaska) Inc. for the production and transportation of oil. The Liberty site is located 5 miles (8 km) offshore in Foggy Island Bay, about midway between Point Brower to the west and Tigvariak Island to the east (Fig. 1). The proposed island site is located between the McClure Islands and the coast in waters 6.4 m deep. The proposed development includes construction of a new gravel island about 1.5 miles (2.4 km) west of Tern Island in Foggy Island Bay, placing drilling and processing facilities on that island, and constructing a buried subsea pipeline south to the mainland.

In the winter of 1997-98, limited surveying and geotechnical activities occurred in the vicinity of Tern Island (Liberty development). Most of this activity was associated with the proposed pipeline corridor between Liberty and the mainland. To help determine whether this light industrial activity affected ringed seal distribution in the Liberty area, we examined ringed seal densities in relation to distance from Tern Island. This analysis was restricted to waters more than 2 miles east of Endicott, inside the barrier islands, and ≥3 m deep. The total area surveyed within this region was about 300 km^2. In addition, many equipment tracks from Vibroseis operations were present on the ice east of Liberty. We also examined seal densities in that 318-km^2 area, including only waters of 3 m to 10 m deep.

The proposed Northstar development site is located at Seal Island, 10 km north of Pt. Storkersen on the mainland coast, 7 km north of Stump Island, and about 10.5 km northwest of the NW end of West Dock. Seal Island is in water about 12 m deep. Development plans for Northstar include rebuilding Seal Island for use as a drilling and production island, installing drilling and processing facilities, and constructing a buried subsea oil pipeline to the mainland. No work was conducted in the Northstar Development area during the winter of 1997-98 either by BP or (apparently) by other exploration companies. The aerial surveyors saw no equipment tracks on the ice near Northstar.

RESULTS

Ringed Seal Abundance and Distribution

Ringed seals were widely distributed throughout the study area during the BP aerial surveys in the spring of 1998 (Fig. 4, 5, 6). A total of 1426 ringed seals were seen on-transect in fast ice habitat during the two complete coverages of the 80 transects. These surveys covered a total of 4079 km^2 of fast ice habitat (approximately 2000 km^2

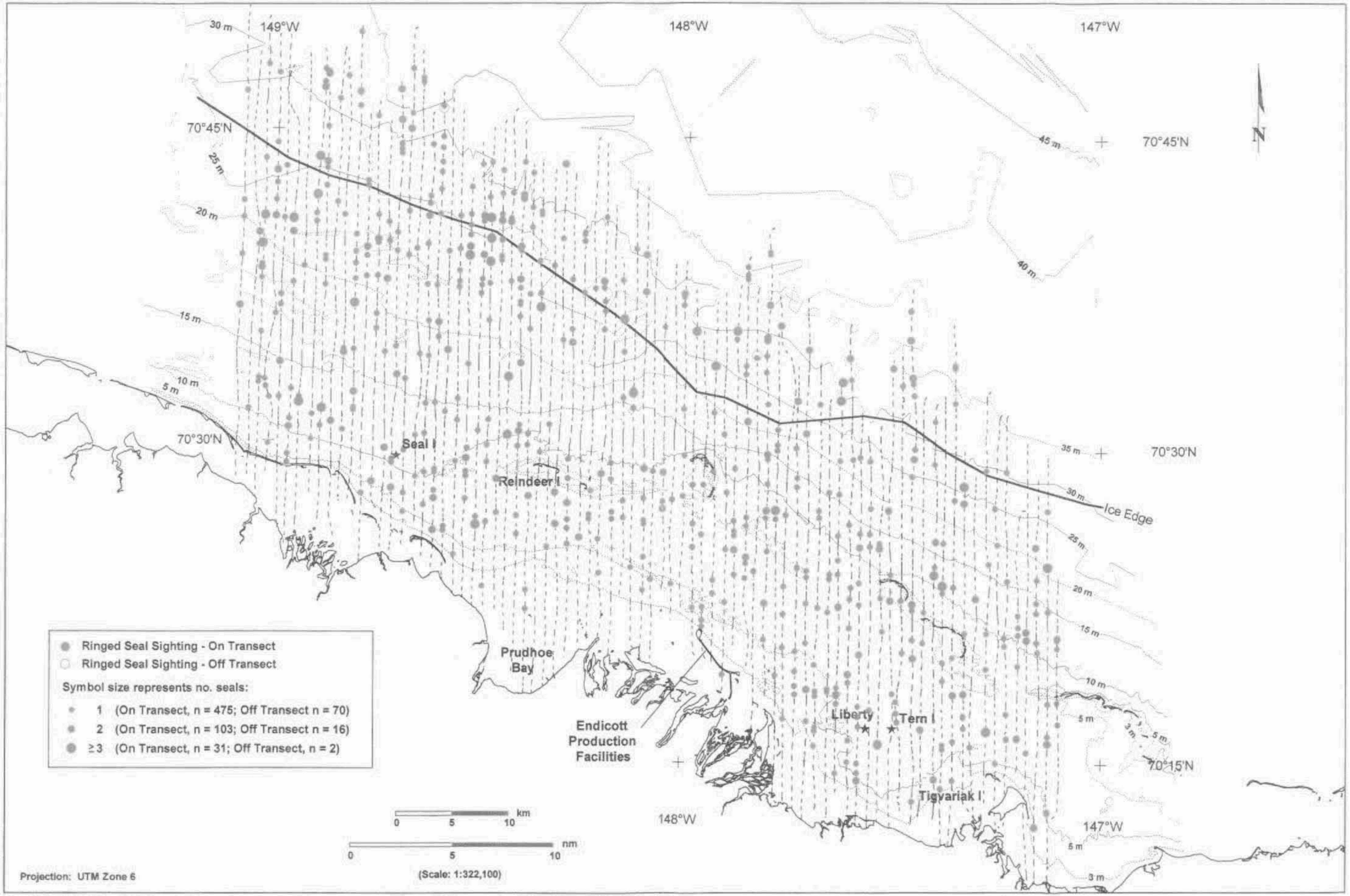

FIGURE 4. Distribution of ringed seals during survey replicate 1 (transects 1-80), 23 - 27 May 1998.

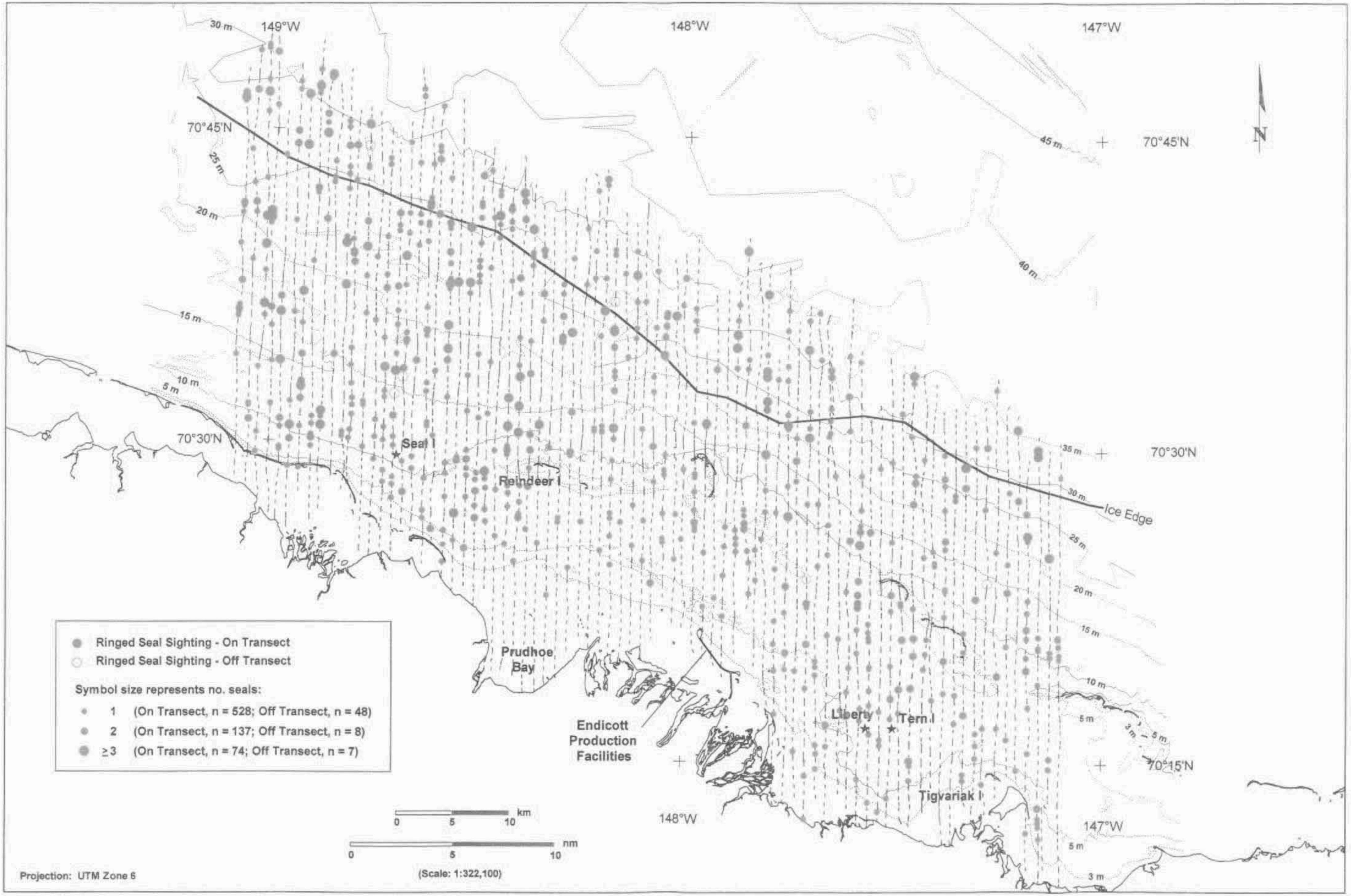

FIGURE 5. Distribution of ringed seals during survey replicate 2 (transects 1-80), 27 - 30 May 1998

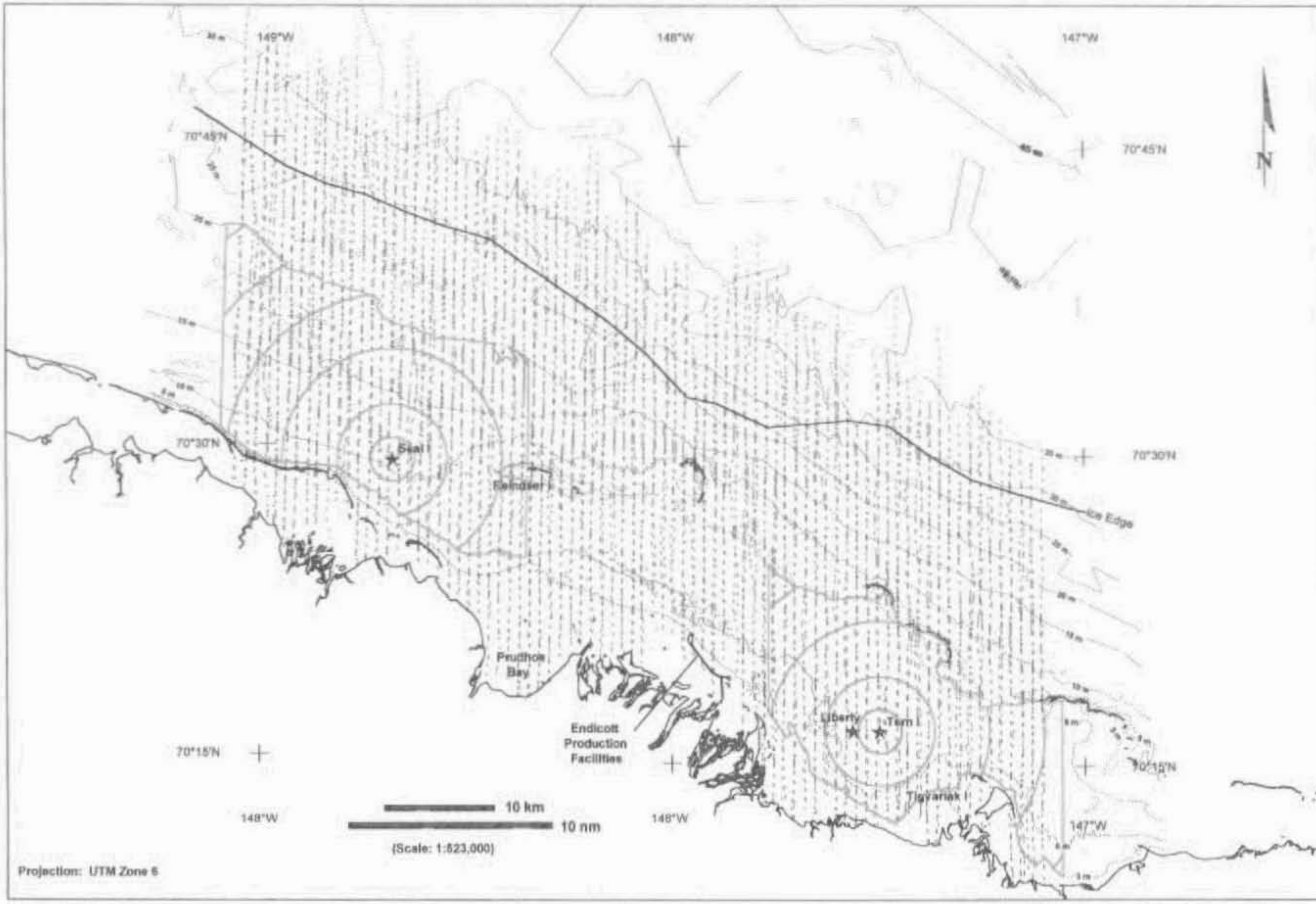

FIGURE 6. Areas and distance intervals used in the analyses of ringed seal densities from the Northstar (Seal Island) and Liberty (Tern Island) development sites.

per replicate coverage). These values exclude the survey coverage and associated seal sightings in areas of close pack ice habitat north of the landfast ice edge depicted in Figures 4 and 5.

The observed overall density of seals in fast ice was 0.34 seals/km^2 in the first survey coverage and 0.45 seals/km^2 in the second coverage. Combining the results from the two replicate coverages an observed seal density of 0.39 seals/km^2. Table A-3 summarizes the seal densities from both 1998 coverages and from the 1997 surveys, both overall and separately for each category of water depth, ice deformation, distance from ice edge, time of day, and weather.

The seal sightings in Figure 4 represent all sightings from the first complete survey coverage (all 80 transects). Figure 5 shows all seal sightings from the second coverage. Although ringed seals were widely distributed in most parts of the study area, there was an obvious tendency for lower densities in the shallowest parts of the lagoons (Fig. 4, 5). There appeared to be some other areas with notably lower densities of seals. However, such patterns should be interpreted cautiously because even a random distribution of points will include apparent clusters and areas of low density. There were about twice as many sightings of groups of ≥3 seals during the second coverage (48 groups) as compared with the first coverage (23 groups).

Factors Affecting Ringed Seal Abundance and Distribution

We examined the observed density of seals on landfast ice in relation to three habitat parameters that may affect seal abundance and distribution: water depth, ice deformation (roughness), and distance from ice edge. The results of these analyses are described below.

The observed average densities in various strata are expected to underestimate the actual densities. Not all seals are hauled out at any one time, and aerial observers miss some proportion of the seals that are hauled out (see INTRODUCTION). However, the observed densities in different strata are believed to be meaningful indicators of the relative utilization of various depths, ice types, and distances from the ice edge.

Water Depth

Observed average densities of ringed seals on landfast ice over different categories of water depth ranged from 0.00 to 0.59 seals/km^2 (Tables 2, 3). The water depth strata used in this analysis were based on the depth contours shown in Figure 1. The sighting rates were strongly dependent on water depth during both survey coverages ($P<0.001$ in each case; Tables 2, 3). The main difference among depth strata was between the 0-3 m zone, where the observed seal density was 0.03 and 0.09 seals/km^2 during the two survey coverages, and all deeper zones, where the observed seal density ranged from 0.20 to 0.59 seals/km^2. The low seal density in water 0-3 m deep was expected. Most of the 0-2 m portion of the 0-3 m zone would be frozen solid in spring and could not be used by seals. The 2-3 m portion would be marginal habitat at best.

If the areas <3 m deep are excluded from the analysis, the densities of seals in the remaining depth categories still differed significantly ($P<0.001$; Tables 2, 3). The differences among strata were attributable to relatively high densities of seals in the

Table 2. Observed and expected numbers of ringed seal sightings on landfast ice in relation to water depth for survey coverage 1, 23-27 May 1998.

Water Depth (m)	Area Surveyed (km^2)	Proportion of Total Area Surveyed	Number of Seal Sightings[1]	Expected Number of Seal Sightings[1]	Proportion of Total Observed in Each Interval	95% Bonferri confidence limits on Proportion of Occurrence		Comparison of Proportion of Total Area with CI	Number of Seals	Density ($seals/km^2$)
						Lower	Upper			
0-3	255.8	0.127	7	59	0.015	0.000	0.030	<Expected	7	0.03
3-5	181.1	0.090	48	42	0.102	0.064	0.141	Within	54	0.30
5-10	591.6	0.293	171	137	0.365	0.304	0.425	>Expected	210	0.35
10-15	302.2	0.150	85	70	0.181	0.133	0.230	Within	116	0.38
15-20	293.7	0.145	55	68	0.117	0.077	0.158	Within	77	0.26
20-25	315.7	0.156	91	73	0.194	0.144	0.244	Within	126	0.40
25-30	78.2	0.039	12	18	0.026	0.006	0.046	Within	16	0.20
30-35	2.0	0.001	0	0	0.000	-	-	Not Defined	0	0.00
Total	2020.4	1.000	469	469	1.000				606	0.30

[1]Observed versus expected number of seals per depth interval for all depth strata: $\chi^2 = 67.82$, df = 7, $P < 0.001$; observed versus expected number of seals per depth interval excluding the <3 m depth stratum: $\chi^2 = 21.61$, df = 6, $P = 0.001$.

Table 3. Observed and expected numbers of ringed seal sightings on landfast ice in relation to water depth for survey coverage 2, 27-30 May 1998.

Water Depth (m)	Area Surveyed (km^2)	Proportion of Total Area Surveyed	Number of Seal Sightings[1]	Expected Number of Seal Sightings[1]	Proportion of Total Observed in Each Interval	95% Bonferri confidence limits on Proportion of Occurrence		Comparison of Proportion of Total Area with CI	Number of Seals	Density ($seals/km^2$)
						Lower	Upper			
0-3	254.6	0.124	17	70	0.030	0.010	0.049	<Expected	17	0.07
3-5	183.1	0.089	38	51	0.067	0.038	0.095	Within	45	0.25
5-10	610.3	0.296	200	169	0.351	0.296	0.406	Within	244	0.40
10-15	304.8	0.148	113	84	0.198	0.153	0.244	>Expected	179	0.59
15-20	295.5	0.144	73	82	0.128	0.090	0.166	Within	132	0.45
20-25	321.6	0.156	106	89	0.186	0.141	0.231	Within	167	0.52
25-30	86.7	0.042	23	24	0.040	0.018	0.063	Within	36	0.42
30-35	2.0	0.001	0	1	0.000	-	-	Not Defined	0	0.00
Total	2058.5	1.000	570	570	1.000				820	0.40

[1]Observed versus expected number of seals per depth interval for all depth strata: $\chi^2 = 63.94$, df = 7, $P < 0.001$; observed versus expected number of seals per depth interval excluding the <3 m depth stratum: $\chi^2 = 23.35$, df = 6, $P = 0.001$.

5-10 m depth stratum during survey coverage 1 and the 10-15 m depth stratum during coverage 2. The highest observed density of seals (0.59 seals/km^2) was at the 10-15 m depth stratum in coverage 2.

The 1998 results are very similar to those from 1997 (*cf.* Miller et al. 1998). In 1997, densities also depended strongly on water depth (P<0.001), with much lower densities in the 0-3 m stratum than in deeper waters. In 1997, as in 1998, densities in waters ≥3 m deep also differed significantly among strata, with highest densities in depths of 5-10 m.

Because of the very low numbers of seals in waters <3 m deep, that depth category has been excluded from all of the following analyses. This eliminated 510 km^2 of surveyed area and 24 seals from further consideration.

Ice Deformation

The sighting rate on landfast ice in 1998 varied among categories of ice deformation during the first survey coverage but not during the second coverage (Tables 4, 5). During the first coverage (23-27 May), there was a general trend toward lower densities in areas with high ice deformation (P=0.008; Table 4). No such trend was evident during the second coverage (27-30 May; P>0.7; Table 5). Sighting rates differed significantly among ice roughness strata in the first survey replicate (P=0.008; Table 4) but not in the second replicate (P=0.761; Table 5). Not including the very small strata (<50 km^2 area), the observed seal densities ranged from 0.15 seals/ km^2 in the 61-70% deformation category of survey coverage 1 to 0.56 seals/km^2 in the 31-40% deformation category in coverage 2. During 1997, there was a strong tendency (P<0.001) for decreasing seal density with increasing ice deformation when all data were combined (Miller et al. 1998). The 1997 data have not been examined separately for the earlier vs. the later portion of the field season.

Distance from Ice Edge

Ringed seal densities did not vary strongly with respect to distance from the ice edge in 1998 (Tables 6, 7). There was a statistically significant χ^2 result from the second survey replicate (P=0.022) but this was largely a result of small sample sizes for distance strata 25-35 km from ice edge (Table 7). Distance from the ice edge is strongly correlated with water depth and the highest density of 0.56 seals/km^2 in the 10-15 km distance for replicate 2 may have been as much related to the 5-10 m depth of this area as it was the distance from the ice edge. In 1997, densities were significantly related to distance from the ice edge (P<0.01), with highest densities 10-20 km from the ice edge (Miller et al. 1998).

Factors Affecting Proportion of Seals Hauled Out

Temporal and weather variables influence the haul-out behavior of ringed seals. In the following sections we look briefly at possible relationships between these variables and observed densities of ringed seals on the landfast ice. This preliminary analysis considers these temporal and weather variables one at a time and not in a multivariate framework.

Table 4. Observed and expected numbers of ringed seal sightings on landfast ice in relation to fast ice deformation for survey coverage 1, 23-27 May 1998.

% Ice Deformation	Area Surveyed (km^2)	Proportion of Total Area Surveyed	Number of Seal Sightings[1]	Expected Number of Seal Sightings[1]	Proportion of Total Observed in Each Interval	95% Bonferri confidence limits on Proportion of Occurrence		Comparison of Proportion of Total Area with CI	Number of Seals	Density ($seals/km^2$)
						Lower	Upper			
0-10	608.2	0.345	170	159	0.368	0.306	0.430	Within	206	0.34
11-20	149.6	0.085	49	39	0.106	0.066	0.146	Within	56	0.37
21-30	148.0	0.084	47	39	0.102	0.063	0.141	Within	59	0.40
31-40	207.6	0.118	63	54	0.136	0.092	0.181	Within	93	0.45
41-50	239.4	0.136	57	63	0.123	0.081	0.166	Within	75	0.31
51-60	218.0	0.124	50	57	0.108	0.068	0.148	Within	78	0.36
61-70	149.3	0.085	18	39	0.039	0.014	0.064	<Expected	23	0.15
71-80	40.1	0.023	8	10	0.017	0.000	0.034	Within	9	0.22
81-90	4.5	0.003	0	1	0.000	-	-	Not Defined	0	0.00
Total	1764.6	1.000	462	462	1.000				599	0.34

[1]Observed versus expected number of seals per ice deformation category: $\chi^2 = 20.87$, df = 8, P = 0.008.

Table 5. Observed and expected numbers of ringed seal sightings on landfast ice in relation to fast ice deformation for survey coverage 2, 27-30 May 1998.

% Ice Deformation	Area Surveyed (km^2)	Number of Seal Sightings[1]	Number of Seals	Density (seals/km^2)
0-10	621.8	195	232	0.37
11-20	152.9	52	66	0.43
21-30	148.0	55	71	0.48
31-40	217.4	67	121	0.56
41-50	239.4	64	107	0.45
51-60	230.5	63	115	0.50
61-70	150.0	43	68	0.45
71-80	40.4	13	22	0.54
81-90	3.4	1	1	0.29
Total	1803.9	553	803	0.45

[1]Observed versus expected number of seals per ice deformation category: $\chi^2 = 4.97$, df = 8, P = 0.761.

Table 6. Observed and expected numbers of ringed seal sightings on landfast ice in relation to distance from ice edge for survey coverage 1, 23-27 May 1998.

Distance (km)	Area Surveyed (km^2)	Number of Seal Sightings[1]	Number of Seals	Density ($seals/km^2$)
0-5	353.9	88	120	0.34
5-10	360.0	83	116	0.32
10-15	356.5	107	136	0.38
15-20	348.1	85	104	0.30
20-25	254.9	76	95	0.37
25-30	83.6	23	28	0.34
30-35	7.7	0	0	0.00
Total	1764.6	462	599	0.34

[1]Observed versus expected number of seals per distance interval: $\chi^2 = 7.34$, df = 6, P = 0.290.

Table 7. Observed and expected numbers of ringed seal sightings on landfast ice in relation to distance from ice edge for survey coverage 2, 27-30 May 1998.

Distance (km)	Area Surveyed (km^2)	Proportion of Total Area Surveyed	Number of Seal Sightings[1]	Expected Number of Seal Sightings[1]	Proportion of Total Observed in Each Interval	95% Bonferri confidence limits on Proportion of Occurrence		Comparison of Proportion of Total Area with CI	Number of Seals	Density (seals/km^2)
						Lower	Upper			
0-5	368.5	0.204	108	113	0.195	0.150	0.243	Within	171	0.46
5-10	366.2	0.203	93	112	0.168	0.125	0.213	Within	141	0.39
10-15	359.7	0.199	124	110	0.224	0.177	0.274	Within	201	0.56
15-20	353.5	0.196	107	108	0.193	0.148	0.241	Within	141	0.40
20-25	255.8	0.142	100	78	0.181	0.137	0.227	Within	124	0.48
25-30	90.3	0.050	20	28	0.036	0.015	0.058	Within	24	0.27
30-35	10.0	0.006	1	3	0.002	-0.003	0.007	Within	1	0.10
Total	1803.9	1.000	553	553	1.000				803	0.45

[1]Observed versus expected number of seals per distance interval: $\chi^2 = 14.72$, df = 6, P = 0.022.

Temporal Factors

Haul out behavior is affected by time of day and time of year. We compared the observed numbers of seal sightings during our spring 1998 aerial surveys at different times of day and on different days.

Sighting rates in 1998 differed significantly across the time of day ($P<0.001$; Table 8). There was a general trend for higher densities to be observed early in the day (10:00 to 12:00 AST) than later in the day (15:00-18:00 ADT). The highest observed density (0.53 seals/km^2) was recorded in the 10:00-11:00 period (Table 8). In contrast, the 1997 surveys revealed no strong relationship between seal densities and time of day.

Average seal densities observed during the seven different survey days in 1998 ranged from 0.27 to 0.56 seals/km^2 (Table 9). The day-to-day differences in sighting rate were highly significant ($P<0.001$), primarily as a result of low seal density observed on the first survey date (23 May) and high density on the penultimate survey date (29 May). Changes in haul-out behavior with survey date may have been related to a general warming trend through the entire survey period and may indicate that time of year was a good surrogate of weather factors in 1998. In 1997, there were also strong day-to-day differences in sighting rate, but the pattern was not the same as in 1998 (Miller et al. 1998).

Weather Factors

Weather factors are known to affect seal haul out behavior. We compared observed densities of ringed seals during different weather conditions.

The sighting rate in 1998 did not differ significantly in relation to percent cloud cover (Table 10; $P=0.125$). The highest observed density was at times when cloud cover was classified as 70-79 percent. However, no specific trend was apparent. In 1997, there were significant differences in observed seal densities among cloud cover categories ($P<0.01$), but with no clear trend across adjacent categories.

The sighting rate in 1998 varied significantly in relation to air temperature at Deadhorse ($P<0.001$; Table 11). The lowest observed density was in the 3-5° C stratum (0.28 seals/km^2) and the highest density was in the 9-12° C stratum (0.56 seals/km^2). In general, observed densities tended to increase with increasing temperature (Table 11). In 1997, there was no clear relationship between observed seal densities and temperature.

The sighting rate in 1998 varied with wind speed at nearby Deadhorse, Alaska ($P=0.003$; Table 12). The highest seal densities were observed when wind speeds were in the intermediate 10-20 km/h range (0.51 seals/km^2; Table 12). No clear trend was evident in the wind speed analysis; the two lowest observed densities occurred at the 0-10 km/h stratum and the 30-40 km/h stratum. In 1997, observed densities also varied with wind speed ($P<0.001$), with the highest observed densities being at times when the wind speed was 20-30 km/h (Miller et al. 1998).

Table 8. Observed and expected numbers of ringed seal sightings on landfast ice in relation to time of day, 23-30 May 1998.

Time (ADST)	Area Surveyed (km^2)	Proportion of Total Area Surveyed	Number of Seal Sightings[1]	Expected Number of Seal Sightings[1]	Proportion Observed in Each Interval	95% Bonferri confidence limits on Proportion of Occurrence		Comparison of Proportion of Total Area with CI	Number of Seals	Density (seals/km^2)
						Lower	Upper			
10-11	358.3	0.100	120	102	0.118	0.091	0.146	Within	189	0.53
11-12	590.9	0.166	212	168	0.209	0.174	0.244	>Expected	294	0.50
12-13	601.1	0.168	168	171	0.166	0.134	0.197	Within	223	0.37
13-14	702.7	0.197	214	200	0.211	0.176	0.246	Within	280	0.40
14-15	484.8	0.136	129	138	0.127	0.099	0.156	Within	185	0.38
15-16	381.9	0.107	84	109	0.083	0.059	0.106	<Expected	119	0.31
16-17	400.9	0.112	81	114	0.080	0.057	0.103	<Expected	103	0.26
17-18	47.8	0.013	7	14	0.007	0.000	0.014	Within	9	0.19
Total	3568.6	1.000	1015	1015	1.000				1402	0.39

[1]Observed versus expected number of seals per time interval: $\chi^2 = 31.47$, df = 7, $P < 0.001$.

Table 9. Observed and expected numbers of ringed seal sightings on landfast ice in relation to survey date, 23-30 May 1998.

Date	Area Surveyed (km^2)	Proportion of Total Area Surveyed	Number of Seal Sightings[1]	Expected Number of Seal Sightings[1]	Proportion of Total Observed in Each Interval	95% Bonferri confidence limits on Proportion of Occurrence		Comparison of Proportion of Total Area with CI	Number of Seals	Density ($seals/km^2$)
						Lower	Upper			
23-May	449.7	0.126	101	128	0.100	0.074	0.125	<Expected	123	0.27
25-May	575.7	0.161	165	164	0.163	0.131	0.194	Within	215	0.37
26-May	574.8	0.161	143	163	0.141	0.112	0.170	Within	192	0.33
27-May	615.2	0.172	177	175	0.174	0.142	0.206	Within	240	0.39
28-May	450.6	0.126	139	128	0.137	0.108	0.166	Within	203	0.45
29-May	447.8	0.125	171	127	0.168	0.137	0.200	>Expected	251	0.56
30-May	454.8	0.127	119	129	0.117	0.090	0.144	Within	178	0.39
Total	3568.6	1.000	1015	1015	1.000				1402	0.39

[1]Observed versus expected number of seals per survey day: $\chi^2 = 24.96$, df = 6, $P < 0.001$.

Table 10. Observed and expected numbers of ringed seal sightings on landfast ice in relation to cloud cover, 23-30 May 1998.

% Cloud Cover	Area Surveyed (km²)	Number of Seal Sightings[1]	Number of Seals	Density (seals/km²)
0-9	1134.6	304	418	0.37
10-19	568.0	145	190	0.33
20-29	86.1	21	31	0.36
30-39	91.2	26	39	0.43
40-49	109.0	39	48	0.44
60-69	39.4	9	13	0.33
70-79	88.6	37	51	0.58
80-89	116.2	32	45	0.39
90-100	1335.4	402	567	0.42
Total	3568.6	1015	1402	0.39

[1]Observed versus expected number of seals per cloud cover category: χ^2 = 12.64, df = 8, P = 0.125.

Table 11. Observed and expected numbers of ringed seal sightings on landfast ice in relation to air temperatures at Deadhorse, Alaska, 23-30 May 1998.

°C	Area Surveyed (km^2)	Proportion of Total Area Surveyed	Number of Seal Sightings[1]	Expected Number of Seal Sightings[1]	Proportion of Total Observed in Each Interval	95% Bonferri confidence limits on Proportion of Occurrence		Comparison of Proportion of Total Area with CI	Number of Seals	Density ($seals/km^2$)
						Lower	Upper			
1 to 3	1221.3	0.342	319	347	0.314	0.277	0.352	Within	415	0.34
3 to 5	419.6	0.118	93	119	0.092	0.068	0.115	<Expected	118	0.28
5 to 7	725.4	0.203	198	206	0.195	0.163	0.227	Within	290	0.40
7 to 9	588.9	0.165	168	168	0.166	0.135	0.196	Within	234	0.40
9 to 12	613.3	0.172	237	174	0.233	0.199	0.268	>Expected	345	0.56
Total	3568.6	1.000	1015	1015	1.000				1402	0.39

[1]Observed versus expected number of seals per survey day: $\chi^2 = 30.90$, df = 4, $P < 0.001$.

Table 12. Observed and expected numbers of ringed seal sightings on landfast ice in relation to wind speed at Deadhorse, Alaska, 23-30 May 1998.

Wind Speed (km/h)	Area Surveyed (km^2)	Proportion of Total Area Surveyed	Number of Seal Sightings[1]	Expected Number of Seal Sightings[1]	Proportion of Total Observed in Each Interval	95% Bonferri confidence limits on Proportion of Occurrence		Comparison of Proportion of Total Area with CI	Number of Seals	Density (seals/km^2)
						Lower	Upper			
0-10	194.1	0.054	47	55	0.046	0.029	0.063	Within	63	0.32
10-20	688.7	0.193	235	196	0.232	0.197	0.266	>Expected	348	0.51
20-30	768.5	0.215	239	219	0.235	0.201	0.270	Within	332	0.43
30-40	875.2	0.245	219	249	0.216	0.183	0.249	Within	284	0.32
40-50	1042.1	0.292	275	296	0.271	0.235	0.307	Within	375	0.36
Total	3568.6	1.000	1015	1015	1.000				1402	0.39

[1]Observed versus expected number of seals per wind speed range: $\chi^2 = 16.08$, df = 4, P = 0.003.

The sighting rate in 1998 varied significantly with the calculated windchill factor at Deadhorse ($P<0.001$; Table 13). These data showed a trend for observed seal densities to increase with the effective temperature. The lowest observed density occurred when the windchill factor was in the −15° to −10° C category. The two highest densities were in the 0° to 5° C stratum and the 5° to 10° C stratum (0.54 and 0.45 seals/km^2, respectively). The observed tendency for a higher number of seals to haul out on the ice with warmer effective temperature was expected. However, the 1997 data did not show this effect ($P>0.3$, Miller et al. 1998).

Observed Ringed Seal Densities Near Development Sites

Northstar (Seal Island)

There were no known industrial activities in the Northstar area during the winter of 1997-98. We examined seal sightings in relation to distance from the proposed development site at Seal Island (Tables 14, 15; Fig. 6). We restricted the analysis to the part of our study area consisting of waters 5-20 m deep west of Reindeer Island and outside the barrier islands (Figures 4, 5). The total area surveyed within this region was 421 km^2 during each of the two coverages.

There was no evidence that seal densities varied with distance from Seal Island in 1998. Sighting rates did not differ significantly among the 5-km strata during either survey coverage ($P=0.184$ and $P= 0.325$; Tables 14 and 15). The overall densities in the Seal Island area were similar to those for the entire study area: 0.35 and 0.68 seals/km^2 at Seal Island during coverages 1 and 2, versus 0.34 and 0.45 seals/km^2 for the entire study area). Likewise, in 1997, observed density in the Seal Island area was not significantly related to distance from the island (Miller et al. 1998).

Liberty (Tern Island)

The overall density of ringed seals in the Liberty area was 0.37 seals/km^2 during both survey replicates (Tables 16, 17). The numbers of seal sightings did not vary with distance from Tern Island ($P=0.846$ and $P=0.900$; Tables 16 and 17). Although based on small areas and few sightings, the highest densities recorded during both coverages were in the 0-2 km distance stratum (0.44 and 0.52 seals/km^2). This preliminary analysis is based only on distances from Tern Island. Winter work in the Liberty area during early 1998, prior to our aerial surveys, included surveying and geotechnical surveys along the proposed pipeline route between Liberty and the mainland. Thus, the industrial activity in the Tern Island/Liberty area during the winter preceding our 1998 surveys was not at a single point. In future analyses of this type it may be desirable to better characterize the boundaries of the area within which the potentially disturbing activities took place, and to measure distances relative to the closest boundary.

In 1997, there was a consistent but non-significant ($P>0.1$) tendency for seal densities to decrease with increasing proximity to Tern Island (Miller et al. 1998). Earlier in 1997, there had been drilling at Tern Island and some Vibroseis activity in the area.

Vibroseis Activity

To help determine whether Vibroseis activity in the eastern portion of the study area during early 1998 affected ringed seal distribution and density, we compared ringed

Table 13. Observed and expected numbers of ringed seal sightings on landfast ice in relation to windchill factor at Deadhorse, Alaska, 23-30 May 1998.

°C	Area Surveyed (km^2)	Proportion of Total Area Surveyed	Number of Seal Sightings[1]	Expected Number of Seal Sightings[1]	Proportion of Total Observed in Each Interval	95% Bonferri confidence limits on Proportion of Occurrence		Comparison of Proportion of Total Area with CI	Number of Seals	Density (seals/km^2)
						Lower	Upper			
-15 to -10	1090.1	0.305	285	310	0.281	0.244	0.317	Within	359	0.33
-10 to -5	972.4	0.272	245	277	0.241	0.207	0.276	Within	348	0.36
-5 to 0	418.7	0.117	109	119	0.107	0.082	0.132	Within	155	0.37
0 to 5	560.0	0.157	210	159	0.207	0.174	0.240	>Expected	305	0.54
5 to 10	527.3	0.148	166	150	0.164	0.134	0.193	Within	235	0.45
Total	3568.6	1.000	1015	1015	1.000				1402	0.39

[1]Observed versus expected number of seals per wind speed range: $\chi^2 = 24.34$, df = 4, $P < 0.001$.

Table 14. Observed and expected numbers of ringed seal sightings on landfast ice in relation to distance from Seal Island for survey coverage 1, 23-27 May 1998.

Distance from Seal Island (km)	Area Surveyed (km^2)	Number of Seal Sightings[1]	Number of Seals	Density (seals/km^2)
0-2	10.7	4	5	0.47
2-5	52.5	10	12	0.23
5-10	141.9	43	58	0.41
10-15	154.0	35	51	0.33
15-20	47.5	8	9	0.19
20-26	14.5	7	11	0.76
Total	421.1	107	146	0.35

[1]Observed versus expected number of seals per distance interval: $\chi^2 = 7.53$, df = 5, P = 0.184.

Table 15. Observed and expected numbers of ringed seal sightings on landfast ice in relation to distance from Seal Island for survey coverage 2, 27-30 May 1998.

Distance from Seal Island (km)	Area Surveyed (km^2)	Number of Seal Sightings[1]	Number of Seals	Density (seals/km^2)
0-2	12.0	7	7	0.58
2-5	51.3	20	22	0.43
5-10	143.3	73	104	0.73
10-15	151.5	57	112	0.74
15-20	47.9	15	32	0.67
20-26	14.8	5	8	0.54
Total	420.8	177	285	0.68

[1]Observed versus expected number of seals per distance interval: $\chi^2 = 5.81$, df = 5, P = 0.325.

Table 16. Observed and expected numbers of ringed seal sightings on landfast ice in relation to distance from Tern Island for survey coverage 1, 23-27 May 1998.

Distance from Seal Island (km)	Area Surveyed (km^2)	Number of Seal Sightings[1]	Number of Seals	Density ($seals/km^2$)
0-2	9.6	3	5	0.52
2-5	53.2	12	13	0.24
5-10	135.8	44	55	0.40
10-15	78.2	25	29	0.37
15-19	14.5	5	6	0.41
Total	291.4	89	108	0.37

[1]Observed versus expected number of seals per distance interval: $\chi^2 = 1.39$, df = 4, P = 0.846.

Table 17. Observed and expected numbers of ringed seal sightings on landfast ice in relation to distance from Tern Island for survey coverage 2, 27-30 May 1998.

Distance from Seal Island (km)	Area Surveyed (km^2)	Number of Seal Sightings[1]	Number of Seals	Density ($seals/km^2$)
0-2	11.4	5	5	0.44
2-5	59.9	16	21	0.35
5-10	140.2	41	47	0.34
10-15	78.9	25	34	0.43
15-19	17.5	5	6	0.34
Total	307.9	92	113	0.37

[1]Observed versus expected number of seals per distance interval: $\chi^2 = 1.06$, df = 4, P = 0.900.

seal densities in this area with densities in a similar-sized area adjacent to and to the west of it (Fig. 7). In order to be consistent among comparisons, we restricted all analyses to the depths of 3 to 10 m (area affected by seismic activity). We identified the areas of Vibroseis activity based on sightings of seismic lines on the ice noted by our aerial surveyors. This may have underestimated the actual area affected somewhat, but served as a good approximation for this analysis. (Specific locations of Vibroseis lines are generally considered proprietary.) Our surveys within the area that was subjected to Vibroseis activity included 318 km^2 of coverage (i.e., about 160 km^2 during each of the two replicate coverages). The adjacent area of no Vibroseis activity included 363 km^2 of coverage (about 180 km^2 per replicate).

We determined the observed densities in the two areas on each of seven days when both were surveyed. The observed density was lower in the Vibroseis area during 5 of these 7 days, the same during one day and higher during another day (Table 18). The difference was statistically significant (P=0.03, Wilcoxon signed-rank test, Table 18). A total of 82 seals were seen within the polygon that encompassed the Vibroseis area (0.26 seals/km^2); a total of 151 seals were observed in the adjacent no-Vibroseis area (0.40 seals/km^2). The latter was similar to the overall density in the whole study area (0.39 seals/km^2) and to the density from all areas (3 to 10 m deep) outside of the Vibroseis area (0.36 seals/km^2) for the entire area. Lower densities in the Vibroseis area were observed during both replicate coverages (Table 18). In 1997, the density in the "1998 Vibroseis area" was 0.46 seals/km^2 as compared with 0.47 seals/km^2 in both the adjacent area and the remainder of the study area (3 to 10 m depth).

DISCUSSION

Observed Ringed Seal Densities

The overall observed seal density (0.39 seals/km^2) based on our spring 1998 surveys of landfast ice habitat is very similar to the overall density of 0.43 seals/km^2 derived from the BP ringed seal surveys conducted by LGL in 1997 (Table A-3; Miller et al. 1998). However, these densities are low compared to seal densities recorded in the same general area in the 1980s. An overall density of 0.74 seals/km^2 was recorded in the Northstar (Seal Island) area following island construction in the winter of 1982, based on repeated surveys of a survey grid centered on Seal Island (Green and Johnson 1983). Seal densities in a similar survey grid centered about 23 km to west of Seal Island area averaged 0.66 seals/km^2 during the same study.

Observed seal densities in fast ice portions of ADF&G's sector B3, which includes our entire study area plus additional areas to the east and west, ranged from 1.01 to 2.94 seals/km^2 during 1985-87 (Table 1) — 2.5 to 7.5 times higher than the density observed during the present study. ADF&G recorded densities of 0.57 and 0.74 seals/km^2 in sector B3 in 1996 and 1997. Within our smaller study area, the overall densities recorded by us in 1997 and 1998 were 0.43 and 0.39 seals/km^2. Dramatic year-to-year changes in the size of Beaufort Sea ringed seal populations have been documented (Stirling et al. 1977; Smith and Stirling 1978). The population in the central Alaskan Beaufort Sea appears to be in a low phase relative to the early 1980s, based on ADF&G's 1996-97 surveys and our 1997-98 surveys.

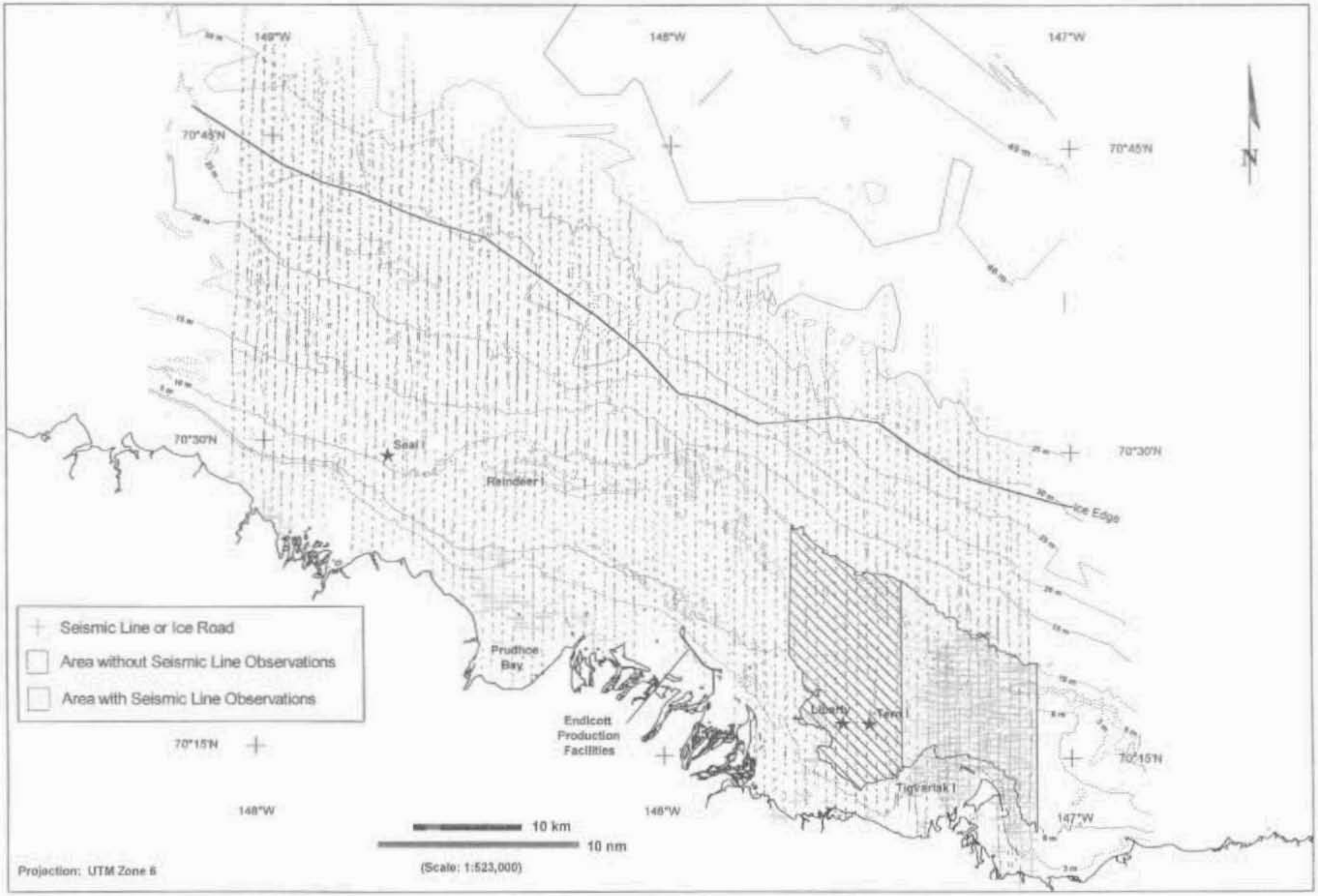

FIGURE 7. Areas used to compare ringed seal densities with and without evidence of Vibroseis activities, 23 - 30 May 1998.

Table 18. The number of ringed seals counted in areas with winter Vibroseis activity, an adjacent, non-active area, and all areas outside of the Vibroseis area, 23-30 May 1998.

	Vibroseis Area (3-10 m depth)			No-Vibroseis Area (adjacent to Vibroseis area, 3-10 m)			No-Vibroseis Area (all 3-10 m depth outside of Vibroseis Area)		
	Area (km^2)	Number of seals	Density	Area (km^2)	Number of seals	Density	Area (km^2)	Number of seals	Density
Date									
23 May	36.6	9	0.25	52.9	13	0.25	110.6	34	0.31
25 May	47.6	8	0.17	34.6	12	0.35	136.9	57	0.42
26 May	34.7	12	0.35	50.7	23	0.45	179.7	55	0.31
27 May	75.2	28	0.37	89.4	47	0.53	131.6	55	0.42
28 May	50.5	5	0.10	34.6	13	0.38	117.6	41	0.35
29 May	34.5	10	0.29	50.9	29	0.57	108.7	55	0.51
30 May	38.8	10	0.26	49.9	8	0.16	117.6	32	0.27
Totals	317.8	82	0.26	363.0	145	0.40	902.7	329	0.36
Survey									
Coverage 1	156.1	45	0.29	174.4	73	0.42	450.9	153	0.34
Coverage 2	161.9	37	0.23	188.7	78	0.41	451.9	176	0.39

The observed density of 0.39 seals/km^2 based on our spring 1998 results is an overall average density based on all surveys flown and, as such, is directly comparable to the densities determined by the other studies cited above. However, it is an underestimate of the actual density of seals present. It is unlikely that all seals were hauled out on the ice even when the maximum count on each transect is considered. In addition, not all of the seals that were hauled out would have been sighted by the aerial observers. Frost et al. (1988) estimated that, in their study, a single experienced observer on each side of the aircraft saw about 82% of the seals present on the ice. If we assume the same detection rate in our study, then the actual average density of ringed seals hauled out during our 1998 surveys was about 0.48 seals/km^2 (0.39/0.82).

Factors Affecting Observed Ringed Seal Densities

The seal densities observed during this study varied considerably across a broad variety of habitat, timing, and weather variables as described in the RESULTS and summarized in Table 19. Habitat variables that appeared to be strongly correlated with seal density were water depth and, during the first survey only, ice deformation.

Densities were notably higher in areas with water depths exceeding 3 m than in areas with depths <3 m, but the relationship with depth was not as strong at depths beyond 3 m. Seals were common in deeper parts of the nearshore lagoons as well as in areas north of the barrier islands. In 1998, the highest observed density was in the 10-15 m depth stratum (0.59 seals/km^2).

There was a general tendency for lower seal density in very rough ice during the first survey coverage (23-27 May), whereas no trend was evident during the second coverage (27-30 May). The results from the first coverage are consistent with those from previous years (Frost et al. 1988; Miller et al. 1998). Frost et al. (1988) speculated that seals prefer smooth ice because they are better able to detect approaching predators in open areas with smooth ice. However, the decline in observed seal densities with increasing ice roughness may also be in some part related to increased difficulty in detecting seals in rough ice conditions.

The lack of a relationship between ice deformation and observed seal density during our second survey coverage may have been attributable to significant changes in the conditions on the ice surface. There was more water on the ice later in the second survey period. This may have caused seals to seek more deformed ice conditions where pooling of water was not as prevalent (in order to avoid basking in puddles of water).

Regional Variation in Observed Ringed Seal Densities

Ringed seal densities varied considerably across the study area (Fig. 8). There were a few areas of relatively high densities concentrated in the western half of the study area, outside of the barrier islands. The reasons for these high-density areas are not known but may be related to prey availability or the suitability of the ice habitat to maintain breathing holes.

The effect of distance from ice edge on seal sightings was stronger in 1997 than it was in 1998. It is possible that the causal influence is water depth or ice deformation rather than distance from ice edge. These variables are intercorrelated and their relative

Table 19. Results of goodness-of-fit analyses of seal sightings in relationship to seal habitat, temporal, and weather variables in the central Alaskan Beaufort Sea, 1997 (26 May - 4 June) and 1998 (23-30 May). Where separate tests were run for the replicate set of 80 transects flown in 1998, the results of both tests are listed. The letters in the body of the table indicate whether the test was significant (S) or not significant (N).

Year	Water Depth	Ice Deformation	Distance from Fast Ice Edge	Time of Day	Survey Date	% Cloud Cover	Wind Speed (km/hr)	Air Temperature	Windchill
1998	S,S	S,N	N,S	S	S	N	S	S	S
1997	S	S	S	S	S	S	S	N	N

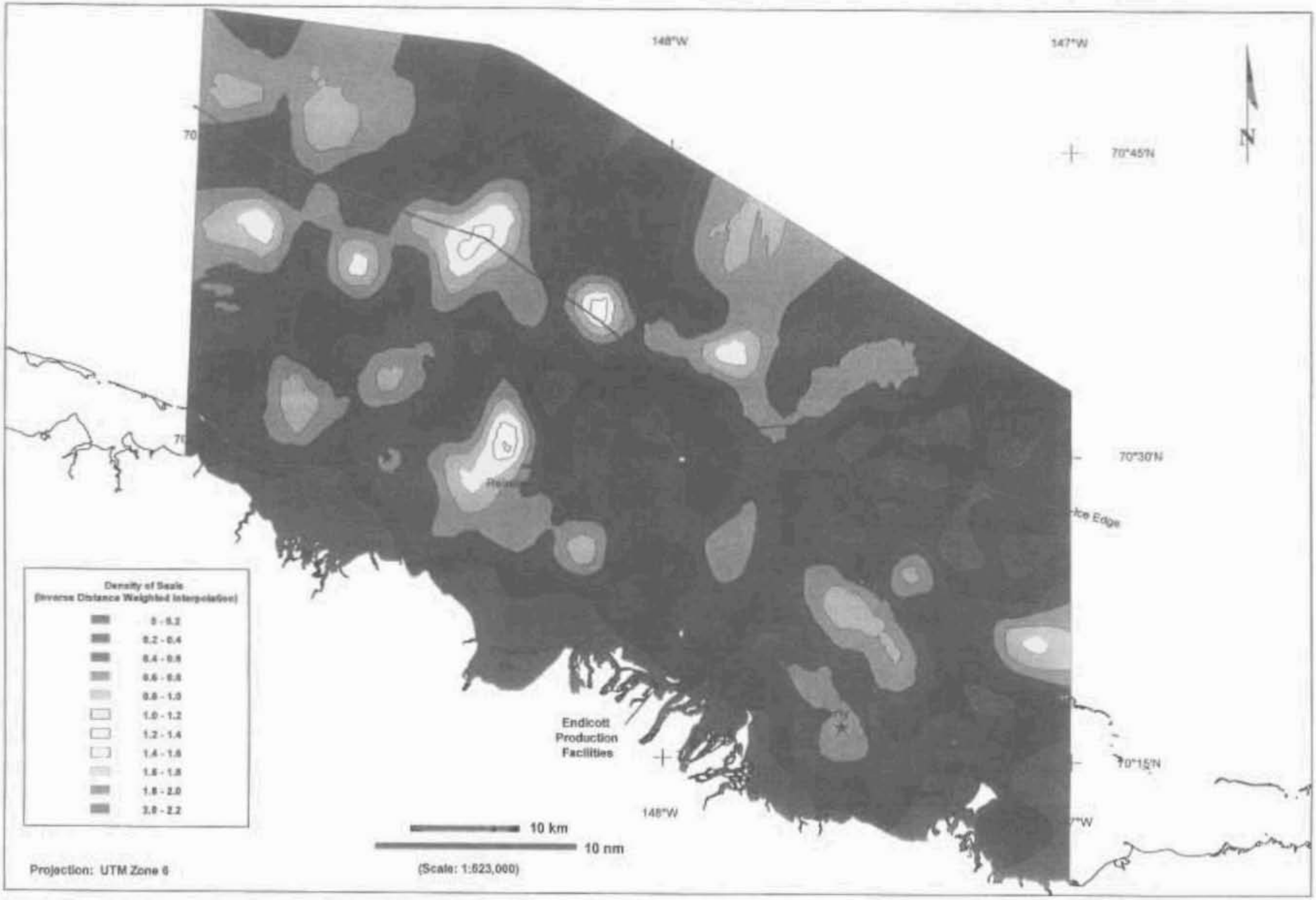

FIGURE 8. Map of ringed seal densities derived from trend surface analysis of all surveys combined, 23-30 May 1998.

effects on seal abundance are not easily distinguished. The ice edge was farther south in 1998 than it was in 1997. Given this, it is possible that the confounding effects may have differed between years.

Factors Affecting Proportion of Seals Hauled Out

Seal sighting rates varied in relation to time of day and survey date in 1997 and 1998 (Table 14). In contrast to 1997 results, we found that seal sighting rates appeared to be strongly affected by air temperature and windchill factor in 1998 (Table 14).

Teasing apart which factors are actually affecting seal behavior and sighting efficiency is difficult with a short time series of data. Several of the factors affecting haul out behavior are correlated with one another, and it is not possible to control any one of them during our a field study such as this. However, the availability of data from the same study area during several different dates within each year provides a basis for conducting such an analysis. The second year of data (1998) is helpful in identifying likely relationships, and in showing that distance from ice edge may not be less important than previously suspected.

Multivariate statistical methods need to be applied to further interpret the survey results in light of variable weather conditions and temporal factors. Such an analysis is planned at a future stage of this project. In the meantime, it will be helpful to eliminate as many of the confounding influences as possible in order to better real changes in seal densities over time and space. Therefore, it will be important to continue to fly surveys during standard or consistent conditions, i.e. between 10:00 and 16:00 h, in winds <37 km/h, and at the same time of year (Frost et al. 1997).

Observed Seal Densities near Industrial Sites

One of the objectives of this study was to obtain baseline data concerning ringed seal distribution and abundance at potential oil development sites. In the general Northstar/Seal Island area, where exploration or development activities have not occurred during winter in recent years, observed seal densities averaged 0.51 seals/km^2 during 1998. The 1998 data did not show any indication of a trend for seal densities to vary with distance from Seal Island (Tables 15, 16). The same was true in 1997 (Miller et al. 1998). With these baseline data, and continued site-specific surveys in the same study area, it should be possible to assess the effects of future industrial development at Northstar on the local distribution and abundance of seals in the Northstar area.

In the Liberty area, observed densities of seals in 1998 did not vary with increasing distance from Tern Island (Tables 17, 18). In 1997, the data from that area showed a tendency for seal densities to increase with distance from the island out to the limit (19 km) of the area under consideration (Miller et al. 1998). No studies of ringed seal numbers and distribution have demonstrated an industry effect beyond about 4 km from any area of island construction, drilling, or on-ice seismic operations (Richardson et al. 1995). It may be that the higher (but not significantly so) densities of ringed seals at locations more than 5 km from Tern Island in 1997 were related to habitat variation and not to the industrial activity that occurred at Tern Island prior to surveys in 1997.

Analysis of data from an area subjected to on-ice seismic activity early in 1998 suggests that seal densities were significantly lower there than in areas where there was little industrial activity in the winter of 1998. These differences were not present between these same areas in 1997 (when there was no Vibroseis). The differences in seal densities between the Vibroseis and no-Vibroseis areas in 1998 (and not in 1997) suggest that the Vibroseis activity in 1998 may have displaced seals from the area.

Further analysis using multivariate methods to assess the simultaneous effects of all measured variables on seal density near Liberty and Northstar will be useful, especially after intensive oil development begins at one of those sites. The objective will be to test for industry effects after accounting for the effects of temporal, habitat, and weather variables. The power of this analysis will be increased as additional comparable data become available through inclusion of data from additional years of surveys, or through combining ADF&G's data with the BP data, or (ideally) by both approaches. When a more elaborate analysis along these lines is done, it will be desirable to take account of the repeated measures aspect of the BP study design in a more formal way than we have done in the preliminary surveys and analyses done in 1997 and 1998.

A summary of this report can be found at the beginning of this document (EXECUTIVE SUMMARY).

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APPENDIX A

Locations of Transects for Ringed Seal Surveys Conduced by LGL,

Definitions of Terms used to Describe Ringed Seal Surveys and Analyses,

and

Summary of Estimated Seal Densities for LGL Ringed Seal Surveys, 1997-98.

Table A-1. Locations of transects for ringed seal surveys conducted by LGL in 1997-98.

ADF&G and LGL Survey Transects						"Alternate" LGL Transects					
Transect Number	Longitude		Transect Number	Longitude		Transect Number	Longitude		Transect Number	Longitude	
1	149	3	2	149	0	41	149	4.5	42	149	1.5
3	148	57	4	148	54	43	148	58.5	44	148	55.5
5	148	51	6	148	48	45	148	52.5	46	148	49.5
7	148	45	8	148	42	47	148	46.5	48	148	43.5
9	148	39	10	148	36	49	148	40.5	50	148	37.5
11	148	33	12	148	30	51	148	34.5	52	148	31.5
13	148	27	14	148	24	53	148	28.5	54	148	25.5
15	148	21	16	148	18	55	148	22.5	56	148	19.5
17	148	15	18	148	12	57	148	16.5	58	148	13.5
19	148	9	20	148	6	59	148	10.5	60	148	7.5
21	148	3	22	148	0	61	148	4.5	62	148	1.5
23	147	57	24	147	54	63	147	58.5	64	147	55.5
25	147	51	26	147	48	65	147	52.5	66	147	49.5
27	147	45	28	147	42	67	147	46.5	68	147	43.5
29	147	39	30	147	36	69	147	40.5	70	147	37.5
31	147	33	32	147	30	71	147	34.5	72	147	31.5
33	147	27	34	147	24	73	147	28.5	74	147	25.5
35	147	21	36	147	18	75	147	22.5	76	147	19.5
37	147	15	38	147	12	77	147	16.5	78	147	13.5
39	147	9	40	147	6	79	147	10.5	80	147	7.5

Table A-2. Definitions of terms used to describe the ringed seal surveys conducted by LGL in 1998.

Term	Description	Comments
Transect strip	An area 411 m wide on each side of the aircraft that was searched for seals	Determined as 9.5 and 35 degrees below the horizon for surveys which were all conducted at 91 m altitude
Survey transect	North-South flight line approx. 37 km (20 n.mi.) long and 822 m wide	
ADF&G Grid	40 unique transects spaced 1.85 km (1 n.mi.) apart	ADF&G Grid transects were flown twice in 1998
Alternate Grid	40 unique transects offset 0.5 n.mi. (0.93 km) east of ADF&G Grid transects	Alternate Grid transects were flown twice in 1998
Survey Coverage	A complete survey of the 80 unique transects (Both Grids)	A total of 2 survey replicates were made in 1998
Seal sighting	Singleton or group of seals observed on ice	Used for all statistical tests, different from number of seals observed
On-transect siting	A seal sighting within the transect strip	Used for all statistical tests
Off-transect siting	A seal sighting outside of the transect strip	Not used for statistical tests
Factor / variable	A condition that may affect abundance and distribution of seals and/or may afffect the proportion of seals hauled out	Examples include bathymetry, ice deformation, distance from ice edge, weather, and time of day
Stratum	Total area applicable to a particular factor	
Seal density	Total number of seals divided by stratum area	

Table A-3. Summary of estimated seal densities (seals/km^2) for BP ringed seal surveys, 1997-98.

	1997	1998		
Category	All Surveys Combined	Coverage 1 and 2 Combined	Coverage 1	Coverage 1
Overall Density[1]	0.43	0.39	0.34	0.45
Water Depth (m)				
0-3	0.09	0.05	0.03	0.07
3-5	0.42	0.27	0.30	0.25
5-10	0.51	0.38	0.35	0.40
10-15	0.42	0.49	0.38	0.59
15-20	0.41	0.35	0.26	0.45
20-25	0.40	0.46	0.40	0.52
25-30	0.32	0.32	0.20	0.42
30-35	0.38	0.00[2]	0.00[2]	0.00[2]
% Ice Deformation				
0-10	0.50	0.36	0.34	0.37
11-20	0.44	0.40	0.37	0.43
21-30	0.47	0.44	0.40	0.48
31-40	0.39	0.50	0.45	0.56
41-50	0.32	0.38	0.31	0.45
51-60	0.36	0.43	0.36	0.50
61-70	0.41	0.30	0.15	0.45
71-80	0.33	0.38	0.22[2]	0.54[2]
81-90	0.24[2]	0.13[2]	0.00[2]	0.29[2]
Distance from Ice Edge (km)				
0-5	0.35	0.40	0.34	0.46
5-10	0.38	0.35	0.32	0.39
10-15	0.47	0.47	0.38	0.56
15-20	0.50	0.35	0.30	0.40
20-25	0.44	0.43	0.37	0.48
25-30	0.45	0.30	0.34	0.27
30-35	0.40	0.10[2]	0.00[2]	0.10[2]
Time of Day (ADST)				
10-11	0.72	0.53	0.42	0.70
11-12	0.44	0.50	0.41	0.62
12-13	0.38	0.37	0.33	0.42
13-14	0.44	0.40	0.31	0.45
14-15	0.43	0.38	0.28	0.48
15-16	0.46	0.31	0.34	0.28
16-17	0.45	0.26	0.25	0.26

Table A-3. Summary of estimated seal densities (seals/km^2) for BP ringed seal surveys, 1997-98.

	1997	1998		
Category	All Surveys Combined	Coverage 1 and 2 Combined	Coverage 1	Coverage 1
17-18	0.30[2]	0.19[2]	-	0.19[2]
18-19	0.17[2]	-	-	-
% Cloud Cover				
0-9	0.40	0.37	0.32	0.40
10-19	0.40	0.33	0.36	0.32
20-29	-	0.36	0.32[2]	0.40[2]
30-39	-	0.43	0.43	-
40-49	0.50	0.44	0.42	0.54[2]
50-59	-	-	-	-
60-69	0.41	0.33[2]	-	0.33[2]
70-79	0.33	0.58	-	0.58
80-89	0.38	0.39	0.30	0.75[2]
90-100	0.46	0.42	0.33	0.56
Temperature (°C)				
-5 to -3	0.47	-	-	-
-3 to -1	0.37	-	-	-
-1 to 1	0.40	-	-	-
1 to 3	0.42	0.34	0.34	-
3 to 5	0.46	0.28	0.30	0.07[2]
6 to 7	-	0.40	0.44	0.39
8 to 9	-	0.40	0.39	0.40
10 to 12	-	0.56	-	0.56
Wind Speed (km/h)				
0-10	-	0.32	-	0.32
10-20	0.39	0.51	0.34	0.55
20-30	0.50	0.43	0.35	0.51
30-40	0.39	0.32	0.34	0.29
40-50	0.39[2]	0.36	0.43	0.39
Windchill (°C)				
-25 to -20	0.40	-	-	-
-20 to -15	0.41	-	-	-
-15 to -10	0.41	0.57	0.33	-
-10 to -5	0.46	0.23	0.36	0.36
-5 to 0	0.42	0.43	0.34	0.41
0 to 5	0.42	0.54	0.39	0.56
5 to 10	-	0.45	-	0.45

Table A-3. Summary of estimated seal densities (seals/km^2) for BP ringed seal surveys, 1997-98.

	1997	1998		
Category	All Surveys Combined	Coverage 1 and 2 Combined	Coverage 1	Coverage 1
Distance from Seal Island (km)				
0-2	0.53[2]	0.53[2]	0.47[2]	0.58[2]
2-5	0.44	0.33	0.23	0.43
5-10	0.46	0.57	0.41	0.73
10-15	0.38	0.53	0.33	0.74
15-20	0.37	0.43	0.19	0.67
20-26	0.63[2]	0.65	0.76[2]	0.54[2]
Total	0.42	0.51[2]	0.35[2]	0.68[2]
Distance from Tern Island (km)				
0-2	0.13[2]	0.48[2]	0.52[2]	0.44[2]
2-5	0.35	0.30	0.24	0.35
5-10	0.45	0.37	0.40	0.34
10-15	0.52	0.40	0.37	0.43
15-19	0.78[2]	0.37	0.41	0.34
Total	0.42	0.37[2]	0.37[2]	0.37[2]

[1]Density is for fast ice, depth > 3 m.

[2]Included <50 km^2 sample area.

APPENDIX B

Incidental Polar Bear Sightings during LGL Ringed Seal Surveys

23 May- 30 May 1998

Incidental Sightings of Polar Bears

during

Ringed Seal Aerial Surveys near Northstar and Liberty, Spring 1998

from

LGL Alaska Research Associates, Inc.
4175 Tudor Centre Drive, Suite 202
Anchorage, AK, 99508

for

BP Exploration (Alaska) Inc.
900 East Benson Blvd., POB 196612
Anchorage, AK, 99519-6612

and

Office of Marine Mammals Management
1011 E. Tudor Rd.
Anchorage, AK, 99503

LGL Report P-430-2

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INTRODUCTION

BP Exploration (Alaska) Inc. (BP) is planning to construct an offshore oil production unit in the Northstar Unit, seaward of the barrier islands northwest of Prudhoe Bay. The Northstar development would be the first offshore oil production facility north of the barrier islands in the Alaskan Beaufort Sea. BP is also planning to construct the Liberty oil production facility in the Stefansson Sound/Foggy Island Bay area, east of Prudhoe Bay.

LGL conducted aerial surveys for ringed seals in the Northstar and Liberty areas from 23 to 30 May 1998. These surveys were designed to provide baseline data concerning the numbers and distribution of ringed seals during the late winter/spring period, before development began at Northstar and during the early stages of development of Liberty. The 1998 surveys were the second year of such surveys; results from 1997 were described by Miller et al. (1999).

Incidental (unintentional) takes of polar bears during the aerial surveys were authorized by a letter dated 16 May 1997 from the U.S. Fish & Wildlife Service under Section 101(a)(5) of the Marine Mammal Protection Act. One requirement of this authorization was that we provide (from incidental sightings of polar bears) information that would prove beneficial to the Fish and Wildlife Service's "understanding of the feeding ecology or distribution of polar bears during this time of year." The following brief letter-report summarizes all of the polar bear sightings during spring ringed seal surveys. Corresponding data from 1997 have been reported to FWS previously.

The surveys were flown at a time of year when ringed seal pupping is over and most pups have left their mothers. Ringed seals haul out on the ice at this time of the year and the aerial surveys were timed to coincide with the expected peak period of ringed seal haul out, when ringed seals are most easily counted from the air.

METHODS

Two "grids" of aerial survey transects were flown between longitudes 147° and 149° W. Each grid consisted of 40 north-south transects spaced 1 n.mi. apart, from the Beaufort Sea shoreline to roughly 20 n.mi. (45 km) offshore. The first and second grids were offset from each other by 0.5 n.mi. Each grid was flown twice during the 23-30 May period. In total, 6,350 km of surveys were flown during 7 days within that period. The surveys were flown in a Shrike Commander twin-engine aircraft at an altitude of 300 ft (91m) ASL and a ground speed of 120 knots (222 km/hr).

RESULTS

Polar Bear

Polar bears were sighted during three of the seven days that surveys were flown (Table B-1). These sightings are mapped in Figure B-1, along with the aerial survey flightlines flown during the surveys. One or two of the polar bear sightings may have been repeated sightings of the same individuals on different days.

Probable Polar Bear Kills

There was one sighting of a probable polar bear kill site (Table B-1, Figure B-1). This site was recognized by blood on the ice and was associated with a seal hole and polar bear tracks. Ringed seals, the only other mammals seen during the aerial surveys, are the primary prey of polar bears and were the likely source of the blood.

Polar Bear Tracks

Polar bear tracks were concentrated in the northern portion of the study area, beyond the 10 m depth contour (Figure B-1).

Factors Affecting the Abundance or Density of Polar Bears

The letter authorizing the incidental take of polar bears requested that we "assess whether abundance or density of polar bears may be influenced by: 1) timing of seal pupping/independence; or 2) presence of other bears of a different sex-age class (i.e., large adult males)." The ringed seal aerial surveys were conducted from 23-30 May, well after the peak of ringed seal pupping (mid April) and after pups had attained independence from their mothers. Thus, the abundance/density of polar bears could not be assessed in relation to the timing of seal pupping/independence. The survey design did not permit us to circle polar bears that were sighted, and so it was not possible to classify the bears as to age and/or sex. This, combined with the relatively small number of sightings, makes our dataset too small to assess polar bear abundance/density in relation to the presence of other bears of different sex-age classes. This small collection of sightings does provide useful information about polar bear distribution in late spring, after ringed seal pupping (and pup independence), when ringed seals haul out on the ice in large numbers.

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Miller, G.W., R.E. Elliot and W.J. Richardson. 1998. Ringed seal distribution and abundance near potential oil development sites in the central Alaskan Beaufort Sea, Spring 1997. Rep. from LGL Ltd., King City, Ont., for BP Exploration (Alaska) Inc., Anchorage, AK. 36 p.

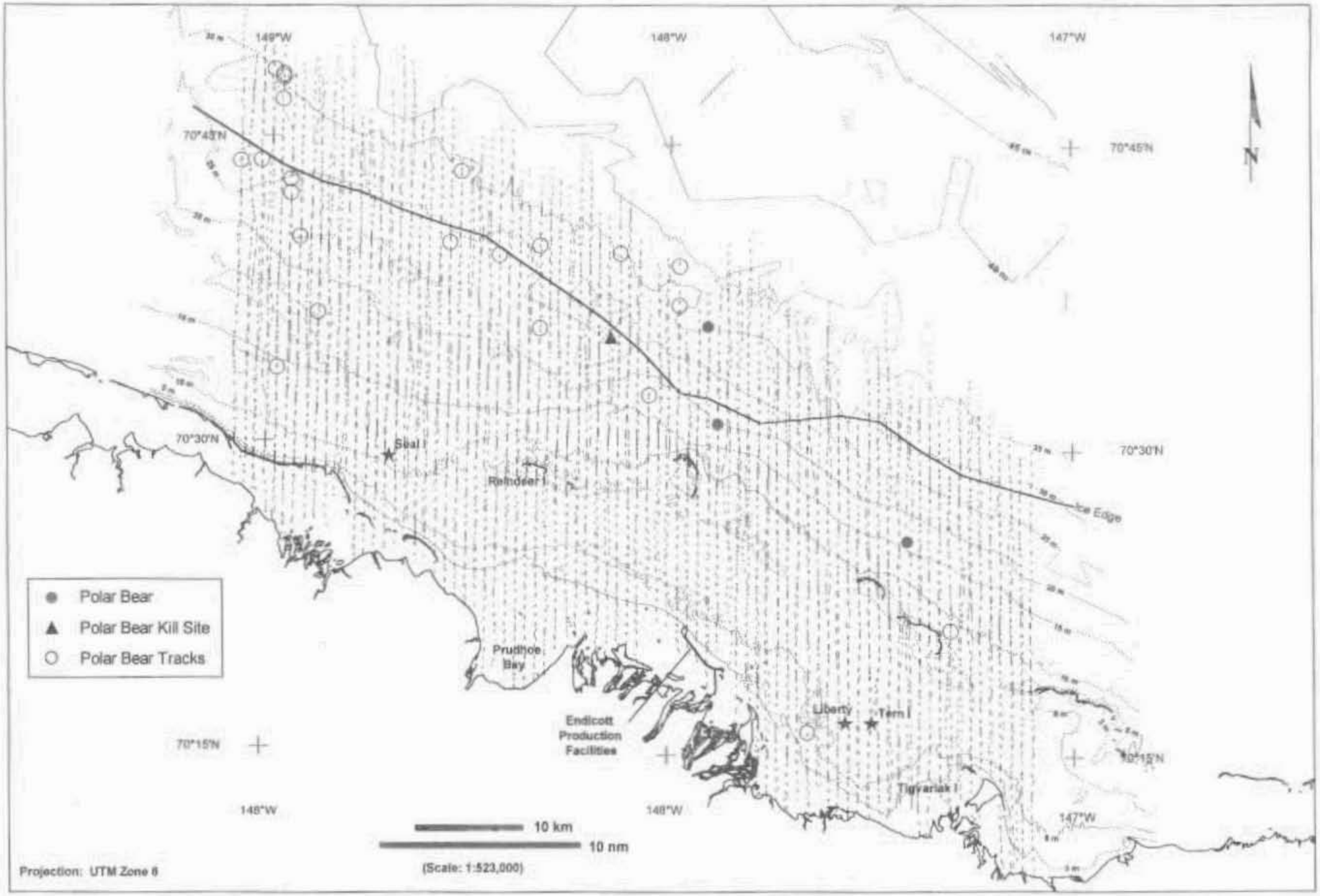

FIGURE B-1. Incidental sightings of polar bears, probable polar bear kill sites, and polar bear tracks recorded during ringed seal aerial surveys conducted in the central Alaskan Beaufort Sea, 23-30 May 1998.

Table B-1. Incidental sightings of polar bears and probable polar bear kills and dens during aerial surveys for ringed seals, 23-30 May 1998.

Date	Time (ADST)	Sighting	Count	Comment	Latitude °N	Longitude °W	% Ice Deformation
25-May	125151	Polar Bear	1	Walking near crack	70.6008	-147.903	70
28-May	164430	Polar Bear	1	Laying down	70.4275	-147.404	40
29-May	125540	Polar Bear	1	Walking, might have looked at us	70.5216	-147.876	60
27-May	165109	Polar Bear Kill Site		Blood around hole; looks like seal was dug out	70.5914	-148.145	30
27-May	115834	Polar Bear Den Site			70.5455	-148.048	40
27-May	124057	Polar Bear Den Site		Possible den site, hollowed out; prints around den	70.2712	-147.650	0