# MONITORING OF INDUSTRIAL SOUNDS, SEALS, AND WHALE CALLS DURING CONSTRUCTION OF BP'S NORTHSTAR OIL DEVELOPMENT, ALASKAN BEAUFORT SEA, 2001

by

LGL

and

**Greeneridge Sciences Inc.**

for

**BP Exploration (Alaska) Inc.**
**Dept of Health, Safety & Environment**
900 East Benson Blvd.
Anchorage, AK 99519-6612

and

**National Marine Fisheries Service**
Anchorage, AK, and Silver Spring, MD

October 2002

# MONITORING OF INDUSTRIAL SOUNDS, SEALS, AND WHALE CALLS DURING CONSTRUCTION OF BP'S NORTHSTAR OIL DEVELOPMENT, ALASKAN BEAUFORT SEA, 2001

edited by

**W. John Richardson** [1] and **Michael T. Williams** [2]

[1] **LGL Ltd., environmental research associates**
22 Fisher St., POB 280, King City, Ont. L7B 1A6
(905) 833-1244; wjr@lgl.com

[2] **LGL Alaska Research Associates Inc.**
1101 E. 76th Ave, Suite B, Anchorage, AK 99518
(907) 562-3339; mwilliams@lgl.com

for

**BP Exploration (Alaska) Inc.**
**Dept of Health, Safety & Environment**
900 East Benson Blvd.
Anchorage, AK 99519-6612

and

**National Marine Fisheries Service**
Anchorage, AK, and Silver Spring, MD

October 2002

## Suggested format for citations:

Richardson, W.J. and M.T. Williams (eds.) 2002. *Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2001.* [Oct. 2002 ed.] Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 309 p.

## Individual chapters can also be cited, as follows:

Williams, M.T. and W.J. Richardson. 2002. *Introduction.* p. 1-1 to 1-6 *In:* ... LGL Rep. TA2563-4.

### *Ice-Covered Season, Nov. 2000 to 15 June 2001*

Perham, C.J. and M.T. Williams. 2002. *Description of BP's on-ice activities, 2000-2001 ice-covered season.* p. 2-1 to 2-10 *In:* ... LGL Rep. TA2563-5.

Blackwell, S.B. and C.R. Greene Jr. 2002. *Sound and vibration measurements during winter drilling at Northstar in early 2001.* p. 3-1 to 3-25 *In:* ... LGL Rep. TA2571-2.

Williams, M.T., T.G. Smith and C.J. Perham. 2002. *Ringed seal structures in sea-ice near Northstar, winter and spring of 2000-2001.* p. 4-1 to 4-33 *In:* ... LGL Rep. P557-2.

Moulton, V.D., R.E. Elliott, W.J. Richardson and T.L. McDonald. 2002. *Fixed-wing aerial surveys of seals near BP's Northstar and Liberty sites in 2001 (and 1997-2001 combined).* p. 5-1 to 5-60 *In:* ... LGL Rep. TA2570-3.

### *Break-Up and Open Water Seasons, 16 June to 31 Oct. 2001*

Perham, C.J. and M.T. Williams. 2002. *Description of BP's activities, break-up and open-water seasons, 2001.* p. 6-1 to 6-8 *In:* ... LGL Rep. TA2563-6.

Blackwell, S.B. and C.R. Greene Jr. 2002. *Sound measurements, 2001 open-water season.* p. 7-1 to 7-39 *In:* ... LGL Rep. TA2572-2.

Greene, C.R. Jr., M.W. McLennan, T.L. McDonald and W.J. Richardson. 2002. *Acoustic monitoring of bowhead whale migration, autumn 2001.* p. 8-1 to 8-79 *In:* ... LGL Rep. TA2573-2.

### *Numbers of Seals and Whales Potentially Affected, Nov. 2000 – Oct. 2001*

Williams, M.T., V.D. Moulton and W.J. Richardson. 2001. *Estimated numbers of seals and whales potentially affected by Northstar activities, Nov. 2000 – Oct. 2001.* p. 9-1 to 9-27 *In:* ... LGL Rep. TA2563-7.

### *Appendices A–C*

# TABLE OF CONTENTS

## ICE-COVERED SEASON

## OPEN-WATER SEASON

# ACRONYMS AND ABBREVIATIONS

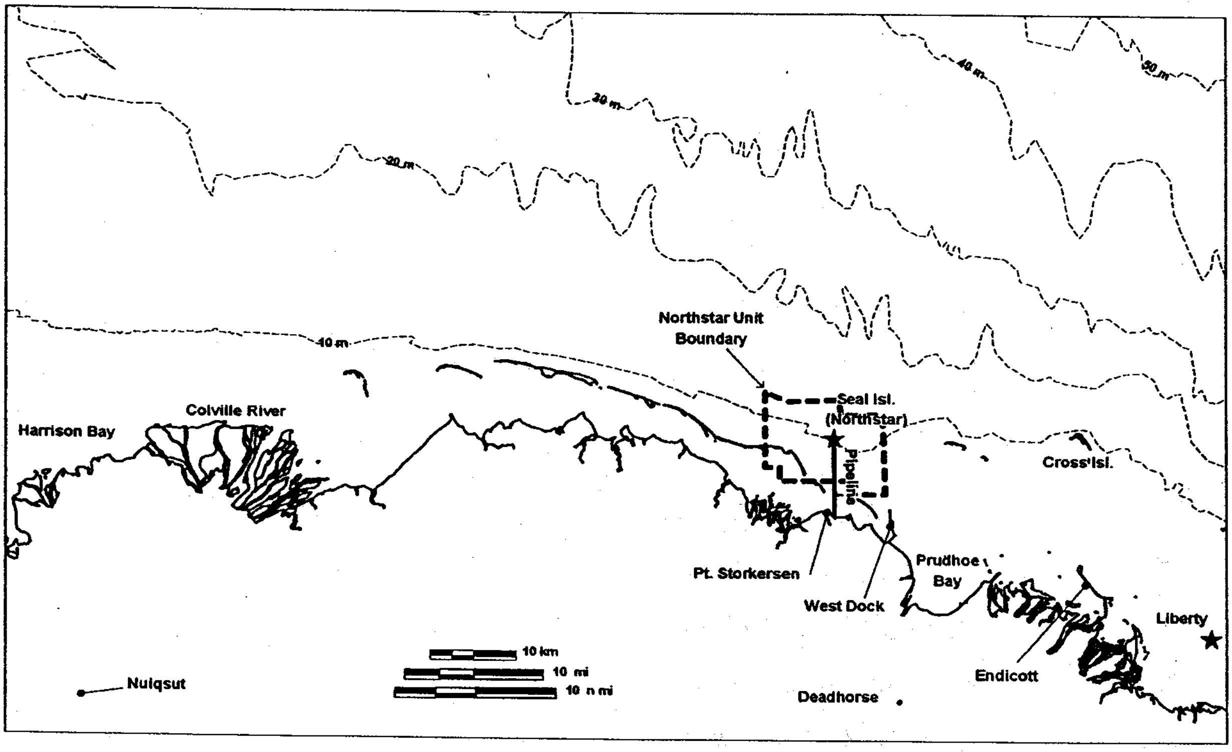
| | |
|---|---|
| ~ | approximately |
| ACS | Alaska Clean Seas |
| ADF&G | Alaska Department of Fish and Game |
| ADST | Alaska Daylight Saving Time |
| AEWC | Alaska Eskimo Whaling Commission |
| AIC | Alaska Interstate Construction |
| AM | Amplitude Modulation |
| ASAR | Autonomous Seafloor Acoustic Recorder (see Chapter 8) |
| ASL | Above Sea Level |
| BPXA | BP Exploration (Alaska) Inc. |
| BACI | Before-After/Control-Impact, a type of study design (see Chapter 5) |
| BIC | Bayesian Information Criterion (see Chapter 5) |
| C.F.R. | Code of Federal Regulations |
| C.H. | Cabled hydrophone |
| CI | Confidence Interval |
| CIDS | Concrete Island Drilling System |
| DASAR | Directional Autonomous Seafloor Acoustic Recorder (see Chapter 8) |
| DAT | Digital Audio Tape |
| dB | decibel, a logarithmic measure of sound strength |
| dBA | "A-weighted" decibel scale, for in-air sounds |
| DIFAR | Directional Frequency and Recording – a directional sonobuoy (see Chapter 8) |
| EIS | Environmental Impact Statement |
| ESA | Endangered Species Act |
| FAA | Federal Aviation Administration |
| FLIR | Forward Looking Infra-Red |
| FM | Frequency Modulation |
| ft | foot or feet (1 foot = 0.305 m) |
| GMT | Greenwich Mean Time, =Alaska Standard Time + 9 hr; ADST + 8 hr |
| GPS | Global Positioning System |
| Hz | hertz, or "cycles per second"; standard measure of sound frequency |
| IHA | Incidental Harassment Authorization |

| | |
|---|---|
| ISI | Industrial Sound Index (see Chapter 8; refers to sound level in 3 specific one-third octave bands, centered at 63, 80 and 160 Hz) |
| ITC | International Transducer Corp. |
| LoA | Letter of Authorization |
| kg | kilogram (= 2.20 lb) |
| km | kilometer (1 km = 3281 ft, 0.62 land miles, or 0.54 n.mi) |
| lb | pound (= 0.454 kg) |
| m | meter (1 m = 1.09 yards or 3.28 ft) |
| mi | land or statute mile (1 mi = 1.61 km or 0.87 n.mi.) |
| MMPA | Marine Mammal Protection Act |
| MMS | Minerals Management Service, U.S. Dept. of the Interior |
| NEPA | National Environmental Policy Act |
| n.mi. | nautical mile (1 n.mi. = 1.15 land miles or 1.853 km) |
| NMFS | National Marine Fisheries Service, U.S. Dept. of Commerce |
| NSB | North Slope Borough |
| OCS | Outer Continental Shelf |
| PLQ | permanent living quarters |
| rms | root mean square (a type of average) |
| s.d. | standard deviation |
| SPL | Sound Pressure Level |
| SSx | Sea State x (a measure of wave and sea-surface conditions) |
| STP | Seawater Treatment Plant |
| TSA | Time Series Analysis |
| UIC | Underground Injection Control [well] |
| μPa | micropascal, a measure of pressure |
| USFWS | U.S. Fish & Wildlife Service |
| UTC | Universal Time Coordinated |
| UTM | Universal Transverse Mercator |
| VFR | Visual Flight Rules |
| WDBO | West Dock Base of Operations |

# EXECUTIVE SUMMARY

## *Introduction*

BP Exploration (Alaska) Inc. began constructing oil-production facilities for the Northstar Development during early 2000, and began producing crude oil from the Northstar Unit during November 2001. The unit extends from 3.2 to 12.9 kilometers (2 to 8 miles) offshore from Point Storkersen, northwest of the Prudhoe Bay industrial complex. Northstar is about 54 miles (87 km) northeast of Nuiqsut, the closest Native Alaskan (Inupiat) community (see map). The Northstar Development was built on the submerged remnants of Seal Island. Seal Island was an artificial island constructed in 1982, used for exploration drilling during the 1980s, and subsequently abandoned. The Northstar Development includes a gravel island for the main facilities and two pipelines connecting the island to the existing infrastructure in Prudhoe Bay. One pipeline transports crude oil to shore, and the other transports natural gas to the island for field injection. The facilities on the island include prefabricated modules for living quarters, utilities, warehouse/shop, grind and inject facilities, drilling rig, and oil production facilities. The Northstar Development is, to date, the only offshore oil production facility in the Beaufort Sea north of the barrier islands.



Location of the Northstar Development at Seal Island in the central Alaskan Beaufort Sea.

"Northstar Island" and the associated pipelines were constructed during early 2000. The necessary ice roads were constructed from November 1999 through March 2000. The island was built and the pipelines were installed from February through May 2000. Gravel hauling to Seal Island (which then became known as Northstar Island) extended from February to April 2000. The pipelines were installed through a trench in the ice from March through May 2000. Follow-up construction activities on and near the island continued during the spring break-up and open water seasons of 2000. The construction activities during November 1999 through October 2000, and associated marine mammal and acoustic monitoring, are described in a previous monitoring report (Richardson and Williams [eds.] 2001a).

BP, the National Marine Fisheries Service (NMFS), and various other stakeholders anticipated that some seals and whales could be disturbed or "taken", as defined in the Marine Mammal Protection Act (MMPA), during construction and subsequent operation of Northstar. Disturbance of seals and whales by various operations of the offshore oil industry has been documented previously (Richardson et al. 1995). Consequently, BP requested that NMFS issue incidental take authorizations under section 101 (a) (5) of the MMPA to authorize "taking" of small numbers of whales and seals. Such authorizations normally require that monitoring studies be conducted to assess the amount and nature of any taking that did occur, and to help determine whether the activities had an unmitigated effect on the accessibility of whales or seals to subsistence hunters.

BP proposed that it would conduct several types of marine mammal and acoustic monitoring during both the ice-covered season and the open-water season. The incidental take authorization issued by NMFS to BP called for the types of monitoring that BP had proposed (NMFS 2000). This report is one of a series of existing and planned reports on BP's Northstar monitoring work:

- Monitoring associated with construction of ice roads in early 1999 was described in Richardson and Williams (eds., 2000). Those ice-roads were abandoned in April 1999 when construction of Northstar was delayed for a year.
- Monitoring associated with construction of Northstar Island (and associated ice-roads and pipelines) from Nov. 1999 through Oct. 2000 was described in Richardson and Williams (eds., 2001a).
- Preliminary accounts of monitoring during the ice-covered and open water seasons from Nov. 2000 through Oct. 2001, during the latter stages of construction, were provided in two "90-day reports", Richardson and Williams (eds., 2001b) and Richardson (ed., 2002).
- The present report includes detailed analyses of monitoring data collected in Nov. 2000 through Oct. 2001. This report incorporates all information from the two preliminary (90-day) reports, along with additional data and analysis. This report supersedes the 90-day reports.
- Additional reports will be submitted later concerning the ongoing monitoring work during the early phases of oil production in late 2001 and 2002, and thereafter.

This report consists of an Introduction, two chapters describing Northstar construction activities during the ice-covered and open-water seasons, five chapters describing five specific monitoring tasks, and a concluding chapter estimating the numbers of seals and whales potentially affected. The report is organized into three main sections:

**Ice-Covered Season:** Chapters 2 – 5, describing (2) BP's construction activities from Nov. 2000 through 15 June 2001, (3) measurements of sounds and vibrations from those activities, (4) seal structures found via dog-assisted searches during winter and spring of 2000-2001, and (5) fixed-wing aerial surveys of seals hauled out in spring 2001.

**Break-Up and Open-Water Seasons:** Chapters 6 - 8, describing (6) BP's construction activities from 16 June through Oct. 2001, (7) acoustic measurements during the 2001 open-water season, and (8) acoustic monitoring of bowhead whale migration during the autumn of 2001.

**Estimated Numbers of Seals and Whales Potentially Affected:** Chapter 9 uses results from all earlier chapters to estimate the numbers of seals and whales that were present and potentially affected by Northstar activities during the period from Nov. 2000 through the end of the 2001 open-water season in Oct. 2001.

The following sections are summaries of Chapters 2 to 9.

## *Description of BP's Activities, 2000-2001 Ice-Covered Season*

Initial construction activities at Northstar began in earnest during February 2000, and much of the construction work was completed before 1 Nov. 2000, the start of the period considered here. Previous reports have documented BP's construction activities through October 2000. Ice road construction, island maintenance, initial drilling, and other preparations for oil production continued during the ice-covered season in late 2000 through mid-2001. Activities during that period are described in Chapter 2 of this report, by C.J. Perham and M.T. Williams.

During early winter, transportation to and from Northstar Island was primarily by helicopter and Hägglunds tracked vehicles. Two Bell 212 helicopters and three Hägglunds were used. Construction of the Northstar ice-roads for the winter of 2000-2001 began in Nov. 2000. The primary ice road, from West Dock to Northstar Island, was ready for standard passenger vehicle traffic in January 2001, and was completed for heavy-load traffic in March 2001. A second ice road was built in Jan. and Feb. 2001 from Northstar Island south along the pipeline alignment to the mainland. A third ice road was constructed along the shoreline on grounded ice.

Ice cutting and supplementary gravel placement along the pipeline alignment was initiated in March 2001 and completed mid April 2001. At each location, these two activities (i.e., cutting and back-filling) occurred in sequence.

Numerous activities occurred on Northstar Island during the 2000-2001 ice-covered season. Major construction activities included completing the assembly of the drilling rig, and construction of the pipe rack and dock improvements. The permanent living quarters, grind and inject module, and foundation blocks for the modules housing the processing plant, compressor, and garage were installed and became operational. Installation of the back-up diesel generator, initially used as the primary power source, and mini-injection effluent skid also occurred.

Equipment testing occurred throughout the season. Two ARKTOS amphibious vehicles, which provide a means of emergency escape from the island, were tested in mid-Dec. 2000 and again in mid-April 2001. The drillrig engines and emergency diesel generator were tested mid-March 2001. An on-ice equipment exercise was conducted on 1 and 2 June 2001 to test several types of equipment on unimproved sea ice during the early stages of snow melt and break up.

A total of 5 wells were drilled during the 2000-20001 ice-covered season. Drilling began on 14 Dec. 2000 with the Underground Injection Control (UIC) well and continued throughout the ice-covered season until 13 June. Drilling was then suspended until autumn. Oil production began at the end of the period covered by this report.

## *Sound and Vibration Measurements During Winter Drilling, Early 2001*

The objective of the winter-spring acoustics measurements in early 2001 was to measure the levels, characteristics, and range-dependence of sounds and vibrations produced by Northstar-related industrial activities occurring during the winter and spring of late 2000 and early 2001, excluding activities whose sounds and vibrations were adequately characterized in 2000. On 6, 8 and 9 March 2001, Greeneridge Sciences made sound recordings at 14 locations up to 7.3 km (4.6 mi) east and northwest of Northstar Island to document sound levels during drilling. Recordings were made in the water, air and ice, using a hydrophone, microphone and geophone, respectively. This work is documented in Chapter 3 of the present report, by S.B. Blackwell and C.R. Greene Jr.

Broadband (10-10,000 Hz) underwater SPLs (sound pressure levels) recorded while drilling was underway reached background levels (close to 80 dB re 1 µPa) at 2-4 km (1.2-2.5 mi) from the drill rig. The highest broadband value recorded was nearly 124 dB re 1 µPa at 990 m (0.61 mi) from the drill rig, and the spreading loss term obtained (for northern recordings) was -32.9 dB/tenfold change in distance. In the absence of drilling, tones associated with power generation were prominent in the underwater sound out to a distance of 3.5 km (2.2 mi), but had disappeared by 7 km (4.3 mi). During drilling, elevated levels across a wide range of frequencies tended to obscure the tones associated with power generation.

Broadband (10-10,000 Hz) A-weighted in-air SPLs during drilling reached background levels (about 40 dBA re 20 µPa) beyond about 1 km (0.6 mi) from the drill rig. Interpretation of the microphone data was hampered by unavoidable wind noise in the recordings. The spreading loss terms obtained with and without drilling taking place were -20.7 and -14.5 dB/tenfold change in distance, respectively.

Broadband (10-500 Hz) particle velocity levels, as recorded by a three-axis geophone, reached background levels (95 dB re 1 pm/s) about 2 km (1.2 mi) north of Northstar. The highest levels (115 dB re 1 pm/s) were recorded 1 km north of the island and were likely due to snowmobile activity about 1 km away from the recording station. The spreading loss term for the H1 geophone axis, which pointed directly toward Northstar, was -14.9 dB/tenfold change in distance during drilling. Wind also had an effect on geophone recordings because the sensor detected the sound of snow blowing around on the ice.

Depending on the direction in which the recordings were taken from Northstar (east or north) and possibly on such factors as drilling depth and substrate quality (i.e., gravel vs. clay), drilling sounds as recorded by a hydrophone reached background levels at distances less than 4 km (2.5 mi). Drilling sounds did not include any consistently strong tones and were broadband in nature, affecting frequencies up to 2 kHz. The microphone data were influenced by wind noise, but seemed to indicate that island noises in general – including drilling noises – reached background levels in air about 1 km (0.6 mi) north of the island. Drilling noises in the air were not audible by the field crew, and could not be separated from overall island noises. Ice vibrations, as detected by the geophone, reached background levels at distances of about 2 km. The geophone was particularly sensitive to sounds originating on the unthickened "natural" sea ice, such as those produced by snowmobiles.

## *Ringed Seal Structures in Sea Ice Near Northstar, Winter and Spring of 2000-2001*

Trained dogs were used to locate ringed seal structures near BP's Northstar construction and drilling activities during three survey periods in late 2000 and early-mid 2001. Within that area, approximately 136 km (84 mi) of transects were searched with dogs from 24 November to 8 December 2000.

Also, 210 km (130 mi) of transects were searched from 2 to 13 March 2001, and 272 km (169 mi) of transects were searched from 4 to 21 May 2001. Additionally, temperature sensors and data loggers were placed in ringed seal structures to determine if temperatures within the structures could be used to determine dates and times when seals were present and absent. Results are described in Chapter 4, by M.T. Williams and C.J. Perham of LGL, and T.G. Smith of E.M.C. Eco Marine Corp.

During the Nov./Dec. 2000 survey, a total of 35 ringed seal structures (0.46 structures/km$^2$ or 1.1 /mi$^2$) were located in the 75.3 km$^2$ (29.1 mi$^2$) study area. Of these structures, 28 were breathing holes and 7 were lairs. Overall, 32 of the 35 structures were in active use (27 breathing holes and 5 lairs). The density of active structures was higher in each 500-m (0.3 mi) interval between 0 and 2 km (0 – 1.2 mi) from existing or planned Northstar facilities than in each such interval from 2 to 3.5 km (1.2 – 2.2 mi) away. During this Nov./Dec. period, Northstar Island was active but work along the primary ice road was just beginning.

During the second survey, in March 2001, a total of 60 new ringed seal structures were found in a slightly expanded study area of total area 84.5 km$^2$ (32.6 mi$^2$). Forty of the structures were breathing holes and 20 were lairs. Fifty-nine of the 60 new structures were open and active (39 breathing holes and 20 lairs) and were widely distributed in the study area. Overall, 23 of the 35 structures (66%) located during the Nov./Dec. 2001 survey had been abandoned by March 2001. In total, at least 95 structures had been used in the study area by 13 March (1.1 structures/km$^2$ or 2.9 /mi$^2$). Of these, 71 were active in March. The density of open, active structures was lower within 500 m (0.3 mi) of Northstar facilities (0.35 /km$^2$ or 0.90 /mi$^2$) than in other 500-m intervals out to 3.5 km (0.70 to 1.30 /km$^2$, or 1.8 to 3.4 /mi$^2$). In March, the density of frozen (abandoned) seal structures was slightly higher within 500 m of Northstar activities than at greater distances.

During the final survey in May 2001, a total of 79 new ringed seal structures were found in the study area. Forty-two of the structures were breathing holes, 36 were lairs, and 1 was of unidentified type. All 42 breathing holes and 35 of the 36 lairs were in active use by ringed seals. The status of all previously located seal structures was also determined during the May 2001 survey. Of the 35 structures located in Nov./Dec. 2000, 68% (19 breathing holes and 5 lairs) had been abandoned by late May 2001. Of the 60 structures located in March 2001, 42% (20 breathing holes and 5 lairs) had been abandoned by May 2001. Additionally, 8 of the 78 (10%) identified structures first located in May were abandoned by 22 May 2001 (2 breathing holes and 6 lairs). During May, the density of open (active) structures was higher in each 500-m (0.3 mi) interval between 0 and 2.5 km (0 – 1.6 mi) from Northstar facilities than in the two more distant intervals. However, there was a slight tendency for density to increase with increasing distance inside the 0 to 2 km zone. The density of frozen (abandoned) structures increased with increasing distances up to 1.5 km (0.9 mi) from Northstar facilities, contrary to expectation if Northstar was causing abandonment of structures.

During all surveys combined, a total of 173 structures were located in the revised study area (2.0 structures/km$^2$ or 5.3 /mi$^2$). Of these, 113 (65%) were in active use on 22 May 2001.

During the three survey periods, 40 temperature sensors were installed in 55 ringed seal structures (25 breathing holes and 30 lairs). Twenty-four of 55 instrumented structures were abandoned during the study. We were able to determine the date of abandonment for 18 of the 24 structures instrumented. Nine instrumented structures froze by 23 Dec. 2000, during early ice road construction. Three more instrumented structures froze between 23 Dec. 2000 and 17 Jan. 2001, during the holiday break in ice road construction. Three more instrumented structures froze by 14 March 2001 (the end of our search period in March), and the three remaining instrumented structures were frozen by 21 March, 27 March, and 1 May 2001. Temperature sensors may also provide data concerning impacts of the research on seal structures, as well as seasonal use of structures.

The evolution of structure use, the abandonment of some structures, and the apparent creation of new structures suggest that ringed seals are well adapted to variable habitat conditions during winter and spring. Although anthropogenic activities (e.g., industrial activities) may increase the rate of structure abandonment by ringed seals, structure status can change from abandoned to re-occupied depending on the time of the season and other factors. Therefore, structure abandonment may not be uniquely important as an indicator of a biologically significant impact to ringed seals during winter.

Results from this study suggest that the abandonment rate for structures within 3.5 km (2.2 mi) of Northstar and the associated on-ice activities was higher than reported previously for similar activities, and substantially higher than the reported "natural" abandonment rate. However, the abandonment rates derived by our methodology may not be comparable to those of previous investigators. Also, within 3.5 km, the abandonment rate as evident in May was lower close to Northstar facilities than farther away. Any reduction in number of active seal structures per unit area was limited to an area extending no more than 0.5 – 1 km (0.3 – 0.6 mi) from Northstar facilities. One complication is the unknown impact of our own monitoring activities on seal use of the area. Nonetheless, the continued presence of ringed seals near Northstar throughout the winter, at densities similar to those farther away, and the creation of new structures near Northstar during winter, suggest that any negative effects to seals may be minor and highly localized.

## *Fixed-Wing Aerial Surveys of Seals Near BP's Northstar & Liberty Sites, Spring 2001*

Intensive, site-specific aerial surveys for seals were conducted during 28 May – 8 June 2001 in the area of landfast ice that surrounded BP's Northstar oil development and the potential Liberty oil development. During the ice-covered season of late 2000 and early 2001, industrial activities at Northstar were less intense than the construction activities that had occurred in the winter of 2000. Liberty, located in Foggy Island Bay, 48 km (30 mi) southeast of Northstar, was inactive in 2000-2001. The survey design provided high-intensity survey coverage within a 75 × 40 km (46 × 25 mi, or 40 × 22 n.mi.) area encompassing both Northstar and Liberty. These surveys were designed to assess possible changes in seal density close to the industrial sites before vs. after oil development began. This was the fifth consecutive year in which BP/LGL surveys of this type had been conducted. Results for 2001 and 1997-2001 combined are given in Chapter 5, by V.D. Moulton et al.

### *Approach and Methods*

The 2001 surveys were very similar to surveys done during the spring of 1997, 1998, 1999, and 2000. The 1997 and 1998 surveys were pre-development "control" surveys (although some limited offshore industrial activities occurred around Liberty in early 1997 and east of Liberty in early 1998). The 1999 survey followed limited industrial activity at Northstar during early 1999. The 2000 surveys were conducted after a period of intensive construction activities within the survey area. In 2001, industrial activities were less intense than the construction activities that had occurred during the previous winter. The aerial surveys in 2001 occurred after ice roads to Northstar were re-built, facilities were installed on the island, several wells were drilled, supplementary gravel was placed along the subsea pipeline route from the island to the shore, and emergency equipment was tested near the island. No major industrial activities occurred near Liberty during the winter of 2000-2001, so the 2001 surveys provide an additional year of pre-development "control" data for that area.

The survey design provided for repeated coverage of the study area within each spring season. This within-season replication was designed, in part, to allow detection and quantification of distributional effects that might be quite localized. Also, the replication was designed to assess and distinguish the relative contributions of industrial effects and various natural factors (e.g., date in season, ice conditions, bathymetry, weather) on numbers of seals hauled out at different places and times. These surveys include the essential elements of a Before-After/Control-Impact (BACI) study design. The surveys include areas potentially Impacted by development of Northstar (and perhaps in future Liberty) plus surrounding Control areas extending out to a substantial distance from both sites. These surveys were initiated Before the Northstar and Liberty oil developments began, and have continued in a consistent manner After construction of Northstar began. BACI designs are considered to be optimal for field studies of environmental impact, especially when they include geographic replication. The survey design provides for spatial replication of at least the "control" area.

## *Observed Seal Densities vs. Natural Factors*

In 2001, the aerial surveys covered 4147 km$^2$ (1600 mi$^2$) of fast ice habitat. A total of 1562 sightings of 2024 ringed seals were recorded on-transect in fast ice habitat during the two survey replicates. The overall observed density was 0.49 seals/km$^2$ (1.27 seals/mi$^2$). Excluding waters <3 m deep where seals were rarely seen, the overall observed density was 0.54 seals/km$^2$ (1.40 seals/mi$^2$). The overall observed density in areas ≥3 m deep was higher in 2001 than in 1997 (0.43 seals/km$^2$), 1998 (0.39 seals/km$^2$), and 2000 (0.47 seals/km$^2$) but lower than in 1999 (0.63 seals/ km$^2$).

Bearded seals were recorded near the fast ice edge as well as in the landfast ice edge. Overall, there were three sightings totaling three individuals.

Two statistical approaches were used to examine factors known or expected to influence ringed seal density within the study area. Data were examined with chi-square goodness-of-fit tests (with Bonferroni adjustment) and with a multivariate Poisson regression analysis. Three groups of variables were investigated: habitat factors that affect the distribution and abundance of ringed seals, temporal and weather factors that affect the proportion of seals hauled out; and industrial activity factors.

Both the univariate and multivariate results indicated that the relationship between seal density and *water depth* was significant. Overall, ringed seals were most abundant in water depths ranging from 10 to 20 m (33 to 66 ft). However, in some years, including 2001, it appears that more ringed seals occurred at shallower depths. The multivariate results suggest that, in most survey years, ringed seals were more abundant near the *edge of the landfast ice*, after accounting for other covariates, even when ice break-up was apparently not advanced. Factors that may account for this relationship include movements of ringed seals that spent the winter outside of the landfast ice, redistribution of seals that spent the winter in the landfast ice, and prey availability. There was a significant trend toward lower observed densities in areas with high *ice deformation* and extensive *melt water* in all five BP/LGL survey years.

The Poisson regression models for 2001 and 1997-2001 data indicated that there was no significant relationship between seal sightings and *time of day* within the mid-day period when surveys were done. Observed ringed seal density was significantly related to *date* within the spring season. It appears that the peak period of haulout for ringed seals in the landfast ice of the central Beaufort Sea varies from year-to-year and occurs from approximately May 30th to June 8th.

Of the four *weather variables* investigated, cloud cover, air temperature, and wind speed were found to be consistently related to ringed seal numbers in both the univariate and multivariate analyses. More ringed seals were observed on cloudy days with relatively low wind speeds and warmer air temperatures. After allowance for those variables, there was no clear relationship to heat loss.

### *Observed Seal Densities vs. Northstar*

There was no indication that industrial activities in the Northstar development area in late 2000 and early 2001 negatively affected the distribution or abundance of ringed seals. In fact, significantly elevated densities of ringed seals occurred close to Northstar as indicated by univariate analysis, the 2001 multivariate model, and a multiyear multivariate model. The multivariate models developed here are important steps toward quantifying the relative contributions of temporal, environmental, and industrial activity variables on the numbers of seals hauled out on the landfast ice.

## *Description of BP's Activities, Break-Up and Open-Water Seasons, 2001*

Chapter 6 of this report, by C.J. Perham and M.T. Williams, describes construction activities during the open-water season from 16 June through 31 Oct. 2001. This period included the latter stages of construction of the Northstar Development, including arrival and installation of production modules, and the gas-turbine generators and compressors.

Two Bell 212 helicopters were used as transportation to and from Northstar Island during break-up and freeze-up. During the open water season, two crew boats, the *Hawk* and *Arctic Express*, were the primary method of transportation, but helicopter flights continued on a less frequent basis. Helicopter flights began on 4 June 2001 from the West Dock base of operations (WDBO) and Deadhorse airport to Northstar and return. The crew boat began transits on 23 July 2001 between West Dock and Northstar; eight round trips were scheduled daily during the summer and early autumn. Crew boat operations ceased on 7 October 2001 when sea ice was forming.

A sealift carrying production facilities, gas-turbine compressors, and other major facilities arrived in the Northstar area from southern Alaska on 10 August. The sealift involved three barges and several tugboats. The modules, gas-turbine system, and other facilities were off-loaded from the sealift barges to the island on 12-20 August using a Scheuerle trailer model MPEK 5200. During this period there was much maneuvering of the sealift barges by tugs. The sealift vessels departed on various dates from 16 to 31 August.

Tugs and barges periodically traveled to Northstar from the Prudhoe Bay area. Eight vessels were used for transport of diesel fuel, 17 vessels were used for cargo transport, and 11 vessels were used for spill response activities (training and standby) around Northstar.

The "emergency" generator in the utility module was used as the primary source of power until 24 Oct. 2001. At that time the primary gas-turbine system brought to the island during the August sealift was integrated into the existing modules and became operational.

The Northstar drill rig, which had been installed in 2000 and operated during the winter and spring of 2000-2001, was shut down from 13 June 2001 to October 2001. Drilling did not resume until Nov. 2001, after the period considered here. The grind and injection module injected seawater and miscellaneous wastes into the disposal well throughout the open water and broken ice periods in 2001.

## *Sound Measurements, 2001 Open-Water Season*

Greeneridge Sciences Inc. measured underwater and airborne sounds during the arrival and offloading of sealift barges in August 2001. In addition, near-island Autonomous Seafloor Acoustic Recorders (ASARs), placed 320 and 299 m (1050 and 981 feet) from the north shore of Northstar, recorded underwater island sounds continuously for 23 days in August and 25 days in September. This work is described in Chapter 7 of the present report, by S.B. Blackwell and C.R. Greene Jr.

### *Boat-based Recordings in Open Water*

Boat-based recordings were made during three days in August 2001 to help characterize sound levels underwater and in air during the arrival and offloading of three sealift barges at Northstar. Four types of sound measurements were made: (1) the arrival of the barge train, (2) tug sounds as they maneuvered barges at the Northstar dock, (3) overall island sounds from nominal distances up to 20 km (11 n.mi.) from Northstar, and (4) sounds produced by the Concrete Island Drilling Structure (CIDS).

***Arrival of Sealift Barges*.**—A logarithmic sound propagation model was fitted to both the underwater and in-air data from the best recording of the arrival of sealift at Northstar on 10 Aug. 2001. The spreading loss term obtained for the underwater data, 14.8 dB/tenfold change in distance, is reasonable for this situation in shallow water and also agrees with the values obtained from open water recordings made north of Northstar on 30 Aug. and 1 Sept. 2000. The highest broadband levels recorded from the tugs and barges were 135-136 dB re 1 µPa and were encountered 357 m and 1450 m (1170 and 4760 ft) from the source. Higher levels might occur at times at closer distances. For the airborne sound, the apparent spreading loss term was 6.4 dBA/ tenfold change in distance. That rate is lower than expected and probably indicative of a substantial contribution (at least at the longer distances) by non-industrial sound. The highest recorded levels were 56 dBA re 20 µPa at a location 328 m (1076 ft) from a tug.

***Tug Activities*.**—Underwater sound levels produced by working tugs were variable, depending on the tugs' activities, but comparable to those during arrival of the barge train (sealift). The highest underwater SPL recorded was 145 dB re 1 µPa at a location 116 m (381 ft) from a tug that was forcing a barge against the dock. Low-frequency tones corresponding to the propeller blade rates of the different types of tugs were recorded. In-air broadband data showed more variation than the underwater data; the maximum A-weighted broadband SPL was 86 dBA re 20 µPa, 60 m (200 ft) from a tug holding a barge against the dock. Underwater broadband levels while the compressor module was being offloaded with a Scheuerle module transporter showed that the tugs are the main sound component underwater and the offloading procedure itself contributes only a small increment of underwater sound over and above the tug sound.

***Overall Island Sounds*.**—Recordings of overall sounds from the island and associated vessel activities were done at distances up to 11 n.mi. (20 km) north and 5 n.mi. (9 km) east of Northstar Island. On a broadband basis, both underwater and airborne sound pressure levels (SPLs) were more variable in August 2001 than at similar distances and locations during the summer of 2000. These differences cannot be explained by sea state or wind. For the underwater data these higher SPLs were mainly a result of strong components at frequencies below about 55 Hz. Continuous near-island recordings by an ASAR (see below) showed that changes in SPLs on the order of 25 dB were not uncommon within a few minutes. These temporal variations could account for much of the variability in SPLs that cannot be attributed to changes in distance from the sound source. The broadband microphone data showed no distance effect on the SPLs at distances beyond about 1 km (3280 ft).

***CIDS*.**—CIDS was present about 1.1 km (3600 ft) northeast of Northstar until 31 August. Generator sound from CIDS contributed to the sound environment near Northstar during August, and shortly before 31 August tugs preparing for departure of CIDS also contributed sounds. A comparison of continuous data recorded by a near-island ASAR, before and after CIDS' departure on 31 Aug., shows that broadband SPLs dropped by an average of 16 dB at that time. Two sealift barges left on 30 Aug. and therefore contributed to these broadband SPLs.

### *Near-island ASAR Recordings*

A near-island ASAR located about 320 m (1050 ft) from the north shore of Northstar recorded island sounds continuously for nearly 23 days in August 2001. The data showed that it was common for there to be large fluctuations (spanning up to 25 dB) in broadband (10-1000 Hz) SPLs within short amounts of time (<0.5 hour). It also showed that the presence of sealift vessels led to the highest broadband levels recorded from Northstar Island during the summers 2000 and 2001, despite the fact that "quiet" and "noisy" days were present both before and after sealift's arrival. The highest recorded broadband value in August was above 137 dB re 1 μPa. There was a reasonable correlation between island sounds as recorded by the near-island ASAR and simultaneously by boat-based hydrophones at varying distances from the island, provided comparisons were limited to broadband frequencies above 20 Hz. The ASARs' locations in shallow water resulted in a cut-off of lower frequencies (below 30-50 Hz). Therefore, when such frequencies were present, the ASARs tended to underestimate island sounds by 10-15 dB. Another ASAR, located about 300 m (1000 ft) north of the island, recorded continuously during September 2001, after both CIDS and sealift had departed. Broadband levels during that period were lower than those recorded during August and approached ambient values as recorded in the Prudhoe Bay area in 1998.

Based on the measured levels close to Northstar and a spreading loss rate of 15 dB/tenfold change in distance, we estimate that typical island-associated sounds (i.e. 50th percentile level) as present in August 2001 would diminish to background levels at distances <0.5 km (0.3 mi) at times with high levels of natural ambient noise, ~1.9 km (1.0 n.mi. or 1.2 mi) with moderate ambient noise, and tens of kilometers at times with little natural noise. The high-ambient and moderate-ambient distances could be as high as 2 km and 19 km (1.2 and 12 mi) in conditions when the low-frequency components propagate out to sea. In September 2001, after both CIDS and sealift had departed, typical island-associated sounds diminished to background levels at distances ranging from <1 km (0.6 mi) at times with moderate and high levels of natural background sounds to ~11.5 km (6.2 n.mi. or 7.1 mi) at times with little natural noise. For both of these months, these distances would be reduced at times when the industrial sounds were less than average, and increased at times with stronger-than-average industrial sounds.

Boats were identified as a major source of sound in the Northstar area. Their contribution to overall sound levels is examined in more detail in Chapter 8.

## *Acoustic Monitoring of Bowhead Whale Migration, Autumn 2001*

During the bowhead whale migration in the autumn of 2001, BP implemented an acoustic monitoring program northeast of BP's Northstar oil development at Seal Island. The primary objective was to assess the effects of Northstar construction activities on the migration corridor and calling behavior of bowhead whales by comparing the offshore distances of calling bowheads at times with varying levels of industrial sound. This project was a follow up to a similar effort in 2000. The 2000 work demonstrated that the acoustic localization approach had promise as a method for detecting and quantifying Northstar effects on the whale migration corridor. However, in 2000 equipment problems prevented determining whether (and to what extent) the migration corridor was related to Northstar construction sounds. The results from 2001 provided evidence that the southern edge of the bowhead migration corridor was deflected offshore at times with high levels of underwater sound near Northstar. This work is described in Chapter 8 of the report, by C.R. Greene Jr. and M.W. McLennan of Greeneridge Sciences, T.L. McDonald of WEST, and W.J. Richardson of LGL.

During 2001, bowhead whale calls were recorded from 29 Aug until 3 Oct in 2001 by instruments placed on the seafloor at locations 6 to 22 km (4 to 14 mi) offshore of Seal Island (Northstar). Eleven autonomous instruments (DASARs) with the capability of recording directional acoustic information about the calls were installed in an array. The directional information from the array provided intersecting bearings to the sources of sound occurring within several kilometers, thereby measuring the locations of whales when their calls were detected at two or more DASARs. About 400 m (¼ mi) north of Seal Island, near-island sounds were recorded continuously during the same time period. These data have been used in a statistical analysis to investigate the extent to which island sounds influence distances from the island at which calling whales are detected, i.e., to what extent strong levels of Northstar-related industrial sound influence whales to swim farther away from shore than they would in the absence of island sound, or change their calling patterns, or both.

Sounds recorded near the north side of the island ranged from about 80 to as high as 140 dB re 1 $\mu$Pa in the 10-1000 Hz band. The low levels correspond to broadband levels expected at times of low sea states. The high levels occurred when vessels were active near the island. Variations in the minimum levels of sound (below the levels attributed to the vessels) were within the range expected from calm seas to well developed wind-driven waves.

For the first nine days after the DASARs were deployed, valid data were acquired from 10 of the 11 DASARs. From then through 28 Sept, data were acquired from at least six DASARs at almost all times. Some DASARs failed and were repaired and replaced. Other DASARs suffered failures that were not detected. By the end of the 36-day recording period on 2-3 Oct, four DASARs were still collecting useful data and providing information about locations of calling whales. The background sounds at the DASARs, even at 13.7 mi (22 km), included vessel sounds from the vicinity of the island, consistent with the boat-based hydrophone measurements at long distances from the island reported in Chapter 7.

In the 36 days of operation, 10,738 bowhead calls were detected. Of these, source locations were computed for 3446 calls, and 1259 were within an area where calls could be monitored effectively even at times with relatively high levels of background noise. That monitoring area extended out to 28.6 km (~18 mi) offshore of Northstar, and to 12 km (7½ mi) east and west of a line running offshore from Northstar. Aerial survey data show that, in an average year, about half of the bowheads migrate west within that distance of Northstar.

Quantile regression was used to assess whether, for calls within the effective monitoring area, the 5th percentile of whale call distance tended to be farther offshore at times with high than with low sound levels at the hydrophone 400 m (¼ mi) from Northstar. The analysis used a bootstrapping method to take account of the fact that the distances-from-shore of whale calls detected at intervals less than 24 hours apart were interdependent. It also applied a weighting factor that was inversely related to the uncertainty in the call locations.

Four indices of underwater sound near Northstar were considered, representing the sound averaged over the 5 min, 15 min, 30 min, and 60 min previous to detection of each whale call. These sound indices included the sound components within three 1/3-octave bands that were dominated by industrial sound. These bands were centered at 63, 80 and 160 Hz. The level in those three bands (industrial sound index, ISI) averaged about 5.8 dB less than the level in the overall 10-1000 Hz band.

Although all conclusions are subject to various caveats and provisos discussed in Chapter 8, the quantile regression lines estimated using 15-, 30-, and 60-min averages of the ISI indicated that the relationship between offshore distance and sound level was positive when ISI (averaged over 15-60 min) was greater than ~95 dB re 1 μPa. The relationship was strongest for the 60-min average ISI. For that analysis, the approximate 95% lower confidence bound indicates appreciable offshore displacement of call locations when sound levels are high. With ISI up to 95-100 dB re 1 μPa, there was no apparent displacement of the 5th percentile of whale call distances. When average (for 60 min) ISI levels near Northstar increased from 95 dB to 105 dB, 115 dB, and 125 dB re 1 μPa, the 5th percentile of offshore whale call distance was estimated to displace farther offshore by 1.26 km (0.78 mi), 5.26 km (3.27 mi), and 14.79 km (9.19 mi), respectively. With nearly 95% confidence, the 5th percentile of offshore whale call distances increased by more than 0.34 km (0.21 mi), 1.41 km (0.88 mi), and 3.01 km (1.91 mi) when 60-min ISI values increased to 105 dB, 115 dB, and 125 dB, respectively. The apparent displacement effect was evident only when the 60-min ISI was above its 90th percentile value. This apparent effect occurred largely if not entirely at times when the industrial sounds were dominated by vessel noise rather than sounds from Northstar island itself.

In general, during the early and middle portion of the bowhead migration season in 2001, we are reasonably certain that higher-than-normal sound levels in the Northstar area (averaged over 60 minutes) were associated with an offshore displacement of the southern edge of the bowhead migration corridor and/or a change in bowhead calling behavior in the area within several kilometers offshore of Northstar. The number of whales potentially affected is estimated in the following Chapter. However, analyses based on sound levels averaged over 5, 15 or 30 min showed less or no evidence of a displacement effect in 2001. With those analysis approaches, we could not be ~95% confident that there was a meaningful tendency for offshore displacement at times when Northstar sound was strongest. Also, the 2001 data are consistent with the possibility of an attraction effect at times with moderate levels of Northstar sounds as compared with times having low levels. Again, all conclusions are subject to caveats discussed in Chapter 8. Because three analyses did not provide substantial evidence of apparent displacement at higher-than-normal sound levels, and one analysis did, conclusions about offshore displacement should be considered provisional until the additional data collected during September 2002 are analyzed.

Additional data from 2002 are expected to allow us to determine which (if any) of these patterns are evident in another year. The same types of data were collected in September 2002, and analysis of those data is (as of October 2002) about to begin. Combined data from 2001 and 2002 will provide a better basis for assessing the potential effects of Northstar than now possible.

There is much year-to-year variation in the migration corridor of bowheads, ice conditions, and other aspects of the environment. The possible "Northstar effect" evident in the southern part of the bowhead migration corridor at times in 2001 might not occur in a year when the overall migration corridor in the central Alaskan Beaufort Sea is farther offshore. The effect might be different, or absent, in a year when ice has a strong effect on the migration corridor. It also may not be evident in future years if the underwater sounds created by Northstar during oil production in 2002 and later years are weaker and/or less variable than those during construction in 2000-2001.

## *Numbers of Seals and Whales Potentially Affected, Nov. 2000 – Oct. 2001*

A Letter of Authorization (LoA) issued by NMFS to BP authorized the "taking" of small numbers of seals and whales incidental to Northstar construction activities (see following Table). The numbers of seals and whales present and potentially affected by Northstar construction activities during the ice-covered, break-up, and open-water periods in November 2000 through October 2001 have been estimated in Chapter 9, by M.T. Williams, V.D. Moulton and W.J. Richardson of LGL. These estimates are based on information from prior chapters, as summarized above. The ice-covered and open-water seasons are not discrete, and the intervening "break-up" period has been combined with the open-water season in estimating the "numbers potentially affected". The following paragraphs summarize the basis for the estimates in the Table.

### *Seals*

During the 2000-2001 ***ice-covered season***, no evidence linking industrial activities to the two observed ringed seal deaths was evident, nor was it expected.

A total of 180 ringed seal structures were found during dog-assisted searches conducted in November/December 2000, March 2001, and May 2001. We estimated that at least 38 to 53 individual seals may have been associated with the structures found by the dogs, based on published structure : seal ratios from other geographic areas. However, the aerial surveys suggested that, during the spring of 2001, ~222 seals may have been present within the area that had been searched by dogs, assuming that the combined ×2.84 correction factor for seals present but missed by aerial surveys was correct. The actual number of seals potentially affected by the dog searches is uncertain. However, the fact that, during spring, the seal density was higher within the area that had been searched by dogs than in otherwise-similar neighboring areas suggests that the dog searches did not have a major impact on the seals.

Authorized annual takes incidental to Northstar construction activities, and estimated numbers of seals and whales present and potentially affected during November 2000 – October 2001.

| | Authorized Annual Harassment Takes | | | # Present &/or Potentially Affected | | |
|---|---|---|---|---|---|---|
| | Ice-Covered Season | Open-Water Seasons | Total | Ice-Covered Season | Break-up & Open-Water Seasons | Total |
| Ringed Seal | 125 [a] | 22 | 147 | 92[b,c,d] | 53[b] | 145[b] |
| Bearded Seal | 5 | 5 | 10 | - | 1 | 1 |
| Spotted Seal | - | 1 | 1 | - | - | 0 |
| Bowhead Whale | - | 717 [e] | 717 [e] | - | ≤200 | ≤200 |
| Gray Whale | - | 5 | 5 | - | ~0 | ~0 |
| Beluga Whale | - | 45 | 45 | - | 10-20 | 10-20 |

[a] In addition, the LoA authorized up to 5 ringed seals to be incidentally killed annually during the ice-covered period. In fact, there was no evidence of any seal deaths as a result of Northstar activities.

[b] Northstar construction probably had little or no effect on most of these seals, as discussed in text.

[c] Excludes an estimated 82 seals that dove in response to the passing aircraft during spring seal surveys; possible disturbance to seals during those surveys was authorized separately by NMFS under provisions of the General Authorization for research on non-endangered species, MMPA §104(c)(3)( C)and 50 C.F.R. §216.45.

[d] Excludes the uncertain number of seals potentially disturbed by the dog-assisted searches required by the LoA. This could have involved as few as 38-53 seals (some of which were among the 92 in the potential impact zone), or as many as 222 seals (including ~130 outside the potential impact zone and thus additional to the estimated 92 in that area).

[e] Up to 717 bowheads annually, with maxima of 1533 bowheads in 2 out of 5 seasons, and 3585 in 5 years.

We estimated that there were approximately 82 occasions when ringed seals (and no occasions when bearded seals) dived into the water in response to aircraft overflights during the aerial surveys in spring 2001. Only a small minority of the seals reacted by diving; most seals showed no apparent response to the aircraft. Seals that dived into the water once or twice in response to aircraft overflights are unlikely to have suffered deleterious effects.

About 59 ringed seals were expected to occur within the area potentially impacted by BP's Northstar development if there had been no industrial activities there during 2001. This estimate is based on the density of seals 4-10 km (2.5-6.2 mi) from the potential impact zone in comparable water depths, corrected for availability and detection biases. In fact, the observed density and the estimated number of seals within the potential impact zone in 2001 were higher than the expected density based on the reference area 4-10 km away. The potential impact zone to which these estimates apply was defined as extending from 0.64 km to 1.85 km (0.4 to 1.15 mi) from various types of industrial activities that occurred during the winter of 2000-2001.

During aerial surveys, eight seals (7 sightings) were observed in the Northstar Development Zone, including artificially-thickened ice roads and an equipment testing area around Northstar Island. These results, along with the presence of 118 active structures near Northstar during the follow-up dog-assisted search in May 2001, indicate that effects of industrial activities were likely minor and localized.

During the ***break-up and open-water seasons***, no evidence of seal injuries or fatalities was evident, nor was it expected. No impact pile driving occurred during the break-up season (or at any other time) in 2001. Approximately 54 different seals (53 ringed seals and 1 bearded seal) are estimated to have occurred within a 1 km (0.62 mi) radius around Northstar (=Seal) Island at some time during the break-up and open-water seasons. This estimate is based on the densities of seals observed during the 2001 aerial surveys (applied to the break-up season) and during vessel-based surveys during 1996-2000 (applied to the open-water season). The estimate takes account of correction factors for missed animals, and assumes weekly turnover of individuals during the break-up and open-water periods. It is unlikely that these seals were affected deleteriously by Northstar activities.

For the ***year as a whole*** (ice-covered and open-water seasons combined), an estimated 145 ringed seals, 1 bearded seal, and probably no spotted seals were present near BP's Northstar activities. These figures are slightly less than the corresponding "takes" authorized by the LoA issued by NMFS to BP (see Table). Furthermore, most of these seals do not seem to have been negatively affected by Northstar activities, and it would appear that very few of them should be counted as "takes". These totals exclude the ~82 seals that dived in response to aircraft overflights during the spring aerial surveys; those incidents were separately authorized via a Letter of Confirmation issued by NFMS to LGL. These totals also exclude the uncertain number of ringed seals in the area searched by dogs. The overall results suggest that any effects of Northstar construction and the associated monitoring on seals were minor, short-term, and localized, with no consequences for the seal populations.

### *Whales*

For ***bowhead whales***, acoustic localization data indicated that whales in the southern part of the migration corridor (closest to Northstar) may have been affected by vessel or Northstar operations during the 10.8% of the time when levels of underwater sound from these activities were highest. At these times, the main components of "Northstar sound" were from maneuvering vessels, not from the island itself. An estimated 1140 bowheads passed Northstar at such times, and an estimated maximum of 200 of these whales (≤2% of the population) were potentially affected by vessel or Northstar operations. This effect consisted of either an offshore displacement of whales traveling near the southern edge of the migration corridor or some change in their calling behavior or both. Most of the affected whales passed Northstar at times when the effect was quite subtle and limited to the southern edge of the migration corridor. However, a small number (<1% of the population) may have been displaced (or otherwise affected) by 15 km (9.3 mi) or more. The LoA authorized the "taking by harassment" of up to 717 bowheads annually, or as many as 1533 as long as this larger number applied to no more than 2 of 5 years. The possible occurrence of a "Northstar effect" on a maximum of 200 bowheads is well within the provisions of the LoA.

There was no specific information on numbers of ***gray or beluga whales*** (if any) that may have been close enough to Northstar to be disturbed by construction operations in 2001. For belugas, the estimated numbers that might approach within an assumed 1-2 km (0.6-1.2 mi) disturbance radius are 10-20 (most probable estimate) and 60-120 (maximum estimate). The LoA authorized the "taking by harassment" of up to 5 gray whales and 45 belugas.

### *Availability for Subsistence*

There was no indication of any effects of the Northstar development on availability of seals to subsistence hunters during the 2001 ice-covered, break-up, or open-water periods. Any localized displacement of ringed seals that may have occurred would not have affected their availability to subsistence hunters.

The bowhead hunt at Cross Island was more protracted and apparently more difficult in 2001 than in some other recent years; 3 whales from the quota of 4 were landed. The difficulties in the hunt were partly because of weather and ice problems, but in addition the whales were described as being skittish and difficult to hunt in 2001. Based on the acoustic monitoring results, Northstar activities during late summer and autumn of 2001 are not expected to have affected the availability of most bowhead whales to subsistence hunters. However, a fraction of the estimated maximum of 200 bowheads suspected to have been displaced offshore or otherwise affected by Northstar might have been less accessible to hunters if the Northstar effect extended eastward somewhat farther than specifically documented during the monitoring work. If there was any such an effect, it was attributable largely if not entirely to sound from vessels rather than sound from the island itself.

## *Literature Cited*

NMFS. 2000. Taking marine mammals incidental to construction and operation of offshore oil and gas facilities in the Beaufort Sea/Final rule. **Fed. Regist.** 65(102, 25 May):34014-34032.

Richardson, W.J. (ed.). 2002. Monitoring of industrial sounds and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, summer and autumn 2001: 90-day report. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 74 p. [Superseded by present report.]

Richardson, W.J. and M.T. Williams (eds.). 2000. Monitoring of ringed seals during construction of ice roads for BP's Northstar oil development, Alaskan Beaufort Sea, 1999. [Final, Dec. 2000.] Rep. from LGL Ltd., King City, Ont., and LGL Alaska Res. Assoc., Anchorage, AK, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 153 p.

Richardson, W.J. and M.T. Williams (eds.). 2001a. Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar oil development, Alaskan Beaufort Sea, 2000. [Draft, April 2001.] Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 316 p.

Richardson, W.J. and M.T. Williams (eds.). 2001b. Monitoring of ringed seals, sounds and vibrations during construction of BP's Northstar oil development, Alaskan Beaufort Sea, winter and spring 2000-2001: 90-day report. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 117 p. [Superseded by present report.]

Richardson, W.J., C.R. Greene Jr., C.I. Malme and D.H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego, CA. 576 p.

# CHAPTER 1:

# INTRODUCTION [1]

by

**Michael T. Williams** [a] and **W. John Richardson** [b]

[a] **LGL Alaska Research Associates, Inc.**
1101 E. 76th Ave., Suite B, Anchorage, AK 99518
(907) 562-3339; mwilliams@lgl.com

[b] **LGL Ltd., environmental research associates**
22 Fisher St., POB 280, King City, Ont. L7B 1A6
(905) 833-1244; wjr@lgl.com

for

**BP Exploration (Alaska) Inc.**
**Dept. of Health, Safety & Environment**
900 East Benson Blvd. P.O. 196612
Anchorage, AK 99519-6612

LGL Report TA2563-4

April 2002

---

[1] Chapter 1 *In:* W.J. Richardson and M.T. Williams (eds.). 2002. Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2001. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences, Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD.

# INTRODUCTION

BP Exploration (Alaska) Inc. (BP) began constructing oil-production facilities for the Northstar Development during early 2000, and began producing crude oil from the Northstar Unit during November 2001. The unit extends from 3.2 to 12.9 kilometers [km] (2 to 8 miles) offshore from Point Storkersen, northwest of the Prudhoe Bay industrial complex, and is approximately 54 miles (87 km) northeast of Nuiqsut, the closest Native Alaskan (Inupiat) community (Fig. 1.1). The Northstar Development was built on the submerged remnants of Seal Island. Seal Island was an artificial island constructed in 1982, used for exploration drilling during the 1980s, and subsequently abandoned. The Northstar Development includes a gravel island for the main facilities and two pipelines connecting the island to the existing infrastructure in Prudhoe Bay. One pipeline transports crude oil to shore, and the other transports natural gas to the island for field injection. The facilities on the island include prefabricated modules for living quarters, utilities, warehouse/shop, grind and inject facilities, drilling rig, and oil production facilities. The Northstar Development is, to date, the only offshore oil production facility in the Beaufort Sea north of the barrier islands.

In 1998 and early 1999, BP's plans were to construct the required gravel island during early-mid 1999 by hauling gravel from the Kuparuk River Delta over ice roads to the old Seal Island location. The ice roads were constructed and maintained from early January to early April 1999. However, construction of the gravel island was delayed by regulatory questions not associated with seals or whales. In early April 1999, BP determined that it would not be possible to complete the necessary gravel hauling before ice break-up, and postponed construction until the winter of 1999-2000. Ice-roads built in early 1999 were abandoned and disappeared during the 1999 spring break-up. The ice-road construction and associated marine mammal monitoring are described in Richardson and Williams [eds.] (2000).

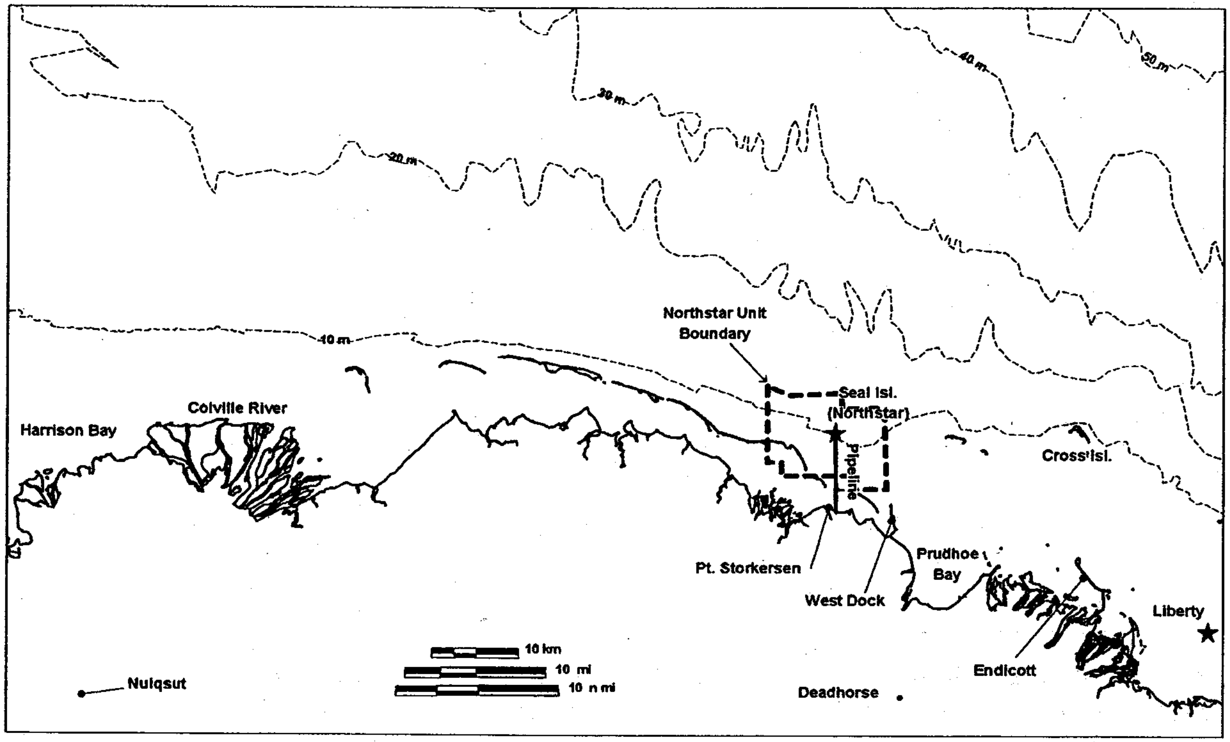


FIGURE 1.1. Location of the Northstar Development at Seal Island in the central Alaskan Beaufort Sea.

"Northstar Island" and the associated pipelines were constructed during early 2000. The ice roads were reconstructed from November 1999 through March 2000. The island was built and the pipelines were installed from February through May 2000. Gravel hauling to Seal Island (which then became Northstar Island)[2] extended from February to April 2000. The pipelines were installed through a trench in the ice from March through May 2000. Follow-up construction activities on and near the island continued during the spring break-up and open water seasons of 2000. The construction activities during November 1999 through October 2000, and associated marine mammal and acoustic monitoring, are described in Richardson and Williams [eds.] (2001a).

The present report describes BP's activities at and near Northstar during the latter stages of construction, from November 2000 through October 2001, and the associated marine mammal and acoustic monitoring. During the period considered here, facilities on the island were completed, production modules were delivered by sealift and installed, and initial wells were drilled. However, oil production did not begin until November 2001, after the period considered in this report.

## MARINE MAMMAL AUTHORIZATIONS AND MONITORING

BP, the National Marine Fisheries Service (NMFS), and various other stakeholders anticipated that, during construction and subsequent operation of Northstar, some seals and whales could be disturbed in a manner that might be considered "taking" under the Marine Mammal Protection Act (MMPA). Disturbance of seals and whales by various operations of the offshore oil industry has been documented previously (Richardson et al. 1995). Consequently, in November 1998 BP requested that NMFS promulgate regulations allowing for the issuance of incidental take authorizations under section 101 (a) (5) of the MMPA to allow "taking" of small numbers of seals and whales.

Williams and Richardson (2000, 2001) described the permitting process for the Northstar Development project. The Regulations that had been requested by BP were issued by NMFS on 25 May 2000 (NMFS 2000). The initial Letter of Authorization (LoA) under those Regulations was issued by NMFS on 18 September 2000, to authorize potential "taking" of whales and seals incidental to construction. A second LoA was issued by NMFS on 14 December 2001 to authorize potential "taking" of whales and seals incidental to production and maintenance operations at Northstar through November 2002.

Such authorizations normally require that monitoring studies be conducted to assess the nature, amount, and geographic extent of any "taking" that did occur, and associated effects on subsistence hunting (NMFS 1996). BP's petition for regulations, supplemented by subsequent detailed monitoring plans, proposed to conduct several types of monitoring studies during both the ice-covered season and the open-water season. The monitoring studies were designed to assess whether effects on seals and whales were limited to behavioral disturbance and/or localized displacement, whether effects on these mammals and their populations were negligible, and whether there were unmitigated adverse effects on availability of seals and whales for subsistence. The studies were also designed to provide the data needed to estimate the numbers of seals and whales that might be affected by BP's Northstar-related activities. Northstar-specific monitoring of marine mammals and sounds began in 1999 and has continued during each succes-

---

[2] The facilities constructed on the remnants of Seal Island are now widely described as "Northstar Island" even though, during the 1980s, the name "Northstar Island" applied to another artificial island constructed by Amerada-Hess at a location a few miles northwest of Seal Island. After being used for exploratory drilling, the original Northstar Island was abandoned and no longer is visible. In this report, all subsequent references to Northstar Island refer to BP's Northstar Development built on the remnants of Seal Island.

sive year. BP's aerial surveys of seals hauled out on the landfast ice in the central Alaskan Beaufort Sea, began in 1997 (Miller et al. 1998) and have continued in a consistent manner annually.

Previous reports on the Northstar monitoring work covered monitoring during

- the construction of ice roads during the ice-covered season in early 1999 (Richardson and Williams [eds.] 2000), and
- the construction of Northstar Island and the associated pipelines during both the ice-covered and open-water seasons of 2000 (Richardson and Williams [eds.] 2001a).

The present report describes monitoring during the latter phases of construction from November 2000 through October 2001 (see below). Additional reports concerning subsequent monitoring work underway during 2002 will be submitted as required by the production LoA issued in November 2001.

The studies during late 2000 and much of 2001 were designed to satisfy the monitoring requirements of the Regulations and LoA issued by NMFS to authorize incidental "taking" of seals and whales during later stages of construction. That LoA required three marine mammal and two acoustical monitoring projects during late 2000 and 2001. All of these projects were continuations of projects conducted in previous years, in some cases with improvements in methodology based on experience in previous years and/or recommendations from a peer/stakeholder review group convened by NMFS. These five projects included three projects conducted during the ***ice-covered season*** in November 2000 – June 2001:

- Winter acoustical measurements to document waterborne (under-ice) sounds, airborne sounds, and iceborne vibrations associated with Northstar, emphasizing sources not studied during the previous year (Chapter 3 of this report);
- On-ice monitoring of the numbers, distribution, and fates of seal structures (breathing holes and lairs) near Northstar during the ice-covered season (Chapter 4); and
- Fixed-wing aerial surveys of seals hauled out on the ice during spring, consistent with similar surveys in 1997-2000 (Chapter 5).

The other two projects were conducted during the ***open-water season*** of 2001:

- Open-water acoustical measurements to document underwater and in-air sounds associated with Northstar in 2001, emphasizing sources not studied during the previous year (Chapter 7);
- Acoustic monitoring of bowhead migration past the Northstar area during the late summer and early autumn of 2001 (Chapter 8).

Preliminary accounts of these five tasks were included in the two most recent 90-day reports submitted to NMFS and distributed to stakeholders (Richardson and Williams [eds.] 2001b; Richardson [ed.] 2002). The present report is an updated and expanded account of all five of the 2001 monitoring tasks, and the present report supersedes the two 90-day reports.

## BP BUSINESS RATIONALE FOR THE MONITORING PROJECT

This project was conducted to satisfy the requirements for marine mammal monitoring and acoustical measurements defined by the National Marine Fisheries Service in various incidental take authorizations issued by NMFS to BP. The general requirements flow from the provisions of the Marine Mammal Protection Act, which prohibits "taking" of whales and seals, including disturbance, unless a specific authorization for "taking" has been issued by NMFS. The MMPA specifies procedures under which such an authorization can be requested. BP requested and received the appropriate authorizations from NMFS, as described above. To meet the provisions of those authorizations, the marine mammal and acoustical monitoring described in this report was necessary.

Similarly, the zoning permit issued by the North Slope Borough (NSB) to BP for construction of Northstar included requirements for some of the types of monitoring conducted in 2001 and described in this report.

One of the key components of the monitoring required by both NMFS and NSB has been monitoring of the autumn bowhead migration past Northstar. The 2001 phase of that work is described in Chapter 8 of this report. A novel acoustic localization approach for monitoring the bowhead migration was proposed by BP, and approved by NMFS and the stakeholders. As compared with a more traditional aerial survey approach, the acoustic method was expected to be more sensitive (and more cost-effective) for detecting a localized effect of Northstar. Statistical power analyses conducted in advance of the fieldwork suggested that the acoustic method could be effective, and that aerial surveys could not be effective. The 2001 acoustic monitoring results described in Chapter 8 show that the acoustic localization method was able to detect and quantify a Northstar effect on a minority of the bowhead whales migrating west in the southern part of the whale migration corridor. The same acoustic localization method is scheduled to be applied again in 2002. That will increase the available sample size and will allow for more precise quantification of the scale of the effect.

---

The remainder of this report consists of the aforementioned five chapters dealing with the five specific monitoring tasks conducted from November 2000 through October 2001, two chapters describing Northstar construction activities during the ice-covered and open-water portions of that period, and a concluding chapter estimating the numbers of seals and whales potentially affected. This information is submitted to comply with the reporting requirements of the “construction LoA” issued to BP on 18 September 2000. Specifically, section 8(d) of that LoA requires BP to

> “…submit a draft final technical report by 1 April 2001 [later revised to 1 May 2002, as specified in the Regulations]. The draft final technical report will contain a full description of the methods, results, and interpretation of all monitoring tasks…”.

## LITERATURE CITED

Miller, G.W., R.E. Elliott and W.J. Richardson. 1998. Ringed seal distribution and abundance near potential oil development sites in the central Alaskan Beaufort Sea, spring 1997. LGL Rep. TA2160-3. Rep. from LGL Ltd., King City, Ont., for BP Explor. (Alaska) Inc., Anchorage, AK. 43 p.

NMFS. 1996. Small takes of marine mammals; harassment takings incidental to specified activities in arctic waters; regulation consolidation. **Fed. Regist.** 61(70, 10 Apr.):15884-15891.

NMFS. 2000. Taking marine mammals incidental to construction and operation of offshore oil and gas facilities in the Beaufort Sea/Final rule. **Fed. Regist.** 65(102, 25 May):34014-34032.

Richardson, W.J. (ed.). 2002. Monitoring of industrial sounds and whale calls during construction of BP’s Northstar Oil Development, Alaskan Beaufort Sea, summer and autumn 2001: 90-day report. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 74 p. [Superseded by present report.]

Richardson, W.J. and M.T. Williams (eds.). 2000. Monitoring of ringed seals during construction of ice roads for BP’s Northstar oil development, Alaskan Beaufort Sea, 1999. [Final, Dec. 2000.] Rep. from LGL Ltd., King

City, Ont., and LGL Alaska Res. Assoc., Anchorage, AK, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 153 p.

Richardson, W.J. and M.T. Williams (eds.). 2001a. Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar oil development, Alaskan Beaufort Sea, 2000. [Draft, April 2001.] Rep. from LGL Ltd., King City, Ont., and LGL Alaska Res. Assoc. Inc., Anchorage, AK, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 316 p.

Richardson, W.J. and M.T. Williams (eds.). 2001b. Monitoring of ringed seals, sounds and vibrations during construction of BP's Northstar oil development, Alaskan Beaufort Sea, winter and spring 2000-2001: 90-day report. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 117 p. [Superseded by present report.]

Richardson, W.J., C.R. Greene Jr., C.I. Malme and D.H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego, CA. 576 p.

Williams, M.T. and W.J. Richardson. 2000. Introduction [1999]. p. 1-1 to 1-9 *In:* W.J. Richardson and M.T. Williams (eds., 2000), *q.v.* LGL Rep. TA2348-1.

Williams, M.T. and W.J. Richardson. 2001. Introduction [2000]. p. 1-1 to 1-17 *In:* W.J. Richardson and M.T. Williams (eds., 2001a), *q.v.* LGL Rep. TA2432-5.

# ICE-COVERED SEASON,

## 1 NOVEMBER 2000 TO 15 JUNE 2001

# CHAPTER 2:

# DESCRIPTION OF BP'S ON-ICE ACTIVITIES, 2000-2001 ICE-COVERED SEASON [1]

by

**Craig J. Perham** and **Michael T. Williams**

**LGL Alaska Research Associates Inc.**
1101 E. 76th Ave., Suite B
Anchorage, AK 99581
(907) 562-3339; mwilliams@lgl.com

for

**BP Exploration (Alaska) Inc.**
**Dept of Health, Safety & Environment**
900 East Benson Blvd., POB 196612
Anchorage, AK 99519-6612

LGL Report TA2563-5

April 2002

---

[1] Chapter 2 *In:* W.J. Richardson and M.T. Williams (eds.). 2002. Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2001. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD.

## INTRODUCTION

This chapter describes construction activities associated with development of the Northstar facilities during the ice-covered season from 1 November 2000 through 15 June 2001. This information complies with the reporting requirements of the Letter of Authorization (LoA) issued to BP on 18 September 2000 by the National Marine Fisheries Service (NMFS). The following information about construction activities during the ice-covered season was originally provided to NMFS and other stakeholders in September 2001 as part of the 90-day report on monitoring work during the Nov. 2000 – June 2001 ice-covered season (Perham and Williams 2001). The present chapter is an updated version of parts of that 90-day report, and supersedes the 90-day version. Likewise, Chapter 6 of the present report provides corresponding information about BP's construction activities during the break-up and open-water seasons of 2001.

Considerable construction work had occurred at Northstar before the period considered in this report. Please refer to Williams and Richardson (2000) and Williams and Perham (2001a,b) for a chronological description of Northstar construction activities in 1999 and 2000, respectively. In summary, island construction began in February 2000. During the winter and spring of 2000, Northstar Island was built by adding gravel to the remnants of Seal Island and installing sheet-pile retaining walls around its perimeter.[1] The undersea pipelines were also installed during the ice-covered season from March to May 2000 (Williams and Perham 2001a). During the break-up and open-water seasons of 2000, the island slopes were graded and concrete slope-protection was installed. Foundation blocks for the island facilities were emplaced. Vibratory and impact pile-driving methods were used to emplace well conductor and insulator pipes. The drilling rig—a top-drive unit—was delivered and assembled late in the open water season of 2000. The Permanent Living Quarters (PLQ), utility module, and pipe racks arrived in August 2000, and a diesel generator in the utility module became operational by late August (Williams and Perham 2001b). The following sections describe BP's subsequent activities at and near Northstar.

## ICE ROAD CONSTRUCTION

Three offshore ice roads were built during the 2000-2001 ice-covered season (Fig. 2.1). The primary ice road was built for transport of personnel, equipment, and construction material between the Prudhoe Bay facilities and Northstar Island. A second offshore ice road was built along the pipeline alignment. This was necessary to provide access to sites along the pipeline route where additional gravel fill was needed over the sub-sea pipeline that had been installed the previous winter. A third ice road, on bottomfast ice, was constructed along the coastline from the Point McIntyre #2 facility on the West Dock causeway to the shore crossing of the pipeline in order to access the valve pad at the pipeline landfall and the backfill sites south of Stump Island.

The ***primary offshore ice road*** for transportation to Northstar Island was built between West Dock and Northstar (Fig. 2.1) from late November 2000 to mid-March 2001. In November 2000, surveyors used snowmachines and a Hägglunds tracked vehicle (Fig. 2.2) to travel offshore from West Dock to the Northstar Island site. The survey for the primary ice road was completed on 18 November 2000.

---

[1] The facilities constructed on the remnants of Seal Island are now widely described as "Northstar Island" even though, during the 1980s, the name "Northstar Island" applied to another artificial island constructed by Amerada-Hess a few miles northwest of Seal Island. In this report, references to Northstar Island refer to BP's Northstar Development built on the remnants of Seal Island.

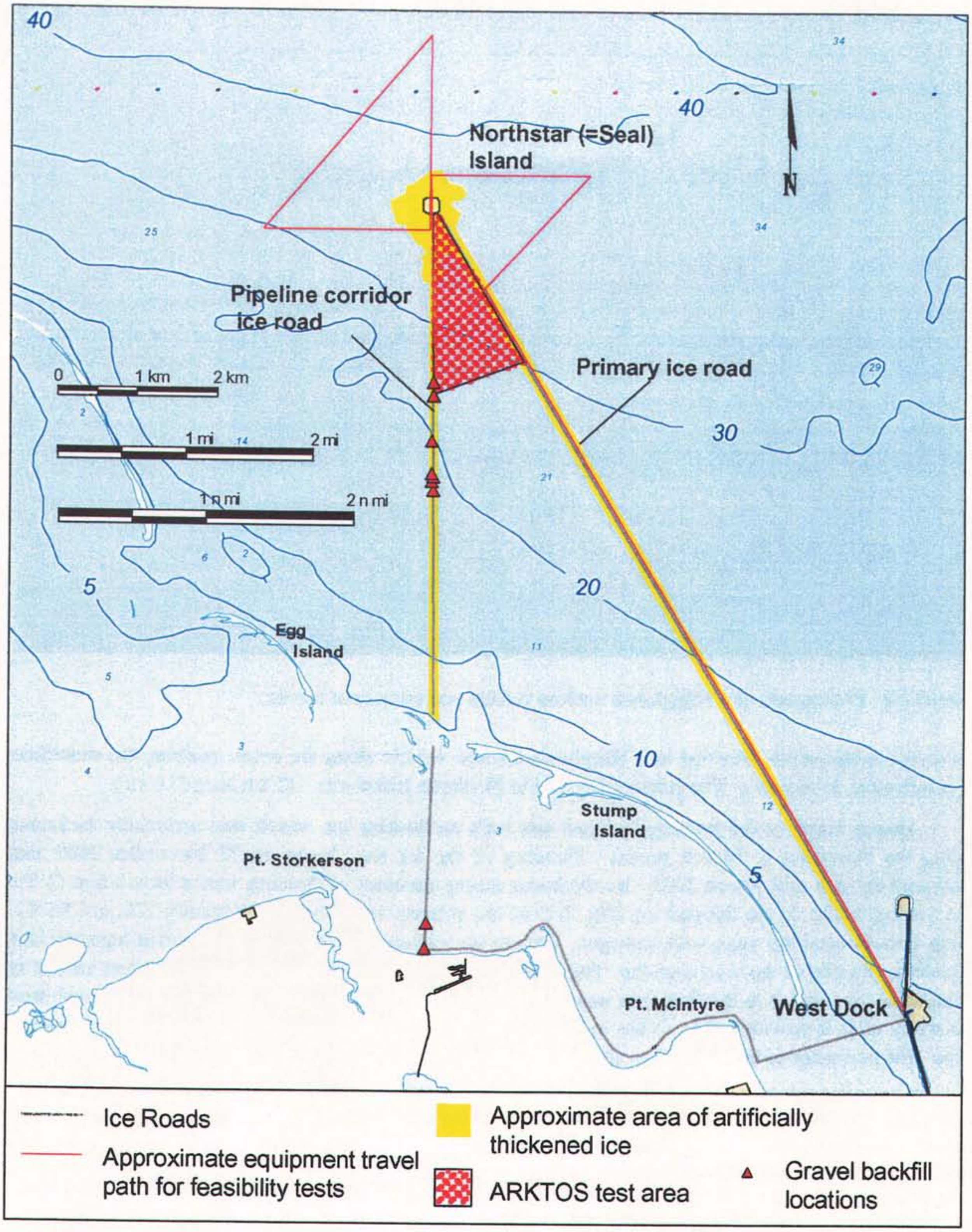


FIGURE 2.1. Northstar construction area northwest of Prudhoe Bay, Alaska, showing ice roads established during the winter of 2000-2001, approximate area of artificially thickened ice, test area for the ARKTOS evacuation craft, and approximate travel route for on-ice equipment tests.

FIGURE 2.2. Photograph of a Hägglunds tracked vehicle and personnel carrier.

Surveyors subsequently traveled in a Hägglunds tracked vehicle along the route, marking the centerline with reflective delineators. The primary ice road to Northstar Island was ~12 km long (7.4 mi).

Almost 100% of the primary ice road was built on floating ice, which was artificially thickened during the December to March period. Flooding of the ice road began on 27 November 2000 and continued through mid March 2001. Ice thickness during the onset of flooding was at least 0.6 m (2 ft). The average width of the flooded ice (Fig. 2.1) of the primary road was approximately 120 m (395 ft). Pump units flooded the route with seawater. Four to six rolligon-powered pumpers worked together as a unit along one side of the road corridor. The pumpers flooded a section of the surface, and then moved to a non-adjacent area while the first area was allowed to freeze. The primary ice road was thickened progressively until it provided safe access to Northstar Island for vehicles and heavier construction equipment. The perimeter of the island was also flooded out to ~100 m (328 ft) offshore of the island.

During late November when flooding began, the ice was too thin to support heavy snow removal equipment. Thus, the snow within the primary road right-of-way was not cleared initially, contrary to the practice in previous years. The road was only cleared when snowdrifts impeded traffic or flooding operations. After construction, the road was maintained until the first week of June 2001 when it was closed to all traffic.

The ***second offshore ice road*** was cleared along the pipeline alignment and lightly flooded to facilitate access to sites along the pipeline route. Access was required in order to emplace additional gravel fill over the sub-sea pipeline to meet specifications of the U.S. Army Corps of Engineers permit. The path along the pipeline alignment initially was cleared of snow in January 2001 to promote accelerated freezing. Flooding for the pipeline ice road began during the third week of February 2001. This ice road extended from Northstar Island to ~100 m north of Stump Island and from ~100 m south of Stump Island to the pipeline landfall (Fig. 2.1).

The ice roads were constructed during double-shifts (each 11 hours long) on a seven-days-per-week basis. Flooding to thicken the ice-roads stopped from 23 December 2000 to early January 2001 for the holiday season, but personnel transport continued. Construction crews were housed in the Prudhoe Bay area and transported by bus to their work sites. The Permanent Living Quarters (PLQ) on the island also housed personnel who worked there on a two-week rotation.

The ***third "offshore" ice road*** was constructed during the same time period (late Nov. 2000 to mid-March 2001) and in the same manner as the primary ice road. It was placed along the coast from the Point McIntyre #2 facility on the West Dock causeway to the shore crossing of the pipeline (Fig. 2.1). This entire ice road was located on bottomfast ice. This road was used to access the valve pad at the pipeline landfall and the backfill sites south of Stump Island. This ice road was an oversize, two-lane road, ~8 km (5 mi) long. The average width of the flooded ice of this road was ~60 m (200 ft). The ice road was maintained until the first week of June 2001 when it was closed to all traffic.

## TRANSPORTATION TO AND FROM NORTHSTAR ISLAND

Helicopters were used for transportation to and from Northstar during the freeze-up period in late 2000. Crew boat operations had ceased on 7 October 2000 (Williams and Perham 2001b), and helicopter flights were in progress at the start of the period covered in this report (1 November 2000). Two Bell 212 helicopters were used to transport crew and materials to and from Northstar Island from 1 November 2000 until 19 November 2000. By the latter date, the ice road from the West Dock base of operations (WDBO) had been marked with reflective delineators and became the primary means of transportation to the island. Recommended flight corridors and altitude restrictions were maintained during regular operations (see Fig. 6.1 *in* Williams and Perham 2001b). For visual flight rules (VFR) conditions, standard flight altitude was 1500 ft (460 m), weather permitting. Construction crews were exchanged approximately every 12 hours. Crew changeover took ~2-3 hours, and typically required up to 6 round trips per shift change during peak construction periods. One-way flight time to Northstar was ~15 min from WDBO and 30 min from the Deadhorse airport.

BP and its contractors maintained the same helicopter routes as had been designated earlier for the open water season of 2000. These routes were negotiated among the U.S. Fish and Wildlife Service (USFWS), NMFS, and BP to minimize impacts on waterfowl and marine mammals. The LoA issued by NMFS stated that helicopter flights to support Northstar construction must be limited to a corridor from Northstar Island to the mainland and, except when taking off, landing or limited by weather, must maintain a minimum altitude of 1000 ft (305 m). During poor weather or emergency conditions, pilots followed FAA (Federal Aviation Administration) altitude regulations and BP safety policy.

Hägglunds tracked vehicles were used to transport personnel and materials from West Dock to Northstar Island from 20 November 2000 to late January 2001. Hägglunds operations ceased during the last week in January 2001 after the ice road surface permitted standard vehicle traffic. Heavy loads were not transported on the ice road until March 2001.

During much of the ice-covered season, from late January 2001 to late May, standard SUVs, crew-cab pick-ups, and buses were the main method of transportation for Northstar personnel. Transits required about 30 min, one-way. Transits included daily scheduled trips during crew changes, freight runs, and supplementary crew and freight trips. The Hägglunds were used again during the first week of June to transport crews during marginal ice conditions after standard vehicular traffic ceased. All travel on the primary ice road ceased on 8 June 2001. Helicopter flights resumed on 9 June 2001 during break-up.

## CHRONOLOGY OF ISLAND ACTIVITIES – CONSTRUCTION, EQUIPMENT TESTING, AND MODULE INSTALLATION

Numerous construction activities occurred during the ice-covered season in late 2000 and early-mid 2001 (Table 2.1). Major activities included completing the assembly of the drilling rig, pipe rack, permanent living quarters, and grind and inject module, along with dock improvements. Installation of the mini-injection effluent skid and of the foundation blocks for modules housing the processing plant, compressor, and garage also occurred.

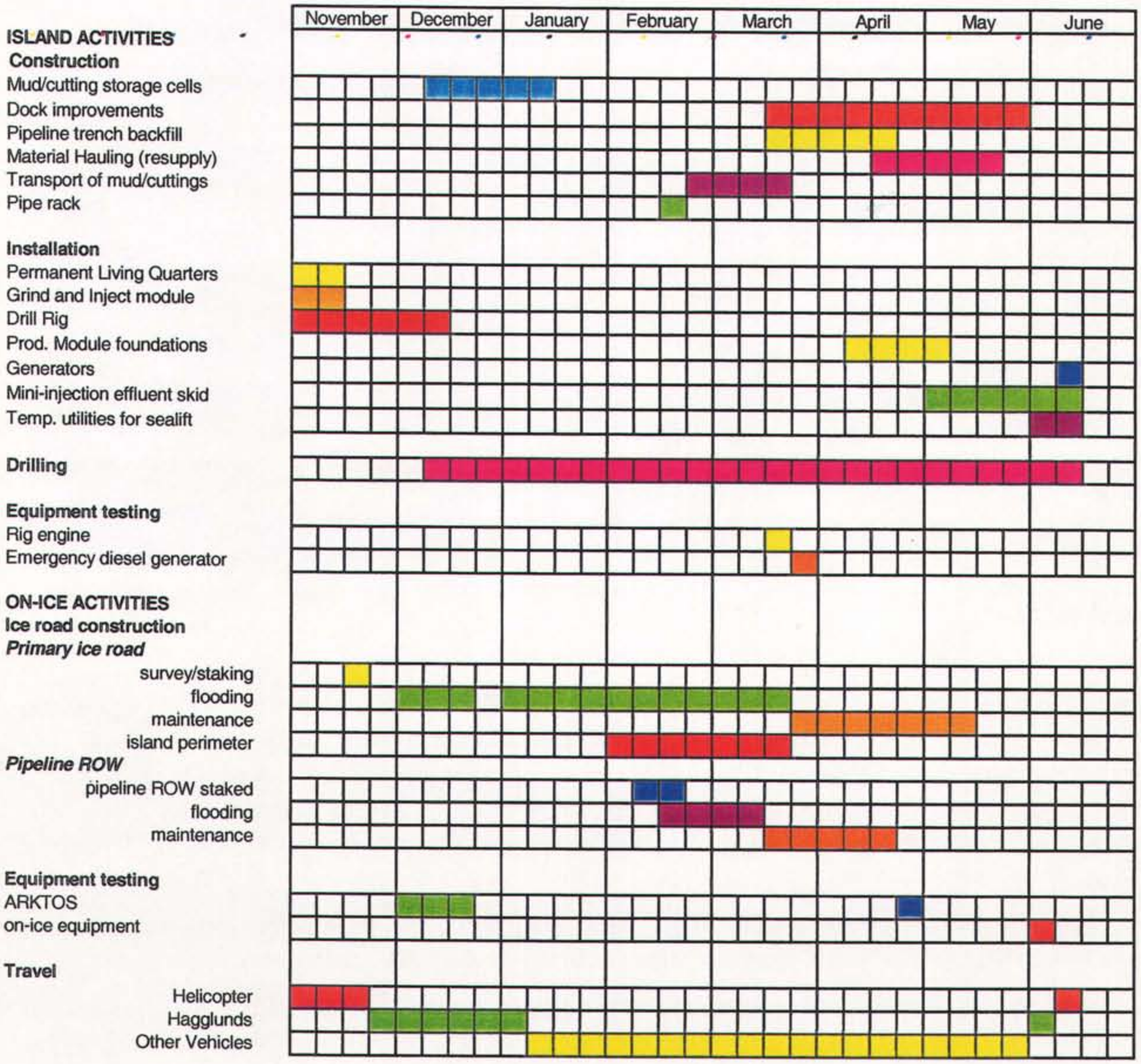
Equipment testing occurred periodically throughout the season. The ARKTOS, the island emergency escape vehicle (Fig. 2.3), was driven to the island and tested during the first two weeks of December 2000 and tested again in mid April 2001. The drillrig engines and "emergency" diesel generators (the primary generators until the gas turbine generator was installed in late summer 2001) were tested for emissions during mid-March 2001. An on-ice equipment exercise was conducted along a linear track on 1 and 2 June 2001 near Northstar Island (Fig. 2.1) to help determine capabilities of several types of equipment in softening ice conditions. Equipment that was tested included a wide-tracked backhoe, a Hägglunds tracked vehicle with a trailer, a Blue Bird rolligon, and a Tucker tracked vehicle.

Five wells were drilled during the 2000-2001 ice-covered season. Drilling for the Underground Injection Control (UIC) well began on 14 December 2000 and was completed during the first week of January 2001. On 26 January the UIC well was commissioned for disposal of muds and cuttings. Drilling of well NS-26 began during the first week of February 2001, but it was abandoned due to collapsing walls. The drilling of wells NS-27, NS-29, and NS-31 occurred from January 2001 to 13 June 2001. Prior to 13 June, wells were drilled to the production zone and prepared for production. However, oil production did not begin until November 2001, after the period covered in this report. After 13 June, drilling was suspended until late 2001 because of the limitations that broken ice would impose on any oil-spill response should that be necessary.

Activities along the Northstar pipeline alignment included constructing an ice road and depositing additional gravel along the subsea pipeline trench to meet U.S. Army Corps of Engineers permit specifications. Backfilling occurred at nine sites between Northstar Island and landfall (Fig. 2.1). During February and March, an ice road was constructed along the pipeline alignment. Seven backfill sites were concentrated 2.1 to 3.6 km (1.3 to 2.2 mi) north of the barrier islands in waters >1.5 m (5 ft) deep. The remaining 2 sites were ~500 m (1650 ft) north of the landfall of the pipeline in waters <1.5 m (5 ft) deep. The backfill placement along the pipeline alignment occurred between mid-March and mid-April 2001. Holes 2.4 m (8 ft) wide were cut through the ice above the pipeline with a Ditchwitch R100. Gravel was dumped through the holes where additional fill was needed. Gravel was transported from the Kuparuk River Oxbow gravel mine site to the fill locations using Volvo A-30 dump trucks. The lengths of the backfill placement sites ranged from 12 to 60 m (40 to 200 ft). The total length of the pipeline that required backfill placement was 314 m (1030 ft). A total of 130 truckloads (3640 cubic yards) of stockpiled gravel were used to backfill the nine locations along the pipeline.

The Concrete Island Drilling Structure (CIDS) is not part of the Northstar Development, and is not the responsibility of BP. However, it was stored ~1.1 km northeast of Northstar from 29 August 2000 until 31 August 2001. Its arrival near Northstar in 2000 was described in Chapters 6 and 7 of Richardson and Williams (2001). Its departure in August 2001 is described in Chapters 6 and 7 of the present report. During the intervening ice-covered season relevant here, the CIDS was unmanned with no operating equipment.

TABLE 2.1. Chronology of Northstar Development activities from 1 November 2000 to 15 June 2001. Activities are divided into island and on-ice activities.



| | November | December | January | February | March | April | May | June |
|---|---|---|---|---|---|---|---|---|
| **ISLAND ACTIVITIES** | | | | | | | | |
| **Construction** | | | | | | | | |
| Mud/cutting storage cells | ⬜⬜⬜⬜ | ⬜🟦🟦🟦 | 🟦🟦⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ |
| Dock improvements | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜🟥🟥 | 🟥🟥🟥🟥 | 🟥🟥🟥🟥 | ⬜⬜⬜⬜ |
| Pipeline trench backfill | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜🟨🟨 | 🟨🟨🟨⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ |
| Material Hauling (resupply) | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜🟪🟪 | 🟪🟪🟪⬜ | ⬜⬜⬜⬜ |
| Transport of mud/cuttings | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜🟪 | 🟪🟪🟪⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ |
| Pipe rack | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜🟩⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ |
| **Installation** | | | | | | | | |
| Permanent Living Quarters | 🟨🟨⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ |
| Grind and Inject module | 🟧🟧⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ |
| Drill Rig | 🟥🟥🟥🟥 | 🟥🟥⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ |
| Prod. Module foundations | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜🟨🟨🟨 | 🟨⬜⬜⬜ | ⬜⬜⬜⬜ |
| Generators | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜🟦⬜⬜ |
| Mini-injection effluent skid | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | 🟩🟩🟩🟩 | 🟩🟩⬜⬜ |
| Temp. utilities for sealift | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | 🟪🟪⬜⬜ |
| **Drilling** | ⬜⬜⬜⬜ | ⬜🟪🟪🟪 | 🟪🟪🟪🟪 | 🟪🟪🟪🟪 | 🟪🟪🟪🟪 | 🟪🟪🟪🟪 | 🟪🟪🟪🟪 | 🟪🟪⬜⬜ |
| **Equipment testing** | | | | | | | | |
| Rig engine | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜🟨⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ |
| Emergency diesel generator | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜🟧 | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ |
| **ON-ICE ACTIVITIES** | | | | | | | | |
| **Ice road construction** | | | | | | | | |
| ***Primary ice road*** | | | | | | | | |
| survey/staking | ⬜⬜🟨⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ |
| flooding | ⬜⬜⬜⬜ | 🟩🟩🟩⬜ | 🟩🟩🟩🟩 | 🟩🟩🟩🟩 | 🟩🟩🟩⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ |
| maintenance | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜🟧 | 🟧🟧🟧🟧 | 🟧🟧⬜⬜ | ⬜⬜⬜⬜ |
| island perimeter | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | 🟥🟥🟥🟥 | 🟥🟥🟥⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ |
| ***Pipeline ROW*** | | | | | | | | |
| pipeline ROW staked | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜🟦🟦⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ |
| flooding | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜🟪🟪 | 🟪🟪⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ |
| maintenance | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜🟧🟧 | 🟧🟧🟧⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ |
| **Equipment testing** | | | | | | | | |
| ARKTOS | ⬜⬜⬜⬜ | 🟩🟩🟩⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜🟦 | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ |
| on-ice equipment | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | 🟥⬜⬜⬜ |
| **Travel** | | | | | | | | |
| Helicopter | 🟥🟥🟥⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜🟥⬜⬜ |
| Hagglunds | ⬜⬜⬜🟩 | 🟩🟩🟩🟩 | 🟩⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | 🟩⬜⬜⬜ |
| Other Vehicles | ⬜⬜⬜⬜ | ⬜⬜⬜⬜ | ⬜🟨🟨🟨 | 🟨🟨🟨🟨 | 🟨🟨🟨🟨 | 🟨🟨🟨🟨 | 🟨🟨🟨🟨 | ⬜⬜⬜⬜ |

## EQUIPMENT USED, 2000-2001

*Transportation:* Two Bell 212 helicopters were used to transport crew and materials to Northstar. These are medium-sized helicopters, each with two turboshaft engines, a 2-bladed main rotor, and a 2-bladed tail rotor (see Fig. 6.2 in Chapter 6).

Up to three Hägglunds tracked vehicles (model 206 SUSV, Fig. 2.2) were used to transport personnel and materials between West Dock and Northstar Island. Three Hägglunds were used simultaneously during crew changes. Each of these vehicles was powered by a Mercedes-Benz 6-cylinder inline

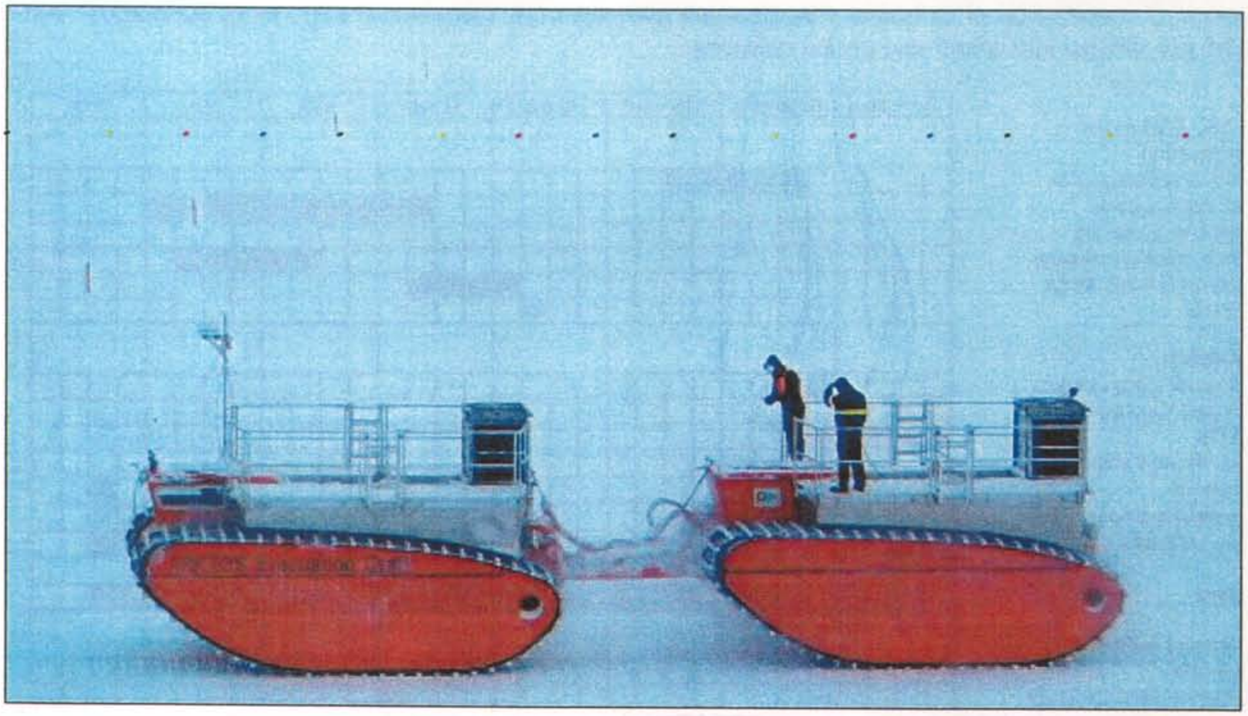


FIGURE 2.3. One of the two articulated ARKTOS evacuation craft that were used as the island emergency escape vehicles.

turbocharged diesel engine capable of 143 hp at 4600 rpm. Total vehicle weight was ~4536 kg (10,000 lbs): 2771 kg (6108 lbs) for the front car and 1750 kg (3859 lbs) for the rear personnel carrier. The Hägglunds can travel at a top speed of 50 km/h (31 mph) over hard ground, and 35 km/h (22 mph) in deep snow. However, average transport speeds were typically 8-16 km/h (5-10 mph) less than top speed. The maximum allowable payloads are 380 kg (838 lbs) for the 4-person front car and 1250 kg (2756 lbs) for the 8-person personnel carrier.

Standard crewcab pickup trucks, SUVs, and buses (for 65, 40, or 14 passengers) were used for transportation over the ice road to Northstar Island from late January 2001 to late May.

*Ice Road Construction:* Surveyors used snowmachines and both a Hägglunds and Tucker tracked vehicle to survey and mark the primary and pipeline ice roads prior to flooding. Blue Bird rolligon-type vehicles with augers and pumps (see Fig. 2.2 in Williams and Perham 2001a) were used to construct ice roads. The drill auger is 12" (30 cm) in diameter with a rotation rate of about 600 rpm. The pump auger is 10.2" in diameter with a rotation rate of about 600 rpm. Caterpillar D-3 and D-4 bulldozers were used to plow snow and ice along the road corridors and around the island. A Caterpillar 14G or 16H grader was used to grade and maintain the ice roads. Diesel generator light plants were located at regular intervals along the ice road around the island.

*Dock Improvements*: A Manitowoc 888 crane lifted and placed the pilings for the dock face. An American Piledriving Equipment (APE) model 200A vibratory pile driver (see Fig. 2.3 in Williams and Perham 2001a) was used to drive piles for dock improvements. These included areas for the crew boat and piles for the dock face that had been damaged by ice. The APE 200A vibrated the piles at a range of 400-1400 vibrations per minute and weighed 13,000 lb.

*Backfilling along Pipeline Alignment:* A Ditchwitch R100 was used to cut the ice from along the pipeline right of way. The R100 had a 75 hp engine and weighed 9500 lb. At each of the nine backfill locations the R100 opened holes approximately 2.4 m (8 ft) wide, ranging between 12 and 60 m (40 and 200 ft) wide. A Caterpillar 330 backhoe was used to remove ice from the slot. The Cat 330 weighed 39,460 kg (87,000 lb). Engineering plans called for the pipeline to be buried by at least 1.8 m (6 ft) of material. Volvo A-30 dump trucks were used to haul stockpiled gravel to the ice trench. A Caterpillar 966 loader was used to place the remaining gravel through the opening, covering the pipeline by at least 1.8 m.

*Emergency Escape and Equipment Testing*: Two articulated ARKTOS evacuation craft were used as the island emergency escape vehicles (Fig. 2.3). Each ARKTOS was powered by two Cummins 260 hp diesel engines and weighed 29,484 kg (65,000 lbs). Propulsion while in the water was by two 14-inch-diameter heavy-duty commercial water jets. Each ARKTOS evacuation craft was 15 m (50 ft) long and 3.9 m (13 ft) high with a beam of 3.8 m (12 ft 9 in). The maximum speed was 16 km/h (10 mph) on land or ice, and 6 knots on water. Exercises using the ARKTOS evacuation craft were conducted during the season to test its capability in various sea and ice conditions. Each ARKTOS was capable of carrying 52 people, 24 in the front section and 28 in the rear section.

The Hägglunds and Tucker tracked vehicles, a wide-track backhoe, and a Bluebird pumper rolligon were operated on the "un-improved" sea ice (Fig. 2.1) during 1 and 2 June 2001. Performance of this equipment on the wet snow and sea ice was tested.

## SUMMARY

Initial construction activities at Northstar began in earnest during February 2000, and much of the construction work was completed before 1 Nov. 2000, the start of the period considered here. Previous reports have documented BP's construction activities and the associated marine mammal and acoustic monitoring work during construction work through October 2000. Ice road construction, island maintenance, initial drilling, and other preparations for oil production continued during the ice-covered season in late 2000 through mid-2001. Activities from 1 November 2000 through 15 June 2001 are described in this chapter.

During early winter, transportation to and from Northstar Island was primarily by helicopter and Hägglunds tracked vehicles. Two Bell 212 helicopters and three Hägglunds were used. Construction of the Northstar ice-roads for the winter of 2000-2001 began in November 2000. The primary ice road, from West Dock to Northstar Island, was ready for standard passenger vehicle traffic in January 2001, and was completed for heavy-load traffic in March 2001. A second ice road was built in January and February 2001 from Northstar Island south along the pipeline alignment to the mainland. A third ice road was constructed along the shoreline on grounded ice.

Ice cutting and supplementary gravel placement along the pipeline alignment was initiated in March 2001 and completed mid April 2001. At each location, these two activities (i.e., cutting and backfilling) occurred in sequence.

Numerous activities occurred on Northstar Island during the 2000-2001 ice-covered season. Major construction activities included completing the assembly of the drilling rig, and construction of the pipe rack and dock improvements. The permanent living quarters, grind and inject module, and foundation blocks for the modules housing the processing plant, compressor, and garage were installed and became operational. Installation of the back-up diesel generator, initially used as the primary power source, and mini-injection effluent skid also occurred.

Equipment testing occurred throughout the season. Two ARKTOS amphibious vehicles, which provide a means of emergency escape from the island, were tested in mid December 2000 and again in mid-April 2001. The drillrig engines and emergency diesel generator were tested mid March 2001. An on-ice equipment exercise was conducted on 1 and 2 June 2001 to test several types of equipment on unimproved sea ice during the early stages of snow melt and break-up.

A total of 5 wells were drilled during the 2000-20001 ice-covered season. Drilling began on 14 December 2000 with the Underground Injection Control (UIC) well and continued throughout the ice-covered season until 13 June. Drilling was then suspended until autumn. No oil production occurred until November 2001, after the period covered by this report.

## ACKNOWLEDGEMENTS

We thank Dr. Bill Streever, Allison Erickson, Wilson Cullor, and Dave Trudgen of BP for their support. We would also like to thank Tom Barnes and Paul Cooley, Northstar Compliance Advisors, Randy Greenway of Alaska Interstate Construction, and Peter Gadd of Coastal Frontiers Corporation for providing valuable information necessary for this report. W. John Richardson and Steve MacLean of LGL and Bill Streever of BP reviewed the draft report.

## LITERATURE CITED

Perham, C.J. and M.T. Williams. 2001. Introduction and description of BP's on-ice activities, late 2000 to mid-2001. p. 1-1 to 1-13 *In:* Richardson, W.J. and M.T. Williams (eds.) 2001. Monitoring of ringed seals, sounds and vibrations during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, winter and spring 2000-2001: 90-day report. LGL Rep. TA2563-1. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 117 p. [Superseded by present report.]

Richardson, W.J. and M.T. Williams (eds.) 2001. Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar oil development, Alaskan Beaufort Sea, 2000. [Draft, April 2001.] Rep. from LGL Ltd., King City, Ont., and Greenridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 316 p.

Williams, M.T. and C.J. Perham. 2001a. Description of BP's activities, 1999-2000 ice-covered season. p. 2-1 to 2 -8 *In:* W.J. Richardson and M.T. Williams (eds., 2001, *q.v.*). LGL Rep. TA2432-6.

Williams, M.T. and C.J. Perham. 2001b. Description of BP's activities, break-up and open-water seasons, 2000. p. 6-1 to 6-11 *In:* W.J. Richardson and M.T. Williams (eds., 2001, *q.v.*). LGL Rep. TA2432-7.

Williams, M.T. and W.J. Richardson. 2000. Introduction. p. 1-1 to 1-9 *In:* W.J. Richardson and M.T. Williams (eds., 2000). Monitoring of ringed seals during construction of ice roads for BP's Northstar oil development, Alaskan Beaufort Sea, 1999. [Final, Dec. 2000.] LGL Rep. TA2348-1. Rep. from LGL Ltd., King City, Ont., and LGL Alaska Res. Assoc., Anchorage, AK, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 153 p.

# CHAPTER 3:

# SOUND AND VIBRATION MEASUREMENTS DURING WINTER DRILLING AT NORTHSTAR IN EARLY 2001 [1]

by

**Susanna B. Blackwell** [a] and **Charles R. Greene Jr.** [b]

**Greeneridge Sciences, Inc.**

[a] 120 Tamarack Drive
Aptos, CA 95003
(831) 685-2773; susanna@greeneridge.com

and

[b] 4512 Via Huerto
Santa Barbara, CA 93110
(805) 967-7720; cgreene@greeneridge.com

for

**BP Exploration (Alaska) Inc.**
**Dept. of Health, Safety & Environment**
900 East Benson Blvd, P.O. Box 196612
Anchorage, AK 99519-6612

LGL Report TA2571-2

April 2002

---

[1] Chapter 3 *In:* W.J. Richardson and M.T. Williams (eds.). 2002. Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2001. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD.

# INTRODUCTION

## *Background*

During the winter of 1999-2000, BP Exploration (Alaska) Inc. began construction of its Northstar production facilities in nearshore waters of the Alaskan Beaufort Sea. Northstar is built on the eroded remains of the original Seal Island, an artificial island constructed by Shell Oil Company in 1982 about 3 mi (5 km) offshore of the closest barrier island, northwest of Prudhoe Bay. It was used in 1984 and 1985 for exploratory drilling, and subsequently abandoned. The artificial island originally named Northstar was built northwest of Seal Island by Amerada-Hess in 1985 for exploratory drilling. However, BP's facilities at the old Seal Island location are now widely known as Northstar Island. The Northstar Development addressed in this report includes the new gravel island itself, living quarters, 30 wells (some still to be drilled), associated oil production facilities on the island, and two buried subsea pipelines that connect the island to the existing production infrastructure in Prudhoe Bay.

Initial construction began in December 1999 with the building of ice roads. Construction of the island itself began in February 2000 by hauling gravel over the ice roads and depositing it at the island site through a hole in the ice. Construction continued during all of 2000, involving pipeline construction (March-May), installation of conductor pipes for the wells by vibratory and impact pile driving (June-July), positioning of the cement block slope protection (June-July), installation of the permanent living quarters (August), and assembly of the drill rig (autumn). These activities are described in Williams and Perham (2001a,b).

Construction of Northstar and preparations for oil production continued during the winter and spring of 2000-2001. Drilling began on 14 December 2000 with the Underground Injection Control (UIC) well. Drilling was suspended on 13 June because of the limitations that broken ice would impose on any oil-spill response that might be necessary. The drill rig used at Northstar is a top drive rig. Activities at Northstar during late 2000 and early-mid 2001 are described in Chapter 2 of this report.

The work described in this chapter corresponds to Task 4 in the Northstar Monitoring Plan for 2000-2001 (LGL and Greeneridge 2000), and includes sound and vibration measurements during the ice-covered season in early 2001. These measurements complement the sound and vibration measurements obtained a year earlier during the initial stages of Northstar construction (Greene and McLennan 2000). Numerous ringed seals (*Phoca hispida*) inhabit the area around Northstar year-around. Data on the sounds and vibrations around Northstar were needed to help interpret the results of studies of ringed seals near Northstar during winter and spring (see Chapters 4 - 5 and 9 of this report).

## *Objectives and Approach*

***BP's business rationale*** for this effort was that additional acoustics measurements were required, during the winter-spring of 2001, to satisfy the monitoring requirements of the Letter of Authorization issued by NMFS to BP on 18 Sept. 2000. This LoA called for acoustic and vibration measurements to document sounds of types that have not been measured in previous years.

The following is quoted from the Northstar Monitoring Plan for 2000-2001: "*The objective of Task 4 in 2001 is to measure and document the levels, characteristics and range-dependence of sounds and vibrations produced by Northstar-related industrial activities occurring during the winter and spring of late 2000 and early 2001, excluding activities whose sounds and vibrations were adequately characterized in 2000. New operations may include some or all of the following:*

- *Drilling from the island;*
- *Power generation on the island during winter if a different power source is in use than was used in early 2000;*
- *New types of maintenance and construction activities, if they occur.*

*... During any previously unstudied late winter or spring operations by BP on or near the island, sound and vibration measurements will be made for representative periods at several distances from the sound source. ... The new data will supplement related data on underwater sounds obtained during winter construction of Northstar Island in 2000 and Seal Island in 1982 at the same location (Greene 1983; Greene et al. in prep.).*"

"New" types of winter sounds that were recorded in early 2001 included the sounds from drilling activity and from the utility generators attached to the Permanent Living Quarters (PLQ). Vibrations caused by these sources were also recorded and analyzed. This chapter describes analyses of these recorded sounds and vibrations.

The planned approach involved making recordings of sounds in air and in the water below the ice, along with recordings of vibrations in the ice, at a series of distances from Northstar Island. The nominal recording distances were planned to be $^1/_8$, ¼, ½, 1, 2 and 4 n.mi. (nautical miles), and farther if Northstar sounds were still detectable 2-4 n.mi. from the island.

## METHODS

Several different measurement units appear in this report. For simplicity most of the measurements are only given in statute miles (mi) and/or kilometers (km). The nominal recording distances in n.mi. mentioned above ($^1/_8$, ¼, ½, 1, 2 and 4) correspond to the following distances in mi (km): 0.14 (0.23), 0.29 (0.46), 0.58 (0.93), 1.15 (1.85), 2.3 (3.7) and 4.6 (7.4). The following conversions can be used:

- 1 m ≅ 3.3 feet
- 1 km = 1000 m ≅ 0.54 n.mi. ≅ 0.62 mi
- 1 n.mi. ≅ 1.85 km ≅ 1.15 mi

Recordings of drilling sounds were obtained on 8 and 9 March 2001. In addition, recordings were made on 6 March 2001, before drilling had begun. All recordings were made at stations on the ice (Fig. 3.1, Table 3.1). Recording stations were accessed using a Hägglunds all-terrain tracked vehicle (see Chapter 2, Fig. 2.2) for transport of equipment and personnel, and a Blue Bird rolligon equipped with a 12" powered ice auger to drill the holes through which underwater recordings were made.

### *Equipment*

The sensors included a hydrophone, a microphone, and a 3-axis geophone, all calibrated. The hydrophone was an International Transducer Corporation (ITC) model 6050C, which includes a low-noise preamplifier next to the sensor and a 98 ft (30 m) cable. The hydrophone cable was attached with cable ties to a fairing to eliminate interference from strumming. Prior to recording, the hydrophone signals were amplified with an adjustable-gain postamplifier. The omnidirectional microphone was an ACO model 7013 condenser microphone with a 4012 preamplifier and a windscreen. The 3-axis geophone was a GeoSpace model 20 with

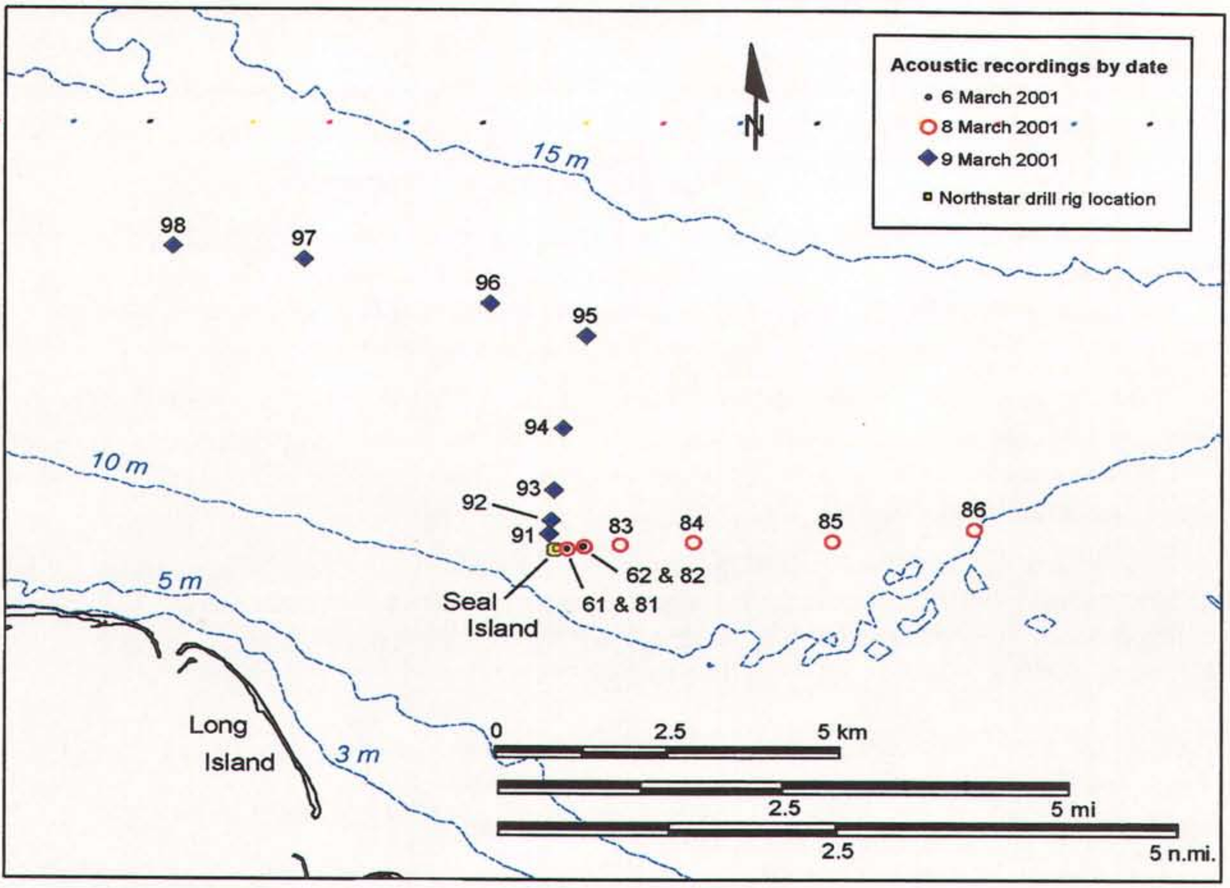


FIGURE 3.1. Acoustic recording locations before and during drilling at Northstar (Seal) Island, Northstar Development Area, Beaufort Sea, Alaska. Locations with numbers 6x, 8x and 9x were occupied on 6, 8 and 9 March 2001, respectively. Northstar (Seal Island) is indicated by the yellow polygon.

critical damping(2) on the two horizontal axes and the vertical axis. During recording on 9 March, the geophone signals were amplified with an adjustable-gain postamplifier, whereas on 6 and 8 March the signals were not amplified. The addition of the postamplifier boosted weaker signals above the noise floor imposed by the data recorder. Without the additional amplification, the data from 6 and 8 March were limited by the recorder's self-noise.

Hydrophone, geophone (3 channels), and microphone signals were recorded on five channels of a SONY model PC208Ax instrumentation-quality digital audio tape (DAT) recorder. All recorded sensor data were equalized in the laboratory so that the calibrated frequency response of each sensor was flat between 4 and 500 Hz for the geophone, and between 4 and 10,000 Hz for the hydrophone and microphone. Quantization was 16 bits, providing a dynamic range of >80 dB between an overloaded signal and the quantization noise. A memo channel on the tape recorder was used for voice announcements, and the date and time were recorded automatically.

---

(2) In a critically-damped sensor there is no peak in sensitivity at a resonance frequency and the response is flat to as low a frequency as is possible with a particular geophone.

TABLE 3.1. Distances from the drill rig on Northstar Island to acoustic recording locations on the ice, 6 - 9 March 2001.

| 6 March 2001 | | | 8 March 2001 | | | 9 March 2001 | | |
|---|---|---|---|---|---|---|---|---|
| Station | Mean distance | | Station | Mean distance | | Station | Mean distance | |
| (E) | mi | m | (E) | mi | m | (N-NW) | mi | m |
| 61 | 0.12 | 200 | 81 | 0.12 | 200 | 91 | 0.16 | 260 |
| 62 | 0.29 | 460 | 82 | 0.28 | 460 | 92 | 0.31 | 490 |
| | | | 83 | 0.61 | 990 | 93 | 0.61 | 990 |
| | | | 84 | 1.26 | 2030 | 94 | 1.24 | 1990 |
| | | | 85 | 2.50 | 4020 | 95 | 2.20 | 3530 |
| | | | 86 | 3.76 | 6050 | 96 | 2.55 | 4100 |
| | | | | | | 97 | 3.67 | 5910 |
| | | | | | | 98 | 4.55 | 7320 |

## *Field Procedures*

In early March 2001, Northstar (=Seal) Island was surrounded by land-fast ice that was about 1.4 m (4.5 feet) thick. Near the island and on the ice road south of the island, the ice had been artificially thickened and sometimes exceeded 2.5 m (8 feet) in depth. The recording procedure was identical on all three days of recording. The first measurements were made as close as possible to Northstar, with subsequent recordings at progressively increasing distances, either eastward (6 and 8 March) or north and northwestward (9 March, see Fig. 3.1). On 9 March the recording locations were constrained by the presence of a pressure ridge about 3.5 km north of the island (see below). The decision to make recordings in these two directions was based partly on the fact that the drill rig was on the eastern side of the island but the drilling was directional and oriented in a northwesterly direction. Also, the water depth increases in those directions and therefore more seals were expected to be found there than to the south and west, where shallower water, barrier islands, and land occur.

For each recording distance, we chose a suitable location using a hand-held GPS receiver (Garmin model 12XL). A laser rangefinder (Bushnell model # 20-0880) was used for distances less than 800 m. All distances were computed from the drill rig. The Blue Bird augered a 12" hole through the ice, after which it moved to the next recording station (or at least 400 m away, whichever was furthest) where it remained idling. No sounds from the idling Blue Bird were detectable at the recording site. Likewise, Greene and McLennan (2000) did not find any differences in sound levels or spectra with and without a Rolligon idling ¼ n.mi. (460 m) away from their recording site.

The recording equipment was set up in the back trailer of the Hägglunds all-terrain vehicle. The hydrophone was lowered through the ice hole and was positioned about 1 m above the bottom. Water depth increased slowly with increasing distance northward from Northstar (Fig. 3.1, Table 3.2). The geophone provided separate data from the vertical axis and from two horizontal axes (H1 and H2) oriented perpendicular to each other. In the field, the geophone was planted in the ice and positioned with H1 pointing directly toward the presumed sound source, Northstar in this case. The microphone was placed about 2 m (6.6 ft) above the ice with an unobstructed path to the island. It was shielded from the wind as much as possible by the Hägglunds vehicle and was fitted with a windscreen.

TABLE 3.2. Water depth and ice thickness at on-ice acoustic recording locations, 6-9 March 2001.

| 6 March 2001 | | | | | 8 March 2001 | | | | | 9 March 2001 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | Water depth | | Ice thickness | | Station | Water depth | | Ice thickness | | Station | Water depth | | Ice thickness | |
| (E) | m | feet | m | feet | (E) | m | feet | m | feet | (N-NW) | m | feet | m | Feet |
| 61 | 11.5 | 38 | 2.1 | 6.8 | 81 | 11.0 | 36 | 2.1 | 6.8 | 91 | 11.8 | 39 | 2.0 | 6.5 |
| 62 | 11.5 | 38 | 1.2 | 4.0 | 82 | 11.8 | 39 | 1.2 | 4.0 | 92 | 11.8 | 39 | 1.5 | 4.8 |
| | | | | | 83 | 11.5 | 38 | 1.7 | 5.5 | 93 | 11.5 | 38 | 1.4 | 4.5 |
| | | | | | 84 | 11.3 | 37 | 1.4 | 4.5 | 94 | 12.0 | 39 | 1.4 | 4.5 |
| | | | | | 85 | 10.0 | 33 | 1.4 | 4.5 | 95 | 12.8 | 42 | 1.4 | 4.5 |
| | | | | | 86 | 9.0 | 30 | 1.5 | 5.0 | 96 | 13.6 | 45 | 1.4 | 4.5 |
| | | | | | | | | | | 97 | 14.0 | 46 | 1.4 | 4.5 |
| | | | | | | | | | | 98 | 14.0 | 46 | 1.5 | 5.0 |

During all recordings an observer remained on Northstar to take notes on the drilling activity. Periods of drilling lasting several minutes were interspersed with periods when the bit was retracted and pipe was added to the total length; these two activities were expected to generate different sounds. The observer also gathered information on the rate of penetration, the length of pipe deployed, and whether other sound-generating activities were taking place. After all three sensors had been set up at the recording station, the observer on the island was contacted by radio to check on the status of the drilling activity. Recording commenced after all sound-generating devices (Hägglunds engine and heater) had been turned off. An average of 5.5 minutes of recordings were obtained at each station, for a total of 1 hr 35 min.

Relevant weather information (particularly wind speed and direction) was obtained from the Northstar weather station, maintained by the Minerals Management Service and accessed on the website http://www.resdat.com/mms.

### *6 March 2001*

Recordings were made at two locations east of Northstar Island (Table 3.1, Fig. 3.1) between 16:00 and 17:00 local time. These recordings were to provide comparative data, as drilling had not yet commenced. Recordings could not be made closer than 0.12 mi from the island because of the ice thickness and shallow water. Wind was a gentle breeze (9-11 mph) from the NE. The temperature was -9°F (-23°C) at 16:00.

### *8 March 2001*

Recordings were made at six stations directly east of Northstar Island (Table 3.1, Fig. 3.1) between 11:00 and 16:00 local time. Wind was 17 mph from the ENE at 11:00, and 18 mph from the ENE at 16:00. The temperature was -22° F (about -30°C) at 11:00 and -18°F at 15:00.

### *9 March 2001*

Recordings were made at eight stations between 08:45 and 15:45 local time. Recording stations were laid out in a northerly direction until we encountered a 2-4 m high pressure ridge about 3.5 km (2.2 mi) from the island (Fig. 3.1). In this area, pressure between the more mobile multi-year pack and the less mobile fast ice had created a belt of ice rubble and broken-up ice chunks up to 2 m (6.6 ft) high that was impassable by both vehicles (Fig. 3.2). This belt extended WNW and ESE as far as we could see; a decision was therefore made to continue west-northwestward along the southern edge of the belt of rubble. At about 7 km (4.3 mi) from Northstar the belt curved to the south so it was not possible to get any farther from the island. The wind was 14 mph from the ENE at 08:00 and 21 mph from the ENE at 16:00. The temperature increased from -21ºF at 08:00 to -18ºF at 16:00.

## *Signal Analysis*

### *Hydrophone Data*

The recorded, digitized hydrophone signals were transferred directly to a computer hard drive as time series. They were then equalized and calibrated in units of sound pressure with flat frequency response over the data bandwidth (4-10,000 Hz). Analysis was done using MATLAB (The MathWorks, 3 Apple Hill Drive, Natick, MA 01760-2098) routines and custom programs. For each recording, a sound pressure time series (waveform) was generated; an example is shown in Figure 3.3. In general, these plots showed varying levels as sound sources started and stopped. The sound was played via a speaker to help the analyst match notes from the field with the recorded sounds. The sound waveform was used to select representative samples for further analysis. If the overall sound pressure levels (SPLs) varied little with time, at least two 8.5-s samples were selected from the recording and analyzed. If the sound waveform showed fluctuations in the SPL (as in Fig. 3.3), then samples were taken from both the stronger and the weaker sections of the recording.

Frequency composition was determined by calculating the sound pressure spectral density by Fourier analysis. The averaging time for such measurements was 8.5 s. The transform length was one second. With windowing, the spectral resolution was 1.7 Hz with 1-Hz bin separation. Transforms were overlapped by 50%. Sixteen power spectral densities were averaged for each 8.5-s measurement.

FIGURE 3.2. Pressure ridge located 3.5 km (2.2 mi) north of Northstar (Seal) Island, 9 March 2001.

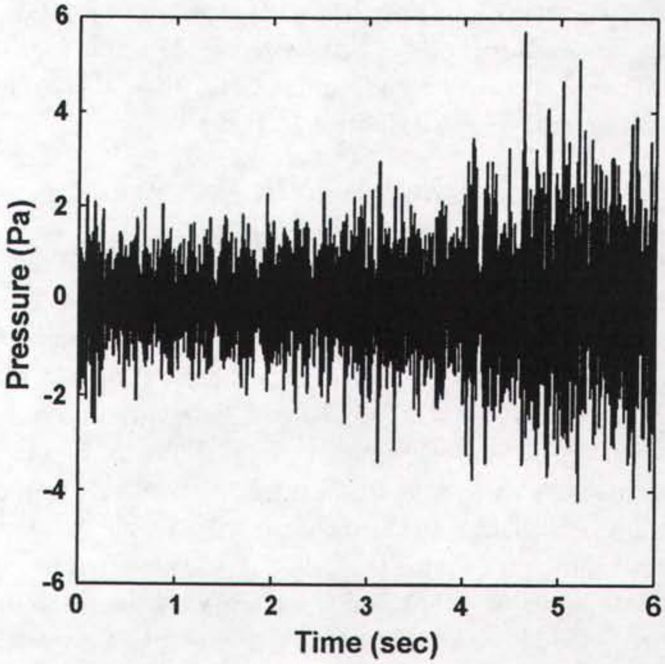


FIGURE 3.3. Typical sound pressure time series, showing received sound pressure vs. time. This 6-s recording was obtained on 8 March 2001, 990 m (0.6 mi) from the drill rig (station 83) while drilling was taking place. Water depth was 38 ft (11.5 m).

To show how received levels varied with distance from the activity, the highest observed "root-mean-square" (rms) broadband levels were plotted against range from the dominant source. These plots are based on the series of sound recordings at varying distances along a given transect. Interpretation of these data is complicated by variability of the sources within and between recordings, and by the possible presence of sound from more than one sound source. Nevertheless, the "received level vs. range" plots give an estimate of the highest levels received at several distances during the activity studied. In addition, where appropriate, a spectral analysis of the sound is included. A tone was automatically recognized when the sound pressure spectral density level (SPSDL) for a given frequency was greater than for both adjacent frequencies, and at least 5 dB above the nearest minimum SPSDL at a lower frequency.

### *Microphone Data*

Microphone data were transcribed to disk files and analyzed in the same way as hydrophone data. Broadband microphone data were A-weighted (and expressed in dBA referred to 20 μPa) to allow comparisons with common airborne sounds described in the literature. During A-weighting, a frequency-dependent weighting factor is applied to the sound in accordance with the sensitivity of the human ear; therefore frequencies below 1 kHz and above 6 kHz are de-emphasized (Kinsler et al. 1982; Kryter 1985). The bandwidth for microphone data in this report is 10-10,000 Hz; in the A-weighted data the energy at frequencies above 200 Hz dominates because the weighting de-emphasizes lower frequencies. One-third octave band data were not A-weighted and are expressed in dB referred to 20 μPa.

### *Geophone Data*

Data from the three geophone channels were transcribed to disk files and analyzed in the same manner as the hydrophone and microphone channels. The geophone sensors are low-frequency devices and the upper frequency limit is 500 Hz. Results from the three channels are presented separately. The 3-axis geophone senses particle velocity levels in three orthogonal directions. The level for each component is expressed in dB re 1 pm/s (picometer per second).

### *Propagation Loss Modeling*

When appropriate, a propagation model was fitted to the broadband data in order to develop a procedure for predicting the propagation loss underwater, in air, and through the ice. The model used was based on logarithmic spreading loss, appropriate for sound loss vs. distance:

$$\text{Received Level (RL, dB re 1 }\mu\text{Pa}^{(3)}) = A - B \times \log(R), \text{ where } R \text{ is range in m.} \qquad \text{Eq. (1)}$$

In this equation, the constant term ($A$) is the extrapolated received level at distance 1 m (dB re 1 μPa$^{(2)}$) based on far-field measurements. The estimated "$A$" value is useful mainly as a basis for comparison with other sound sources operating in the same region. Expected values for the spreading loss term ($B$) are -20 dB/tenfold change in distance for spherical spreading (such as occurs in the open ocean for isovelocity sound profiles far from surface, bottom, or other boundaries) and -10 dB/tenfold change in distance for cylindrical spreading. Spreading loss coefficients ranging from -10 to -40 dB per tenfold change in distance may be expected for situations with deep or shallow source depths in deep or shallow water (Richardson et al. 1995).

## RESULTS

Results are presented below by the type of sensor (hydrophone, microphone and geophone), for all three days of recording.

### *Hydrophone Data*

Received broadband (10-10,000 Hz) levels of underwater sound are shown in Figure 3.4A for eastern recording stations (6 and 8 March 2001) and in Figure 3.4B for northern recording stations (9 March 2001). The highest broadband SPLs were recorded about 990 m east of Northstar (station 83) on 8 March 2001 and reached nearly 124 dB re 1 μPa. "Background" values including island noise but no drilling were recorded on 6 March about 460 m from the drill rig. These background values (filled green squares in Fig. 3.4A) were comparable to values obtained at the same location on 8 March while the bit was retracted, i.e. spinning but not actually drilling (filled red triangles in Fig. 3.4A). On both 8 and 9 March the broadband sound levels leveled off 2-6 km from the island, at SPLs close to 80 dB re 1 μPa. This leveling-off suggests that the data at these greater distances were dominated by background noise.

The sound propagation model represented by equation (1) was fitted by least-squares to mean broadband (10-10,000 Hz) levels of underwater sound recorded during drilling on 9 March. The resulting

---

(3) The units dB re 1 μPa are used for underwater sound pressures; units for in-air sound pressure levels are dB re 20 μPa, applicable to all microphone data; units for ice vibration measurements are dB re 1 pm/s, applicable to all geophone data.

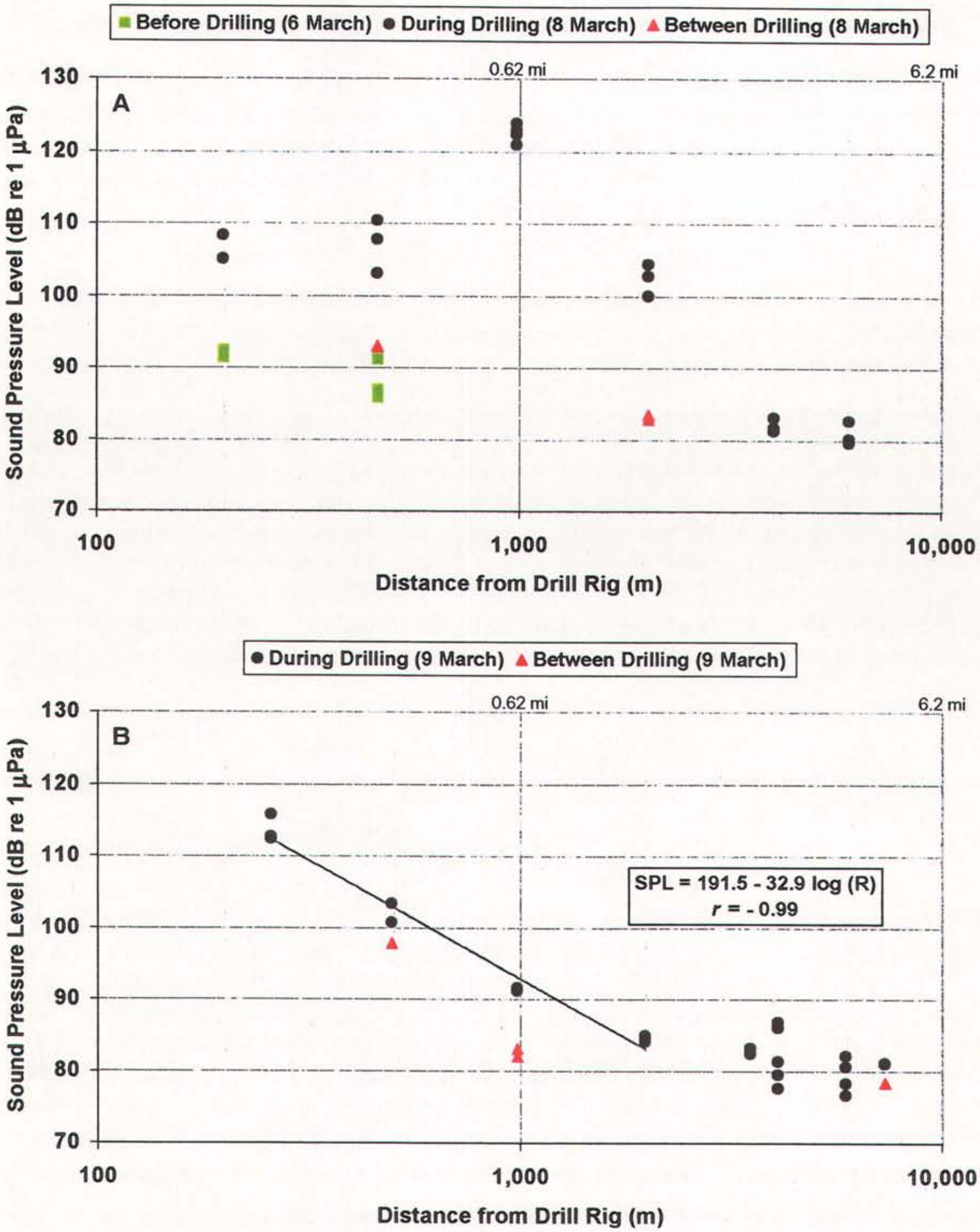


FIGURE 3.4. Broadband (10-10,000 Hz) levels of underwater sound as a function of drilling activity and distance from the drill rig on Northstar (Seal) Island, March 2001. ***(A)*** Eastern recordings. Recordings on 6 March were made before drilling began. On 8 March samples taken during drilling (black circles) are distinguished from those when the bit was withdrawn but turning and reaming the well (red triangles). ***(B)*** Northern recordings. Also shown is the logarithmic spreading loss model (R in meters). See text (p. 3-9) for rationale for excluding some data. 10 km = 6.2 mi.

regression line and equation are shown in Figure 3.4B. Only data from the first four stations were used in the model, as broadband levels from further stations (3.5-7.3 km) had leveled off, indicative of reaching background values. The spreading loss term obtained for the northern recordings was -32.9 dB/tenfold change in distance. During the recording at the 1000-m station on 9 March there was snowmobile traffic east of the island about 1 km from the recording station. The snowmobiles were faintly audible on the recordings and contributed to the overall broadband SPLs at that station. Broadband levels from the island may actually have reached ambient levels closer to Northstar than shown in Figure 3.4B.

On 8 March (Fig. 3.4A), the sound source was too variable to justify fitting the propagation model to the data. It seems that, during recordings at the 1-km station, a new (and unidentified) sound source became evident, or the drilling sounds became stronger at the source, or physical characteristics of the bottom geology and bathymetry caused the drilling sounds to transmit particularly well to that location. Of these three possible explanations, the first is less likely than the other explanations. While in the field, the drilling sounds were particularly easy to hear at the 1-km station. The gain setting on the postamplifier had to be turned down relative to the setting required at closer distances; that is counter-intuitive as gain settings are normally turned up with increasing distance from the sound source. If the higher levels recorded at the 1-km station were due to higher source levels, then it is not known if and for how long these higher source levels were maintained. However, it is clear from the data that the received broadband levels had flattened out by the 4-km station.

Figure 3.5 shows SPLs for six selected one-third octave bands during drilling on 8 and 9 March. Sound pressure levels were generally higher for most frequencies on 8 March than on 9 March. However, at and beyond 4 km from Northstar the levels were very similar during the two days, and probably represent background values. On 8 March, SPLs for all frequencies above 25 Hz rose at the 1-km recording station by up to 19 dB.

Recordings were made from the same two locations east of the island both before drilling commenced on 6 March and during drilling on 8 March 2001. Figure 3.6 compares the received one-third octave band levels for these two activities as recorded 200 m (Fig. 3.6A) and 460 m (Fig. 3.6B) from the drill rig. Drilling activity had the strongest effect on overall sound levels at frequencies up to 2 kHz and had no effect beyond frequencies of about 3 kHz. The higher levels at frequencies 30-60 Hz as compared with other nearby frequencies during non-drilling as well as drilling times suggest that those frequencies reflect power generation on the island. This is also visible in a comparison of narrowband spectra (10-10,000 Hz) from the same stations, as recorded before drilling (Fig. 3.7A, 6 March) and during drilling (Fig. 3.7B, 8 March). Before drilling began (top plot), spectral peaks at 20, 30, 40, and 60 Hz are obvious and can be linked to power generation. Peaks at 45 and 52 Hz are also very apparent and may be due to other industrial activities on the island. During drilling (bottom plot) most of these peaks are still present but they are less well defined because of higher overall broadband levels. Received levels are higher during drilling for all frequencies up to 2-3 kHz, above which the background levels dominated.

Tones detected in the recordings at the two closest stations on 6 and 8 March were compared. Tones at 7, 20, 30 and 60 Hz were prevalent in all recordings, before drilling began and during drilling. None of the tones that were prominent in the recordings during drilling (8 March) were absent in the recordings preceding drilling (6 March), with the possible exception of the 36 Hz tone. This was the most common tone during drilling on 8 and 9 March, present at 3 stations on both days, but completely absent on 6 March. Figure 3.8 shows a narrowband spectrum for one representative 8.5-s sample from each of four different stations during drilling on 9 March. A number of tones are visible below 100 Hz, but there

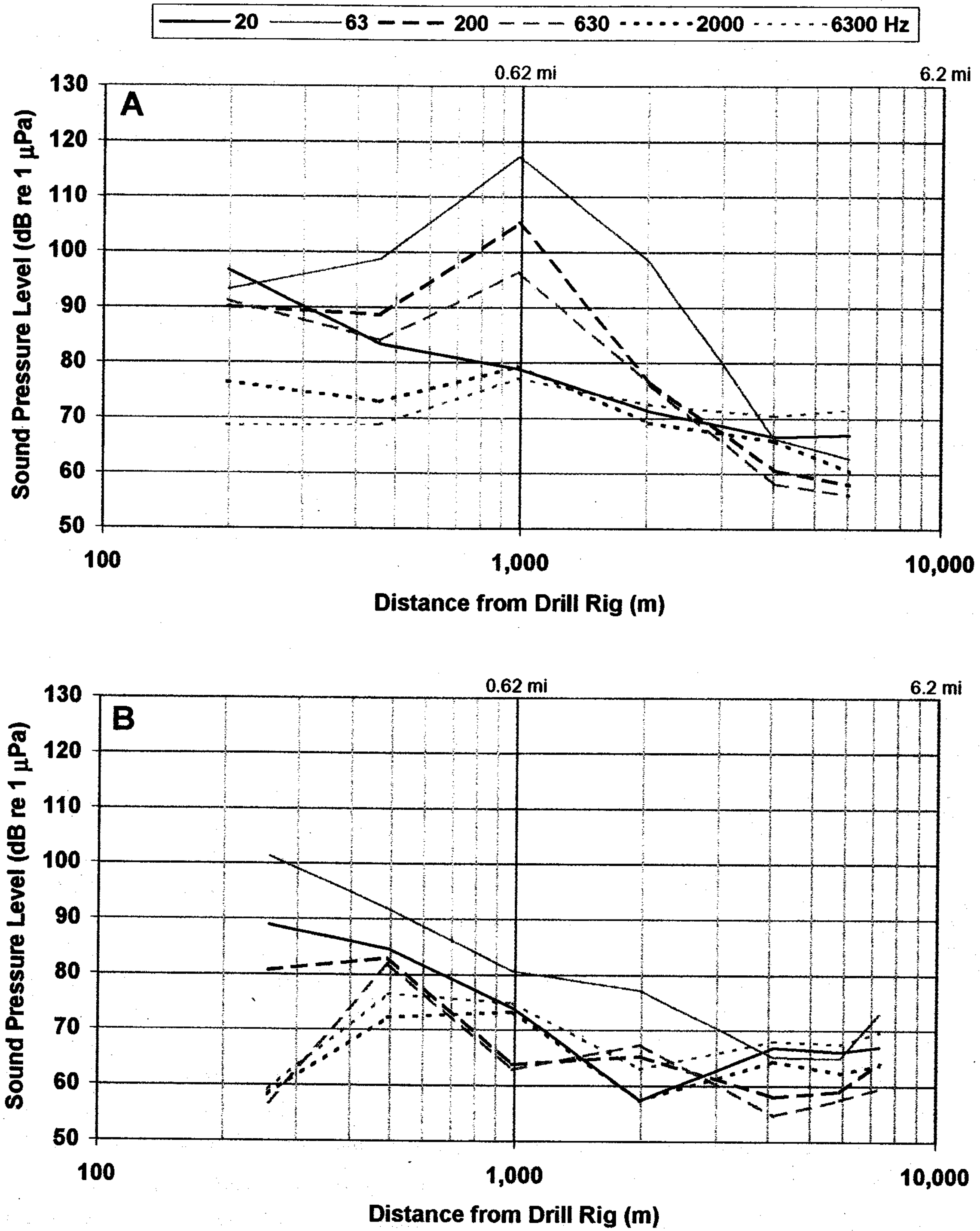


FIGURE 3.5. One-third octave band levels of underwater sound during drilling vs. range for six selected frequencies, March 2001. ***(A)*** Recordings of 8 March (east). ***(B)*** Recordings of 9 March (north). 10 km = 6.2 mi.

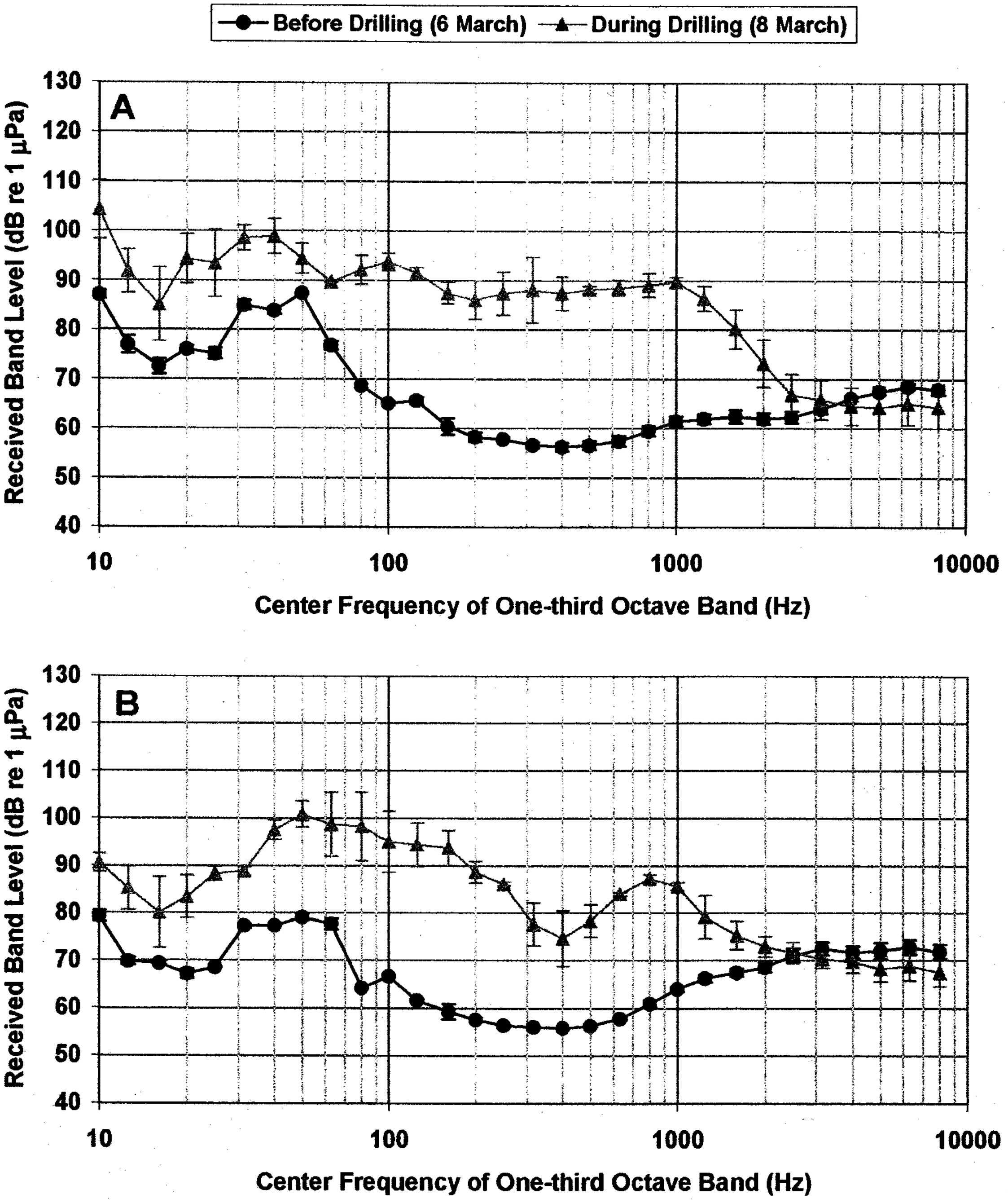


FIGURE 3.6. Received underwater sound pressure levels for one-third octave bands at two easterly recording stations before and during drilling, March 2001. ***(A)*** 200 m from drill rig. ***(B)*** 460 m from drill rig. Symbols and vertical bars show mean values (± 1 s.d.).

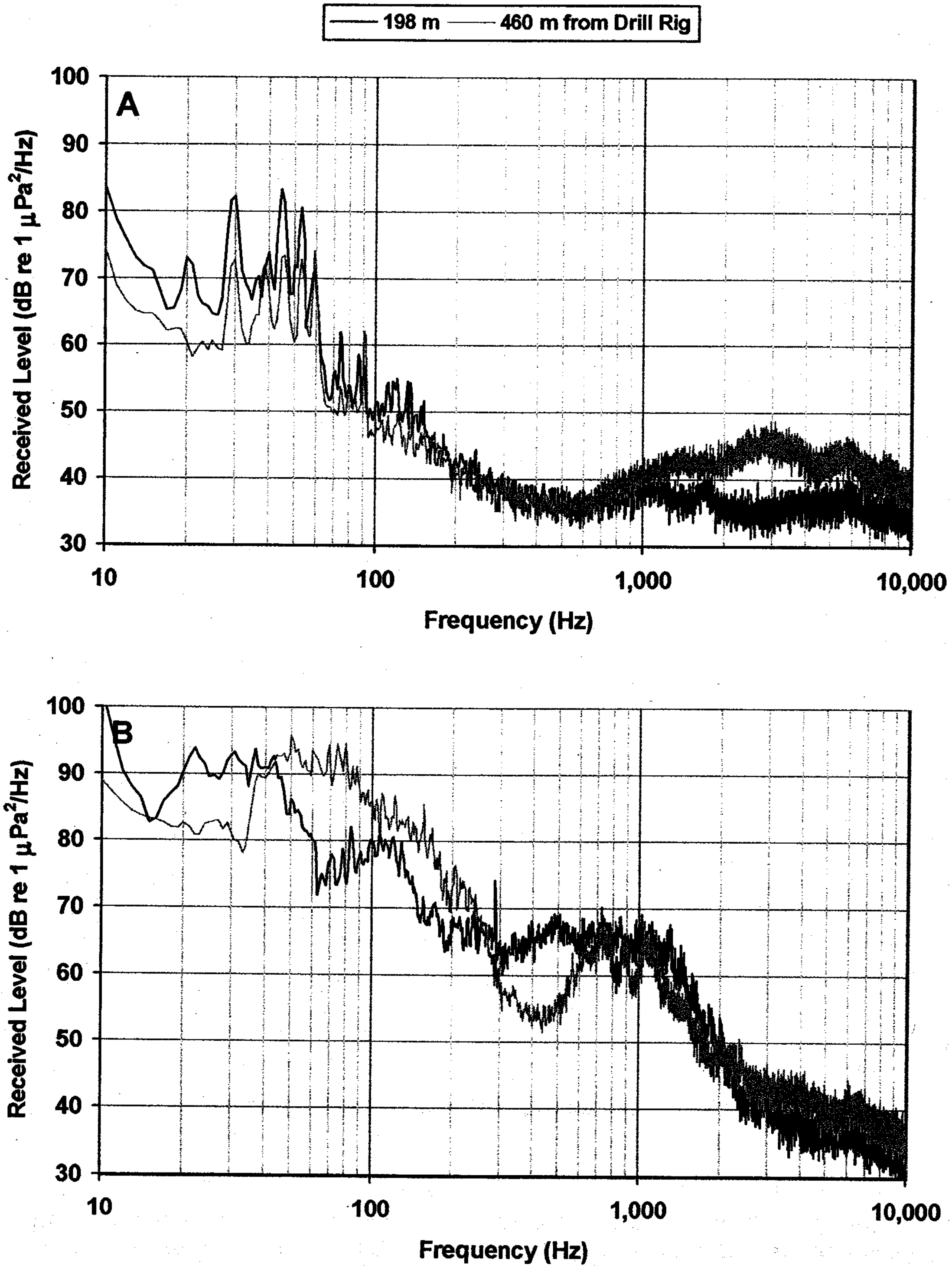


FIGURE 3.7. Narrowband spectra (10-10,000 Hz) of underwater sound recorded at the two stations closest to the drill rig on 6 and 8 March 2001. ***(A)*** 6 March, before drilling began. ***(B)*** 8 March, during drilling. 500 m = 0.31 mi.

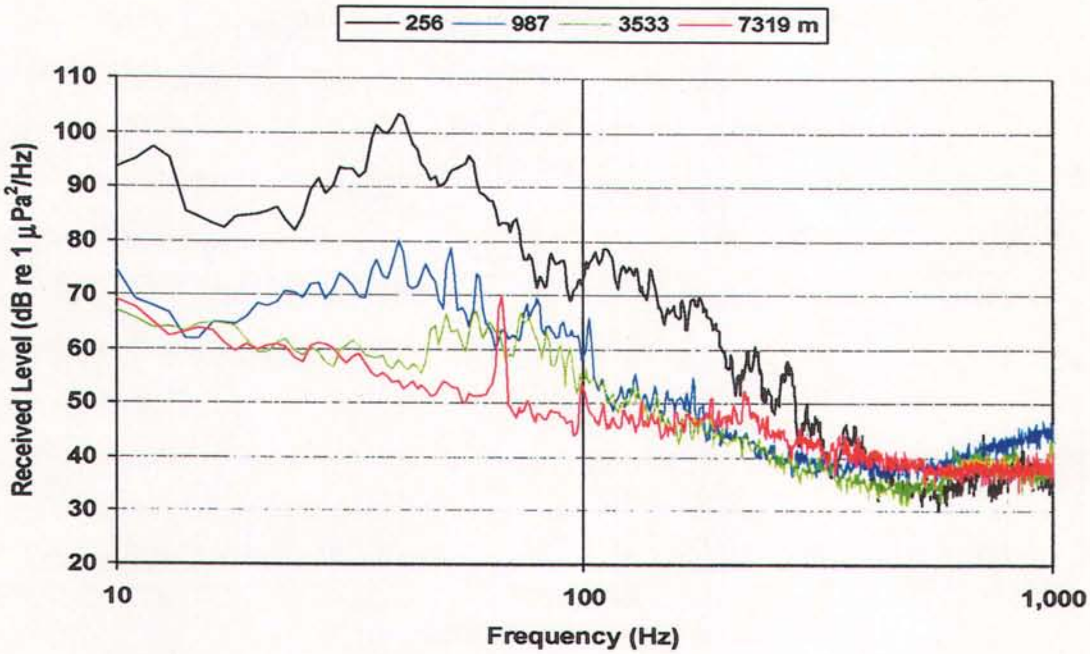


FIGURE 3.8. Narrowband spectra (10-1000 Hz) of underwater sound recorded at four distances from drilling, 9 March 2001. One representative 8.5-s sample was chosen from each station. 1000 m = 0.62 mi.

is little repeatability from one recording distance to the next. On 6 March, in the absence of drilling activity, power generation tones were clearly detected at 460 m from the drill rig (Fig. 3.7A). On 9 March, recordings "between drilling" (with the bit turning but retracted) were obtained at the 1-km, 3.5-km, and 7-km stations (recording locations 93, 95 and 98, respectively). In those recordings, several power generation tones (i.e. 30, 60, 80 Hz) were obvious at 1 and 3.5 km, but completely absent at 7 km.

## *Microphone Data*

Microphone function was unreliable on 8 March, so only data from 6 and 9 March are presented. Received broadband (10-10,000 Hz) A-weighted levels of in-air sound are shown in Figure 3.9 for the recordings east of Northstar on 6 March and those north and northwest of the island on 9 March 2001. Island sounds were audible to the field crew at both stations on 6 March (i.e. up to 460 m). On 9 March they were clearly audible at stations 91 and 92 (up to about 500 m) and faintly so at station 93 (990 m). It is important to point out, however, that the audible sounds were general island sounds, not drilling sounds in particular. In air it was not possible for the field crew to hear when drilling was taking place and when it was not, even close to the island. The wind was from the NE on 6 March and from the ENE on 9 March. On 9 March the wind was strong enough to have a major influence on the recordings, both by the noise it made on the microphone itself and by the sound produced by snow being blown around on the ice. The field crew's notes state that the wind increased over the course of the day and was particularly strong at station 98, furthest from the island; broadband SPLs in air are particularly elevated at that recording location (Fig. 3.9). The variation in SPLs seen at most stations is mainly a function of the wind; the lowest levels at each station are therefore the closest to representing the actual SPLs as would be recorded without wind. The highest broadband A-weighted SPL was recorded at the closest station on the island's northern side (station 91, about 250 m from the drill rig) on 9 March and reached about 55 dBA re 20 μPa. This is comparable to the sound level produced by light traffic at 30 m (100 feet), (Kinsler et al. 1982).

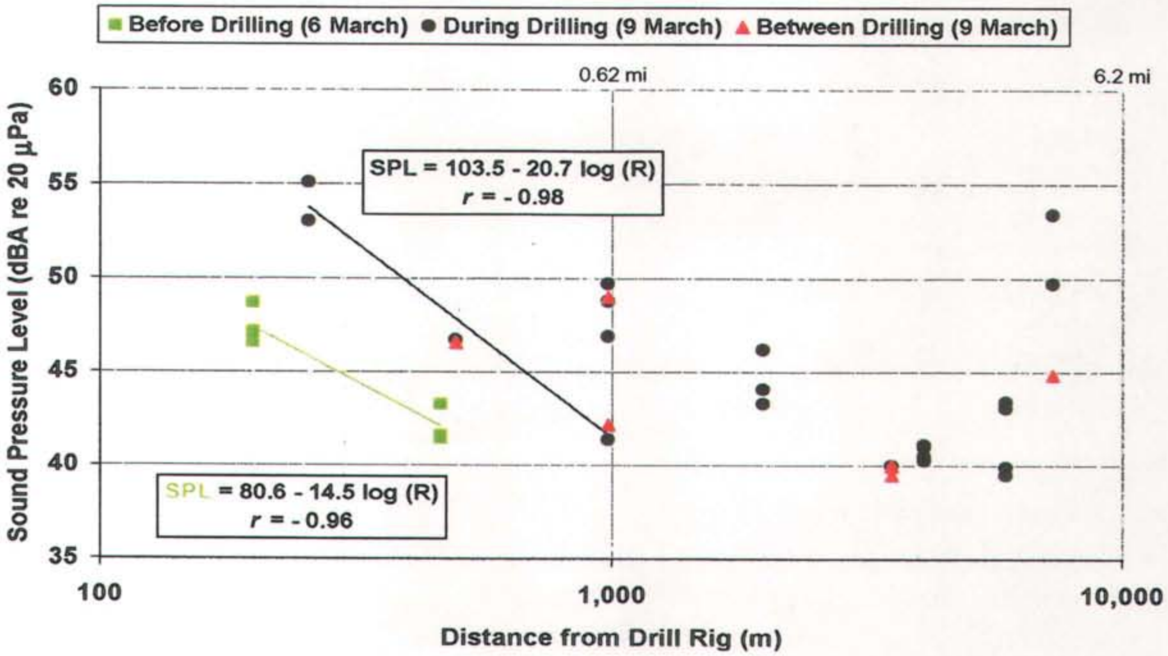


FIGURE 3.9. Broadband (10-10,000 Hz) A-weighted levels of airborne sound as a function of drilling activity and distance from the drill rig on Northstar (Seal) Island, March 2001. Recordings on 6 March were made before drilling began. On 9 March, samples taken during drilling (black circles) are distinguished from those when the bit was withdrawn but turning and reaming the well (red triangles). Also shown are the logarithmic spreading loss models (R in meters). See text (p. 3-16) for rationale for excluding some data. 10 km = 6.2 mi.

The sound propagation model represented by equation (1) was fitted by least-squares to mean A-weighted broadband (10-10,000 Hz) levels of in-air sound from 6 and 9 March, and the resulting regression lines and equations are shown in Figure 3.9. On 9 March, the lowest-level value recorded at the 990-m (0.61 mi) station during drilling (i.e. the least influenced by the wind) was used in the model, together with all data from the two closer stations. The fitted spreading-loss terms were similar for the non-drilling (eastern) and the drilling (northern) recordings and were reasonable for this situation, -14.5 and -20.7 dB/tenfold change in distance, respectively.

Figure 3.10 shows narrowband spectra from stations 61 and 91, i.e. the closest stations to the east of the island before drilling (6 March, 200 m) and to the north of the island during drilling (9 March, 260 m). The levels were higher on 9 March for all frequencies up to 2000 Hz; how much of this difference is attributable to the stronger wind on 9 March is not known.

Figure 3.11 shows SPLs vs. distance for six selected one-third octave bands during drilling on 9 March. Sound levels beyond 1000 m from the drill rig chiefly reflect wind noise. Recordings from the closer stations show that sound levels in the one-third octave bands centered at 630, 2000 and 6300 Hz have already flattened out by the second station (station 92 located 490 m from the drill rig). As seen in the hydrophone data, SPLs for low frequencies rise at the 1-km station.

A tone analysis revealed that a 1600 Hz tone was present in 19 8.5-s samples from 4 different stations, and was the most common tone. Seven other tones (91, 172, 200, 291, 395, 3898 and 9158 Hz) appeared at 3 stations each. Interestingly, the 60 Hz power line frequency did not appear (as a tone) in the airborne sound recorded at any station.

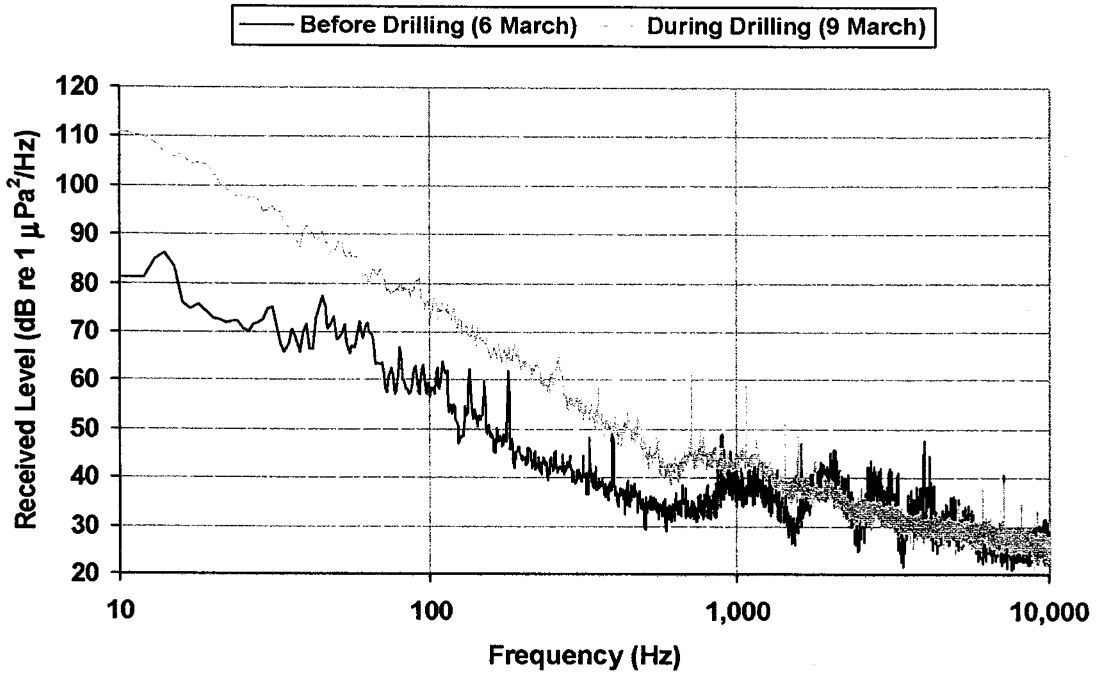


FIGURE 3.10. Narrowband spectra (10-10,000 Hz) of airborne sound from the closest recording stations east and north of Northstar (Seal) Island: station 61 at range 200 m (650 ft) on 6 March, before drilling began; station 91 at 256 m (840 ft) on 9 March, during drilling. A representative 8.5-s sample was chosen from each station.

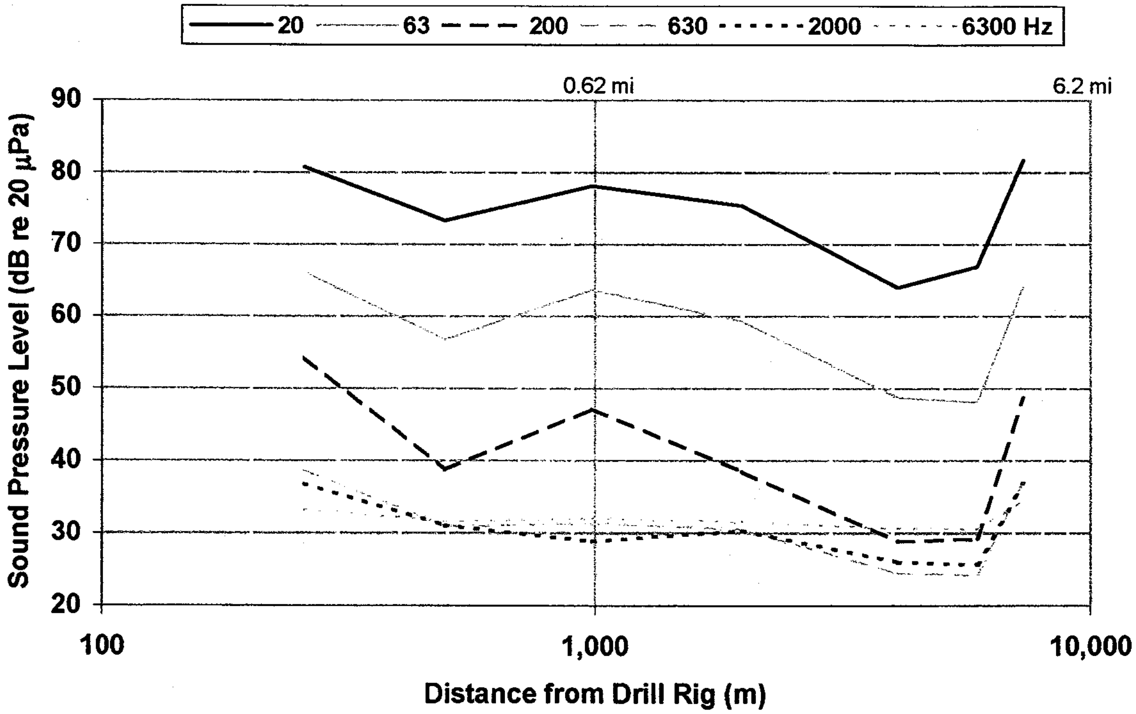


FIGURE 3.11. One-third octave band levels of airborne sound vs. range for six selected frequencies, 9 March 2001. 10,000 m = 10 km = 6.2 mi.

## *Geophone Data*

Mean broadband (10-500 Hz) particle velocity (PV) levels, as recorded by the three geophone channels, are shown in Figure 3.12 as a function of distance from the drill rig on 9 March. On 6 and 8 March the geophone signals were not sufficiently amplified and the recordings therefore mainly reflected instrument (recorder) noise. A mean value is shown for each channel at each station. For each channel, there was a fair amount of variation within each recording; standard deviation bars have been left out for clarity. The highest mean levels (115 dB re 1pm/s) were recorded about 1 km from the drill rig (station 93), but not by geophone channel H1 (whose axis pointed directly toward the island). Geophone broadband levels leveled out by the 2-km station; beyond that distance the variation in the data can again be attributed to wind noise. Sounds of snow blowing on the ice could be heard by listening to the geophone signal in the field through headphones.

The sound propagation model represented by equation (1) was fitted by least-squares to mean broadband (10-500 Hz) particle velocity levels for the geophone axis H1, which pointed toward Northstar. The resulting regression line and equation are shown in Figure 3.12. Measurements from the first four stations, or until values leveled out, were used in the model. The spreading loss term obtained was -14.9 dB/tenfold change in distance, comparable to the spreading loss rates found for the hydrophone and microphone data.

Figure 3.13 shows particle velocity levels for six selected one-third octave bands as a function of distance from the drill rig for all three geophone channels on 9 March. The most striking features of these plots are the higher values at the 1-km and 7.2-km stations than at adjacent stations. During the recording at 1 km, three snowmobiles were seen in the distance, approximately 1 km away, east of Northstar Island.

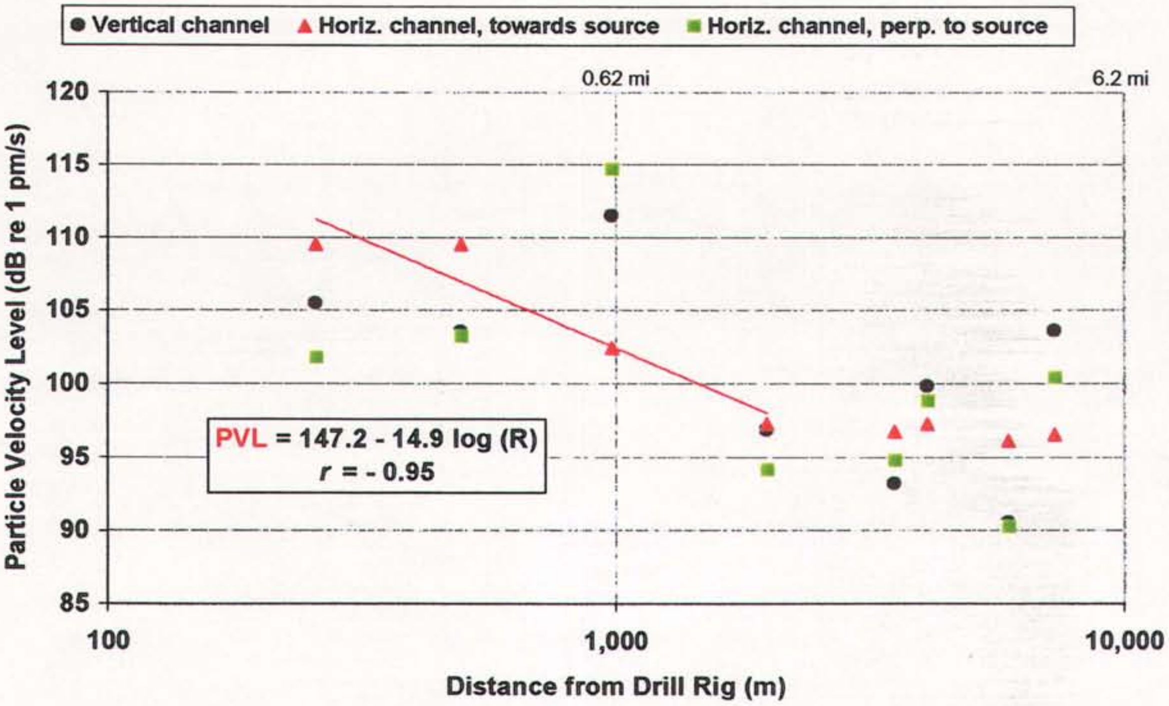


FIGURE 3.12. Mean broadband (10-500 Hz) particle velocity levels during drilling as a function of distance from the drill rig, for all three geophone channels, 9 March 2001. 10,000 m = 10 km = 6.2 mi.

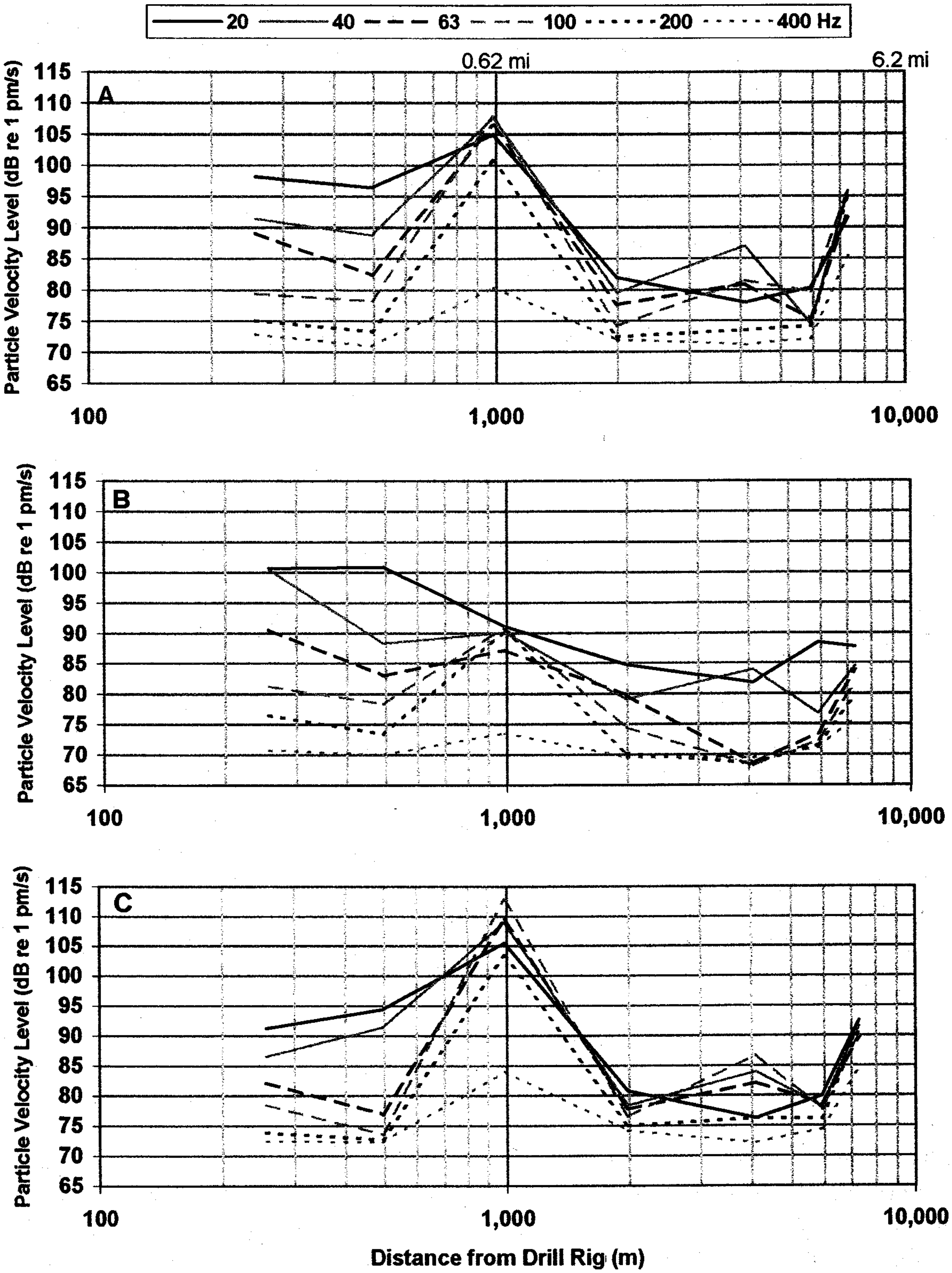


FIGURE 3.13. One-third octave band particle velocity (PV) levels vs. range for six selected frequencies, 9 March 2001. *(A)* Vertical PV. *(B)* H1 horizontal PV. *(C)* H2 horizontal PV. 10,000 m = 10 km = 6.2 mi.

They were not heard via the microphone and were heard only faintly via the hydrophone, but it is possible that the geophones picked up the vibrations they created on the ice. This would also explain why the H1 axis picked up the least of this noise – the snowmobiles were not on a line between the geophone and the island; they were off to the side. The elevated levels at the farthest recording location (7.2 km) were caused by the strong wind at that station.

### *Summary*

On 6, 8 and 9 March 2001 Greeneridge Sciences made sound recordings at 14 locations up to 6.1 km (3.8 mi) east and 7.3 km (4.6 mi) northwest of Northstar Island. Recordings were made in the water, air and ice, using a hydrophone, microphone, and geophone, respectively. Sound levels were documented during drilling activity (8 and 9 March), as well as before drilling commenced (6 March).

Broadband (10-10,000 Hz) underwater SPLs recorded while drilling was underway reached background levels beyond 2 km (1.2 mi) during measurements to the north of Northstar, and by 4 km (2.5 mi) during measurements to the east of Northstar. Background levels were close to 80 dB re 1 μPa. The highest broadband level recorded was nearly 124 dB re 1 μPa at 990 m (0.61 mi) east of the drill rig. The spreading loss term obtained during drilling was -32.9 dB/tenfold change in distance for northern recordings. Drilling activity had effects on the recorded sound at frequencies up to about 2 kHz. In the absence of drilling, tones associated with power generation were prominent in the underwater sound out to a distance of 3.5 km (2.2 mi), but had disappeared by 7 km (4.3 mi). During drilling, elevated levels across a wide range of frequencies tended to obscure the tones associated with power generation.

Broadband (10-10,000 Hz) A-weighted in-air SPLs during drilling reached background levels (about 40 dBA re 20 μPa) beyond about 1 km (0.6 mi). Interpretation of the microphone data was hampered by unavoidable wind noise in the recordings. The spreading loss terms obtained with and without drilling taking place were similar, -20.7 and -14.5 dB/tenfold change in distance, respectively.

Broadband (10-500 Hz) particle velocity levels, as recorded by a three-axis geophone, reached background levels (95 dB re 1 pm/s) about 2 km (1.2 mi) north of Northstar. The highest mean level (115 dB re 1 pm/s) was recorded 1 km north of the island and was most likely due to snowmobile activity about 1 km away from the recording station. The spreading loss term for the H1 geophone axis, which pointed directly toward Northstar, was -14.9 dB/tenfold change in distance. Wind also had an effect on the geophone recordings because the sensor detected the sound of snow blowing around on the ice.

## DISCUSSION

### *Hydrophone Data*

On both 8 and 9 March, broadband SPLs during drilling seemed to level off 2-6 km from Northstar, at values close to 80 dB re 1 μPa. Measurements at greater distances from the sound source would be needed to confirm this, however, ice conditions limited safe transit beyond this distance. Broadband background levels around 80 dB re 1 μPa are reasonable and can be expected for this season and environment (see Greene and McLennan 2000). Greene and Buck (1964) present spectrum-level measurements of under-ice ambient noise (25-1000 Hz) from three separate expeditions in the Arctic, in both shallow deep water. They also compare their under-ice measurements to standard estimates of open-water ambient noise vs. frequency and sea state (Knudsen et al. 1948; see also Richardson et al. 1995). Values obtained for under-ice ambient sounds (vs. frequency) ranged from about 6 dB above to 25 dB below the spectrum levels expected at sea state 0. In comparison, spectra from the recordings made at the 7-km station on 9 March (not shown) were up to 12 dB lower than the Knudsen et al. curve for sea state 0, and therefore fall within the range of other under-ice ambient noise measurements.

Underwater drilling noise from icebound islands generally has a low source level with an average audible range of about 2 km, extending to 10 km in unusually quiet conditions (Richardson et al. 1995). Richardson et al. (1990) reported the noise from a rotary-table drill rig on an ice-pad to be barely detectable at 2 km. Finally, Malme and Mlawski (1979) measured the noises associated with drilling rigs operating on two icebound gravel islands (one natural and one man-made) near Prudhoe Bay during the month of March. With high ambient noise, broadband levels reached ambient values by about 1.5 km from the islands. These data are all in agreement with the findings of the present study.

Except for the closest station to the island, broadband levels tended to be higher on 8 March during measurements to the east than on 9 March during measurements to the north. There are several factors that could contribute to this difference: (1) The composition of the layer being drilled through, which was gravel on 8 March and clay on 9 March. (2) The depth of drilling, which is related to the length of pipe out (drilling was vertical for the first 500 feet or so, but then the angle of drilling was made shallower until it reached about 41 degrees from vertical, toward the NE, by 1500 feet of depth). During recording on 8 March there was 835-1171 feet of pipe out, versus 2229-2813 feet on 9 March; these figures correspond to depths of about 835-1130 feet and 1930-2370 feet, respectively. The drilling depth on 9 March was therefore twice that of 8 March. (3) The rate of penetration, which varied between <20 feet/hour to nearly 500 feet/hour during our recordings. This rate is a function of the layers being drilled through and the phase of the drilling procedure (i.e. slower rate at the beginning and end of a drilling session). (4) The bathymetry, which may be different to the east and north of the island and which may vary to some extent from one year to the next (because of ice gouging). (5) The closer proximity of the eastern measurements to other potential sources of industrial noise, i.e. West Dock and the Point McIntyre #2 drilling site.

Figure 3.5A, showing SPLs for six selected frequencies during drilling on 8 March, shows that measured SPLs increased at the 1-km station (relative to values at closer stations) for all but a single one-third octave band. We do not know if this increase was due to another activity taking place, of which the field crew was unaware, or if it represents simply increased levels of drilling sounds. The latter could be the result of

1. Increased SPLs at the source. The type (i.e. hardness) of the geological formation being drilled through will likely influence the SPLs. We do not have information on the formations, but if we look at the penetration rate of the bit, it was about the same for the 200-m, 460-m and 1000-m stations (~200 feet / hour), then dropped during the recording at the 2000-m station (~130 feet / hour) and dropped again during the recording at the 4000-m station (~55 feet / hour; no penetration rate information was available for the 6000-m station). These factors may have an effect on emitted sounds, but we are unable to determine whether there was any direct influence in this case.
2. Sound propagation differences at different locations around Northstar could be another way to explain higher SPLs at 1 km as compared to stations closer to the source. During 2 of 3 days with open water measurements in Aug. and Sept. 2000 (north of Northstar), the highest SPLs recorded by a hydrophone were about 600 m from the source and not at the closest (300 m) station (Blackwell and Greene 2001). They found a similar effect during pile-driving measurements in June

and July 2000, and hypothesized that the structure of the underwater gravel moat surrounding the island may differentially affect the propagation of sound at different frequencies.

The comparisons of sounds recorded at the same two stations on different days, before the onset of drilling and during drilling (Fig. 3.6, 3.7), suggest that drilling activity introduces broadband sound at frequencies up to 2-3 kHz. Drilling activity did not, however, produce strong tones at frequencies below 100 Hz. In fact, low-frequency tones evident before the onset of drilling (Fig. 3.7A) tended to be less obvious when drilling activity elevated the levels at all frequencies (Fig. 3.7B). These low-frequency tones were also detected in recordings made during the summer of 2000 north of Northstar Island (see Blackwell and Greene 2001). During summer 2001, low-frequency tones were only heard at close distances (up to 2 n.mi.) on the quieter of the two days of recording (10 Aug.; see Chapter 7).

The narrowband spectra shown in Figure 3.8 also illustrate that, during drilling, tonal structure at frequencies below 100 Hz was not well defined. Tones are apparent but were not very consistent from one distance to another. No single tonal frequency was found at more than 3 stations. This was also true if all the analyzed 8.5-s samples were examined, not only the ones presented in Figure 3.8. This suggests that the sounds produced during drilling vary enough as a function of the substrate and drilling speed that no single dominant tone is detectable over several hours of drilling.

## *Microphone Data*

Beyond about 1 km from Northstar, acoustic personnel in the field could not hear in-air noise from the island. Even at a very close range the sounds heard were not specifically identifiable as drilling sounds, but rather island construction noises in general. The A-weighted broadband levels presented in Figure 3.9 are somewhat difficult to interpret because of the undetermined importance of wind noise in the measurements. A-weighting the data tends to de-emphasize the wind noise on the microphone itself, but the sounds made by the snow as it blows over the ice are clearly audible on many of the recordings. This sound tended to increase in importance as the day went on, the wind picked up, and measurements were made farther and farther from Northstar. We consider the measurements on 6 March to be largely unaffected by wind, and all measurements at or beyond 1000 m on 9 March to represent mainly wind noise. The wind is likely responsible for the elevated values at the 7-km station on 9 March (station 98) and for the fact that non-drilling values at that station are higher than drilling values closer to the island, at 4 km (station 96). Because of the difference in wind speed on 6 and 9 March (in addition to the different recording locations), the data from those two days (Fig. 3.9) can only be compared on a relative scale. Considering the short distances over which a logarithmic spreading loss model was fitted to the data, the spreading loss terms for 6 and 9 March are reasonably similar, -14.5 and -20.7 dB/tenfold change in distance.

The narrowband spectra shown in Figure 3.10 are difficult to interpret because of wind noise, which is broadband and would affect a wide range of frequencies. If anything, drilling activity did not affect frequencies in air above 2 kHz. The increase in SPLs at the 1000-m station on 9 March, visible in the one-third octave band levels shown in Figure 3.11, could be due to snowmobile activity near Northstar.

## *Geophone Data*

Broadband levels of particle velocity from geophone axis H1, pointing toward the presumed noise source, decreased with distance from the island and leveled out about 2 km north of Northstar, although there was variation in the data both within and between channels. The spreading loss term obtained from the best-fit relationship (-14.9 dB/tenfold change in distance) is consistent with the spreading losses found for the hydrophone and the microphone. The recording conditions on 9 March were not ideal, as snow blowing on the ice created noise on the geophone recordings. This factor is probably responsible for much of the variation seen in the data (Fig. 3.12).

Greene and Buck (1964) reported spectrum levels of vertical velocity (25–1000 Hz band) as received by a seismometer (geophone) in thin (15 in.) ice in the Beaufort Sea. We compared their results to the values recorded by our vertical channel at 2 km from Northstar. At that distance, geophone levels seemed to have reached background values (Fig. 3.12). Mean values at 25 Hz were equal during the two studies, at about 78 dB re 1 $(pm/s)^2/Hz$. However, mean values measured by Greene and Buck (1964) were increasingly higher than those from the present study at increasing frequencies: by about 12 dB at 100 Hz, and by about 20 dB at 500 Hz.

The particle velocity levels for six selected one-third octave bands, shown in Figure 3.13, indicate that snowmobile activity affected all frequencies on 9 March, but least so the highest band (400 Hz). Snowmobile activity was faintly detected on the hydrophone, but the vibrations in the ice were transmitted more efficiently than the corresponding underwater sounds. The perception of such a source by a seal could therefore be quite different depending on whether the animal is hauled out or in the water.

## SUMMARY

The objective of the winter-spring acoustics measurements in early 2001 was to measure and document the levels, characteristics and range-dependence of sounds and vibrations produced by Northstar-related industrial activities occurring during the winter and spring of late 2000 and early 2001, excluding activities whose sounds and vibrations were adequately characterized in 2000. On 6, 8 and 9 March 2001, Greeneridge Sciences made sound recordings at 14 locations up to 7.3 km (4.6 mi) east and northwest of Northstar Island to document sound levels during drilling. Recordings were made in the water, air and ice, using a hydrophone, microphone and geophone, respectively.

Broadband (10-10,000 Hz) underwater SPLs (sound pressure levels) recorded while drilling was underway reached background levels (close to 80 dB re 1 µPa) at 2-4 km (1.2-2.5 mi) from the drill rig. The highest broadband value recorded was nearly 124 dB re 1 µPa at 990 m (0.61 mi) from the drill rig, and the spreading loss term obtained (for northern recordings) was -32.9 dB/tenfold change in distance. In the absence of drilling, tones associated with power generation were prominent in the underwater sound out to a distance of 3.5 km (2.2 mi), but had disappeared by 7 km (4.3 mi). During drilling, elevated levels across a wide range of frequencies tended to obscure the tones associated with power generation.

Broadband (10-10,000 Hz) A-weighted in-air SPLs during drilling reached background levels (about 40 dBA re 20 µPa) beyond about 1 km (0.6 mi) from the drill rig. Interpretation of the microphone data was hampered by unavoidable wind noise in the recordings. The spreading loss terms obtained with and without drilling taking place were -20.7 and -14.5 dB/tenfold change in distance, respectively.

Broadband (10-500 Hz) particle velocity levels, as recorded by a three-axis geophone, reached background levels (95 dB re 1 pm/s) about 2 km (1.2 mi) north of Northstar. The highest levels (115 dB re 1 pm/s) were recorded 1 km north of the island and were likely due to snowmobile activity about 1 km away from the recording station. The spreading loss term for the H1 geophone axis, which pointed directly toward Northstar, was -14.9 dB/tenfold change in distance during drilling. Wind also had an effect on the geophone recordings because the sensor detected the sound of snow blowing around on the ice.

Depending on the direction in which the recordings were taken from Northstar (east or north) and possibly on such factors as drilling depth and substrate quality (i.e., gravel vs. clay), drilling sounds as recorded by a hydrophone reached background levels at distances less than 4 km (2.5 mi). Drilling sounds did not include any consistently strong tones and were broadband in nature, affecting frequencies up to 2 kHz. The microphone data were influenced by wind noise, but seemed to indicate that island noises in general – including drilling noises – reached background levels in air about 1 km (0.6 mi) north of the island. Drilling noises in the air were not audible by the field crew, and could not be separated from overall island noises. Ice vibrations, as detected by the geophone, reached background levels at distances of about 2 km. The geophone was particularly sensitive to sounds originating on the unthickened "natural" sea ice, such as those produced by snowmobiles.

## ACKNOWLEDGEMENTS

We thank Bruce Dunbar and Darin Otton with Alaska Interstate Construction (AIC) for being our Hägglunds and Blue Bird drivers in the field. Michael Williams, Shelly Schwenn, and Craig Perham from LGL Alaska, and Jonah Leavitt from Barrow, helped with logistics and fieldwork, and Craig created Figure 3.1. For logistical support and problem solving at Northstar we thank Jeff Huey and Lois Eychaner of BP, Randy Greenway of AIC, the medics and security guards on the island, as well as Wilson Cullor and Allison Erickson from BP's Environmental Studies Group. We thank Dr. Bill Burgess from Greeneridge Sciences and Dr. Bill Streever of BP for reviews of the manuscript. Dr. W. John Richardson, LGL Ltd., provided program direction and guidance as well as helpful criticism of this report — we thank him. Finally, we thank Dr. Ray Jakubczak, Dr. Bill Streever and Dave Trudgen of BP for their support.

## LITERATURE CITED

Blackwell, S.B. and C.R. Greene Jr. 2001. Sound measurements, 2000 break-up and open-water seasons. p. 7-1 to 7-55 *In:* W.J. Richardson and M.T. Williams (eds.), Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar oil development, Alaskan Beaufort Sea, 2000. [Draft April 2001.] LGL Rep. TA2429-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 316 p.

Greene, C.R. 1983. Characteristics of underwater noise during construction of Seal Island, Alaska, 1982. p. 118-150 *In:* B.J. Gallaway (ed.), Biological studies and monitoring at Seal Island, Beaufort Sea, Alaska 1982. Rep. from LGL Ecol. Res. Assoc. Inc., Bryan, TX, for Shell Oil Co., Houston, TX. 150 p.

Greene, C.R., and B.M. Buck. 1964. Arctic Ocean ambient noise. **J. Acoust. Soc. Am.** 36(6):1218-1220.

Greene, C.R., Jr., and M.W. McLennan, with R.W. Blaylock. 2000. Sound and vibration measurements during Northstar construction in early 2000. p. 4-1 to 4-31 *In:* W.J. Richardson and M.T. Williams (eds.), Monitoring of ringed seals and sounds during construction of BP's Northstar oil development, Alaskan Beaufort Sea, winter and spring 1999-2000: 90-day report. LGL Rep. TA2426-1. Rep. from LGL Ltd., King City, Ont., and LGL Alaska Res. Assoc. Inc., Anchorage, AK, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 107 p.

Kinsler, L.E., A.R. Frey, J.V. Sanders and A.B. Coppen. 1982. Fundamentals of acoustics, 3rd edition. Wiley, New York, NY. 480 p.

Knudsen, V.O., R.S. Alford and J.W. Emling. 1948. Underwater ambient noise. **J. Mar. Res.** 7(3):410-429.

Kryter, K.D. 1985. The effects of noise on man, 2nd edition. Academic Press, Orlando, FL. 688 p.

LGL and Greeneridge. 2000. Technical plan for marine mammal and acoustic monitoring during construction of BP's Northstar Oil Development in the Alaskan Beaufort Sea, 2000-2001, August 2000 ed. Rep. from LGL Alaska Res. Assoc. Inc. (Anchorage), LGL Ltd. (King City, Ont.), and Greeneridge Sciences Inc. (Santa Barbara, CA), for BP Explor. (Alaska) Inc., Anchorage, AK. 80 p.

Malme, C.I. and R. Mlawski. 1979. Measurements of underwater acoustic noise in the Prudhoe Bay area. BBN Tech. Memo. 513. Rep. from Bolt Beranek & Newman Inc., Cambridge, MA, for Exxon Prod. Res. Co., Houston, TX. 74 p.

Richardson, W.J. and M.T. Williams (eds.). 2001. Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2000. [Draft, April 2001.] Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 316 p.

Richardson, W.J., C.R. Greene, Jr., W.R. Koski, C.I. Malme, G.W. Miller, M.A. Smultea and B. Würsig. 1990. Acoustic effects of oil production activities on bowhead and white whales visible during spring migration near Pt. Barrow, Alaska–1989 phase. OCS Study MMS 90-0017. Rep. from LGL Ltd., King City, Ont., for U.S. Minerals Manage. Serv., Herndon, VA. 284 p. NTIS PB91-105486.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme and D.H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego, CA. 576 p.

Williams, M.T. and C.J. Perham. 2001a. Description of BP's activities, 1999-2000 ice-covered season. p. 2-1 to 2-8 *In:* W.J. Richardson and M.T. Williams (eds., 2001, *q.v*). LGL Rep. TA2432-6.

Williams, M.T. and C.J. Perham. 2001b. Description of BP's activities, break-up and open-water seasons, 2000. p. 6-1 to 6-11 *In:* W.J. Richardson and M.T. Williams (eds., 2001. *q.v.*). LGL Rep. TA2432-7.

# CHAPTER 4:

# RINGED SEAL STRUCTURES IN SEA ICE NEAR NORTHSTAR, WINTER AND SPRING OF 2000-2001 [1]

by

**Michael T. Williams** [a], **Thomas G. Smith** [b], and **Craig J. Perham** [a]

[a] **LGL Alaska Research Associates, Inc.**
1101 E. 76th Ave., Suite B
Anchorage, AK 99518
(907) 562-3339; mwilliams@lgl.com

and

[b] **E.M.C. Eco Marine Corporation and Drakesheath Kennels**
5694 Camp Comfort Road
Garthby Station, Quebec G0Y 1B0, Canada
(418) 458-2604; emccorp@globetrotter.net

for

**BP Exploration (Alaska) Inc.**
Dept. of Health, Safety & Environment
900 East Benson Blvd. P.O. 196612
Anchorage, AK 99519-6612

LGL Report P557-2

April 2002

---

[1] Chapter 4 *In:* W.J. Richardson and M.T. Williams (eds.). 2002. Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2001. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD.

## INTRODUCTION

Landfast ice is important winter and spring breeding habitat for ringed seals, *Phoca hispida* (McLaren 1958; Burns 1970; Smith 1973). Studies conducted in Alaska and the Canadian High Arctic indicate that ringed seals start to construct and maintain a series of breathing holes as soon as ice begins to form in late autumn or early winter (Smith and Stirling 1975; Frost and Burns 1989). As sufficient snow accumulates around these breathing holes, some are developed into lairs, which afford protection from predators and weather (Smith and Stirling 1975; Kelly et al. 1986; Williams et al. 2001). Individual seals may have as many as four lairs plus multiple breathing holes. Ringed seal pups are born in lairs during late winter. Breathing holes and lairs are described, collectively, as "seal structures".

The breathing holes and lairs used by a given ringed seal may cover a relatively large area. Kelly and Quakenbush (1990) found that, during March-May, mean distances between lairs were 2 km (1.2 mi) for male seals and 0.6 km (0.4 mi) for females. The maximum distance between 2 lairs used by a single seal was 3.4 km (2.1 mi, Kelly and Quakenbush 1990). Pups may use more holes than adults (mean 8.7, Lydersen and Hammill 1993), but these holes are generally closer together; the maximum documented distance between holes used by a single pup was 0.9 km (0.56 mi).

Previous on-ice studies of ringed seals have been conducted primarily during late winter and early spring (e.g., Smith and Stirling 1975; Smith and Hammill 1981; Kelly et al. 1986; Frost and Burns 1989; Kelly and Quakenbush 1990; Kelly and Wartzok 1996). Little is known about ringed seal ecology during November through January when much of the construction of the Northstar ice roads occurred.

Ringed seals are thought to maintain many of the same breathing holes and lairs throughout the ice-covered period, although there appears to be a natural process whereby some are abandoned over the winter (e.g., Frost and Burns 1989; Williams et al. 2001). Natural abandonment of structures suggests that ringed seals adapt to changes in their habitat due to variations in ice deformation, ice thickness, accumulation of snow, local food availability, and predation intensity. Anthropogenic changes in the environment, such as ice roads or introduced sounds, may increase the abandonment rate of holes in otherwise suitable habitat (Kelly et al. 1986; Frost and Burns 1989; Williams et al. 2001). The impacts of these anthropogenic effects on ringed seals at the individual and population levels are unknown. Displacement from breathing holes in early winter may result in the use of alternate holes farther away from the disturbance source. Abandonment of holes and lairs in late winter and early spring might disrupt mating and birthing; females with pups might be displaced from their lairs, thus disrupting lactation. However, neither of these possibilities has been evaluated directly.

The ice roads and construction areas for the Northstar Development were located within the landfast ice zone, including some areas known to be used by ringed seals in winter. Aerial and on-ice monitoring in previous years have documented the use of this area by overwintering ringed seals. A study in December 1999 – May 2000 provided information about the occurrence, persistence, and turnover of seal structures during that period of intense Northstar construction activity (Williams et al. 2001).

On 18 September 2000 the National Marine Fisheries Service (NMFS) issued a Letter of Authorization (LoA) to BP Exploration (Alaska) Inc. (BP) authorizing the "taking" of a small number of marine mammals incidental to continued construction activities at the Northstar Development. The monitoring stipulations in the LoA stated, "*Any ice-roads or other construction activities that are initiated, after January 1, 2001, in previously undisturbed areas in waters deeper than 3 meters (10 ft), must be surveyed, using trained dogs, in order to identify and avoid ringed seal structures by a minimum of 150 m (492 ft). After 20 March, activities should avoid, to the greatest extent practicable, disturbance of any located ringed seal structure.*" In addition, BP was requested by NMFS, "[to collect] *at least one more year* *of data on potential impacts to ringed seals during the winter resulting from ice road construction.*" To comply with these monitoring stipulations, BP implemented a program to locate and determine the status of seal structures (i.e., occupied recently or abandoned) found before and during BP's on-ice activities, and to compare their status near the end of the ice covered period (late May) with their status earlier in the winter.

On 18 November 2000, BP began construction of an ice road from West Dock to the Northstar Production Island (hereafter referred to as Northstar Island) as part of the Northstar Development Project (Fig. 4.1). The 12-km (7.4 mi) long primary ice road was completed in mid-February 2001. The primary road was used subsequently for transport of personnel, supplies, and equipment to Northstar Island. After initiation of the primary access road, another ice road was built along the pipeline alignment. This road was required to allow placement of additional gravel over the pipe at nine sites (see Chapter 2; Fig. 2.1). Additional fill was required to meet specifications in the Army Corps of Engineers permit for pipeline construction. The ice above the pipeline was cleared of snow in January 2001 to promote more rapid freezing and thickening, which was necessary to support heavy equipment to be used later. In previous winters, ice roads for the Northstar Development Project had been constructed from 22 November 1999 to mid-February 2000 and from 9 January to 8 April 1999 (see Richardson and Williams 2000; Williams and Perham 2001).

Because ringed seals were present within the Northstar Development area during previous ice-covered seasons, BP contracted LGL Alaska Research Associates Inc. and Eco Marine Corporation (EMC) to conduct on-ice searches of the planned ice roads and the areas surrounding the ice roads and Northstar Island for ringed seal structures. Initial searches were conducted during November-December 2000, after the centerline of the primary offshore ice road was surveyed, but before its construction began. In March and May 2001 the study area was searched again to identify any new (or previously undetected) seal structures, and the previously identified structures were checked to determine whether they were still active. In addition, temperature sensors and data loggers were placed in structures to determine the date of abandonment. This work was conducted under provisions of the LoA issued to BP on 18 September 2000.

The objectives of this project were

1. to locate and record in early winter, prior to ice road construction, the status of on-ice structures of ringed seals in the Northstar Development area, in the adjacent area that might be influenced by Northstar activities (i.e., potential impact zone), and in a more distant area;
2. to check the status of these structures during mid-winter, and again in the spring after the majority of construction activities had been completed; and
3. to locate and record the status of new ringed seal structures in March and May.

From this information, the persistence and turnover of structures were to be documented, including analysis of the possible influence of distance from industrial activities associated with Northstar on the abandonment of seal structures.

## METHODS

### *Study Area*

Surveys for ringed seal structures were conducted within the area near Northstar (lat x long.) where the summer water depth was greater than 5 ft (1.5 m). By mid-late winter, shallower areas are frozen to (or close to) the bottom and may be unsuitable as ringed seal habitat in the spring (Miller et al. 1998; Link et al. 1999; Moulton et al. 2000, 2001; Chapter 5 of this volume).

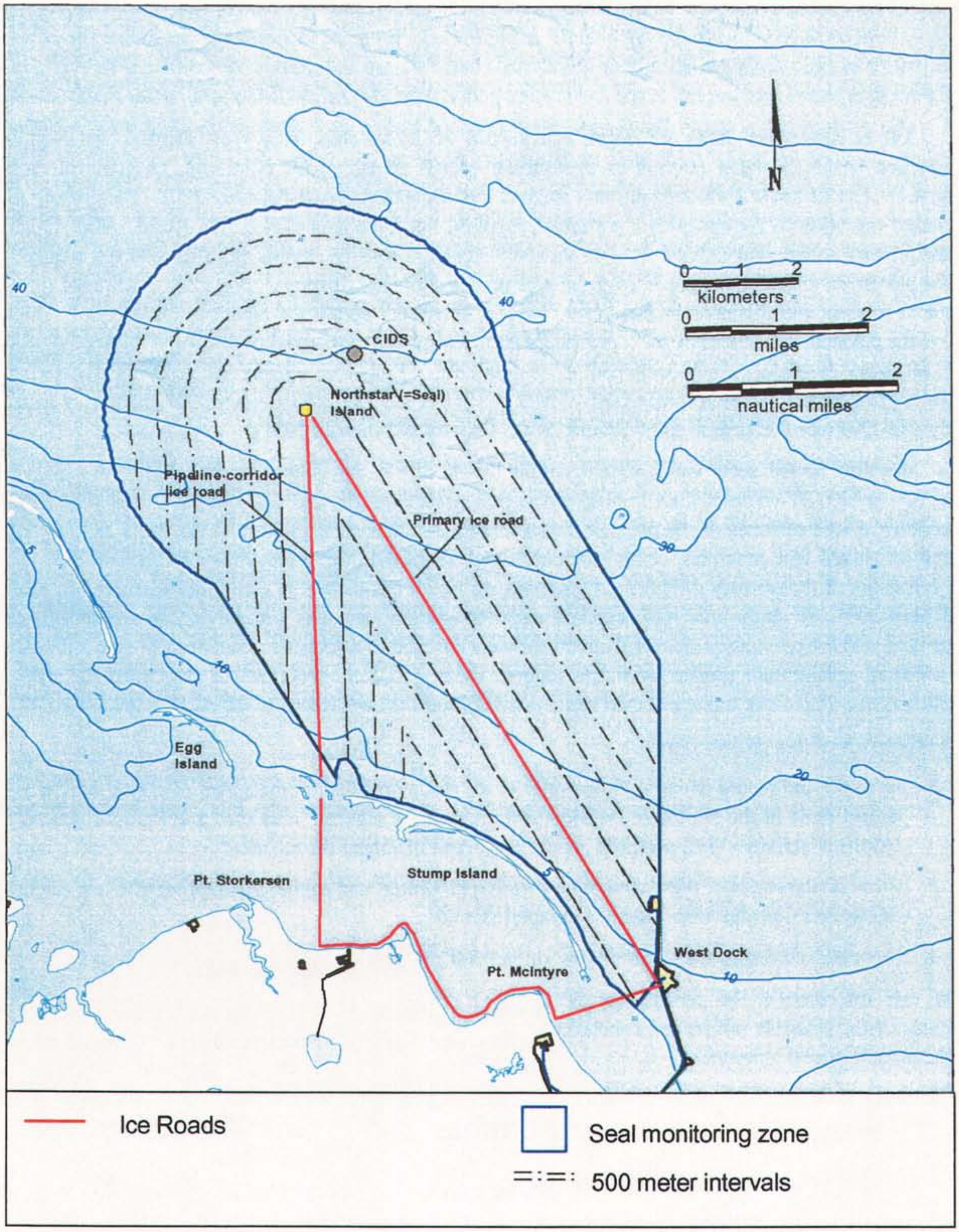


FIGURE 4.1. Study area in November and December 2000, with locations of Northstar (=Seal) Island and the primary ice road. Dashed lines show distances from the island and ice road, by 500 m intervals. The Concrete Island Drilling System (CIDS) was in cold storage about 1.1 km northeast of the island.

The original study area of 75.3 km$^2$ (29.1 mi$^2$) was established with the expectation that the only offshore ice road would be the primary ice road to Northstar Island. The original study area included all of the ice that was to be physically disturbed during the winter and spring, as well as a zone extending 3 km (1.8 mi) beyond the primary ice road and 3.5 km (2.2 mi) around Northstar Island (Fig. 4.1). The physically-disturbed area included the artificially-thickened ice road, the ice that was cleared of snow and rubble, and the adjacent areas that were covered with additional snow by snow removal equipment. The total area that was physically disturbed was 2.7 km$^2$.

In January 2001, it was determined that additional work was required along the pipeline alignment. Therefore, the study area was enlarged by 9.2 km$^2$ (3.5 mi$^2$) to include a 30 m (98 ft) strip along the pipeline alignment and the associated 3 km monitoring zone around the pipeline (Fig. 4.2). Nearly all sea ice that would be physically disturbed along the pipeline alignment had already been searched for seal structures during November and December 2000 because most of the pipeline alignment within areas >5 ft deep was within 3 km of the primary ice road (Fig. 4.2). The overall study area was 84.5 km$^2$ after including the 9.2 km$^2$ "monitoring zone addition" west of the pipeline. The additional 9.2 km$^2$ area was not included in the initial November/December search for seal structures because, at that time, no winter work was expected to occur along the pipeline. The additional area was searched in March and May and information on seal structures in this area was included when assessing the fate of structures.

The original study area was divided into six 500-meter intervals to analyze the occurrence and fate of seal structures in relation to distance from industrial activities. The intervals were created by forming "concentric" 500 m zones around Northstar Island, the primary ice road, and the pipeline corridor ice road, which were the zones of highest activity in the study area. In these analyses, we considered only the structures found in the original study area (Fig. 4.1) at distances out to 3.5 km. We did not have data for the 3001-3500 m interval from the ice roads, and we did not have Nov./Dec. data from the 9.2 km$^2$ area west of the pipeline. The ice-area for each of the resulting 500 m intervals was as follows: 0-500 m – 17.3 km$^2$, 501-1000 m – 14.5 km$^2$, 1001-1500 m – 11.5 km$^2$, 1501-2000 m – 9.3 km$^2$, 2001-2500 m – 8.7 km$^2$, and 2500-3000 m – 8.6 km$^2$. Those areas, as depicted in Figure 4.1, were searched in a consistent way in Nov./Dec., March, and May. In March and May our search effort was consistent for the entire revised study area, which included the pipeline route (Fig. 4.2).

## *Search Methodology Using Trained Dogs*

The results from the monitoring work in 1999 (Williams and Perham 2000) and 2000 (Williams et al. 2001), as well as the requirements in the LoA, prompted BP to assess how many new structures were created and abandoned near Northstar during the entire ice-covered season. It was assumed that the study area was large enough to include zones both inside and outside the area influenced by industrial activities.

Dog-assisted searches were conducted during three periods: (1) 24 November through 8 December 2000, (2) 2 March through 13 March 2001, and (3) 4 May through 21 May 2001. The searches were conducted by biologists using one to four trained Labrador retriever dogs. The dog-based searches were performed using methods similar to those of previous investigators (Smith and Stirling 1975; Kelly et al. 1986, 1988; Kelly and Quakenbush 1990; Furgal et al. 1996), and most resembling the methods of Lydersen and Ryg (1991) and Williams et al. (2001). The primary dog handler in 2001 was Dr. Thomas G. Smith of EMC.

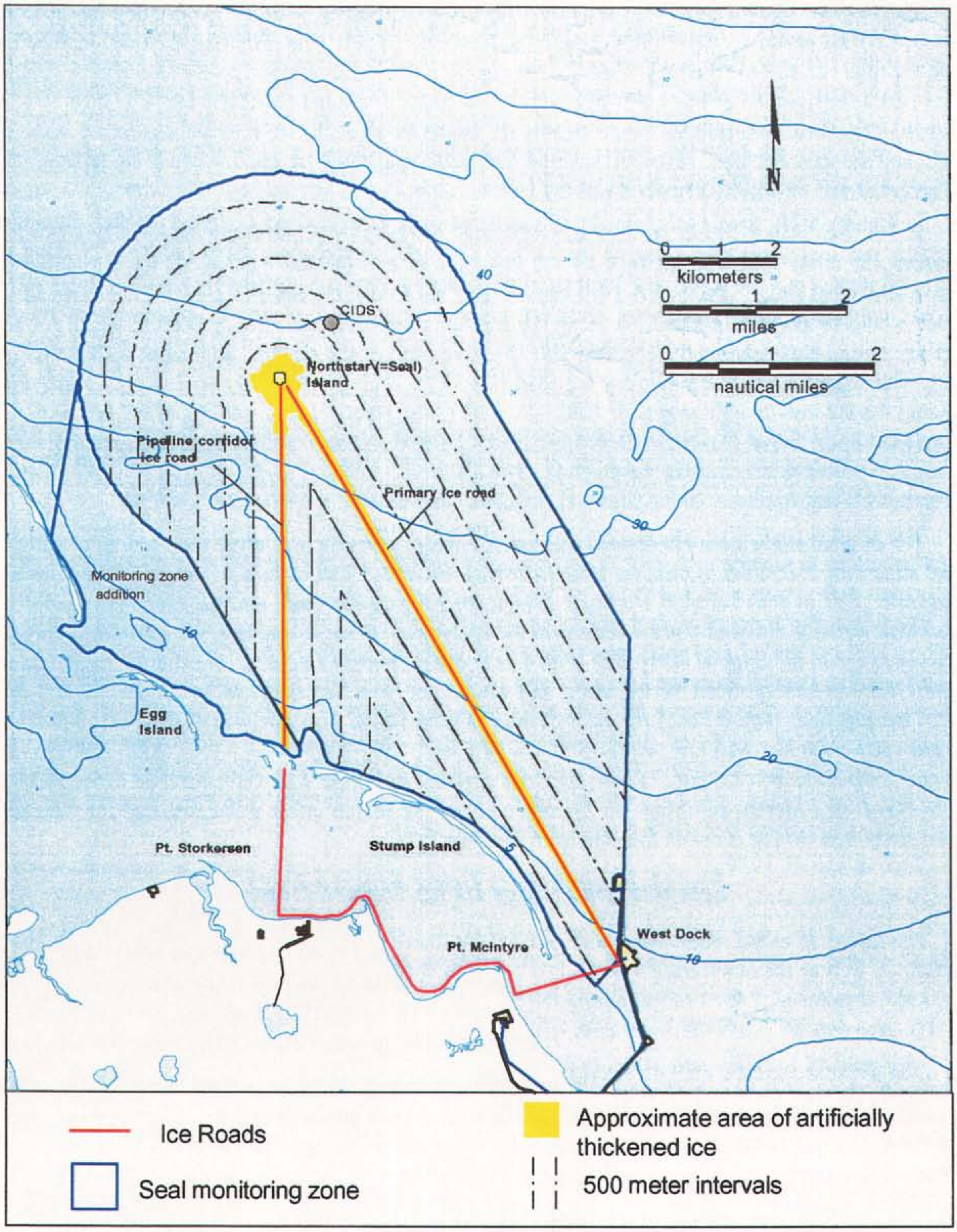


FIGURE 4.2. Revised study area in January – May 2001, showing southwestward extension of monitoring zone and portions of ice-roads that were artificially thickened. Otherwise as in Figure 4.1.

The centerline of the primary ice road was marked by surveyors prior to the first search, and these markers were used as visual reference points for the dog-assisted surveys of the study area. In addition, GPS locations were used, especially in areas distant from the ice road. Transect routes and lengths were determined daily depending on (1) priority construction areas identified by BP, (2) wind speed and direction, and (3) condition of dogs.

The daily search coverage was planned by plotting previous daily transects over the study area. The extent of the area searched was estimated assuming that dogs could reliably detect seal structures up to 1 km away in the upwind direction (T.G. Smith, pers. comm.). Transect locations were logged at two-second intervals using a Garmin® 12 XL or 2 Plus GPS receiver. The program MapSource™ was used in the field to plot transects and seal structures as a GIS layer over a map of the study area.

Near the border of the study area we were not able to divert the dogs from locating structures outside the study area. We have included structures located outside the study area in the maps. However, we have not included structures outside the study area in density calculations or analysis of distance from activities.

One 6-year-old bitch had previous experience searching for ringed seal structures. All survey transects were searched by the experienced dog, which was usually accompanied by one inexperienced dog. All dogs were highly trained and able to respond consistently and reliably to the handler on command. Each dog was active for approximately 60 to 120 min and then was given a 30 to 60 min break to prevent fatigue and the effects of extreme cold. Every fourth day, the experienced dog rested for the entire day. On some of these days, biologists rechecked structures and data-loggers.

Most of the study area was surveyed using dogs followed by biologists on snow machines. The experienced dog, generally accompanied by an inexperienced dog, searched for seal structures ahead of the biologists/dog handlers (Fig. 4.3). The dogs were guided by hand signals from the primary dog handler to keep them on transect. Limited areas near Northstar Island and the Concrete Island Drilling System (CIDS; Fig. 4.1) were sufficiently rough that the snow machines could not keep up with the dogs. In these rough areas the dogs were followed by the handlers on foot, generally for less than 1 km. The handler returned to following the dogs via snow machine once ice conditions along the transect allowed.

The experienced dog worked at much closer distances (10-20 m) to the handler than during the previous winter (*cf.* 20-50 m; Williams et al. 2001). This was done in order to cover the area consistently using a repeatable transect design. When the dog scented a structure, she diverted upwind from the transect until she located the structure. After marking the structure, we returned to the point of departure from the transect and continued along the transect. Our coverage of the area within 500 m of the transect was more thorough than in the previous year's wider-ranging transect survey. Periodically the experienced dog located structures at distances greater than 1 km. It was the opinion of the dog handlers in both 1999-2000 and 2000-2001 that two searches along transects through the same area (assuming a standard detection distance of ~1 km) would detect a consistently high proportion of the seal structures present (T. Smith pers. obs.; L. Quakenbush and B. Kelly, pers. comm.). The entire study area was surveyed at least twice during each of the three search periods. The small triangle shaped area (Fig. 4.2) to the west of the pipeline alignment was not searched in Nov./Dec. 2000, but was searched twice in each of March and May 2001.

FIGURE 4.3. Photo of dog searching ahead of the snow machine with Northstar Island in the background (facing North).

## *Structure Recording and Marking*

All seal structures found during the first two field periods were marked with wooden stakes, and locations were recorded using a GPS receiver. In May, we used carved snow blocks to mark newly-located basking sites. This was intended to minimize any response from basking seals to the foreign visual cue presented by a wooden stake. We did use wooden stakes to mark newly located non-basking structures in May.

When a structure was first located, we carefully tunneled through the snow into the structure to determine its type and status. We then replaced the snow cover to minimize the disturbance. We recorded the following data for each location: type of structure (e.g., resting lair, basking site, birth lair, pup lair, breathing hole), status of structure (open or frozen), structure and site description, snow depth at seal hole, evidence of predation, air temperature, indication (smell) of a reproductively active male (*tiggak*: McLaren 1958; Smith and Stirling 1975; Smith and Hammill 1981; Hardy et al. 1991; Furgal et al. 1996), and local wind speed and direction. Individual structures and their re-check status are listed in Appendix A.

We defined ringed seal structures based on their function. Lairs were categorized as resting, birth, or pup lairs. The Inupiat and Inuit recognize additional lair types (Smith and Stirling 1975); however we limited our typing to these three categories. Birth lairs were characterized by blood in the floor, placental remains, and/or a newborn dead pup. Resting lairs showed no sign of pup occupation (i.e., no lanugal hairs or small pup chambers excavated into the surrounding snow). Pup lairs showed signs of pup occupation (i.e., lateral excavations, lanugal hairs), but no signs of birth. Basking sites were either lairs with collapsed, excavated or melted ceilings, or breathing holes excavated to allow access to the surface. In this report we have, for simplicity, shown the structures simply as breathing holes or lairs. Status of a seal structure was defined based on whether the structure was recently used (breathing hole open) or abandoned (frozen). An intermediate status (inactive) was recorded for any lair where the seal was no longer hauling out but the breathing hole was still in use. This type of structure was still considered to be open and in use.

We name and track each structure as it was defined when originally found. In our records, a structure maintained its original type (i.e., breathing hole or lair) throughout the study even if it was used in a different manner during subsequent checks. The status or fate of each structure was recorded for each survey period. For example, a structure recorded as an active breathing hole in December might, when re-examined in March, have accumulated sufficient snow for the seal to excavate and actively use a resting lair. This structure is listed as a breathing hole (its original structure type when found) that was still open in March. Analysis of structure type is confounded by the fact that all lairs originate as breathing holes (Smith and Stirling 1975). Analysis of abandonment is confounded by the fact that frozen structures are sometimes re-opened by seals (Williams et al. 2001; see also "Results", later). Additional analysis of the data by structure type, status, and distance from industrial activity will be completed for a future comprehensive technical report.

### *Assessing Fate of Seal Structures*

In March and May 2001, we physically checked the status of the previously located structures and we searched for new structures.

To check the status of a previously located structure and document abandonment rate, we probed with a stainless steel rod to see if the breathing hole was still open. If necessary, we physically excavated the structure to determine its status. However, this was done only when status could not be determined with the rod. This excavation was typically less invasive than the initial examination.

Temperature sensors and data loggers were used to obtain more detailed data on abandonment rates of ringed seal structures relative to Northstar activities, including specific abandonment dates. (A similar approach had been used by Kelly and Quakenbush (1990) to verify structure-attendance by radio-tagged seals.) The sensors were deployed in seal structures beginning in November and December 2000. Data loggers (Onset Computers; HOBO® H8 Pro) were used to record air temperature inside and outside the structure. Each data logger was equipped with a built-in temperature sensor and an external plug-in sensor with a 4-ft cable. The cabled sensor was placed within a structure (Fig. 4.4), and its data were recorded on one of two channels within the data logger. The built-in sensor recorded ambient air temperature outside the structure on the other channel, for comparison to temperature changes within the seal structure. The data loggers were programmed to record both temperature values at five-minute intervals.

Based on the manufacturer's specifications, we anticipated approximately 115 days of memory and battery life. After the initial deployment in December, we returned on 17-18 January 2001 to check the status of the data loggers and battery life in field conditions. Then and during searches for new structures in March and May, data were transferred in the field to a remote device ("shuttle"; Fig. 4.4), and later uploaded from there to an office-based computer. In addition, the data logger was restarted automatically by the shuttle to continue collecting additional temperature data for the remainder of the season.

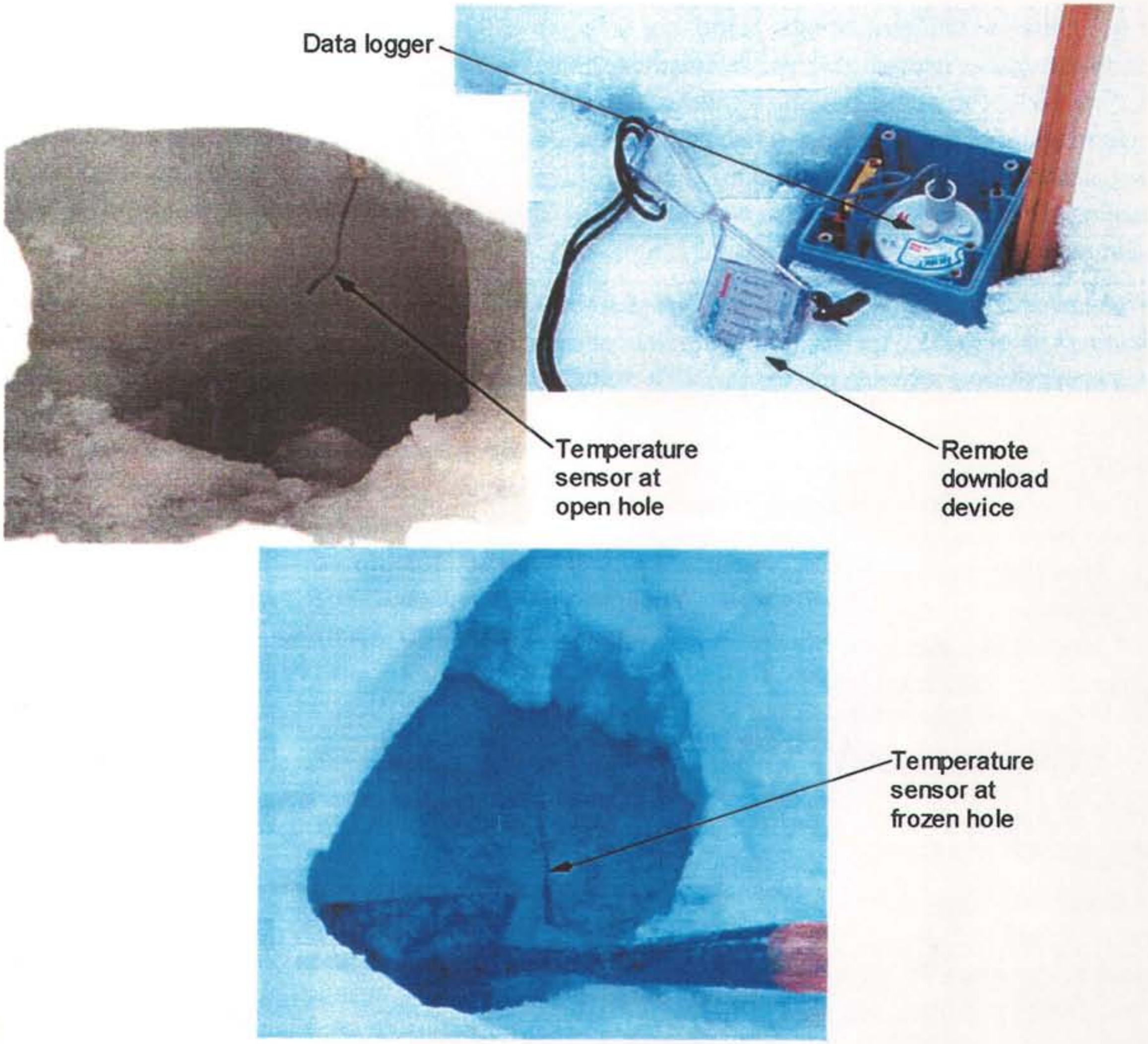


FIGURE 4.4. Photos of temperature data logger and remote data-transfer device ("shuttle") at a seal structure.

Sensor placement within the lair, which ideally was 6 inches above the breathing hole, was checked visually during initial deployment. When the data were transferred to the shuttle, sensor placement was re-checked visually at structures where physical disturbance to these structures could be minimized. Data records from each logger were reviewed each evening while in the field. If the temperature data showed obvious errors, erroneous temperatures, or did not correspond to the physical check of structure status with the metal rod, the structure was revisited and the temperature sensor was repositioned within the structure. In cases where (during a re-check) the external temperature sensor was found to be encased in ice and the structure was frozen, we could not determine the actual date of abandonment.

To maximize the time series of temperature data from active structures, we did not remove the data loggers from active structures during the first re-check in May 2001. Instead we transferred the data into the shuttle, physically checked the status of the structure with the metal rod, and continued to collect temperature data during the remaining dog-survey days in May. If a structure was frozen, we removed the data logger. During 16-22 May 2001, the final status of all structures was checked and the data loggers were removed from the remaining active structures.

Temperature data were inspected visually to establish the date that instrumented structures were frozen. Temperatures within the structure were compared to ambient conditions measured simultaneously (Fig. 4.5). Any increase in temperature within the structure that was not associated with a simultaneous increase in ambient temperature was assumed to indicate the presence of a seal. Date of abandonment was recorded as the day after the last occasion when temperature in the seal structure increased in a manner not paralleling the ambient temperature.

## RESULTS

### *Initial Survey for Seal Structures*

Approximately 136 km of transects were searched during November/December 2000 in the 75.3 $km^2$ (29.1 $mi^2$) study area. A total of 35 ringed seal structures (0.46 structures/$km^2$) were found within the study area during that period (Fig. 4.6). Overall, 32 of the 35 structures found in Nov./Dec. were open and in active use by seals. There were no signs of polar bear or fox predation in the study area by the end of the initial survey on 8 Dec. 2000.

#### *Structure Type*

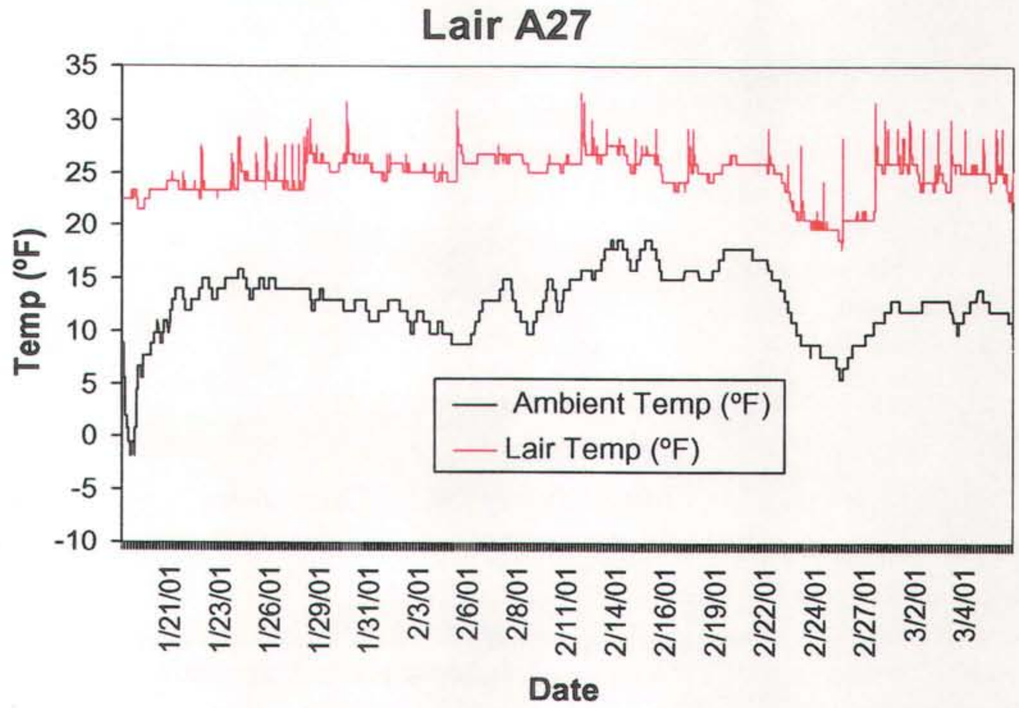
Of the 35 structures found within the study area in Nov./Dec., 28 (80%) were breathing holes and 7 or 20% were lairs at this time (Appendix A). Ice deformation in the study area during Nov./Dec. 2000 was judged to be less than that observed in December 1999. However, we did not measure deformation quantitatively to verify this observation. Snow accumulation and consolidation in Nov./Dec. 2000 were still limited, and marginal for the excavation of lairs.

The number of open breathing holes found in each 500 m interval with respect to Northstar infrastructure ranged from 1 to 6 (mean = 3.9), and the number of open lairs found in each interval ranged from 0 to 2 (mean = 0.7; Table 4.1). During Nov./Dec., more lairs were found north of Stump Island than in other areas (Fig. 4.6).

#### *Density of Structures*

The overall density of all structures (holes and lairs; both open and frozen) found in the area out to 3.5 km during Nov./Dec. 2000 was 0.46 structures/$km^2$. Considering only the open structures, the density was 0.42 structures/$km^2$. The densities in the various 500 m intervals ranged from 0.11 to 0.65 open structures/$km^2$ (mean = 0.39; Fig. 4.7). Similar densities of active structures (holes and lairs combined) were found in each of the four 500-m intervals within 2 km of Northstar infrastructure. Densities within 2 km were higher than in the three 500-m intervals beyond 2 km. Note that, at the time of the Nov./Dec. searches, Northstar Island was active but re-construction of the primary ice road was just beginning, and there was no activity along the pipeline route.

*(A)*



*(B)*

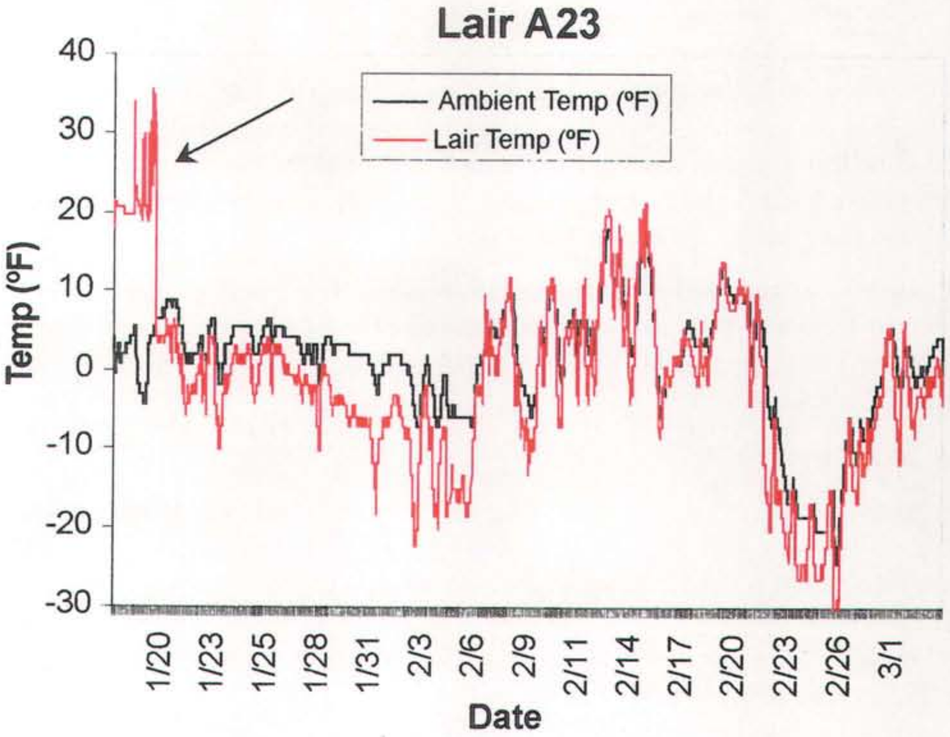


FIGURE 4.5. Plot of internal lair temperature and external ambient temperature for one breathing hole and one lair. ***(A)*** Continuous record of internal lair temperature showing increases interpreted to indicate presence of ringed seal in breathing hole A27. ***(B)*** Temperature record showing abandonment of lair A23 (indicated by the arrow) soon after installation of temperature sensor.

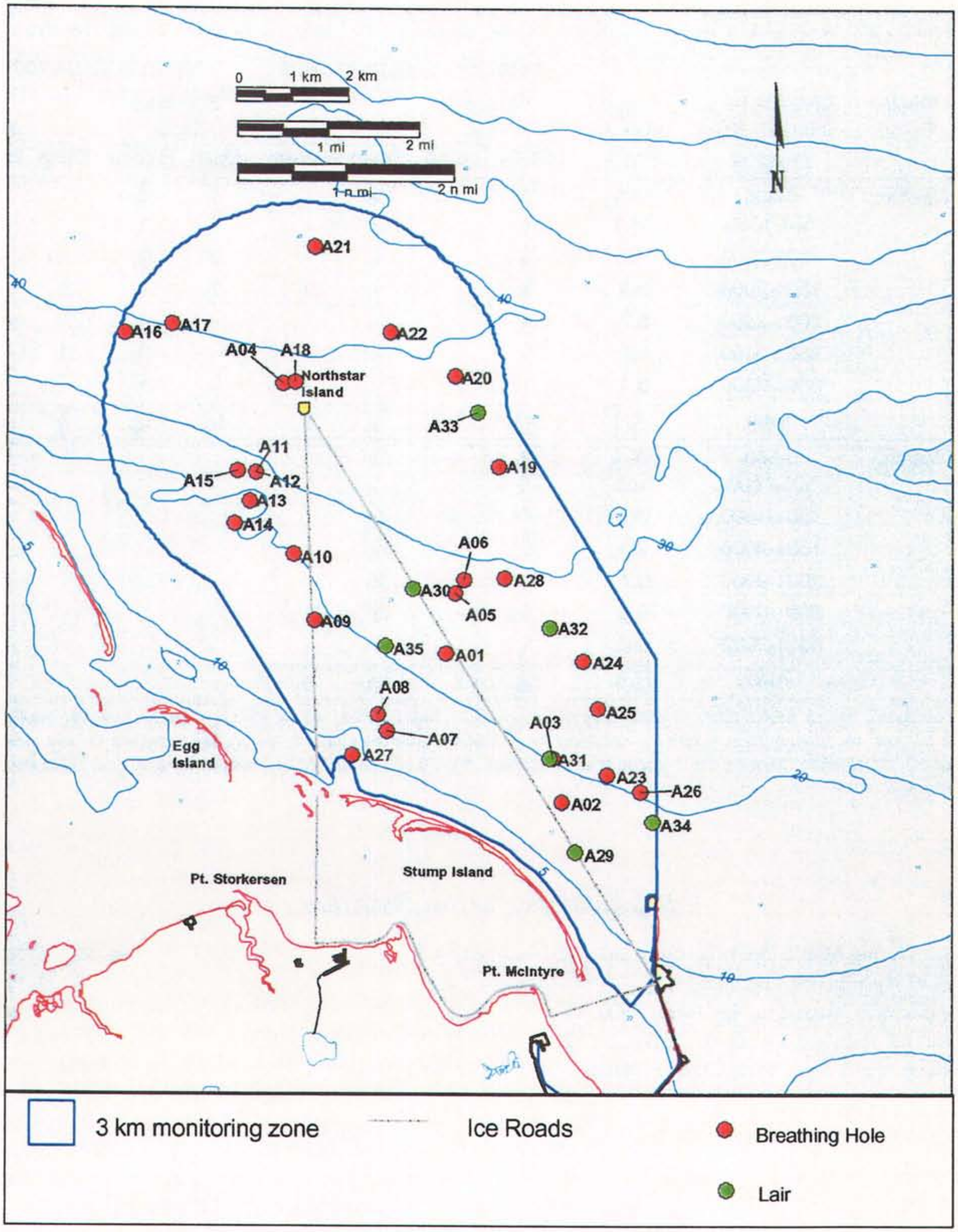


FIGURE 4.6. Locations of ringed seal structures found in the original study area near Northstar Island, the primary ice road, and west to the pipeline route during Nov./Dec. 2000.

TABLE 4.1. Status of ringed seal structures found during searches in November/December and during searches and re-checks in March[a] at 500-m distance intervals from Northstar activities on the sea ice.

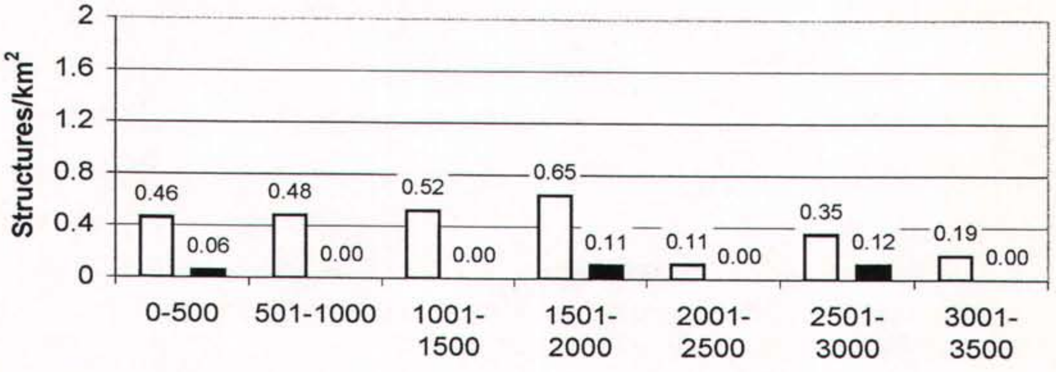
| | | | Status when Initially Located | | | | Status in March 2001 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Month Found | Distance from Infrastructure (meters) | Area of Interval (km$^2$) | Breathing Hole | | Lair | | Breathing Hole | | Lair | |
| | | | Open | Frozen | Open | Frozen | Open | Frozen | Open | Frozen |
| Nov/Dec | 0-500 | 17.3 | 6 | 1 | 2 | - | 1 | 6 | - | 2 |
| | 501-1000 | 14.5 | 5 | - | 2 | - | 4 | 1 | - | 2 |
| | 1001-1500 | 11.5 | 5 | - | 1 | - | 3 | 2 | - | 1 |
| | 1501-2000 | 9.3 | 6 | - | - | 1 | 2 | 4 | 1 | - |
| | 2001-2500 | 8.7 | 1 | - | - | - | - | 1 | - | - |
| | 2501-3000 | 8.6 | 3 | - | - | 1 | - | 3 | 1 | - |
| | 3001-3500 | 5.4 | 1 | - | - | - | - | 1 | - | - |
| | Total | 75.3 | 27 | 1 | 5 | 2 | 10 | 18 | 2 | 5 |
| March[a] | 0-500 | 17.3 | 2 | - | 3 | - | | | | |
| | 501-1000 | 14.5 | 7 | - | 4 | - | | | | |
| | 1001-1500 | 11.5 | 7 | 1 | 5 | - | | | | |
| | 1501-2000 | 9.3 | 5 | - | 1 | - | | | | |
| | 2001-2500 | 8.7 | 6 | - | 2 | - | | | | |
| | 2501-3000 | 8.6 | 3 | - | 2 | - | | | | |
| | 3001-3500 | 5.4 | 5 | - | 1 | - | | | | |
| | Total | 75.3 | 35 | 1 | 18 | 0 | | | | |

[a] For March, values shown above include only those structures found in the original 75.3 km$^2$ study area and not those in the 9.2 km$^2$ monitoring zone addition. Including the additional area searched in March, the numbers of new structures found in March were 39 open and 1 frozen breathing holes, and 20 open and 0 frozen lairs (total of 60 new structures)–see Table 4.2.

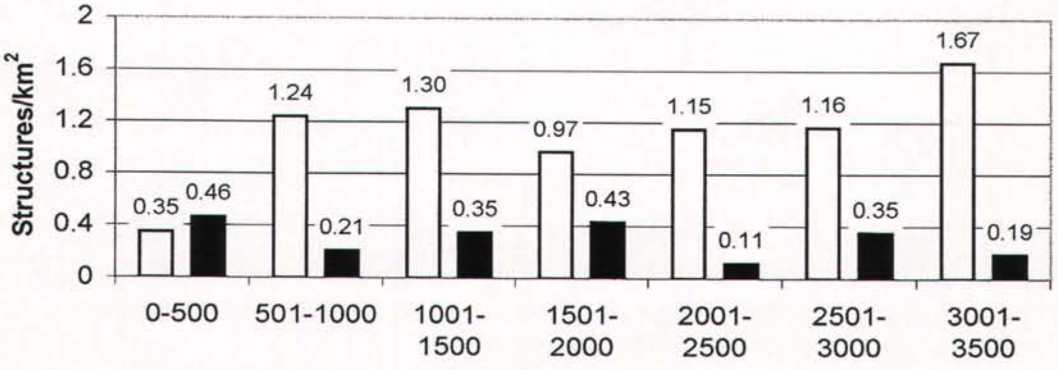
## *Second Survey for Seal Structures*

During March 2001 the study area was enlarged by 9.2 km$^2$ to include additional area out to 3 km west of the pipeline alignment (Fig. 4.2), and approximately 210 km of transects were searched. Of the 35 structures located in Nov./Dec. 2000, 12 (34%) were open and active and 23 (66%) were frozen and presumed abandoned when re-checked in March 2001. In addition, 63 previously unknown structures (59 of them open) were found during March (Fig. 4.8). Three lairs (B50, B57, and B58), however, were found slightly west of the systematic study area (Fig. 4.8) and are not included in the analysis or the Tables. The body of Table 4.1 also excludes structures found in the additional area searched in March but not in Nov./Dec.; 54 of the 60 previously unknown structures found during March were in the original study area (Table 4.2). Including the 35 structures found in Nov./Dec., at least 95 structures had been used within the enlarged study area by 13 March (Fig. 4.8; 1.1 structures/km$^2$). Of these, 71 were open and active during March 2001 (0.84 active structures/km$^2$).

**A: November-December 2000**



**B: March 2001**



**C: May 2001**

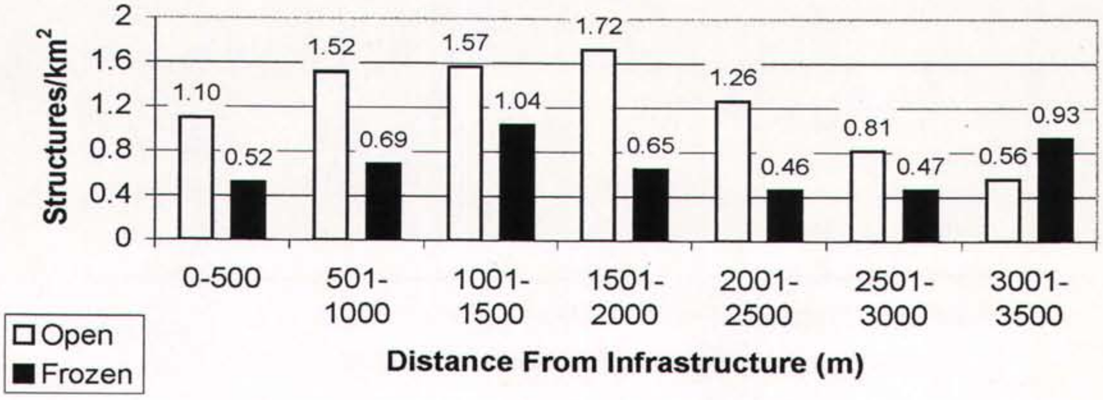


FIGURE 4.7. Cumulative density of seal structures found in each 500 m distance interval measured from the on-ice activities near Northstar Island and the ice roads ***(A)*** in Nov./Dec. 2000, ***(B)*** through March 2001, and ***(C)*** through May 2001. (B) includes structures first found in Nov./Dec. as well as March, and (C) includes structures first found during all three field periods. Based on data from the original 75.3 km$^2$ study area only (Fig. 4.1).

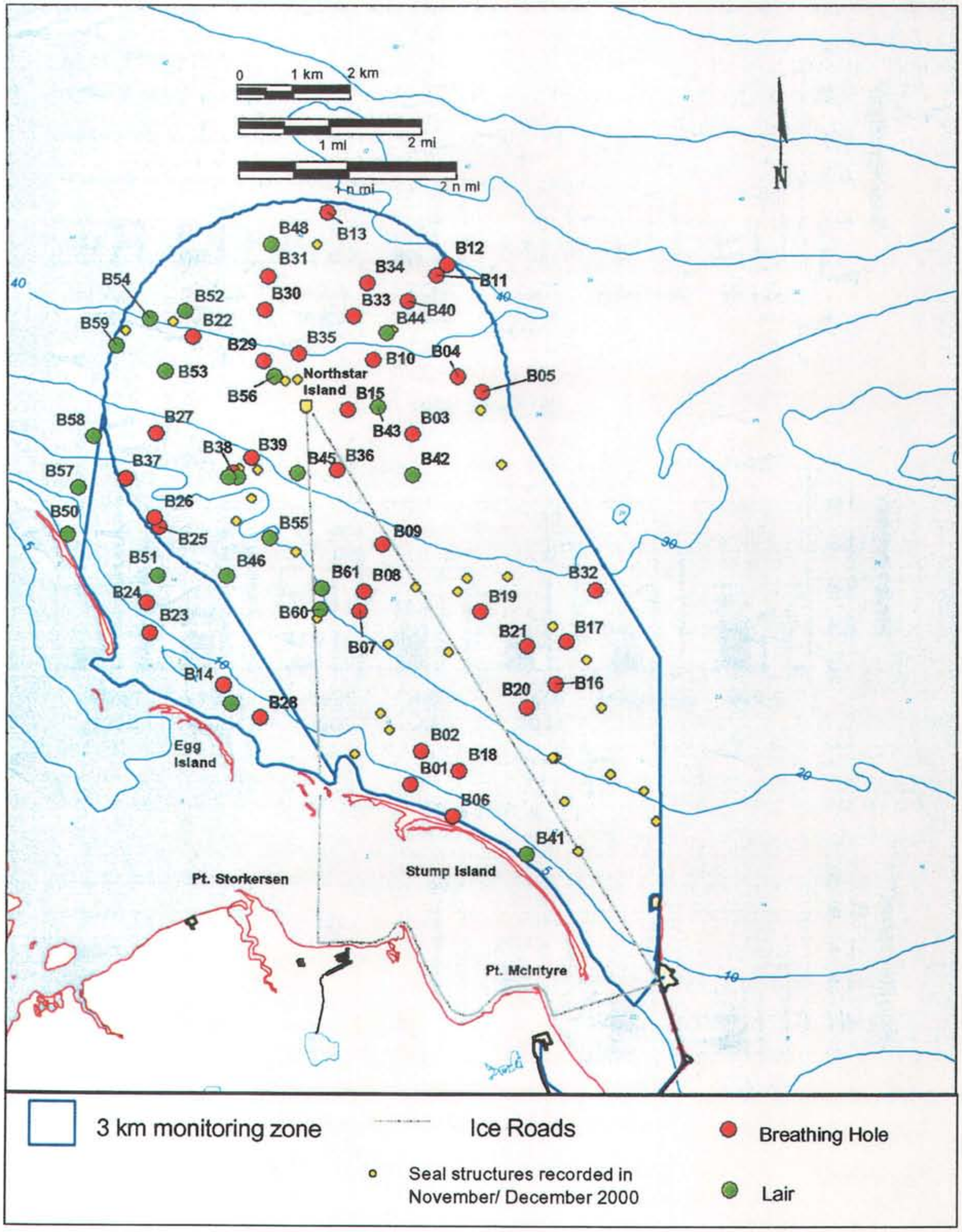


FIGURE 4.8. Locations of ringed seal structures found in the expanded study area near Northstar Island, the primary ice road, and the pipeline alignment during March 2001.

TABLE 4.2. Number (and density per km$^2$) of new structures found near the Northstar Development during each of three survey periods (Nov./Dec. 2000, March, May) in both the original 75.3 km$^2$ study area (Fig. 4.1) and the enlarged 84.5 km$^2$ study area (Fig. 4.2). In Nov./Dec., only the 75.3 km$^2$ area was searched.

| | Nov./Dec. 2000 | | | | March 2001 | | | | May 2001[a] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Breathing Hole | | Lair | | Breathing Hole | | Lair | | Breathing Hole | | Lair | |
| | Open | Frozen | Open | Frozen | Open | Frozen | Open | Frozen | Open | Frozen | Open | Frozen |
| 75.3 km$^2$ study area | 27<br>(0.36) | 1<br>(0.01) | 5<br>(0.07) | 2<br>(0.03) | 35<br>(0.46) | 1<br>(0.01) | 18<br>(0.24) | 0 | 33<br>(0.44) | 0 | 30<br>(0.40) | 1<br>(0.01) |
| 84.5 km$^2$ study area | - | - | - | - | 39<br>(0.46) | 1<br>(0.01) | 20<br>(0.24) | 0 | 42<br>(0.50) | 0 | 35<br>(0.41) | 1<br>(0.01) |

[a] One additional structure of unknown type was found in May within the original 75.3 km$^2$ study area. Total number of structures found in May was 65 in the original study area and 79 in the enlarged area.

### *Structure Type*

A total of 60 new ringed seal structures were found within the enlarged study area (Fig. 4.8; Table 4.2) during March 2001. Forty of the newly found structures were breathing holes and 20 were lairs (Table 4.2; Appendix A). Ringed seals were actively using all 20 lairs found in March. In March 2001, the number of new breathing holes found in each 500-m interval of the original study area ranged from 2 to 7 (mean = 5.0; Table 4.1). The number of new lairs found in each interval ranged from 1 to 5 (mean = 2.6; Table 4.1). Including structures found in Nov./Dec., the total number of known active structures in March ranged from 6 to 15 (mean 9.3) in the various 500-m intervals of the original Nov./Dec. study area (Table 4.1).

Three pupping lairs were found during searches in March. However, our searches generally occurred earlier than the expected dates of parturition for present study area. The pupping lairs are included as "lairs" for this analysis. Only one new lair was found within the area extending 4 km (2.5 mi.) north of Stump Island in March (Fig. 4.8), whereas six of the seven lairs found in Nov./Dec. were located there (Fig. 4.6).

### *Density of Structures*

The density of all new structures (both open and frozen combined) in the enlarged study area was 0.71 structures/km$^2$ (60 structures in 84.5 km$^2$; Table 4.2). The density of all new structures (both open and frozen combined) found in all 500-m intervals in the original study area during March 2001 was 0.72 structures/km$^2$ (0.70 open new structures/km$^2$). The density of all structures found from Nov. 2000 to March 2001, considering all 500-m intervals in the original study area, was 1.18 structures/km$^2$ (89 in 75.3 km$^2$). The density of all structures found from Nov. 2000 to March 2001 that were open in March was 0.86 structures/km$^2$ in the original study area (65 in 75.3 km$^2$) and 0.84 /km$^2$ in the enlarged study area (71 in 84.5 km$^2$).

The density of new, open breathing holes in each 500-m interval of the original study area ranged from 0.12 to 0.93 holes/km$^2$ (mean = 0.54), and the density of new, open lairs in each interval ranged from 0.11 to 0.43 lairs/km$^2$ (mean = 0.23).

The density of all structures known to be open in March (first found in either Nov./Dec. or March) was lowest within 500 m of the island and ice roads (0.35 structures/km$^2$) and higher in all subsequent

500-m intervals out to 3500 m (0.70 – 1.3 /km$^2$; Fig. 4.7B). The density of structures found in either Nov./Dec. or March and determined to be frozen in March appeared to show no trend. However, the (marginally) highest density of frozen structures was within 500 m of the Northstar infrastructure (0.46 /km$^2$), while the lowest density of frozen structures was in the 2001-2500 interval (0.11/km$^2$; Fig. 4.7B).

### *Status of Structures*

The fates of seal structures located in Nov./Dec. 2000 were assessed during the follow-up surveys in March 2001 (Appendix A).

Of the five lairs open in December, two were covered by Northstar construction activities and the remaining three were frozen and presumed abandoned. The two lairs that had been frozen in Nov./Dec. were open when re-checked in March (A32 and A33). Seventeen previously open breathing holes were frozen at the time of the re-check. Of these, one had been converted into a lair and subsequently frozen. Ten breathing holes were still open and, of these, one had been converted into an active lair. Overall, 23 of the 35 structures (69%) located in Nov./Dec. 2000 were frozen in March 2001. Structures that had become inactive between Nov./Dec. and March included most of those 2000-3500 m from Northstar infrastructure as well as some of those at the closer distances, especially those located within 500 m of the Northstar infrastructure.

Open (i.e., actively used) seal structures were widely distributed in the study area in March. Fifty-nine of the 60 new structures found in the expanded study area during March were open (Table 4.2). The frozen structure was a breathing hole. Five new open structures (8%) were found within 500 m of the ice road construction, whereas 9 structures (26%) were found there during Nov./Dec. (Table 4.1). In the area 501-1000 m from Northstar activities, 11 new structures (all open) were found in March (18% of the total structures found in March), whereas 7 structures were found within that interval in Nov./Dec. (20% of the Nov./Dec. total; Table 4.1). In the two most distant intervals (2501-3500 m combined), 11 new structures were found in March (18% of the March total), whereas 5 structures were found there in Nov./Dec (14% of the Nov./Dec. total). Figure 4.7 shows the cumulative density of open and frozen structures as of March 2001.

## *Final Survey for Seal Structures*

Approximately 272 km of transects were searched in the 84.5 km$^2$ study area during May 2001. Of the 95 structures found during previous searches, 46 were still open and active in May. (Of these, 40 were in the original 75.3 km$^2$ study area–Table 4.3.) An additional 79 previously-unknown structures were found in the expanded study area during May (Fig. 4.9). Three additional breathing holes (C07, C24, and C30) were found outside the designated study area and are not included in the analysis or Tables, but are shown in Figure 4.9. Of the 174 structures found within the expanded study area during the three search periods (2.06 structures/ km$^2$; Fig. 4.9), 111 were still open and in active use during late May. Of these, 95 were in the original study area–Table 4.3.

During May, active seal structures, both new and old, were found at all distances from the Northstar facilities. In the 0-500 m, 500-1000 m, and 1000-1500 m intervals of the original study area, 16, 14 and 12 new structures were found, respectively (Table 4.3). Progressively fewer new structures were found in each of the four more distant intervals than in the closest two intervals. Each 500-m interval also contained additional active structures that were first found in Nov./Dec. or March (Table 4.3).

TABLE 4.3. Status of ringed seal structures when initially found and during late-May 2001[a], subdivided by 500-m distance intervals from Northstar activities on the sea ice.[b]

| | | | Status when Initially Located | | | | Status in May 2001[a] (Final Recheck) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Month Found | Distance from Infrastructure (meters) | Area of Interval (km$^2$) | Breathing Hole | | Lair | | Breathing Hole | | Lair | |
| | | | Open | Frozen | Open | Frozen | Open | Frozen | Open | Frozen |
| Nov/Dec | 0-500 | 17.3 | 6 | 1 | 2 | - | 1 | 6 | - | 2 |
| | 501-1000 | 14.5 | 5 | - | 2 | - | 3 | 2 | - | 2 |
| | 1001-1500 | 11.5 | 5 | - | 1 | - | 2 | 2 | - | 1 |
| | 1501-2000 | 9.3 | 6 | - | - | 1 | 2 | 4 | 1 | - |
| | 2001-2500 | 8.7 | 1 | - | - | - | | 1 | - | - |
| | 2501-3000 | 8.6 | 3 | - | - | 1 | | 3 | 1 | - |
| | 3001-3500 | 5.4 | 1 | - | - | - | | 1 | - | - |
| | Total | 75.3 | 27 | 1 | 5 | 2 | 8 | 19 | 2 | 5 |
| March[b] | 0-500 | 17.3 | 2 | - | 3 | - | 1 | 1 | 3 | - |
| | 501-1000 | 14.5 | 7 | - | 7 | - | 2 | 5 | 4 | - |
| | 1001-1500 | 11.5 | 7 | 1 | 5 | - | 2 | 5 | 2 | 3 |
| | 1501-2000 | 9.3 | 5 | - | 1 | - | 4 | 1 | - | 1 |
| | 2001-2500 | 8.7 | 6 | - | 4 | - | 4 | 2 | 2 | - |
| | 2501-3000 | 8.6 | 3 | - | 6 | - | 2 | 1 | 2 | - |
| | 3001-3500 | 5.4 | 5 | - | 4 | - | 1 | 4 | - | - |
| | Total | 75.3 | 35 | 1 | 29 | 0 | 16 | 19 | 13 | 4 |
| May[b] | 0-500 | 17.3 | 9 | - | 7 | - | 8 | - | 6 | - |
| | 501-1000 | 14.5 | 9 | - | 4 | 1 | 9 | - | 3 | 2 |
| | 1001-1500 | 11.5 | 5 | - | 7 | - | 5 | - | 6 | 1 |
| | 1501-2000 | 9.3 | 5 | - | 6 | - | 4 | - | 5 | - |
| | 2001-2500 | 8.7 | 3 | - | 4 | - | 2 | - | 3 | 1 |
| | 2501-3000 | 8.6 | 2 | - | - | - | 2 | 0 | - | - |
| | 3001-3500 | 5.4 | - | - | 2 | - | 0 | | 2 | - |
| | Total | 75.3 | 33 | 0 | 30 | 1 | 30 | 0 | 25 | 4 |
| | | Total | 95 | 2 | 64 | 3 | 54 | 38 | 40 | 13 |

[a] Status in May does not include those structures for which status could not be determined or those structures, which could not be relocated in May.

[b] Includes only those structures found in the original 75.3 km$^2$ study area (Fig. 4.1). See Table 4.2 for numbers of "new" structures found in the enlarged study area (Fig. 4.2) during March and May.

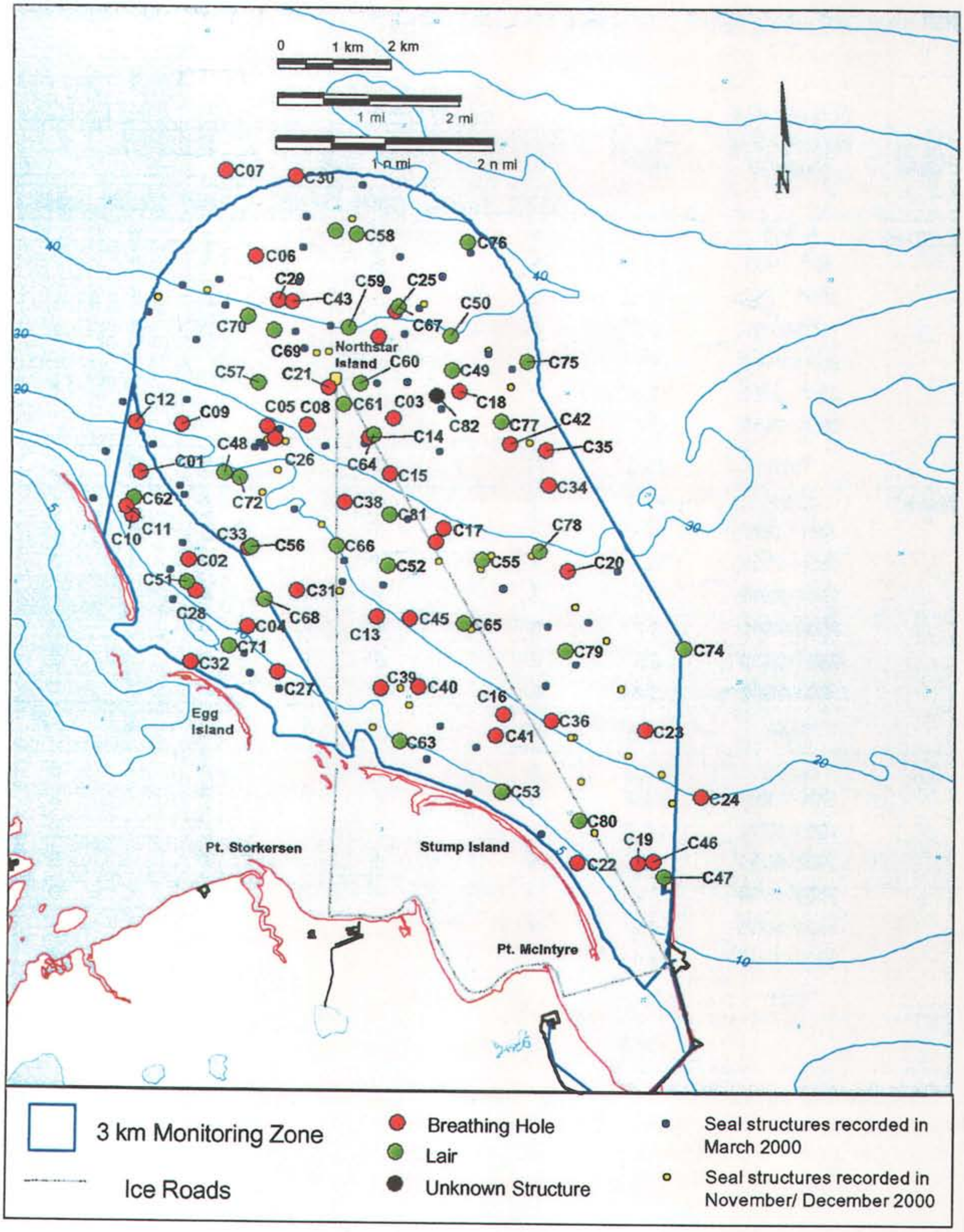


FIGURE 4.9. Locations of ringed seal structures found in the expanded study area near Northstar Island, the primary ice road, and the pipeline alignment during May 2001.

### *Structure Type*

A total of 79 new ringed seal structures were found within the expanded study area during May 2001 (Fig. 4.9, Table 4.2). Forty-two of the newly-found structures were breathing holes and 36 were lairs; one was an unidentified structure (Table 4.2; Appendix A). Within the original study area, the number of open structures first found in May within each 500-m interval ranged from 2 to 9 breathing holes (mean = 4.7), and from 2 to 7 lairs (mean = 4.2). By the end of the study, 30 structures had been found within 500 m of the Northstar infrastructure, and 35 in the 501-1000 m interval. Beyond that distance, the total number of structures that had been found over the course of the winter (both frozen and open) decreased.

### *Structure Density*

The overall density in May for all structures found in the expanded study area from November to May, whether open or frozen in May, was 2.06 structures/km$^2$ (174 structures in 84.5 km$^2$). The density for all structures that were open in the expanded study area during May was 1.31 open structures/km$^2$. Corresponding values for the original (smaller) study area were 2.06 structures/km$^2$ and 1.25 open structures/km$^2$. In May, the density of newly-found open structures in each 500 m interval ranged from 0 to 0.62 new holes/km$^2$ (mean = 0.39), and from 0 to 0.65 lairs/km$^2$ (mean = 0.40), respectively.

Considering all known open structures, regardless of the date first found, the density in each of the five 500-m intervals within 500 m to 2.5 km of Northstar facilities was higher than the density in the two more distant 500-m intervals (Fig. 4.7C). This pattern was similar to that observed in Nov./Dec. 2000 but different from that for March 2001 (*cf.* Fig. 4.7A,B). However, during both March and (to a lesser degree) May, the densities of known open structures tended to be lower within 500 m from Northstar facilities than in the next few 500-m intervals (Fig. 4.7B,C). This is the relationship expected if Northstar activities caused ringed seals to abandon structures.

In May, the density of abandoned structures increased with increasing distance up to 1.5 km from industry activities, and then decreased somewhat at least out to 3 km (Fig. 4.7). This is opposite trend to that predicted if Northstar activities caused higher abandonment of structures.

### *Status of Structures*

All 42 newly-located breathing holes were open and in active use by ringed seals in May. Ringed seals were actively using 35 of the 36 newly-found lairs, whereas one newly-found lair was frozen (Table 4.2). Of 35 active lairs and 42 active breathing holes that were newly located in early May, at least 4 (11%) and 1 (2%), respectively, had been abandoned by 22 May (Fig. 4.10). Three breathing holes and three lairs, open when first found in May, could not be found for the final recheck in late May, so their final status was unknown. The one frozen lair located in early May was still frozen by 22 May. At least 5 of the 78 open structures (6%) first located and examined in May were frozen by 22 May 2001. This could be an underestimate of abandonment for this short period since ambient temperature is higher in May than earlier, and abandoned holes would freeze more slowly than earlier in the year.

The fates of previously located seal structures were assessed based on the follow-up surveys in May 2001 (Appendix A). The two lairs found in Nov./Dec. and still active in March were also still active in May. The other lairs found in Nov./Dec. and frozen in March were still frozen in May. With the exception of one breathing hole (A13), all structures (breathing holes and lairs) that were frozen in March remained frozen in May. The breathing hole from Nov./Dec. that became an active lair in March was still open in May. Of the eight remaining breathing holes that were open when found in December and again

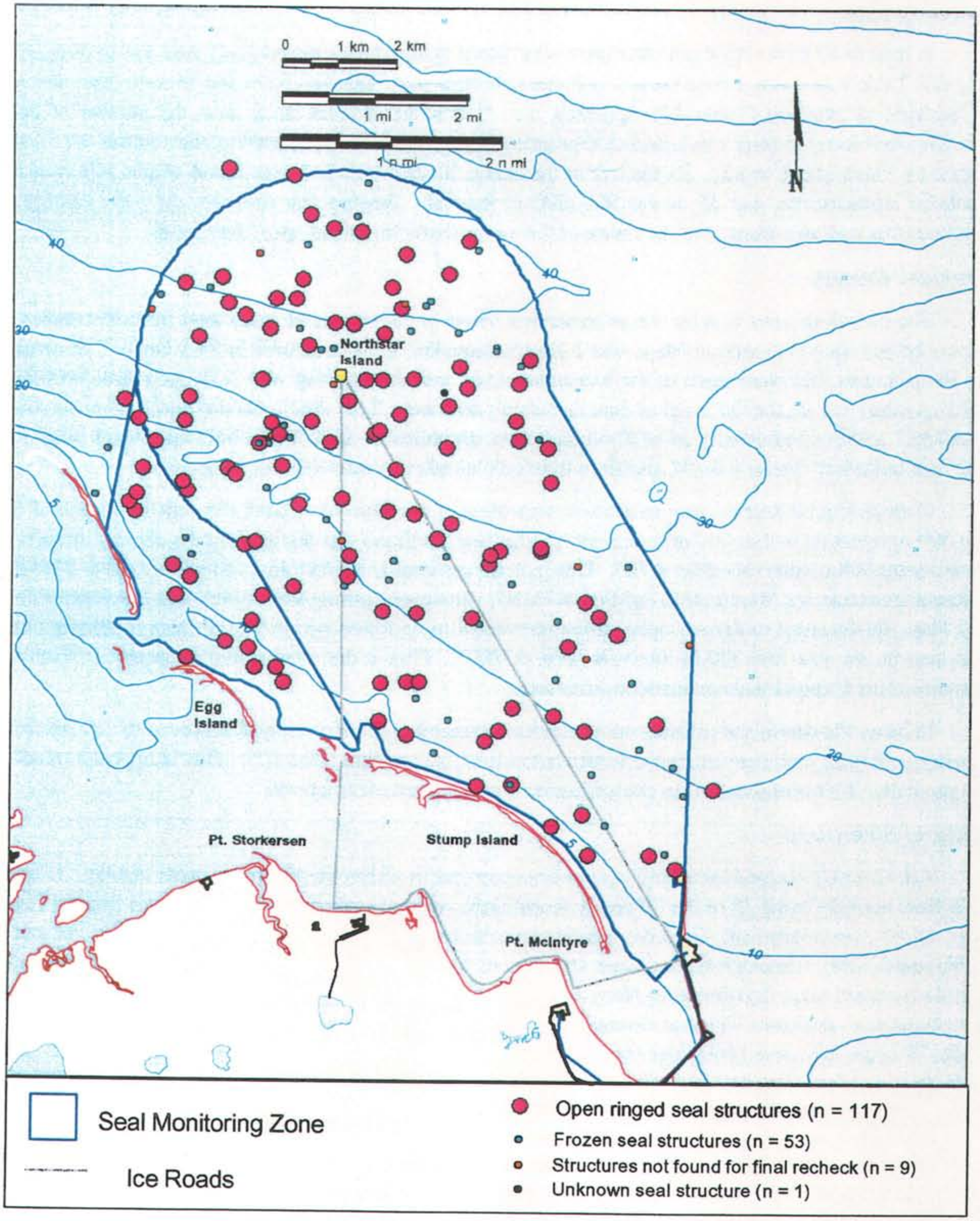


FIGURE 4.10. Locations and status (active or frozen) for the final recheck (as of 22 May) for all structures found near Northstar Island, the primary ice road, and the pipeline alignment during the Nov. 2000 – May 2001 period.

when re-checked in March, one was frozen in May (A11). One breathing hole (A15), which was frozen in March, but not found in May, was presumed to be frozen. Overall, of the 35 structures located in Nov./Dec. 2000, 23 (66%) were frozen by March 2001, and 24 (69%) were frozen by May 2001.

Fourteen of the 20 open, active lairs first located in March (Table 4.2) were still open in May. Twenty of the 39 open breathing holes first located in March were still open in May. The remaining 19 breathing holes were frozen including one not found (B16) and presumed to be frozen. Overall, 26 of 60 structures (43%) first located in March 2001 were frozen by 22 May 2001.

### *Transition of Structure Type*

The transition of structures from one type to another indicates a change in the manner of use of structures by ringed seals. We have not yet evaluated the seasonal trends in use in any detailed way. However, of the structures first located in Nov./Dec. 2000 and re-examined by 22 May 2001,

- three breathing holes were subsequently converted into lairs (one was abandoned by March);
- four lairs were excavated and subsequently used only as breathing holes when re-examined; and
- none of the structures were converted into basking locations.

Of the structures first located during March 2001 and re-examined by 22 May 2001,

- five breathing holes were subsequently converted into lairs (none were frozen);
- six lairs were excavated and subsequently used only as breathing holes when re-examined (three were frozen);
- five breathing holes were subsequently converted to basking locations (one was frozen); and
- three lairs were opened to the surface as basking locations.

Of the structures first located during early May 2001 and re-examined by 22 May 2001,

- eight lairs were excavated and subsequently used only as breathing holes (four were frozen);
- two breathing holes were opened to the surface as basking locations (none were frozen); and
- seven lairs were excavated that later were opened to the surface as basking locations.

## *Temperature Sensor Data*

In November/December 2000, 25 temperature sensors were installed in four lairs and 21 breathing holes (Table 4.4). One structure (00BH04; A4 in Fig. 4.3), open when first found on 26 Nov. 2000, was frozen when we returned to install a temperature sensor on 7 Dec. 2000. We re-opened the breathing hole manually and installed a sensor, but the thermistor data showed the structure refroze immediately. In January 2001, 11 of the 25 sensors were removed from frozen structures (two lairs and nine breathing holes). By the time ice road construction was temporarily suspended for the holidays (23 Dec. 2000 to early January 2001), nine of the eleven frozen structures had already frozen. The two other structures froze on 30 Dec. and 17 Jan. 2001. The 14 remaining sensors logged data until March 2001. Three structures froze between the intermediate status check on 17 and 18 Jan. 2001 and the March survey. One froze on 17 Jan. shortly after the status check, one on 14 Feb. 2001, and the remaining structure was frozen by 6 March 2001 (data logger malfunction). The remaining eleven sensors continued to log data until 21 May 2001.

In March 2001, 28 additional temperature sensors were deployed. Initially the sensors were installed in seven breathing holes and 21 lairs; however, due to the easier deployment and installation in lairs and the better quality of data obtained in lairs, three sensors were removed from breathing holes and re-deployed in lairs found during searches later in March. Twenty-six of 28 sensors logged data until 21 May. One was removed on 8 May during the re-check of the structure and one was lost.

On 8 May 2001, two additional temperature sensors were deployed; both were installed in lairs. These sensors logged data until 21 May.

TABLE 4.4. Date of abandonment indicated by temperature sensor data in the instrumented structures during the study.

| Structure | Period with Sensor Installed (x) | | | Date | # of Days between |
|---|---|---|---|---|---|
| | Nov to Jan | Jan to March | March to May | Frozen[1] | Installation & Abandonment |
| 00LA03 | X | - | - | 05-Dec-01 | 8 |
| 00BH04 | X | - | - | 07-Dec-01 | 0* |
| 00BH07 | X | - | - | 04-Jan-01 | 37 |
| 00BH10 | X | - | - | 15-Dec-00 | 17 |
| 00BH11 | X | X | X | (14-May-01)[2,a] | - |
| 00BH14 | X | - | - | 10-Dec-01 | 12 |
| 00BH16 | X | X | - | 14-Feb-01 | 76 |
| 00BH17 | X | X | - | 17-Jan-01 | 48 |
| 00BH18 | X | - | - | 02-Dec-00 | 2 |
| 00BH20 | X | - | - | 03-Dec-00 | 2 |
| 00BH21 | X | - | - | 09-Dec-00 | 7 |
| 00BH22 | X | - | - | 30-Dec-00 | 27 |
| 00LA06 | X | - | - | 07-Dec-00 | 4 |
| 00BH23 | X | X | X | (17-May-01)[2,b] | - |
| 00BH25 | X | X | X | (06-Mar-01)[2,c] | - |
| 00BH26 | X | - | - | 08-Dec-00 | 1 |
| 00LA07 | X | X | - | (06-Mar-01)[2,a] | - |
| 01LA04 | - | - | X | 11-Mar-01 | 8 |
| 01LA06 | - | - | X | 14-Mar-01 | 10 |
| 01LA10 | - | - | X | 01-May-01 | 58 |
| 01LA11 | - | - | X | 21-Mar-01 | 14 |
| 01LA17 | - | - | X | 27-Mar-01 | 16 |
| 01LA19 | - | - | X | (21-May-01)[2,a] | - |
| 01LA23 | - | - | X | (14-May-01)[2,a] | - |

[1] Day after the final internal temperature increase within the structure.

* Structure was frozen when rechecked for installation on 7 Dec. 2000.

[2] Latest date from recheck: [a] (logger malfunction); [b] (logger destroyed); [c] (logger lost)

Thirty-one instrumented structures remained open until late May. Eight instrumented structures remained open for the entire study period (Nov./Dec. 2000 to May 2001). Twenty-four structures equipped with temperature sensors were abandoned and eventually froze during the study. Approximate abandonment dates were recorded for 18 of these structures. The abandonment dates for the remaining 6 structures were unknown due to sensor malfunction or sensor destruction by animals (seals or foxes). The number of days between the installation of the sensor in the structure and the presumed abandonment of the structure varied widely (range 1-76 days). Researcher impact may have been responsible for the abandonment of certain instrumented structures, specifically 00BH04, 00BH18, 00BH20, 00BH26, and 00LA06, given the small number of days between instrumentation and abandonment.

## *Ringed Seal Sightings*

Two dead pups were found in lairs during this study. *(1)* On 7 March 2001 we found a dead male pup in a lair approximately 2.5 mi (4 km) southwest of Northstar Island, near Long Island in structure B50 (Fig. 4.8). The pup was sent to veterinarian, Dr. John Blake, of the University of Alaska Fairbanks (UAF) via the Alaska Marine Mammal Tissue Archival Program (Geoff York, U.S. Geological Survey). The cause of death for the pup was unknown, although there was no evidence the pup ever nursed and the umbilicus was still present and fresh-looking. *(2)* On 11 May 2001, we found a dead female pup in a lair approximately 1.1 mi (1.8 km) northeast of Northstar in structure B44 (Fig. 4.8). The pup was more decomposed than the first and a necropsy determined that the pup was most likely stillborn. There were no signs of predation or industrial activity at either location. Snow depth at this location (B44) was in excess of 3 ft (1 m).

A total of 57 of the seal structures found or re-checked in May were classified as basking sites based on the criteria described in the "Methods". In May, we located 36 basking sites. Two additional breathing holes and 11 lairs first found in May were converted into basking sites by 22 May. Seals were sighted at 32 of these 57 basking locations. A total of 44 individuals were sighted at the 32 locations, but many sightings were likely repeated sightings of the same individuals. At eight of the basking locations, we saw a seal on more than one day during May. No structures located during Nov./Dec. were converted into basking sites by late May. Only eight (five breathing holes and three lairs) of the 60 structures located during March were used as basking sites in May.

Many seals near the ice roads did not respond to passing vehicle traffic. When we approached new structures where seals were hauled out, the seals typically did not dive until the dog(s) were within 300 ft (91 m). On at least two occasions the dogs approached within about 50 ft (15 m) before the seal dove into the hole. Thirteen of the haulout locations had small amounts blood around the basking hole or within the melted depression adjacent to the hole.

## DISCUSSION

### *Ringed Seal Density and Winter Ecology*

The density of all ringed seal structures (both open and frozen) that had been located by the end of May (2.06 structures/km$^2$) is within the range of structure densities (0.81 to 3.6 structures/km$^2$) estimated for this area during the March-May period by Kelly et al. (1986) and Frost and Burns (1989). Considering only the structures that were open and active in May 2001, the density of structures was 0.83 structures/km$^2$.

This study also confirms the speculations of Furgal et al. (1996) regarding structure evolution as the season progresses. The continuous evolution of structure use, as well as the apparent creation of new structures throughout the ice-covered season, suggest that ringed seals are able to respond to highly variable habitat availability. Transitions between structure types were common, with basking structures being a final structure type that became evident late in the ice-covered season. It is interesting to note that a majority (36 of 57; 63%) of the basking structures found in May had not been found, as another structure-type, earlier in the season. Only a minority (21 of 128; 16%) of the basking structures found in May had been converted from other types of structures found during earlier searches. Some structures are apparently created in April and May specifically for basking. During the 8-month (approx.) ice-covered season, it is likely that, through changes in utilization of various structures, ringed seals are able to adapt to local variability and changes in snow cover, predator pressure, intraspecific competition, and food availability (Hammill and Smith 1989).

The detection of seven lairs during November and December 2000 supports previous results (Williams et al. 2001) that some ringed seals overwintering near Northstar begin to excavate and use lairs early in the winter. Our findings are consistent with the hypothesis that the timing of lair construction depends on snow accumulation and consolidation. Construction of lairs apparently begins as soon as snow accumulates to sufficient depth and consolidates enough for a chamber to be excavated.

In December 1999, Williams et al. (2001) found structures with a strong odor of reproductively active, male ringed seals (*tiggak*) in the same area as this study. We did not find any structures with the tiggak odor in November or December 2000. The searches in 1999 were conducted from 2 to 8 Dec.; the searches in 2000 were conducted from 24 Nov. to 8 Dec. 2000. Evidence from samples collected in January indicate that there can be spermatozoa in the epididymis of male ringed seals at that date (Nazarenko 1968). Furgal et al. (1996) and Smith and Stirling (1976, 1978) identified "tiggak" structures from April to June, and in 2001 we found many "tiggak" structures in March and May.

It is unclear what may have caused the mortality of the two pups found during the searches in March and May 2001. These pups were 4 km and 1.8 km from Northstar Island. There was no obvious indication of either predation or human involvement. Williams and Perham (2000) reported a dead pup that B. Kelly found in a lair on 22 May 1999 ~1.5 km east of the Northstar ice road in a season when there had been minimal activity at Northstar other than construction of the ice roads. That pup was not necropsied and the cause of death was not determined. The rate of pup mortality, from causes other than predation, is unknown. The date of birth (7 March or earlier) is earlier than previously recorded for this latitude (T. Smith, pers. obs.).

The small amounts of blood found at some of the basking locations were likely the result of seal interactions during mating, from scratching during the molt, or possibly from territorial aggression directed at competing males. It has been suggested that sub-adult seals may depend on breathing holes created by adults, and may be susceptible to increased agonistic interactions if adults abandon structures due to industrial activities (B. Kelly, pers. comm.). However, this scenario seems unlikely given previous studies indicating that subadult seals are actively excluded from the prime breeding habitat in the stable landfast ice (McLaren 1958; Smith 1973; Lydersen and Gjertz 1987; Holst et al. 1999). Reproductive males are thought to become more territorial in the late winter and early spring and defend their breathing holes and lairs or some space beneath the ice in the area of the holes, which they have maintained (Smith and Hammill 1981a,b).

## *Northstar Effect on Structure Use?*

Our data show no widespread evidence that the use by ringed seals of the landfast ice near Northstar Island or the ice roads was much different than that of the ice 2 – 3.5 km away (Fig. 4.7). In both Nov./Dec. 2000 and May 2001, the density of active seal structures was higher within 2 km of Northstar activities than 2 – 3.5 km away. In March 2001 the density of active structures 0 – 0.5 km away was lower than that farther away, and the density of frozen structures was marginally higher than that farther away. Additionally, in May there was a slightly lower density of active structures within 0.5 or 1 km relative to that 1 – 2 km from Northstar activities. These results probably indicate that any Northstar effect on the number of active structures was quite localized and may be seasonally influenced.

An alternative possibility is that there was an effect that extended far enough (at least 3 or 3.5 km) to affect the full study area. However, if that were the case, one would expect a stronger effect at the closer than at the farther distances within the monitored area. The densities of structures calculated for various distance intervals out to 3.5 km did not show a trend for increasing density at distances out to 3 or 3.5 km. To the extent that there was any such a trend (e.g., in March 2001), it did not appear to extend beyond ~0.5 or at most 1 km. Also, if seal numbers in the area during spring were reduced out to anything approaching 3 km, this would have been evident during our intensive and systematic aerial surveys. No such effect was evident during either 2001 or 2000 (see Chapter 5 and Moulton et al. 2001). In fact, during 2001, densities of basking seals as evident during aerial surveys in late May and early June decreased significantly, rather than increasing, with increasing distance from Northstar facilities (see Fig. 5.13 and 5.18 *in* Chapter 5).

Overall densities of active structures (or of seals hauled out on the ice during aerial surveys) might not reveal subtle effects of industrial development on the types of structures present, transitions from one structure type to another, or structure abandonment rates, if any such effects occur. We have not analyzed these possibilities in detail. However, we observed similar types of structures, and substantial numbers of new structures during March and May, in all distance intervals. In March there was an indication of a lower density of active structures near Northstar activities, and perhaps a slightly higher density of abandoned structures close to Northstar. However, the relationship between densities of abandoned structures and distance was weak in March, and not evident in May (Fig. 4.7B,C). Structures used by ringed seals are not distributed randomly and are usually concentrated along pressure ridges, cracks, leads, or other surface deformations (Smith and Stirling 1975; Furgal et al. 1996). Habitat features are distinguished by seals and utilized as needed during the ice-covered season, and have a large influence on the distribution of structures on the sea ice.

If Northstar was responsible for the lower density of active structures within 0.5 km of Northstar infrastructure in March, this effect was reduced by May (Fig. 4.7B,C). It is possible that continuous active flooding around the island and along the ice roads from November to March reduced the number of new cracks forming near Northstar activities during these months, thereby reducing the availability of cracks for exploitation by seals. Active flooding ceased after March. One might predict that ice of "natural thickness" (~6 ft; 2 m) adjacent to the thickened areas (8-10 ft; 2.5-3.2 m) would crack more easily than the thickened ice during tidal and storm surges. This might account for a seemingly reduced "Northstar effect" late in the ice-covered season as cracks become available for seals to use.

Ringed seals seem to prefer areas that accumulate snow early and continuously throughout the winter. When we initiated our searches on 24 Nov. 2000, a majority of the ice was less than two feet thick. The surface of the ice had fresh ice crystals and little snow cover. The available snow accumulation in the area was extremely limited and dictated where the ringed seals could create early-winter lairs. We found two active lairs in the lee of surface deformations immediately adjacent to the centerline of the (subsequently-built) primary ice road, even though surveyors had been working along the area the week before finding the lairs. The surrounding area was otherwise very flat ice, and the deformation in the snow and ice used by the seals may have been the result of the survey. When we were first on the ice in November, the sheets of ice were still mobile and seawater often surfaced through cracks between adjoining sheets.

The distribution of structures throughout the study area appeared patchy. Apparent "clumping" can occur even when locations are random, and we have not analyzed the spatial patterns in the distribution of the structures. Ringed seal structures are generally not distributed randomly because habitat suitable for lairs depends on ice deformation and snow cover. Therefore, a patchy distribution of structures would be expected based on both fine-scale and larger-scale variation in habitat. The influence of the barrier islands in creating deformed ice adequate for snow accumulation and subsequent lair excavation may account for the high proportion of lairs found in the area immediately north of Stump Island in Nov./Dec. Northeast of the primary ice road, the ice was a flat continuous sheet with little surface relief. Adjacent areas contained small hummocks and ridges, habitat typically used by seals to construct lairs. Data on ice deformation acquired during aerial surveys indicated that the closest areas with lightly deformed ice were 2 – 3 km northeast of Northstar Island (see Fig. 5.5 *in* Chapter 5) at the edge of our study area. Lairs were found at all distances from the barrier islands out to the outer edge of the study area, in an area described in Chapter 5 as 0-10% deformed (see Fig. 5.5). This indicates that snow accumulation was adequate throughout the study area. However, observations of surface deformations by aerial observers and personnel on the sea ice are difficult to compare directly.

Ringed seals abandon breathing holes and lairs naturally in response to predation, lack of snow, or changing ice conditions (Kelly et al. 1988; Frost and Burns 1989). Kelly et al. (1988) estimated the natural abandonment rate of seal structures in shore-fast ice to be 4% over the late February or March to June interval, based on studies in the Beaufort Sea (Reindeer Island area) from 1983 through 1987. The number of frozen structures located by dogs during the first search over a given area of sea ice was used to calculate the 4% natural abandonment rate (Kelly et al. 1988; Frost and Burns 1989). However, the detection rate of frozen structures, and its dependence on time since last use, are unknown and difficult to assess. It is likely that the detection rate by dogs decreases as the seal scent dissipates over time.

Natural abandonment of structures suggests that ringed seals adapt to changes in their habitat during the course of the winter. Anthropogenic activities, however, may increase abandonment rate. Kelly et al. (1988) reported a significant increase in abandonment rate of seal structures near industrial activities relative to those distant from industrial activities. We have not yet fully analyzed rates of structure creation, transition, and abandonment in relation to distance from Northstar during the winter of 2000-2001.

Structure status can change from open to frozen (abandoned), or from frozen to open (re-occupied), depending on the time of the season and other factors that influence the use of structures by ringed seals. As the winter progresses, ringed seals are able to reopen a previously frozen structure and to create new structures either through newly formed cracks or possibly even through solid ice (Hammill 1987). Little is known about the ability of seals to create new structures through thick ice, but some evidence indicates that it might occur (M. Hammill and T. Smith, pers. comm.). We have documented that a frozen structure is not necessarily a permanently abandoned structure. Two structures frozen in Nov./Dec. 2000 were open in March 2001, and one structure frozen in March was open in May. Williams et al. (2001) found one open structure in May 2000 that had been frozen when first located in Dec. 1999. These results indicate that structure abandonment may not be a direct indicator of biologically significant impact to ringed seals. Further analyses of the existing data on seasonal structure use may provide further evidence relevant to this hypothesis.

Finally, there is a need to consider the impact of our own monitoring activities on seal structures, as this disturbance may have been more immediate and severe than that of industry. The impact due to the presence of researchers was generally similar at all structures within the monitored area regardless of distance from Northstar. (The "monitoring zone addition" in the southwestern part of the study area was an exception, as this area was not searched until March.) The timing and number of visits to different structures within our study area varied, and this may provide some basis for assessing investigator effects. Kelly et al. (1988) reported structure abandonment of 32.7% due to investigator disturbance and industrial disturbance. We have not yet examined the existing data to determine if they provide information about the impact of our investigations.

## *Monitoring Approach and Effectiveness*

Currently, use of trained dogs provides the only effective method with which to locate ringed seal structures in the ice. Relative to previous dog-assisted searches for seal structures during the ice-covered season of 1999-2000 (Williams et al. 2001), the present methodology for monitoring seal structures has improved. For example, the 1999-2000 study lacked a survey for new structures in March or a complete survey in May. Therefore, Williams et al. (2001) were only able to determine the proportion of the early-winter structures that had been abandoned by 20 May 2000, and the presence in May of many structures that were either absent or undiscovered during early winter search. The present study was standardized and used a more comprehensive methodology with three survey periods, and double coverage of the search area per survey period. This study provides a better basis for estimating the rate at which structures are created and abandoned throughout the ice-covered season. Even so, the estimated rates of structure-creation will be artificially high due to structures missed during the previous survey period. This bias, however, will be comparable throughout the study area and study period, given that the same search methodology was used throughout.

One limitation of the present methodology is that it cannot verify what proportion of the structures present are found by dogs during the two searches within each study period. Hammill and Smith (1990) suggested that four or more surveys are needed to obtain an accurate estimate of the number of seal structures within a study area. Hammill and Smith (1990) used a removal method to determine the proportion of structures found by dogs and to estimate more accurately the number of structures present. It is unknown if the low density of structures in the central Alaskan Beaufort Sea may allow accurate estimates with only two surveys, or (conversely) whether more search effort would be required in the Alaskan Beaufort than in areas of higher density. Previous studies have shown that even researchers conducting multiple surveys with trained dogs cannot confirm that they have located every structure present. If the objective of searches is to estimate the number of structures present and their turnover rate during the winter, then failure to detect some of the structures constitutes a bias. However, if the objective is to determine the fate of a sample of the structures present, then detection of only a significant fraction of the structures present may be satisfactory. These searches provide an index of the abundance of ringed seal structures. Consistent methodology from survey to survey will provide a basis for comparisons, but much remains unknown regarding structure creation, abandonment, reoccupation, and the dog's relative ability to detect different types of structures and those previously abandoned.

It is likely that locating and excavating structures mimics natural predation and therefore influences the continued use of structures by ringed seals. In the early winter, ringed seals may be more sensitive to physical disturbance of their structures and thus our monitoring actions may have contributed to the high proportion of structures abandoned from Nov./Dec. to May. Alternatively, ringed seals may be more mobile in early winter because of shifting ice and accumulating snow, naturally abandoning and creating structures at a faster rate than later in the winter and spring. In particular, Hammill and Smith (1990) reported that repeated dog-assisted surveys of the same area over several days caused some seals to abandon their structures. Frost and Burns (1989) reported investigator-induced abandonment as well. The details of investigator effects, their relationship to the number of times or dates the structure is visited, and whether structure abandonment has significant biological effects on these seals is yet to be determined.

## SUMMARY

Trained dogs were used to locate ringed seal structures near BP's Northstar construction and drilling activities during three survey periods in late 2000 and early-mid 2001. Within that area, approximately 136 km (84 mi) of transects were searched with dogs from 24 November to 8 December 2000. Also, 210 km (130 mi) of transects were searched from 2 to 13 March 2001, and 272 km (169 mi) of transects were searched from 4 to 21 May 2001. Additionally, temperature sensors and data loggers were placed in ringed seal structures to determine if temperatures within the structures could be used to determine dates and times when seals were present and absent.

During the Nov./Dec. 2000 survey, a total of 35 ringed seal structures (0.46 structures/km$^2$ or 1.1 /mi$^2$) were located in the 75.3 km$^2$ (29.1 mi$^2$) study area. Of these structures, 28 were breathing holes and 7 were lairs. Overall, 32 of the 35 structures were in active use (27 breathing holes and 5 lairs). The density of active structures was higher in each 500-m (0.3 mi) interval between 0 and 2 km (0 – 1.2 mi) from existing or planned Northstar facilities than in each such interval from 2 to 3.5 km (1.2 – 2.2 mi) away. During this Nov./Dec. period, Northstar Island was active but work along the primary ice road was just beginning.

During the second survey, in March 2001, a total of 60 new ringed seal structures were found in a slightly expanded study area of total area 84.5 km$^2$ (32.6 mi$^2$). Forty of the structures were breathing holes and 20 were lairs. Fifty-nine of the 60 new structures were open and active (39 breathing holes and 20 lairs) and were widely distributed in the study area. Overall, 23 of the 35 structures (66%) located during the Nov./Dec. 2001 survey had been abandoned by March 2001. In total, at least 95 structures had been used in the study area by 13 March (1.1 structures/km$^2$ or 2.9 /mi$^2$). Of these, 71 were active in March. The density of open, active structures was lower within 500 m (0.3 mi) of Northstar facilities (0.35 /km$^2$ or 0.90 /mi$^2$) than in other 500-m intervals out to 3.5 km (0.70 to 1.30 /km$^2$, or 1.8 to 3.4 /mi$^2$). In March, the density of frozen (abandoned) seal structures was slightly higher within 500 m of Northstar activities than at greater distances.

During the final survey in May 2001, a total of 79 new ringed seal structures were found in the study area. Forty-two of the structures were breathing holes, 36 were lairs, and 1 was of unidentified type. All 42 breathing holes and 35 of the 36 lairs were in active use by ringed seals. The status of all previously located seal structures was also determined during the May 2001 survey. Of the 35 structures located in Nov./Dec. 2000, 68% (19 breathing holes and 5 lairs) had been abandoned by late May 2001. Of the 60 structures located in March 2001, 42% (20 breathing holes and 5 lairs) had been abandoned by May 2001. Additionally, 8 of the 78 (10%) identified structures first located in May were abandoned by 22 May 2001 (2 breathing holes and 6 lairs). During May, the density of open (active) structures was higher in each 500-m (0.3 mi) interval between 0 and 2.5 km (0 – 1.6 mi) from Northstar facilities than in the two more distant intervals. However, there was a slight tendency for density to increase with increasing distance inside the 0 to 2 km zone. The density of frozen (abandoned) structures increased with increasing distances up to 1.5 km (0.9 mi) from Northstar facilities, contrary to expectation if Northstar was causing abandonment of structures.

During all surveys combined, a total of 173 structures were located in the revised study area (2.0 structures/km$^2$ or 5.3 /mi$^2$). Of these, 113 (65%) were in active use on 22 May 2001.

During the three survey periods, 40 temperature sensors were installed in 55 ringed seal structures (25 breathing holes and 30 lairs). Twenty-four of 55 instrumented structures were abandoned during the study. We were able to determine the date of abandonment for 18 of the 24 structures instrumented. Nine instrumented structures froze by 23 Dec. 2000, during early ice road construction. Three more instrumented structures froze between 23 Dec. 2000 and 17 Jan. 2001, during the holiday break in ice road construction. Three more instrumented structures froze by 14 March 2001 (the end of our search period in March), and the three remaining instrumented structures were frozen by 21 March, 27 March, and 1 May 2001. Temperature sensors may also provide data concerning impacts of the research on seal structures, as well as seasonal use of structures.

The evolution of structure use, the abandonment of some structures, and the apparent creation of new structures suggest that ringed seals are well adapted to variable habitat conditions during winter and spring. Although anthropogenic activities (e.g., industrial activities) may increase the rate of structure abandonment by ringed seals, structure status can change from abandoned to re-occupied depending on the time of the season and other factors. Therefore, structure abandonment may not be uniquely important as an indicator of a biologically significant impact to ringed seals during winter.

Results from this study suggest that the abandonment rate for structures within 3.5 km (2.2 mi) of Northstar and the associated on-ice activities was higher than reported previously for similar activities, and substantially higher than the reported "natural" abandonment rate. However, the abandonment rates derived by our methodology may not be comparable to those of previous investigators. Also, within 3.5 km, the abandonment rate as evident in May was lower close to Northstar facilities than farther away. Also, any reduction in number of active seal structures per unit area was limited to an area extending no more than 0.5 – 1 km (0.3 – 0.6 mi) from Northstar facilities. One complication is the unknown impact of our own monitoring activities on seal use of the area. Nonetheless, the continued presence of ringed seals near Northstar throughout the winter, at densities similar to those farther away, and the creation of new structures near Northstar during winter, suggest that any negative effects to seals may be minor and highly localized.

## ACKNOWLEDGEMENTS

This study was conducted for BP Exploration (Alaska) Inc. We thank Dave Trudgen, Bill Streever and Allison Erikson of BP for their support. We thank Bob Hall, Earl Beverly, and Jeff Huey of BPXA and Jim Workman, Randy Greenway, and Ken Yockey of Alaska Interstate Construction for their logistical support. The Hägglunds drivers Marcel, Bruce, and John were extremely helpful and patient. We thank Jonah Levitt and Billy Adams, who worked with us and shared their knowledge of ringed seals and sea ice. Thanks to Valerie Moulton and Shawn Haskell, both of LGL, for their help with field work and data collection. Thanks to Jessy Coltrane and Steve MacLean for help with data analyses and review of early drafts of this report. Thanks to Tom Simpson of Riverrun Kennels for helping in the field and keeping us laughing. Drs. Bill Streever (BP) and W. John Richardson (LGL) reviewed previous versions of this report. Finally, this project would have been impossible without the help of the dogs, Taps, Mist, Breeze, Madison, Otter, and Corky.

## LITERATURE CITED

Burns, J.J. 1970. Remarks on the distribution and natural history of pagophilic pinnipeds in the Bering and Chukchi seas. **J. Mammal.** 51(3):445-454.

Frost, K.J. and J.J. Burns. 1989. Winter ecology of ringed seals (*Phoca hispida*) in Alaska. Outer Cont. Shelf Environ. Assess. Progr., Final Rep., NOAA Proj. RU-232, Anchorage, AK (1989). 108 p. Contract NA-81-RAC-00045.

Furgal, C.M., S. Innes and K.M. Kovacs. 1996. Characteristics of ringed seal, *Phoca hispida*, subnivean structures and breeding habitat and their effects on predation. **Can. J. Zool.** 74(5):858-874.

Hammill, M.O. 1987. Ecology of ringed seal (*Phoca hispida* Schreber) in the fast-ice of Barrow Strait, Northwest Territories. Ph.D. thesis, Dep. Renewable Resources, Macdonald College of McGill University, Montreal, Que. 108 p.

Hammill, M.O. and T.G. Smith. 1989. Factors affecting the distribution and abundance of ringed seal structures in Barrow Strait, Northwest Territories. **Can. J. Zool.** 67(9):2212-2219.

Hammill, M.O. and T.G. Smith. 1990. Application of removal sampling to estimate the density of ringed seals (*Phoca hispida*) in Barrow Strait, Northwest Territories. **Can. J. Fish. Aquatic Sci.** 47(2):244-250.

Hardy, M.H., E. Roff, T.G. Smith and M. Ryg. 1991. Facial skin glands of ringed and grey seals, and their possible function as odoriferous organs. **Can. J. Zool.** 69(1):189-200.

Holst, M., I. Stirling and W. Calvert. 1999. Age structure and reproductive rates of ringed seals (*Phoca hispida*) on the northwestern coast of Hudson Bay in 1991 and 1992. **Mar. Mamm. Sci.** 15(4):1357-1364.

Kelly, B.P. and L.T. Quakenbush. 1990. Spatiotemporal use of lairs by ringed seals (*Phoca hispida*). **Can. J. Zool.** 68(12):2503-2512.

Kelly, B.P. and D. Wartzok. 1996. Ringed seal diving behavior in the breeding season. **Can. J. Zool.** 74(8):1547-1555.

Kelly, B.P., L. Quakenbush and J.R. Rose. 1986. Ringed seal winter ecology and effects of noise disturbance. Outer Cont. Shelf Environ. Assess. Program, Final Rep. Princ. Invest., NOAA, Anchorage, AK 61(1989): 477-536. 536 p. OCS study MMS 89-0026; NTIS PB89-234645.

Kelly, B.P., J.J. Burns and L.T. Quakenbush. 1988. Responses of ringed seals (*Phoca hispida*) to noise disturbance. p. 27-38 *In:* W.M. Sackinger, M.O. Jeffries, J.L. Imm and S.D. Treacy (eds.), Port and Ocean Engineering under Arctic Conditions, Vol. II; Symposium on Noise and Marine Mammals. Geophysical Inst., Univ. Alaska, Fairbanks, AK. 111 p.

Link, M.R., T.L. Olson and M.T. Williams. 1999. Ringed seal distribution and abundance near potential oil development sites in the Central Alaskan Beaufort Sea, spring 1998. LGL Rep. P-430. Rep. from LGL Alaska Res. Assoc. Inc., Anchorage, AK, for BP Explor. (Alaska) Inc., Anchorage, AK. 58 p.

Lydersen, C. and I. Gjertz. 1987. Population parameters of ringed seals (*Phoca hispida* Schrèber, 1775) in the Svalbard area. **Can. J. Zool.** 65(4):1021-1027.

Lydersen, C. and M.O. Hammill. 1993. Diving in ringed seal (*Phoca hispida*) pups during the nursing period. **Can. J. Zool.** 71(5):991-996.

Lydersen, C. and M. Ryg. 1991. Evaluating breeding habitat and populations of ringed seals *Phoca hispida* in Svalbard fjords. **Polar Record.** 27(162):223-228.

McLaren, I.A. 1958. The biology of the ringed seal (*Phoca hispida* Schreber) in the eastern Canadian Arctic. **Fish. Res. Board Can.** Bull. 118. 97 p.

Miller, G.W., R.E. Elliot and W.J. Richardson. 1998. Ringed seal distribution and abundance near potential oil development sites in the central Alaska Beaufort Sea, spring 1997. LGL Rep. TA2160-3. Rep. from LGL Ltd., King City, Ont., for BP Explor. (Alaska) Inc., Anchorage, AK. 43 p.

Moulton, V.D., T.L. McDonald, W.J. Richardson, R.E. Elliott and M.T. Williams. 2000. Fixed-wing aerial surveys of seals near BP's Northstar and Liberty sites, 1999 (and 1997-99 combined). p. 3-1 to 3-71 *In*: W.J. Richardson and M.T. Williams (eds., 2000, *q.v.*). LGL Rep. TA2349-3.

Moulton, V.D., R.E. Elliott, T.L. McDonald and W.J. Richardson. 2001. Fixed-wing aerial surveys of seals near BP's Northstar and Liberty sites, 2000 (and 1997-2000 combined). p. 5-1 to 5-66 *In*: W.J. Richardson and M.T. Williams (eds., 2001, *q.v.*). LGL Rep. TA2428-3.

Nazarenko, Y.I. 1968. Sizes, growth and sexual dimorphism of the ringed seal (*Pusa hispida* Schreber 1775). Marine Mammal Comm. Int. Council for the Exploration of the Sea.

Richardson, W.J. and M.T. Williams (eds.). 2000. Monitoring of ringed seals during construction of ice roads for BP's Northstar oil development, Alaskan Beaufort Sea, 1999. [Final, Dec. 2000.] Rep. from LGL Ltd., King City, Ont., and LGL Alaska Res. Assoc. Inc., Anchorage, AK, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 153 p.

Richardson, W.J. and M.T. Williams (eds.). 2001. Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2000. [Draft, April 2001.] Rep. from

LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 316 p.

Smith, T.G. 1973. Censusing and estimating the size of ringed seal populations. **Fish. Res. Board Can. Tech. Rep.** 427. 26 p.

Smith, T.G. 1980. Polar bear predation of ringed and bearded seals in the land-fast sea ice habitat. **Can. J. Zool.** 58(12):2201-2209.

Smith, T.G. and M.O. Hammill. 1981. Ecology of the ringed seal, *Phoca hispida*, in its fast ice breeding habitat. **Can. J. Zool.** 59(6):966-981.

Smith, T.G. and I. Stirling. 1975. The breeding habitat of the ringed seal (*Phoca hispida*). The birth lair and associated structures. **Can. J. Zool.** 53(9):1297-1305.

Williams, M.T. and C. Perham. 2000. On-ice monitoring of seals along the Northstar ice roads, 1999. p. 2-1 to 2-10 *In:* W.J. Richardson and M.T. Williams (eds., 2000, *q.v.*). LGL Rep. P446-3.

Williams, M.T. and C.J. Perham. 2001. Description of BP's activities, 1999-2000 ice-covered season. p. 2-1 to 2-8 *In*: W.J. Richardson and M.T. Williams (eds., 2001, *q.v.*). LGL Rep. TA2432-6.

Williams, M.T., J.A. Coltrane and C.J. Perham. 2001. On-ice location of ringed seal structures near Northstar, December 1999 and May 2000. p. 4-1 to 4-22 *In:* W.J. Richardson and M.T. Williams (eds., 2001, *q.v.*). LGL Rep. P485-2.

# CHAPTER 5:

# FIXED-WING AERIAL SURVEYS OF SEALS NEAR BP'S NORTHSTAR AND LIBERTY SITES IN 2001 (AND 1997-2001 COMBINED)[1]

by

**Valerie D. Moulton** [a], **Robert E. Elliott** [a], **W. John Richardson** [a] and **Trent L. McDonald** [b]

[a] **LGL Ltd., environmental research associates**
22 Fisher St., POB 280, King City, Ont. L7B 1A6
(905) 833-1244; vmoulton@lgl.com

[b] **Western EcoSystems Technology, Inc.**
2003 Central Ave., Cheyenne, WY 82001
(307) 634-1756; tmcdonald@west-inc.com

for

**BP Exploration (Alaska) Inc.**
**Dept of Health, Safety & Environment**
900 East Benson Blvd., POB 196612
Anchorage, AK 99519-6612

LGL Report TA2570-3

April 2002

---

[1] Chapter 5 *In:* W.J. Richardson and M.T. Williams (eds.). 2002. Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2001. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD.

# INTRODUCTION

This is the fifth in a series of annual reports describing results of intensive, site-specific aerial surveys for ringed seals, *Phoca hispida* (Fig. 5.1), on landfast ice surrounding BP Exploration (Alaska) Inc.'s Northstar offshore oil development and the potential Liberty oil development. The surveys during the spring of 1997, 1998, 1999, 2000, and 2001 (Miller et al. 1998; Link et al. 1999; Moulton et al. 2000a, 2001; this study) provided intensive and replicated survey coverage of this area within each spring season. The 1997 and 1998 surveys were pre-development "control" surveys (although some limited offshore industrial activities occurred around Liberty in early 1997 and east of Liberty in early 1998). The 1999 survey followed limited industrial activity at Northstar. However, construction of the gravel island and pipeline at Northstar did not occur until early 2000. During the following ice-covered season of late 2000 and early 2001, ice roads to Northstar were re-built, facilities were installed on the island, several wells were drilled, supplementary gravel was placed along the subsea pipeline route from the island to the shore, and emergency equipment was tested near the island (see Chapter 2, DESCRIPTION OF BP'S ON-ICE ACTIVITIES).

The high intensity of survey coverage within a 75 × 40 km (46 × 25 mi, or 40 × 22 n.mi.) area was designed to assess possible changes in seal density close to the industrial sites after oil development began. The within-season replication was designed, in part, to allow detection and quantification of distributional effects that might be quite localized. Also, the replication was designed to assess and distinguish the relative contributions of industrial effects and various natural factors (e.g., date in season, ice conditions, bathymetry, weather) on numbers of seals hauled out at different places and times.

These surveys include the essential elements of a Before-After/Control-Impact (BACI) study design. The surveys include areas potentially Impacted by oil development and other Control areas a substantial distance away. These surveys were initiated Before the Northstar and Liberty oil developments began, and have continued After Northstar development began. BACI designs are considered to be optimal for field studies of environmental impact (Green 1979; Underwood 1992). The present study design provides for spatial replication of the "control" areas. It also provides for spatial replication of the "impact" areas if oil development proceeds at Liberty or some other offshore site within the study area, and if the surveys continue (or resume) during development of that second offshore location.

The present study in May and June 2001 was a continuation of the work begun in 1997-2000, using the same survey design and methodology. It was the second year of surveys following the full-scale construction activities at Northstar in 2000. Some disturbance and localized displacement effects on seals overwintering near Northstar were a possibility in early 2001. This study was designed to monitor these potential effects, with allowance for other factors (natural and otherwise) that might influence seal sightings within the study area. No industrial activities are known to have occurred at Liberty during the winter of 2000-2001, so the 2001 surveys provide an additional year of pre-development "control" data for that area.

A Letter of Authorization (LoA) called for BP to conduct monitoring work as had been proposed by BP in the revised monitoring plan submitted to the National Marine Fisheries Service (NMFS) in September 2000. The aerial surveys described here are part of that monitoring program and provide density estimates that are used in calculations of the numbers of seals potentially affected by BP's Northstar activities (see Chapter 9). Thus, ***BP's business rationale*** for inclusion of the present chapter is to address the LoA requirement to conduct the aerial survey component of its monitoring program and to provide densities used to estimate the numbers of seals potentially affected by BP's Northstar activities.

The following subsections provide background information on seals in the study area, along with the specific objectives of this study.

FIGURE 5.1. A ringed seal (*Phoca hispida*). Photograph by I. Stirling, Canadian Wildlife Service.

## *Observed Ringed Seal Densities in the Area*

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), and has conducted such surveys periodically up to 1999 (Frost and Lowry 1988, 1998, 1999; Frost et al. 1988, 1997). Recent ADF&G survey results (mid 1980s to 1998) have been summarized by Frost et al. (1997) and Frost and Lowry (1998, 1999). The survey effort by ADF&G in the 1996-99 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 zones considered to be industrial areas, parallel north-south transects spaced as closely as 1.85 km (1.15 mi; 1 n.mi.) apart are surveyed once each spring season. In other areas the ADF&G transects are 3.7 km apart and at least 60% of the transects are randomly selected to be flown once per year. Relevant density data from those reports are shown in Table 5.1. These studies have included aerial surveys of both fast ice and pack ice habitats. The Northstar and Liberty sites are 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).

Considering only fast ice habitats in sector B3, observed ringed seal densities in 1985-87 and 1996-98 ranged from 0.57 to 2.94 seals/km$^2$. Thus, seal densities observed on fast ice in this sector varied by about a factor of five among these six years of ADF&G surveys. These density estimates include seals sighted both at holes and at cracks.

TABLE 5.1. Observed seal densities (seals/km$^2$) in fast ice for ADF&G sectors B3 and B4 (from Frost et al. 1997; Frost and Lowry 1998, 1999).

| | Sector B3[a] | | | Sector B4[b] |
|---|---|---|---|---|
| Year | Industrial Prospect | Non-Industrial | Overall | Overall |
| 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 | 0.66 |
| 1997 | | | 0.74 | 1.17 |
| 1998 | | | 0.83 | 1.16 |

Note: Results from 1999 were unavailable when this report was produced.

[a] Extends from Oliktok Point (149°51'W) to Flaxman Island (146°03'W).

[b] Extends from Flaxman Island to Barter Island (143°45'W).

Sector B3 has been sub-divided by ADF&G into an "industrial prospect area" and a "non-industrial area". 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 area" than in other fast ice areas within Sector B3 in 2 of 3 years for which data were presented (1986-87 but not 1985; Table 5.1). Observed ringed seal densities in adjacent sector B4 (Flaxman Island to Barter Island, 143°45'W) were generally higher than in Sector B3 in five of the six 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 observed in a control area centered about 23 km (14 mi) west of the Seal Island survey grid averaged 0.66 seals/km$^2$. Both the industrial and control areas were in the landfast ice zone, and the density calculations excluded areas of predominantly rough ice, areas inside the barrier islands, and areas with water <5.5 m (18 ft) deep.

The 1997, 1998, 1999, and 2000 phases of the present study provided specific information about densities of ringed seals observed on the landfast ice near Northstar and Liberty in those years. Considering all surveyed areas >3 m (10 ft) deep, the observed densities in 1997-2000 were 0.43, 0.39, 0.63, and 0.47 seals/km$^2$, respectively. In 1997, 1998, and 2000, densities were highest in shallower water depths. Based on surveys conducted during late May – early June 1997, the highest ringed seal density was observed in depths of 5 to 10 m (0.51 seals/km$^2$; Miller et al. 1998). Similarly, in 2000, densities were highest in water depths ranging from 3-10 m; with the highest density observed in the 5-10 m stratum (0.69 seals/km$^2$; Moulton et al. 2001). In late May 1998, ringed seal densities varied significantly with water depth, and the highest densities were found in water depths of 10 to 15 m (0.59 seals/km$^2$; Link et al. 1999). In 1999, more seals were sighted in deeper water; highest densities were observed in water depths ranging from 10-20 m and 30-35 m (0.88-1.40 seals/km$^2$; Moulton et al. 2000a). All four surveys found very low seal densities in water <3 m deep (0.01-0.09 seals/km$^2$) as compared with densities in areas ≥3 m deep (0.39-0.63 seals/km$^2$). Much of the area <3 m deep is frozen to the bottom by late winter, and the remainder of this area has very little water below the ice.

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 37 km (23 mi) north of the ice edge. Pack ice habitat ≥18.5 km (12 mi) beyond the fast ice edge typically supports observed seal densities of about 0.29 seals/km$^2$. During the six years for which ADF&G data are available (1985-87 and 1996-98), 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; Frost and Lowry 1998, 1999).

Prior to the 1997-2000 phase of this study, there were few data on seal densities in lagoons such as the Stefansson Sound/Foggy Island Bay area where the Liberty Development is planned. Previous spring surveys of seals on the ice in the central Alaskan Beaufort Sea have concentrated on the landfast ice zone seaward of the barrier islands. Some surveys extended south into the more northerly parts of the lagoons, but generally did not attempt to survey the shallower parts of the lagoons. In 1997-2000, BP/LGL seal surveys found (as expected) very low densities of ringed seals in areas <3 m deep (Miller et al. 1998; Link et al. 1999; Moulton et al. 2000a, 2001). However, in 1997-98 and 2000, lagoon areas ≥3 m deep had seal densities similar to those on landfast ice seaward of the barrier islands. The prospective Liberty Development, in lagoon water 6.4 m (21 ft) deep, is an area where ringed seals do occur in late winter/spring.

## Factors Influencing Numbers of Seals Counted

Aerial surveys for ringed seals are usually flown in late May and June in the Alaskan Beaufort Sea when ringed seals haul out on the ice to molt and are therefore most easily counted from the air. However, ringed seals are not uniformly distributed on the ice and not all ringed seals haul out at the same time. Many habitat factors are known or suspected to influence ringed seal abundance and distribution. Similarly, temporal and weather factors likely influence the proportion of ringed seals hauled out and hence available to be counted by observers.

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 (Stirling et al. 1977; Frost et al. 1988). However, some differences are inevitable and the proportion seen will vary with observer abilities and alertness, visibility, and glare. Furthermore, even an attentive observer will see less than 100% of the seals on the ice along the flight track. As compared with many other marine mammals, ringed seals hauled out on the ice are relatively easy to count. They are usually conspicuous because of their dark appearance, which contrasts with the white background, 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 single seals hauled out on the ice within the aerial survey coverage.

### Factors Affecting Seal Abundance and Distribution

Ringed seals inhabit a dynamic physical environment that makes between-year, and even within-year, comparisons of abundance and distribution problematic. Variable levels of ice deformation and snow conditions influence where ringed seals occur during their winter occupation of breathing holes and subnivean lairs (Smith and Stirling 1975, 1978). Frost et al. (1988) speculated that ringed seals prefer flat ice on which to bask, because they are better able to detect predators in areas of unobstructed vision.

Breakup of the sea ice occurs earlier in some years than in others as a result of storm events or mild temperatures. Ice deterioration usually involves the formation of cracks and increased levels of melt water. The formation of cracks during spring break-up can result in an early influx of ringed seals as some individuals may move from unstable pack ice into adjacent areas of landfast ice (Finley 1979). Ringed seal densities observed during spring surveys, especially after the ice starts to deteriorate, may be biased upward by the presence of seals that spent the winter elsewhere (Smith and Harwood 2001). It is thought that pack ice seals may have biased the 1999 BP/LGL survey results upwards as concentrations of seals were observed near cracks extending from the pack ice into the landfast ice (Moulton et al. 2000a). This influx of pack ice seals may increase group size as well (Moulton et al. 2000a). However, group size at holes is also known to increase in stable fast ice as the molt season progresses (Smith and Hammill 1981), probably in response to increased numbers of seals hauling out as molt proceeds and the decrease in availability of suitable haul-out holes due to melt water draining into them. Seals probably avoid hauling out in areas with higher levels of melt water because it is important that their skin be dry and warm to promote the growth of new hair during the molt.

Water depth, which is relatively constant from year-to-year, may also influence seal abundance and distribution. Previous aerial surveys conducted by LGL in the Northstar area have shown that ringed seals are observed most frequently in water depths ranging from 3 to 20 m (10 to 66 ft; Miller et al. 1998; Link et al. 1999; Moulton et al. 2000a, 2001).

### *Factors Affecting the Proportion of Seals Hauled Out*

Both temporal and weather factors influence the proportion of ringed seals that haul out on the ice at any given time. As for other phocids that associate with ice, these factors are known or suspected to include: date within the spring season, time of day, solar radiation, cloud cover, temperature, wind speed, and wind chill (Finley 1979; Smith and Hammill 1981; Thomas and DeMaster 1983; Kovacs 1987; Lydersen and Kovacs 1993; Moulton et al. 2000b). The effects and interactions of these variables are not fully understood. However, the proportion of ringed seals hauled out and the observed seal densities are usually found to be negatively correlated with wind speed (Finley 1979; Smith and Hammill 1981). Multivariate analysis of results from the 1997-2000 BP/LGL surveys indicate that the numbers of seals seen were positively related to cloud cover and negatively related to wind speed, but were not strongly related to air temperature and heat loss (Moulton et al. 2001).

More ringed seals haul out around the mid-day period than at other times of day (Finley 1979; Smith and Hammill 1981; Kelly and Quakenbush 1990). The mid-day period is approximately 11:00-17:00 h in Alaska, where solar noon occurs around 14:00. The multivariate analysis of the 1997-2000 BP/LGL surveys, which were usually conducted between 10:00 and 18:00 h, did not indicate a consistent relationship between time of day (within that range of hours) and seal sighting rate (Moulton et al. 2001).

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, or at different times during the same day, may result in different proportions of ringed seals hauling out on the ice, and thus differences in the observed numbers of seals.

## *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 reported within 3.7 km (2.3 mi) of artificial islands during some but not all years with industrial activity (Frost and Lowry 1988; Frost et al. 1988). In ***1985***, two artificial islands were being constructed (Northstar and Sandpiper islands) and drilling was underway at Seal Island (now referred to as Northstar) during aerial surveys. A 50-70% reduction in seal density was noted within 3.7 km as compared to 3.7-7.4 km (2.3-4.6 mi) away from the three islands in 1985. In ***1986***, in contrast, ringed seal density during one survey was 60% higher within 3.7 km vs. 3.7-7.4 km of Sandpiper Island, the only island active when surveys were flown in 1986. In ***1987***, all three artificial islands were inactive and seal densities were 12-30% lower closer to the islands. All of these results should be treated with caution, as the small amount of survey coverage limits meaningful comparisons of densities relative to distance from the island. Also, analyses did not account for factors like water depth that varied within 3.7 km vs. 3.7-7.4 km from the islands.
- 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.
- Lower seal densities (but non-significantly so) were found near Tern Island, in the Liberty area, during the spring of 1997 after drilling and limited Vibroseis activity occurred months before (Miller et al. 1998). This possible effect was not observed in 1998 when there was no industrial activity in that immediate area.
- Seal densities in an area of Vibroseis activity east of Tern Island in 1998 were significantly lower than those in an adjacent non-Vibroseis area in 1998. No such difference was evident between those same two areas during the previous year when there was no Vibroseis east of Tern Island (Link et al. 1999).

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).

The studies summarized above were not designed specifically to control for the potential effects of other factors known to influence seal abundance and haul-out behavior—weather, local ice conditions, water depth, etc. Moulton et al. (2001) used a multivariate statistical approach to identify and account for those factors that are known or expected to affect ringed seals, based on data from the 1997-2000 phases of the present study. They found no indication of a reduced ringed seal density near the Northstar development in 2000 after allowance for other factors.[2] We hypothesized that the potential effects of the Northstar development on densities of ringed seals close to the Northstar facilities are likely to be even smaller in 2001 and subsequent years, when there will be less ice-road traffic and less construction activity than during 2000.

In most of these studies, with the exception of BP/LGL surveys in 1997-2001, the survey coverage and number of seal sightings close to the industrial operations were small. This limited the ability to detect and quantify any avoidance effect that might exist. The present 1997-2001 study included

---

[2] That analysis also showed no evidence of industry effects on seal density near Liberty in 1997 or the vibroseis area in 1998 after allowance for other factors influencing numbers of seals (Moulton et al. 2001).

intensive site-specific survey coverage, replicated within each year, around the Northstar and Liberty oil development sites. This approach was used in order to obtain larger sample sizes in areas close to the development sites. In addition, the study was designed as a multi-year study. A more comprehensive analysis is possible by combining results from different years into a single overall analysis.

## *Objectives of BP Aerial Survey*

The task that pertained specifically to the fixed-wing aerial survey of seals was summarized in NMFS (2000, p. 34029) as follows:

> *"Continue an ongoing (since the spring, 1997) Before-After/Control-Impact Study on the distribution and abundance of ringed seals in relation to development of the oil and gas resources in the Central Beaufort Sea. Collection and analysis of data before and after construction is expected to provide a reliable method for assessing the impact of oil and gas activities on ringed seal distribution in the Northstar construction area."*

The specific objectives we considered necessary to address the above requirements include the following:

1. Conduct repeated surveys of the study area during spring 2001, consistent with those conducted in 1997-2000, to obtain estimates of the relative abundance and observed density of ringed seals on the fast ice.
2. Determine the observed densities of ringed seals in the study area in relation to weather, time, and habitat variables in 2001.
3. Compare seal densities at varying distances from industrial sites active during early 2001 (especially Northstar).
4. Use a multivariate analysis approach appropriate to determine which factors (environmental and industrial) are related to observed densities of ringed seals on the fast ice, and to characterize the nature of those relationships.
5. Based on the results of (2), (3) and (4), 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.
6. Based on the results of (5), review the adequacy of the study approach, 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.

The fieldwork conducted for this specific study dealt with seals seen on the ice in the spring of 2001, and the "Results" section describes the specific 2001 results. However, the overall study design provided for collection of consistent data from a number of years before and after construction of the Northstar Development. This report includes multi-year analyses based on results from 2001 plus the previous 1997-2000 surveys. Both univariate and multivariate approaches are applied to the combined 1997-2001 data. This part of the work addressed objective (4) from the above list. It is planned that the surveys will continue in a consistent way for one additional spring season (2002), and a final analysis of the combined 1997-2002 data will be completed thereafter.

# METHODS

## *Survey Design*

In 2001, as in 1997-2000, two "grids" of aerial survey transects were flown between longitudes 147°06'W and 149°04.5'W, an east-west extent of about 75 km or 40 n.mi. (46 mi). Each grid consisted of 40 north-south transects spaced 1.85 km or 1 n.mi. (1.15 mi) apart. Each transect extended from the Beaufort Sea shoreline to roughly 37 km (23 mi) offshore or to the edge of the landfast ice if it was encountered and recognizable <37 km offshore (Fig. 5.2). One of the grids that was surveyed included some of the same transects flown by ADF&G during their wider-ranging ringed seal surveys in previous years. The second or alternate grid was offset from the first by 0.9 km (0.6 mi) to the east. In this report, we define a *survey replicate* as a complete survey of the 80 unique transects. In 2001, as in 1998, 1999, and 2000, two complete survey replicates were completed.[3] Survey replicate 1 was flown on 28 May-4 June 2001 and replicate 2 was flown on 4-8 June 2001. In total, 5154 linear kilometers (3203 mi) of surveys were flown over landfast ice by LGL during the 12-day survey period.

A 40-transect grid usually required two days to complete and an 80-transect survey replicate took four days to complete. Ideally, the 20 odd-numbered transect lines from one grid were flown on one day, and the 20 even-numbered lines from that grid were flown on the next day. The odd and even numbered lines from the alternate grid were then (ideally) flown on the third and fourth days. In this way, each day's flight was designed to sample 20 of the 80 distinct transects within the study area, rather than sampling the eastern portions one day and the western portions the next. Thus, the entire study area was to be sampled four times during each replicate survey, and eight times during each year. In 2001, fog or low cloud prevented the timely completion of 20 full transects during two survey days (2-3 June). The coverage of those 20-transect groups was completed on another day. In 2001, the survey took 12 days to complete.

The northern ends of repeated transects varied somewhat from day to day. Northbound transects were usually terminated when we had flown at least 37 km (23 mi) or when it was apparent that we had reached the northern edge of the fast ice.

The southern ends of transects were usually defined by the coastline. However, 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 (0.6-1.2 mi) north of Howe Island to avoid flying close to bird colonies located there.

## *Survey Procedures*

The 2001 surveys, like the 2000 surveys, were flown in a Turbo Commander 690A operated by Commander Northwest Ltd. of Wenatchee, Washington (Fig. 5.3). This twin-engine high-wing aircraft was equipped with turbo-prop engines, a GPS navigation system, and large bubble windows installed in the emergency exits. Two pilots were present during the entire survey.

The survey procedures 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. Surveys were conducted at an altitude of 91 m (300 ft) above sea level (ASL) and a ground speed of 222 km/h (120 knots).

---

[3] In 1997, only one complete survey replicate (Replicate 1: 80 unique transects) was surveyed. Forty of the 80 transects were surveyed two additional times, referenced here as "Replicate 2" and "Replicate 3". Thus, for 1997, Replicate 1 was complete but Replicates 2 and 3 were only 50% complete (Miller et al. 1998).

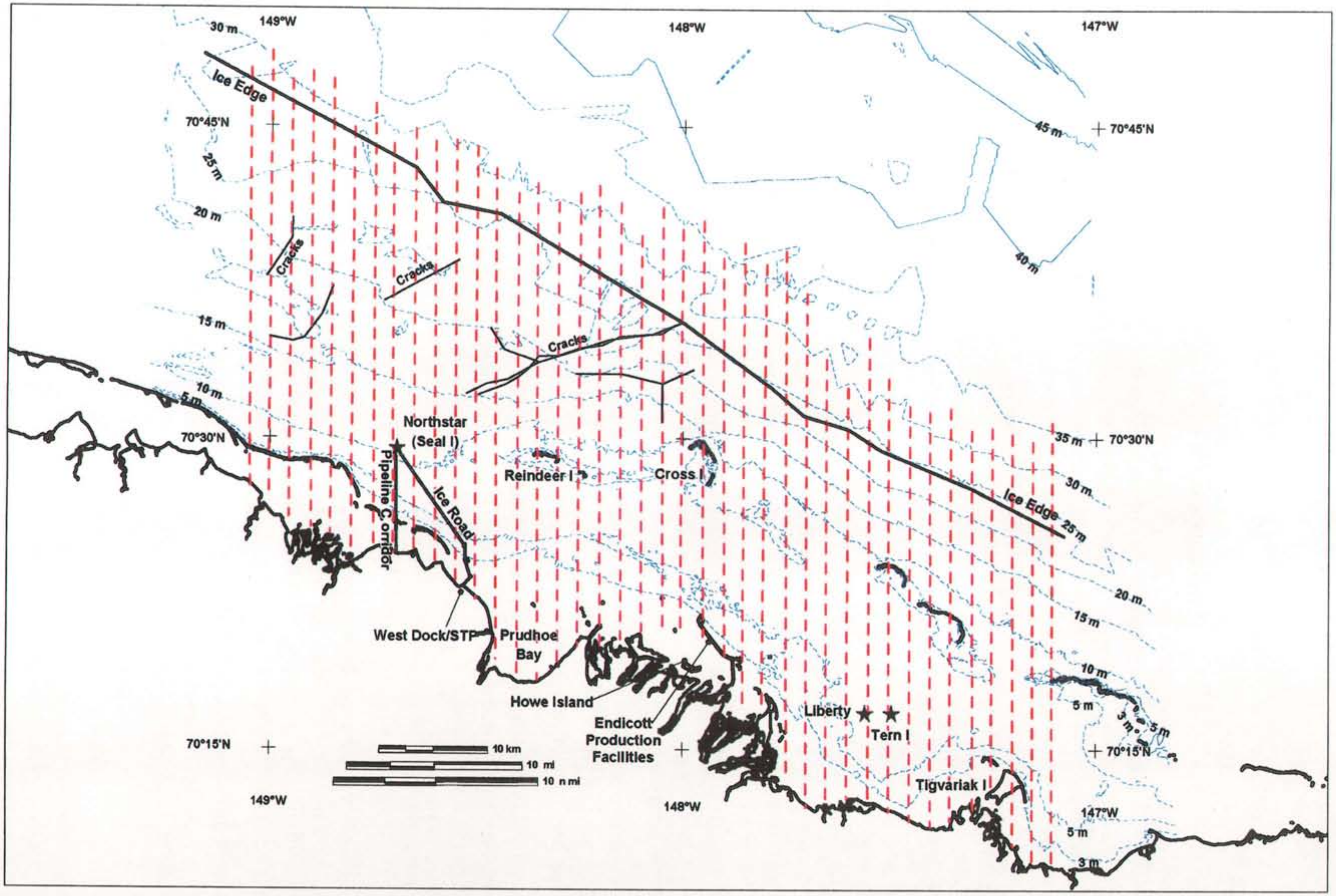


FIGURE 5.2. Central Alaskan Beaufort Sea showing locations of Northstar (Seal Island) and Liberty (Liberty and Tern Islands) in relation to aerial survey transects flown twice in May-June 2001. A similar grid of 40 transects offset 0.5 n.mi. (0.58 mi; 0.93 km) to the east was also flown twice.

FIGURE 5.3. The Turbo Commander aircraft used to fly the survey in 2001 (and 2000).

We surveyed transect strips 411 m (1350 ft) in width on each side of the aircraft. These strips extended from 135 m (443 ft) to 546 m (1791 ft) 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 altitude. Sightings of seals inside 135 m or beyond 546 m were recorded as off-transect sightings. For consistency with previous ringed seal surveys, we have *not* attempted to adjust the strip boundaries or calculated densities to take account of the "earth curvature" corrections described by Lerczak and Hobbs (1998). The transect width used in the BP/LGL surveys is likely underestimated but the error associated with inclinometer angles >5° is negligible. Also, the use of consistent survey methodology across years permits meaningful comparisons of survey results.

The two primary observers occupied the right seat behind the co-pilot and the left seat behind the pilot. A third observer operated a computerized data logger and recorded the time transects began and ended, and polar bear sightings. (Appendix B provides information on the polar bear sightings.) This third observer did not record seal sightings and was positioned behind the right observer. The two primary observers sat at large bubble windows that allowed greater downward visibility than standard windows. The surveys were usually flown between 10:00 and 18:00 h Alaska Daylight Time, when numbers of seals hauled out on the ice were expected to be highest. (In the Prudhoe Bay area, the sun reaches its highest elevation near 14:00 h.) When sightability was severely impaired (usually by fog) for more than approximately five of the 1-min time periods along a transect, that transect was generally re-surveyed later, and the data from the initial incomplete survey were discarded.

## *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, GPS unit (Garmin, model 12XL), and GeoLink data logging software (Version 6.0). At keystrokes initiated by the computer operator, the time and position of the aircraft were automatically logged at the start and end of each transect. Polar bear sightings were also logged via GeoLink.

The two primary observers recorded the time, visibility (n.mi.), ice cover (%), ice deformation (%), melt water (%), sunglare (none, moderate, or severe), and overall sightability conditions (ranging from "excellent" to "impossible") onto audio tape at the end of each 1-min (~3.7 km or 2.3 mi) time period. An electronic timer signaled the observers at 1-min intervals. Ice deformation was estimated by the 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%. Cracks and leads in the ice were also noted by the observers at the specific times when seen, allowing their locations to be extracted subsequently from the GeoLink files.

Environmental parameters were recorded by the computer operator (with the assistance of the pilots) at the start of each transect. These variables included cloud cover (in tenths), ceiling height (ft), visibility (n.mi.), wind speed (knots), wind direction (°T), and air temperature (°C). Wind data were acquired from the aircraft's GPS and air temperature from a thermometer mounted externally on the aircraft.

For each seal sighting, the observer dictated onto audio tape 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 (see Appendix B).

The observers recorded the times of any sightings of industrial sites or activity, including ice roads, areas with evidence of seismic surveys, or artificial islands. Observers also recorded the times of any sightings of research activity on the ice associated with a study of ringed seal haul-out behavior by researchers from the University of Alaska.

## *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. Time periods with severely impaired sightability conditions were excluded from all analyses. Each sighting was also linked to the environmental variables recorded for the corresponding 1-min (3.7 km) time period. The fast-ice edge was subjectively located by mapping open leads; areas with leads were classified as pack ice and were excluded from analyses.

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 entire study period. Each 1-min time period was assigned a wind speed and air temperature value by interpolating from the values obtained from the nearest preceding and following airport weather records. Airport data and data collected from the plane were highly correlated in all survey years. The airport data, with the exception of cloud cover, were used in analyses because they provided finer temporal coverage. Cloud cover data collected from the survey aircraft were used in analyses because cloud cover as observed over the ice often differed from the airport data. From the airport data, an index of wind chill called heat loss was calculated by using the following formula (Siple and Passel 1945):

$$H = (12.1452 + 11.6222\,(v^{1/2}) - 1.16222\,(v))\,(33\text{-}t)$$

Here $H$ is the heat loss in Watts/m$^2$, $v$ is the wind speed in m/s, and $t$ is the temperature in °C. Weather conditions experienced by seals on the ice undoubtedly varied from weather data collected at the Deadhorse airport. However, we believe that the airport data provide a good approximation to "on-ice" weather during the days when the weather was satisfactory for aerial surveys.

The percent ice deformation data collected at 1-min intervals during all surveys were, for corresponding locations, averaged across days and plotted at the midpoint of the 1-min time period. The averaging procedure involved comparing the GPS coordinates for 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 (2625 ft) apart, they were treated as independent values. These data were contoured at 5% intervals using Vertical Mapper for MapInfo (Version 5.0.1). 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 the various ice deformation categories. Seal sightings were overlaid on the ice deformation layer, and 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, water 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.

Five kilometer "bins" of distance as measured 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.

A seal density contour map (see Fig. 5.8, later) was created using Vertical Mapper for MapInfo by contouring the ringed seal density (seals/km$^2$) calculated for each time period segment midpoint. More specifically, the density contours were created from the irregularly spaced midpoints of time period segments by using the inverse distance method (Vertical Mapper) with the following parameters: 1 zone, minimum 1 point, maximum 25 points, 200 m cell size, 18,660 m search and display radius, exponent 1.

Date, time-of-day, and weather effects were analyzed using the 1-min 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 at 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.

To investigate potential changes in size of ringed seal groups during the survey period, group size (number of individual seals/number of seal sightings) was calculated based on every sighting in 2001 and averaged by date. Seals were considered a group when there was <5 m separation between individuals. Group size was further divided by sightings at cracks and those at holes. The percent of the total individual seals (and also sightings) observed hauled out along cracks (vs. holes) in the ice was also calculated for each survey date. These procedures were repeated for data from the 1997-2000 surveys to permit year-to-year comparisons.

We examined seal sightings in relation to distance from the Northstar development area in 2001. Ten 1-km "bins" of distance from the edge of the development area (including the ice roads, pipeline, Seal/Northstar Island, and the area used for testing of emergency equipment) were plotted and used as a GIS layer (Fig. 5.17, later). The on-transect area per bin was calculated, and the seal sighting data were overlaid onto this layer to permit density calculations relative to distance from on-ice activities. The results from survey replicates 1 and 2 were combined because of the relatively small areas and numbers of sightings involved in this localized analysis. Water depths <3 m were excluded from these calculations.

As part of a multiyear analysis (see "Poisson Regression" section, later) to examine the potential influence of industry, a similar approach was taken for examining seal sightings in relation to distance from industrial activities that occurred in 1997-2001. Industrial areas included Tern Island in 1997 and 1998, two areas of vibroseis operations in 1998, ice roads to Northstar in 1999, a transit route and shallow hazards survey area (McCovey site) near Reindeer Island in 2000, and the ice roads, pipeline, and ice dump area associated with Northstar in 2000 (Fig. 5.4). Data were organized into ten 1-km bins around each of these industrial areas. For 2001, two industry variables were included in the Poisson regression models:

- "Distance from Northstar in 2001", measuring distance from the closest section of ice road, subsea pipeline, and test-area for testing of emergency equipment, and
- "Distance from Vibroseis Site", measuring distance from the closest edge of one area of on-ice Vibroseis that occurred in early 2001.

In the 1997-2001 Poisson regression model, industry variables were organized into

- "Distance from Vibroseis Sites", measuring distance from the closest portion of two areas of Vibroseis in 1998 and one area of Vibroseis in 2001,
- "Distance from Northstar in 2000", considering Northstar (=Seal) Island, pipeline route, and ice roads in 2000,
- "Distance from Northstar in 2001",
- "Distance from McCovey Site", a transit route and shallow hazards survey area, and
- "Distance from Other Industry Sites", considering distance from Tern Island in 1997-98 and the abandoned ice roads to Northstar in 1999.

## *Statistical Tests*

Two statistical approaches were used to examine potential factors known or expected to influence ringed seal density within the study area. Data were examined with univariate tests and with a multivariate Poisson regression analysis. Although univariate tests do not control for influences of other factors on observed seal density, they summarize the actual direct observations and provide a basis for observing trends and for interpreting multivariate analyses. Results were considered statistically significant based on the $\alpha$=0.05 criterion, and marginally significant for $0.10 > \alpha > 0.05$.

### *Univariate Tests*

We used the chi-square ($\chi^2$) goodness-of-fit test to assess the significance of observed differences in ringed seal densities with respect to physical (e.g., % deformation), weather (e.g., air temperature), and temporal (e.g., time of day) variables. Strata (categories) were defined for each explanatory variable for statistical purposes (see "Results" for stratum boundaries). 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 landfast ice within those strata. Simultaneous Bonferonni-corrected 95% confidence intervals (CIs) were calculated for the observed proportions of the seal sightings in each stratum. The expected proportion was calculated based on the areas surveyed by stratum. An expected proportion falling outside the CI for the observed proportion for that stratum was considered significantly different

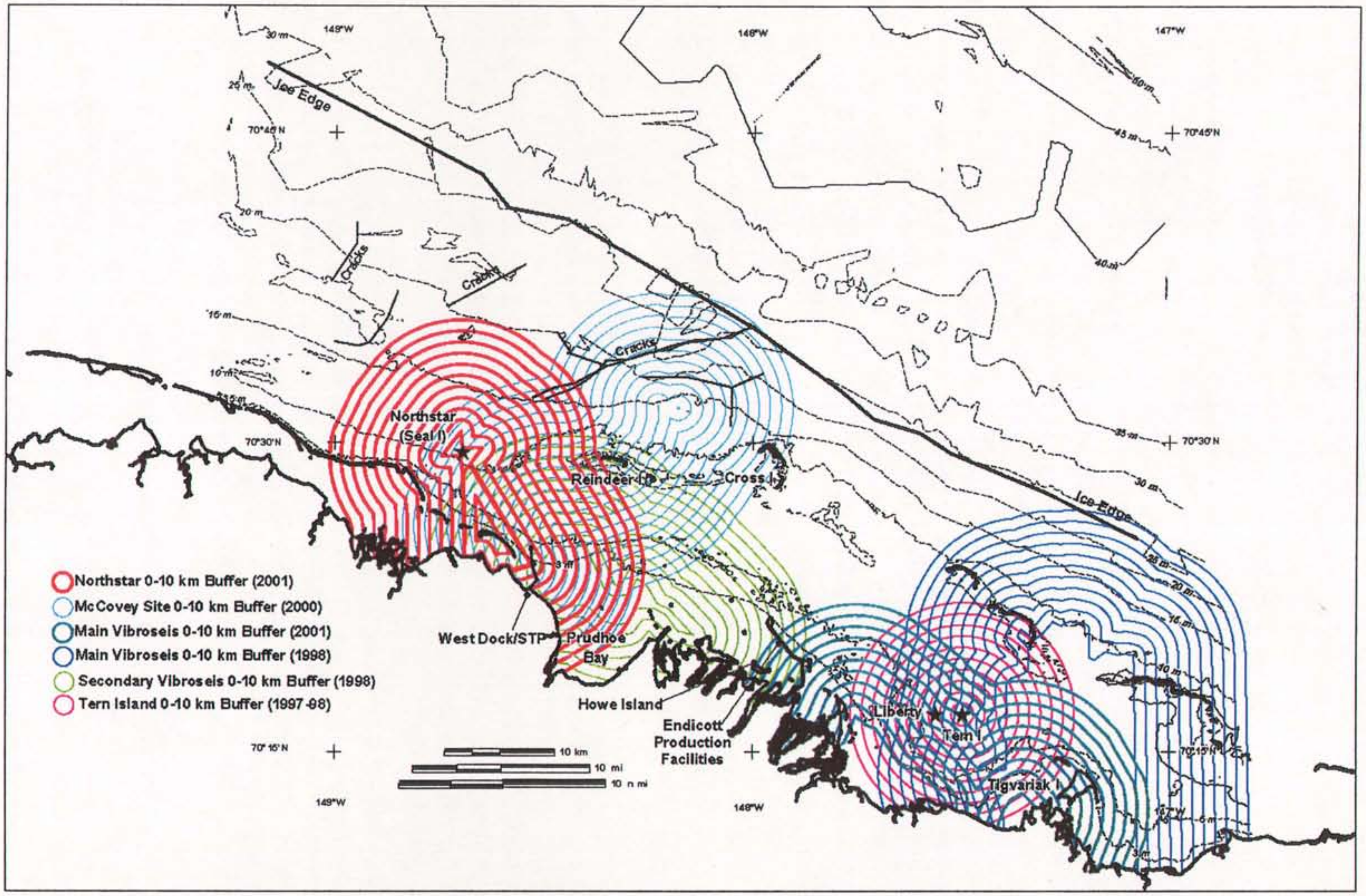


FIGURE 5.4. Location of on-ice industry sites in the Central Alaskan Beaufort Sea study area during 1997-2001. Successive 1-km distance categories from each industry site are shown. 1 km = 0.62 mile = 0.54 n.mi.

(Manly et al. 1993). Strata with very small surveyed areas of <30 km$^2$ are excluded from analyses. Strata with relatively small areas of 30-50 km$^2$ are highlighted with brackets in all univariate plots (see Figures 5.12, 5.15 and 5.16, later). All tests were conducted based on numbers of seal sightings (singletons or groups) rather than numbers of individual seals. The different seals within a closely spaced group are not statistically independent. 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$^2$). This permitted comparison of our results to the findings of other studies.

For univariate comparisons of seal densities with respect to physical factors that did not change during the course of the study, such as water depth, we considered the survey replicates to be non-independent. At any given location along each of those transects, these variables would be the same during each survey, and some of the same seals may have been seen repeatedly. To avoid pseudoreplication problems associated with the lack of independence of these "repeated measures", we examined each survey replicate (group of 80 unique transects) separately whenever possible. It should be noted that the locations of survey lines varied somewhat from replicate to replicate.

For analyses of observed seal densities vs. weather and temporal variables, we pooled the data across replicates. We assumed that numbers of seal sightings at a given location would vary as a result of variation in the temporal and weather factors between replicate surveys. This would make each replicate partially independent with respect to these variables. However, there is still some concern about interdependence of results given the presumably fixed number of seals in the area and the close spacing of adjacent transects.

The non-parametric Page's *L* test (Page 1963) was used to test for progressive seasonal trends in group size (at cracks, holes, and overall) and in percent of total ringed seal sightings that were at cracks in the landfast ice. We hypothesized that group size and percent of seals observed at cracks would increase during the survey period. These analyses were performed separately for each of the five survey years.

### *Poisson Regression*

Poisson regression models (McCullagh and Nelder 1989; Cameron and Trivedi 1998) were used to assess the relationship between seal counts in small segments of the survey transects and several variables known or expected to influence seal abundance and haul-out behavior. The ultimate objective is to quantify any influence of oil industry activities on the number of seals hauled out, after allowing for natural factors that also influence the number of seals seen. The remainder of this subsection is a technical description of the Poisson regression procedures, and can be skipped by readers not concerned about the specific statistical procedures used.

Prior exploratory analysis had revealed that ringed seal count data within 1-min segments of the aerial surveys exhibited a Poisson distribution. The Poisson distribution often applies in describing random occurrences when the probability of an occurrence at any given place or time is small. It is a positive discrete distribution in which only positive integers are acceptable values. Tests based on this distribution were more appropriate for the ringed seal count data than tests assuming a normal distribution, where non-integers and negative values would also be assumed to be permissible. Separate Poisson regression models were fitted to the 2001 data alone and to combined data from the years 1997 to 2001.

The unit of observation in these analyses was normally a segment of a survey transect 500 m in length. This was approximately a 0.41 km$^2$ area, i.e. a segment 500 m along the flightline × 0.822 km wide (411 m on each side of the aircraft). Some survey segments located at the ends of transects were smaller than 500 m. To account for the fact that larger survey areas would probably contain more ringed seals than smaller areas, the logarithm of the survey area was fitted as an offset variable in all Poisson regression models (Venables and Ripley 1999).

The values for environmental parameters, including percent ice deformation and percent melt water, were averaged for combined right and left observer data. Treating data from left and right observers separately would have resulted in pseudoreplication, as environmental conditions were highly correlated between left and right sides of the plane. Also, seal sightings by left and right observers were not always independent of each other, e.g., when ringed seals were counted at an ice crack extending across both observers' fields of view beneath the aircraft. Although the same seals were not counted by both observers (their fields of view were separated by a 270-m-wide strip underneath the plane that was considered off-transect), the occurrence of a crack within the surveyed area on one side of the aircraft was not entirely independent of such an occurrence on the other side

The names of the covariates and factors used in the analyses are listed in Table 5.2. All covariates were required in order for a transect segment to be included in the Poisson regression analyses. All variables in the Poisson regression, except survey replicate number and year, were considered continuous. Variables that were organized in ordered bins (e.g., distance from ice edge or industry) were considered continuous and not discrete, resulting in a model that was easier to interpret. The survey replicate and (in multi-year analyses) year were considered discrete and treated as factors in the models. Quadratic terms were included for the covariates water depth, ice deformation, distance from the ice edge, heat loss, wind speed, air temperature, cloud cover, time of day (hour), and date to investigate possible non-linear trends.

The response variable was the number of observed ringed seal sightings (singletons or groups) in a transect segment, with log (segment area) as an offset variable. The number of seals was not used as the response variable because different seals within a closely-spaced haul-out group should not be treated as statistically independent. Data collected during conditions of poor sightability, in water depths < 3 m, and over pack ice were excluded from analyses.

Forward model selection (Rawlings et al. 1998) was employed to derive the final model. Forward model selection is a variable selection technique that sequentially adds candidate variables to a base model one-at-a-time and, after the addition of each variable to the model, assesses the potential statistical contribution of each covariate not yet included in the model. The base model was the y-intercept plus the offset variable. At each step, the covariate added to the model is the one that would, if included, be most effective in "explaining" the remaining variability in seal numbers (i.e., highest *F*-value). The process was repeated until 20 covariates were added to the base model for 2001 and until 13 covariates were added to the base model for 1997-2001 (Table 5.2). We employed the Bayesian information criterion (BIC) to assess how many of these covariates should be included in the final "best-fit" model (Venables and Ripley 1999). Values of BIC were calculated and plotted at each of the model "steps". When values of BIC increased rather than decreased from one step to the next, indicating that the model fit was not improving, the model was limited to this number of covariates. This resulted in the inclusion of four variables in the 2001 model and 10 variables in the 1997-2001 model (Table 5.2). Northstar construction in 2000 was the most intensive industrial activity in the study area during the winters in question. To verify that it did not affect seal density significantly, the variable "Distance from Northstar in 2000" was added to the 1997-2001 model with 10 covariates, notwithstanding the indication from the BIC criterion that this term was unnecessary.

Significance of terms in the model was assessed by approximate *F*-tests, which account for overdispersion of the raw seal-sighting data using a quasi-likelihood approach. Overdispersion occurs when the variance of the response variable exceeds its mean. If this occurs and no adjustment is done, test statistics and standard errors will be erroneously inflated (Cameron and Trivedi 1998). Calculations were done with S-Plus Version 6 (Venables and Ripley 1999).

The forward selection process using 2001 data alone involved considering all the variables listed in Table 5.2A for inclusion in the model, plus the interaction of each with survey replicate (1 or 2). For 1997-2001 data, all variables listed in Table 5.2B, plus the interaction of year and each of the other variables, were considered for inclusion in the model. In the 1997-2001 model, survey replicate was nested within year and within all year interactions. Main effects were not considered for elimination from the model if they were involved in a statistically-significant interaction.

Due to the potential for temporal (and spatial) correlation among seal counts collected within successive transect segments, the deviance residuals of all final models were checked for correlation that might adversely affect reported significance levels. Correlation among residuals from adjacent transect segments would constitute a form of pseudoreplication and could potentially cause model terms to appear more significant than is justified by the data.

TABLE 5.2. List of variables included in the Poisson regression models of seal sightings in relation to environmental parameters, for 2001 and 1997-2001 combined. The response variable in both models was the number of seal sightings.

| Data Set | Factors | All Covariates Tested [a] | Covariates Selected in the First 20 Steps (2001) and 13 Steps (1997-2001) of Models [b, c] |
|---|---|---|---|
| A. 2001 | Survey replicate | Water Depth (m) | ***Ice Deformation*** |
| | | Dist. from Ice Edge (km) | ***Air Temperature*** |
| | | Ice Deformation (%) | ***Air Temperature*** $^2$ |
| | | Melt Water (%) | ***Dist. from Northstar 2001*** |
| | | Time of Day (hr-ADST) | ***Cloud Cover*** |
| | | Date (day of year) | Heat Loss $^2$ |
| | | Air Temperature (°C) | Date |
| | | Wind Speed (km/h) | Melt Water |
| | | Heat Loss (W/m$^2$) | Cloud Cover $^2$ |
| | | Cloud Cover (%) | Wind Speed |
| | | Dist. from Northstar 2001 (1-km bins) | Replicate x Ice Deformation |
| | | Dist. from Vibroseis Site (1-km bins) | Replicate x Melt Water |
| | | | Water Depth $^2$ |
| | | | Dist. from Ice Edge $^2$ |
| | | | Replicate x Water Depth |
| | | | Dist. from Vibroseis Site |
| | | | Ice Deformation $^2$ |
| | | | Replicate x Cloud Cover $^2$ |
| | | | Replicate x Time of Day $^2$ |
| | | | Replicate x Date $^2$ |
| B. 1997-2001 | Year | Water Depth (m) | ***Ice Deformation*** |
| | | Dist. from Ice Edge (km) | ***Cloud Cover*** |
| | Survey replicate nested within year | Ice Deformation (%) | ***Wind Speed*** |
| | | Melt Water (%) | ***Dist. from Ice Edge*** |
| | | Time of Day (hr-ADST) | ***Melt Water*** |
| | | Date (day of year) | ***Air Temperature*** $^2$ |
| | | Air Temperature (°C) | ***Date*** $^2$ |
| | | Wind Speed (km/h) | ***Year x Ice Deformation*** |
| | | Heat Loss (W/m$^2$) | ***Year x Date*** |
| | | Cloud Cover (%) | ***Water Depth*** $^2$ |
| | | Dist. from Northstar 2000 (1-km bins) | ***Year x Dist. from Ice Edge*** |
| | | Dist. from Northstar 2001 (1-km bins) | ***Dist. from Northstar 2001*** |
| | | Dist. from Vibroseis Sites (1-km bins) | Year x Dist. from Northstar 2001 |
| | | Dist. from McCovey Site (1-km bins) | |
| | | Dist. from Other Industry (1-km bins) | |

[a] For all these variables, with the exception of the "industry" variables, a quadratic as well as a linear term was considered for inclusion in the model. Also, the interaction of the factors with each of these covariates was analyzed.

[b] These variables are presented in the order in which they entered the model. For instance, in the 2001 model "Ice Deformation" entered the model first as it was most effective in "explaining" the variability in seal numbers and "Replicate x Date $^2$" entered last as it was least effective. A "2" indicates that the variable contained a quadratic term.

[c] Covariates highlighted with bold, italic font were included in the final model based on the BIC. "Distance from Northstar 2000" was added to the final multiyear model to verify that it did not significantly affect seal density.

To check for this autocorrelation, Moran's $I$ statistic (Moran 1950) and associated standard error were computed using pairs of residuals from the final model that were separated by less than five 500-m survey segments. Five 500-m segments were chosen for testing because less than five segments did not contain a sufficient number of pairs for testing using Moran's *I*. Moran's *I* was computed separately for each transect and averaged for all transects. When this average Moran's *I* was not significantly different from zero or was negative, temporal correlation was deemed to have an insignificant influence on model estimation.

Final model fit was examined by computing the minimum, lower quartile (25th percentile), median, upper quartile (75th percentile), and maximum deviance residual for each model. The absolute values of the lower and upper quartile were compared to 2.0 and, if greater, model fit was further examined for systematic factors producing the large number of high residuals. Deviance residuals greater than 2.0 were considered large because deviance residuals typically are approximately normally distributed (McCullagh and Nelder 1989; Cameron and Trivedi 1998), so 95% should be less than 2.0 if the model fits adequately. In addition, deviance residuals were plotted against key environmental variables and examined for trends. These tests revealed that there were no residual quartiles greater than 2.0 in absolute value. This examination of residuals was deemed to validate all final models.

Results from these analyses (reported later in Tables 5.4 and 5.5) include the following: estimates and standard errors of the coefficients, approximate *F*-values, *P*-values, dispersion estimates, and Pearson's *r* values for temporal correlation. The Tables also show the expected percent increase or decrease in the number of seal sightings (with 95% CI) for a 1-unit change in the value of the covariate. Degrees of freedom (sample size minus number of terms in the model) are also reported for each model.

## DESCRIPTION OF THE STUDY AREA

Chapter 2, DESCRIPTION OF BP'S ON-ICE ACTIVITIES, describes the specific area around BP's Northstar offshore oil development, including the ice roads, Northstar Island, pipeline corridor, and emergency equipment testing area during the winter of 2000-2001. The following paragraphs describe the broader study area where the fixed-wing aerial surveys were conducted in 2001. This is the same study area as used for the corresponding 1997-2000 surveys.

### *Water Depth*

The study area is about 75 km (47 mi) in east-west extent, and extends about 40 km (25 mi) offshore (Fig. 5.2). Within this area, maximum water depth reaches about 30 m (98 ft) near the north ends of the survey transects. Barrier islands occur across much of the study area (Fig. 5.2). West of Prudhoe Bay, these barrier islands are fairly close to the mainland shore (2-7 km or 1-4 mi). 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 (12 mi) from shore.

Waters inside the barrier islands are shallow. West of Prudhoe Bay, maximum depths of about 4.5 m (14.8 ft) 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 (30 ft). The water depth is 12 m (39 ft) at the Northstar development site (formerly known as Seal Island), and 6.4 m (21 ft) at the potential Liberty development site in Foggy Island Bay.

### *Ice Conditions*

The study area in the spring of 2001 extended slightly beyond the edge of the landfast ice. However, 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 (6.6 ft) 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 (early October in 2000), 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. Rougher (more deformed) ice was very evident offshore of the barrier islands based on the data collected by aerial observers in 2001 (Fig. 5.5).

Breakup of the sea ice usually occurs in June or July. Breakup was not far advanced even at the end of the 2001 seal survey (8 June). By 29 May 2001, Sagavanirktok River floodwater extended over very small portions of the landfast ice. Rivers had extensively opened up by 4 June and river floodwater had covered large areas of nearshore ice near the mouths of the rivers. However, little or no melt water was present during the 2001 survey. No changes in the location of the fast ice edge were evident during our 2001 study period. Several large leads were present in the eastern portion of the study area during the entire duration of the survey period. Leads were farther offshore in the western portion of the study area and were "closed-up" with pack ice. The exact location of the fast ice edge was sometimes difficult to recognize during aerial surveys, as consolidated pack ice was present north of the landfast ice through 8 June.

## RESULTS

### *Ringed Seal Abundance and Distribution*

Ringed seals were widely distributed throughout the study area during the BP/LGL aerial surveys in the spring of 2001 (Fig. 5.6, 5.7). A total of 2024 ringed seals were seen on-transect in fast ice habitat during the two complete replicates of the 80 transects. These surveys covered a total of 4147 km$^2$ of fast ice habitat (~2075 km$^2$ per replicate). These values exclude the survey coverage and associated seal sightings in areas of closed pack ice habitat north of the landfast ice edge depicted in Figures 5.6 and 5.7. (Total survey coverage, including both fast and pack ice, totaled 5855 linear km or 4748 km$^2$.) The observed overall density of seals on fast ice in 2001 was 0.38 seals/km$^2$ during the first survey replicate and 0.61 If that area (largely bottom-fast ice) is excluded, the overall observed densities in areas ≥3 m deep during replicates 1, 2, and both combined were 0.42, 0.67 and 0.54 seals/km$^2$, respectively. All of these densities are "raw" densities of seals observed per km$^2$ of fast ice surveyed, with no adjustments for the estimated proportions of seals not hauled out (availability bias) or on the ice but missed (detection bias).

Although ringed seals were observed in most parts of the study area, there was again in 2001 an obvious tendency for lower densities in the shallowest parts of the lagoons (Fig. 5.6-5.8). However, from Prudhoe Bay eastward, many seals were sighted in the area seaward of the 3 m depth contour in the northern parts of lagoons. West of Prudhoe Bay, very few seals were seen in the lagoons, which are narrower there than farther east. North of the barrier islands, seals were concentrated in areas inshore of the 15 m depth contour, with lower sighting densities farther offshore. However, north of the 15 m contour there was a tendency for seals to occur in larger groups (≥ 3 individuals), especially during replicate 2 (Fig. 5.6, 5.7). seals/km$^2$ during the second replicate. Combining the results from the two replicates yielded an observed seal density of 0.49 seals/km$^2$. These averages include the part of the study area where water depth is <3 m.

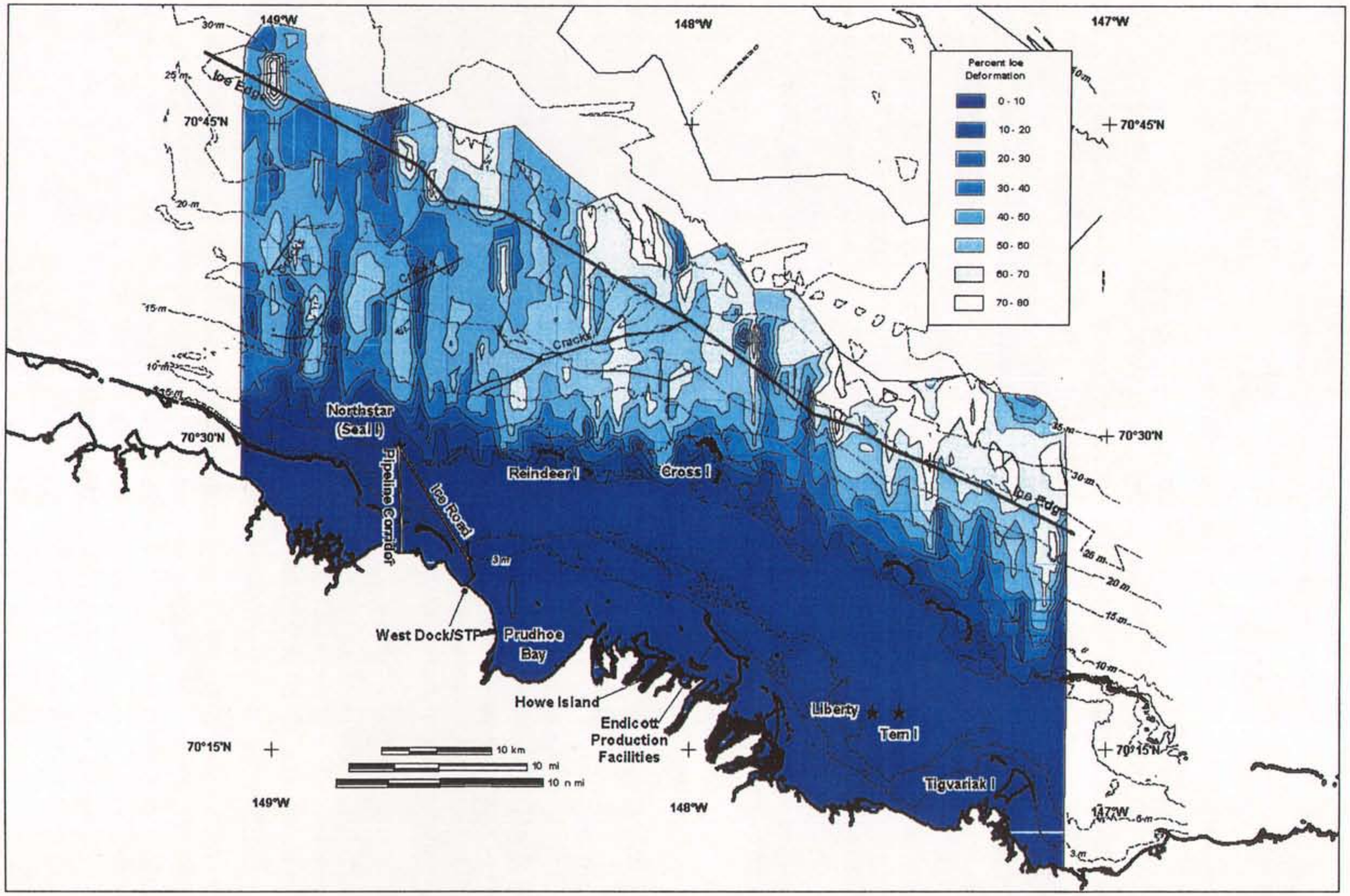


FIGURE 5.5. Percent ice deformation and location of the landfast ice edge in the Central Alaskan Beaufort Sea study area, 28 May - 8 June 2001.

### *Group Size*

*2001.*—There was a significant tendency for the average group size of ringed seals at holes to increase progressively from day to day in 2001 (Page's *L* Test; $L_{date} = 265$, $n = 1, 9$, $P < 0.05$; Page 1963). Daily average group sizes ranged from 1.0 to 1.4 at holes. Average group size at cracks (1 to 8.3 seals) did not show a consistent trend from day to day in 2001 (Fig. 5.9A). Overall, group size at cracks and holes combined (1.0 to 1.4 seals) increased throughout the survey period but this trend was not significant ($L_{date} = 251$, $n = 1, 9$, $P > 0.05$).

*1997-2001.*—Observed group sizes were much lower in 1997, 1998, 2000, and 2001 than in 1999 (Fig. 5.9); note the different vertical scales in Fig. 5.9. There was little variation in daily average group size during 1997 (cracks, 1.1 to 1.6; holes, 1.2 to 1.7; overall, 1.2 to 1.7), 1998 (cracks, 1.2 to 2.7; holes, 1.2 to 1.5, overall: 1.2 to 1.5), 2000 (cracks, 1.0 to 5.3; holes, 1.1 to 1.4; overall, 1.2 to 1.4) or during 2001 (see above). During 1997, there were no significant trends in average group size ($P > 0.10$). During 1998, despite the limited day-to-day variability, there was a significant tendency for the overall average group size to increase progressively from day to day ($L_{date} = 139$, $n = 1, 7$, $P < 0.01$) and for average group size at cracks to increase marginally ($L_{date} = 130$, $n = 1, 7$, $0.10 > P > 0.05$). During 1999 and 2000 (like 2001), there was a significant tendency for the average group size of ringed seals at holes to increase progressively from day to day (1999: $L_{date} = 262$, $n = 1, 9$, $0.05 > P > 0.01$; 2000: $L_{date} = 193$, $n = 1, 8$, $P < 0.05$ ). Average group size at cracks (4.5 to 10.8 seals) and overall (1.6 to 3.1 seals) generally increased from day to day in 1999 (Fig. 5.9B). However, these trends were not statistically significant at cracks ($L_{date} = 249$, $n = 1, 9$, $P > 0.10$) and only marginally significant overall ($L_{date} = 259.5$, $n = 1, 9$, $0.10 > P > 0.05$).

Average group sizes at cracks generally were higher than group sizes at holes, and more variable from day to day (Fig. 5.9). This was especially so in 1999.

### *Seals Observed at Cracks vs. Holes*

The majority of ringed seals were observed near holes in all five survey years (Fig. 5.10A-E). However, in 1999, relatively more ringed seals occurred at cracks (overall 22.8%) than in 1997 (6.5%), 1998 (10.5%), 2000 (2.5%), and 2001 (5.9%). There was a significant tendency for the percent of ringed seals at cracks to increase progressively from day to day in 1998 (Page's *L* Test; $L_{date} = 131$, $n = 1, 7$, $0.05 > P > 0.01$). There was no significant tendency for percent of ringed seal sightings at cracks to either increase or decrease from day to day in 1997, 1999, 2000, and 2001 ($P > 0.10$).

## *Bearded Seal Sightings*

Three bearded seals were recorded during the 2001 aerial surveys (Fig. 5.11). One sighting was in the landfast ice within 5 km (3 mi) of the fast ice edge, and another sighting was in the pack ice north of the ice edge. The remaining bearded seal sighting was well within the landfast ice, near Endicott.

Two bearded seals were observed near holes and one bearded seal was observed at a crack. None of these seals were observed exhibiting a dive or other obvious reaction to the aircraft: two were recorded as looking at the aircraft and the other bearded seal showed no apparent reaction. Density calculations and further analyses were not conducted because of the small number of bearded seals seen. Several bearded seals were sighted in the study area during 1999 and 2000 (Moulton et al. 2000a, 2001) but none were seen during 1997-98 (G. Miller, LGL Ltd., pers. comm.).

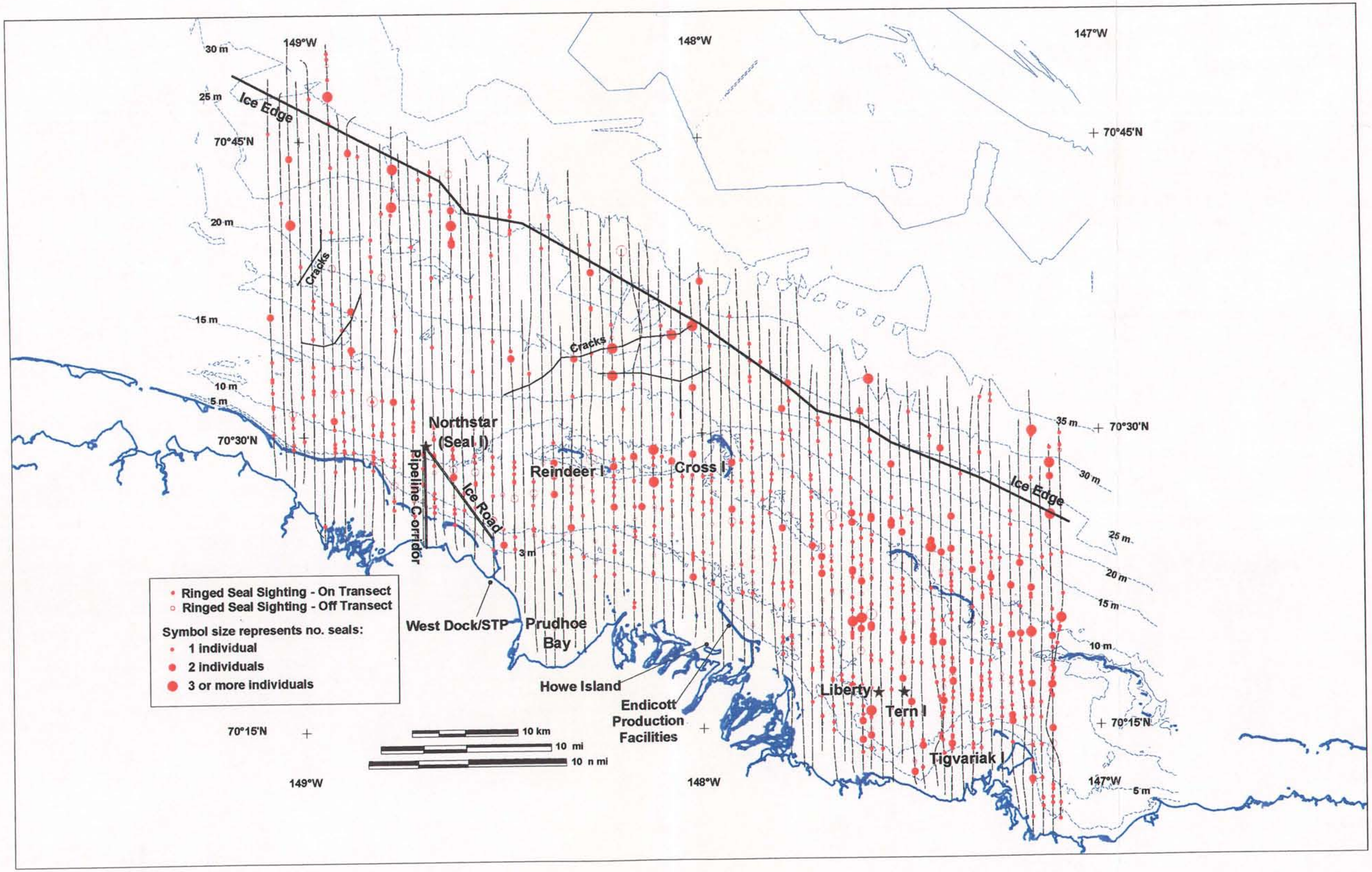


FIGURE 5.6. Distribution of ringed seal sightings during survey replicate 1 (transects 1-80), 28 May - 4 June 2001.

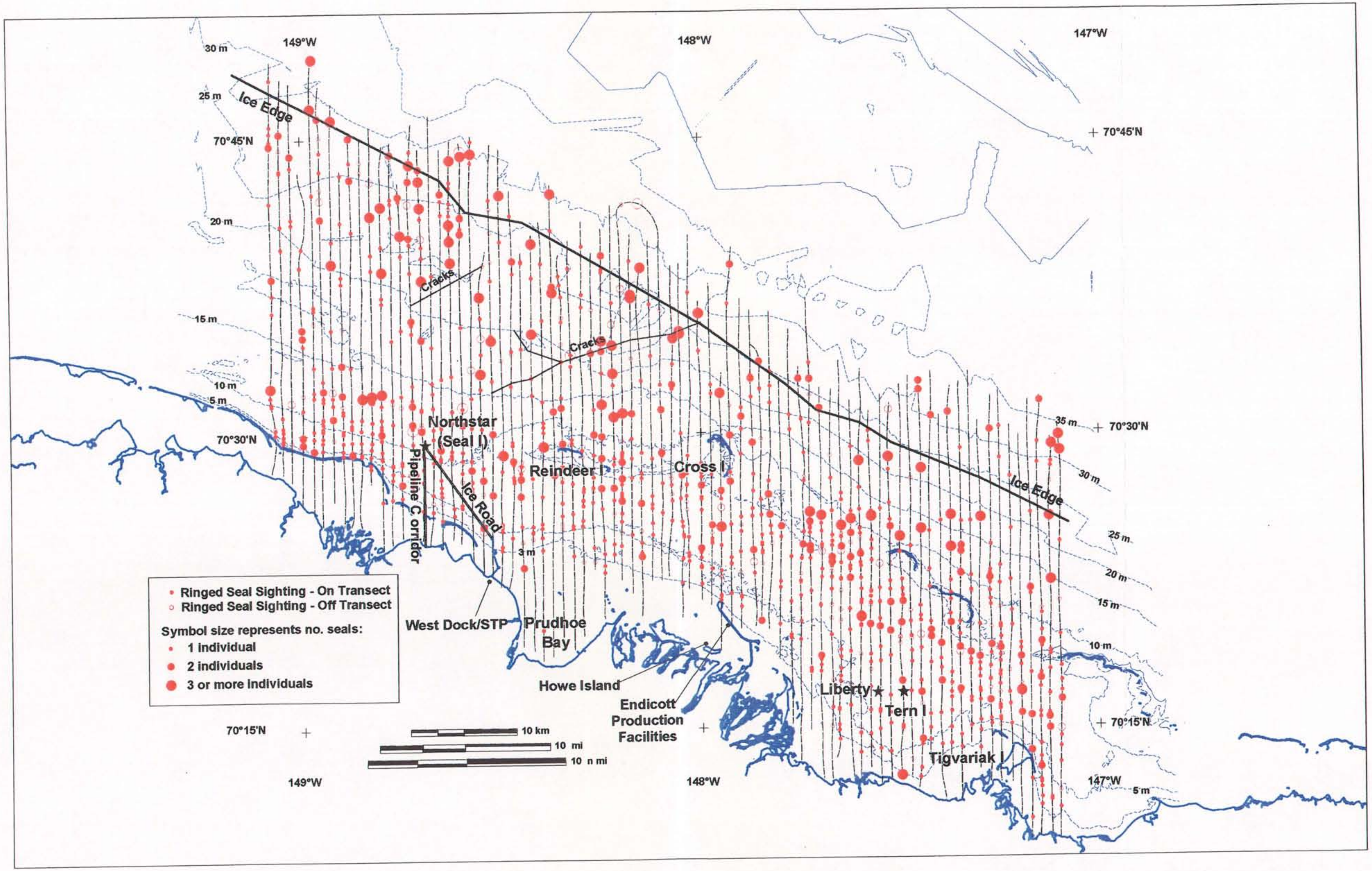


FIGURE 5.7. Distribution of ringed seal sightings during survey replicate 2 (transects 1-80), 4-8 June 2001.

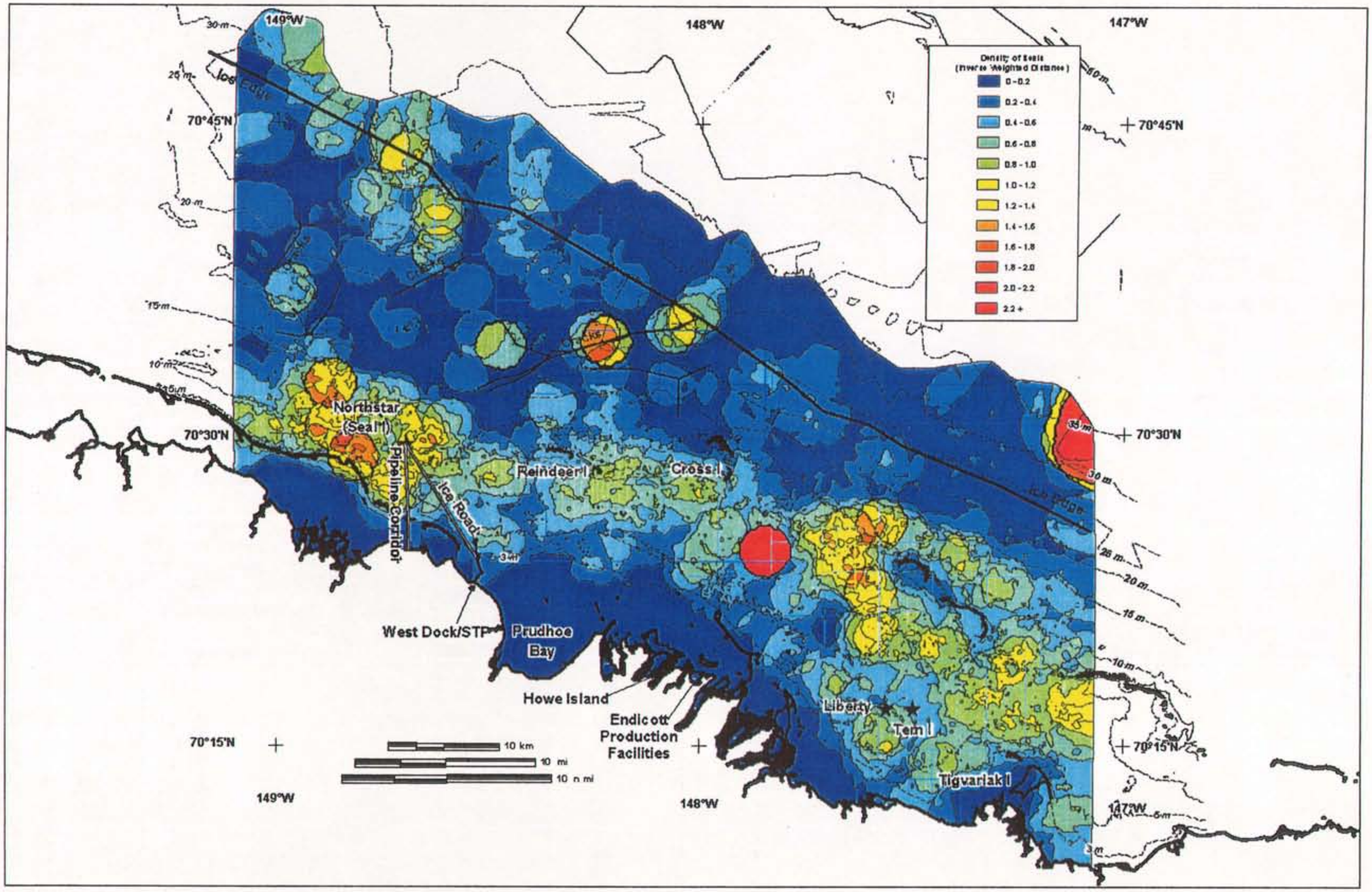


FIGURE 5.8. Ringed seal densities derived from trend surface analysis of replicates 1 and 2 combined, 28 May - 8 June 2001.

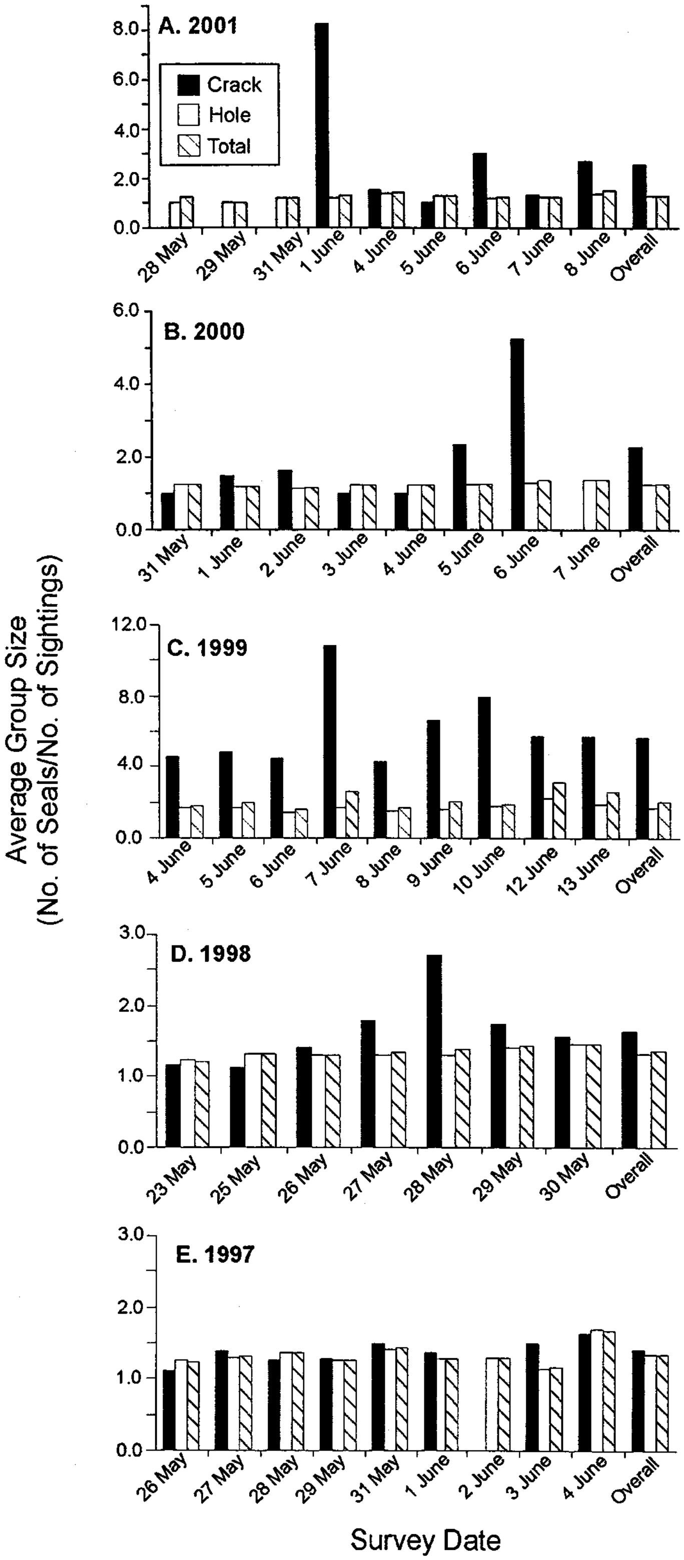


FIGURE 5.9. Average size of ringed seal groups (no. of seals/no. of sightings) observed at cracks, holes, and overall for each survey date during *(A)* 2001, *(B)* 2000, *(C)* 1999, *(D)* 1998, and *(E)* 1997. Note the difference in the scales of the y-axes and the different date ranges on the x-axes.

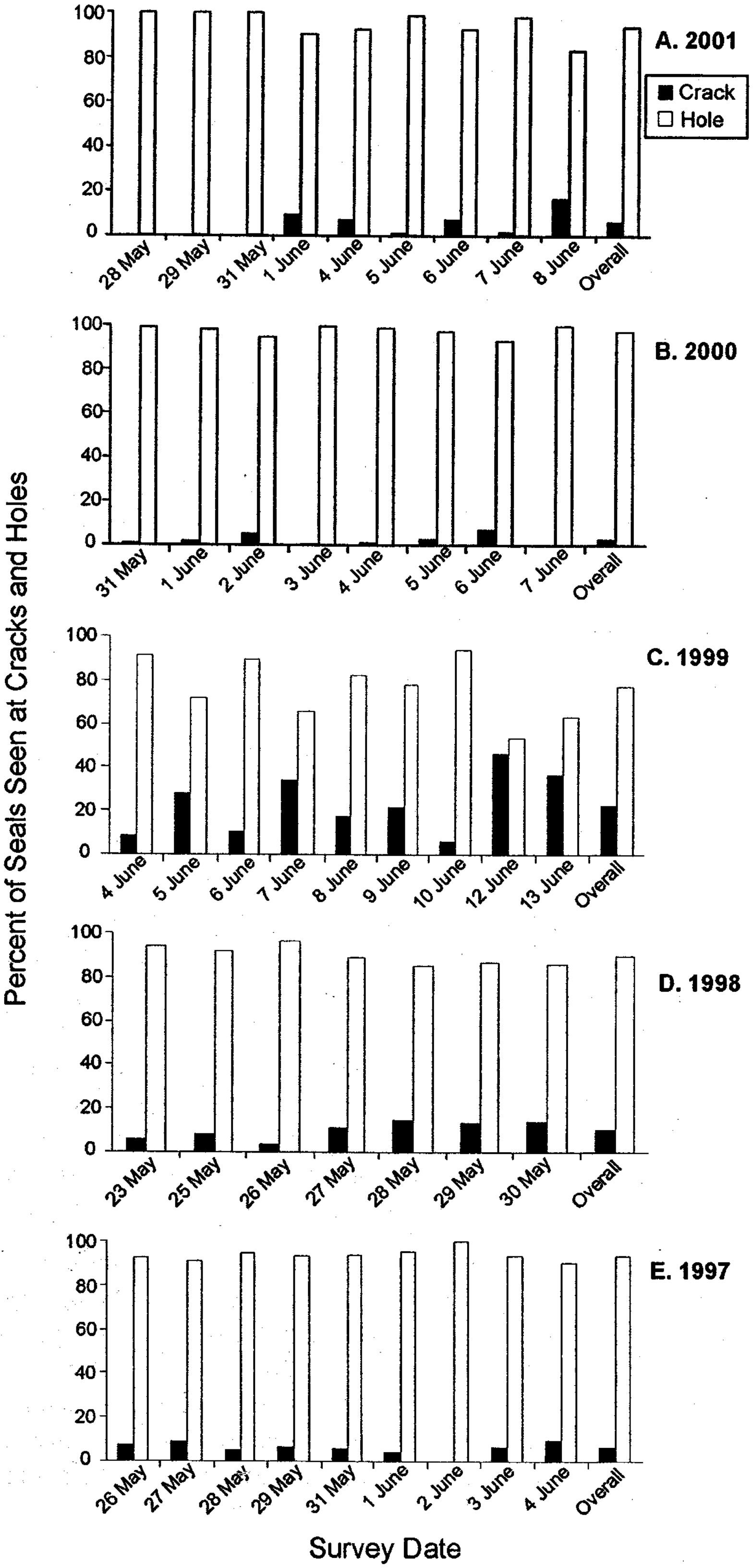


FIGURE 5.10. Percent of ringed seal individuals observed at cracks versus holes for each survey date during ***(A)*** 2001, ***(B)*** 2000, ***(C)*** 1999, ***(D)*** 1998, and ***(E)*** 1997. Note different date ranges on the x-axes.

## *Habitat Factors Affecting Ringed Seal Abundance and Distribution*

We examined the observed density of ringed seals on landfast ice in relation to four habitat parameters that may affect seal abundance and distribution: water depth, distance from the edge of the landfast ice, ice deformation, and melt water. The observed average densities in various habitat 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 (Frost et al. 1988; Kelly and Quakenbush 1990). However, the observed densities in different strata are believed to be meaningful indicators of the relative utilization of various depths, ice conditions, and distances from the ice edge.

In the subsections below, both the univariate and multivariate results for each habitat factor are presented based on the 2001 data, followed by the univariate and multivariate results for 1997-2001 combined. The multivariate results are based on Poisson regression models, which assessed the relative contributions not only of various habitat variables, but also the temporal, weather, and industrial activity variables, in affecting the number of seal sightings during BP/LGL surveys. This approach allows the effects of natural factors on seal sightings to be taken into account before assessing whether seal density is related to proximity to industry. Table 5.3A and Figure 5.12 summarize the results of the univariate analyses. Table 5.4 and Figure 5.13 summarize the Poisson regression results for 2001, and Table 5.5 and Figure 5.14 summarize the Poisson regression results for 1997-2001.

Seal density was significantly related to all four habitat factors in most analyses, and these relationships were generally consistent between univariate and multivariate results. High seal densities tended to occur with little melt water and low ice deformation. In some years, high seal densities also tended to occur close to the edge of the landfast ice (at least in 1997 and 1999) and at intermediate water depths of 10-20 m (33-66 ft). Detailed results are presented below.

### *Water Depth*

*2001.*—Univariate analyses indicated that sighting rates depended strongly on water depth during both survey replicates ($P < 0.001$ in each case; Table 5.3A and Fig. 5.12A). The water depth strata used in this analysis were based on the depth contours shown in Figure 5.2. Average densities of ringed seals observed on landfast ice within different water depth strata during the two survey replicates ranged from 0.12 to 0.89 seals/km$^2$ (Fig. 5.12A). The observed seal densities in the 0-3 m zone were 0.13 and 0.12 seals/km$^2$ during replicates 1 and 2, respectively. These densities were much lower than densities observed in deeper strata, which ranged from 0.22 to 0.89 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 univariate analysis, the observed densities of seals in the remaining depth categories still differed significantly ($P < 0.001$). During replicate 1, the overall significant difference among strata was attributable mainly to the relatively high densities of seals in the 3-5 m and 5-10 m depth strata and lower than expected densities in water >15 m deep. Similarly, during replicate 2, the overall significant difference among strata was attributable mainly to the higher than expected numbers of sightings in shallower water (5-10 m stratum), and lower than expected numbers in water >15 m. During both replicates, the highest densities were observed in the 5-10 m stratum.

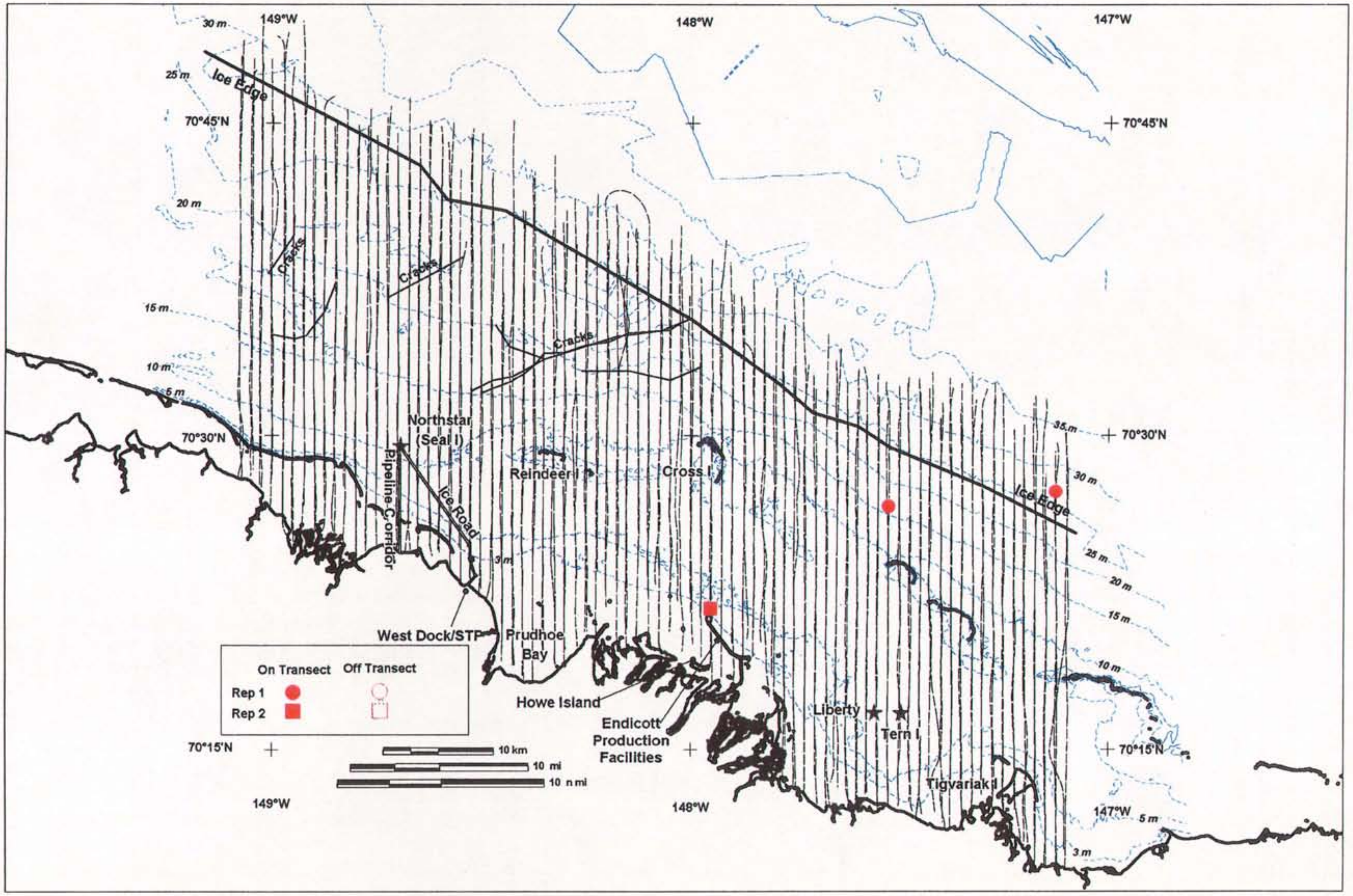


FIGURE 5.11. Distribution of bearded seal sightings during both survey replicates (transects 1-80), 28 May – 8 June 2001.

TABLE 5.3. Summary of chi-square analyses of ringed seal density in relation to variables affecting ***(A)*** seal abundance and distribution, and ***(B)*** the proportion of seals hauled out.

| A. Habitat Factors Affecting Abundance and Distribution | | | | |
|---|---|---|---|---|
| Variable | Chi-square | *df* | *P*-value | Pooled $P^a$ |
| Water Depth | | | | |
| 1997 Rep 1 | 28.44 | 6 | 0.0001 | |
| 1997 Rep 2 | 22.53 | 6 | 0.001 | |
| 1997 Rep 3 | 35.66 | 6 | 0.0001 | |
| 1998 Rep 1 | 15.22 | 5 | 0.010 | |
| 1998 Rep 2 | 15.43 | 5 | 0.010 | |
| 1999 Rep 1 | 67.66 | 6 | <0.0001 | <0.0001 |
| 1999 Rep 2 | 114.14 | 6 | <0.0001 | |
| 2000 Rep 1 | 275.98 | 6 | <0.0001 | |
| 2000 Rep 2 | 209.74 | 6 | <0.0001 | |
| 2001 Rep 1 | 232.40 | 6 | <0.0001 | |
| 2001 Rep 2 | 237.29 | 6 | <0.0001 | |
| Distance from Ice Edge | | | | |
| 1997 Rep 1 | 15.06 | 5 | 0.01 | |
| 1997 Rep 2 | 12.27 | 5 | 0.031 | |
| 1997 Rep 3 | 26.51 | 5 | 0.0001 | |
| 1998 Rep 1 | 5.32 | 5 | 0.380 | |
| 1998 Rep 2 | 13.27 | 5 | 0.020 | |
| 1999 Rep 1 | 5.74 | 5 | 0.330 | <0.0001 |
| 1999 Rep 2 | 93.64 | 5 | <0.0001 | |
| 2000 Rep 1 | 129.97 | 5 | <0.0001 | |
| 2000 Rep 2 | 102.35 | 5 | <0.0001 | |
| 2001 Rep 1 | 97.85 | 5 | <0.0001 | |
| 2001 Rep 2 | 103.83 | 5 | <0.0001 | |
| Ice Deformation | | | | |
| 1997 Rep 1 | 34.39 | 5 | <0.0001 | |
| 1997 Rep 2 | 18.90 | 5 | 0.002 | |
| 1997 Rep 3 | 33.71 | 5 | <0.0001 | |
| 1998 Rep 1 | 14.84 | 5 | 0.011 | |
| 1998 Rep 2 | 11.83 | 5 | 0.037 | |
| 1999 Rep 1 | 8.74 | 5 | 0.120 | <0.0001 |
| 1999 Rep 2 | 52.60 | 5 | <0.0001 | |
| 2000 Rep 1 | 168.14 | 5 | <0.0001 | |
| 2000 Rep 2 | 120.65 | 5 | <0.0001 | |
| 2001 Rep 1 | 202.16 | 5 | <0.0001 | |
| 2001 Rep 2 | 178.77 | 5 | <0.0001 | |
| Melt Water[b] | | | | |
| 1998 Rep 1 | 5.61 | 4 | 0.23 | |
| 1998 Rep 2 | 8.18 | 4 | 0.085 | |
| 1999 Rep 1 | 4.36 | 1 | 0.038 | 0.0001 |
| 1999 Rep 2 | 113.31 | 5 | <0.0001 | |
| 2001 Rep 2 | 15.99 | 2 | 0.0003 | |

| B. Factors Affecting Proportion of Seals Hauled Out | | | | |
|---|---|---|---|---|
| Variable | Chi-square | *df* | *P*-value | Pooled $P^a$ |
| Time of Day | | | | |
| 1997 | 21.01 | 8 | 0.007 | |
| 1998 | 36.00 | 7 | <0.0001 | |
| 1999 | 17.11 | 7 | 0.017 | <0.0001 |
| 2000 | 16.20 | 8 | 0.030 | |
| 2001 | 26.70 | 7 | 0.017 | |
| Date | | | | |
| 1997 | 52.77 | 8 | <0.0001 | |
| 1998 | 25.49 | 6 | 0.0003 | |
| 1999 | 160.95 | 8 | <0.0001 | <0.0001 |
| 2000 | 46.49 | 7 | <0.0001 | |
| 2001 | 255.76 | 8 | <0.0001 | |
| Air Temperature | | | | |
| 1997 | 3.57 | 2 | 0.168 | |
| 1998 | 12.69 | 3 | 0.005 | |
| 1999 | 125.99 | 4 | <0.0001 | <0.0001 |
| 2000 | 13.67 | 1 | 0.0002 | |
| 2001 | 229.1 | 2 | <0.0001 | |
| Wind Speed | | | | |
| 1997 | 19.29 | 3 | 0.0002 | |
| 1998 | 16.66 | 4 | 0.002 | |
| 1999 | 100.67 | 3 | <0.0001 | <0.0001 |
| 2000 | 27.21 | 3 | <0.0001 | |
| 2001 | 51.58 | 3 | <0.0001 | |
| Heat Loss | | | | |
| 1997 | 10.09 | 3 | 0.0178 | |
| 1998 | 33.66 | 3 | <0.0001 | |
| 1999 | 93.14 | 4 | <0.0001 | <0.0001 |
| 2000 | 19.05 | 3 | 0.0003 | |
| 2001 | 189.07 | 3 | <0.0001 | |
| Cloud Cover | | | | |
| 1997 | 19.98 | 7 | 0.006 | |
| 1998 | 30.42 | 9 | 0.0004 | |
| 1999 | 128.33 | 7 | <0.0001 | <0.0001 |
| 2000 | 34.13 | 8 | <0.0001 | |
| 2001 | 249.14 | 8 | <0.0001 | |

---

[a] A pooled *P*-value was calculated for each variable by adding the standard normal deviates (*Z*s) associated with the *P*-values obtained from the $\chi^2$ tests and dividing this sum by the square root of the number of replicates and/or years being combined (Rosenthal 1978).

[b] There were insufficient data during 1997, 2000, and replicate 1 in 2001 to conduct $\chi^2$ tests.

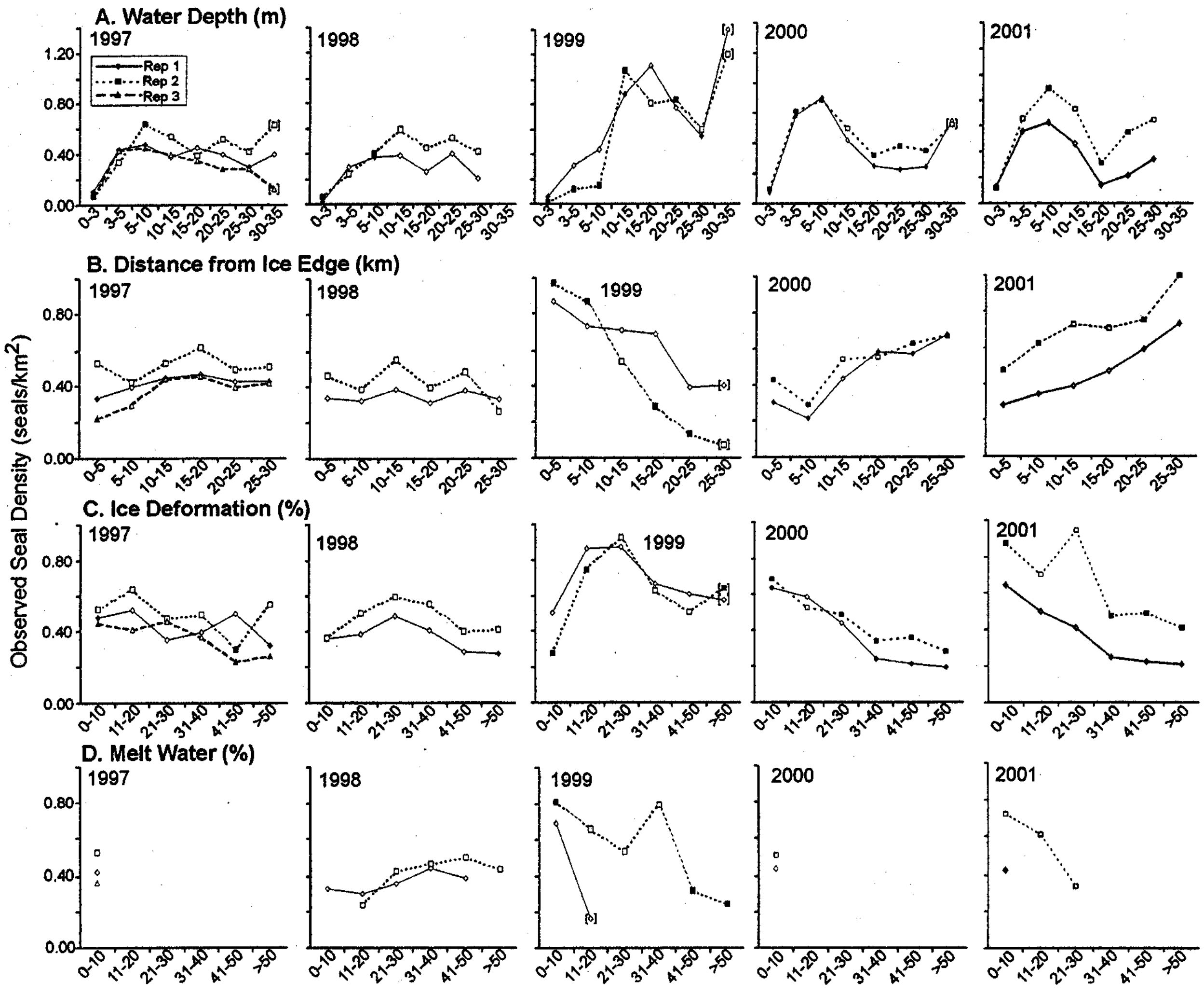


FIGURE 5.12. Observed densities of ringed seals during 1997, 1998, 1999, 2000, and 2001 at differing ***(A)*** water depths, ***(B)*** distances from the ice edge, ***(C)*** percent ice deformation, and ***(D)*** percent melt water. For all four habitat factors, differences among strata were significant for most individual replicates and years, and highly significant when replicates and years were combined (Table 5.3A). Solid symbols represent strata where the number of sightings was significantly lower or higher than expected based on the overall average sighting rate ($\alpha$=0.05; chi-square test with Bonferroni adjustment). Bracketed symbols indicate strata where only a relatively small area of fast ice (30-50 km$^2$) was surveyed. No symbol is plotted when the area surveyed was <30 km$^2$. In (B) – (D), data from water depths 0-3 m are excluded. Note the difference in y-axis scales for (A) vs. (B, C, D).

TABLE 5.4. Number of ringed seal sightings in 2001 in relation to environmental variables, as estimated by a Poisson regression model. The reference level for survey replicate number was replicate 1 (28 May - 4 June). Data from water depths 0-3 m excluded.

| Model Term | Coefficient | Standard Error | $F$-value (approx.) | $P$-value | % Change in sighting nos. for one unit increase of covariate | 95% CI for percent change |  | Covariate Unit |
|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | Lower | Upper |  |
| **Intercept** | -0.2157 | 0.1125 |  |  |  |  |  |  |
| **Main Effects** [a] |  |  |  |  |  |  |  |  |
| Ice Deformation | -0.021 | 0.0013 | 287.69 | <0.0001 | -2.05 | -2.31 | -1.80 | 10% |
| Air Temperature | 0.128 | 0.0171 | 57.29 | <0.0001 | 13.64 | 10.24 | 17.03 | 1°C |
| Air Temperature $^2$ | -0.021 | 0.0047 | 20.38 | <0.0001 |  |  |  |  |
| Dist. from Northstar 2001 | -0.034 | 0.0092 | 12.81 | 0.0003 | -3.34 | -5.16 | -1.52 | 1 km |
| Cloud Cover | 0.003 | 0.0008 | 11.68 | 0.0006 | 0.26 | 0.11 | 0.41 | 10% |

Note: $df = 9969$; Dispersion = 1.06; residual correlation (Pearson's $r$) = -0.008.

[a] The relationships of seal sightings to these covariates were the same across replicates; i.e., there was no significant interaction between survey replicate and each of these covariates.

The 0-3 m depth category has been excluded from all of the following univariate analyses, with the exception of the univariate tests for water depth in 1997 to 2000, because of the very low numbers of seals in waters <3 m deep. The 0-3 m depth category was also excluded from the Poisson regression analyses. This eliminated 555 km$^2$ of surveyed area and 68 seals (61 sightings) from further consideration in the analyses of the 2001 data. The Poisson regression model for 2001 data indicated that there was no strong relationship between seal sightings and water depth when areas <3 m deep were excluded. This covariate was not "selected" for inclusion in the model (*cf.* Table 5.4).

*1997-2001.*—Univariate analyses indicated that sighting densities were significantly related to water depth during all five survey years (Table 5.3A and Fig. 5.12A). Maximum densities tended to occur in slightly shallower water in 1997, 2000, 2001 and possibly 1998 than in 1999 (5-10 m vs. 10-15 m; Fig. 5.12A). During all five survey years, lowest seal densities were observed in the 0-3 m stratum. As noted for 2001, the low seal density in water 0-3 m deep was expected. The Poisson regression model for 1997-2001 data indicated that sighting density peaked in water depths 10 to 20 m, and that this effect did not differ strongly from year to year (Fig. 5.14A; Table 5.5).

### *Distance from Landfast Ice Edge*

*2001.*—Univariate analyses indicated that, in 2001, observed ringed seal densities varied significantly with distance from the edge of the landfast ice during both survey replicates (Fig. 5.12B; Table 5.3A). There were more sightings inshore from the ice edge, and fewer sightings close to the ice edge, than would be expected if seal distribution were uniform ($P < 0.001$). The stratum of highest density during each replicate was the one 25-30 km inshore of the ice edge (0.73 and 1.05 seals/km$^2$ in replicates 1 and 2, respectively). The stratum of lowest density during each replicate was the one within 5 km inshore of the ice edge (observed densities 0.28 and 0.48 seals/km$^2$ in replicates 1 and 2, respectively). The Poisson regression model for 2001 data indicated that consideration of distance from the ice edge did not result in a significant improvement in the ability to predict seal sighting rate.

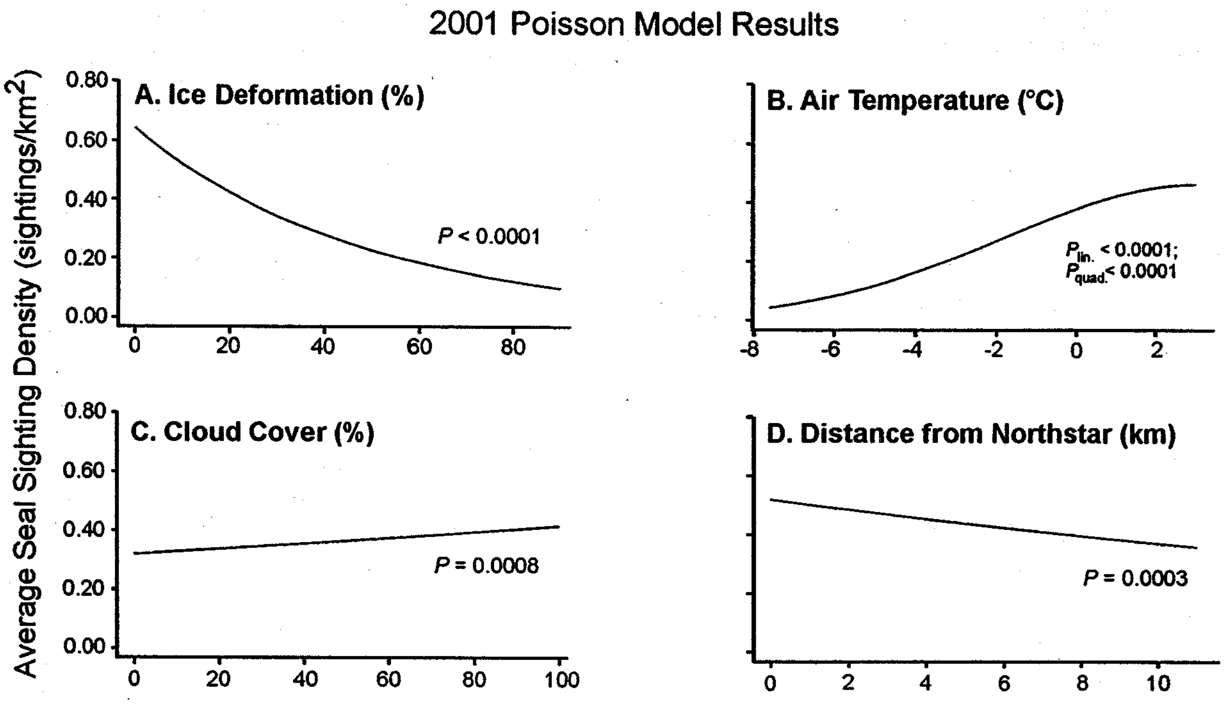


FIGURE 5.13. Number of ringed seal sightings in relation to environmental variables in 2001 as estimated by a Poisson regression model. Data from water depths 0-3 m are excluded.

*1997-2001.*—Univariate analyses indicated that sighting densities in relation to distance from the edge of the landfast ice varied amongst years. In 1997, 2000 and 2001, seal density increased with increasing distance from the ice edge. The opposite trend was observed in 1999. In 1998, no consistent pattern in seal density was observed (Fig. 5.12B). Most of these univariate results were statistically significant except for those involving replicate 1 in 1998 and 1999 (Table 5.3A). Like the results of the univariate analysis, the Poisson regression model for 1997-2001 data indicated that the average sighting rate in relation to distance from the ice edge varied amongst years (Fig. 5.14B; Table 5.5). In 1998 and 1999, sightings were significantly higher closer to the ice edge; this relationship was more pronounced in 1999 (Fig. 5.14B). In 1997 and 2001, there was a negative relationship but the result was not statistically significant at the $\alpha$=0.05 level. In 2000, there was some indication that seal sightings were higher farther from the ice edge (Fig. 5.14B) but the result was not significant.

### *Ice Deformation*

*2001.*—Univariate analyses indicated that observed seal density on landfast ice decreased significantly as ice deformation increased. This trend was consistent during both survey replicates (Table 5.3; Fig. 5.12C). The Poisson regression model for 2001 indicated that sightings were negatively related to percent ice deformation. This relationship was consistent between replicates (Table 5.4; Fig. 5.13A).

*1997-2001.*—Univariate analyses indicated that observed seal density on landfast ice varied significantly among categories of ice deformation during each survey year (Table 5.3A). In 1998 and 1999, observed seal densities were highest at intermediate levels of ice deformation, and lower for both low deformation (<10%) and high deformation (>40%) (Fig. 5.12C). In 1997, 2000 and 2001, significantly

TABLE 5.5. Number of ringed seal sightings in 1997-2001 in relation to environmental variables, as estimated by a Poisson regression model. The reference level for the year factor was 1997. Data from water depths 0-3 m excluded.

| Model Term | Coefficient | Standard Error | *F*-value (approx.) | *P*-value | % Change in sighting nos. for one unit increase of covariate | 95% CI for percent change | | Covariate Unit |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Lower | Upper | |
| **Intercept** | | | | | | | | |
| 1997 | -419.23 | 49.96 | 15.44 | <0.0001 | | | | |
| 1998 | -413.19 | 47.15 | | | | | | |
| 1999 | -463.32 | 55.68 | | | | | | |
| 2000 | -448.50 | 53.59 | | | | | | |
| 2001 | -446.82 | 52.75 | | | | | | |
| **Main Effects** [a] | | | | | | | | |
| Cloud Cover | 0.0020 | 0.0004 | 24.81 | <0.0001 | 0.20 | 0.12 | 0.27 | 10% |
| Wind Speed | -0.0082 | 0.0020 | 16.20 | <0.0001 | -0.82 | -1.22 | -0.42 | 1 km/h |
| Melt Water | -0.0114 | 0.0019 | 37.73 | <0.0001 | -1.13 | -1.51 | -0.76 | 10% |
| Air Temperature | 0.0241 | 0.0071 | 11.69 | 0.0006 | b | | | |
| Air Temperature $^2$ | -0.0015 | 0.0011 | 2.09 | 0.1483 | | | | |
| Water Depth | 0.0411 | 0.0099 | 17.59 | <0.0001 | b | | | |
| Water Depth$^2$ | -0.0015 | 0.0003 | 33.70 | <0.0001 | | | | |
| Date | 5.5406 | 0.6654 | | | b | | | |
| Date$^2$ | -0.0183 | 0.0022 | 69.75 | <0.0001 | | | | |
| Dist. from Northstar Site 2001 | -0.0350 | 0.0109 | 10.03 | 0.0015 | -3.43 | -5.58 | -1.28 | 1 km |
| Dist. from Northstar Site 2000 | 0.0147 | 0.0144 | 1.07 | 0.3017 | 1.48 | -1.38 | 4.33 | 1 km |
| **Interactions** [c] | | | | | | | | |
| Ice Deformation-1997 | -0.0089 | 0.0019 | 7.73 | <0.0001 | -0.88 | -1.26 | -0.51 | 10% |
| Ice Deformation-1998 | -0.0108 | 0.0021 | | | -1.07 | -1.47 | -0.67 | |
| Ice Deformation-1999 | -0.0075 | 0.0028 | | | -0.75 | -1.29 | -0.20 | |
| Ice Deformation-2000 | -0.0178 | 0.0022 | | | -1.77 | -2.19 | -1.34 | |
| Ice Deformation-2001 | -0.0200 | 0.0019 | | | -1.97 | -2.34 | -1.60 | |
| Distance from Ice Edge-1997 | -0.0118 | 0.0060 | 13.15 | <0.0001 | -1.17 | -2.35 | 0.01 | 5 km |
| Distance from Ice Edge-1998 | -0.0283 | 0.0088 | | | -2.79 | -4.53 | -1.04 | |
| Distance from Ice Edge-1999 | -0.0556 | 0.0091 | | | -5.40 | -7.20 | -3.59 | |
| Distance from Ice Edge-2000 | 0.0009 | 0.0084 | | | 0.09 | -1.57 | 1.75 | |
| Distance from Ice Edge-2001 | -0.0169 | 0.0086 | | | -1.67 | -3.38 | 0.03 | |
| Date-1997 | 5.5406 | 0.6654 | 15.52 | <0.0001 | b | | | |
| Date-1998 | 5.5030 | 0.6459 | | | | | | |
| Date-1999 | 5.8272 | 0.7023 | | | | | | |
| Date-2000 | 5.7289 | 0.6890 | | | | | | |
| Date-2001 | 5.7221 | 0.6838 | | | | | | |

Note: *df* = 51444; Overdispersion = 1.08; residual correlation (Pearson's *r*) = -0.01.

[a] The relationships of seal sightings to these covariates were the same across years; i.e., there was no significant interaction between year and each of these covariates.

[b] This value and the corresponding CI were not calculated because it is difficult to define a covariate unit for quadratic terms.

[c] *F*-values indicate a significant interaction between the covariate and "Year"; i.e., coefficients changed significantly from year to year. The coefficients presented here represent the actual slopes for each year.

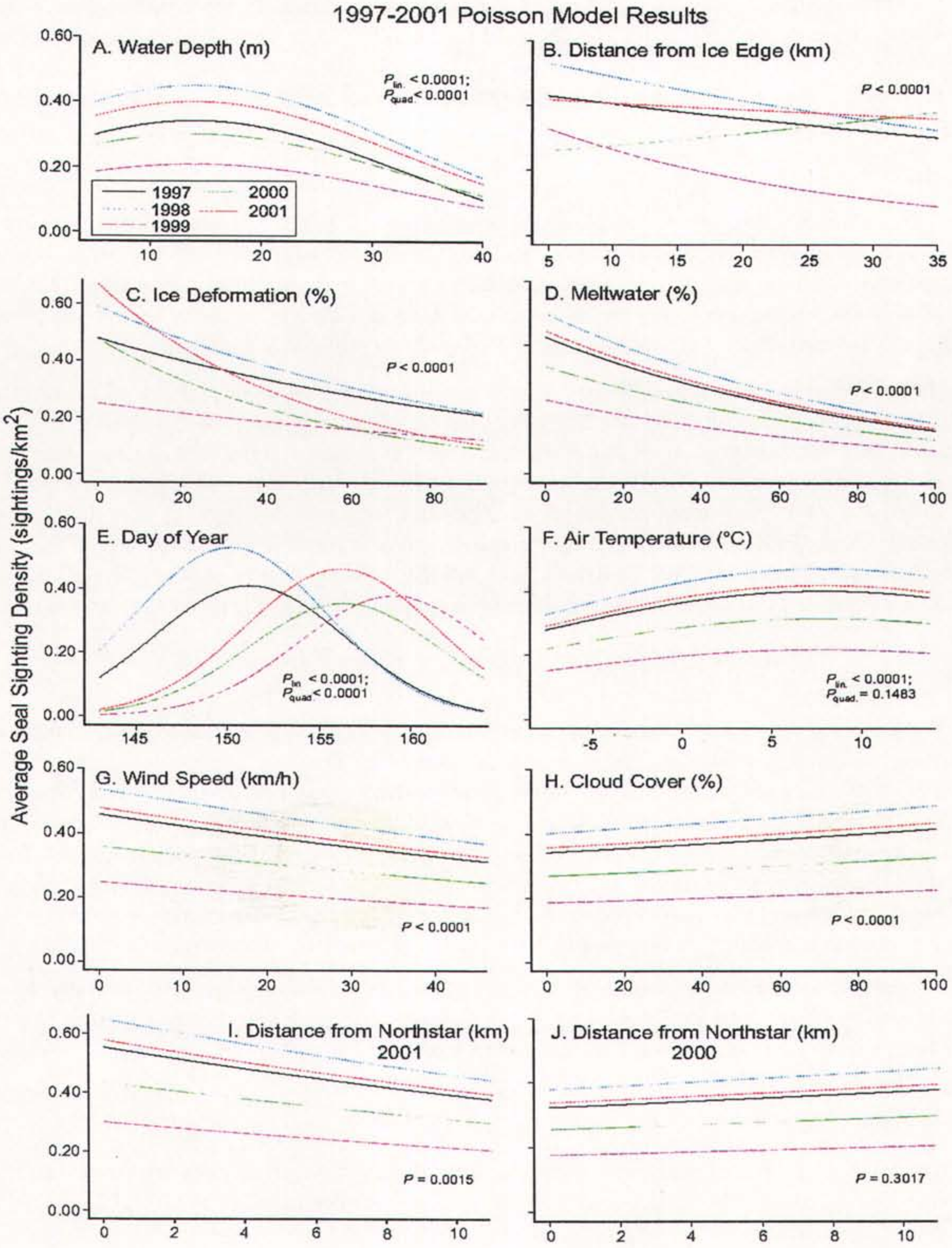


FIGURE 5.14. Number of ringed seal sightings in relation to environmental variables in 1997-2001 as estimated by a Poisson regression model. The reference level for the year factor was 1997. There were significant interactions between year and ice deformation ($F = 7.73$, $P < 0.0001$), distance from the ice edge ($F = 13.15$, $P < 0.0001$), and date ($F = 15.52$, $P < 0.0001$) in this model. Data from water depths 0-3 m are excluded.

lower numbers of sightings occurred in areas of rough ice and significantly more sightings occurred in areas of smooth ice (0-10%; Fig. 5.12C). The model for 1997-2001 data showed that, after allowance for other factors, sightings decreased as ice deformation increased. The trend was significantly negative in all survey years (Fig. 5.14C; Table 5.5). This relationship was more pronounced in 2001 and less pronounced in 1999 (Fig. 5.14C).

### *Melt Water*

*2001.*— In 2001, there was little melt water during replicate 1, so a $\chi^2$ test was not conducted. During replicate 2, coverage by melt water ranged from 0 to 30%. Significantly more seals were sighted in areas with little melt water and fewer seals were seen in areas where melt water exceeded 10% coverage (Fig.12D; Table 5.3A). The Poisson regression model for 2001 data indicated that there was no strong relationship between seal sightings and melt water. This covariate was not "selected" for inclusion in the model.

*1997-2001.*— In 1997, as in 2000, coverage by melt water rarely exceeded 10% during the survey, so a $\chi^2$ test was not conducted. In 1999 and 2001, there was very little melt water during replicate 1. During replicate 2, by which time melt water had increased, there was a general trend toward lower densities in areas with high melt water ($P < 0.001$; Fig. 5.12D). In 1998, melt water levels were higher than in 1997, 1999, 2000, and 2001. Univariate analysis of the 1998 data suggested that sighting rates did not differ significantly among melt water categories during either replicate 1 or 2 (Fig. 5.12D; Table 5.3A). The Poisson regression model for 1997-2001 data indicated that sighting density was negatively related to percent melt water, and that this effect did not differ strongly from year to year (Fig. 5.14D; Table 5.5).

## *Factors Affecting the Proportion of Seals Hauled Out*

We examined the observed density of ringed seals on landfast ice in relation to both temporal and weather factors that may affect the proportion of seals hauled out. Temporal factors included time of day and survey date. Weather factors included air temperature, wind speed, heat loss, and cloud cover. The 2001 and 1997-2001 results, both univariate and multivariate, are presented in the same manner as used above for habitat factors. Table 5.3B and Figures 5.15 - 5.16 summarize the univariate results. Tables 5.4 and 5.5 summarize the Poisson regression results for 2001 and 1997-2001, respectively. Some of these variables were intercorrelated with one another and with factors discussed above (e.g., melt water). Therefore, caution is necessary in interpreting these results and especially in imputing causal links.

In general, wind speed, air temperature, cloud cover, and date were significantly related to seal sightings, and the 1997-2001 model showed that the period when peak numbers of sightings occurred varied from year to year. In contrast, heat loss and time of day were not strongly related to seal sighting density in the Poisson regression models. Detailed results are presented below.

### *Time of Day*

*2001.*—Univariate analyses indicated that, in 2001, observed ringed seal densities varied significantly with time of day within the hours when aerial surveys were conducted ($P = 0.017$; Fig. 5.15A and Table 5.3B). Lowest densities were observed at the beginning of the daily survey period (0.36 seals/km$^2$ around 10:00). Higher densities were observed later in the day, with a maximum at 17:00 (0.81 seals/km$^2$). However, there was no one hour when the number of sightings was significantly ($\alpha$=0.05) lower or higher than expected if numbers hauled out were independent of time of day. The Poisson regression model for 2001 data indicated that, after allowance for other variables, there was no strong relationship between seal sightings and time of day. This covariate was not "selected" for inclusion in the model.

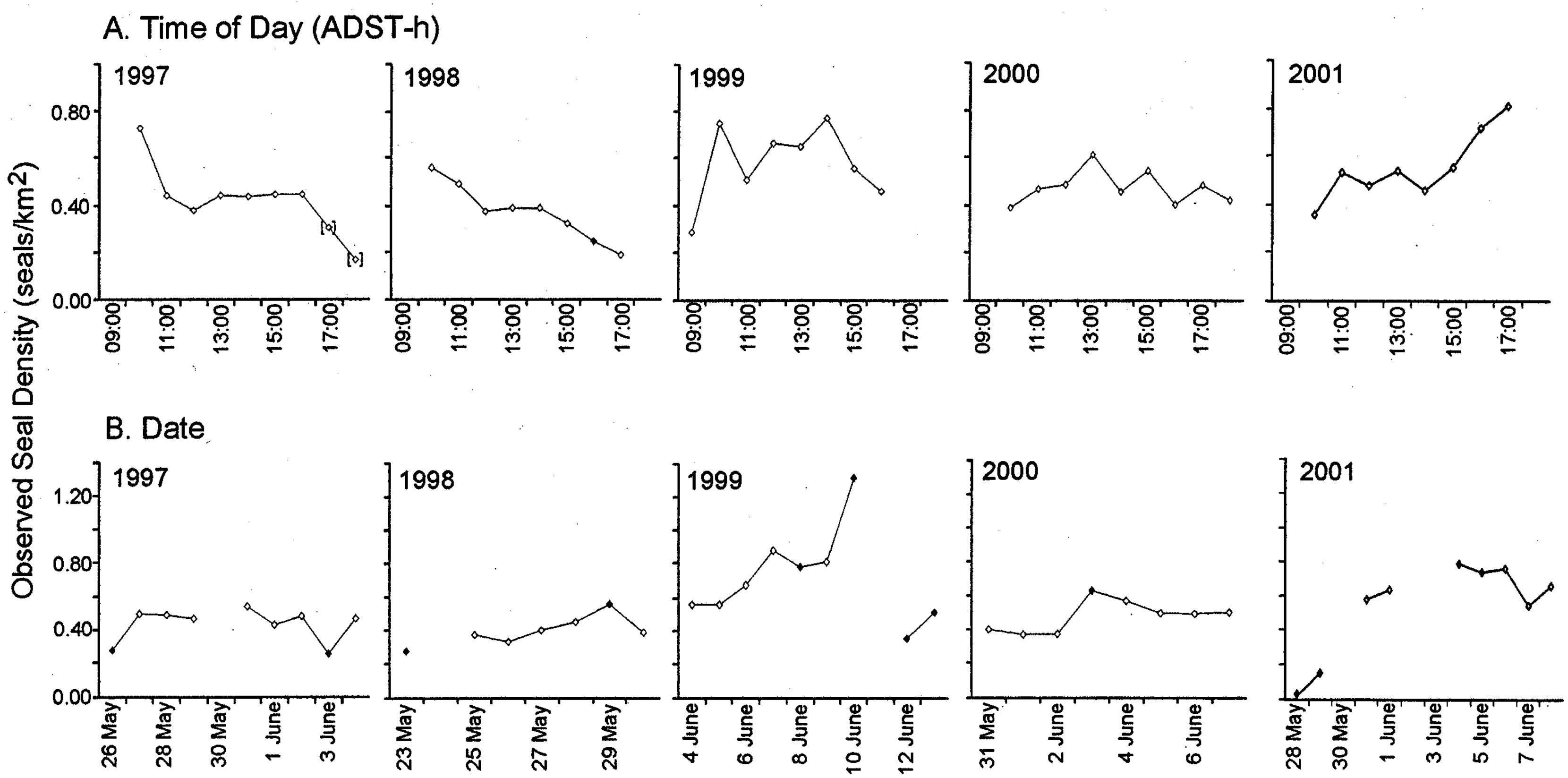


FIGURE 5.15. Observed densities of ringed seals during 1997, 1998, 1999, 2000, and 2001 at differing ***(A)*** times of day, and ***(B)*** dates. For both factors, differences among strata were significant for each individual year, and highly significant when years were combined (Table 5.3B). Note the difference in y-axis scales for (A) vs. (B), and the year-to-year difference in x-axis scales in (B). Otherwise as in Fig. 5.12.

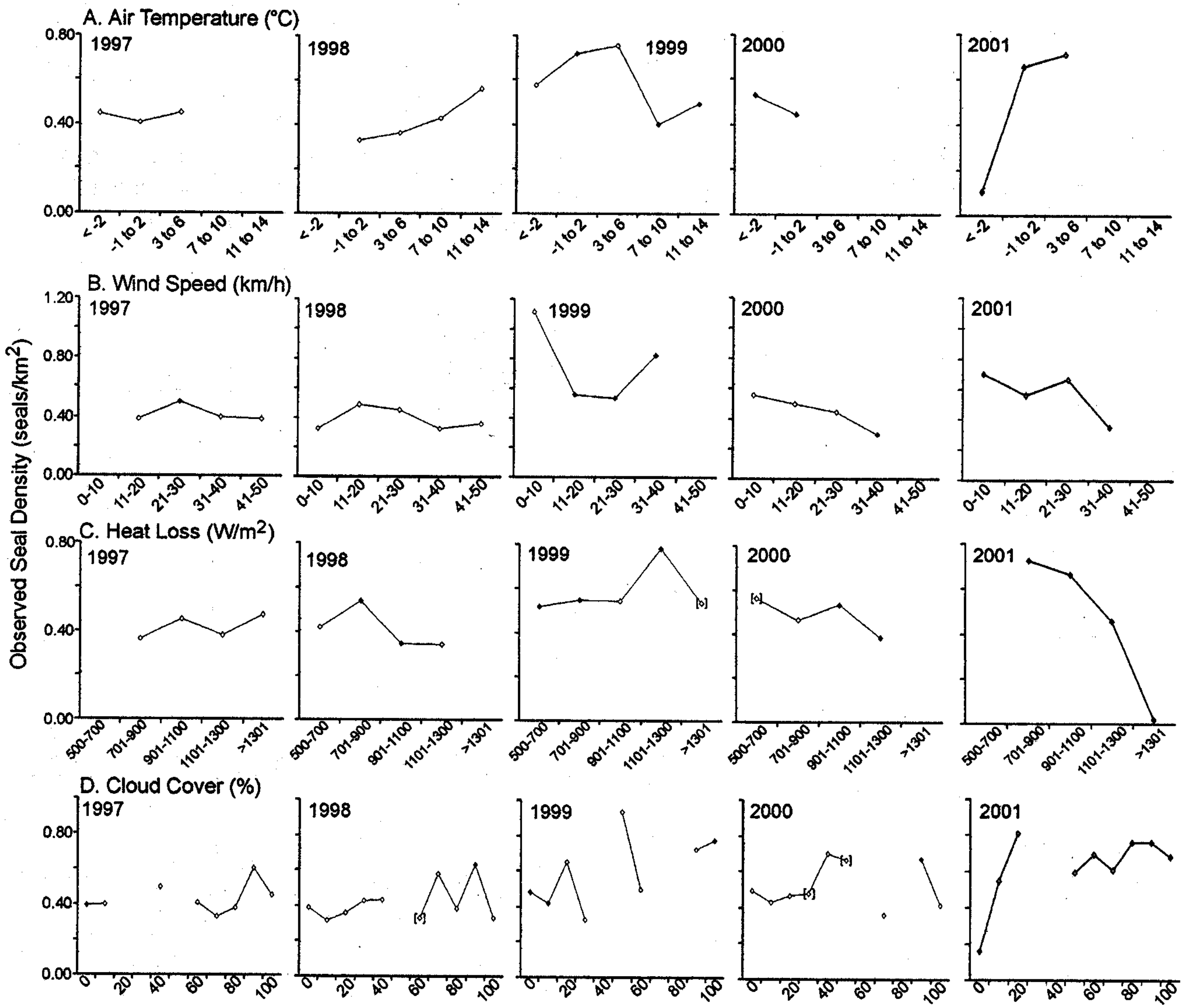


FIGURE 5.16. Observed density of ringed seals during 1997, 1998, 1999, 2000, and 2001 at differing values of ***(A)*** air temperature, ***(B)*** wind speed, ***(C)*** heat loss, and ***(D)*** cloud cover. For all factors, differences among strata were significant for each individual year, except air temperature in 1997, and highly significant when years were combined (Table 5.3B). Note the difference in y-axis scales for (A) and (C) vs. (B) and (D). Otherwise as in Fig. 5.12.

*1997-2001.*—The univariate analyses for 1997 and 1998 suggested that observed ringed seal densities varied significantly with time of day (Table 5.3B), tending to decline through the day (Fig. 5.15A). In 1999 and 2000, there were significant differences in sighting rates among hours, but in both years sighting rates tended to be higher near mid-day than earlier or later in the day. In 2001, sighting rates were lowest early in the day and highest later in the day. The Poisson regression model for 1997-2001 data indicated that, after allowance for other factors, there was no strong relationship between seal sighting rate and time of day within the range of hours when surveys were conducted. This covariate was not "selected" for inclusion in the model.

### Survey Date

*2001.*—Univariate analysis indicated that average densities of ringed seals observed on landfast ice on different dates in 2001 ranged from 0.02 to 0.79 seals/km$^2$ and differed significantly amongst dates ($P < 0.001$; Fig. 5.15B; Table 5.3B). Very few seals were seen on the first two survey dates (28-29 May). There was a general tendency toward higher densities in the middle portion of the survey, with a peak in observed density on 4 June, with marginally lower densities thereafter. The Poisson regression model for 2001 data indicated that there was no strong relationship between seal sightings and survey date. This covariate was not "selected" for inclusion in the model.

*1997-2001.*—Univariate analysis of the 1997 data indicated that significantly lower seal densities were observed at the beginning (26 May) and end (3 June) of the survey, with highest observed densities occurring in the middle of the survey period. Similar results were observed in 2000 and 2001, when there was a general tendency toward higher densities in the middle portion of the survey. This was also observed in 1999. However, the 1999 survey was conducted later in the season than during the other four years, in part because spring warming was delayed in 1999. In 1998, observed seal densities generally increased during the survey period as indicated by the univariate analysis results (Fig. 5.15B). This may be related to the earlier start and end dates in 1998 (23 and 30 May) than during any other year (Fig. 5.15B). The Poisson model for the 1997-2001 data indicated that survey date significantly influenced numbers of seal sightings in each survey year, and that sighting rates peaked in the middle of each survey year (Fig. 5.14F; Table 5.5). This trend is supported by the univariate analysis results with the exception of 1998 (Fig. 5.15B).

### Air Temperature

*2001.*— In 2001, there was a relatively large range of air temperatures (-7.6 to 3.0°C) and the $\chi^2$ test showed that sighting rates did differ significantly with air temperature (Table 5.3B; Fig. 5.16A). The significant difference was attributable to the relatively low densities of seals observed when the temperature was low (-7.6 to -2°C and –1 to 2°C). The Poisson regression model for 2001 data indicated that significantly higher sighting densities occurred during warmer periods (Fig. 5.13B and Table 5.4).

*1997-2001.*—Univariate analysis indicated that relationships between sighting rates and temperature differed among years. In 1997, there was a relatively small range of air temperatures (-4.3 to 2.7°C) and the $\chi^2$ test showed that sightings did not differ significantly with air temperature (Table 5.3B). As already mentioned, in 2001, observed seal density tended to be low during colder periods. The opposite trend was observed in 2000; more seals were observed at lower temperatures and fewer than expected were observed during slightly warmer temperatures. In 1998, observed seal densities increased significantly with increasing air temperature (Table 5.3B), even though there was no one temperature category for which the number of sightings was significantly ($\alpha$=0.05) low or high (Fig. 5.16A). In 1999, relatively low densities of seals were observed when the air temperature was high (>7°C), and the sighting rate was higher when the temperature was moderate. The Poisson regression model for 1997-2001 data indicated that the sighting rate was related to air temperature as this covariate was selected for inclusion in the model based on the BIC. Significantly more seals were seen during warmer periods (Fig. 5.14F) and there was some evidence (positive quadratic term selected based on the BIC but not significant at the $\alpha = 0.05$ level) that fewer seals occurred at the highest air temperatures (Table 5.5).

### *Wind Speed*

***2001.***—Average densities of ringed seals observed on landfast ice in 2001 at various wind speeds ranged from 0.35 to 0.70 seals/km$^2$ and differed significantly among categories of wind speed ($P < 0.001$; Fig. 5.16B and Table 5.3B). The overall significant difference among categories was attributable mainly to the relatively high density of seals observed when the wind speed was low (0 to 10 km/h) and to the relatively low density of seals observed when the wind speed was high (31 to 40 km/h). However, the Poisson regression model for 2001 data indicated that, after allowance for other variables, there was no strong relationship between seal sightings and wind speed. This covariate was not "selected" for inclusion in the model.

***1997-2001.***—Univariate results indicated that observed seal densities were significantly related to wind speed in each year (Table 5.3B). In 1997 and 1998, slightly higher seal densities were observed at intermediate wind speeds. In particular, during 1997, significantly more seals were sighted when wind speeds were 21-30 km/h (Fig. 5.16B). In 1999, an opposite pattern was observed; significantly fewer seals were observed when wind speeds were 11-30 km/h (Fig. 5.16B; Tables 5.3B). As already mentioned, in 2001 significantly fewer seals were observed at higher wind speeds and more seals were observed at lower wind speeds (Fig. 5.16B). A similar trend was observed in 2000. The Poisson regression model for 1997-2001 indicated that there was a significant relationship between seal sightings and wind speed and that the relationship was consistent among years (Fig. 5.14G; Table 5.5). Significantly fewer seals were observed when wind speeds were high.

### *Heat Loss*

***2001.***—Heat loss was calculated as described in the "Methods" from the recorded wind speed and temperature. Univariate analysis revealed that, in 2001, average densities of ringed seals observed on landfast ice at various values of heat loss ranged from 0.02 to 0.73 seals/km$^2$ and differed significantly among categories of heat loss ($P < 0.001$; Fig. 5.16C and Table 5.3B). The overall significant difference among categories was attributable mainly to the relatively high density of seals observed when the heat loss was moderate (701-1100 W/m$^2$) and the lower than expected number seen when heat loss was high (1101-1300 W/m$^2$ and >1301 W/m$^2$). However, the Poisson regression model for 2001 data indicated that there was no significant relationship between seal sightings and heat loss after allowance for other factors, including air temperature.

***1997-2001.***—Although univariate results indicated that numbers of sightings were significantly related to heat loss in each survey year (Table 5.3B), there were no consistent trends across years (Fig. 5.16C). In 1997, there was no one heat loss category when the number of sightings was significantly ($\alpha$=0.05) lower or higher than expected if numbers hauled out were independent of heat loss. In 1998, 2000, and 2001 relatively high densities of seals were observed when the heat loss was moderate and low numbers were seen when heat loss was higher. In 1999, relatively high densities of seals were observed when the heat loss was 1101-1300 W/m$^2$ and low numbers were seen when it was 500-900 W/m$^2$. The Poisson regression model for 1997-2001 data indicated that there was no significant relationship between seal sightings and heat loss after allowance for other factors, including wind speed and air temperature.

### *Cloud Cover*

*2001.*—Univariate results showed that, in 2001, average densities of ringed seals observed on landfast ice differed significantly in relation to cloud cover ($P < 0.001$). Observed densities ranged from 0.16 to 0.76 seals/km$^2$ under different cloud conditions (Fig.5.16D). The overall significant difference was attributable mainly to the relatively high density of seals observed when cloud cover was >80% and low density when there was no cloud cover. The Poisson regression model for 2001 data indicated that sighting rate was positively related to cloud cover (Table 5.4; Fig. 5.13C).

*1997-2001.*—The univariate analyses indicated that, in all five survey years, higher densities of ringed seals were observed with high amounts of cloud cover (Fig. 5.16D). The Poisson model based on the 1997-2001 data also showed a significant positive relationship between numbers of seal sightings and cloud cover. That trend was consistent from year to year (Table 5.5; Fig. 5.14H). The slope of the relationship was shallow, however, with only a 0.20% change in sighting rate per 10% increase in cloud cover.

## *Observed Ringed Seal Densities Near Development Sites*

### *Northstar Activities*

*2001.*— Figure 5.17 shows the locations of both the on-transect and off-transect seal sightings in the area close to Northstar during both of the 2001 survey replicates. Only the on-transect sightings are considered in the remainder of this subsection.[4] Eight seals (seven sightings) were observed within the Northstar development zone. This development zone encompasses the area covered by ice roads, the pipeline corridor, Northstar island, and the area around the island where emergency equipment was tested (see area shaded dark gray in Fig. 5.17). There were 48 sightings (involving 52 seals) within 1 km of the development zone, and an additional 51 sightings (58 seals) at locations 1-2 km from the development zone (Table 5.6).

The observed seal density in the Northstar development zone and within 10 km of that zone was 0.61 seals/km$^2$, based on replicates 1 and 2 combined. The numbers of seal sightings within the development zone and in various 1-km increments of distance from the Northstar development zone (solid line in Fig. 5.18) differed significantly from the numbers expected based on the amount of survey coverage within each distance increment ($P < 0.001$; Table 5.6). Observed ringed seal density was higher closer to the Northstar development zone than farther away (Fig. 5.18). The overall significant difference among strata was attributable mainly to the higher than expected numbers of sightings within 1-2 km of the development zone, and lower than expected numbers 6-8 km from the development zone.

Inclusion of the variable "Distance from Northstar in 2001" did significantly improve the fit of the Poisson regression models for 2001 and for 1997-2001 combined ($P = 0.0003$ and $P = 0.0015$, respectively). Both models indicated that, after allowance for other factors related to sighting rate, significantly more seals occurred close to the Northstar development area in 2001. If industrial activities had negatively impacted seals we would have expected fewer seals to occur close to Northstar.

---

[4] Off-transect sightings are excluded because their positions were not recorded with sufficient precision to be useful in this fine-scale analysis. Sighting locations mapped in Figure 5.17 (and elsewhere) are the locations of the survey aircraft at the specific time that the sighting was recorded. The outer edge of the transect strip was 0.55 km from the aircraft. Recorded times could differ by as much as 5 s from the time when the aircraft was closest to the seal, and the aircraft traveled ~0.3 km along the transect during 5 s. Thus, plotted positions could be as much as 0.62 km, i.e. $\sqrt{(0.55^2 + 0.3^2)}$, from actual positions, though most will be closer than this.

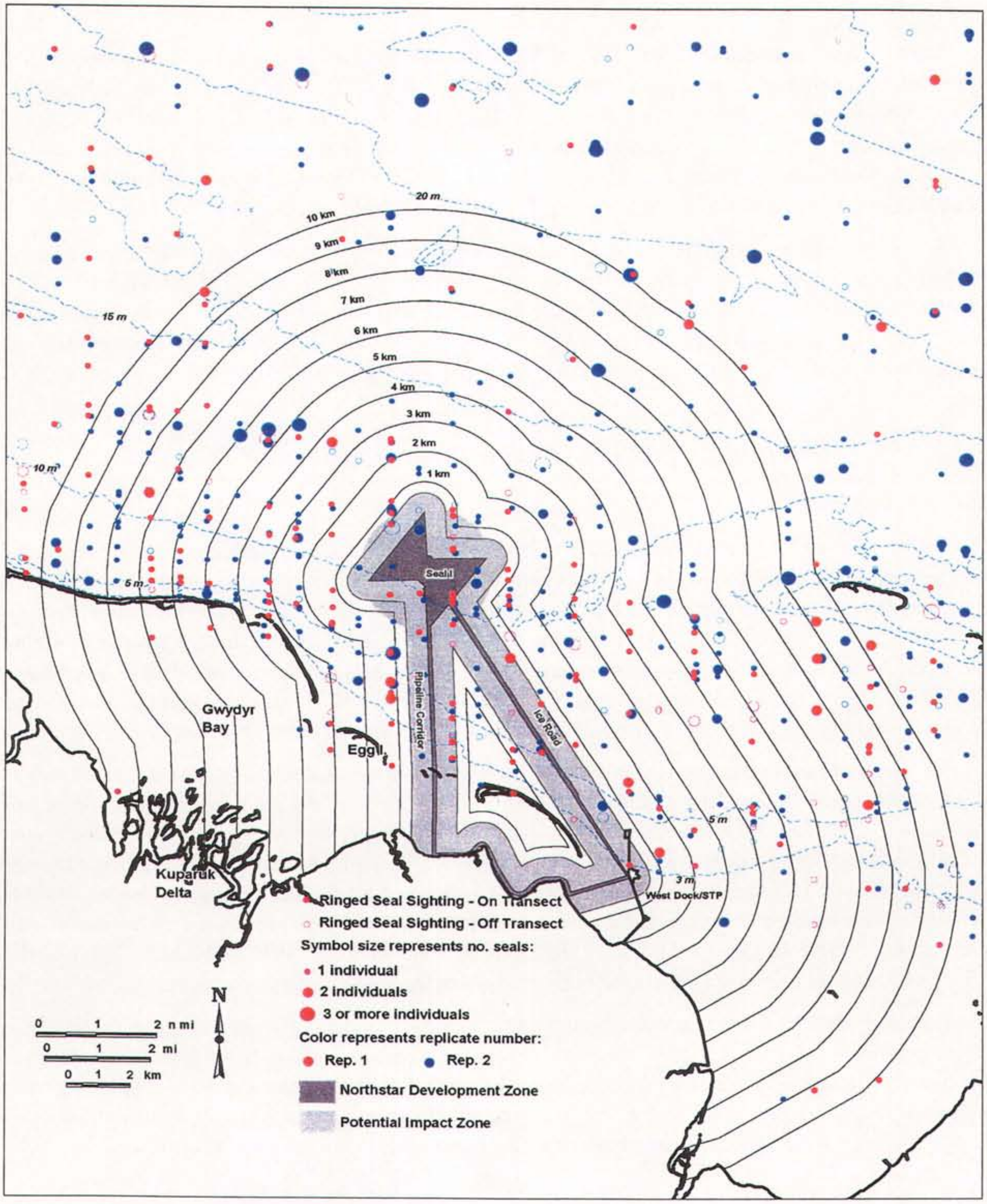


FIGURE 5.17. Distribution of ringed seal sightings during replicate 1 (28 May – 4 June 2001) and replicate 2 (4-8 June 2001) within 10 km of the edges of the Northstar development zone. Successive 1-km distance categories from the edges of the ice roads, pipeline, artificial island, and the area around the island where emergency equipment was tested are shown. 1 km = 0.62 mi = 0.54 n.mi. The "Northstar development zone" and a larger "Potential impact zone" (see Chapter 9) are indicated with dark gray and light gray shading, respectively.

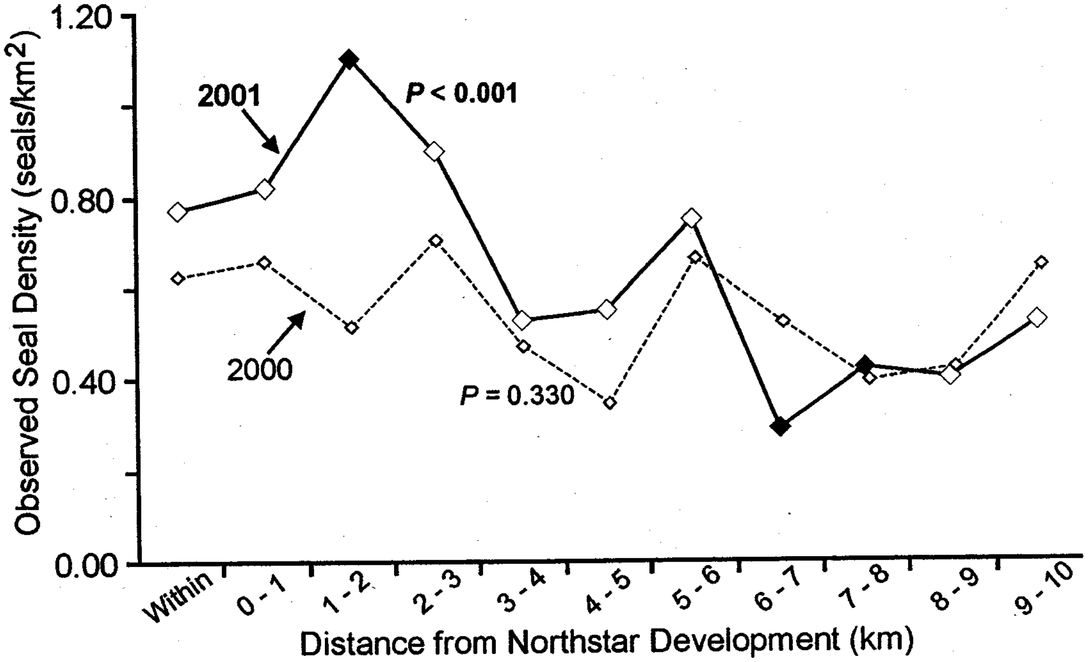


FIGURE 5.18. Observed density of ringed seals during survey replicates 1 and 2 combined at differing distances from the edge of the Northstar development zone and within the development zone. Densities for 2001 (28 May – 8 June 2001) are indicated with a solid line and those for 2000 (31 May – 7 June 2000) are indicated with a dashed line. The *P*-value is the significance level for the overall $\chi^2$ test (see Table 5.6 for 2001). Solid symbols represent strata where the number of sightings was significantly lower or higher than expected based on the overall average sighting rate ($\alpha$=0.05; chi-square test with Bonferroni adjustment). Results from areas with water depths 0-3 m are excluded.

***2000.***—Northstar construction activities during the ice-covered season were most intense in early 2000, the year when the island was rebuilt and the pipelines were constructed. It had been hypothesized that observed seal density would be reduced close to Northstar in 2000 as a result of displacement of seals through disturbance effects. The report on the seal surveys in 2000 (Moulton et al. 2001) provides a detailed description of seal sightings and densities near Northstar during the spring of 2000, following the intense construction activity. Univariate (see dashed line in Fig. 5.18) and multivariate analyses similar to those described above for 2001 showed no evidence of reduced seal densities close to Northstar during the spring of 2000.

The 2000 data were also included in the 1997-2001 analysis conducted during the present study. When treated like other variables, "Distance from Northstar in 2000" was excluded from the 1997-2001 Poisson regression model as being not significantly related to seal sighting rate. Because of its central importance in this study, "Distance from Northstar in 2000" was included in the final 1997-2001 model even though it would have been excluded by the usual criteria. When this variable was "forced" into the 1997-2001 model, no significant relationship was evident after allowance for other factors ($P$ = 0.3017; Fig. 5.14J). This, along with other previously-reported results from 2000 (Moulton et al. 2001), indicates that most seals did not avoid the Northstar development area in 2000. If there was any net displacement of seals in 2000, it must have involved a limited number of seals and must have been quite localized.

TABLE 5.6. Distance from the Northstar development zone vs. observed and expected numbers of ringed seal sightings on landfast ice during 2001. Survey replicates 1 and 2 are combined; excludes water depths < 3 m.

| Distance from Development Zone (km) | Area Surveyed (km$^2$) | Proportion of Total Area Surveyed | Observed No. of Seal Sightings | Expected No. of Seal Sightings | Proportion of Total Observed in Each Interval | 95% Bonferroni Confidence Limits on Proportion of Occurrence | | Observed Proportion Relative to CI | Observed No. of Seals | Observed Density (seals/km$^2$) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Lower | Upper | | | |
| Within[1] | 10.37 | 0.02 | 7 | 5 | 0.02 | 0.00 | 0.04 | Within | 8 | 0.77 |
| 0 - 1 | 63.53 | 0.10 | 48 | 34 | 0.15 | 0.09 | 0.20 | Within | 52 | 0.82 |
| 1 - 2 | 52.62 | 0.08 | 51 | 28 | 0.15 | 0.10 | 0.21 | >Expected | 58 | 1.10 |
| 2 - 3 | 53.25 | 0.08 | 41 | 28 | 0.12 | 0.07 | 0.18 | Within | 48 | 0.90 |
| 3 - 4 | 50.80 | 0.08 | 26 | 27 | 0.08 | 0.04 | 0.12 | Within | 27 | 0.53 |
| 4 - 5 | 56.33 | 0.09 | 26 | 30 | 0.08 | 0.04 | 0.12 | Within | 31 | 0.55 |
| 5 - 6 | 57.17 | 0.09 | 35 | 30 | 0.11 | 0.06 | 0.15 | Within | 43 | 0.75 |
| 6 - 7 | 62.24 | 0.10 | 17 | 33 | 0.05 | 0.02 | 0.09 | <Expected | 18 | 0.29 |
| 7 - 8 | 68.23 | 0.11 | 21 | 36 | 0.06 | 0.03 | 0.10 | <Expected | 29 | 0.43 |
| 8 - 9 | 74.66 | 0.12 | 27 | 39 | 0.08 | 0.04 | 0.12 | Within | 30 | 0.40 |
| 9 - 10 | 78.32 | 0.12 | 32 | 41 | 0.10 | 0.05 | 0.14 | Within | 41 | 0.52 |
| **Total** | **627.52** | **1.00** | **331** | **331** | **1.00** | | | | **385** | **0.61** |

[1] Includes area within the ice roads, pipeline corridor, and the area around Northstar used to test emergency equipment. See Figure 5.17.

[2] Expected numbers are proportional to area surveyed, i.e. assuming the same number of sightings/km$^2$ in each distance interval.

Observed vs. expected number of seal sightings vs. distance (replicates 1 and 2 combined): $\chi^2 = 53.22$, $df = 10$, $P < 0.001$.

### *Other Industry Activities*

***2001.***—In 2001, one additional offshore industrial activity was known to have occurred within a part of the study area during the months preceding the aerial surveys: on-ice Vibroseis operations in the southeast part of the study area from east of Point Brower to the Shaviovik River (see Fig. 5.4). The Poisson regression model for 2001 data suggested that the density of ringed seal sightings distance was not significantly related to distance from this area of Vibroseis. This variable was not included in the 2001 model based on the BIC index.

***1997-2001.***—The Poisson regression model for 1997-2001 data suggested that seal density in all survey years combined was not significantly related to distances from industrial activities other than Northstar. The covariates "Vibroseis", "McCovey shallow-hazards survey" and "Other Industry" did not enter the model. The "Vibroseis" variable represented the occurrence of substantial Vibroseis activity in two areas during 1998 (Link et al. 1999) and the aforementioned smaller area in 2001. The "Other Industry" variable represented the occurrence of drilling and limited Vibroseis in the Tern Island/Liberty area during 1997 (Miller et al. 1998) and 1998 (Link et al. 1999), and construction of ice roads near Northstar in 1999 (Moulton et al. 2000a). The "Vibroseis" and "Other Industry" variables were not strongly related to numbers of seal sightings after allowance for other variables (see "Discussion").

### *Liberty*

Ringed seals were seen near Liberty and near Tern Island during 2001 (Fig. 5.6, 5.7). There was no industrial activity at these sites during the winter of 2000-2001. The survey data from the Liberty area in 2001 (and 1997-2000) are available for possible future use if oil development goes ahead at Liberty.

## *Observed Ringed Seal Behavior*

Most ringed seals seen in 2001 did not exhibit any obvious "negative" response to the aircraft as it flew overhead. More than half (52.5%) of all ringed seals observed, including those seen on pack ice as well as fast ice, showed no obvious response ("None"), while 34.9% were observed to look up at the aircraft (Table 5.7). Only 1.3% (36 seals) of the observed ringed seals were seen to dive into their holes or cracks in apparent response to the aircraft. An additional 1.4% (39 seals) were recorded as moving on the ice without diving into the water (Table 5.7).

# DISCUSSION

## *Observed Ringed Seal Densities*

The overall observed ringed seal density based on our spring 2001 surveys of landfast ice habitat was 0.49 seals/km$^2$, or 0.54 seals/km$^2$ if areas <3 m deep are excluded. The overall density in areas ≥3 m deep was lower in 2001 (0.54 seals/km$^2$) than found during BP/LGL surveys in 1999 (0.63 seals/km$^2$; Moulton et al. 2000a) but higher than densities in 1997, 1998, and 2000 (0.43, 0.39 and 0.47 seals/km$^2$, respectively; *cf.* Miller et al. 1998; Link et al. 1999; Moulton et al. 2001). During 1996, 1997, and 1998, ADF&G recorded densities of 0.57, 0.74, and 0.83 seals/km$^2$ in their sector B3, which includes our entire study area plus additional areas to the east and west (Frost et al. 1997; Frost and Lowry 1998, 1999). All of these recent density estimates are low compared to seal densities recorded in the same general area in the 1980s. During 1985-87, observed seal densities in fast ice portions of ADF&G's sector B3 ranged from 1.01 to 2.94 seals/km$^2$ (Table 5.1) — 1.7 to 5.1 times higher than the density observed during the present study.

TABLE 5.7. Number of ringed seals observed showing various behaviors during survey replicates 1 and 2 in 2001. Both fast ice and pack ice observations are included.

| Behavior | | Fast Ice | Pack Ice | **Total** |
|---|---|---|---|---|
| Dive | | | | |
| | No. of Seals | 25 | 11 | **36** |
| | % of Total | 1.0 | 5.0 | **1.3** |
| Move | | | | |
| | No. of Seals | 38 | 1 | **39** |
| | % of Total | 1.5 | 0.5 | **1.4** |
| Look | | | | |
| | No. of Seals | 866 | 79 | **945** |
| | % of Total | 34.9 | 35.9 | **34.9** |
| None | | | | |
| | No. of Seals | 1307 | 113 | **1420** |
| | % of Total | 52.6 | 51.4 | **52.5** |
| Unknown | | | | |
| | No. of Seals | 248 | 16 | **264** |
| | % of Total | 10.0 | 7.3 | **9.8** |
| **Total** | | **2484** | **220** | **2704** |

These variable densities are not especially surprising given what is known about inter-annual variations of ringed seal body condition and reproduction in the Beaufort Sea in earlier years (Stirling et al. 1977; Smith and Stirling 1978; Smith 1987; Kingsley and Byers 1998; Harwood et al. 2000). Recent BP/LGL (1997-2000) and ADF&G (1996-98) survey results suggest that the central Alaskan Beaufort Sea population of ringed seals may be smaller than in the early 1980s.

### *Distribution of Seals and Observed Group Size*

In 2001, ringed seals were observed in most parts of the study area, but there was a tendency for higher densities in the deeper parts of the lagoons in the eastern portion of the study area, and between the 3 m and 15 m depth contour (mainly seaward of the barrier islands) in the western portion of the study area. Similarly, ringed seals were more common in deeper parts of the nearshore lagoons in both 1997 and 1998 (*cf.* Miller et al. 1998; Link et al. 1999). However, in 1999, there was a tendency for lower densities inside the lagoons as seals were concentrated in waters 15-25 m deep (Moulton et al. 2000a). The reasons for these high-density areas and for the interannual variation in their locations are not known but may be related to factors like prey availability or the suitability of ice habitat for maintaining seal structures.

Some seals may move from pack ice into adjacent areas of landfast ice as cracks form in the landfast ice during breakup (Finley 1979; Frost et al. 1988). Although the majority of ringed seals were observed at holes in all years, relatively more seals occurred at cracks in 1999 (22.8%) than in 1997 (6.5%), 1998 (10.5%), 2000 (2.5%), and 2001 (5.9%). It appears that cracks were more prevalent in 1999 and that more cracks became available for haulout as the 1999 field season progressed (Moulton et al. 2000a). This may have resulted in an influx of ringed seals from pack ice into the adjacent fast ice during the 1999 survey. The 1999 survey results may be biased upward (at least during replicate 2) by the presence of seals that spent the winter elsewhere. This may also explain why ringed seals tended to be concentrated in deeper parts of the study area in 1999 vs. other years, and why the overall density for 1999 was higher. Nevertheless, any movement of ringed seals from pack ice into the offshore portions of the landfast ice zone during any survey year is not likely to have affected seal densities near Northstar, which is closer to the barrier islands than to the edge of the landfast ice.

We expected group size of seals to increase as the season progressed given that more cracks became available for haulout and that larger groups are usually found at cracks (Finley 1979; Smith et al. 1979; Frost and Lowry 1999). Also, other studies have revealed that the number of ringed seal groups increases as the molting season progresses (Smith and Hammill 1981; Frost et al. 1988). In 1999, the mean group size was 5.6 at cracks and 1.7 at holes. In 1999, increases in group size were observed both at cracks and at holes as the season progressed, but only at holes was the increase significant. (No significant seasonal trends in group size were detected in 1997, average group size observed at cracks increased marginally in 1998, and average group size at holes increased slightly in 2000 and 2001.) This suggests that factors other than crack availability play a key role in determining group size. It is plausible that, as melt water increases, seals abandon these flooded areas and haul out with other seals at holes located in "drier" areas. Ringed seals are known to share breathing holes (e.g., Smith et al. 1979; Smith and Hammill 1981) and there is some evidence that they share lairs as well (Kelly et al. 1986). Indeed, melt water has a negative influence on the number of seals observed (see "Melt Water", later). Another possible explanation is that seals haul out for longer periods and more regularly later in the season to facilitate molt (Kelly and Quakenbush 1990; Kelly et al. 2000), thereby increasing group size.

### *Habitat Factors Affecting Ringed Seal Abundance and Distribution*

The distribution of ringed seals in the landfast ice during the springtime molt is thought to be mostly predetermined during the fall freeze-up (Smith et al. 1979; Kelly et al. 1986) when habitat factors like water depth, ice deformation, and distance from the ice edge influence where seals create breathing holes and subsequent lairs. Ringed seals may maintain many of the same breathing holes and lairs throughout the ice-covered period, although some appear to be abandoned for natural reasons over the winter (see Chapter 4). Also, it is likely that some (perhaps many) "new" breathing holes and lairs are created when cracks in the landfast ice form later in winter (Kelly et al. 1986; Frost and Burns 1989; T. Smith, pers. comm.; see Chapter 4). Nonetheless, habitat factors play a major part in influencing seal distribution and abundance as evidenced by the present results.

In 2001, all four habitat factors examined at the univariate level were significantly related to the abundance and distribution of ringed seals. However, of those four factors, only ice deformation was significantly related to seal density in the 2001 Poisson model. All four habitat factors were significantly related to seal density in the multiyear Poisson regression model. Trends sometimes differed amongst years in the multiyear model, as there were significant interactions between year and ice deformation, and year and distance from edge of the landfast ice.

***Water Depth.***—Prior to this study little specific information was available about the relationship between water depth and abundance of ringed seals inhabiting landfast ice in the central Alaskan Beaufort Sea during spring. It has generally been reported that ringed seals in this area are more abundant on the landfast ice than on the pack ice farther offshore, with little focus on distribution within the landfast zone in relation to water depth (Frost et al. 1988; Frost and Lowry 1999). [Frost and Lowry (1999) proposed to include water depth as a covariate in future analyses.] The seals inhabiting the landfast ice in our study area were limited to maximal water depths of approximately 30 m, as that was where the most seaward extent of the ice edge was typically located. In all five BP/LGL surveys, observed densities were notably lower in areas with water depths <3 m (Miller et al. 1998; Link et al. 1999; Moulton et al. 2000a; Moulton et al. 2001; this study). As already mentioned, this was expected as 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, and the 2-3 m portion would be marginal habitat at best. The multiyear model indicates that seals were most abundant over water depths of approximately 10-20 m, and that this trend was consistent from year to year after accounting for other covariates.

Both the univariate and multivariate results indicated that the relationship between seal density and water depth differed amongst survey years. Univariate results suggested that more seals occurred in relatively shallow waters in 1997, 1998 (5-15 m), and 2000 and 2001 (3-10 m). In 1999, observed densities peaked at intermediate water depths of 10 to 20 m as indicated by univariate results. Ringed seals were more common in deeper parts of the nearshore lagoons in 1997, 1998, 2000 and 2001 than in 1999, and there were greater concentrations of ringed seals in deeper waters near the ice edge in 1999. It is possible that ringed seals in the survey area are more abundant at shallower water depths, which are generally found shoreward or not far seaward of the barrier islands, because these waters offer more favorable habitat in terms of ice conditions and possibly prey abundance. The higher numbers of seals observed in deeper water in 1999 may be attributed to the influx of seals from the ice edge area or pack ice.

***Distance from Landfast Ice Edge.***—The distribution and abundance of ringed seals relative to the ice edge varies as break-up of the landfast ice begins. This occurs in both the central Alaskan Beaufort Sea (Frost et al. 1988) and in the Canadian Arctic (Smith 1973a; Finley 1979). It has generally been accepted that, prior to break-up, ringed seals are relatively widely distributed at holes in the landfast ice away from the unstable ice edge; during break-up, large numbers of seals occur near the ice edge, particularly along cracks (Frost et al. 1988). Our results indicate that in most survey years, when other covariates are taken into account, more ringed seals occur close to the ice edge even before ice break-up. It appears that the increase in seal density near the ice edge is influenced by the stage of ice break-up.

The multiyear Poisson model suggests that higher densities of seals occurred close to the ice edge (as compared with farther inshore) in four of the five survey years. The only exception was in 2000 where there appears to be a positive relationship between seal density and distance from the ice edge. However, this finding was not statistically significant. Significantly more seals were found near the ice edge in 1999, as indicated by both univariate and multivariate results. It appears that our 1999 survey (at least replicate 2) was conducted as the outer portions of the landfast ice were breaking up (Moulton et al. 2000a). The overall density for 1999 was higher than in 1997, 1998 and 2000 – particularly within 5 km of the landfast ice edge. The 1999 results may be biased upward by the presence of seals that spent the winter elsewhere.

Previous studies concerning seal density vs. distance from ice edge have produced variable results. Frost and Lowry (1999) found that ringed seal density decreased with increasing distance from the ice edge in the central and eastern Alaskan Beaufort Sea during 1996-98. In contrast, Burns and Harbo (1972) found that ringed seal density on landfast ice in the central Alaskan Beaufort increased with increasing distance from the ice edge. However, this effect was not observed within the zone 12.9 km (8 mi) from the ice edge and their analysis did not control for other factors known to influence seal density.

***Ice Deformation.***—In our study area, landfast ice is usually very smooth and stable shoreward of the barrier islands as storm events there are less severe and the ice is more firmly anchored to shore and (in some areas) to the bottom. 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. Ice deformation data collected by aerial surveyors showed that, in 2001, rougher (more deformed) ice was very evident offshore of the barrier islands (Fig. 5.5).

In 2001, there was a significant trend toward higher observed densities in areas with low ice deformation and lower observed densities in areas with high ice deformation. This same trend was noted in 1997 to 2000 and was also evident from the multiyear Poisson regression model after other factors were taken into account. Similar results were obtained by other researchers in Alaska (Burns 1981; Burns and Kelly 1982; Frost et al. 1988). In several areas of the Canadian Arctic, ringed seals showed a preference for fast ice with <40% deformation (Hammill and Smith 1989 *in* Reeves 1998). Frost et al. (1988) speculated that ringed seals prefer smooth ice because they are better able to detect approaching predators in open areas of smooth ice. Also, very jumbled ice occurs in areas of great instability, which are vacated by seals during storm events. However, the decline in seal numbers with increasing ice roughness may also be related, in part, to an observer's increased difficulty in detecting seals in rough ice conditions. In fact, a certain degree of ice deformation is necessary for snow accumulation and hence provides more suitable habitat for lairs.

***Melt Water***.—Analyses indicated that increased melt water on the ice was associated with reduced numbers of seals. The multiyear Poisson regression model indicated that the decrease in number of sightings for each 10% increase in melt water was 1.1%.

Seals probably avoid hauling out in areas with much melt water because it is important for molting animals to have dry skin. Exposure to melt water would conduct heat away from the skin, thereby inhibiting the molt process (Feltz and Fay 1966; Fay 1982). This effect may also (at least in part) explain why there was an increase in group size of ringed seals later during the survey period in years with higher levels of melt water. As melt water levels increased during the survey period, some seals may have abandoned areas with higher levels of melt water and moved into adjacent areas with lower melt water levels and joined other seals at these "drier" holes or cracks.

## *Factors Affecting the Proportion of Seals Hauled Out*

Both temporal and weather factors were significantly related to the density of ringed seal sightings. Air temperature, wind speed, and cloud cover were significantly related to seal density, and survey date was significantly related only in the multiyear model.

***Time of Day***.—It appears that limiting the survey period to 10:00 to 18:00 h (ADST) eliminated significant variation in ringed seal density in relation to time of day. This covariate was not selected for inclusion in either the 2001 or the 1997-2001 model. Many studies of ringed seal haul-out behavior have documented diel patterns (Smith 1973a; Smith and Hammill 1981; Kelly and Quakenbush 1990), although few have controlled for other influences on haulout. The peak period of haulout of ringed seals varies seasonally (Smith 1973a; Smith and Hammill 1981; Kelly and Quakenbush 1990). For instance, Kelly and Quakenbush (1990) found that ringed seals near Reindeer Island (within our study area) hauled out in the evening and early morning in March and April, but this peak period shifted to midday in May and early June. In the eastern Canadian Arctic, at the beginning of the haul-out period (early June), peak numbers of ringed seals were observed between 14:00 and 19:00 local time (GMT - 4 h). Later in the molt period, the largest numbers of seals were observed from 12:00 to 14:00, and seals spent more time hauled out (Smith 1973b). Smith (1973b) suggested that these changes in the diurnal pattern of haul out may be related to the marked change in the angle of solar radiation, increases in air temperature, and (perhaps most importantly) the more advanced molt stage of ringed seals and their reluctance to enter the water in this condition.

*Date.*—Based on five years of survey data, it appears that (after allowance for other variables influencing numbers of seals seen on the ice) the peak period of haulout for ringed seals in the landfast ice of the central Beaufort Sea varies from year-to-year and occurs from approximately May 30th to June 8th (Fig. 5.14E). This finding of the multiyear Poisson regression model is generally supported by the univariate analyses of the 1997-2001 data for BP/LGL surveys and by the results of a preliminary ADF&G multivariate analysis of survey data for 1996-98 (Frost et al. 1999). They found that observed ringed seal density steadily increased in late May, with the maximal density occurring on their last survey date of May 31st. We expect that, if ADF&G had continued surveying into June, they would have found a similar peak in observed density in the early part of June and diminishing densities thereafter.

*Air Temperature.*—In 2001, average air temperatures were relatively low (-0.2°C), especially during the first two survey dates (average –5.4°C on May 28-29). Ringed seal densities were consistently lower when air temperatures were low and densities increased as temperatures increased. Previous studies have reported that responses of ringed seals to air temperature vary (Burns and Harbo 1972; Finley 1979; Smith and Hammill 1981; Frost et al. 1988). A positive relationship between air temperature and sightings was found by Frost et al. (1988) and is also consistent with the fact that increased skin temperatures facilitate molt (Feltz and Fay 1966). However, Finley (1979) suggested that, on warm, bright and relatively calm days, ringed seals retreated to the water, perhaps to avoid hyperthermia. Burns and Harbo (1972) also noted a decrease in ringed seal density in the central Alaskan Beaufort Sea during a survey day when "exceptionally warm and clear" conditions prevailed. This response has been noted in other phocids that associate with ice (Weddell seals, *Leptonychotes weddelli* – Harrison and Kooyman 1968; harp seals, *Pagophilus groenlandicus* – Øritsland and Ronald 1978; Moulton et al. 2000b). Seals may avoid hauling out on extremely warm days to avoid hyperthermia but it appears that, after allowance for other factors in the multiyear model, air temperatures experienced during our surveys were rarely if ever high enough to elicit this potential response.

*Wind Speed.*—Wind speed was negatively related to seal density based on our multiyear model results. Similarly, the univariate results for 1997-98 and 2000-2001 reveal that higher densities were observed at lower wind speeds. Most studies of ringed seals (and other phocids as well) have concluded that haulout is reduced when wind speed is high (Smith 1973a; Finley 1979; Smith and Hammill 1981; Frost et al. 1988).

*Heat Loss.*—Heat loss (index of wind chill) does not appear to be related to ringed seal density. There were no consistent trends in the univariate results, and no significant relationships between seal density and heat loss were evident in either the 2001 or the 1997-2001 regression model. Smith and Hammill (1981) also found that there was no significant relationship between wind chill and ringed seal haulout. However, a study investigating the effects of aircraft overflights on ringed seal behavior found that the probability of seals escaping into their breathing holes increased during colder wind chill conditions (Born et al. 1999).

*Cloud Cover.*—Slightly but significantly more ringed seal sightings occurred when it was cloudy. Both Poisson regression models as well as the univariate results for 1997-2001 indicated that this positive relationship exists. Others who have investigated the relationship between cloud cover and ringed seal haul-out behavior have reported conflicting findings. Finley (1979) found that haul-out bouts of ringed seals tended to be longer on bright clear days but a re-analysis of data from Smith (1973a) by Finley (1979) indicated that there was no significant relationship with cloud cover. Frost and Lowry (1999) found that ringed seal density peaked when cloud cover ranged from 20 to 60%. It is likely that some combination of weather conditions including cloud cover, solar radiation, air temperature, and wind speed interact to affect ringed seal haulout. It is also possible that aerial observers may detect more ringed seals under cloudy conditions as glare is reduced.

### *Effects of Industrial Activity on Ringed Seal Abundance and Distribution*

One of the main objectives of this study is to determine whether (and to what extent) industrial activity at BP's Northstar offshore oil development influences the local distribution and abundance of ringed seals. Industrial activities at Northstar in 2001 were less intensive than those in 2000 when construction of Northstar Island (the Northstar production facility) and its associated pipeline occurred. The aerial surveys provided no clear evidence of reduced seal densities near Northstar during the spring of 2000. We hypothesized (Moulton et al. 2001) that the potential effects of the Northstar development on densities of ringed seals close to the Northstar facilities were likely to be even smaller in subsequent years (including 2001), when there would be less ice-road traffic and less construction activity than during 2000. Nonetheless, industrial activities associated with Northstar in 2001 had the potential to displace ringed seals from the area.

***Northstar*.**—One of the main purposes of the multivariate analyses described above is to separate the effects of natural environmental variables and industrial factors on numbers of seals detected on the ice. The results described here provide a basis for assessing relationships between seal sightings and proximity to industry after partial allowance for natural factors that influence seal numbers and haul-out behavior.

In 2001, *significantly more ringed seals occurred close to the Northstar development area than in otherwise-comparable situations farther away*. This finding was consistent in the 2001 univariate analysis, the 2001 multivariate model, and the multiyear multivariate model. If Northstar was negatively impacting ringed seals in early 2001, we would expect lower densities of seals near Northstar, but this was not the case in 2001 (or 2000). It is uncertain why ringed seal density was higher close to Northstar but higher densities could be attributed to factors like prey density. Another possibility is observer bias. At least one aerial observer (M. Williams, LGL, pers. comm.), who participated in the on-ice searches for ringed seal structures (see Chapter 4), believes his knowledge of structure location increased the probability of detecting seals within the dog-search area around Northstar (3 km) vs. farther away.

Moulton et al. (2001) found that construction activities at Northstar in 2000 did not significantly influence ringed seal distribution insofar as this could be determined from aerial surveys. To further verify this finding, "Distance from Northstar in 2000" was "forced" into the model based on the 1997-2001 data. Once again, there was no indication of a significant negative effect on ringed seal density and distribution (Fig. 5.14J).

***Vibroseis*.**—The results of the multiyear multivariate model do not corroborate the univariate relationship between seal density and occurrence of vibroseis identified by Link et al. (1999), based on the same 1997-98 data plus additional vibroseis in 2001. In 1998, Link et al. found statistically significant evidence of reduced seal numbers in an area east of Liberty where Vibroseis had occurred earlier that winter as compared with an otherwise-similar reference area nearby. In 1997, in the absence of Vibroseis, there was no such difference between the two areas. The 1998 analysis was complicated by the fact that a portion of the "reference" area, which encompassed Liberty, was potentially disturbed by on-ice surveying and geotechnical surveys. Also, in earlier univariate analyses, other possible influences were only partially taken into account. Covariates like melt water, cloud cover, and wind speed, which influence seal densities and which may have varied between reference and industrial sites even on the same survey day, were not taken into account. Based on all evidence now available, taking account of confounding factors via multivariate analysis, it appears that any vibroseis effect on seal densities and distribution was smaller than indicated by the initial analyses, if it occurred at all.

***Shallow-Hazards Surveys.***—The Poisson regression model for 1997-2001 data indicated that ringed seal density in the McCovey area in 2000 was not significantly related to the occurrence there of on-ice shallow-hazards surveys and an associated transit route. A previous analysis based on the 2000 data alone gave some indication that slightly fewer than expected seals may have been visible near the McCovey site (including transit route) during the aerial surveys ($P = 0.087$; see Moulton et al. 2001). It is unclear whether this potential marginal decrease in seal numbers was related to the shallow hazards survey activities or to seal research activities that occurred in the same area in April-June 2000.

***Other On-Ice Industrial and Research Activities.***—The Poisson regression model for 1997-2001 data indicated that other industrial activities in the study area were not significantly related to ringed seal density. Other "minor" industrial activities were drilling and limited Vibroseis near Tern Island (Liberty area) in 1997, geotechnical activities near Tern Island in 1998, and construction of ice roads to Seal Island (now Northstar Island) in 1999. (Northstar construction in 2000, substantial areas of Vibroseis in 1998 and 2000, and the McCovey shallow hazards surveys were not considered "minor", and were treated separately in the multiyear analysis.)

In 2001, as in 1998-2000, a ringed seal research project was on-going near Reindeer Island, within the central part of our study area, during the aerial survey period (Kelly et al. 2000; V. Moulton, pers. obs.). It is possible that seal haul-out behavior in that area may have been altered by research activities. Researchers had used dogs to search for seal structures and subsequently captured and deployed radio transmitters (only in 1999-2000) on several ringed seals in April and May. Researchers traveled the area on snow machines and cross-country skis, and conducted visual observations from on-ice sites close to hauled out seals. These activities had some potential to affect the numbers of seals counted by aerial observers. We are investigating whether the areas and times potentially affected can be defined with sufficient precision to allow inclusion of this factor in the multivariate model.

### *Adequacy of Present Approach*

This study is based on the use of unusually intensive (closely spaced) aerial surveys that are repeated within each season. The nominal design calls for each part of the study area to be sampled on eight different days within each spring season. This approach provides more data on the seals occurring close to industrial developments than have been available from other surveys with broader objectives and broader (but less intensive) survey coverage. The results to date suggest that this methodology is capable of documenting localized effects on the scale that has been hypothesized to occur.

We have investigated the statistical power of these surveys (based on aerial survey data from 1997-2000) for detecting changes in seal density in industrialized areas and within small distances around industrial facilities. The intensive aerial survey method used by BP since 1997 has substantial (at least 80%) power to detect a reduction in seal density of reasonable magnitude (e.g., 30-40%) if it extends out to 4 km from the Northstar facilities, provided the surveys continue for an additional two years after 2000 (see Appendix A in Moulton et al. 2001). The power to detect a 40% reduction in seal density extending only out to 2 km from the Northstar facilities is considerably reduced. However, the power calculations were based on a simplified statistical approach that did not allow for covariates. For that and other reasons, the power of the Poisson regression analyses reported in this chapter, which do allow for covariates, is higher (by unknown amounts) than calculated in the power analysis.

This study was begun in 1997 when it was considered possible that construction activities might begin in 1998 or at least by 1999. When the delay in full-scale construction of Northstar extended to 2000, we had available three seasons of consistent, intensive, surveys during years with little offshore industrial activity. This provided a good basis against which to compare seal distribution during subsequent years of Northstar construction and operation. In hindsight, one year of pre-construction data would not have been adequate, given the observed variability in 1997-99 and the many factors that affect numbers of seals visible on the ice.

The area surveyed in this project includes the potential Liberty development area in Foggy Island Bay as well as Northstar. This study has shown that seals are common in the lagoon around Liberty as well as in the open sea around Northstar. (Previous aerial surveys for seals often did not extend very far south into the lagoons.) Specific development and monitoring plans for Liberty have not yet been determined, although a draft Environmental Impact Statement has been released (MMS 2001). This study has already provided five years of baseline data from the Liberty area. Additional data from the Liberty area are expected to be obtained during planned aerial surveys in 2002. If the Liberty project eventually goes ahead, and if these aerial surveys are continued or resumed during development of Liberty, then the data for the Liberty area will provide an opportunity to test whether the results found at Northstar are replicated at a second development site.

The Poisson regression approach used in this report is an important step toward quantifying the relative contributions of temporal, environmental, and industrial activity variables on the numbers of seals hauled out on the fast ice. The models in this report should be considered subject to refinement. Additional data will assist in determining precise relationships of seal sightings to industrial activities and various environmental covariates. The BP/LGL surveys are planned to continue in a consistent manner in spring 2002, following the first winter of oil production and associated activities at Northstar.

The available weather data from Deadhorse airport and from the survey aircraft do not fully characterize conditions to which seals on the landfast ice are exposed. Weather data, including solar radiation data, have been collected at the Northstar site since late November 2000. During future surveys, these data should provide better information about on-ice meteorological conditions affecting seals.

## SUMMARY

Intensive, site-specific aerial surveys for seals were conducted during 28 May – 8 June 2001 in the area of landfast ice that surrounded BP's Northstar oil development and the potential Liberty oil development. During the ice-covered season of late 2000 and early 2001, industrial activities at Northstar were less intense than the construction activities that had occurred in the winter of 2000. Liberty, located in Foggy Island Bay, 48 km (30 mi) southeast of Northstar, was inactive in 2000-2001. The survey design provided high intensity survey coverage within a 75 × 40 km (46 × 25 mi, or 40 × 22 n.mi.) area encompassing both Northstar and Liberty. These surveys were designed to assess possible changes in seal density close to the industrial sites before vs. after oil development began.

### *Approach and Methods*

The 2001 surveys were very similar to surveys done during the spring of 1997, 1998, 1999, and 2000. The 1997 and 1998 surveys were pre-development "control" surveys (although some limited offshore industrial activities occurred around Liberty in early 1997 and east of Liberty in early 1998). The 1999 survey followed limited industrial activity at Northstar during early 1999. The 2000 surveys were conducted after a period of intensive construction activities within the survey area. In 2001, industrial activities were less intense than the construction activities that had occurred during the previous winter. The aerial surveys in 2001 occurred after ice roads to Northstar were re-built, facilities were installed on the island, several wells were drilled, supplementary gravel was placed along the subsea pipeline route from the island to the shore, and emergency equipment was tested near the island. No major industrial activities occurred near Liberty during the winter of 2000-2001, so the 2001 surveys provide an additional year of pre-development "control" data for that area.

The survey design provided for repeated coverage of the study area within each spring season. This within-season replication was designed, in part, to allow detection and quantification of distributional effects that might be quite localized. Also, the replication was designed to assess and distinguish the relative contributions of industrial effects and various natural factors (e.g., date in season, ice conditions, bathymetry, weather) on numbers of seals hauled out at different places and times. These surveys include the essential elements of a Before-After/Control-Impact (BACI) study design. The surveys include areas potentially <u>Impact</u>ed by development of Northstar (and perhaps in future Liberty) plus surrounding <u>Control</u> areas extending out to a substantial distance from both sites. These surveys were initiated <u>Before</u> the Northstar and Liberty oil developments began, and have continued in a consistent manner <u>After</u> construction of Northstar began. BACI designs are considered to be optimal for field studies of environmental impact, especially when they include geographic replication. The survey design provides for spatial replication of at least the "control" area.

### *Observed Seal Densities vs. Natural Factors*

In 2001, the aerial surveys covered 4147 $km^2$ (1600 $mi^2$) of fast ice habitat. A total of 1562 sightings of 2024 ringed seals were recorded on-transect in fast ice habitat during the two survey replicates. The overall observed density was 0.49 seals/$km^2$ (1.27 seals/$mi^2$). Excluding waters <3 m deep where seals were rarely seen, the overall observed density was 0.54 seals/$km^2$ (1.40 seals/$mi^2$). The overall observed density in areas ≥3 m deep was higher in 2001 than in 1997 (0.43 seals/$km^2$), 1998 (0.39 seals/$km^2$), and 2000 (0.47 seals/$km^2$) but lower than in 1999 (0.63 seals/ $km^2$).

Bearded seals were recorded near the fast ice edge as well as in the landfast ice edge. Overall, there were three sightings totaling three individuals.

Two statistical approaches were used to examine factors known or expected to influence ringed seal density within the study area. Data were examined with chi-square goodness-of-fit tests (with Bonferroni adjustment) and with a multivariate Poisson regression analysis. Three groups of variables were investigated: habitat factors that affect the distribution and abundance of ringed seals, temporal and weather factors that affect the proportion of seals hauled out; and industrial activity factors.

Both the univariate and multivariate results indicated that the relationship between seal density and *water depth* was significant. Overall, ringed seals were most abundant in water depths ranging from 10 to 20 m (33 to 66 ft). However, in some years, including 2001, it appears that more ringed seals occurred at shallower depths. The multivariate results suggest that, in most survey years, ringed seals were more abundant near the *edge of the landfast ice*, after accounting for other covariates, even when ice break-up was apparently not advanced. Factors that may account for this relationship include movements of ringed seals that spent the winter outside of the landfast ice, redistribution of seals that spent the winter in the landfast ice, and prey availability. There was a significant trend toward lower observed densities in areas with high *ice deformation* and extensive *melt water* in all five BP/LGL survey years.

The Poisson regression models for 2001 and 1997-2001 data indicated that there was no significant relationship between seal sightings and *time of day* within the mid-day period when surveys were done.

Observed ringed seal density was significantly related to *date* within the spring season. It appears that the peak period of haulout for ringed seals in the landfast ice of the central Beaufort Sea varies from year-to-year and occurs from approximately May 30th to June 8th.

Of the four *weather variables* investigated, cloud cover, air temperature, and wind speed were found to be consistently related to ringed seal numbers in both the univariate and multivariate analyses. More ringed seals were observed on cloudy days with relatively low wind speeds and warmer air temperatures. After allowance for those variables, there was no clear relationship to heat loss.

### *Observed Seal Densities vs. Northstar*

There was no indication that industrial activities in the Northstar development area in late 2000 and early 2001 negatively affected the distribution or abundance of ringed seals. In fact, significantly elevated densities of ringed seals occurred close to Northstar as indicated by univariate analysis, the 2001 multivariate model, and a multiyear multivariate model. The multivariate models developed here are important steps toward quantifying the relative contributions of temporal, environmental, and industrial activity variables on the numbers of seals hauled out on the landfast ice.

## ACKNOWLEDGEMENTS

We thank Inupiat observer B. Adams for his enthusiastic participation as an aerial observer (along with V. Moulton and M. Williams) during the 2001 BP/LGL aerial surveys. We are grateful to the late Tom Blaesing, Dave Weintraub, and Kevin Sutton of Commander Northwest Ltd. for piloting the survey aircraft and providing other logistical support. We thank Shelly Schwenn for providing logistical support. This study was designed in 1997 by W.R. Koski, G.W. Miller, and W.J. Richardson of LGL. We are grateful to C. Herlugson of BP for initiating this project, and R. Jakubczak and B. Streever of BP for their support throughout the 2001 phase of the study. Acknowledgements concerning the 1997, 1998, 1999, and 2000 fieldwork are listed in Miller et al. (1998), Link et al. (1999), and Moulton et al. (2000, 2001). B. Streever of BP reviewed a draft of this document. Anne Wright formatted and helped produce this report. We thank Meike Holst and Arturo Serrano, along with Anne Wright, for helping with data entry.

The 2001 aerial surveys were conducted under the General Authorization for scientific research on non-endangered species, MMPA §104(c)(3)(C) and 50 C.F.R. §216.45. Its applicability to this project was confirmed by the National Marine Fisheries Service in NMFS Letter of Confirmation 481-1626 dated 8 May 2001. We thank Permits Division of the NMFS Office of Protected Resources for processing the authorization.

## LITERATURE CITED

Born, E.W., F.F. Riget, R. Dietz and D. Andriashek. 1999. Escape responses of hauled out ringed seals *(Phoca hispida)* to aircraft disturbance. **Polar Biol.** 21(3):171-178.

Burns, J.J. 1981. Bearded seal—*Erignathus barbatus* Erxleben, 1777. p. 145-170 *In*: S.H. Ridgway and R.J. Harrison (eds.), Handbook of marine mammals, vol. 2. Academic Press, London, U.K. 359 p.

Burns, J.J. and B.P. Kelly. 1982. Studies of ringed seals in the Alaskan Beaufort Sea during winter: impacts of seismic exploration. Unpubl. annual report, OCSEAP RU 232, to U.S. Dep. Commer., NOAA, Off. Mar. Pollut. Assess., Juneau, AK. 57 p.

Burns, J.J. and S.J. Harbo, Jr. 1972. An aerial census of ringed seals, northern coast of Alaska. **Arctic** 25(4):279-290.

Cameron, A.C. and P.K. Trivedi. 1998. Regression analysis of count data. Cambridge Univ. Press, New York, NY. 412 p.

Fay, F. H. 1982. Ecology and biology of the Pacific walrus, *Odobenus rosmarus divergens* Illiger, 1811. N. Am. Fauna No. 74.

Feltz, E. T. and F.H. Fay. 1966. Thermal requirements *in vitro* of epidermal cells from seals. **Cryobiology** 3(3):261-264.

Finley, K.J. 1979. Haul-out behaviour and densities of ringed seals (*Phoca hispida*) in the Barrow Strait area, N.W.T. **Can. J. Zool.** 57(10):1985-1997.

Frost, K.J. and J.J. Burns. 1989. Winter ecology of ringed seals (*Phoca hispida*) in Alaska. Outer Cont. Shelf Environ. Assess. Program, Final Rep. from Alaska Dep. of Fish & Game, Fairbanks, AK for U.S. Minerals Management Service, Anchorage, AK. NA-81-RAC-00045, NOAA Project RU 232.

Frost, K.J. and L.F. Lowry. 1988. Effects of industrial activities on ringed seals in Alaska, as indicated by aerial surveys. p. 15-25 *In*: W.M. Sackinger et al. (eds.), Port and Ocean Engineering Under Arctic Conditions. Volume II. Symposium on Noise and Marine Mammals. Geophysical Inst., Univ. Alaska, Fairbanks, Fairbanks, AK. 111 p.

Frost, K.J. and L.F. Lowry. 1998. Monitoring distribution and abundance of ringed seals in northern Alaska/Interim report, April 1997-March 1998. Rep. from Alaska Dep. Fish & Game, Fairbanks, AK, for U.S. Minerals Manage. Serv., Anchorage, AK. 48 p.

Frost, K.J. and L.F. Lowry. 1999. Monitoring distribution and abundance of ringed seals in northern Alaska/Interim report, April 1998-March 1999. Rep. from Alaska Dep. Fish & Game, Fairbanks, AK, for U.S. Minerals Manage. Serv., Anchorage, AK. 44 p.

Frost, K.J., L.F. Lowry, J.R. Gilbert and J.J. Burns. 1988. Ringed seal monitoring: relationships of distribution and abundance to habitat attributes and industrial activities. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 61 (1989):345-445. NTIS PB89-234645.

Frost, K.J., L.F. Lowry, S. Hills, G. Pendleton and D. DeMaster. 1997. Monitoring distribution and abundance of ringed seals in northern Alaska. Rep. from Alaska Dep. Fish & Game, Fairbanks, AK, for U.S. Minerals Manage. Serv., Anchorage, AK. 42 p.

Green, J.E. and S.R. Johnson. 1983. The distribution and abundance of ringed seals in relation to gravel island construction in the Alaskan Beaufort Sea. p. 1-28 *In*: B.J. Gallaway (ed.), Biological studies and monitoring at Seal Island, Beaufort Sea, Alaska 1982. Rep. from LGL Ecol. Res. Assoc. Inc., Bryan, TX, for Shell Oil Co., Houston TX. 150 p.

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley, New York, NY. 257 p.

Hammill, M.O. and T.G. Smith. 1989. Factors affecting the distribution and abundance of ringed seal structures in Barrow Strait, Northwest Territories. **Can. J. Zool.** 67(9):2212-2219.

Harrison, R.J. and G.L. Kooyman. 1968. General physiology of the Pinnipedia. p. 133-158 *In*: R.J. Harrison, R.C. Hubbard, R.S Peterson, C.E. Rice and R.J. Schusterman (eds.), The behavior and physiology of pinnipeds. Appleton-Century-Crofts, New York, NY. 411 p.

Harwood, L.A., T.G. Smith and H. Melling. 2000. Variation in reproduction and body condition of the ringed seal (*Phoca hispida*) in western Prince Albert Sound, NT, Canada, as assessed through a harvest-based sampling program. **Arctic** 53(4):422-431.

Kelly, B.P. and L.T. Quakenbush. 1990. Spatiotemporal use of lairs by ringed seals (*Phoca hispida*). **Can. J. Zool.** 68(12):2503-2512.

Kelly, B.P., L.T. Quakenbush and J.R. Rose. 1986. Ringed seal winter ecology and effects of noise disturbance. Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators, National Oceanic & Atmospheric Administration, Anchorage, Alaska, 61:447-536. OCS Study MMS 89-0026, NTIS PB89-234645.

Kelly, B.P., J.J. Burns and L.T. Quakenbush. 1988. Responses of ringed seals (*Phoca hispida*) to noise disturbance. p. 27-38 *In:* W.M. Sackinger et al. (eds.), Port and Ocean Engineering Under Arctic Conditions. Vol. II. Symposium on Noise and Marine Mammals. Geophysical Institute, Univ. Alaska, Fairbanks, Fairbanks, AK. 111 p.

Kelly, B.P., L.T. Quakenbush and B.D. Taras. 2000. Correction factor for ringed seal surveys in northern Alaska. p. 51-64 *In:* Annu. Rep. 6, Coastal Marine Institute, Univ. Alaska Fairbanks. OCS Study MMS 2000-046

Kingsley, M.C.S. 1986. Distribution and abundance of seals in the Beaufort Sea, Amundsen Gulf, and Prince Albert Sound, 1984. Environ. Stud. Revolv. Funds Rep. 25. Dep. Fish. & Oceans, Winnipeg, Man. 16 p.

Kingsley, M.C.S. and T.J. Byers. 1998. Failure of reproduction in ringed seals (*Phoca hispida*) in Amundsen Gulf, Northwest Territories in 1984-1987. p. 197-210 *In*: M.P. Heide-Jørgensen and C. Lydersen (eds.), Ringed seals in the North Atlantic. Tromsø, Norway: NAMMCO Scientific Publications, Vol.1.

Kovacs, K.M. 1987. Maternal behaviour and early behavioural ontogeny of harp seals, *Phoca groenlandica*. **Anim. Behav.** 35(3):844-855.

Lerczak, J.A. and R.C. Hobbs. 1998. Calculating sighting distances from angular readings during shipboard, aerial, and shore-based marine mammal surveys. **Mar. Mamm. Sci.** 14(3):590-599.

Link, M.R., T.L. Olson and M.T. Williams. 1999. Ringed seal distribution and abundance near potential oil development sites in the central Alaskan Beaufort Sea, spring 1998. LGL Rep. P-430. Rep. from LGL Alaska Res. Assoc. Inc., Anchorage, AK, for BP Explor. (Alaska) Inc., Anchorage, AK. 58 p.

Lydersen, C. and K.M. Kovacs. 1993. Diving behaviour of lactating harp seal, *Phoca groenlandica*, females from the Gulf of St. Lawrence, Canada. **Anim. Behav.** 46(6):1213-1221.

Manly, B.F.J., L.L. McDonald and D.L. Thomas. 1993. Resource selection by animals. Chapman & Hall, New York, NY. 177 p.

McCullagh, P. and J.A. Nelder. 1989. Generalized linear models, 2nd ed. Chapman & Hall, London, U.K. 511 p.

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. LGL Rep. TA2160-3. Rep. from LGL Ltd., King City, Ont., for BP Explor. (Alaska) Inc., Anchorage, AK. 36 p.

MMS. 2001. Liberty Development and Production Plan, Draft Environmental Impact Statement. Three volumes. OCS EIS/EA MMS 2001-001. Minerals Manage. Serv., Anchorage, AK. Var. pag.

Moran, P. A. P. 1950. Notes on continuous stochastic phenomena. **Biometrika** 37:17-23.

Moulton, V.D., T.L. McDonald, W.J. Richardson, R.E. Elliott and M.T. Williams. 2000a. Fixed-wing aerial surveys of seals near BP's Northstar and Liberty sites in 1999 (and 1997-1999 combined). p. 3-1 to 3-71 *In:* W.J. Richardson and M.T. Williams (eds.), Monitoring of ringed seals during construction of ice roads for BP's Northstar oil development, Alaskan Beaufort Sea, 1999. [Final, Dec. 2000]. LGL Rep. TA2349-3. Rep. from LGL Ltd., King City, Ont., and LGL Alaska Res. Assoc. Inc., Anchorage, AK, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 153 p.

Moulton, V.D., E.H. Miller and H. Ochoa-Acuña. 2000b. Haulout behaviour of captive harp seals (*Pagophilus groenlandicus*): incidence, seasonality, and relationships to weather. **Appl. Anim. Behav. Sci.** 65(4):367-378.

Moulton, V.D., R.E. Elliott, T.L. McDonald and W.J. Richardson. 2001. Fixed-wing aerial surveys of seals near BP's Northstar and Liberty sites in 2000 (and 1997-2000 combined). p. 5-1 to 5-66 *In:* W.J. Richardson and M.T. Williams (eds.), Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar oil development, Alaskan Beaufort Sea, 2000. [Draft, April 2001]. LGL Rep. TA2428-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 316 p.

Øritsland, N.A. and K. Ronald. 1978. Aspects of temperature regulation in harp seal pups evaluated by *in vivo* experiments and computer simulations. **Acta Physiol. Scand.** 103:263-269.

Page, E.B. 1963. Ordered hypotheses for multiple treatments: a significant test for linear ranks. **J. Am. Stat. Assoc.** 58:216-230.

Rawlings, J.O., S.G. Pantula and D.A. Dickey. 1998. Applied regression analysis: a research tool, 2nd ed. Springer-Verlag, New York, NY. 657 p.

Reeves, R.R. 1998. Distribution, abundance and biology of ringed seals (*Phoca hispida*): an overview. p. 9-45 *In*: M.P. Heide-Jørgensen and C. Lydersen (eds.), Ringed seals in the North Atlantic. Tromsø, Norway: NAMMCO Scientific Publications, Vol.1.

Rosenthal, R. 1978. Combining results of independent studies. Psychol. Bull. **85**: 185-193.

Siple, P.A. and C.F. Passel. 1945. Measurements of dry atmospheric cooling in subfreezing temperatures. **Proc. Am. Phil. Soc.** 89:177-199.

Smith, T.G. 1987. The ringed seal, *Phoca hispida*, of the Canadian western Arctic. **Can. Bull. Fish. Aquat. Sci.** 216: 81 p.

Smith, T.G. 1973a. Censusing and estimating the size of ringed seal populations. **Fish. Res. Board Can. Tech. Rep.** 427: 22 p.

Smith, T.G. 1973b. Population dynamics of the ringed seal in the Canadian eastern Arctic. **Fish. Res. Board Can. Bull.** 181: 55 p.

Smith, T.G. and M.O. Hammill. 1981. Ecology of the ringed seal, *Phoca hispida*, in its fast ice breeding habitat. **Can. J. Zool.** 59(6):966-981.

Smith, T.G. and L. A. Harwood. 2001. Observations of neonate ringed seals, *Phoca hispida*, after early break-up of the sea ice in Prince Albert Sound, Northwest Territories, Canada, spring 1998. **Polar Biol.** 24(3):215-219.

Smith, T.G. and I. Stirling. 1975. The breeding habitat of the ringed seal (*Phoca hispida*). The birth lair and associated structures. **Can. J. Zool.** 53(9):1297-1305.

Smith, T.G. and I. Stirling. 1978. Variation in the density of ringed seal (*Phoca hispida*) birth lairs in the Amundsen Gulf, Northwest Territories. **Can. J. Zool.** 56(5):1066-1071.

Smith, T.G., K. Hay, D. Taylor and R. Greendale. 1979. Ringed seal breeding habitat in Viscount Melville Sound, Barrow Strait and Peel Sound. Dep. Indian and Northern Affairs, Environmental - Social Program Northern Pipelines Rep. No. AI-22. 85 p.

Stirling, I., W.R Archibald and D. DeMaster. 1977. Distribution and abundance of seals in the eastern Beaufort Sea. **J. Fish. Res. Board Can.** 34(7):976-988.

Thomas, J.A. and D.P. DeMaster. 1983. Diel haul-out patterns of Weddell seal (*Leptonychotes weddelli*) females and their pups. **Can. J. Zool.** 61(9):2084-2086.

Underwood, A.J. 1992. Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. **J. Exp. Mar. Biol. Ecol.** 161(2):145-178.

Venables, W.N. and B.D. Ripley. 1999. Modern applied statistics with S-Plus, 3rd ed. Springer-Verlag, New York, NY. 501 p.

# BREAK-UP AND OPEN-WATER SEASONS,

## 16 JUNE TO 31 OCTOBER 2001

# CHAPTER 6:

# DESCRIPTION OF BP'S ACTIVITIES, BREAK-UP AND OPEN-WATER SEASONS, 2001 [1]

by

**Craig J. Perham and Michael T. Williams**

**LGL Alaska Research Associates, Inc.**
1101 E. 76th Ave., Suite B
Anchorage, AK 99518
(907) 562-3339

for

**BP Exploration (Alaska) Inc.**
**Dept of Health, Safety & Environment**
900 East Benson Blvd., POB 196612
Anchorage, AK 99519-6612

LGL Report TA2563-6

April 2002

---

[1] Chapter 6 *In:* W.J. Richardson and M. T. Williams (eds.). 2002. Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2001. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD.

## INTRODUCTION

This chapter describes construction activities associated with the development of the Northstar facilities during the break-up and open-water seasons from 16 June through 31 October 2001. This information is provided in compliance with the reporting requirements of the Letter of Authorization (LoA) issued to BP on 18 September 2000 by the National Marine Fisheries Service (NMFS). The following information about construction activities during the break-up and open-water seasons of 2001 was originally provided to NMFS and other stakeholders in January 2002 as part of the 90-day report on monitoring work during those seasons (Williams 2002). The present chapter is an updated description of those BP activities, and supersedes the 90-day version.

For a chronological description of BP's previous activities at Northstar from late 1998 through October 2000, please refer to Williams and Richardson (2000) and Williams and Perham (2001a,b). Chapter 2 of the present report provides corresponding information about BP's construction activities during the ice-covered season in late 2000 through mid-2001.

During the open-water season of 2001, BP transported major equipment modules to Northstar by sealift, and installed them on the island. In addition, during the spring break-up and open-water seasons as a whole (16 June – 31 October 2001), there were frequent transits of helicopters, crew boats, tugs, barges and other vessels between the Prudhoe Bay area and Northstar. Drilling was suspended during the 2001 open-water season, and oil production did not begin until after the period covered by this report.

## TRANSPORTATION TO AND FROM NORTHSTAR ISLAND

Bell 212 helicopters were used as transportation to and from Northstar (=Seal) Island during the break-up and freeze-up periods in 2001. During the open-water season, a crew vessel was the primary method of transportation, but helicopter flights continued on a less frequent basis.

Helicopter flights began on 4 June in 2001 from the West Dock base of operations (WDBO) and Deadhorse airport to Northstar and return, depending on weather and helicopter availability. Prior to that date, vehicle traffic on the ice roads had been the primary method of transportation to and from the island (see Chapter 2 of this report). Routine helicopter operations followed recommended flight corridors (Fig. 6.1). Two Bell 212 helicopters were used to transport crew and materials to and from Northstar. Construction crews were exchanged approximately every 12 hours. Crew changeover took ~2-3 hours. One-way flight time to Northstar was ~15 min from WDBO and 30 min from Deadhorse airport. Helicopter flights were less frequent from break-up to freeze-up – the period when the crew vessel was in service. For the period covered by this report (16 June through 31 October 2001), there were ~989 round-trip flights.

The crew vessel began transits between the #2 dock at West Dock and Northstar on 23 July in 2001. Crew vessel operations were re-routed when necessary to avoid ice that moved into the transit route. Transits typically required ~40-45 minutes, one-way. Eight round trips were scheduled daily during summer and autumn operations. Crew vessel operations ceased on 7 October 2001 as sea ice formed. During the period of vessel operations, the crew boat completed 824 round-trips between West Dock and Northstar Island.

In addition, there were 69 round-trips by barges and one round-trip by a sealift (comprised of three barges and several tugs) to the island during that same period. Eleven Alaska Clean Seas (ACS) tugs and barges were deployed around Northstar for training and fuel transfers on 23 days during the 2001 open-water season.

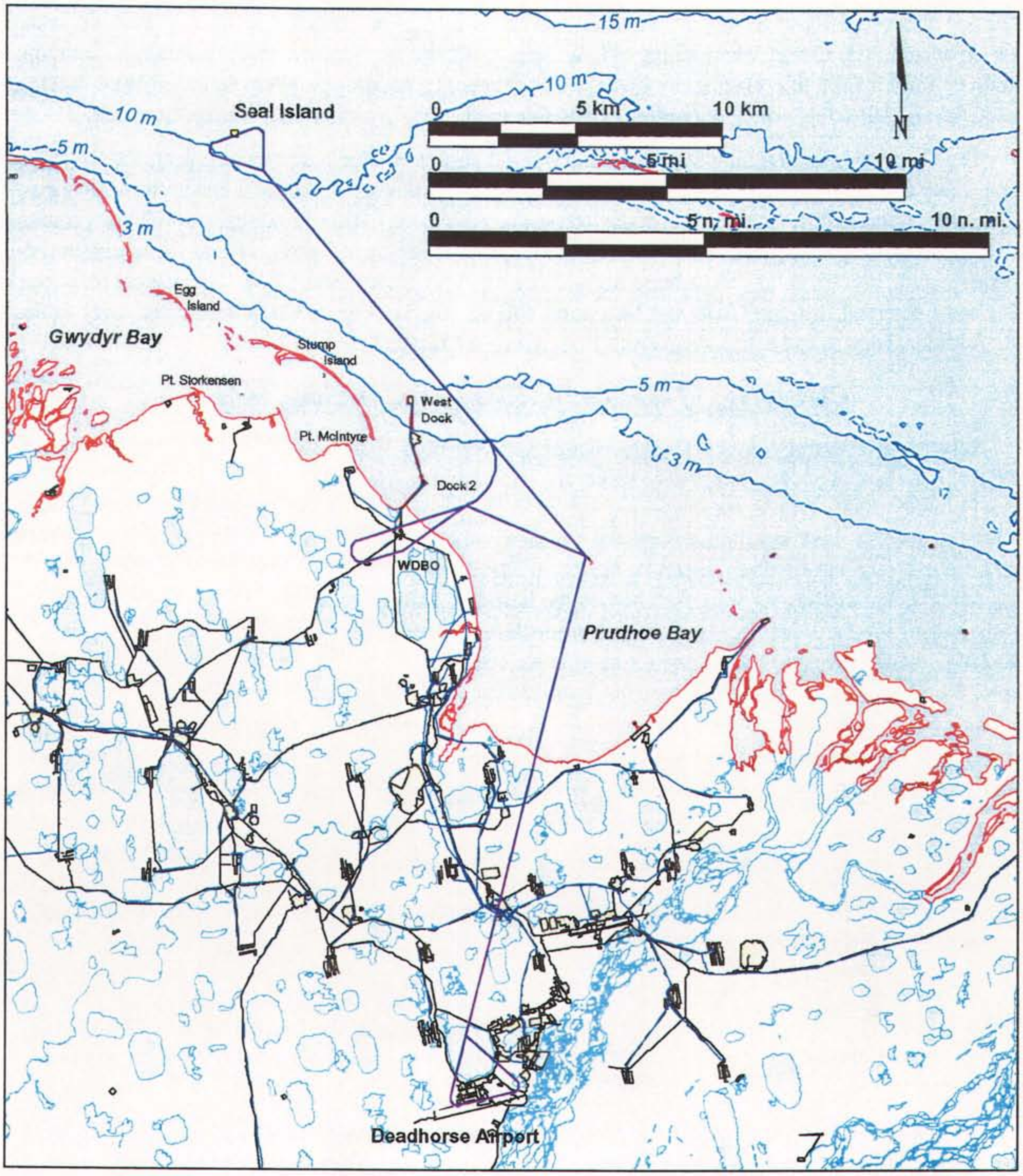


FIGURE 6.1. Route flown by helicopters (purple line) between Deadhorse airport, the West Dock base of operations (WDBO), and the Northstar Development at Seal Island. After break-up, the crew vessel traveled between the island and West Dock along a similar route.

Helicopter and vessel routes were negotiated among the U.S. Fish and Wildlife Service (USFWS), NMFS, and BP to minimize impacts to waterfowl and marine mammals. The LoA issued by NMFS stated that helicopter flights to support Northstar construction must be limited to a corridor from Northstar to the mainland and, except when taking off, landing or limited by weather, must maintain a minimum altitude of 1000 ft (305 m). During poor weather or emergency conditions, pilots followed FAA altitude regulations and BP safety policy regardless of possible impacts to waterfowl and marine mammals.

The Concrete Island Drilling Structure (CIDS) is not part of the Northstar Development, and is not the responsibility of BP. However, this caisson was stored ~1.1 km northeast of Northstar Island from 29 August 2000 until 31 August 2001. During most of the intervening period, the CIDS was unmanned with no operating equipment. However, during August 2001 it was mobilized for departure to Russia. During the weeks preceding its departure, two small tugs and a large ice-breaking tug were present near CIDS. Intermittent helicopter flights were observed between CIDS and Deadhorse airport. On 31 August, CIDS was towed away to the west. Additional details and sound measurements are given in Chapter 7.

## *Chronology of Module Installation and Drilling, 2001*

Substantial construction had already occurred at Northstar before the period covered here. The surface of the abandoned Seal Island was below the water (and ice) level prior to the start of construction during February 2000. During the winter and spring in early-mid 2000, Seal Island was rebuilt and sheet-pile retaining walls were installed around the perimeter of the island. The undersea pipeline was also installed during the ice-covered season in March to May 2000. The permanent living quarters (PLQ), utility module, and drilling rig were installed on the island by November 2000. These comprised approximately half of the facilities necessary for oil production at Northstar. During the winter and spring of 2000-2001, drilling began, and various construction activities continued on the icebound island (see Chapter 2). However, drilling was suspended from 13 June 2001 until November 2001.

Three sealift barges arrived in the Prudhoe Bay area from southern Alaska on 10 August 2001, towed by two Ocean-class tugs (the *Bulwark* and *Navigator*), and assisted by three River-class tugs (the *Kavik River*, *Sag River* and *Toolik River*). The Point-class tugs *Pt. Barrow* and *Pt. Oliktok* were also used when required by ice and weather conditions. The three barges carried the following facilities:

- Barge 420: the gas-turbine compressor module and pumphouse.
- Barge 400: North and South processor modules; these two buildings constituted by far the largest shipment and are shown in Figure 7.4 in Chapter 7.
- Barge 411: the warehouse, flare boom, and some pipe rack sections.

Barges 420 and 411 arrived first, followed by Barge 400. Offloading of the first barge started on 12 August and continued until 20 August 2001. During this period there was much maneuvering of the sealift barges by tugs.

The sealift vessels departed on various dates from 16 to 31 August. Ocean-class tug *Bulwark* departed with Barge 420 on 16 August (15:30). Ocean-class tug *Navigator* departed with Barges 400 and 411 on 30 August (16:00). Two additional tugs were involved in towing CIDS when it departed.

Installation of modules began immediately after they were moved onto the island, and the "A" gas compressor was tested and began operating on 24 October 2001. The gas turbine system is made up of two compressors that rotate clockwise at 8400-9800 rpm. Depending on ambient temperature they can operate at up to 32,000 hp. The "B" gas compressor was not tested or operated during the summer or autumn 2001.

The "emergency" generator in the utility module, as installed during 2000, was used for primary power until 24 October 2001. This generator was powered by a 4-cycle, 16-cylinder diesel engine operating at 1800 rpm.

## EQUIPMENT USED, 2001

*Transportation:* Two Bell 212 helicopters (Fig. 6.2) were used to transport crew and materials to Northstar. After breakup, two 61.5-foot (18.7 m) crew vessels, *Hawk* (Fig. 6.3) and *Arctic Express*, were used to transport crew and materials to the island. The vessels had dual 200 hp inboard Detroit diesel engines and were equipped with four-bladed propellers.

Other tugs and barges periodically traveled to Northstar bringing equipment. Eleven vessels were used for transport of diesel fuel to the island. The barges ranged in length from to 150 to 430 ft (45 to 130 m), and the tugs from 80 to 136 ft (25 to 41 m). Seventeen vessels were used for cargo transport to and from the island. The vessels used for cargo transport ranged in size from 200 to 400 ft (61 to 122 m) for barges and 46 to 136 ft (14 to 41 m) for tugs. Eleven vessels were used for spill response activities in and around Northstar during spill response exercises and on a standby basis during actual fuel transfers to the island. The spill response vessels ranged in size from a 25-foot (7.6-m) aluminum utility craft to a 55-foot (17 m) landing craft. Tugs and barges were also used for spill response training and fuel transfers.

*Island Construction and Maintenance:* A Caterpillar 966 loader, a Volvo 150 front end loader, and a Volvo A30 end dump were used to transport materials and equipment around the island. A Manitowoc 888 crane powered by a 330 hp Cummins diesel lifted and placed various equipment and materials around the island. A Caterpillar 330 backhoe, a Caterpillar D5 bulldozer, a mechanic's box truck, an 80 ft and a 125 ft mobile aerial lifting platform, three to four light plants, various plate and drum-roller compactors, a Caterpillar 988B forklift, and one Polaris 6-wheeler were used intermittently for various tasks around the island.

*Drilling and Support:* Drilling was temporarily suspended from 13 June 2001 until November 2001, and the drill rig as a whole was shut down until October when the generators were again operational. However the grind and injection module continued injecting seawater and miscellaneous wastes into the disposal well throughout the open water and broken ice periods. Minor welding repairs were made on the rig during the summer.

*Module and Gas Turbine Installation:* The production modules, a warehouse, pump house, and a gas turbine system were off-loaded from the sealift barges to the island using a Scheuerle trailer model MPEK 5200. The Scheuerle trailer was equipped with four 454 hp (1816 hp total) Deutz diesel engines.

## SUMMARY

This chapter describes construction activities during the open-water season from 16 June 2001 through 31 October 2001, as required by the LoA (Letter of Authorization) issued by NMFS to BP.

Two Bell 212 helicopters were used as transportation to and from Northstar Island during break-up and freeze-up. During the open water season, two crew boats, the *Hawk* and *Arctic Express*, were the primary method of transportation, but helicopter flights continued on a less frequent basis. Helicopter flights began on 4 June 2001 from the West Dock base of operations (WDBO) and Deadhorse airport to Northstar and return. The crew boat began transits on 23 July 2001 between West Dock and Northstar.

FIGURE 6.2. Bell 212 helicopter used for transportation to and from Northstar (Seal Island), especially during break-up and freeze-up, and to a lesser degree during the open-water season.

FIGURE 6.3. Crew-boat *Hawk* used for transportation between West Dock and Northstar (Seal Island) during the open-water season.

Eight round trips were scheduled daily during the summer and early autumn. Crew boat operations ceased on 7 October 2001 when sea ice was forming.

A sealift carrying production facilities, gas-turbine compressors, and other major facilities arrived in the Northstar area from southern Alaska on 10 August. The sealift involved three barges and several tugboats. The modules, gas-turbine system, and other facilities were off-loaded from the sealift barge to the island on 12-20 August using a Scheuerle trailer model MPEK 5200. During this period there was much maneuvering of the sealift barges by tugs. The sealift vessels departed on various dates from 16 to 31 August.

Tugs and barges periodically traveled to Northstar from the Prudhoe Bay area. Eight vessels were used for transport of diesel fuel, 17 vessels were used for cargo transport, and 11 vessels were used for spill response activities (training and standby) around Northstar.

The "emergency" generator in the utility module was used as the primary source of power until 24 October 2001. At that time the primary gas-turbine system brought to the island during the August sealift was integrated into the existing modules and became operational.

The Northstar drill rig, which had been installed in 2000 and operated during the winter and spring of 2000-2001, was shut down from 13 June 2001 to October 2000. Drilling did not resume until November 2001, after the period considered here. The grind and injection module injected seawater and miscellaneous wastes into the disposal well throughout the open water and broken ice periods in 2001.

## ACKNOWLEDGEMENTS

We thank Dr. Bill Streever, Allison Erickson, Wilson Cullor, and Dave Trudgen of BP's Environmental Studies Group for their specific support of the 2001 open-water season work, and Dr. Ray Jakubczak for overall support of the Northstar monitoring efforts. Dr. Bill Streever reviewed this report. We also thank Tom Barnes and Paul Cooley, Northstar Compliance Advisors; Randy Greenway of Alaska Interstate Construction; and Dr. Susanna Blackwell of Greeneridge Sciences for providing valuable information necessary for this report. Dr. John Richardson of LGL reviewed and contributed to this chapter.

## LITERATURE CITED

Williams, M.T. 2002. Introduction and description of BP activities. p. 1-1 to 1-10 *In:* W.J. Richardson (ed.), Monitoring of industrial sounds and whale calls during construction of BP's Northstar oil development, Alaskan Beaufort Sea, summer and autumn 2001: 90-day report. LGL Rep. TA2563-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 74 p. [Superseded by present report.]

Williams, M.T and C.J. Perham. 2001a. Introduction and description of BP's activities, 1999-2000 ice-covered season. p. 2-1 to 2-8 *In:* W.J. Richardson and M.T. Williams (eds.), Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar oil development, Alaskan Beaufort Sea, 2000. [Draft, April 2001.] LGL Rep. TA2432-6. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 316 p.

Williams, M.T and C.J. Perham. 2001b. Description of BP's activities, break-up and open-water seasons, 2000. p. 6-1 to 6-11 *In:* W.J. Richardson and M.T. Williams (eds.), Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar oil development, Alaskan Beaufort Sea, 2000. [Draft, April 2001.] LGL Rep. TA2432-7. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 316 p.

Williams, M.T. and W.J. Richardson. 2000. Introduction. p. 1-1 to 1-9 *In:* W.J. Richardson and M.T. Williams (eds.), Monitoring of ringed seals during construction of ice roads for BP's Northstar oil development, Alaskan Beaufort Sea, 1999. [Final Dec. 2000 ed.] LGL Rep. TA2348-1. Rep. from LGL Ltd., King City, Ont., and LGL Alaska Res. Assoc., Anchorage, AK, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 153 p.

# CHAPTER 7:

# SOUND MEASUREMENTS, 2001 OPEN-WATER SEASON[1]

by

**Susanna B. Blackwell** [a] and **Charles R. Greene Jr.** [b]

**Greeneridge Sciences, Inc.**

[a] 120 Tamarack Drive
Aptos, CA 95003
(831) 685-2773; susanna@greeneridge.com

and

[b] 4512 Via Huerto
Santa Barbara, CA 93110
(805) 967-7720; cgreene@greeneridge.com

for

**BP Exploration (Alaska) Inc.**
**Dept. of Health, Safety & Environment**
900 East Benson Blvd, P.O. Box 196612
Anchorage, AK 99519-6612

LGL Report TA2572-2

Revised October 2002

---

[1] Chapter 7 *In:* W.J. Richardson and M.T. Williams (eds.). 2002. Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar oil development, Alaskan Beaufort Sea, 2001. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD.

## INTRODUCTION

### *Background*

During the winter of 1999 - 2000, BP Exploration (Alaska) Inc. began construction of its Northstar production unit in nearshore waters of the Alaskan Beaufort Sea. Northstar is built on the eroded remains of the original Seal Island, an artificial island constructed by Shell Oil Company in 1982 about 3 mi (5 km) offshore of the closest barrier island, northwest of Prudhoe Bay. It was used in 1984 and 1985 for exploratory drilling, and subsequently abandoned. Another island named Northstar was built northwest of Seal Island by Amerada-Hess in 1985 for exploratory drilling. However, BP's facilities at the old Seal Island location are now widely known as Northstar Island. The Northstar Development addressed in this report includes the gravel island itself, living quarters, 30 wells (some still to be drilled) and associated oil production facilities on the island, and two buried subsea pipelines that connect the island to the existing production infrastructure in Prudhoe Bay.

Initial construction began in December 1999 with the building of ice roads. Construction of the island itself began in February 2000 by hauling gravel over the ice roads and depositing it at the island site through a hole in the ice. Construction continued during all of 2000, involving pipeline construction (March - May), installation of conductor pipes for the wells by vibratory and impact pile driving (June - July), positioning of the cement block slope protection (June - July), installation of the permanent living quarters (August), and assembly of the drill rig (autumn). These activities are described in Richardson and Williams (eds., 2001).

During the 2000-2001 ice-covered season, the ice-roads to the island were rebuilt and a total of five wells were drilled. Drilling began on 14 December 2000 with the Underground Injection Control (UIC) well. Drilling was suspended on 13 June because of the limitations that broken ice would impose on any oil-spill response that might be necessary. Additional details are given in Chapter 2 of this report.

The main event of the open-water season of 2001 (the period of specific concern here) was the arrival of the sealift. This consisted of three barges carrying modular buildings and equipment to complete the construction of the oil processing facilities on the island. Activities at Northstar during the late spring, summer, and early-mid autumn of 2001 (break-up and open-water seasons) are described in Chapter 6 of this report.

Work described in this chapter is a continuation of open-water acoustics work described in the Northstar Monitoring Plan for 2000-2001 (LGL and Greeneridge 2000), consisting of sound measurements during the open water season in 2001. These measurements complement sound measurements obtained a year earlier during the first summer of Northstar construction (Blackwell and Greene 2001).

### *Objectives and Approach*

***BP's business rationale*** for this work was driven both by corporate values and by regulatory requirements. BP corporate values support studies that objectively assess environmental effects that may result from BP operations. Also, additional acoustics measurements were required, during the open-water season of 2001, to satisfy provisions of a North Slope Borough zoning ordinance and the monitoring requirements of the Letter of Authorization (LoA) issued by NMFS to BP on 18 Sept. 2000.

The objective of Task 5 in 2001 was to measure and document sounds of construction activities on and around Northstar (=Seal) Island during the open-water season, in particular the sounds that had not been recorded during the summer of 2000. Received levels, spectral characteristics, specific sources, and transmission loss were to be determined. "New" types of sound sources that were recorded during summer 2001 consisted of the arrival of sealift in the Northstar area and offloading of the three sealift barges.

Two methods were to be used during the open-water period to obtain sound measurements: *(1)* A hydrophone and a microphone were to be deployed from a boat at various distances from Northstar and from specific sound sources. *(2)* A fixed, bottom-mounted hydrophone was to be deployed 300-500 m (984-1640 ft) seaward of Northstar Island and connected to the island by a cable. This was to obtain continuous data at one distance over a period of a week or more, primarily to document temporal variability. This second effort was to be continued for all of September as part of Task 7, the acoustic monitoring of the bowhead whale migration (see Chapter 8). Backup recordings and frequent checks on the quality of the incoming data were to assure that these data were acquired in 2001.

The boat-based samples were intended primarily to provide information on propagation characteristics. The cabled-hydrophone data were to document a variety of operational sounds over an extended period, allowing assessment of source variability. Analysis of the data from the fixed recording site also allows us to recognize and quantify any changes in sound characteristics among the different periods when boat-based recordings were acquired. Propagation characteristics are unlikely to change significantly over periods of hours. In combination, the data from the brief recordings at various stations plus the "reference" data from the fixed hydrophone should be sufficient to characterize propagation on a given day.

Boat-based hydrophone and microphone data were acquired in the Northstar area on three dates in August during the arrival and offloading of the sealift barges. The "cabled hydrophone" set-up actually consisted of two cabled hydrophones plus two Autonomous Seafloor Acoustic Recorders (ASARs) deployed at various locations within a few hundred meters NNW to NNE of the island (Fig. 7.1). One cabled hydrophone and (for backup) one ASAR were deployed from late July to late August. An additional cabled hydrophone and ASAR were deployed in late August for further redundancy; during the bowhead whale migration in September, it was critical to monitor continuously for purposes of Task 7 (see Chapter 8). Figure 7.1A shows that one or more systems collected data for 27 days before 1 September, and at least two systems operated at all times from then until 3 October. There were no recordings during the period 23-27 August, but a total of 27 days of data were obtained before 1 September—well in excess of the Task 5 requirement to obtain continuous near-island recordings for about one week.

## METHODS

Several different measurement units appear in this report. The following conversions can be used:

- 1 m ≅ 3.3 feet
- 1 km = 1000 m ≅ 0.54 n.mi. (nautical mile) ≅ 0.62 mi
- 1 n.mi. ≅ 1.85 km ≅ 1.15 mi

### *Boat-based Recordings in Open Water*

The 2001 sealift to Northstar, consisting of 3 barges and 5 accompanying tugs, arrived at Northstar on 10 August 2001. Recordings made on that and the ensuing days in August fall under four categories:

1. Recordings of the arrival of the barge train itself (10 Aug.).
2. Recordings of tug activities as they positioned or held a barge at the dock at Northstar (10, 12 and 13 Aug.), and during offloading of a barge (13 Aug.).

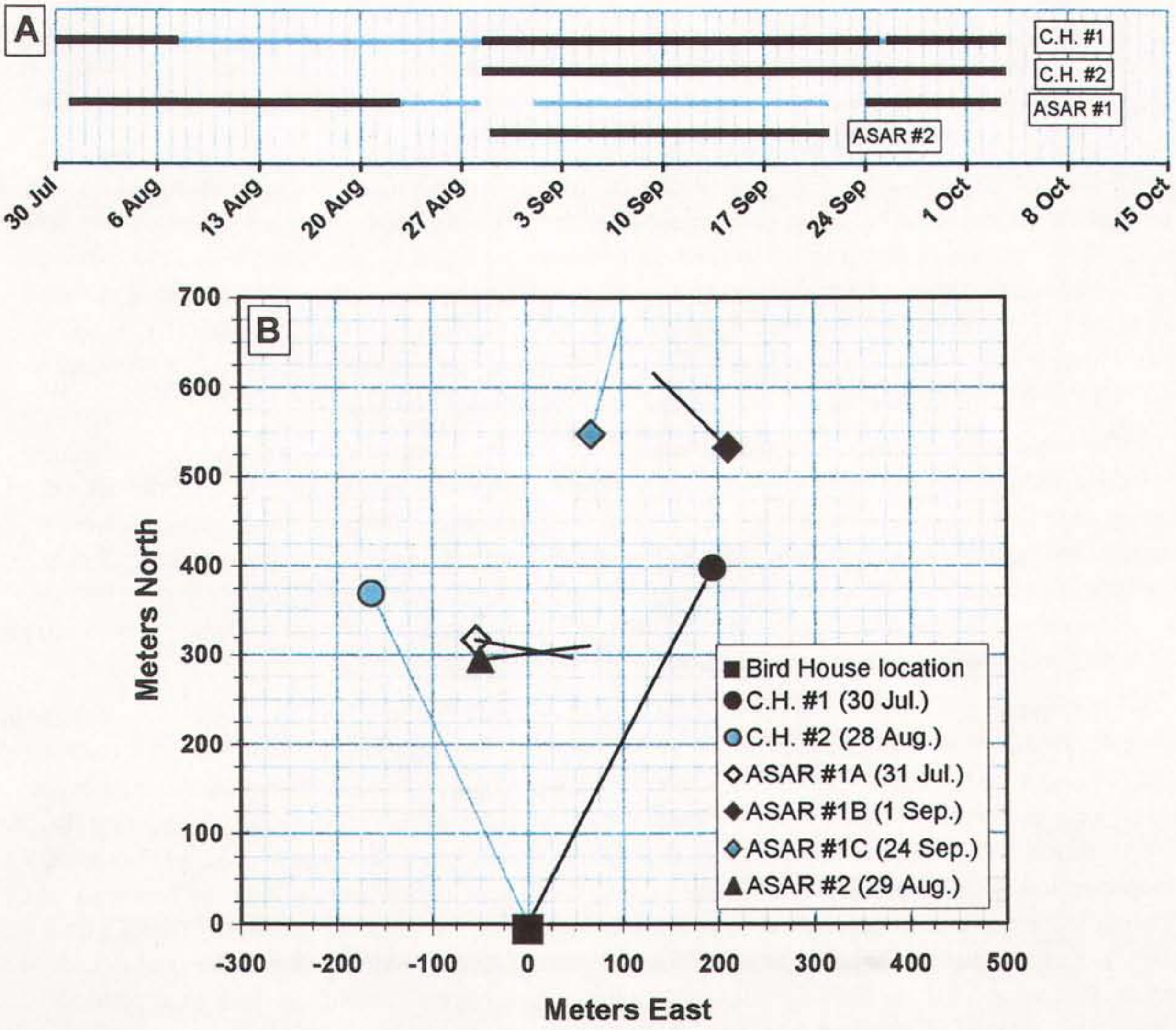


FIGURE 7.1. Times and locations when sounds near Northstar (=Seal) Island were recorded continuously by two cabled hydrophones (C.H.) and two Autonomous Seafloor Acoustic Recorders (ASARs). ***(A)*** Periods of data collection; black lines indicate times with useable data; gray lines indicate times when a system was deployed but not providing useful data. ***(B)*** Locations of C.H.'s and ASARs in relation to the Bird House (black square on x-axis). The Bird House was located centrally on the north shore of Northstar Island and housed the recorders for the C.H. systems. Lines projecting from ASAR symbols are cables connecting the recorders to their anchors. To allow retrieval, care had to be taken not to overlay lines. Dates on which the instruments started recording are indicated in parentheses. ASARs started recording at midnight on the day following their deployment.

3. Recordings of overall island sounds during sealift activity, as received at various nominal distances of up to 11 n.mi. north of Northstar (10 and 12 Aug.) and 5 n.mi. east of Northstar (12 Aug.).
4. Recordings of the Concrete Island Drilling Structure (CIDS, 10 Aug.). The CIDS caisson is not part of the Northstar Development, and is not the responsibility of BP. However, it had been stored ~1.1 km northeast of Northstar from 29 August 2000 until August 2001, when it was mobilized and (on 31 Aug.) towed away.

All of these recordings were obtained using Alaska Clean Seas (ACS) "Bay" boats of length 12.8 m or 42 feet as recording platforms. The specific vessels used were the *Mikkelsen Bay* on 10 Aug., *Gwydyr Bay* on 12 Aug. and *Harrison Bay* on 13 Aug.

### *Equipment*

The sensors included a hydrophone and a microphone, both calibrated. The hydrophone was an International Transducer Corporation (ITC) model 6050C (S/N 617), which includes a low-noise preamplifier next to the sensor and a 98 ft (30 m) cable. The hydrophone cable was attached with cable ties to a fairing to avoid strumming. Prior to recording, the hydrophone signals were amplified with an adjustable-gain postamplifier. The omnidirectional microphone was a G.R.A.S. Sound and Vibration ½" prepolarized free field microphone model 40AE with an ICP preamplifier model TMS426C01 and a windscreen. Prior to recording, the microphone signals were amplified with an adjustable-gain postamplifier.

Hydrophone and microphone signals were recorded on two channels of a SONY model PC208Ax instrumentation-quality digital audio tape (DAT) recorder. The recorder was run at its regular speed for 2-channel recording (4-channel recording, by mistake, on 10 Aug.), providing a frequency response that was nearly flat from <4 to 20,000 Hz on each channel (<4 to 10,000 Hz on 10 Aug.). Both sensors were calibrated from 4 to 20,000 Hz. Quantization was 16 bits, providing a dynamic range of >80 dB between an overloaded signal and the instrumentation noise. A memo channel on the tape recorder was used for voice announcements, and the date and time were recorded automatically.

### *Field Procedures*

On 10 August, the three sealift barges arrived in the Prudhoe Bay area, towed by two Ocean-class tugs (the *Bulwark* and *Navigator*), assisted by three River-class tugs (the *Kavik River*, *Sag River* and *Toolik River*). The Point-class tugs *Pt. Barrow* and *Pt. Oliktok* were also used when required by ice and weather conditions. Offloading of the first barge started on 12 August and continued for several days thereafter. During the entire sealift operation, the acoustics field crew had no control over the movement paths or actions of the barges or tugs, so all recordings were opportunistic in nature and supplemented by visual observations. But even at close distances visual observations were incomplete; for example, as a general rule we did not know what relative amount of sound the individual tugs contributed to the overall sound levels. The only tug(s) whose specific activities were evident to the acoustics crew were those whose stern(s) were visible from the recording vessel.

All sound recordings were obtained from an ACS "Bay" boat. After selecting an appropriate recording location, the hydrophone and spar buoy to which it was connected were lowered into the water with hydrophone depth = 8.5 m. This was somewhat shallower than our usual hydrophone depth of 10 m; the 8.5 m depth was used to allow us to make recordings in some of the shallower areas, if necessary, without having to reposition the hydrophone relative to the spar buoy. A depth reading was taken with the recording vessel's depth sounder before all sound-generating devices (engines, generator, depth sounder) on that vessel were turned off. A microphone was positioned on the deck of the vessel in such a way that it had an unobstructed path to the sound source at all times. During recording, the recording vessel drifted with the current. (A few recordings were obtained while anchored but this procedure was abandoned as it did not allow us to start up and move to the next opportunistic recording fast enough.) A laser rangefinder (Bushnell model # 20-0880) was used to get at least a beginning and end distance to the sound source; usually several intermediate readings were also recorded. For recordings at nominal distances north and east of Northstar Island, a GPS position (Garmin model 12XL) was obtained at the beginning and end of each recording. These positions were used to calculate a mean distance from the northern or eastern shore for each station. A total of 136.5 min of boat-based recordings were obtained.

TABLE 7.1. Acoustic data recordings obtained at various nominal distances N or E of Northstar (=Seal) Island on 10 and 12 August 2001.

| Date and Station | Distance* km | Distance* mi | Water depth feet | Water depth m |
|---|---|---|---|---|
| **10 August 01** | | | | |
| 1 n.mi. N | 1.7 | 1.2 | 47 | 14.3 |
| 2 n.mi. N | 3.3 | 2.1 | 49 | 14.9 |
| 5 n.mi. N | 9.2 | 5.7 | 64 | 19.5 |
| **12 August 01** | | | | |
| 1 n.mi. N | 2.0 | 1.2 | 48 | 14.6 |
| 2 n.mi. N | 3.8 | 2.4 | 46 | 14.0 |
| 5 n.mi. N | 9.5 | 5.9 | 66 | 20.1 |
| 10 n.mi. N | 18.2 | 11.3 | 72 | 21.9 |
| 11 n.mi. N | 19.7 | 12.2 | 82 | 25.0 |
| ¼ n.mi. E | 0.5 | 0.3 | 40 | 12.2 |
| ½ n.mi. E | 0.9 | 0.6 | 35 | 10.7 |
| 1 n.mi. E | 2.1 | 1.3 | 36 | 11.0 |
| 2 n.mi. E | 3.7 | 2.3 | 36 | 11.0 |
| 5 n.mi. E | 9.4 | 5.8 | 27 | 8.2 |

* Distances to N and E stations are measured from the north and east shores of the island, respectively.

Listed below are specific field procedures that pertained to each of the four categories of boat-based recordings listed earlier:

1. *Recordings of the arrival of the barge train itself:* Care was taken to make recordings from as wide a range of distances as possible and to minimize the influence of other sound sources (i.e., Northstar Island, CIDS). For that reason the recording of the arrival of the last barge, recorded the farthest from the island and from the other barges and tugs, yielded the best information (i.e., the least confounded by other sound sources).

2. *Recordings of tug activities as they positioned or held a barge at the dock at Northstar during offloading:* These recordings were all done relatively close to the dock (usually <500 m away) on the south side of Northstar Island. As mentioned earlier, it was often not possible to see which tugs were working and which were not as they were spread around at least two sides of the barge. A special recording was made of the compressor module offloading on 13 Aug. The module was driven off the barge onto the dock on a Scheuerle trailer while tugs were holding the barge in place. This recording was made as close as possible to the dock in an attempt to detect the sound made by the offloading itself over the sounds generated by the tugs.

3. *Recordings of overall island sounds during sealift activity, as received at various nominal distances N and E of Northstar Island:* These recordings (see Fig. 7.2 and Table 7.1) were made to allow comparisons with similar measurements obtained during the summer of 2000. Recordings at stations north of Northstar were obtained on 10 and 12 August; in both cases the farthest station (5 n.mi. on the 10th; 11 n.mi. on the 12th) was limited by the presence of impassable pack ice. Recordings at stations east of Northstar were obtained on 12 August to a distance of 5 n.mi. They provided comparative data in shallower water and in the approximate direction from which bowhead whales might approach later in the open-water season.

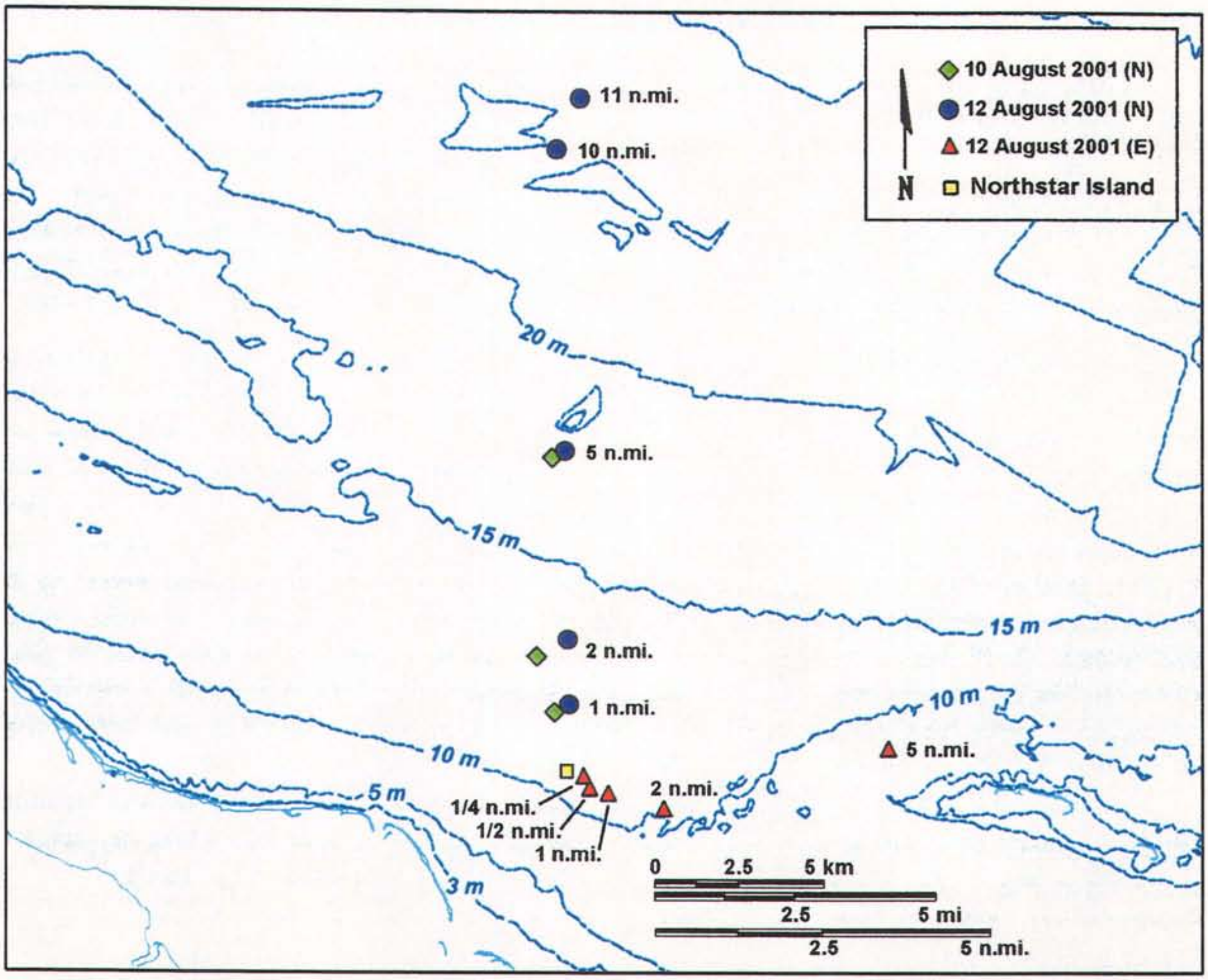


FIGURE 7.2. Acoustic recording locations north (N) and east (E) of Northstar (=Seal) Island, 10 and 12 August 2001. Northstar is indicated by the yellow square.

4. *Recording of the Concrete Island Drilling Structure (CIDS):* The CIDS was present in the Northstar area from 29 Aug. 2000 until 31 Aug. 2001, when it was towed westward (to Russia). During the weeks preceding its departure, it was readied for the trip. Two small tugs and a large ice-breaking tug were present in its vicinity. To characterize the frequency composition of sounds emanating from the CIDS, a recording was made on the northeastern side of the structure. This location, with CIDS between the hydrophone and Northstar, was chosen to minimize the contribution of sounds emanating from Northstar and the three barge and tug combinations involved in the Northstar sealift, which arrived that day. In addition, continuous recordings of overall sounds in the area about 300 m north of Northstar (and 995 m SW of the CIDS) were also available from one of the ASARs (see *Cabled Hydrophone* section below) during ~3 days preceding and 22 days following the CIDS' departure. These data are presented as they provide some information on the contribution of the CIDS to overall island sounds.

## *Cabled Hydrophone and ASARs*

At most times from late July through early October 2001, one or more hydrophones provided continuous acoustic data from locations just above the sea floor a few hundred meters north of Northstar Island (see Fig. 7.1). These data came from one or two (depending on date) cabled hydrophones (CHs), and one or two Autonomous Seafloor Acoustic Recorders (ASARs) deployed as redundant systems. The system was designed to provide a continuous record of sounds emanating from Northstar (plus ambient noise) over an extended period, including the period of bowhead whale migration in September (Task 7, see Chapter 8). For the present task, the Monitoring Plan called for a recording period of at least 1week.

Cabled hydrophone #1 (CH 1) was initially deployed on 30 July 2001 at a site 442 m northeast of the north side of Northstar Island (see Fig. 7.1B and Chapter 8). The cable extended to a recording system located in the "Bird House" on the north side of Northstar. At the time of deployment, a considerable number of ice floes were still present around the island. During early August floes caught the cable several times, applying tremendous tension and pulling the cable out from the groove between the cement blocks (slope protection) where it had been fastened with cable ties. On 7 August a walkway for pedestrians was placed in front of the Bird House, on the cement blocks. The cable, at that point unprotected by the cement blocks, was inadvertently pinched. The conductor wires were shorted and the recorder stopped recording data. On 28 August the CH 1 system was fixed by cutting the cable at the location of the pinch and reconnecting it to the recorder. That same day, a second cabled hydrophone system (CH 2) was deployed about 360 m farther west (see Fig. 7.1B), 404 m NNW of the Bird House. From then until both systems were retrieved on 3 Oct., at least one of the two recorders (and usually both) collected data.

In addition to the duplicate set of cabled hydrophones, one or two Autonomous Seafloor Acoustic Recorders (ASARs) were used as additional redundant systems at almost all times throughout the period of data collection (Fig. 7.1A). The two ASARs were deployed a total of four times. One ASAR (#1A) was deployed for most of August; both were deployed for the first part of September but only one (#2) obtained useful data; finally ASAR #1C was redeployed during late September and early October (see Fig. 7.1A). Water depth at the ASAR sites was 12-13 m.

Fig. 7.1A shows periods of coverage for the cabled hydrophones (2) and ASARs (2) from 30 July to 3 Oct. 2001. The only dates when only ASAR data were available are 7-22 Aug., after the first cabled hydrophone had shorted and before the first ASAR ran out of disk space. This was the period of primary interest for this chapter. Thus, near-island data reported here were all collected by ASARs located 300-550 m north of the north shore of Northstar Island. The cabled hydrophone systems and associated data are described in Chapter 8.

### *Equipment*

ASARs are described in Greene et al. (1997). They consist of a PVC housing (54" long, 6" in diameter, or 137 × 15 cm) and aluminum end caps with double O-rings at each end. The ITC 8212 hydrophone, located adjacent to one of the end caps, is connected directly to the signal conditioning card, which is located inside the housing together with the rest of the electronics and the batteries. Most of the time, ASARs sample at a rate of 1000 samples/s (samples/second) with a quantization of 16 bits. The data samples are buffered for 14 min 24 s (1/100th of a 24-hour day), and then written to a 4.3 GB disk. For the final minute before disk writing, the sample rate is increased to 2000 samples/s. ASARs therefore provide continuous data for the 10-500 Hz band (i.e., 1000 samples/s), and also provide data for the 10-1000 Hz band (i.e., 2000 samples/s) for 1 min out of every 14 min 24 s period (or 100 times per day). A single disk can store such samples continuously for about 23 days, after which it must be replaced. ASARs are functionally similar to the cabled hydrophone and are a suitable substitute.

### Field Procedures

ASARs are designed to be lowered to the seafloor by rope. One end of the ASAR tube was connected by a 100 m (328 ft) line or cable to a 2-kg (4.4 lb) Danforth anchor. After deploying the anchor, the line or cable was laid out in a straight line and the ASAR was lowered to the bottom with a rope. The GPS locations of both the anchor and ASAR were recorded during deployment. For retrieval, a double grapnel anchor assembly with 6 m (20 ft) of chain was towed perpendicular to the line or cable and across it. Retrieval was usually accomplished on the first or second pass.

## Signal Analysis

### Boat-based Recordings

The recorded, digitized hydrophone signals were transferred as time series to a computer hard drive for processing. They were then equalized and calibrated in units of sound pressure with flat frequency response over the data bandwidth (4-20,000 Hz, or 4-10,000 Hz for data collected on 10 Aug.). Analysis was done using MATLAB (The MathWorks, 3 Apple Hill Drive, Natick, MA 01760-2098) routines and custom programs for analysis of both transient and continuous signals. For each recording, a sound pressure time series (waveform) was generated; an example is shown in Figure 7.3. In general, these plots showed varying levels as sound sources approached or receded, or started and stopped. The sound was played via a speaker to help the analyst identify the probable source of the sound and to facilitate matching notes from the field with the recorded sounds. The sound waveform was used to select representative samples for further analysis. If the overall sound pressure levels (SPLs) varied little with time, at least two 8.5-s samples were selected from the recording and analyzed. If the sound waveform showed fluctuations in the SPL (as in Fig. 7.3), then 8.5-s samples were taken from both the stronger and the weaker sections of the recording. Throughout this report and unless specified otherwise, the term "sample" (of sound) refers specifically to these 8.5-s long slices of the time series.

Frequency composition was determined by calculating the sound pressure spectral density by Fourier analysis. The averaging time for such measurements was 8.5 s.

To show how received levels varied with distance from the activity, the highest observed root-mean-square (rms) broadband levels (sound pressure level, SPL) were plotted against range from the dominant source. These plots are based on the series of sound recordings at varying distances along a given transect. Interpretation of these data is complicated by variability of the sources within and between recordings, and by the presence (at some recording stations) of significant sound from more than one sound source. Nevertheless, the "received level vs. range" plots give an estimate of the highest levels received at several distances during the various activities studied. In addition, where appropriate, spectral analyses of the dominant sounds are included.

Microphone data were transcribed to disk files and analyzed in the same way as boat-based hydrophone data. Broadband microphone data were A-weighted (and expressed in dBA referred to 20 μPa) to allow comparisons with common airborne sounds described in the literature. During A-weighting, a frequency-dependent weighting factor is applied to the sound in accordance with the sensitivity of the human ear; therefore frequencies below 1 kHz and above 6 kHz are de-emphasized (Kinsler et al. 1982; Kryter 1985). One-third octave band data were not A-weighted and are expressed in dB re 20 μPa.

***Propagation Loss Modeling.***—We fitted a simple propagation model to broadband levels received by both hydrophone and microphone in order to develop equations that characterize propagation loss underwater and in air. The model used was based on logarithmic spreading loss:

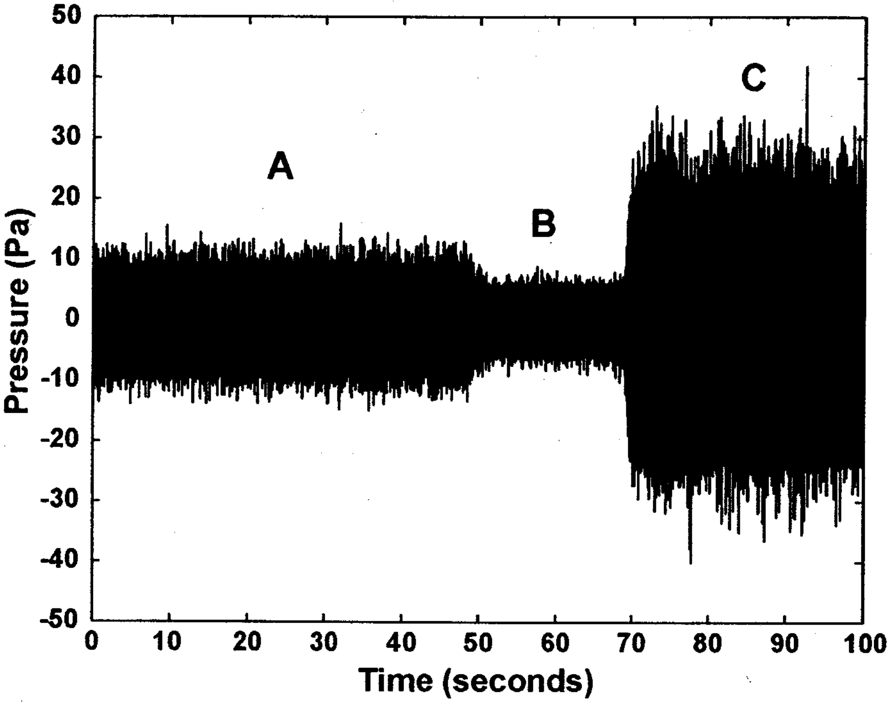


FIGURE 7.3. Typical sound pressure time series, showing received sound pressure vs. time. This 100-s recording was obtained on 12 Aug. 2001, about 250 m from a barge being held by two tugs at the dock at Northstar. Three different overall sound levels can be distinguished: a River-class tug pushing on the barge (section A), the tugs idling (section B), and an Ocean-class tug pushing on the barge (section C).

$$\text{Received Level (RL, dB re 1 } \mu\text{Pa}^{(2)}) = A - B \times \log(R), \text{ where } R \text{ is range in m.} \qquad \text{Eq. (1)}$$

In this equation, the constant term ($A$) is the hypothetical extrapolated received level at distance 1 m (dB re 1 μPa[2]) based on far-field measurements. The estimated "$A$" value is useful mainly as a basis for comparison with other sound sources operating in the same region. Expected values for the spreading loss term ($B$) are 20 dB/tenfold change in distance for spherical spreading (such as seen in the open ocean far from surface, bottom or other boundaries) and 10 dB/tenfold change in distance for cylindrical spreading (Richardson et al. 1995). Spreading-loss terms exceeding 20 dB/tenfold change are possible with shallow sources and/or receivers.

### *ASAR Hydrophone Signals*

The one-minute records of sound sampled at 2000 samples/s were analyzed to determine sound spectral densities (i.e., the sound levels at different frequencies) at frequencies up to 1000 Hz. These data were used to determine the overall levels in the 10-1000 Hz band, and the levels in one-third octave bands within this frequency range. There were 100 such analyses per day of recording. Broadband and one-third octave band levels are presented for days before and during the arrival of the sealift barges, as well as after their departure.

---

(2) The units dB re 1 μPa are used for underwater sound pressure levels; units for in-air sound pressure levels are dB re 20 μPa, applicable to all microphone data. When A-weighting is applied to in-air measurements, the sound pressure levels are cited as dBA re 20 μPa.

# RESULTS

## *Boat-based Recordings in Open Water*

Results are presented below for all three days of recordings and for both underwater and in-air measurements.

### *Weather*

10 Aug. 2001: increasing wind speed throughout the day, from 12 mph at 06:00 local time (wind from S) to 18 mph at 18:00 (W)(3). Sea state 2-3, decreasing to 1 beyond 2 n.mi. north of Northstar where ice floes became numerous.

12 Aug. 2001: increasing wind speed throughout the day, from 12 mph at 06:00 (S) to 22 mph at 18:00 (W)(3). Rain in the afternoon. Sea state 2-3, decreasing to ½ at 11 n.mi. north of Northstar.

13 Aug. 2001: fairly constant wind speed throughout the day, between 7 and 10 mph. Wind direction N changing to E(3). Light rain during the afternoon and evening recordings. Sea state 1-2.

### *Arrival of Sealift Barges*

Boat-based recordings were made on 10 Aug. between 14:05 and 15:54 local time. The three barges carried the following items:

- barge 420: the compressor module and pumphouse.

- barge 400: North and South processor modules. These two buildings constituted by far the biggest shipment and are shown in Figure 7.4.

- barge 411: the warehouse, flare boom and some pipe rack sections.

Barges 420 and 411 arrived first, followed by 400. During the recordings, barges 420 and 411 were fairly close together (~0.5 n.mi.), whereas barge 400 lagged somewhat behind (2.5-3 n.mi. from barge 411).

***Underwater Sounds***.—Figure 7.5 shows broadband (10-10,000 Hz) SPLs recorded during the arrival of these barges. The highest levels recorded were 136 dB at 1450 m and 135 dB at 357 m from the source. The high levels at distances of 1300-1700 m from barges 420 and 411 together (filled circles) could be due either to a variation in tug effort due to maneuvering, or to the influence of another sound source. This recording was taken reasonably close to Northstar Island (2.5 n.mi.) and there were several other vessels in the water (i.e., the crew boat, the ACS barge *Endeavor* with its tug, and some smaller ACS vessels). The recording of barge 400 covered the widest range of distances and was obtained the farthest away from the influence of the other barges and all the activity around Northstar Island. Therefore, a logarithmic sound propagation model was fitted to these data (Fig. 7.5). This yielded a spreading loss term of 14.8 dB/tenfold change in distance.

One-third octave band levels for seven selected frequencies, based on the same recording of the arrival of barge 400, are shown in Figure 7.6. Note that SPLs for the one-third octave band centered at 20 Hz are lower than those for the band centered at 6.3 Hz as well as for the bands centered at some higher frequencies (63, 200 and 630 Hz). This result is explained by shallow water sound transmission theory and will be addressed in the "Discussion" section.

---

(3) Weather data collected by MMS weather station located on the roof of the Permanent Living Quarters (PLQ) on Northstar Island, http://www.resdat.com/mms/.

FIGURE 7.4. Sealift barge 400, with the N and S process modules, upon its arrival in Prudhoe Bay on 10 August 2001. The Ocean-class tug *Navigator* can be seen holding the barge on one side.

***Airborne Sounds***.—Figure 7.7 shows broadband (20-10,000 Hz) A-weighted SPLs recorded during the arrival of the barges. Wind speed increased over the day from 12 to 18 mph on 10 Aug. but the microphone's windscreen prevented wind noise from being an issue on the recordings. Waves slapping against the hull of the boat were much more of a concern and are probably responsible for part of the variation in SPLs seen in Fig. 7.7. Efforts were made during the analysis to sample the quieter sections, i.e. least contaminated by wave-slap. As the vessel was drifting during recording, it was not possible to minimize the effect of this source of noise. The highest SPL was 56 dBA re 20 μPa and was obtained during all three recordings: at 328 m (1076 feet) during the recording of barge 411 (bow aspect), at 365 m (1198 feet) during the recording of barge 400, and at 1640 m (5381 feet) during the recording of barges 420 and 411 together. Since the recording of barge 400 was the least influenced by other sound sources, a logarithmic sound propagation model was fitted to those results. In this model the spreading loss term was 6.4 dBA/tenfold change in distance. This is an unexpectedly low loss-rate, suggesting that longer-range data were affected substantially by local noise sources (e.g., wave slap), or that the emitted noise varied over the duration of the recording.

One-third octave band levels for six selected frequencies, based on the same recording of the arrival of barge 400, are shown in Figure 7.8. These data are not A-weighted. One-third octave bands centered at and above 63 Hz show a similar (low) rate of propagation loss with increasing distance. Results for the band centered at 25 Hz display more variability and a greater decrease in SPLs with distance.

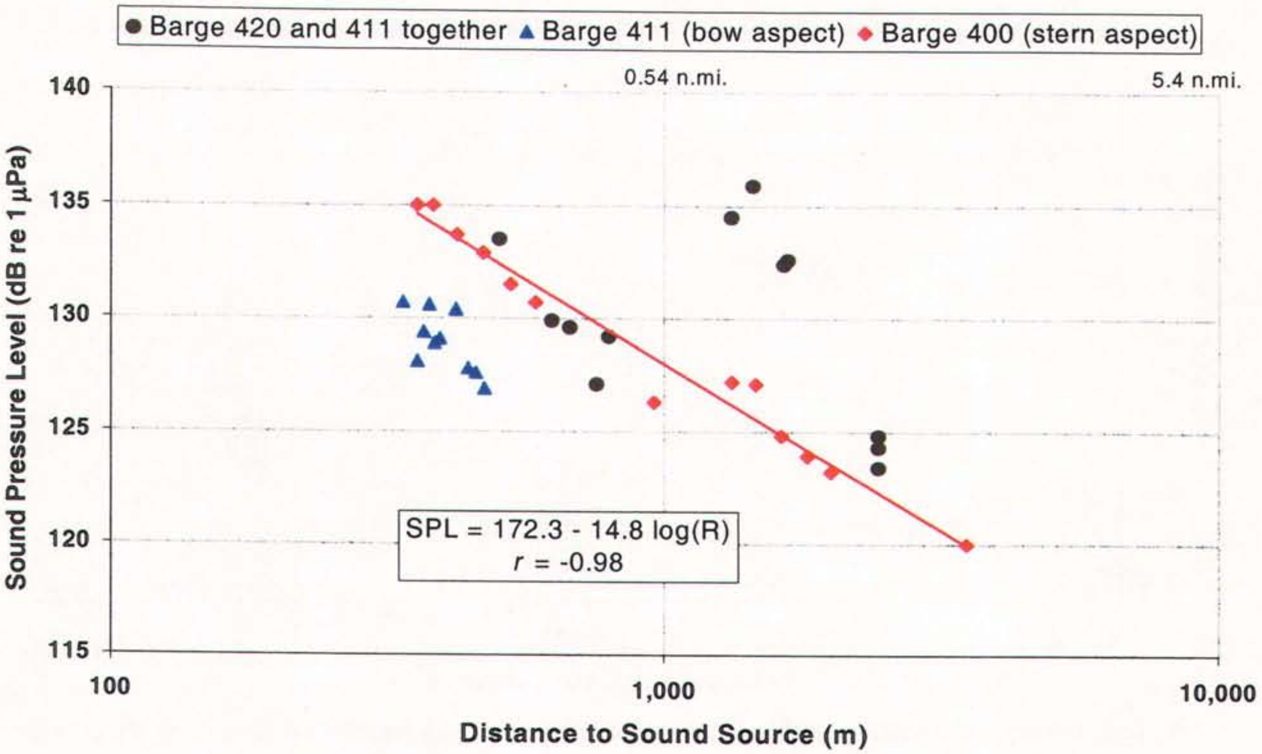


FIGURE 7.5. Broadband (10-10,000 Hz) levels of underwater sound as a function of distance from sound source during the arrival of the three sealift barges on 10 Aug. 2001. The logarithmic regression model shown was fitted to the data for barge 400 only (red diamonds). R is in meters. 10 km = 5.4 n.mi. or 6.2 mi.

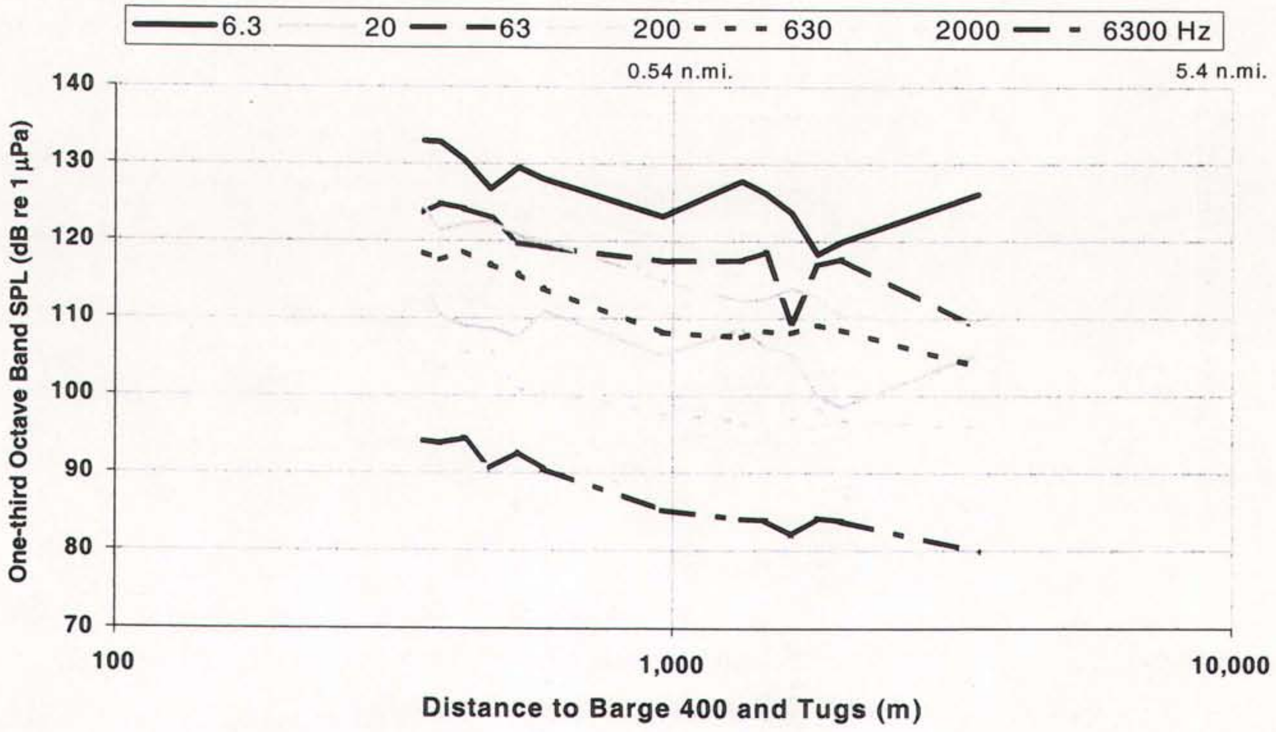


FIGURE 7.6. One-third octave band levels of underwater sound vs. range for 7 selected frequencies during the arrival of sealift barge 400, carrying the two process modules, 10 Aug. 2001. 1 n.mi. = 1.15 mi or 1.85 km.

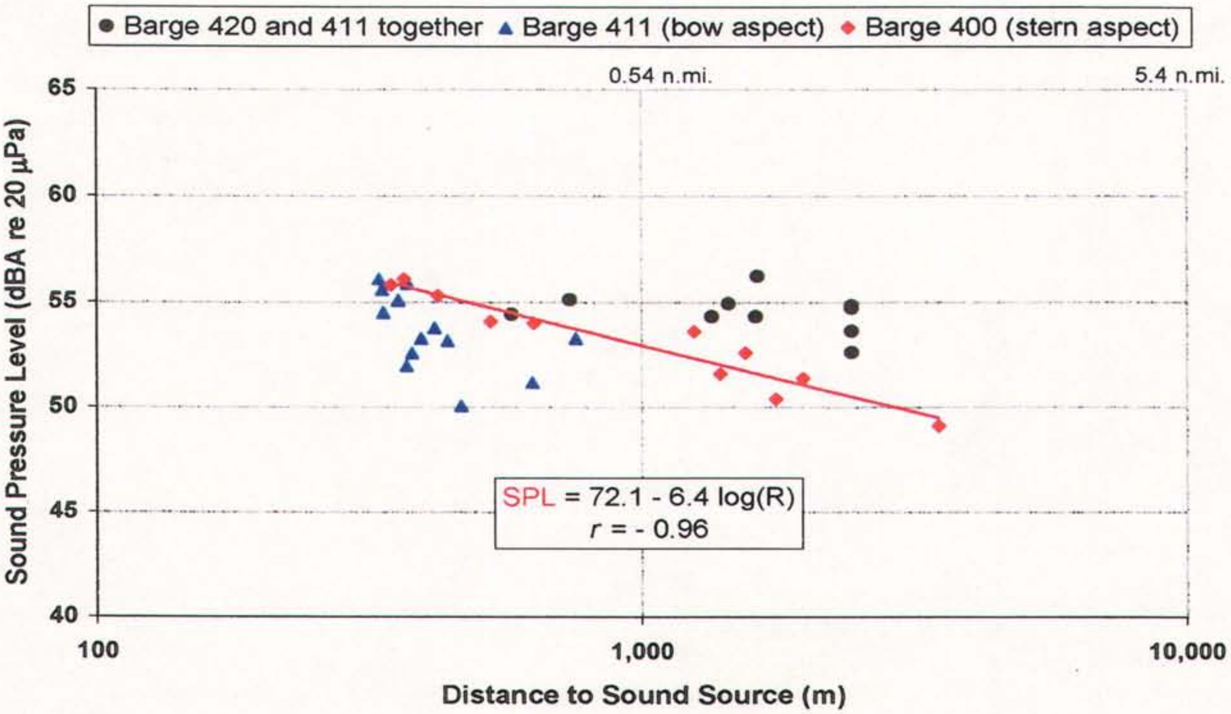


FIGURE 7.7. A-weighted, broadband (20-10,000 Hz) levels of airborne sound as a function of distance from sound source during the arrival of the three sealift barges on 10 Aug. 2001. The logarithmic regression model shown was fitted to the data for barge 400 only (red diamonds). R is in meters. 10 km = 5.4 n.mi. or 6.2 mi.

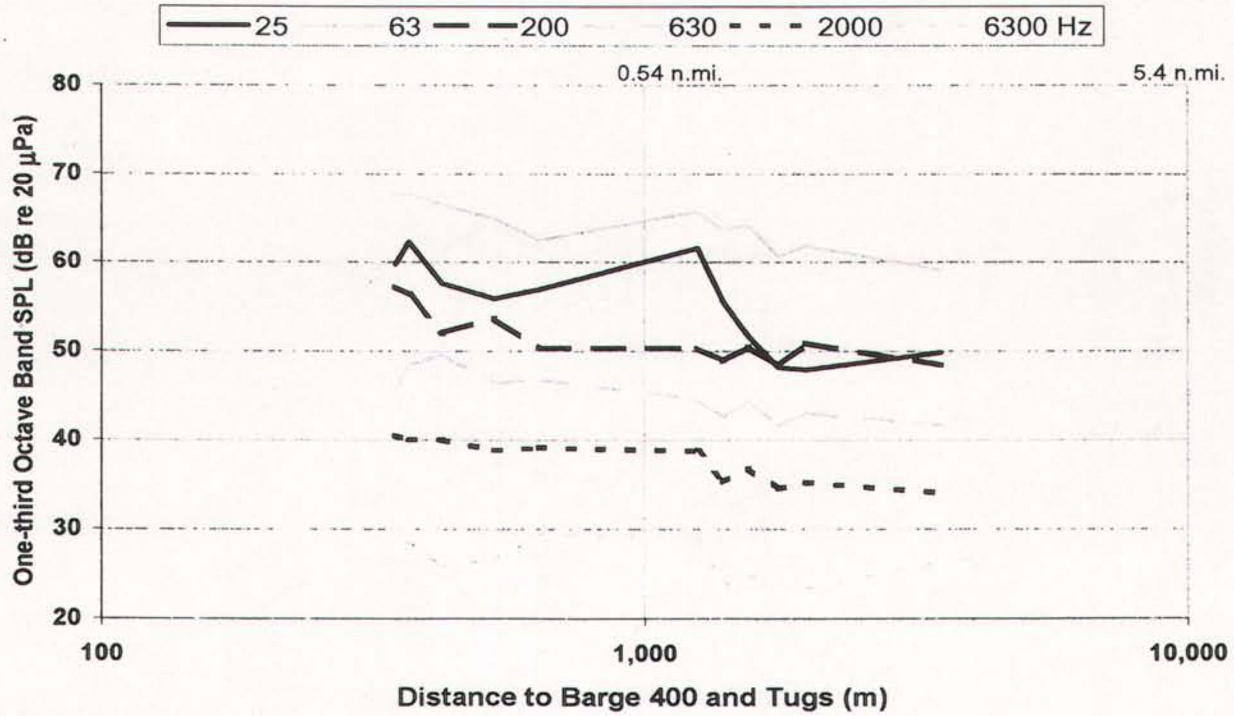


FIGURE 7.8. One-third octave band levels of airborne sound vs. range for 6 selected frequencies during the arrival of sealift barge 400, carrying the two process modules, 10 Aug. 2001. 1 n.mi. = 1.15 mi or 1.85 km.

***Summary.***—Both underwater and in-air data from a recording of the largest barge's arrival were used to fit a logarithmic sound propagation model. The spreading loss terms obtained were 14.8 and 6.4 dB/tenfold change in distance, respectively. The highest broadband levels of underwater sound recorded from the tugs and barges were 135-136 dB re 1 μPa and were encountered 357 m and 1450 m from the source. Higher levels are expected to occur at closer distances. The highest in-air broadband level recorded was 56 dBA, 328 m from barges 420 and 411.

### *Tug Activities*

On 12 and 13 August 2001 recordings were made of the sounds produced by tugs as they maneuvered a barge to position it at the Northstar dock and then held it in place for offloading. On 13 August a more specific recording was made while the compressor module was being offloaded using a Scheuerle trailer (also called a self-propelled module transporter). After being driven under the module, the Scheuerle trailer jacks the module onto itself. The computer-controlled trailer is self-propelled (with diesel engines) and can move in any direction, allowing the module to be positioned exactly in place on Northstar Island. The rate at which the module moved off the barge was slow, but detectable by eye.

***Underwater Sounds.***—Broadband (10-10,000 Hz) SPLs recorded during various activities performed by the tugs are shown in Figure 7.9. Recordings of an Ocean-class tug and a River-class tug, working alternately (see Fig. 7.3) at a distance of about 250 m, showed that broadband levels at that distance were about 8 dB higher for the Ocean-class tug (solid black circles) than for the River-class tug (solid black triangles). A

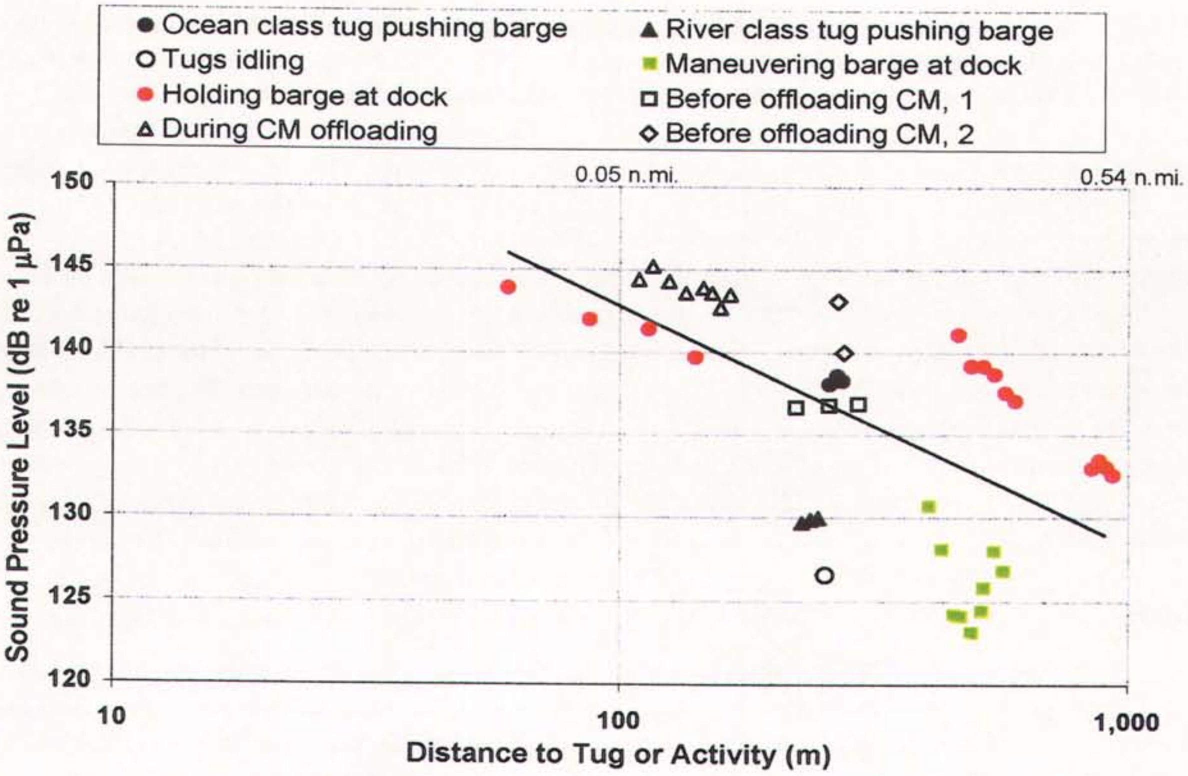


FIGURE 7.9. Broadband (10-10,000 Hz) levels of underwater sound as a function of distance from sound source during various tug activities, 12 and 13 Aug. 2001. CM = compressor module. The line corresponds to the logarithmic fit calculated from the recording of the arrival of barge 400 (Fig. 7.5) and is shown only for comparison. 1 km = 0.54 n.mi. or 0.62 mi.

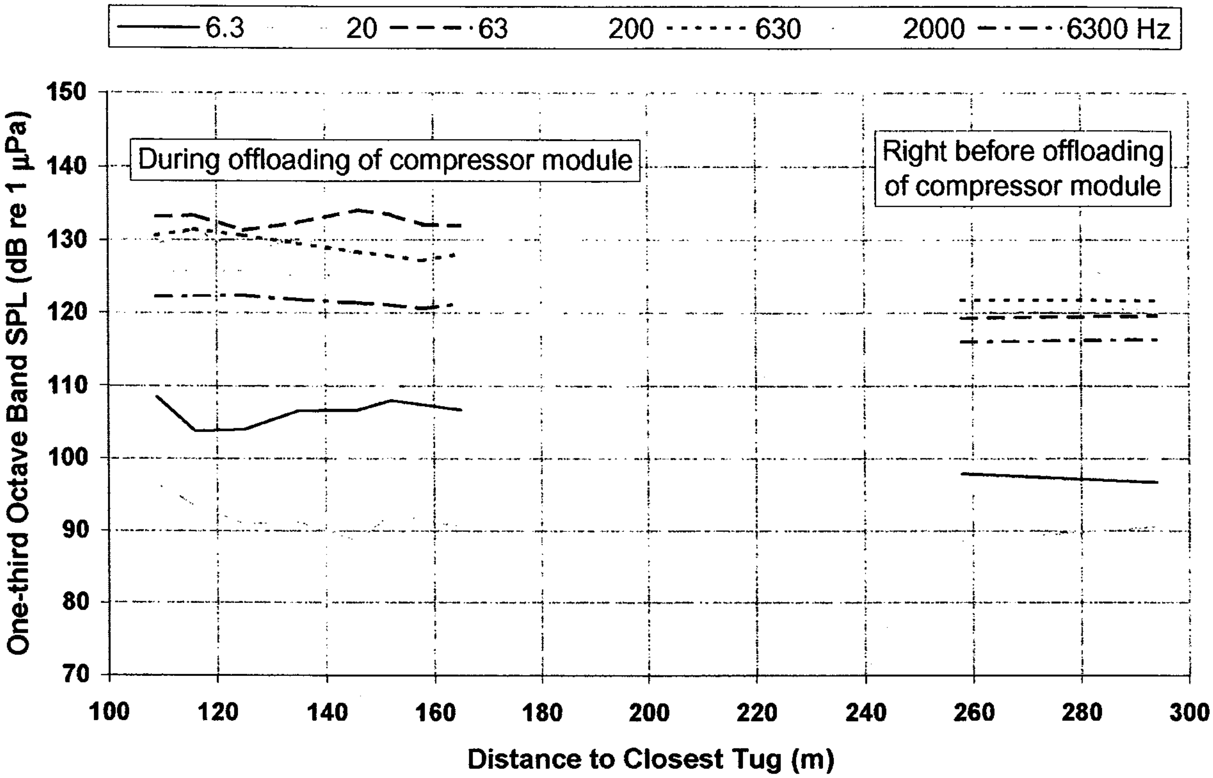


Figure 7.10. One-third octave band levels of underwater sound vs. range for 7 selected frequencies, during (left) and just preceding (right) offloading of the compressor module, 13 Aug. 2001. The frequency value indicated for each band corresponds to the center value for that band. 200 m = 0.12 mi or 0.11 n.mi.

recording was made while an Ocean-class and a River-class tug maneuvered a barge at the dock, turning it by 90 degrees (solid green squares). Three other recordings (at 60-140 m, 460-600 m and 850-900 m) were made while the same two tugs held the barge at the dock (solid red circles); two other tugs were present but were only standing by. The open circle in Figure 7.9 is the SPL when all three tugs present were seemingly only idling. During the evening of 13 Aug. the compressor module was offloaded from barge 420 onto Northstar Island (gray filled triangles). During this operation four tugs (one Ocean-class and three River-class) were present, but usually only two were working at any point in time. This was the situation when the highest SPLs were recorded, reaching 145 dB re 1 µPa at a recording site 116 m from the closest tug. Despite the variation these values are comparable to those recorded during the arrival of the barge train on 10 Aug. (Fig. 7.5); for comparison, the logarithmic fit calculated in Figure 7.5 from the arrival of barge 400 is shown by the straight line in Figure 7.9. Two different recordings were also obtained during the three hours preceding the offloading of the compressor module, when the barge was in place at the dock but was being readied for the offloading itself. These are shown in solid gray diamonds and squares (Fig. 7.9).

To examine if the offloading process itself (i.e., Scheuerle trailer moving the module) produced detectable sounds in addition to the sounds produced by the tugs holding the barge in place, we plotted one-third octave band SPLs as a function of distance to the closest tug holding the barge for seven selected frequencies (Fig. 7.10). One-third octave band levels are shown during the offloading process itself (left side of Fig. 7.10) and during one of the recordings that preceded the offloading, when the tugs were holding the barge but the Scheuerle trailer was immobile (right side of Fig. 7.10). The most notable difference is the

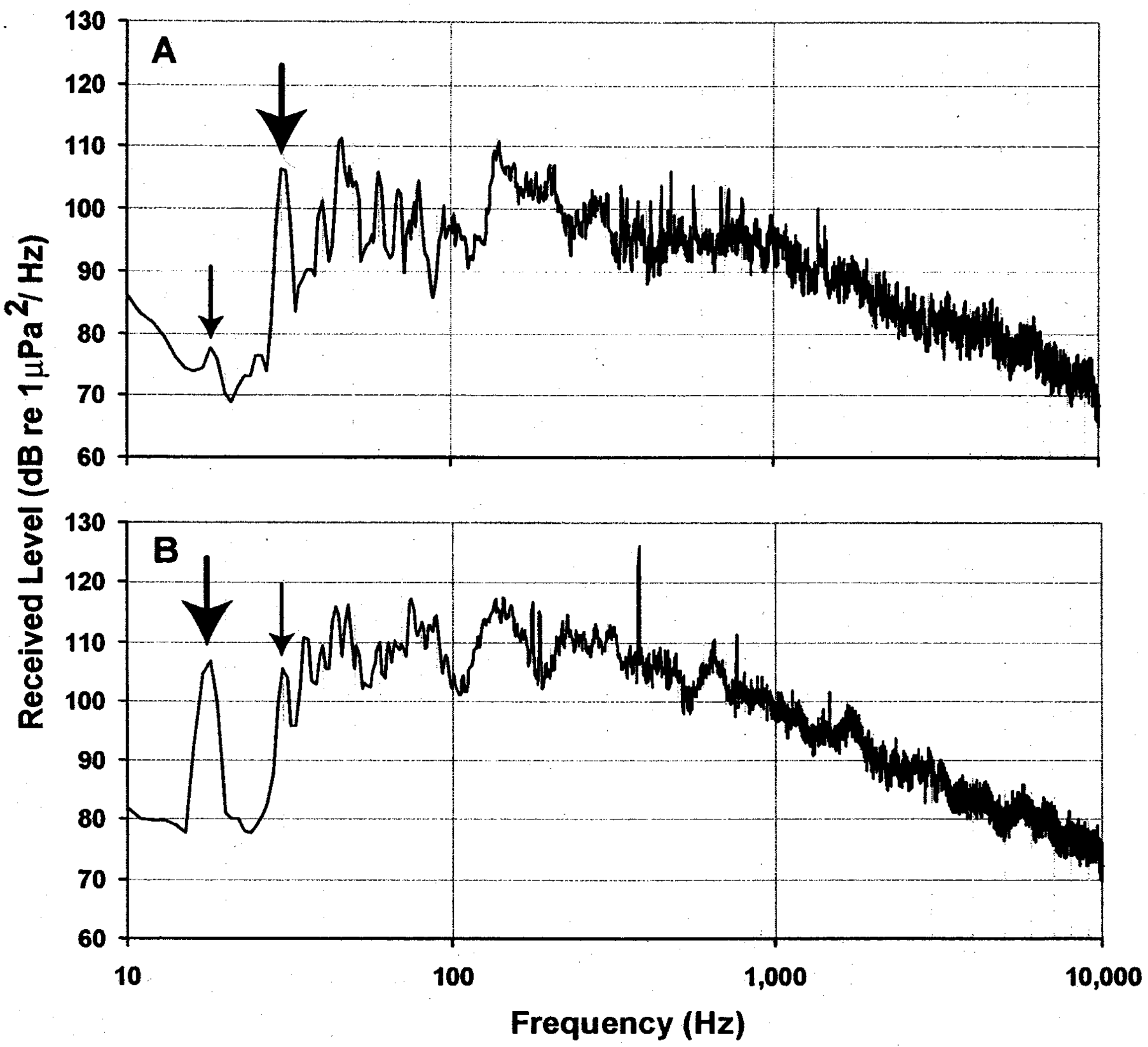


FIGURE 7.11. Narrowband spectra for 10 to 10,000 Hz and two different types of tugs, 12 Aug. 2001. ***(A)*** River-class tug pushing at 229 m. ***(B)*** Ocean-class tug pushing at 274 m. The tones expected for each type of tug are indicated with large arrows. Tones that likely originated from the other type of tug (not pushing) are shown with a small arrow. 1 n.mi. = 1.15 mi or 1.85 km.

relative position of the one-third octave band centered at 63 Hz. That was the strongest band during offloading of the compressor module, but not during the preceding "reference" period. Tones produced during offloading of the compressor module were similar to those produced when the tugs were simply holding the barge against the dock. Exceptions include tones at 201, 402, 71 and 770 Hz, common while the compressor module was being offloaded but non-existent right before offloading began.

The maximum engine and prop shaft rates, respectively, were 915 and 210 rpm for the Ocean-class tugs and 1400 and 466 rpm for the River-class tugs. The Ocean-class tugs had two five-bladed propellers, and the River-class tugs had either three five-bladed or three four-bladed propellers. Expected tones corresponding to the blade-turning rate were therefore 17.5 Hz (210 x 5 / 60) for the Ocean-class tugs and 31.1 or 38.8 Hz for the River-class tugs. Narrowband spectra were plotted for 8.5-s samples of sound from each type of tug (Fig. 7.11). The samples were taken from the same recording that provided the data for Figure 7.3. A prominent peak in SPL is seen at 30 and 31 Hz in the sample from when the River-class tug was pushing (Fig. 7.11A), and at 17 and 18 Hz for when the Ocean-class tug was pushing (Fig. 7.11B). Neither of these samples was limited to sounds from a single sound source, and each sample also shows evidence of sounds from the 2nd type of tug, which was not pushing at the recording time (small arrows in Fig. 7.11).

***Airborne Sounds.***—A-weighted in-air SPLs are shown in Figure 7.12 for the same tug activities as those shown in Fig. 7.9 for underwater sounds. The highest sound pressure level obtained was 86 dBA re 20 µPa, recorded 60 m from the barge while it was held at the dock by two tugs while two other tugs stood by.

One-third octave band SPLs as a function of distance to the barge are shown in Figure 7.13, again during the offloading process (left side of Fig. 7.13) and earlier when the tugs were holding the barge but the Scheuerle trailer was immobile (right side of Fig. 7.13). For most one-third octave bands, levels of airborne sound were higher during offloading than before (Fig. 7.13). During offloading of the compressor module, 27 strong tones were measured at frequencies from 39 to 17,296 Hz. There were only 9 tones in a narrower range (39-473 Hz) when the tugs were simply holding the barge against the dock.

***Summary.***—Underwater sound levels produced by working tugs were variable, depending on the tugs' activities, but were comparable to those obtained from recordings of the barge train arrival. The highest underwater SPL recorded was 145 dB re 1 µPa at a location 116 m from a tug that was forcing a barge against the dock. Tones corresponding to the propeller blade rates of the different types of tugs were recorded. In-air broadband data showed more variation than underwater data; the maximum A-weighted broadband SPL was 86 dBA re 20 µPa, 60 m from a barge. Underwater broadband levels while the compressor was being offloaded with a Scheuerle module transporter showed that the tugs are the main sound component underwater; the offloading procedure itself contributes only a small increment of underwater sound over and above the tug sound.

### *Overall Island Sounds*

***Underwater Sounds.***—Three series of recordings were made at nominal distances N and E of Northstar Island in order to record overall sound levels from the island and compare them to data collected during the summer of 2000. On 10 Aug. recordings were made 1-5 n.mi. N of the island. (At the 5 n.mi. station we reached the edge of the pack ice and could go no further.) On 12 Aug. recordings were made 1-11 n.mi. N of the island, again to the edge of the pack ice, and ¼-5 n.mi. E of Northstar (see Table 7.1 and Fig. 7.2). Mean broadband (10-10,000 Hz) SPLs for all these recordings are shown in Figure 7.14. For comparison, mean broadband levels from similar recordings made on 30 Aug. and 1 Sept. 2000 (see Blackwell and Greene 2001) are also shown.

Broadband levels during 30 Aug. 2000 were the highest recorded during the open water measurements of that summer, and those obtained on 1 Sept. 2000 had intermediate values. However, the highest broadband values recorded in either year were found north of Northstar on 12 Aug. 2001 (solid red squares in Fig. 7.14). The highest single value was 147 dB re 1 µPa at a location 1965 m (1 n.mi. or 1.2 mi) from the island at 16:49 on 12 Aug. 2001. At 11 n.mi. from Northstar, we had penetrated the belt of pack ice where the water was mirror still and the recording conditions were unusually quiet. This may in part explain the drop in broadband levels between the 10 and 11 n.mi. stations (18.5 and 20 km in Fig. 7.14). There was no noticeable change in activity at those times on the island (see *Near-Island ASAR Recordings* section below). It is of course possible that a non-island source of sound was recorded at 10 n.mi. and had quieted down by the time the 11 n.mi. recording was made. Comparisons will be made in the *Near-Island ASAR Recordings* section between the broadband levels recorded by the near-island ASARs and those recorded during the open-water measurements.

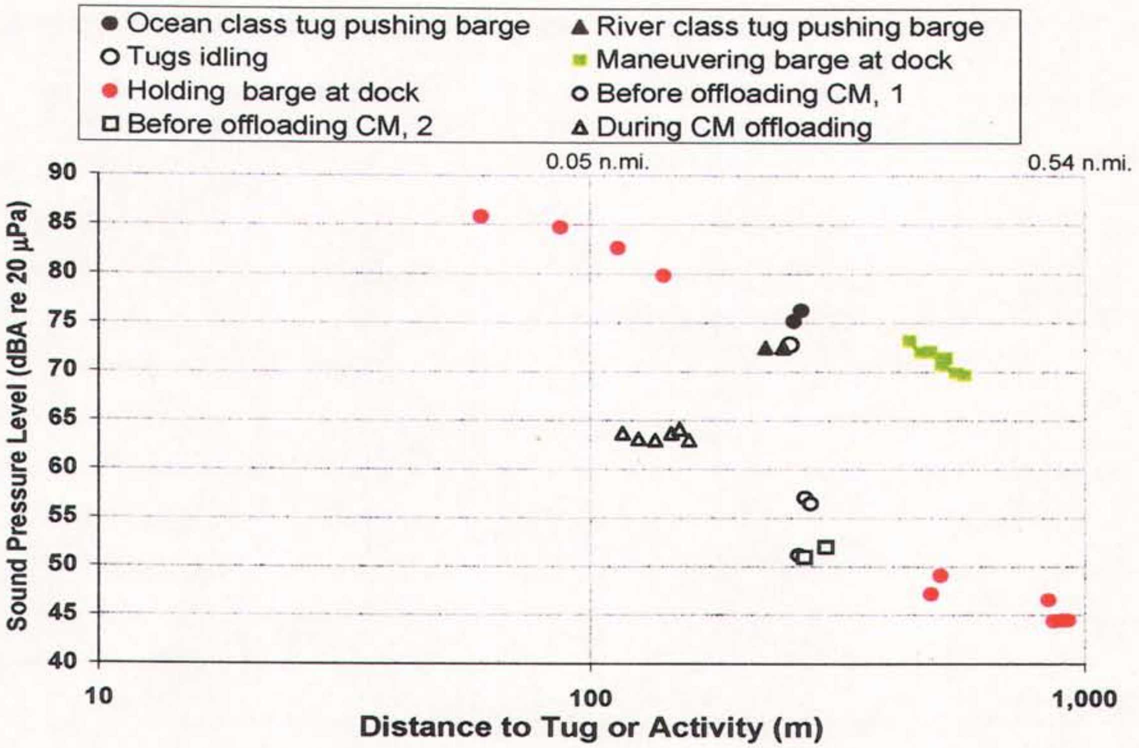


FIGURE 7.12. A-weighted broadband (20-10,000 Hz) levels of airborne sound as a function of distance from sound source during various tug activities, 12 and 13 Aug. 2001. CM = compressor module. 1 km = 0.54 n.mi. or 0.62 mi.

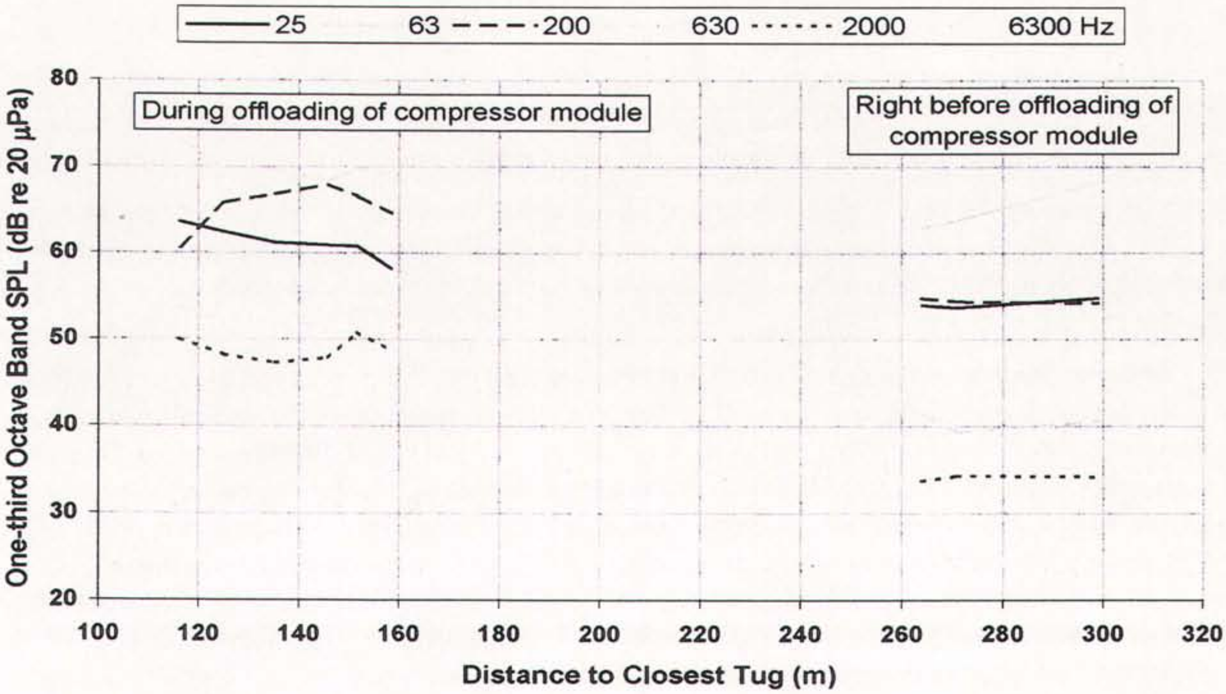


FIGURE 7.13. One-third octave band levels of airborne sound vs. range for 6 selected frequencies, during (left) and just preceding (right) offloading of the compressor module, 13 Aug. 2001. The frequency value indicated for each band corresponds to the center value for that band. 200 m = 0.12 mi or 0.11 n.mi.

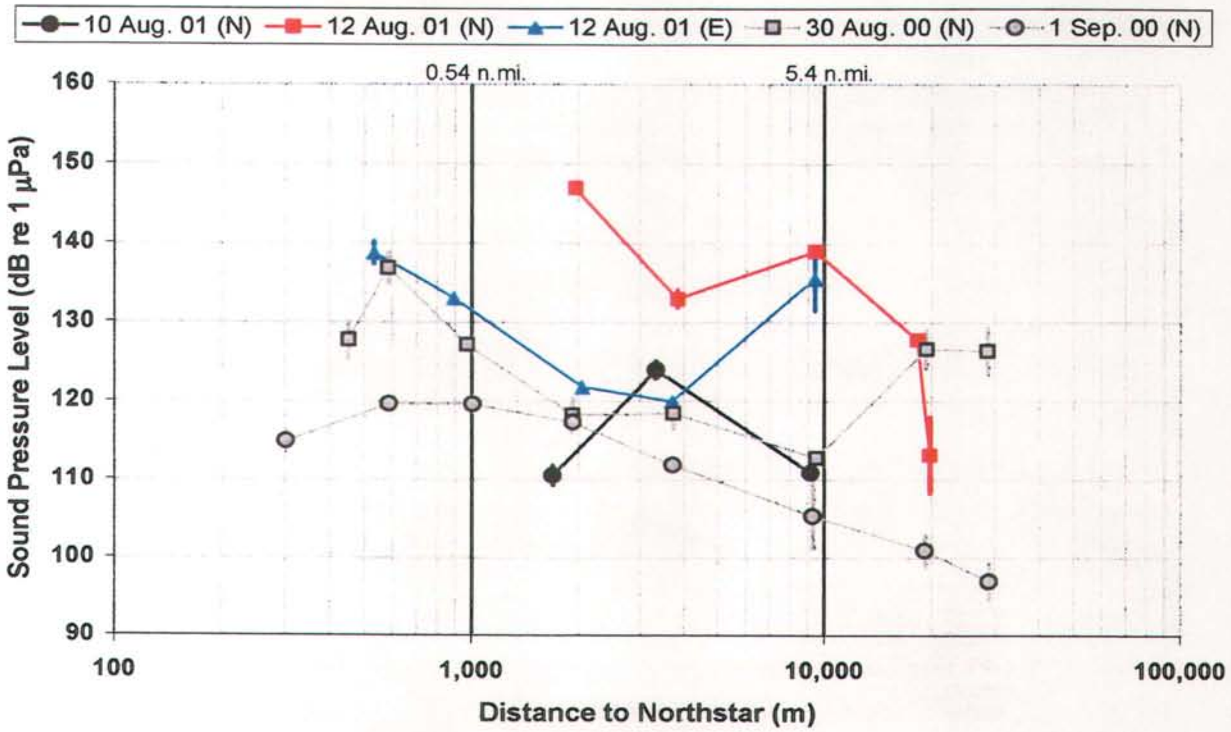


FIGURE 7.14. Broadband (10-10,000 Hz) levels of underwater sound as a function of distance from Northstar, for three sets of open water recordings north and east of the island, 10 and 12 Aug. 2001. Broadband values for similar measurements made on 30 Aug. and 1 Sept. 2000 are also shown for comparison. Symbols and vertical bars show mean values (± 1 s.d.). 10 km = 5.4 n.mi. or 6.2 mi.

In general, levels recorded during the three sets of measurements on 10-12 Aug. 2001 were quite variable and did not show steadily decreasing levels with increasing distance from Northstar. This was to be expected given the variable activities of vessels around the island.

Selected one-third octave band SPLs for the three sets of recordings in 2001 are shown in Figure 7.15. The high SPLs recorded north of Northstar on 12 Aug. (Fig. 7.15B) were mainly attributable to frequencies below about 55 Hz. These same frequencies were responsible for the heightened values 5 n.mi. east of Northstar on 12 Aug. (Fig. 7.15C).

***Airborne Sounds***.—A-weighted broadband SPLs are shown in Figure 7.16 for in-air measurements made on 10 and 12 Aug. north and east of Northstar. To allow comparison of the variability in airborne vs. underwater levels (*cf.* Fig. 7.14), the same range of received levels (70 dBA) is used on the y-axis. Measurements made on 1 Sept. 2000 are also shown for comparison. As for the underwater measurements, the highest values were obtained north of the island on 12 Aug. 2001, with maximum levels of 64 dBA re 20 μPa at both 3844 m and 9455 m from Northstar (2 and 5 n.mi. stations, respectively). However, in-air SPLs were not related to distance beyond about 1 km from Northstar, suggesting that Northstar activities did not contribute much airborne sound beyond that distance. The high values on 12 Aug. may have been artifacts of rain striking the recording vessel (see "Discussion").

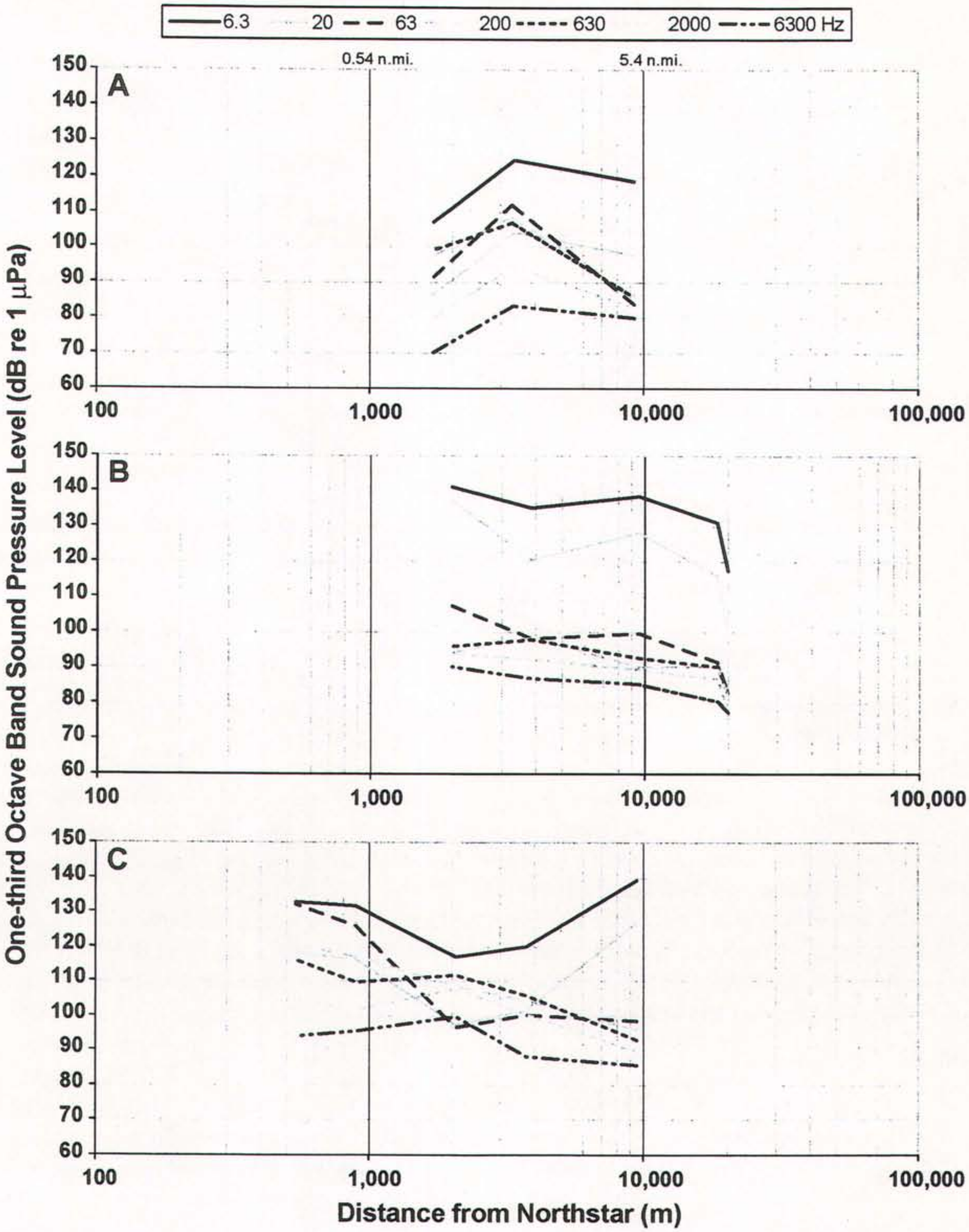


FIGURE 7.15. One-third octave band levels of underwater sound vs. distance for 7 selected frequencies and three sets of measurements north and east of Northstar Island, 10 and 12 Aug. 2001. ***(A)*** 10 Aug. (N). ***(B)*** 12 Aug. (N). ***(C)*** 12 Aug. (E). The frequency value indicated for each band corresponds to the center value for that band. 10 km = 5.4 n.mi. or 6.2 mi.

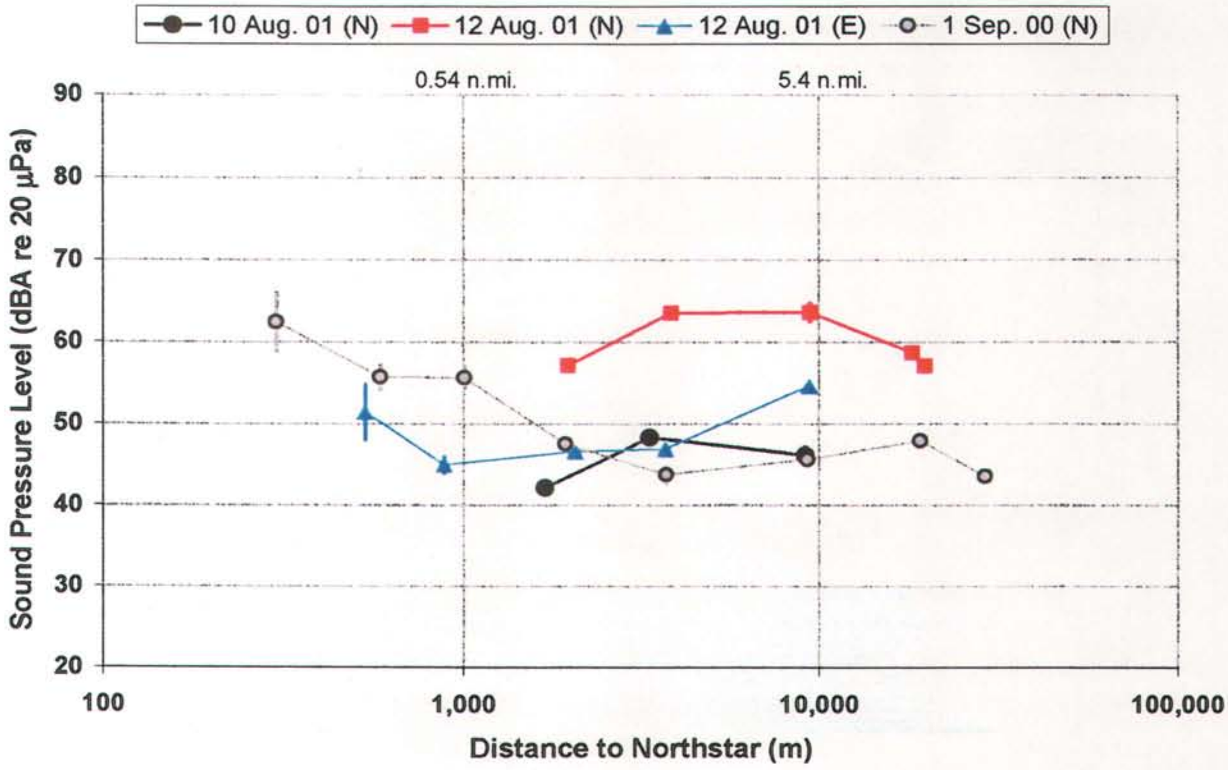


FIGURE 7.16. A-weighted broadband (20-10,000 Hz) levels of airborne sound as a function of distance from Northstar, for three sets of open water recordings north and east of the island, 10 and 12 Aug. 2001. Broadband values for similar measurements made on 1 Sept. 2000 are also shown for comparison. Symbols and vertical bars show mean values (± 1 s.d.). 10 km = 5.4 n.mi. or 6.2 mi.

***Summary***.—Recordings of overall sounds from the island and associated vessel activities were done at distances up to 11 n.mi. north and 5 n.mi. east of Northstar Island during 2001. Broadband underwater SPLs were comparable to data collected in 2000 in most cases; the highest recorded value was 147 dB re 1 μPa about 2 km (1.1 n.mi. or 1.2 mi) from Northstar, and was mainly attributable to frequencies below about 55 Hz. Broadband in-air data showed less variation than the underwater data. The highest recorded value was 64 dBA re 20 μPa at about 3850 and 9450 m from Northstar (2 and 5 n.mi. stations, respectively), but Northstar had little effect on in-air SPLs beyond about 1 km range.

### *CIDS*

***Underwater Sounds***.—At a mean distance of 82 m from the CIDS, broadband (10-10,000 Hz) underwater values on 10 Aug. 2001 were on average 127 dB re 1 μPa. These measurements were taken in the acoustic shadow of the CIDS in relation to the island and sealift barges, but it is impossible to determine what part of that sound pressure level can be attributed to the CIDS itself. At this time, the main activity on and near CIDS that might have produced sounds was operation of generators. None of the tugs, which were seen later readying the CIDS for departure, were present during these recordings. Three 8.5-s samples of sound recorded near CIDS were analyzed; all three contained the following tones: 54, 60, 74, 80, 1402 and 1472 Hz. However, only the tones at 54, 60 and 80 Hz decreased in level with increasing distance from CIDS; such a decrease is expected if CIDS was the source. The 54 Hz tone, however, was also present in all but one sample from the recordings of sealift arrival, making it more likely that it was produced by vessel activity.

Figure 7.17 shows 16 days of broadband (10-1000 Hz) SPLs as recorded by ASAR #2 (see Fig. 7.1 for location). That instrument was ~995 m SW of the CIDS location, and ~300 m from Northstar Island. The ASAR started collecting data just past midnight on 29 Aug., so earlier data are not available. Mean broadband SPLs dropped from 116 dB re 1 µPa (± s.d. 9 dB) for 29-31 Aug. to 100 dB re 1 µPa (± 9 dB) for 1-21 Sept. The large and gradual decrease late in the day on 31 Aug., visible in Fig. 7.17, corresponds to the time of the actual CIDS departure. Two of the Crowley sealift tugs were involved in towing CIDS, and a large Canadian tug served as an icebreaker and also departed the area at that time. When CIDS started to move away at 18:30 local time, broadband SPLs (as recorded by the ASAR) were about 136 dB re 1 µPa. At 20:00 they were 133 dB, at 22:18 they were 121 dB, and at midnight they were 109 dB re 1 µPa. The equivalent peak on 30 Aug, visible in Fig. 7.17, can probably be attributed to the Ocean-class tug *Navigator* escorting barges 400 and 411, as the trio left the Prudhoe Bay area on that day.

***Airborne Sounds***.—At a mean distance of 82 m from CIDS, A-weighted in-air broadband (20-10,000 Hz) levels were, on average, 49.3 dBA re 20 µPa on 10 Aug. 2001. That level is similar to levels of airborne sound recorded at varying distances from Northstar (*cf.* Fig. 7.16).

***Summary***.—CIDS was present about 1.1 km northeast of Northstar until 31 August. Generator sound from CIDS contributed to the sound environment near Northstar during August. Shortly before 31 August, tugs preparing for departure of CIDS also contributed sounds. A comparison of continuous data recorded by the near-island ASAR #2, before and after CIDS' departure on 31 Aug., shows that mean broadband SPLs dropped by 16 dB when CIDS departed. At least some of the high SPLs recorded before CIDS' departure were due to tugs.

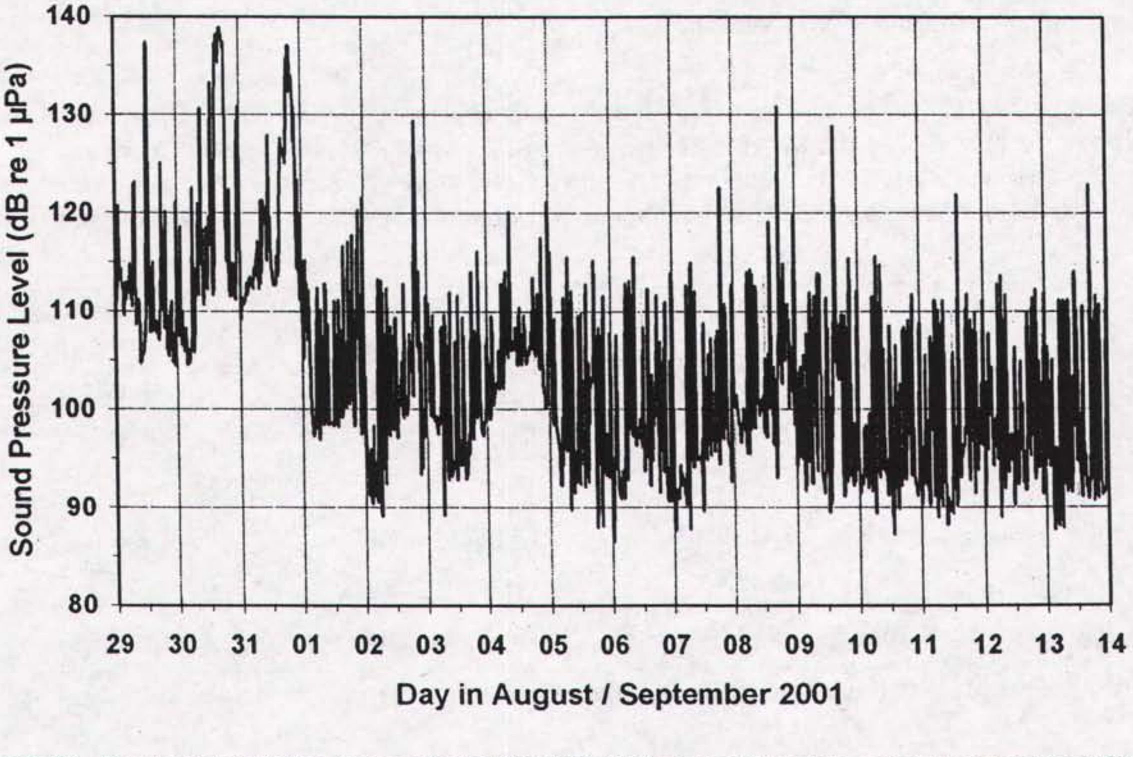


FIGURE 7.17. Temporal variation in broadband (10-1000 Hz) sound pressure levels received by ASAR #2 located about 300 m (984 feet) N of Northstar Island, during the days preceding and following the CIDS' departure on 31 Aug.

## *Near-Island ASAR Recordings*

### *Sealift Period*

ASAR #1A (see Fig. 7.1) recorded sounds from the island and the vessels servicing the island, including sealift, for nearly 23 days (00:13 on 31 July to 18:34 on 22 Aug.). The ASAR was located about 320 m N of the island, and the received sound levels pertain to that location. Broadband (10-1000 Hz) SPLs are shown for four different days in Figure 7.18: 5 Aug., which preceded the arrival of sealift; 10 Aug., the day sealift arrived at Northstar; 14 Aug., one of the most quiet days during the period sealift was in the area; and 19 Aug., one of the noisier days. Barge 420 was done offloading on 15 August and left the area the next day with the Ocean-class tug *Bulwark*. Barges 400 and 411 were done offloading by 23 Aug., but held up their departure due to ice conditions. They were anchored off the Seawater Treatment Plant (STP, on the coast 5.5 n.mi. SE of Northstar) until 30 Aug., when they left the area with the Ocean-class tug *Navigator*. The highest recorded broadband (10-1000 Hz) level (one-min average) at the ASAR #1A location was above 137 dB re 1 μPa, but could not be determined accurately because the recorder overloaded. This happened whenever vessels passed right over the ASAR; the origin of these high SPLs was therefore not the island itself but rather the boat traffic associated with it.

The minimum, 5th percentile, 50th percentile (median), 95th percentile, and maximum broadband (10-1000 Hz) values were computed from data collected by ASAR #1A between 31 July and 22 Aug. The following values were obtained: 94, 102, 111, 124 and 137 dB re 1 μPa, respectively (see Table 7.2 for a summary). Thus, half the time, the overall sound levels as recorded at the ASAR's location 320 m north of the island were at or below 111 dB re 1 μPa, and 95% of the time they were at or below 124 dB. These data represent the total of all underwater sounds present at the recording site, including sounds originating from the island, from sealift and other transportation activities, from any other human activities in the area, and from natural sources including wind, waves and ice.

TABLE 7.2. Minimum, 5th, 50th and 95th percentile, and maximum levels of underwater sound recorded near Northstar Island by ASAR #1A in August 2001 and ASAR #2 in September 2001. Values for both the 10-1000 Hz and 20-1000 Hz bands are shown, to allow comparison with 20-1000 Hz ambient data collected in 1998 by Burgess and Greene (1999) via ASAR. All levels are in dB re 1 μPa.

| | August 2001 (sealift and CIDS) | | September 2001 (no sealift, no CIDS) | | Ambient in 1998 |
|---|---|---|---|---|---|
| | 10-1000 Hz | 20-1000 Hz | 10-1000 Hz | 20-1000 Hz | 20-1000 Hz |
| Minimum | 93.5 | 93.5 | 70.5 | 70.1 | 68 |
| 5th percentile | 101.9 | 101.9 | 77.0 | 76.5 | 79 |
| 50th percentile | 110.5 | 110.4 | 100.8 | 100.8 | 99 |
| 95th percentile | 123.7 | 123.7 | 112.8 | 112.8 | 114 |
| Maximum | 137.1* | 137.1* | 130.9 | 130.9 | 132 |

*Overloaded signal due to a boat nearly overhead

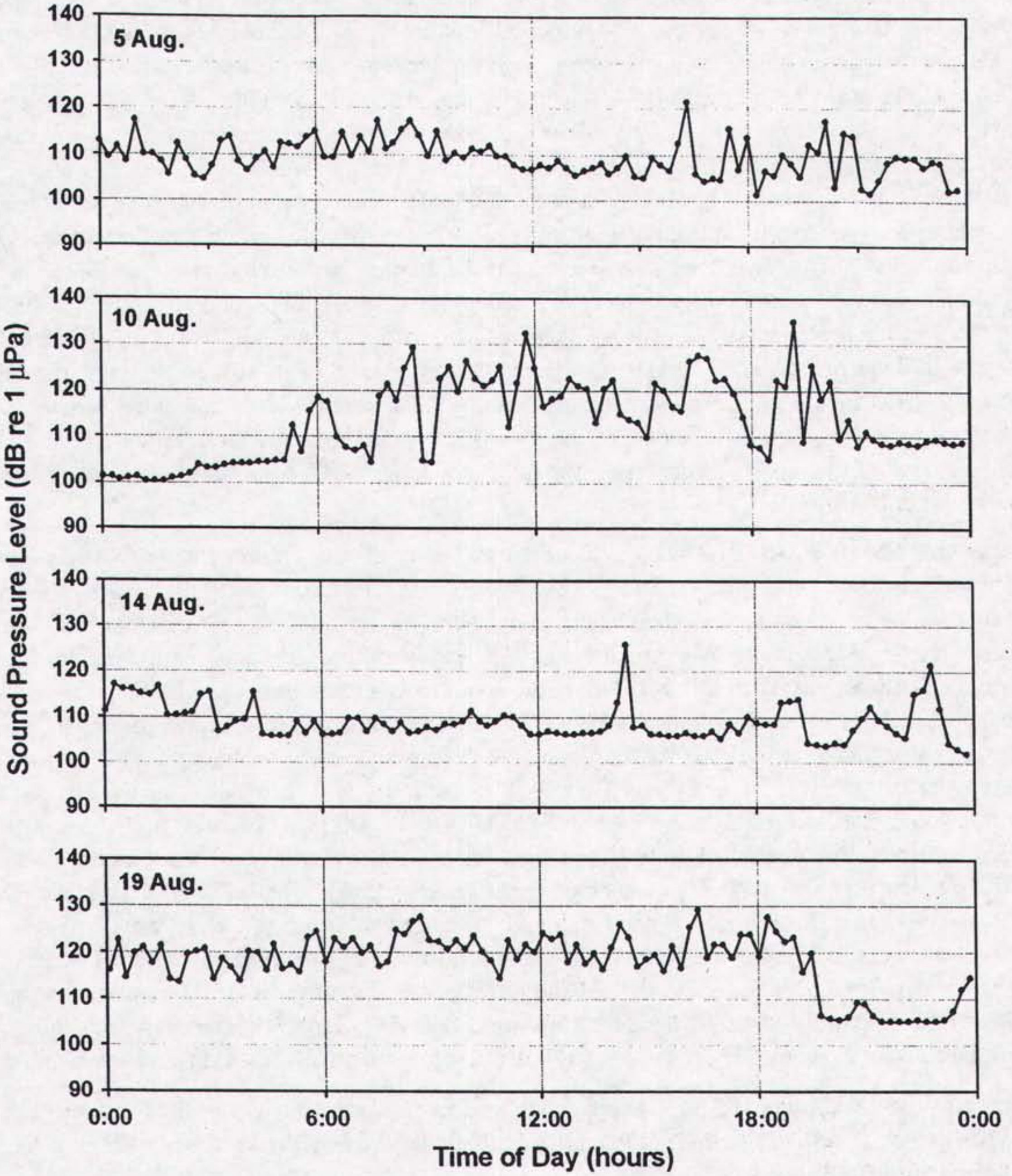


FIGURE 7.18. Temporal variation in broadband (10-1000 Hz) sound pressure levels received during August 2001 by ASAR #1A, located about 320 m (1050 feet) N of Northstar Island. Four different days are shown: *5 Aug.*, preceding arrival of sealift; *10 Aug.*, the day sealift arrived; *14 Aug.*, one of the quieter days while sealift was in the area; and *19 Aug.*, one of the noisier days. Each dot is a one-min average; there are 100 averages per day or one every 14 min 24 s.

Figure 7.19 presents "statistical" spectra showing the minimum, 5th percentile, median, 95th percentile and maximum levels by frequency over the 23-day period in late July and August while ASAR #1A was recording. Thus, the upper curve in each panel shows, for each frequency, the highest levels observed in all of the 2277 one-minute samples analyzed. The spectrum below the maximum shows the 95th percentile values in each individual frequency bin; 95% of the time the sound levels were at or below the plotted value for each frequency. The same reasoning is applied throughout the graph down to the lowest line, showing the lowest levels observed for each frequency in all of the 2277 one-minute samples. The presence of tones in these ordered spectra is significant, indicating the regular occurrence of certain tones and harmonic families from machinery. The tones tend to be more prominent when background levels are lower, e.g., they stand out more in the 5th than in the 95th percentile spectrum. Overall, the strongest components were generally in the 30 to 100 Hz range, but at times there was a prominent cluster of tones at 147-150 Hz. Received levels at frequencies below 30 Hz were generally low even though at least some of the tugs operating in the area during the August 2001 recording period emitted strong sounds at low frequencies (see above). The low received levels of components below 30 Hz at the ASAR #1A location 320 m N of Northstar is indicative of the rapid attenuation of low-frequency long-wavelength sounds in shallow water (depth 12 m = 39 ft at Northstar).

The data collected by ASAR #1A close to Northstar in August give us an opportunity for comparison with the open water recordings obtained on 10 and 12 Aug. 2001. Figure 7.20 shows 120 minutes of ASAR data recorded while the open water measurements were done north of Northstar on 12 Aug. For 1 minute of each 15 min (approx.) period, the ASAR sampled at 2 kHz, providing acoustic data for frequencies up to 1 kHz; the rest of the time it sampled at 1 kHz, providing acoustic data to 500 Hz (see "Methods"). ASAR results from both sampling regimes are plotted in Figure 7.20. The broadband levels received during the boat-based open-water recordings at various distances north of Northstar are also shown, at their respective sampling times, for the 10-1000 Hz and 20-1000 Hz bands. Note that the bandwidths for the open-water recordings in this Figure are narrower than shown in Fig. 7.14 (10-10,000 Hz). Because the ASAR was in shallow (12-13 m) water, frequencies below 10 Hz were cut off, and ASAR broadband values for the 10-1000 Hz band differed by only a fraction of a dB, on average, from broadband values for the 20-1000 Hz band. This phenomenon was also seen in the open water recordings made east of Northstar Island on 12 August in shallow water (water depth <12.2 m), but not in the recordings made northwards (water depth = 14.0-25.0 m). Therefore, ASAR data should be compared to the band levels that exclude the 10-20 Hz components (open circles in Fig. 7.20). These boat-based measurements were at widely variable distances from Northstar, complicating the comparison with ASAR data, but it is instructive to look at these levels in a relative manner:

- The boat-based recording at 1 n.mi. happened to be done while there was a peak of sound-producing activity on the island, as evident from the ASAR data; this resulted in the highest boat-based measurements of the transect.
- At 2 n.mi. the broadband levels from the boat-based recording were considerably lower – more so than expected simply on the basis of the doubling of distance. The ASAR data confirmed that sound levels near the island had decreased in the interim.
- At the 5 n.mi. station, the broadband levels increased by 5 dB, despite the island sound levels remaining much the same as those during the 2 n.mi. recording. This indicates that the recording at 5 n.mi. picked up a sound source that was absent or weak near the island recorder. This situation is not surprising considering the number of simultaneous activities taking place while the sealift vessels were in the Northstar area and, in particular, the number of sound-generating vessels performing tasks in a wide area around the island.

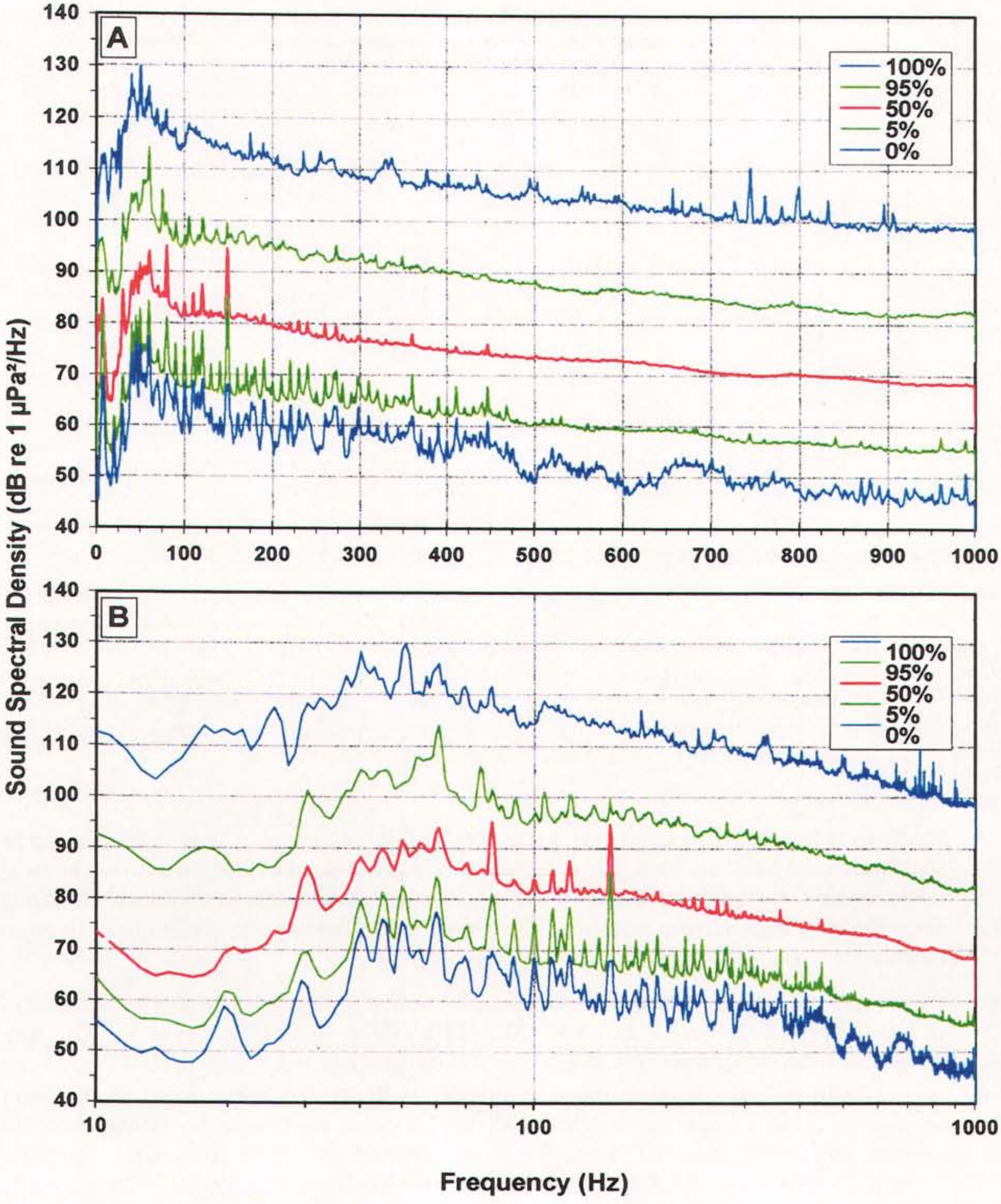


FIGURE 7.19. Percentile sound spectral densities for sounds recorded by near-island ASAR #1A, 31 July - 22 August. The same sound spectral densities are shown on both linear ***(A)*** and logarithmic ***(B)*** scales. The hydrophone was 320 m N of Northstar; sample size = 2277 measurements. Measured levels in each frequency bin were sorted independently to determine the minimum, 5th-percentile, 50th-percentile (median), 95th-percentile, and maximum level for that frequency.

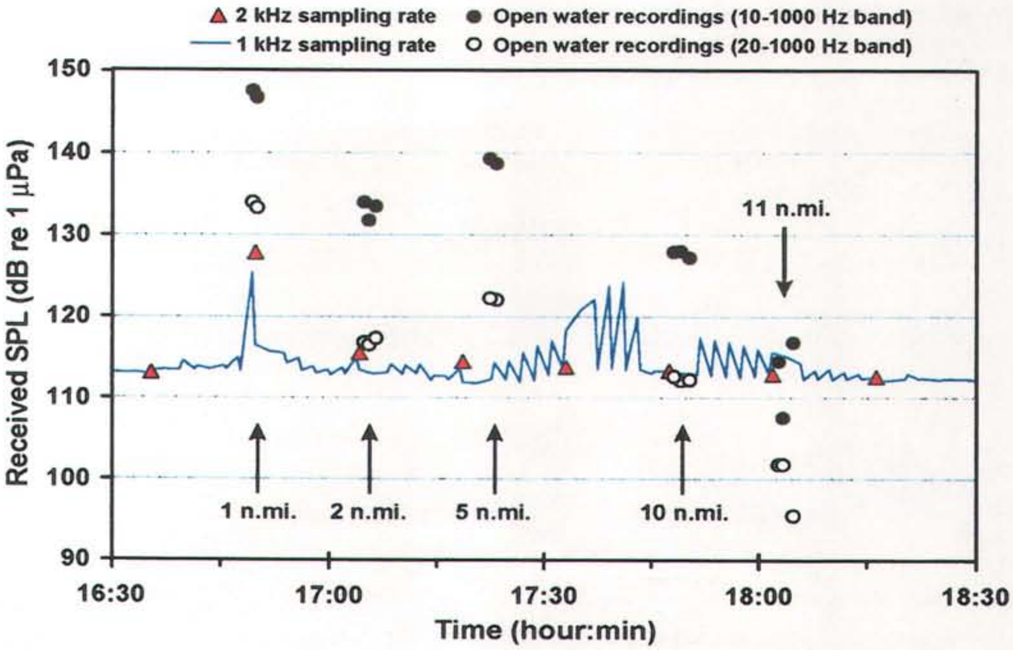


FIGURE 7.20. Broadband levels of underwater sound received near Northstar by ASAR #1A during two hours on 12 August 2001, while boat-based open water recordings were made north of the island at five different stations. ASAR #1A was located 320 m from the island. It provided acoustic data for the 10-500 Hz band when sampling at 1 kHz sampling rate (blue line) and for the 10-1000 Hz band when sampling at 2 kHz rate (red triangles). Broadband levels for the boat-based open water recordings are shown for the 10-1000 Hz band (filled circles) and the 20-1000 Hz band (open circles). These broadband levels are the levels at the recording stations, not at the island. Note that the bandwidths for the boat-based (and ASAR) recordings are narrower than for the boat-based data shown in Fig. 7.14.

- Received levels were notably lower at the 11 n.mi. than at the 10 n.mi. station. ASAR data show that levels near the island were similar at these two times, so the difference in received levels at 11 vs. 10 n.mi was apparently caused by something other than a change in the sounds emanating from the immediate vicinity of Northstar. The difference in recording conditions is likely to account for much of this difference (see "Discussion").

Two additional general patterns evident from Figure 7.20 are noteworthy: (1) There was only a small difference between the ASAR data for the 10-500 Hz and 10-1000 Hz bands (blue line vs. red triangles). This illustrates the small contribution of sounds in the 500-1000 Hz frequency range to the overall sound levels. (2) Broadband levels for the open-water recordings in the bandwidth 10-10,000 Hz were essentially identical to those for the bandwidth 10-1000 Hz, indicating that frequencies between 1 and 10 kHz contributed very little to the overall sound levels. In contrast, values in the bandwidth 20-1000 Hz were on average 15 dB lower (range 6-22 dB) than those in the bandwidth 10-1000 Hz. This difference was seen at all stations shown in Figure 7.20, including the very quiet 11 n.mi. station. This indicates that the source of the 10 to 20 Hz frequencies was not a self-noise, like waves slapping against the hull of the recording vessel. Other than the tugs (see Fig. 7.11), we do not know specifically what sound source generated these 10 to 20 Hz frequencies. Figure 7.19B shows that peak sound spectral density levels were around 50-60 Hz. This indicates that all lower frequencies were being attenuated in the shallow water, not only the ones below 20 Hz. This could help explain the fact that the broadband levels obtained during the boat-based open water measurements near Northstar were slightly higher than those recorded by the ASAR.

### *Post-Sealift Period*

ASAR #2, located about 300 m N of Northstar, recorded sounds at that site continuously from 29 August until its memory was filled on 21 Sept. Data collected by this instrument from 1 to 21 Sept., after the sealift and CIDS had departed, were used to characterize underwater sounds near Northstar in the absence of those activities (Table 7.2). Half the time, the island sounds as recorded at ASAR #2's location were at or below 101 dB re 1 µPa, and 95% of the time they were at or below 113 dB. These (and other) percentile values determined for September 2001 were lower than the corresponding percentile levels recorded during August 2001, and similar to ambient levels recorded in the general Prudhoe Bay area during 1998 (Table 7.2).

### *Summary*

A near-island ASAR located about 320 m (1050 ft) from the north shore of Northstar recorded island sounds continuously for nearly 23 days in August 2001. The data showed that it was common for there to be large fluctuations (spanning up to 25 dB) in broadband (10-1000 Hz) SPLs within short amounts of time (<0.5 hour). It also showed that the presence of sealift vessels led to the highest broadband levels recorded from Northstar Island during the summers 2000 and 2001, despite the fact that "quiet" and "noisy" days were present both before and after sealift's arrival. The highest recorded broadband value in August was above 137 dB re 1 µPa. Despite the multiple activities taking place during the sealift period, there was a reasonable correlation between island sounds as recorded by the near-island ASAR and (simultaneously) by boat-based hydrophones at varying distances from the island, for frequency bands above 20 Hz. Another ASAR, located about 300 m (1000 ft) north of the island, recorded continuously during September 2001, after both CIDS and sealift had departed. Broadband levels during that period were lower than those recorded during August and approached ambient values as recorded in the Prudhoe Bay area in 1998.

# DISCUSSION

## *Boat-based Recordings in Open Water*

### *Arrival of Sealift Barges*

***Underwater Sounds***.—Broadband levels recorded during the arrival of sealift, as a function of distance (Fig. 7.5), show a large amount of variation. Such variation is expected in this type of recording situation, when many sound sources were present at variable directions and distances, and were engaged in a variety of (changing) activities. The recording that was the least influenced by these complications, that of the arrival of barge 400 (filled red diamond symbols in Fig. 7.5; see also Fig. 7.4), yields a reasonable fit to a logarithmic sound propagation model (*r* value of -0.98). The spreading loss term of 14.8 dB/tenfold change in distance is reasonable for this shallow-water situation. (The recordings were made E of Northstar where water depth remains fairly constant over the range of distances considered.) The loss-rate is very similar to the value obtained from open-water recordings made north of Northstar on 1 Sept. 2000 (14.4 dB/tenfold change in distance), when self-propelled barges were present at the island.

The one-third octave band levels for the arrival of barge 400 (Fig. 7.6) show lower levels for the band centered at 20 Hz as compared to bands centered at lower or higher frequencies (e.g., 6.3, 63 or 200 Hz). This phenomenon is actually seen in most of the underwater sound results presented in this chapter. The modal cutoff frequency is around 50 Hz for the shallow waters near Northstar (see Fig. 7.19B), and sound components at frequencies below 50 Hz are received at lower levels than components at higher frequencies, other attributes being equal (especially the source energy in the various one-third octave bands). The higher received levels at very low frequencies (like 6.3 Hz) result from the sound at those frequencies propagating primarily in the sea bottom. Wavelengths for the very low frequencies (238 m for 6.3 Hz) are so long, compared to the water depth (12 m), that they do not propagate in the shallow fluid layer (the water) overlying the thick bottom. Instead, the energy at very low frequencies travels almost entirely as "ground waves" in the bottom, where the sound speed is greater than in the water layer above. Officer (1958) explains these phenomena both mathematically and physically in his chapter "Transmission in Shallow Water".

***Airborne Sounds*.**—In-air broadband sound pressure levels during the arrival of sealift (Fig. 7.7), like underwater levels, were quite variable. The effect of varying activity apparently overrides the effect of distance for most of these recordings; an exception is the recording of barge 400's arrival. When a logarithmic propagation model was fitted to those data, a spreading loss term of 6.4 dB/tenfold change in distance was found. This loss-rate is lower than expected, and was probably the result of contamination, especially at the longer ranges, by local noise (wave slap). The lowest broadband values from these recordings, obtained about 3.5 km from the sound source, were 49 dBA re 20 µPa, and may still be above background levels. The field crew could still hear barge 400 and its tugs 3.5 km away, at the farthest recording station. Measurements at the same distance from Northstar the previous summer, but north of the island (instead of east), yielded A-weighted broadband levels that were about 7 dBA lower (Blackwell and Greene 2001).

The one-third octave SPLs during arrival of barge 400 were quite variable and showed only a slight dependence on distance from barge 400 (Fig. 7.8). The reason for this is not known with certainty, but is again most likely a result of variability in ambient noise (e.g., wave slap).

### *Tug Activities*

***Underwater Sounds*.**—The variation in broadband SPLs recorded near operating tugs (Fig. 7.9) is a result of variation in tug activities, in the number of active sound sources from one minute to the next, and in the type(s) of tugs that were active. All of these factors were unpredictable in time and space. Despite this, the results obtained while tugs were performing various activities around the barges (Fig. 7.9) are in general agreement with those obtained during the arrival of sealift when the tugs were towing the barges. (The regression line in Figure 7.9 is the logarithmic fit to the sound levels measured during the arrival of barge 400.) Not surprisingly, a working Ocean-class tug produces a stronger sound than a smaller River-class tug. The difference was about 8 dB as measured at 250 m distance (solid black circles and triangles in Fig. 7.9). At a distance of 400-600 m, the broadband levels from holding a barge at the dock were higher than those produced while maneuvering a barge. This can be explained by the fact that, while holding a barge, the tugs usually pushed hard and constantly for minutes at a time, with no forward speed. While maneuvering a barge they alternated instead between a few seconds of hard pushing or pulling, followed by gently assisting the barge in its movements.

In the comparison of one-third octave band levels before and during offloading of the compressor module, the band centered at 63 Hz was the strongest during the offloading process but not before (Fig. 7.10). The island's electric power generators could account for a 60-Hz tone in the band centered at 63 Hz. However, the Scheuerle module transporter is diesel powered, and it is not clear why the offloading process would cause elevation of levels specifically in the band centered at 63 Hz.

In addition to revealing different signature tones from two types of tugs, the spectra depicted in Figure 7.11 show the "high pass filter" effect of shallow water on low frequencies. In other words, there is a sharp decline in the received levels of frequencies below about ~50 Hz because those frequencies transmit poorly in shallow water.

***Airborne Sounds***.—The highest A-weighted broadband SPL recorded during tug activities, 86 dBA re 20 µPa (60 m from a barge being held at the dock, Fig. 7.12), is analogous to the sound of a heavy truck driving by at 64 km/h at 15 m (40 mph at 50 feet; Kinsler et al. 1982). Similarly, the lowest SPL recorded, 44 dBA re 20 µPa (900 m from a barge being held at the dock), is comparable to the sound levels in a quiet neighborhood during the daytime (Kinsler et al. 1982). Broadband levels in air (Fig. 7.12) during tug activities did not relate well to the corresponding levels recorded underwater (Fig. 7.9). In-air measurements are more prone to being influenced by recording conditions, which were most often chosen to satisfy the requirements of the underwater recordings and safety procedures. For example, recording sites were sometimes upwind and sometimes downwind of the sound source; this would have no effect on the underwater measurements but could have a substantial effect on the levels received in air. (In general, less sound is received near the surface in the upwind than in the downwind direction – section 4.6 *in* Richardson et al. 1995). Also, the tugs could be on either side of the barges, which were huge above the waterline and could completely hide a tug. Obstruction of the propagation path by an intervening barge probably influenced the in-air recordings more than the underwater recordings.

### *Overall Island Sounds*

***Underwater Sounds***.—Broadband SPLs, as recorded up to 11 n.mi. from Northstar during sealift activities in 2001, were more variable and somewhat higher than those recorded at similar distances from Northstar during the summer of 2000. Several of the measurements on 12 Aug. 2001 were noticeably higher than the values recorded the previous year (Fig. 7.14). The wind and sea state were the same on 10 and 12 Aug., so they cannot account for the differences in received levels between the two sets of northern measurements in 2001(4). It was raining on 12 Aug. and rain adds "white noise" to background levels (from the bubbles collapsing at the surface). However, this effect is not large enough to account for the difference in broadband levels seen in Fig. 7.14 for 10 vs. 12 Aug. 2001. Heightened SPLs for frequencies below ~55 Hz were chiefly responsible for the high broadband values at some 12 Aug. stations (see Fig. 7.15). Also, sound components in the 10-20 Hz band contributed 6 to 22 dB to the overall broadband levels. It is not known what specific sound source produced these frequencies, but tugs are likely an important contributor. Given the rotation rates of their propellers and the number of propeller blades, strong components are expected at 17.5, 31.1 and 38.8 Hz (see "Tug Activities" in "Results").

ASAR #1A, located ~320 m N of Northstar, provided data on broadband sound levels from the island and nearby sources (Fig. 7.18). These data show that, within a few minutes, SPLs could vary by 25 dB, which is more than the full range of received levels obtained for at least two of the three recording series (10 Aug. N and 12 Aug. E). In these recordings, time is therefore at least as important a factor as distance from the sound source in predicting sound levels.

***Airborne Sounds***.—A comparison of the microphone and hydrophone broadband data (Fig. 7.16 vs. 7.14) shows that the microphone data are less variable. Beyond ~1 km range, there is no distance effect on the sound pressure levels recorded, suggesting that levels at the longer ranges represent something other than industrial sounds from Northstar. Raindrops hitting the aluminum recording vessel were very audible on the recordings of 12 Aug. and could have contributed to the heightened values from the northern recordings and the 5 n.mi. eastern recording on 12 Aug.

---

(4) Weather conditions during the 2000 measurements were as follows: 30 Aug., sea state 3-4 and 17-23 mph wind; 1 Sept., sea state 1 and 6 mph wind.

### *CIDS*

Acoustic measurements made near CIDS while it was idle in the Beaufort Sea (Hall and Francine 1991) showed the structure to be comparatively quiet. Recordings made during the open water season near Northstar Island in 2001 provided another opportunity to assess sounds from this structure. The boat-based measurements were useful for identifying tones, but not for quantifying the actual sound levels contributed by CIDS to the overall sound environment near Northstar. The data recorded by a near-island ASAR (Fig. 7.17) indicate that broadband SPLs were on average 16 dB higher when CIDS was present as compared to after it left. Broadband levels during the days preceding CIDS' departure were probably mainly attributable to the preparations then underway to ready the structure for towing, including the presence of two small tugs and one large ice-breaking tug that would normally not be present near CIDS. In addition, two of the sealift barges (400 and 411) left the area on 30 Aug. with an Ocean-class tug and contributed to the overall sound levels. The spike seen in Fig. 7.17 in mid-afternoon on 30 Aug. is due to this departure. Unfortunately, we only have 2-3 days of ASAR data before CIDS left, because ASAR #2 did not start recording until the early morning of 29 Aug.

## *Near-Island ASAR Recordings*

Both before the arrival of sealift and during the time the three barges were near the island and offloading, there were days with "high" and "low" average broadband levels. In that respect, sealift was not revealed as a constant and predictable source of higher sound levels than are recorded routinely near the Northstar Development at Seal Island. However, the highest broadband levels recorded during the summers of 2000 and 2001 were obtained while sealift was in the area – see "Overall Island Sounds" above. In September 2001, ASAR recordings revealed the Northstar area to be much quieter than it had been during August.

Figure 7.19 shows how the tonal structure of sounds in the water near Northstar during August 2001 changed with the intensity of the sound-making activity. The strong cluster of tones at 147-150 Hz was from an unknown source, but it was associated with times of median and low sound levels. It was also at times with low sound levels that tones at 20, 30, 40 and 50 Hz (and so on) were evident. The "low-frequency cut-off" for frequencies below ~50 Hz is also visible on Fig. 7.19B and is due to filtering by the shallow water.

## *Sound Field Around Northstar*

Estimated distances at which sounds from a specific source reach background levels vary with the variable source levels of the sound in question, and with the ambient noise levels. The latter depend on sea state and wind. Estimated distances at which Northstar sounds reach background levels are presented in Figure 7.21 for two contrasting situations: *(A)* A period in August that included sealift and preceded the departure of CIDS; and *(B)* a period in September after both CIDS and sealift had departed. Figure 7.22 shows some of the September estimates in map format.

- Natural ambient noise levels near Northstar, as measured by Burgess and Greene (1999), are shown in Figure 7.21 as horizontal dashed lines. Ambient levels cannot be determined from the present 2001 data because these data often included industrial sounds. Burgess and Greene (1999) measured broadband (20-1000 Hz) ambient noise levels in the Prudhoe Bay area and found the following 5th, 50th, and 95th percentile values: 79, 99 and 114 dB re 1 μPa, respectively. We show the 5th percentile value as 77 dB rather than 79 dB because the 5th percentile broadband level as measured by ASAR #2 during September 2001 was 77 dB re 1 μPa. This is not a true "ambient" noise level because it was recorded near Northstar. However, the true 5th percentile ambient noise level for the Northstar area during September 2001 must have been no higher than 77 dB.

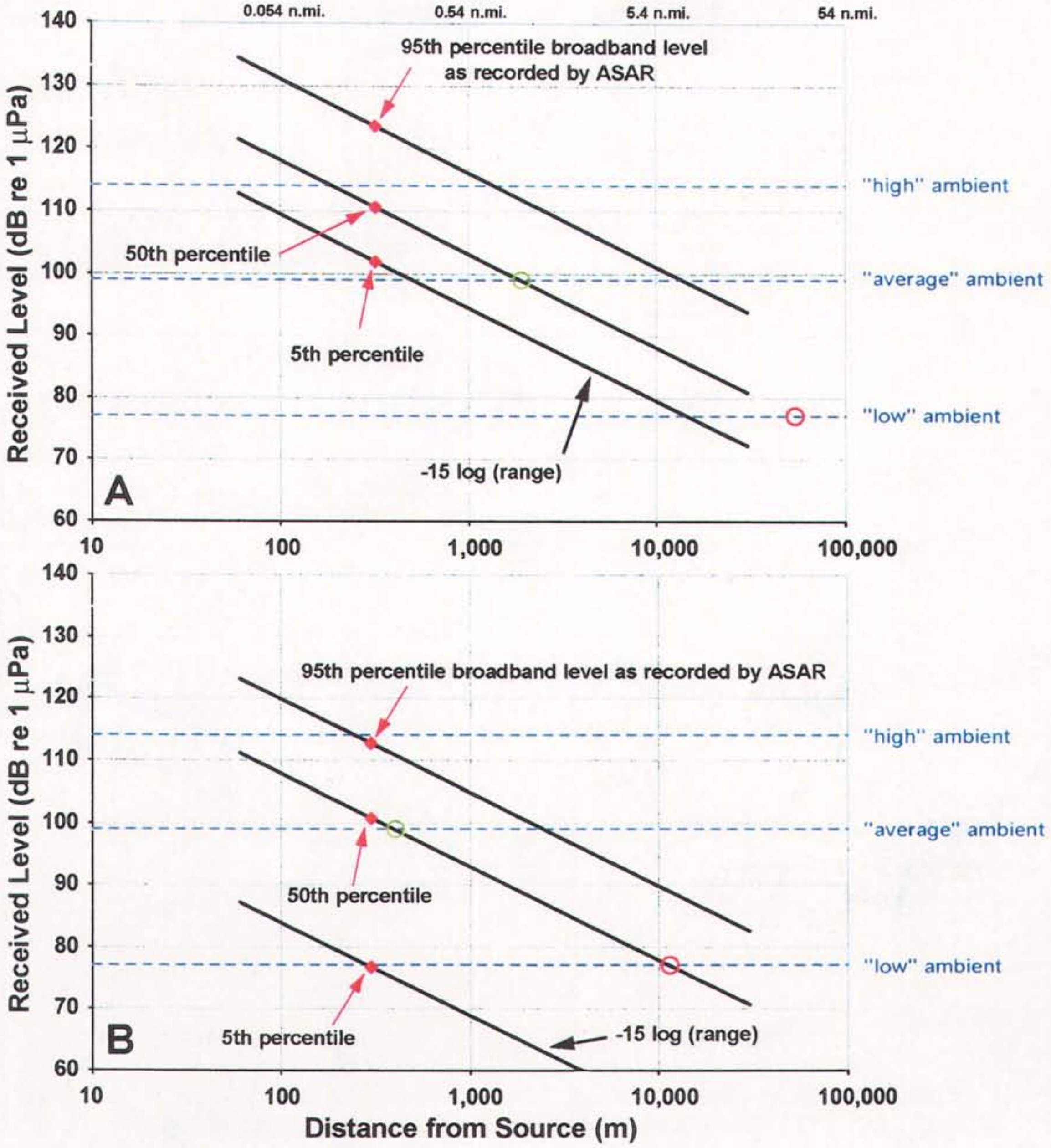


FIGURE 7.21. Audibility range of Northstar sounds as recorded in ***(A)*** August 2001 and ***(B)*** September 2001. Horizontal dashed lines represent "low", "average" and "high" ambient sound levels (5th, 50th and 95th percentile values; see text). Red ♦ symbols show 5th, 50th and 95th percentiles of 20-1000 Hz broadband island sounds as recorded 320 m N of the island in August, and 299 m N of the island in September. Sloping lines show estimated levels of island sounds at other distances, assuming a spreading loss rate of 15 log (R), as documented by 2000 and 2001 open-water measurements. Gray portions of sloping lines are extrapolated beyond the range of 2000-2001 measurements. Intersections of sloping Northstar-sound lines with horizontal ambient noise lines show approximate maximum distances at which Northstar sounds would be audible underwater with various combinations of industrial and ambient levels. Distances corresponding to green and red circles are those where median Northstar sound would diminish below, respectively, the median and 5th percentile ambient noise; see corresponding circles on Figure 7.22.

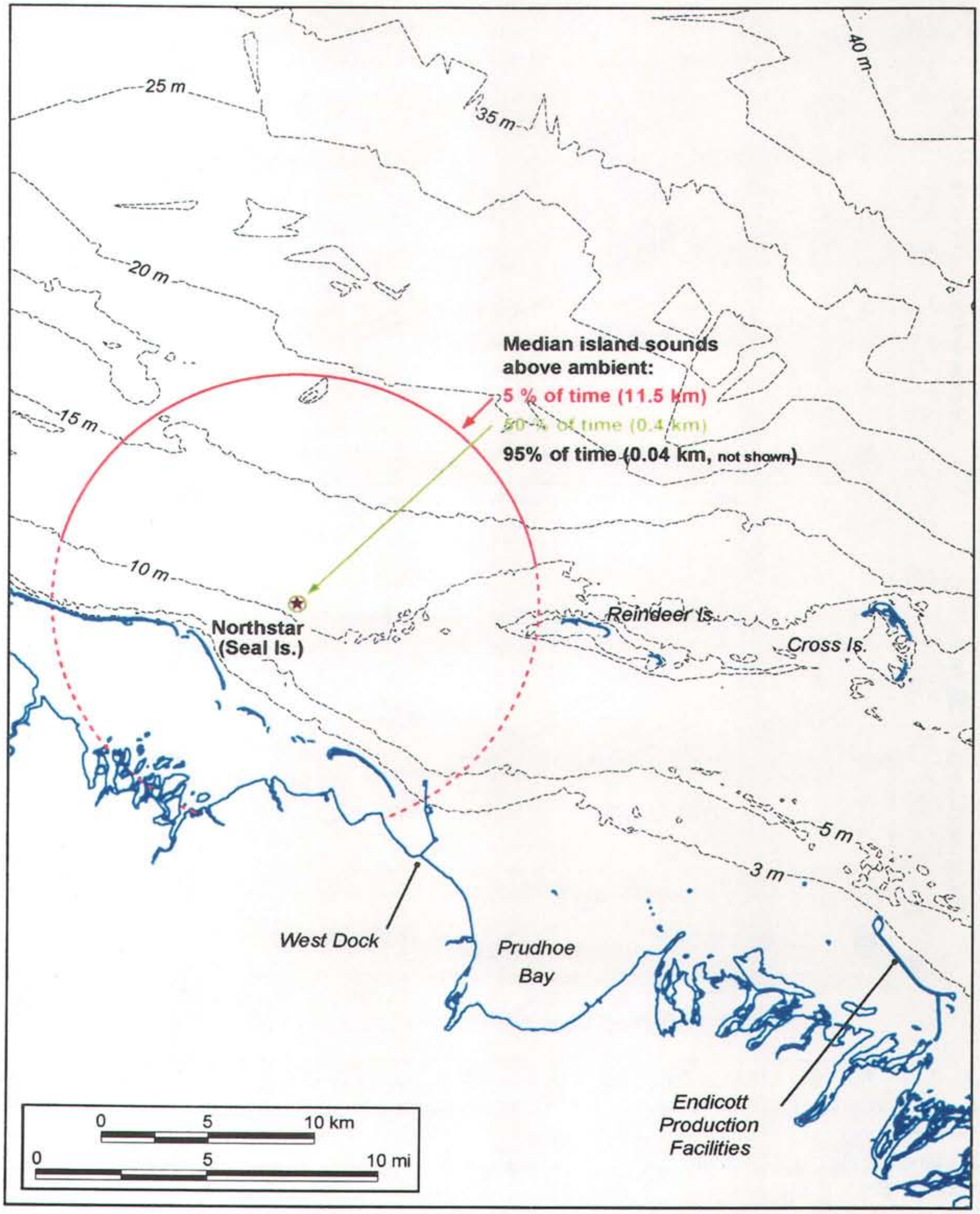


FIGURE 7.22. Distances from Northstar at which typical island sounds, as measured in September 2001, would be detectable 5% of the time (red circle, radius 11.5 km or 6.2 n.mi.), 50% of the time (green circle, 392 m or 1290 ft), and 95% of the time (40 m or 130 ft). These distances are those where the middle of the three sloped lines shown in Figure 7.21B (50th percentile island sound) descends below the three ambient noise lines shown in that Figure. Data from September are shown in this Figure, as opposed to data from August, for reasons explained on page 7-35 (facing).

- The 5th, 50th and 95th percentile Northstar sounds at various distances are shown by the sloped lines in Figure 7.21. The values recorded 321 m N of the island from 31 July to 22 Aug. 2001 (ASAR #1A) are plotted on Figure 7.21A at the "R = 321 m" location. These values are for the 20-1000 Hz band, consistent with the ambient noise data of Burgess and Greene (1999). Corresponding levels recorded 299 m N of the island from 1 to 21 Sept. 2001 (ASAR #2) are plotted on Figure 7.21B at the "R = 299 m" locations. Approximate levels that would prevail at other distances are shown by the "15 log (R)" spreading-loss curves plotted through those three percentile values. This 15 log (R) rate was obtained from the recording of the arrival of barge 400. However, it closely matches results obtained during open water measurements in 2000 when barges were present at Northstar: 18.3 log (R) on 30 Aug. and 14.4 log (R) on 1 Sept.
- At times with median levels of island sounds as reported in August (i.e., 110 dB re 1 μPa at distance ~320 m), those sounds are expected to diminish below the median ambient level (99 dB) at a distance of about 1830 m (~6000 ft) from the island. These median-level island sounds would theoretically diminish below the 5th percentile ambient level (77 dB) at a distance of over 50 km (27 n.mi. or 31 mi) from the island, assuming that simple 15 log (R) propagation loss applies to that long range (it often does not). These two cases are shown by the green and red circles (respectively) in Figure 7.21A. It should be noted, however, that the 50 km estimate (for island sounds in August) requires extrapolation far beyond the range of distances within which the measurements were made. At such long distances, additional effects not included in the simple 15 log (R) calculation are expected to reduce the estimated range where the received level would diminish below the 5% ambient, i.e., the 50 km figure is probably an overestimate.
- Corresponding results for September, when island sounds were weaker, are shown in Figure 7.21B. Median levels of island sounds reached median ambient levels at a distance of 392 m (~1290 feet) and reached the 5th percentile ambient level by about 11.5 km (6.2 n.mi. or 7.1 mi). These two cases are also shown with green and red circles, respectively, in Figure 7.21B.

  Figure 7.22 is an alternative way of showing some of the same information. Data from September are shown in this Figure, as opposed to data from August, for two reasons: (1) the bowhead whale migration and hunt take place primarily in September; and (2) sealift, which took place during much of August in 2001, was an exceptional activity. Therefore, the sound levels documented during September 2001 (but not those documented during August 2001) are representative of conditions during the 2001 bowhead migration and hunt. The estimated distances at which median levels of island sounds during September 2001 reached background levels are shown as circles. As indicated, when ambient noise levels are low (e.g., 5th percentile), island sounds are audible farther away from the source than would occur with median or high levels of ambient noise (Fig. 7.22).
- At times with higher (e.g., 95th percentile) levels of island sound, the distances at which those sounds would diminish below various possible levels of ambient noise are correspondingly higher (Fig. 7.21A,B).
- At times when island sound was weak (e.g., 5th percentile), that sound would be below ambient beyond ~14.5 km (7.8 n.mi. or 9.0 mi) in August and beyond ~275 m (900 feet) in September, even at times with relatively low ambient noise. Corresponding distances would be much less at times with average or (especially) high ambient noise (Fig. 7.21).

If the true 5th percentile ambient was slightly less than the 77 dB re 1 µPa derived from the 2001 ASAR data, then the distances at which received levels of island sounds diminish below the ambient level under "low" ambient conditions would slightly exceed those shown in Figure 7.21 and 7.22.

As described earlier in relation to Figure 7.20, there was evidence that the ASARs underestimated low-frequency components of island-associated sounds. Frequencies below 30-50 Hz do not propagate well in shallow water (Officer 1958) and are therefore absent or underrepresented at the ASAR locations. During the boat-based measurements north of Northstar Island on 10 Aug., recordings obtained at the deepest of the three stations (5 n.mi.) included the lower frequencies. The difference in broadband levels (between the 10-10,000 and 20-10,000 Hz bands) was 9-11 dB. On 12 Aug. similar recordings were made but this time the lower frequency components were detected at all five stations, with a difference between the two frequency bands of 6-22 dB. August 12 had the highest broadband levels of all recording days in the summers of 2000 and 2001 (see Fig. 7.14) and unusual tug activity.

If the ASARs underestimated broadband levels by 15 dB in August while there was much tug activity, then the range of detectability for typical (median) island sounds would increase from 0.18 to 1.84 km for conditions of high ambient noise and from 1.8 to 18.4 km for conditions of median ambient noise. For conditions of low ambient noise, the range of detectability would extend well beyond the distance range of our measurements.

Similarly, if the ASARs underestimated broadband levels by 10 dB in September (which was a quieter month with less tug and boat traffic), then the range of detectability for typical island sounds would increase:

- from 0.04 to 0.18 km for conditions of high ambient noise,
- from 0.4 to 1.8 km with median ambient noise ("50 % of time" circle in Fig. 7.22), and
- from 11.5 km to well beyond our furthest measurement distance (11 n.mi. = 20.4 km = 12.7 mi) with low ambient noise ("5 % of time" in Fig. 7.22).

However, the difference in broadband levels (10-10,000 vs. 20-10,000 Hz bands) during boat-based open water recordings on 17 Sept. 2000 was on average only 0.6 dB (range 0-2.6 dB) for locations up to 10 n.mi. from Northstar. On 17 Sept. 2000, there was little boat traffic and no self-propelled barge at the island. This suggests that boat traffic, tugs in particular, may be the main contributor to frequencies below 50 Hz. Therefore, in conditions of low boat traffic as experienced at times in September of both 2000 and 2001, the detectability ranges presented in Figures 7.21B and 7.22 are probably valid.

Another complication is that "island sounds" as discussed here include sounds both from the island and from the boats that occurred around the island during September 2001. Even though these sources are difficult to separate, it is evident from both the fieldwork (i.e., the field crew listening to the recordings on headphones) and the data analysis that the boats are a major source of sound in the Northstar area. In future open-water seasons, there will be less boat traffic to Northstar Island than occurred during the sealift period in August 2001. Results from September 2001 are more representative of those expected in the future.

## SUMMARY

Greeneridge Sciences Inc. measured underwater and airborne sounds during the arrival and off-loading of sealift barges in August 2001. In addition, near-island Autonomous Seafloor Acoustic Recorders (ASARs), placed ~320 and 300 m (~1050 and 985 feet) from the north shore of Northstar, recorded underwater island sounds continuously for 23 days in August and 25 days in September.

## *Boat-based Recordings in Open Water*

Boat-based recordings were made during three days in August 2001 to help characterize sound levels underwater and in air during the arrival and offloading of three sealift barges at Northstar. Four types of sound measurements were made: (1) the arrival of the barge train, (2) tug sounds as they maneuvered barges at the Northstar dock, (3) overall island sounds from nominal distances up to 20 km (11 n.mi.) from Northstar, and (4) sounds produced by the Concrete Island Drilling Structure (CIDS).

### *Arrival of Sealift Barges*

A logarithmic sound propagation model was fitted to both the underwater and in-air data from the best recording of the arrival of sealift at Northstar on 10 Aug. 2001. The spreading loss term obtained for the underwater data, 14.8 dB/tenfold change in distance, is reasonable for this situation in shallow water and also agrees with the values obtained from open water recordings made north of Northstar on 30 Aug. and 1 Sept. 2000. The highest broadband levels recorded from the tugs and barges were 135-136 dB re 1 µPa and were encountered 357 m and 1450 m (1170 and 4760 ft) from the source. Higher levels might occur at times at closer distances. For the airborne sound, the apparent spreading loss term was 6.4 dBA/tenfold change in distance. That rate is lower than expected and probably indicative of a substantial contribution (at least at the longer distances) by non-industrial sound. The highest recorded levels were 56 dBA re 20 µPa at a location 328 m (1076 ft) from a tug.

### *Tug Activities*

Underwater sound levels produced by working tugs were variable, depending on the tugs' activities, but comparable to those during arrival of the barge train (sealift). The highest underwater SPL recorded was 145 dB re 1 µPa at a location 116 m (381 ft) from a tug that was forcing a barge against the dock. Low-frequency tones corresponding to the propeller blade rates of the different types of tugs were recorded. In-air broadband data showed more variation than the underwater data; the maximum A-weighted broadband SPL was 86 dBA re 20 µPa, 60 m (200 ft) from a tug holding a barge against the dock. Underwater broadband levels while the compressor module was being offloaded with a Scheuerle module transporter showed that the tugs are the main sound component underwater and the offloading procedure itself contributes only a small increment of underwater sound over and above the tug sound.

### *Overall Island Sounds*

Recordings of overall sounds from the island and associated vessel activities were done at distances up to 11 n.mi. (20 km) north and 5 n.mi. (9 km) east of Northstar Island. On a broadband basis, both underwater and airborne sound pressure levels (SPLs) were more variable in August 2001 than at similar distances and locations during the summer of 2000. These differences cannot be explained by sea state or wind. For the underwater data these higher SPLs were mainly a result of strong components at frequencies below about 55 Hz. Continuous near-island recordings by an ASAR (see below) showed that changes in SPLs on the order of 25 dB were not uncommon within a few minutes. These temporal variations could account for much of the variability in SPLs that cannot be attributed to changes in distance from the sound source. The broadband microphone data showed no distance effect on the SPLs at distances beyond about 1 km (3280 ft).

### *CIDS*

CIDS was present about 1.1 km (3600 ft) northeast of Northstar until 31 August. Generator sound from CIDS contributed to the sound environment near Northstar during August, and shortly before 31 August tugs preparing for departure of CIDS also contributed sounds. A comparison of continuous data recorded by a near-island ASAR, before and after CIDS' departure on 31 Aug., shows that broadband SPLs dropped by an average of 16 dB at that time. Two sealift barges left on 30 Aug. and therefore contributed to these broadband SPLs.

## *Near-island ASAR Recordings*

A near-island ASAR located about 320 m (1050 ft) from the north shore of Northstar recorded island sounds continuously for nearly 23 days in August 2001. The data showed that it was common for there to be large fluctuations (spanning up to 25 dB) in broadband (10-1000 Hz) SPLs within short amounts of time (<0.5 hour). It also showed that the presence of sealift vessels led to the highest broadband levels recorded from Northstar Island during the summers 2000 and 2001, despite the fact that "quiet" and "noisy" days were present both before and after sealift's arrival. The highest recorded broadband value in August was above 137 dB re 1 μPa. There was a reasonable correlation between island sounds as recorded by the near-island ASAR and simultaneously by boat-based hydrophones at varying distances from the island, provided comparisons were limited to broadband frequencies above 20 Hz. The ASARs' locations in shallow water resulted in a cut-off of lower frequencies (below 30-50 Hz). Therefore, when such frequencies were present, the ASARs tended to underestimate island sounds by 10-15 dB. Another ASAR, located about 300 m (1000 ft) north of the island, recorded continuously during September 2001, after both CIDS and sealift had departed. Broadband levels during that period were lower than those recorded during August and approached ambient values as recorded in the Prudhoe Bay area in 1998.

Based on the measured levels close to Northstar and a spreading loss rate of 15 dB/tenfold change in distance, we estimate that typical island-associated sounds (i.e. 50th percentile level) as present in August 2001 would diminish to background levels at distances <0.5 km (0.3 mi) at times with high levels of natural ambient noise, ~1.9 km (1.0 n.mi. or 1.2 mi) with moderate ambient noise, and tens of kilometers at times with little natural noise. The high-ambient and moderate-ambient distances could be as high as 2 km and 19 km (1.2 and 12 mi) in conditions when the low-frequency components propagate out to sea. In September 2001, after both CIDS and sealift had departed, typical island-associated sounds diminished to background levels at distances ranging from <1 km (0.6 mi) at times with moderate and high levels of natural background sounds to ~11.5 km (6.2 n.mi. or 7.1 mi) at times with little natural noise. For both of these months, these distances would be reduced at times when the industrial sounds were less than average, and increased at times with stronger-than-average industrial sounds.

Boats were identified as a major source of sound in the Northstar area. Their contribution to overall sound levels is examined in more detail in Chapter 8.

## ACKNOWLEDGEMENTS

We thank Jim Nevels, Barron Rutherford, Eric Olsen, Walter Henry, Fred McAdams, Warren Brown, Charles Crabaugh, Lonny Gish, Ron Kohler, Marshall Morris, Jason Nichols, William Nye, Gene Pennington, Karl Pulliam, Robin Reed, Greg Rønne, Jason Selitsch, Mark Theriault, Bob Venable and Paul Wellong from Alaska Clean Seas for their cooperation, enthusiasm, and expert boating skills. We thank Jonah Leavitt from Barrow for help with fieldwork, Michael Williams and Shelly Schwenn from LGL Alaska for help with logistics, Craig Perham from LGL Alaska for creating Figure 7.2, and Bob Blaylock from Greeneridge Sciences for help with the analysis. For logistical support and problem solving on Northstar we thank Jeff Huey, Tom Barnes and Paul Cooley. Jeff in particular answered numerous questions during the report writing and provided pictures. Paul Nave from Crowley provided information on the tugs. We also thank Allison Erickson and Wilson Cullor of BP's Environmental Studies Group for their help with logistics. The medics and security guards on the island were also supportive. Dr. W. John Richardson, LGL Ltd., provided program direction and guidance as well as helpful criticism of this report—we thank him. Drs. Bill Streever and Ray Jakubczak of BP, and Dr. Bill Burgess of Greeneridge Sciences, provided valuable comments on the manuscript. Finally, we thank Dr. Ray Jakubczak, Dr. Bill Streever, Dave Trudgen, and BP's Environmental Studies Group generally, for their support of this project.

## LITERATURE CITED

Blackwell, S.B. and C.R. Greene Jr. 2001. Sound measurements, 2000 break-up and open-water seasons. p. 7-1 to 7-55 *In:* Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2000. [Draft, April 2001.] LGL Rep. TA2429-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 316 p.

Burgess, W.C. and C.R. Greene, Jr. 1999. Physical acoustics measurements. p. 3-1 to 3-65 *In*: W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA2230-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 390 p.

Greene, C.R., Jr., with J.S. Hanna and R.W. Blaylock. 1997. Physical acoustics measurements. p. 3-1 to 3.63 *In*: W.J. Richardson (ed.), Northstar marine mammal monitoring program, 1996: marine mammal and acoustical monitoring of a seismic program in the Alaska Beaufort Sea. LGL Rep. TA2121-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 245 p.

Hall, J.D. and J. Francine. 1991. Measurements of underwater sounds from a concrete island drilling structure located in the Alaskan sector of the Beaufort Sea. **J. Acoust. Soc. Am.** 90(3):1665-1667.

Kinsler, L.E., A.R. Frey, J.V. Sanders and A.B. Coppen. 1982. Fundamentals of acoustics, 3rd edition. Wiley, New York, NY. 480 p.

Kryter, K.D. 1985. The effects of noise on man, 2nd edition. Academic Press, Orlando, FL. 688 p.

LGL and Greeneridge. 2000. Technical plan for marine mammal and acoustic monitoring during construction of BP's Northstar Oil Development in the Alaskan Beaufort Sea, 2000-2001. [August 2000 ed.] Rep. from LGL Alaska Res. Assoc. Inc. (Anchorage), LGL Ltd. (King City, Ont.), and Greeneridge Sciences Inc. (Santa Barbara, CA), for BP Explor. (Alaska) Inc., Anchorage, AK. 80 p.

Officer, C.B. 1958. Introduction to the theory of sound transmission with application to the ocean. McGraw-Hill Book Co., New York, NY. 284 p.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme and D.H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego, CA. 576 p.

Richardson, W.J. and M.T. Williams (eds.). 2001. Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2000. [Draft, April 2001.] Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 316 p.

# CHAPTER 8:

# ACOUSTIC MONITORING OF BOWHEAD WHALE MIGRATION, AUTUMN 2001 [1]

by

**Charles R. Greene Jr.**[a], **Miles Wm. McLennan**[a],
**Trent L. McDonald**[b] and **W. John Richardson**[c]

[a] **Greeneridge Sciences, Inc.**
4512 Via Huerto, Santa Barbara, CA 93110
(805) 967-7720; cgreene@greeneridge.com

[b] **Western EcoSystems Technology, Inc.**
2003 Central Ave., Cheyenne, WY 82001
(307) 634-1756; tmcdonald@west-inc.com

[c] **LGL Ltd., environmental research associates**
22 Fisher St., POB 280, King City, Ont. L7B 1A6
(905) 833-1244; wjr@lgl.com

for

**BP Exploration (Alaska) Inc.**
**Dept. of Health, Safety & Environment**
900 East Benson Blvd, P.O. Box 196612
Anchorage, AK 99519-6612

LGL Report TA2573-2

Revised October 2002

---

[1] Chapter 8 *In:* W.J. Richardson and M.T. Williams (eds.). 2002. Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar oil development, Alaskan Beaufort Sea, 2001. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD.

# INTRODUCTION

This chapter describes acoustic monitoring near the Northstar development during the 2001 bowhead migration season, including results from an array of eleven directional autonomous seafloor acoustic recorders (DASARs) and other supplementary acoustical recording systems. The array of DASARs was designed to detect and determine the locations of bowhead whales that called within the southern (nearshore) part of their migration corridor offshore of Northstar (formerly known as Seal Island). The DASARs were installed on 29 August 2001 and began recording underwater sounds immediately. Figure 8.1 is a map of the DASAR locations in relation to Seal Island.

As part of the monitoring, sounds needed to be recorded with hydrophones about ¼ mile north of the island. Two ASARs (autonomous seafloor acoustic recorder, non-directional) and two cabled hydrophones were installed and operated for various parts of the 30 July through 3 October period (see "Methods" and Fig. 8.2). During the bowhead migration season starting in August, sounds near Northstar were recorded continuously by one or (generally) more of these sensors from 28 August until retrieval of the equipment on 3 October.

***BP's business rationale*** for this work was driven both by corporate values and by regulatory requirements. BP corporate values support studies that objectively assess environmental effects that may result from BP operations. In addition, monitoring of the autumn migration of bowhead whales past Northstar was required, during the open-water season of 2001, to satisfy provisions of a North Slope Borough zoning ordinance and the monitoring requirements of the Letter of Authorization (LoA) issued by NMFS to BP on 18 Sept. 2000.

A key objective was to estimate the offshore displacement of the southern edge of the bowhead migration corridor, if any, at times when higher-than-average levels of underwater sound were being emitted from Northstar. If such a displacement was found, it was hoped that sound sources causing higher-than-average underwater sound levels could be identified, and that this information would assist with design of mitigation efforts. The array of DASARs provided a basis for determining locations of calling whales in the southern part of the bowhead migration corridor. The ASARs and cabled hydrophones near the island provided the necessary continuous record of sounds emitted at and near Northstar. Besides addressing specific questions about Northstar effects on the whale migration, the acoustical monitoring systems were also designed to provide extensive general data on bowhead migration, bowhead calling behavior, and sound levels at various locations close to and offshore of Northstar.

The conclusions of this chapter are subject to caveats and provisos created by the data collection and analysis methods, and by the fact that this chapter is based on results from one field season in 2001. We have attempted to list the most significant of the caveats and provisos in the "Discussion" section of this chapter. In particular, the "Discussion" section contains subsections entitled "Statistical Analysis Issues", "Limitations of the Acoustical Monitoring Approach", and "Ability of Approach to Meet Objectives". Excerpting conclusions from this chapter without reference to these caveats would be inappropriate. Although the technical sophistication of some material contained in this chapter is high, it is important that all parts of this chapter, including caveats, be understood before the weight of evidence concerning the key questions is assessed. Comparable fieldwork has been conducted again in September 2002, and those additional data are expected to help resolve uncertainties remaining after the 2001 work.

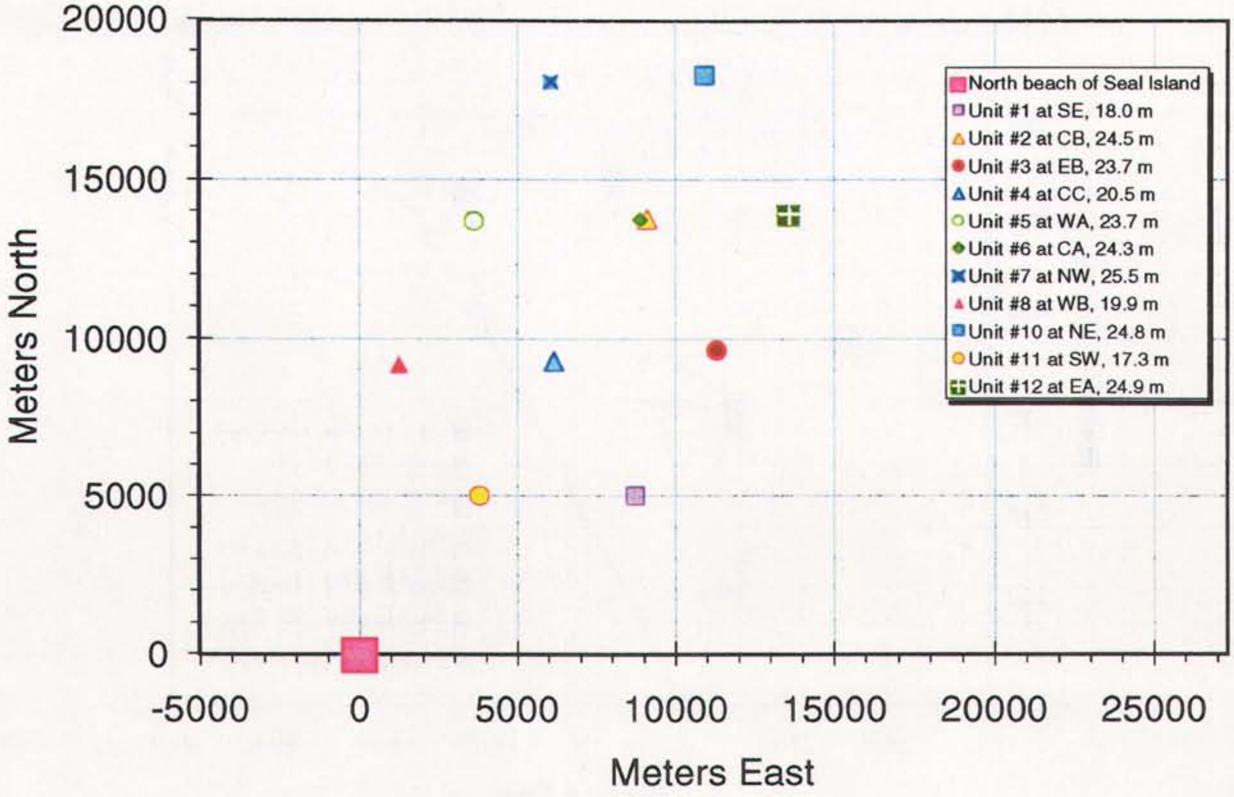


FIGURE 8.1. Map of DASAR locations in 2001 in relation to Seal Island (Northstar). The numbers following the unit numbers and locations in the legend box are water depths in meters (1 m = 3.3 ft).

## *Background*

Concern has been expressed that the autumn migration corridor of bowhead whales might be deflected offshore in the Northstar area in response to underwater sounds from construction, operations, and associated vessel and aircraft traffic. Whales, including bowhead whales, are known to avoid various industrial activities when the received sounds are sufficiently strong (Richardson et al. 1995). Previous studies, including work at Seal Island when it was constructed in 1982 by Shell Oil Company (Hickie and Davis 1983), showed that most underwater sounds propagating from a gravel island like Northstar are quite weak and usually not detectable beyond a few kilometers offshore of the island. Sounds from impact pile driving are an exception (Moore et al. 1984; Johnson et al. 1986; Blackwell and Greene 2001), but BP has not driven piles at Northstar during the bowhead migration seasons of 2000 or 2001. Sounds from boat traffic are another exception, although vessel (and aircraft) traffic associated with Northstar construction have rarely extended more than 0.6 mi (1 km) north of Northstar toward the bowhead migration corridor (see Chapter 6). During the 2001 open-water season, the sealift and offload of production facilities involved substantial vessel activity around Northstar, but that was completed by late August, before the start of the main bowhead migration (see Chapter 6).

During the planning phase of this project, it was assumed that construction (and operational) sounds from Northstar would be detectable underwater for only a relatively short distance, typically on the order of a few kilometers. Hence any effects of Northstar construction (or operations) on the autumn migration corridor were expected to be limited to the small minority of bowheads that move along the southern edge

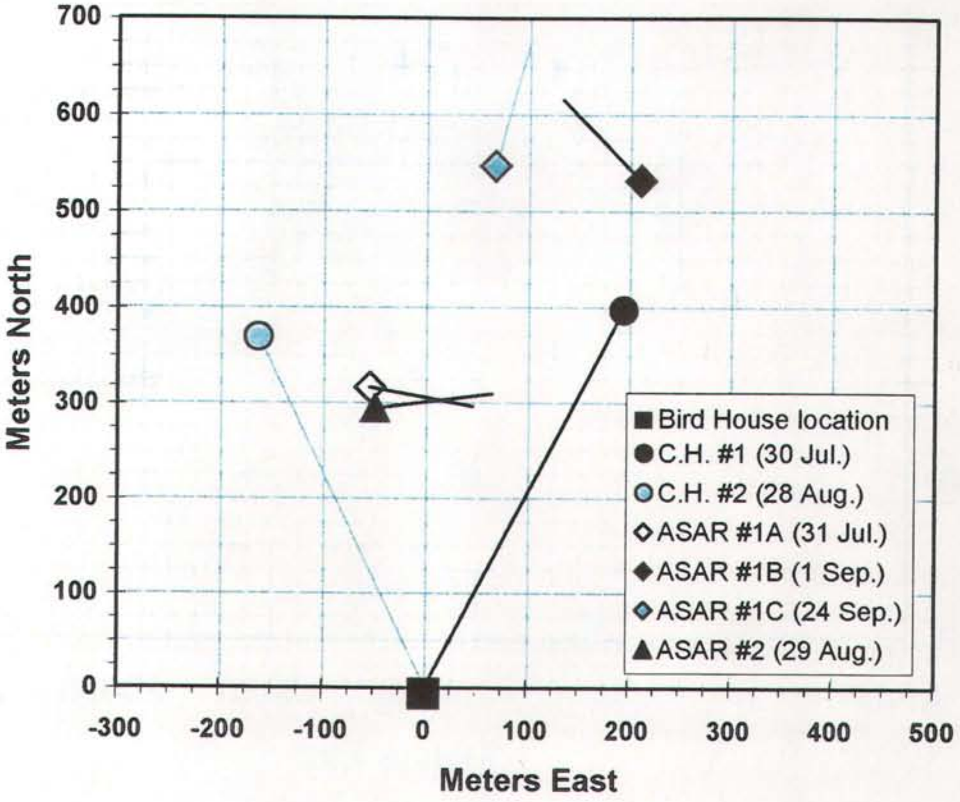


FIGURE 8.2. Map of near-island ASARs and cabled hydrophones north of Northstar (=Seal) Island, 2001. The large square symbol at the bottom represents the approximate position of the recording site (Bird House) near the center of the north edge of the island. Water depth was about 40 ft (12 m). Dates indicate when data collection began. "Tail" on each ASAR symbol shows location of "tag-line" to anchor.

of the migration corridor. For this reason, any effort to monitor Northstar effects on bowhead migration near Northstar needed to concentrate on the southern part of the migration corridor, and had to be designed to detect small-scale effects. In actuality, during the bowhead migration seasons in 2000 and 2001, sounds from Northstar were often detectable farther offshore, as documented in Blackwell and Greene (2001) for 2000 and Chapter 7 of this report for 2001. This was primarily attributable to boat operations, including crewboats and daily tug-and-barge operations.

Acoustic monitoring of the bowhead migration in Sept 2000 fell short of expectations, primarily due to equipment problems. Most importantly, the reference axis directions of the DASARs were poorly known, resulting in whale call locations with poor reliability. However, the extensive data collected in 2000 were analyzed and interpreted (Greene et al. 2001). That effort identified strengths and weaknesses in the 2000 approach, and contributed to preparations for the more successful monitoring in 2001 reported here.

## *Specific Objectives*

During 1999 and early 2000, BP and its contractors devised a new type of acoustic localization system intended for application during September-October 2000 and future years as necessary to monitor the autumn migration corridor of bowheads passing Northstar. The main objectives were to document the occurrence of calling bowhead whales in the southern part of their migration corridor in relation to distance north-northeast of Northstar, and to determine whether their distances from the island varied in direct relation to the sound levels emanating from the island. If so, this would indicate that Northstar affected the distribution and/or the calling behavior of the whales. If there was an apparent offshore displacement, the geographic extent of the displacement was to be determined, and this information was to be used to estimate the number of whales that were apparently affected. In addition, a secondary goal was to attempt identification of the sources of underwater sounds, especially if a displacement of whales was found. More specifically, the objectives in 2001 (closely following those for 2000) were

1. to monitor the year 2001 bowhead migration past Northstar by acoustic localization methods, primarily to document the relative numbers of bowhead calls vs. distance offshore in the southern part of the bowhead migration corridor seaward of Northstar;
2. to document continuously • the characteristics and potential sources of the sounds propagating away from Northstar, as determined at a close-in monitoring site approximately 300-500 m (1000-1600 ft) offshore from the island, as well as • the characteristics of the background sounds (industrial plus ambient) reaching the recording devices farther offshore in the southern part of the migration corridor;
3. to estimate the effects of Northstar activities on the migration corridor and calling behavior of bowheads by comparing the distances of calling whales from Northstar at times with varying levels of industrial sound;
4. to determine whether any individual bowheads or bowhead groups can be tracked acoustically. If so, the tracks will be analyzed to determine whether there is evidence of deflection as the whales approach Northstar and, if so, at what distances and received sound levels;
5. to compare the acoustic monitoring results with results from MMS or any other available aerial surveys to further assess the strengths and limitations of acoustic and aerial methods in documenting the bowhead migration corridor past Northstar and in detecting any change (probably small-scale, if at all) in the migration corridor near a site like Northstar;
6. to estimate the number of bowhead whales whose movements and/or calling behavior were affected by the presence of industrial activities at Northstar in autumn 2001.

Our working hypothesis was that "the lower (nearshore) tail of the distribution of calling whales detected north of Northstar may at times be deflected offshore, with the extent of deflection being correlated with the level of industrial sound from Northstar". Our approach was to estimate the size of the apparent offshore displacement (if any) as a function of the industrial sound level, thus addressing objective (3) above. The principal concern was that whales would be displaced offshore when exposed to high sound levels, so a 1-sided approach was adopted (in advance) to estimate the extent of offshore deflection. (The advisability of a 1- vs. 2-sided approach is addressed further in the "Discussion" section of this chapter.) Throughout, the estimation procedures allowed for possible lack of independence among whale calls received from nearby locations at approximately the same time. To estimate deflection, data on industrial sounds were also needed (objective 2).

## *General Approach*

Our approach was based on the working hypothesis stated above, and a general consensus that any displacement, if it occurred, would probably be small in spatial scale and intermittent. We expected the effect to be difficult to detect and quantify given those factors, natural variability, and the lack of any true "no Northstar" control data. Therefore, considerable effort was devoted to developing a method that would have high sensitivity, and to development of consensus among stakeholders regarding the approach that should be taken.

Two potential monitoring approaches were considered by BP, the Department of Wildlife Management of the North Slope Borough (NSB), National Marine Fisheries Service (NMFS), and the peer/stakeholder review group: aerial surveys and acoustic localization. BP did not propose to use aerial surveys, on the rationale that even an intensive site-specific aerial survey would provide too few sightings of bowhead whales to detect and characterize a small-scale displacement of the southern edge of their migration corridor. Results of a power analysis supporting that view were presented at the peer/stakeholder meeting in Seattle in May 2000. The power analysis was described in more detail in an Appendix to the final monitoring plan for 2000 (LGL and Greeneridge 2000), and was repeated as an Appendix to Greene et al. (2001).

Instead, BP proposed to use an acoustic localization technique to document the occurrence and locations of calling bowhead whales in the southern part of the migration corridor. In particular, this approach would determine whether the distribution of calling whales in that area is related to hour-to-hour variability in sounds emitted by Northstar operations. If so, this would suggest that Northstar sounds have an effect on migrating whales. The geographic scale of this effect should also be determinable, which (in turn) would provide much of the information needed to estimate the numbers of bowheads affected. This approach was discussed and provisionally accepted at the peer/stakeholder review meeting in Seattle in May 2000. This acceptance was subject to completion of a statistical power analysis addressing whether the proposed acoustic approach was likely to detect an effect of the anticipated magnitude if it occurred. That power analysis was completed, and it confirmed that the proposed approach did have the necessary statistical power (see Appendix C *in* LGL and Greeneridge 2000), also repeated in Greene et al. (2001).

A complication in monitoring effects of Northstar construction (and, in subsequent years, Northstar operations) on bowheads is the fact that the island is present continuously. During recent (1996-98) seismic-monitoring projects, effects of the industrial activities on the bowhead migration corridor were assessed by comparing locations of migrating bowheads during times when the airguns were operating vs. shut down (Miller et al. 1999). This approach, involving within-season comparisons between "seismic" and "control" periods, largely avoided the complications associated with known year-to-year variability in the north-south location of the bowhead migration corridor. Within-season comparisons were expected to be less effective in assessing effects of a stationary facility such as Northstar on the migration corridor, i.e., no "control" periods. Nonetheless, at least during the construction phase, appreciable hour-to-hour variability in the industrial sounds was anticipated. This variability was expected to provide a basis to determine the extent (if any) to which Northstar sounds affect the distribution of calling whales.

Another potential and recognized complication was the presence of the Concrete Island Drilling System (CIDS), which was moved to a location about $^2/_3$ mile (1.1 km) northeast of Northstar in late August 2000. CIDS was subsequently shut down for cold storage at that site. During summer 2001, CIDS was prepared for tow to Russia. One large ice-breaking tug and two smaller tugs operated around CIDS during August 2001, and on 31 Aug CIDS was towed away (see Chapters 6, 7).

This report describes fieldwork done in 2001, the acoustical and statistical analysis procedures, the basic results concerning numbers and locations of detectable whale calls, and relationships between call locations and Northstar-associated sounds. Chapter 9 uses some of the results as a basis for estimating numbers of bowhead whales that might have been affected by Northstar sounds in 2001.

# METHODS

To implement the acoustical approach to monitoring effects of Northstar sound on the whale migration corridor, it was essential to determine the locations of calling whales in the southern part of the whale migration corridor, and the underwater sound levels near the island. If island sounds caused whales to swim farther away from the island, all other aspects of whale behavior being the same, then whale locations during noisy times at the island would be farther offshore than during quiet times at the island. The acoustical localization ability was to come from an array of directional autonomous seafloor acoustic recorders (DASARs) located in the southern part of the migration corridor (Fig. 8.1). Each DASAR was to provide a bearing to a call; the intersections of the bearings from multiple DASARs were to define the whale location.

The island sound measurements were to be made with two cabled hydrophone systems and one or two autonomous seafloor acoustic recorders (ASARs). Only one of these systems was required to be operating; the others were for redundancy. ASARs had been used to record whale vocalizations during seismic surveys in 1996-98 and are described by Greene et al. (1997). Each cabled hydrophone system, described in Greene et al. (2001), included an International Transducer Corporation model 8212 hydrophone with internal preamplifier. The hydrophones were installed 1440 and 1300 ft (440 and 400 m) from the north edge of the island and connected by double-armored cables to sound recording apparatus in the "Bird House" hanging from the retaining wall of the north side of the island, recording 24 hours/day. The sample rate was 2000 samples/s, permitting sounds at frequencies up to about 1000 Hz to be recorded accurately. The data provided by the cabled hydrophones and ASARs characterized underwater sounds from Northstar during the open water season, as described in Chapter 7.

The DASARs are described here, followed by short accounts of the analysis methods associated with the cabled hydrophones and ASARs. Whale call analysis is described by means of an example.

## *Directional Autonomous Seafloor Acoustical Recorder (DASAR)*

### *Electronic Components*

The central component of a DASAR is a directional sensor adopted from the Navy's DIFAR sonobuoy, model AN/SSQ-53E. DIFAR is an acronym for Directional Frequency and Recording, although there is no recording capability in the DIFAR sonobuoy itself. Included in the standard DIFAR sensor are a fluxgate compass, an omnidirectional acoustic pressure sensor (hydrophone), and two horizontal particle motion sensors mounted at right angles to one another. The two directional sensors have receiving sensitivity patterns corresponding to the cosine of the angle off the sensor axis. Thus, at right angles to the axis, the sensitivity is zero. Sound from one direction along the sensor axis is out of phase with sound coming from the opposite end. The angle from which a sound is received can be computed as the angle whose tangent is the ratio of the outputs of the two directional sensors. The phase relationship of the directional channel signals with respect to the phase of the omnidirectional channel is unique to the azimuthal quadrant from which a sound is received, permitting the angular ambiguities associated with the arctangent to be resolved. The compass permits the angles to be referred to magnetic north.

The compass included in the sonobuoy sensor could not be used because of its high power consumption and extraneous high frequency modulation elements essential to the sonobuoy function but not to the DASAR. Instead, a Precision Navigation model V2X fluxgate compass was substituted.

Each DASAR included an embedded Persister Instruments CF1 computer, which is a 3.3 volt 68338 Computer Module with CompactFlash Operating System. This controls signal acquisition, which involved sampling the three acoustic signals and storing the resulting data in a continuous stream on a 25.38 gigabyte (GByte) disk drive. The acoustic data received over a 46.6 min period were stored in buffer memory; the disk then operated for about 25 sec while the data were written onto disk. It was a design goal that a DASAR be able to record continuously for 45 days, sufficiently long to operate during an entire bowhead migration season. Battery life and the space on a 25.38 Gbyte disk drive were adequate for this.

As implemented in 2001, the V2X compass signal was stored in flash memory and recovered separately from the acoustic data on the disk. In addition, calibration sounds from known locations (see below) were used as independent calibrations of the reference direction for each DASAR as installed. These were compared to the stored compass readings.

The three acoustic channels were low-pass filtered at 480 Hz and sampled at 1000 samples per second, which permitted an acoustic bandwidth from 10 to 480 Hz. This frequency band was adequate for bowhead whale vocalizations, most of which are at frequencies between 50 and 400 Hz. (In fact, most of the bowhead calls recorded by DASARs were at frequencies <200 Hz.) The aliasing problem present in year 2000 was eliminated for the 2001 season. A switching transient occurring with a period of about five seconds was greatly diminished in amplitude in 2001, but was not eliminated.

### *Physical Construction*

The mechanical housing was a 12" diameter by 13.5" high cylinder (30 × 34 cm) of anodized aluminum mounted on end. The top plate, which was 1" (2.5 cm) thick, incorporated a double O-ring seal, and was bolted to the body. All electronics were mounted on the inside of the top plate. The plate accommodated a watertight penetration for the wires from the sensor and included the wet end of an acoustic transponder (see below). A pair of brackets was bolted to the top plate and extended about 8.75" (22 cm) above so that the directional acoustic sensor could be compliantly suspended concentric to and above the cylinder. Figure 8.3 is a photograph of the assembled package.

The DASAR cylinder was bolted on top of an aluminum T-structure that also served as the base for a "Dogloo", a plastic shell used to protect the entire instrument from water currents. The Dogloo included an entry in one side that was covered by duct tape to reduce currents from swirling inside. The T-structure also included an attachment point for the rope tag line used for retrieval.

An acoustic transponder was incorporated in each DASAR. The transponder (a modified UAT-376 from Datasonics) provided a method by which each DASAR could report on its operational "health" and status while it was operating on the seafloor. Health status reports indicated whether data were being written to the disk recorder. Health checks did not report failed sensor channels. A boat with a surface-deployed transducer (a pole-mounted DRI-267A transponder interrogator from Datasonics) interrogated each DASAR during a cruise past each unit on an (approximately) weekly schedule. The transponder replied with a signal reporting on the status of the unit. Frequencies of 29, 31, and 32 kHz were used with ping lengths of 10 – 50 ms. This allowed a malfunctioning unit to be detected, retrieved, and replaced. The system worked well. A few DASARS failed their health check and were replaced shortly after they were interrogated, thus avoiding prolonged periods with inoperable DASARs.

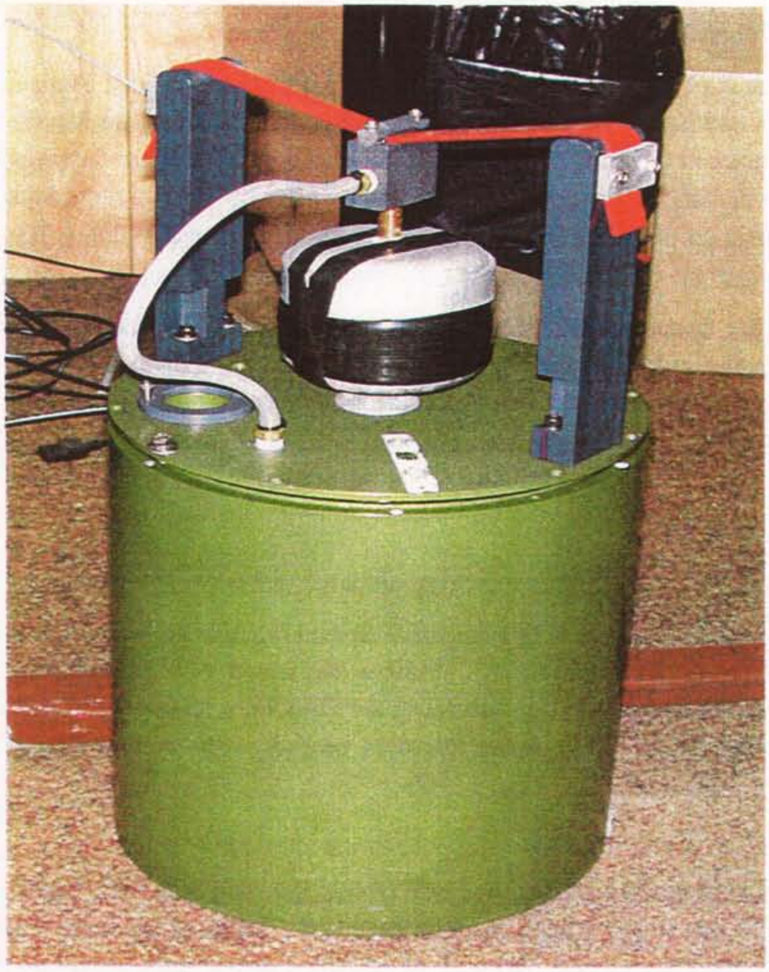


FIGURE 8.3. Photograph of a DASAR, as implemented in 2001, showing sensor suspension at top.

### *Deployment and Retrieval*

Each DASAR was attached to a light Danforth anchor by 360 ft (110 m) of ground or "tag" line. After the anchor was deployed, the DASAR was lowered to the seafloor by rope. The DASARs were deployed in the same hexagonal patterns used in 2000 except that, in 2001, each unit was 1.15 mi (1850 m) south of the 2000 position, the better to observe whales in areas near Northstar. Also, for 2001 another DASAR location was added to the array (WB in Fig. 8.1) to enhance coverage. DASARs were located at distances 4 to 13.7 mi (6.5 to 22 km) from Northstar. The vessels used for deployment and retrieval were the 12.8-m "Bay" boats operated by Alaska Clean Seas.

The GPS location of the anchor and DASAR were recorded during deployment using a Garmin 12MAP hand-held GPS receiver. For retrieval, a double grapnel anchor assembly with 20 ft (6 m) of chain was towed perpendicular to the tag line and across it. After the boat captain became accustomed to controlling his boat by reference to the small GPS map, retrieval was usually accomplished on the first pass.

## *Time and Direction Calibration*

To make the DASAR recordings useful, two quantities had to be measured: (1) the orientation of the DASAR reference axis as installed, and (2) the drift rate of the DASAR sample clock.

### *Reference Axis Calibration*

For convenience in calculations, all positions are expressed in Universal Transverse Mercator (UTM) coordinates (northings and eastings), which give earth-based locations that are locally Cartesian (X-Y) and have the same scale factor in the north and east directions. It is natural to use bearings expressed relative to the same grid. In the vicinity of Northstar, these bearings differ by 1.4° counter-clockwise from true north and 28.3° from magnetic north. (The magnetic variation in this area near Prudhoe Bay is 26.9° east of true north.) Formally, all bearings in this chapter are referenced to UTM grid north.

In the calibration operation we generated pings at known GPS locations and received them at DASARs, which were also at known GPS locations. From the GPS locations we calculated a grid bearing $b_{gps}$ from a DASAR to a ping source location. Measuring the relative bearing to the ping source by processing the DIFAR information, we obtained $b_{rel}$. The grid bearing of the DASAR reference axis is related to $b_{gps}$ and $b_{rel}$ by

$$b_{ref} = b_{gps} - b_{rel}$$

Once $b_{ref}$ is known, it can be used to get grid bearing of all relative angle measurements for whale calls.

The compass bearings from the V2X compasses in the DASARs did not agree well with the reference bearings determined from the calibration pings. Further, the stored V2X compass bearings did not change while the units were on the bottom. In our judgment, the DASAR reference bearings were best determined by the ping bearing calibrations. Thus, those reference bearings were used in determining the whale call locations.

### *Time Calibration*

The other quantity to be measured is the DASAR sample clock drift. The times of all acoustic events are measured relative to the 1-kHz sample clock in each unit. These clocks were selected for low current drain first and absolute accuracy second. Because of the near-constant temperature on the sea floor, the rate of drift is stable but results in times different from the GPS clock (Universal Time Coordinated, UTC) by a few seconds per day. Over the course of weeks the accumulated error can introduce significant time errors, making it difficult to match the data from different DASARs. The calibration pings were timed by a GPS receiver that produced control pulses at precise times as determined from the GPS satellites. We measured the arrival time of pings at the DASAR as defined by the (drifting) DASAR clock. We compared that with the precisely-known (from GPS) ping transmit time plus the ping travel time; the latter is directly related to the GPS distance from the ping location to the DASAR. This provided a measure of the DASAR clock drift. For each DASAR, we expressed the time errors as determined on the calibration dates as a linear function of GPS time. In processing the whale calls, we used this drift rate to determine the GPS (UTC) time corresponding to the DASAR time at which each whale call was received.

### *Ping Calibration Method*

A program was written to link the accurate GPS receiver, a laptop computer with sound card, a power amplifier (Mackie FR Series M-800), and an underwater sound projector (USN model J-9). The maximum source level safely useful (without hazard of overloading the projector) from the J-9 for frequencies between 100 and 500 Hz is about 150 dB re 1 $\mu$Pa-m, which is 10-30 dB less than the estimated source levels of many bowhead whale calls (Clark et al. 1986; Cummings and Holliday 1987).

The boat was maneuvered to a desired calibration position as measured by the GPS, and the sound projector was lowered into the water to a depth of 10 m. At the start of a specified second as determined by a synchronizing pulse from the accurate GPS receiver, a wave file was played through the computer sound card to the projector. The wave files included five types of sounds:

- Single-frequency ping burst at 400 Hz for 5 seconds (p400)
- Single-frequency ping burst at 300 Hz for 5 seconds (p300)
- FM (frequency modulation) sweep from 100 to 500 Hz over 5 seconds (sw15)
- FM sweep from 200 to 400 Hz over 5 seconds (sw24)
- FM sweep from 300 to 400 Hz over 5 seconds (sw34).

(The parenthetical symbols are used in later Figures.) The different waveforms were used to determine if one or more types of waveforms were more effective than other types. The single-frequency pings were the easiest to distinguish in the spectrogram display; however, the sweeps appeared to give more consistent and accurate bearings, with better resistance to bias from reflections, than the single-frequency pings.

The laptop computer recorded a log file including GPS time and location of the ping and the name of the wave file used. On each date with ping calibrations, 10 to 20 such pings were emitted at each of ten locations inside the array and eight locations outside. The locations were selected so each DASAR would receive pings from several directions. Pings were generated at the centers of the ten equilateral triangles formed by considering all groups of three "adjacent" DASARs. An additional eight calibration locations were spaced around the outside the array. The entire series was repeated about once a week, subject to weather and boat availability, for a total of six calibration days.

After the DASARs were retrieved, their acoustic time series data for the entire field period were transferred to three 100-Gbyte disks on a computer configured as a network server such that any selected minute of data could be retrieved for every operating DASAR.

A calibration ping-processing program (named pp) was written to retrieve, display, and measure the relative bearings of the pings. Processing one DASAR at a time, the ping log file pointed to a time when a ping was emitted. Using graphic input crosshairs and a spectrogram display (frequency vs. time with levels coded as shades and colors), the operator clicked on the ping start time and frequency, and then the end time and frequency, to define a box enclosing the main ping energy in time and frequency. Program pp measured the arrival time, relative bearing, and signal level during the ping. The program also measured the background noise level just before the start of the ping. The signal and background levels were both measured in the bandwidth of the calibration ping as identified by the operator. The program then wrote a text record including

- GPS ping time,
- range from ping location to DASAR,
- actual bearing from DASAR location to ping source location, from GPS,
- difference between actual bearing and measured relative bearing,
- time error between GPS time and DASAR sample clock time,
- received sound pressure level (SPL) of the ping in decibels referred to one micropascal, and
- signal-to-noise ratio in decibels.

Later, another program was used to display and average the ping calibration records. Based on the plots produced, the analyst edited out wild points. Interfering sound at the ping frequency, from any direction, can result in serious bearing errors, particularly if the signal-to-noise ratio is low. "Wild points" were those differing from the nominal average bearing by more than about 30°. The average or median values from the measurements (wild points excluded) were placed in calibration tables for use by the whale call location program.

## *Whale Call Location Method and Example*

This section illustrates how a call was processed. As an example, we consider an actual call received by seven DASARs. (Most calls that could be located were received by only 2-4 DASARs.)

The data from all the DASARs were accumulated on three 100-gigabyte computer disks mounted on a single network server, as previously noted. Custom software allowed random access to all the DASAR data for any selected time.

Using the custom software, the operator specified the date and time of a one-minute period to be examined. The program fetched that minute of sound data for each DASAR that had been recording, and displayed a spectrogram from each. Figure 8.4 is an example of the multiple-spectrogram screen. Each spectrogram is a plot of one minute of time on the horizontal axis, frequency (pitch) on the vertical axis, and different colors for the sound intensity at a particular time and frequency. Bowhead whale calls often sound like a low-pitched "wooooo!" whose pitch rises or falls in the range 100 to 300 Hz. Calls showed up on the spectrogram plots as "lines" one or two seconds long, usually as a red line against a yellow background. Several can be seen in Figure 8.4. Using mouse-driven cross hairs, the operator could select any one of the DASAR spectrograms for closer examination. The selected spectrum was redrawn at full size as shown in Figure 8.5. This was the primary call-detection screen. The operator used cross hairs in Figure 8.5 to define a box enclosing the lowest and highest frequencies and the beginning and ending times. The program then filtered the sound to exclude all other frequencies and thereby enhance the call. The filtered time series is shown in Figure 8.6. (The three high-amplitude, short bursts are probably not part of the call but arise in the background sounds.) The program played the sound over speakers so the operator could better judge its nature.

The program also processed the DIFAR directional hydrophone signals to yield north-south and east-west components, as plotted in Figure 8.7. The scatter shown in Figure 8.7 represents variation in bearings calculated for samples taken at 1/1000th second intervals over the duration of the whale call. The average values of the bearing components were used to define the direction of the calling whale by computing the arctangent of their ratio. This measurement was repeated for each DASAR on which the call was detected.

When a given call had been identified and measured for each DASAR that received the call, the program proceeded to the classification and location section. The operator selected a classification from the following types of calls (Clark 1983):

1. up-call, an FM (frequency modulation) up-sweep
2. down-call, an FM down-sweep
3. constant call, small FM tolerated, but generally a monotone

4.1. inflected call, FM undulation down, then up ("U"-shaped)

4.2. inflected call, FM undulation up, then down ("^"-shaped)

5. high call, an FM sweep with most energy higher than 200 Hz
6. complex call, a mixture of FM and/or AM (amplitude modulation), often with some broadband energy

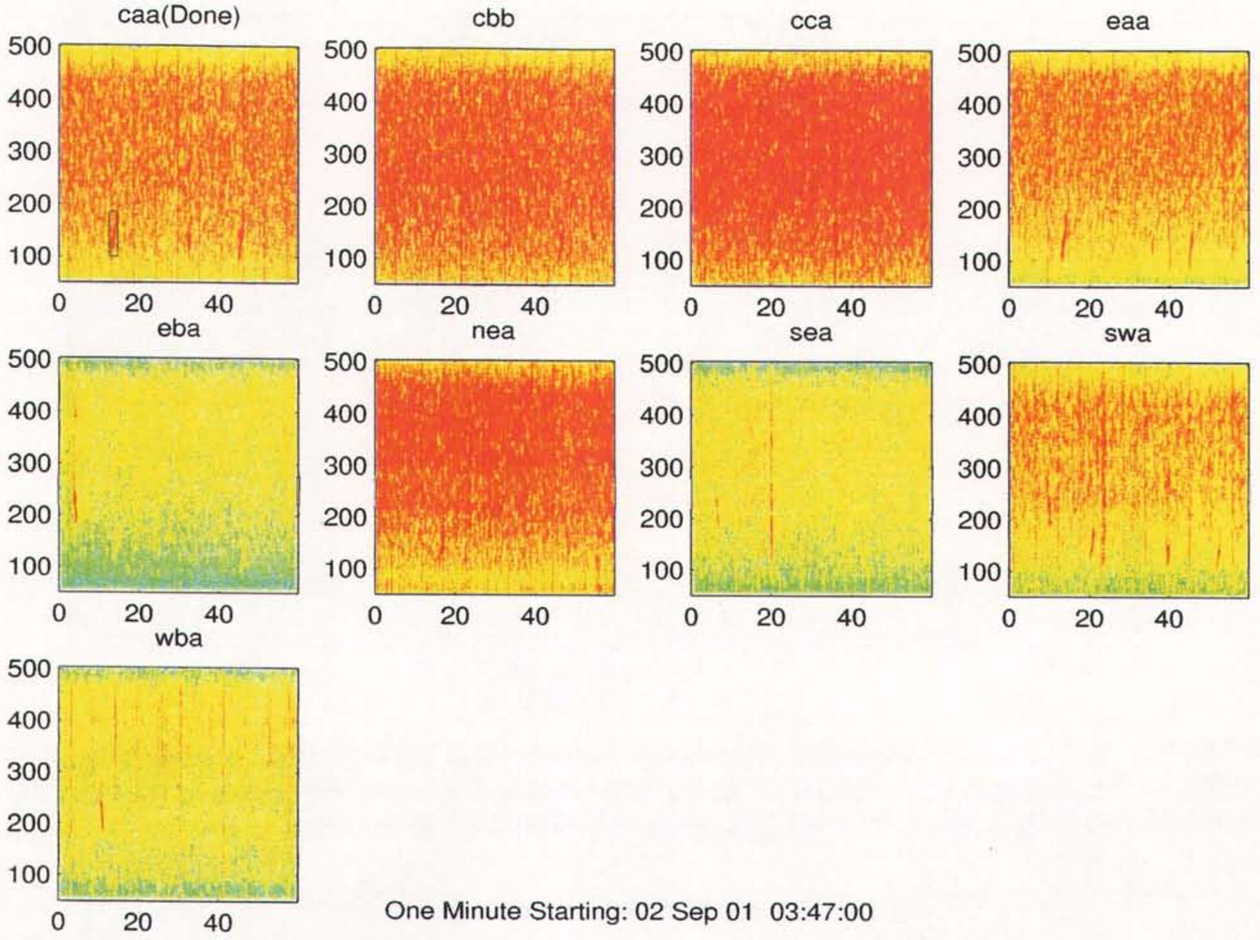


FIGURE 8.4. An example of the multiple-spectrogram display used by the operator to detect bowhead calls within a specified one-minute period, 2 Sept 2001. On each spectrogram, horizontal axis is time in seconds and vertical axis is frequency from 0 to 500 Hz. Colors range from red for high sound spectrum levels down through yellow to green to blue for low spectrum levels.

7. slap: either breach or fluke slap, or sharp report
8. seal call
9. ping
10. other (described in the comment).

The estimated location of the calling whale was determined from the intersecting DASAR bearings. When 3 or more DASARs detected the call, the bearings normally intersect at 2 or more somewhat different locations. In that case, the estimated location of the calling whale was considered to be the x,y coordinate that minimized the sum of the square bearing errors measured from each DASAR. Figure 8.8 shows the locations of the DASARs plus the estimated bearing of the calling whale from each DASAR that detected the call. A circle depicts the "best estimate" of the whale's location. The operator could delete wild bearings, e.g., when a DASAR bearing did not intersect the other DASAR bearings, before computing the "best estimate". (A non-intersecting bearing can occur when the DASAR in question received another sound, or some other type of interference, simultaneous with the whale call.) All data gathered from the call were then saved in a file as a record of that call.

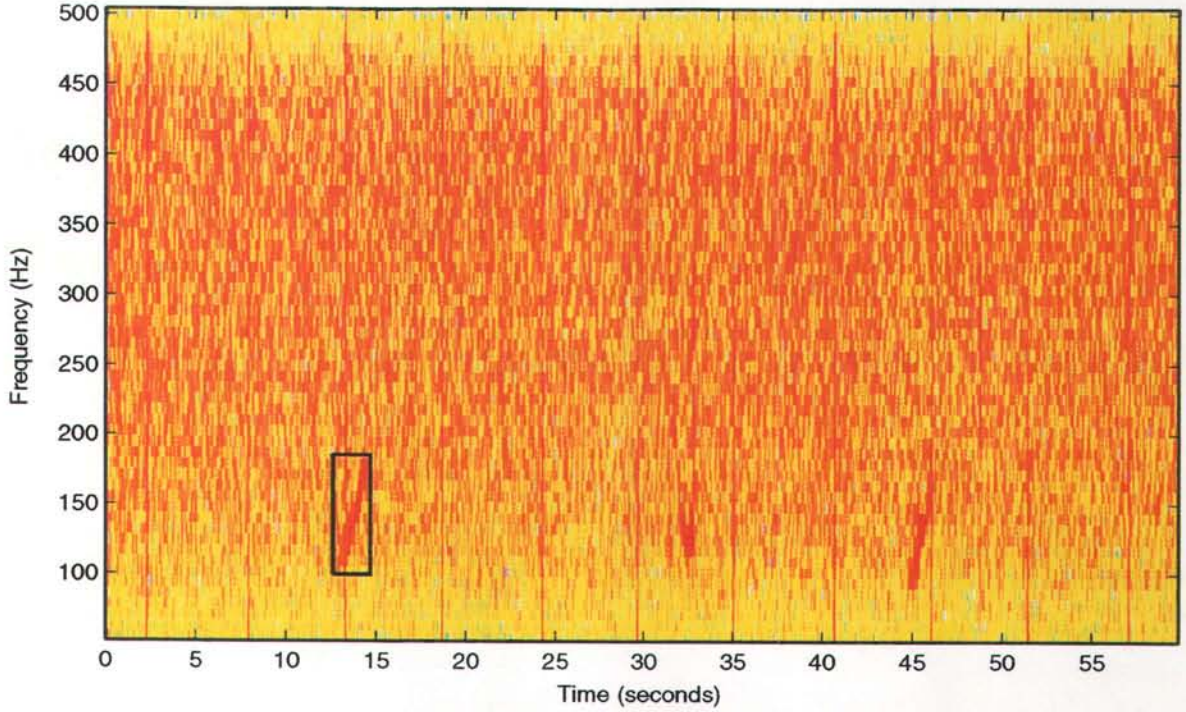


FIGURE 8.5. An example of an enlarged spectrogram, which the operator used to set time and frequency bounds on the up-sweep whale call (noted by the box). This enlargement corresponds to DASAR CAa from Figure 8.4 (2 Sept 2001). Note two other whale calls occurring later in Figure.

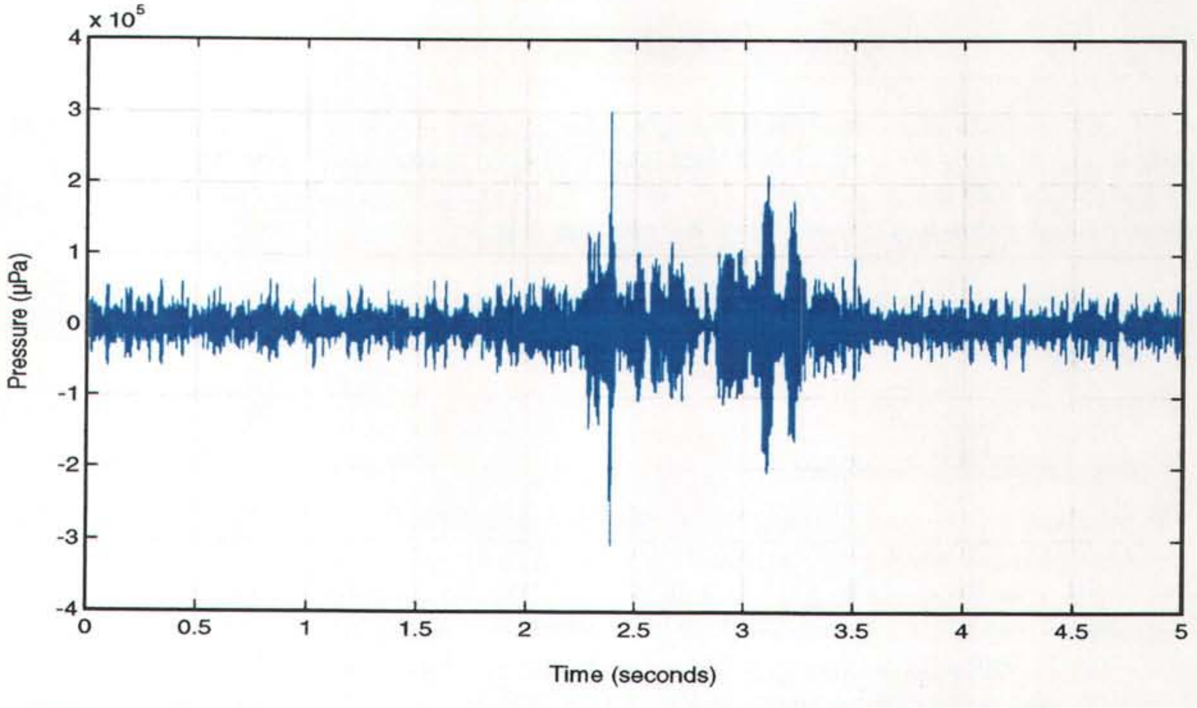


FIGURE 8.6. Sound pressure waveform of the whale call selected in Figure 8.5 from 2 Sept 2001. More time is shown than is selected within the box in Figure 8.5 because the background noise is measured in advance of the call and because the call can better be distinguished from the background when several seconds of background are displayed.

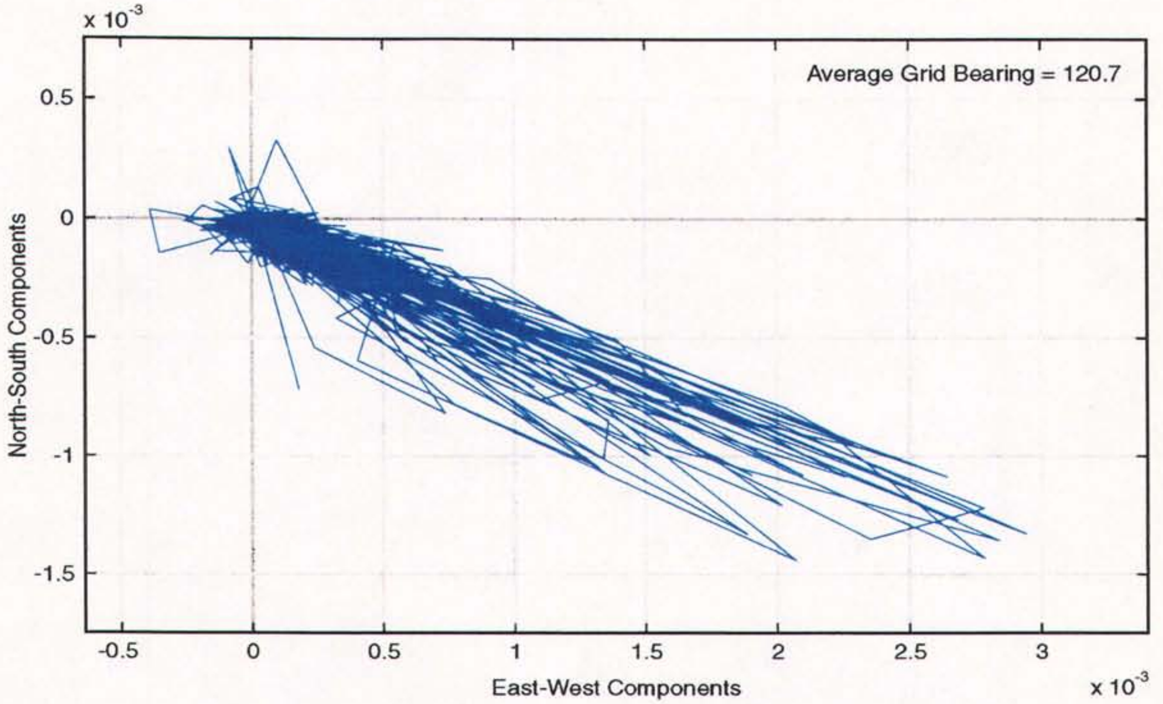


FIGURE 8.7. A polar plot of the directions calculated for each time sample in the whale call of Figures 8.5 and 8.6, from 2 Sept 2001.

The example described above and illustrated in Figures 8.4-8.8 is an actual location from the data. However, most calls were heard on one, two, or three DASARs rather than the seven DASARs that detected the illustrated call.

## *Calibration Ping Examples*

Figure 8.9 presents two examples of calculated DASAR reference angles vs. ping number. These examples show data from the DASARs at locations SE and NE; those locations are mapped in Figure 8.1. (In references to specific DASARs, e.g., SEa, the 3rd character – an "a", "b" or "c" – identifies whether this was the 1st, 2nd or 3rd deployment of a DASAR at that location in 2001.) Each symbol in Figure 8.9 represents a calibration ping recorded during one of the six days on which calibrations were conducted, plotted by date and time. As illustrated, there was considerable ping-to-ping variation in the calculated reference angles.

## *Near-Island Sound Measurements*

Near-island measurements were obtained via a combination of cabled hydrophones and non-directional Autonomous Seafloor Acoustic Recorders (ASARs). Only one functional instrument was required; the others were for redundancy. Two ASARs and two cabled hydrophones were installed and operated about 300-550 m north of Northstar (Fig. 8.2) for various parts of the 30 July through 3 Oct period in 2001. During the bowhead migration season starting in August, sounds near Northstar were recorded continuously by one or (generally) more of these sensors from 28 Aug until retrieval of the equipment on 3 Oct. Figure 7.1A (in Chapter 7) shows the specific recording periods for each instrument.

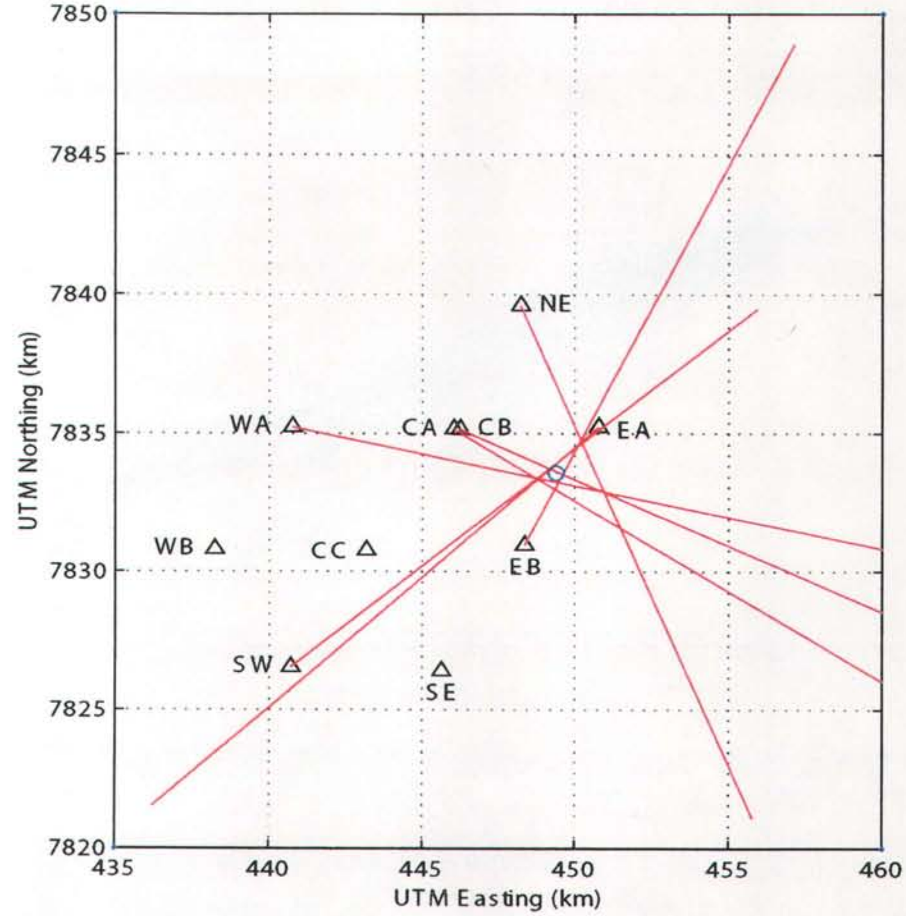


FIGURE 8.8. Map display of estimated call bearings from the seven DASARs that detected the whale call of Figures 8.5 and 8.6, 2 Sept 2001. Circle denotes best estimate of whale location at time of call.

## *Cabled Hydrophones*

Two cabled hydrophone signals were recorded in the "Bird House" on the north side of the island. One cabled hydrophone was installed on 30 July but ice floes grounding on the sub-sea berm north of the island dragged the cable. The resulting damage caused recording to stop on 7 Aug. The cable was repaired and recording resumed on 28 Aug, but the location of that hydrophone was no longer known with confidence because ice had dragged the cable. A second cabled hydrophone was installed on 28 Aug. Figure 8.2 shows the sensor locations adjacent to the north shore of Seal Island.

An International Transducer Corporation (ITC) model 8212 hydrophone, which contains a low-noise preamplifier, was spliced to the conductors of an 1800 ft (550-m) double armored well-logging cable to form a "cabled hydrophone". In the first system, the hydrophone was mounted on a small stand and deployed 1440 ft (440 m) to the north-northeast from the north edge (the water line) of the concrete mat at Northstar in late July. The shore end of the cable was placed in the "cracks" between adjacent concrete blocks comprising the slope-protection outside the island retaining wall. This cable then extended into the "Bird House", a small shelter (about 3' by 6' and 7' high) that had been suspended over the retaining wall as an observatory for wildlife. A battery was connected to two of the conductors to power the preamplifier in the hydrophone. The recording of signals from the first hydrophone ended on 7 Aug, as described above. A second cabled hydrophone was installed 1300 ft (400 m) north-northwest of the north shore at the end of August.

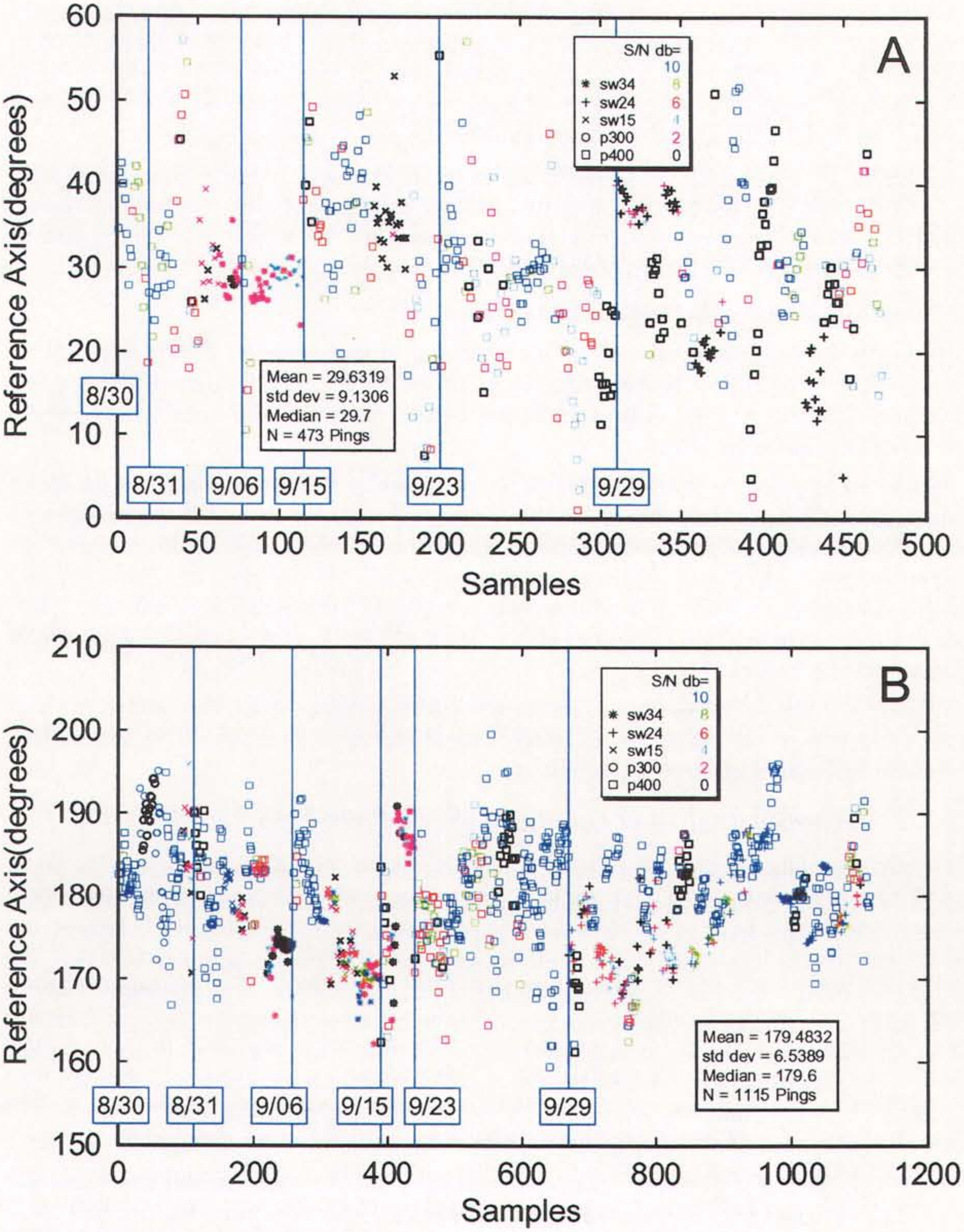


FIGURE 8.9. Calibration ping angles vs. ping number for two DASARs deployed in 2001. ***(A)*** is for SEa; ***(B)*** is for NEa. "sw" is a sweep, which could extend from 300 to 400 Hz (sw34), 200-400 Hz (sw24), or 100-500 Hz (sw15). "p" is a tone ping, which could be at 300 or at 400 Hz. Signal-to-noise ratio is keyed by color. Vertical lines separate the six dates in Aug and Sept 2001 with calibration tests.

During both installations, the hydrophone signals were recorded digitally in the "Bird House". The hydrophone signals were connected to DASAR-like electronics for signal conditioning and recording on 25-gigabyte disks. Sampling was at 2000 samples/second, twice as fast as in the DASARs, to permit recording sounds at frequencies up to 1000 Hz. Sixteen bits quantized the samples. The disk capacity and battery life were sufficient to record without interruption for over 40 days.

Analysis of the cabled hydrophone records was by spectrum analysis of one-minute's sound every 4.37 minutes, or ~330 times per 24-h day, with 10 – 1000 Hz acoustic bandwidth. Narrowband spectra, one-third octave band levels, and broadband levels (e.g., 10-500, 10-1000, 20-500, 20-1000 Hz) were all computed and saved to computer files for additional analyses.

### *Autonomous Seafloor Acoustic Recorders (ASARs)*

An ASAR was installed 323 m north of the north edge of Seal Island on 30 July (Fig. 8.2). It recorded near-island sounds until 22 Aug. Another ASAR was installed on 28 Aug; it recorded continuously from 29 Aug until 22 Sept. A third ASAR was installed on 23 Sept and recorded continuously from 24 Sept until retrieved on 3 Oct.

ASARs are described in Greene et al. (1997). An ASAR is functionally similar to the cabled hydrophone described above except that there is no well-logging cable and the recording electronics are different. The hydrophone signal is wired directly to the signal conditioning card and the electronics and batteries are housed in a PVC cylinder 54" long and 6" in diameter (137 × 15 cm). Aluminum end caps with double O-ring seals complete the pressure housing. ASARs were deployed to and retrieved from the seafloor in a manner similar to that described earlier for the DASARs. Disk capacity is sufficient for continuous recording for over 22 days.

Analysis of ASAR recordings was automatic, under software control. Sound levels and spectra were computed for each of the 100 one-minute recordings obtained each day with acoustic bandwidth 10-1000 Hz. All results were logged for additional analysis.

## *Statistical Analysis of Localized Calls vs. Underwater Sound* [2]

Objective (3) of the present project was "to estimate the effects of Northstar activities on the migration corridor and calling behavior of bowheads by comparing the distances of calling whales from Northstar at times with varying levels of industrial sound." As noted in the Introduction to this Chapter, our approach acknowledged that some amount of displacement (or some change in calling behavior) was possible at high-sound times, and we estimated the size of that displacement. The relationship between industrial sound and distance to whales was assessed with a 1-sided approach. This approach was consistent with monitoring plans and discussions at peer review/stakeholder workshops in Seattle in 2000 and 2001. This analysis allowed for possible lack of independence among whale calls received from nearby locations at short time intervals, and weighted call locations inversely proportional to their estimated uncertainty. For this analysis, continuous data on industrial sounds are also required.

The basic analysis relating distance offshore to industrial sound levels was repeated four times, once when sound was averaged for 5 minutes, once when averaged for 15 minutes, once when averaged for 30 minutes, and once when averaged for 60 minutes. This was done because the duration of sustained sound necessary to induce a calling whale to displace (or to call less often) was unknown. These four analyses were

---

[2] This subsection prepared by Dr. Trent L. McDonald assisted by Ryan Nielson, WEST Inc., Cheyenne, WY.

conducted in such a way as to maintain approximate 95% confidence in the results of any single analysis, but were not specifically "corrected" for the fact that we ran four analyses on the same data set. Whether and how to make this "correction" is controversial among statisticians, and it is unclear whether we should have derived a simultaneous confidence level for the four analyses. More discussion on this and other caveats of the analysis can be found in the "Statistical Analysis Issues" subsection in the "Discussion".

In this part of the "Methods" section, the sound data and whale location data used in the analysis are described, followed by a description of the statistical techniques applied to those data.

### *Industrial Sounds*

Sound data used in the statistical analysis were collected by a single non-directional hydrophone connected by a cable to the northern edge of Northstar (=Seal) Island. The data used here came from Cabled Hydrophone 2 (C.H. 2), which was deployed 400 m north-northwest of the northern edge of Seal Island on 28 Aug 2001 (Fig. 8.2). It provided continuous acoustic data from 14:00 on 28 Aug until 13:30 on 3 Oct, with the exception of a 20-min gap during servicing on 21 Sept.

From the recorded data, sound levels in decibels re 1 µPa (dB) were determined for 1 min every 4.37 minutes, producing a 23% systematic sample of near-island sound through time. For each 1 min sampling time, sound level was determined in each one-third octave band between 1 Hz and 800 Hz. Analysis of these data indicated that industrial sound was most evident in the 1/3-octave bands centered at 63, 80, and 160 Hz (see Fig. 8.13, later). These three 1/3-octave bands will be called the *industrial bands*, although some background noise was present in these bands, and some industrial sound was present in other 1/3-octave bands as well. Pressure levels in the industrial bands were added together as described in Richardson et al. (1995, p. 30) to create a measure of cumulative industrial sound, or Industrial Sound Index (ISI):

$$ISI = 10\log_{10}(10^{dB_{63}/10} + 10^{dB_{80}/10} + 10^{dB_{160}/10})$$

where $dB_{63}$, $dB_{80}$ and $dB_{160}$ were the 1/3-octave band levels in each of the industrial bands, in dB re 1 µPa.

### *Accuracy of Whale Call Locations*

An estimate of the precision of each whale call location was needed for use as a weighting factor in subsequent analyses. The precision of whale call locations, in the form of error polygons, was estimated following the methods of Lenth (1981). Under this method, individual bearings from a DASAR to a received whale call were assumed to follow a Von Mises distribution (Mardia 1973). The Von Mises distribution is analogous to the normal distribution, but applies to directional data in which angles $x$ and $x + 360°$ are the same. The Von Mises distribution has probability density function

$$f(\theta;\mu,\kappa) = [2\pi I_0(\kappa)]^{-1}\exp[\kappa\cos(\theta-\mu)]$$

where $\mu$ is the mean bearing, $\kappa$ is the concentration parameter, and $I_0$ is a modified Bessel function. Assuming $s$ is the standard deviation of bearings calculated in the usual way from a random sample of bearings, the concentration parameter can be calculated approximately as

$$\kappa^{-1} = 2(1-A) + \frac{(1-A)^2(0.48794 - 0.82905A - 1.3915A^2)}{A}$$

$$A = \exp\left[\frac{-1}{2}\left(\frac{s\pi}{180}\right)^2\right].$$

Estimates of $s$ for each DASAR were computed from the calibration data collected by Greeneridge Sciences (see Table 8.1, later). During calibration, true bearing from each DASAR to the source of the test sound (acoustic ping or sweep) was known. Assuming $\mu$ is the true bearing, $\theta_i$ is the measured bearing during the $i$-th ping or sweep, and $n$ pings or sweeps were performed, $s$ was estimated as

$$s=\sqrt{\sum_{i=1}^{n}(\theta_i-\mu)^2/(n-1)}$$

Histograms of the differences between measured bearings and true bearings (i.e., $\theta_i - \mu$) confirmed that it was reasonable to assume, for bearings, a distribution of the Von Mises type.

When two or more DASARs received the same call, the $(x,y)$ location with maximum statistical likelihood was used as the estimate of the call's location. Random errors in bearings (observed bearing – true bearing) from each DASAR to a given call were assumed to be independent. The statistical likelihood of the bearings was constructed and maximized as described in footnote ([3]). An estimate of the variance-covariance matrix of $(x,y)$,

$$Q=\begin{bmatrix} Var(x) & Cov(x,y) \\ Cov(x,y) & Var(y) \end{bmatrix},$$

was obtained using formulas given in Lenth (1981) and White and Garrott (1990). Relying on the fact that maximum likelihood estimates are asymptotically normally distributed, the area of a 95% confidence ellipse for the true call position was calculated as

$$a=\pi|Q|^{1/2}\chi^2_{2,0.05},$$

where $\chi^2_{2,0.05}$ was the 5th quantile of a Chi-square distribution having 2 degrees of freedom and $|Q| = Var(x)Var(y) - Cov(x,y)^2$ (White and Garrott 1990).

Values proportional to the inverses of $a$ at every estimated call location were used as weights in the quantile regression analysis outlined below. This resulted in calls with small $a$ being given large weights in the analysis, while calls with large $a$ were given small weights in the analysis. The actual weights used in quantile regression were proportional to $1/a$ and scaled to sum to the number of received calls. Calls where $a$ could not be calculated could not be used in the quantile regression. Area of the 95% confidence ellipse could not be calculated if the variance-covariance matrix $Q$ was not positive-definite. A small fraction of the estimated $Q$ matrices were not positive-definite because the bearings involved were nearly parallel. Nearly parallel bearings typically occurred at locations far from the DASAR array or along lines connecting pairs of DASARS. If error estimates somehow could have been calculated for locations where

---

[3] The statistical likelihood was a function of the unknown parameters $\kappa$ and $\mu_i$, where $i = 1, 2, \ldots$, indexed the various DASARs receiving the call. The statistical likelihood represented the probability of observing the bearings given hypothetical values of $\mu_i$ and $\kappa$. To assure that all $\mu_i$ intersected at a common point, the statistical likelihood was re-parameterized by setting $\mu_i = arctan((y-y_i)/(x-x_i))$, where $(x_i,y_i)$ was the location of the $i^{th}$ DASAR and $(x,y)$ was the point where all $\mu_i$ intersected. After re-parameterization, the statistical likelihood was a function of the unknown parameters $x$, $y$, and $\kappa$. Given estimates of $\kappa$ from the calibration data, estimates of $x$ and $y$ (the call's location) were obtained by repeatedly evaluating the statistical likelihood over a range of values until the probability of the observed bearings was maximized. The $(x,y)$ point that maximized the statistical likelihood was used as the estimate of the call's location.

$a$ could not be computed, the locations' weights in the analysis would have been small because these locations were generally far from the DASARs and involved intersections of similar bearings.

To display precision of estimated call locations near the DASAR array, values of $a$ and $\sqrt{a}$ were associated with the call's estimated location and smoothed using a simple moving window average. The moving window average at a particular point $(x',y')$ was computed by centering a 2 km × 2 km square window on $(x',y')$ and averaging all values inside the window. Values of $a$ represented the magnitude of statistical weight used in the quantile regression. Values of $\sqrt{a}$ represented the average error vector length as quantified by the approximate average of the lengths of the major and minor axes of the error ellipse.

### *High Background Noise Cutoff*

A potential source of bias existed in the data because whale calls are more difficult to detect during times of high background noise. This difficulty in detecting calls could introduce bias into the analysis because calls far from the DASARs that would be detectable at times of low noise could go undetected by the hydrophone system during times with high background noise. If this happened, large distances from shore would be over represented in the data at times of low background noise. This could potentially cause us to conclude that offshore displacement was occurring at such times, and conversely could hide a possible offshore displacement during times with high background noise. To assess this potential bias, distance from the "CBa" unit in the center of the DASAR array (Fig. 8.1) to each call was calculated, and these distances were summarized for times with high and low levels of background noise (see Fig. 8.21 in "Results"). A cutoff distance was established at a distance where the number of calls detected under high-background-noise conditions dropped appreciably. (As described in the "Results", a 12 km cutoff distance was chosen.) Observed calls were eliminated from analysis if their calculated positions were outside the area defined by the cutoff distance (as measured from the CBa DASAR) and if they were also beyond that distance from a straight line connecting the CBa unit with Northstar Island itself.[4] Based on these conditions, we included calls detected within an area consisting of a 24-km-wide rectangle oriented NNE from Northstar to CBa (a distance of 16.63 km) and topped with a half circle of radius 12 km at the offshore end.

Background noise levels used to determine the cutoff were broadband (10-500 Hz) levels recorded at the DASAR farthest from Northstar, the NEa unit (Fig. 8.1). For this DASAR, the average broadband pressure level was available for a 1-min period once every 15 min. High noise conditions were defined to be times with broadband noise levels greater than the 75th and 90th percentiles of all noise levels measured in this way at NEa. Low noise conditions were defined to be times with broadband noise levels less than the 25th percentile.

### *Offshore Distances*

The offshore distances of whale calls were measured perpendicular to a baseline approximately parallel to the Beaufort Sea coast and through Northstar Island. These distances were then analyzed relative to underwater sound level near Northstar in order to determine whether there was evidence of an offshore deflection of calling whales when Northstar (or vessels near Northstar) produced large amounts of underwater sound.

---

[4] The second criterion was included to retain in the analysis the very small number of calls detected at locations more than 12 km inshore of CBa and close to Northstar (see Fig. 8.21, later), on the rationale that these were the most likely to be affected by Northstar and needed to be retained in the analysis.

The baseline used for these calculations was oriented 108° right of true north (109.4° relative to our UTM grid orientation). Two UTM points on this line were (0, 7975362.82) and (1000000, 7623202.82). The location of Northstar Island was 70.491581 latitude, 148.693517 longitude (NAD 1927), or WGS-84 UTM location (436747, 7821558). Assuming $(x,y)$ was the estimated location of a whale call and $(x_1,y_1)$ and $(x_2,y_2)$ were two points on the baseline, the perpendicular distance from the whale call to the line was

$$D=\sqrt{(x-x_p)^2+(y-y_p)^2}$$

where

$$x_p = x_1 + u(x_2 - x_1),$$
$$y_p = y_1 + u(y_2 - y_1),$$

and

$$u=\frac{(x-x_1)(x_2-x_1)+(y-y_1)(y_2-y_1)}{(x_2-x_1)^2+(y_2-y_1)^2}.$$

### *Analysis of Offshore Distance and Sound*

To detect and quantify any offshore displacement of calling whales during times of high industrial sound, we applied a technique called quantile regression (Koenker and Bassett 1978). Our approach acknowledged that some amount of displacement (or some change in calling behavior) might occur at high-sound times, and we estimated the size of that displacement. We did not test a null-hypothesis of no displacement. Both approaches, estimation of the amount of displacement and hypothesis testing, are valid and can arrive at the same conclusion. The estimation approach was adopted for the following reasons: *(1)* It was acknowledged prior to data collection that the null hypothesis of no displacement may not be true. *(2)* If a null hypothesis of no displacement were tested, an important effect might be declared non-significant if statistical power were low, or an unimportant effect might be declared significant if variability were less than anticipated. *(3)* The estimation approach was simpler conceptually and avoided difficulties in interpretation that would arise if the study failed to reject the null hypothesis of no displacement.

The underlying sound avoidance model used here assumes that calling whales in the general Northstar area increase their distance from shore (or call less often) as sound from Northstar, including nearby vessels, increases. Under this model, maximum displacement is expected during periods of high Northstar sound when calling whales would, in the absence of that sound, be expected to occur near Northstar. Displacement is expected to diminish as sound levels near Northstar decrease and/or as initial distances of the whales from Northstar increase. Whales far from shore are expected to show little or no displacement at high-noise times due to the decay of received sound levels with distance. As a result, displacement of the lower tail of the distance-from-shore distribution would provide evidence for offshore displacement of calling whales.

The 5th percentile of offshore distance quantified the position of the distribution's lower tail. The 5th percentile of offshore distance was the distance below which 5% of all distances included in the

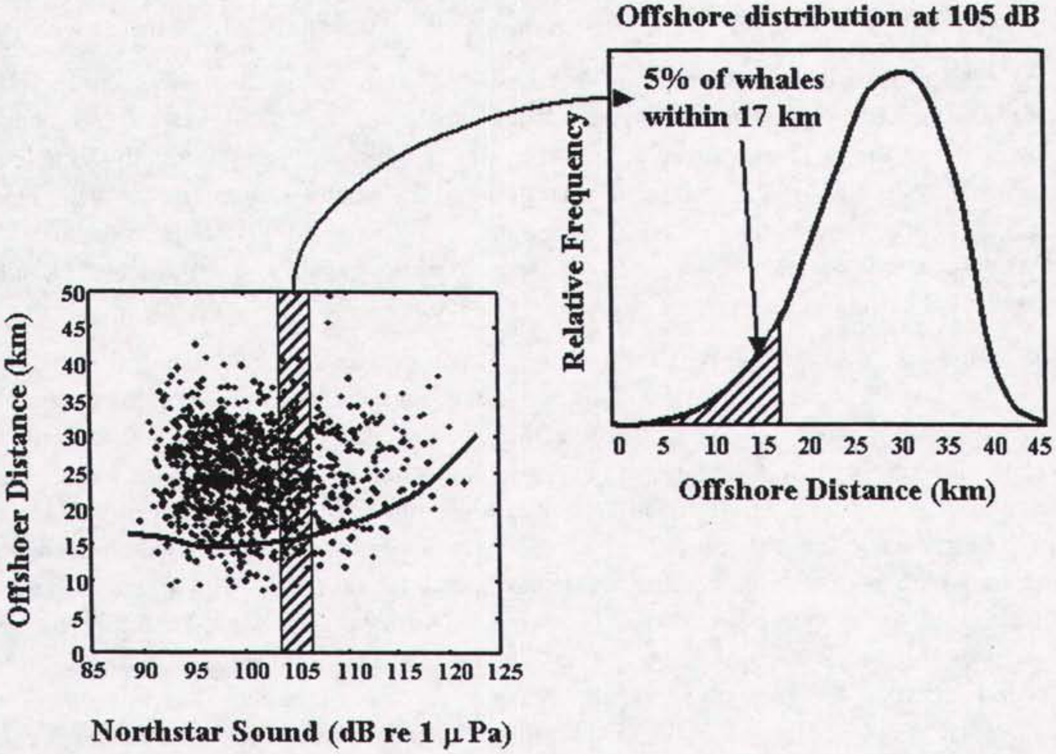


FIGURE 8.10. Pictorial representation of the quantile regression method. Offshore distance is the perpendicular distance from the location of a calling whale to a line drawn parallel to shore and through Northstar (=Seal) Island. Northstar sound is a measure of the level of underwater sound as received at a constant location near the island. Quantile regression connects the 5th percentile of offshore distance in successive small intervals of sound level. If calling whales are displaced (or if calling becomes less frequent) during periods with high levels of Northstar sound, there should be few points in the lower right corner of the left-hand scatter plot.

analysis area occurred.[5] An increasing or positive relationship between the 5th percentile of offshore distance and industrial sound levels was taken as evidence that whales were being displaced away from shore during periods of high underwater sound near Northstar, or that whales close to Northstar were calling less often than normal. Although these two effects are not readily distinguished based on the call data alone, either of these effects would (if demonstrated) constitute an effect of Northstar on the behavior of the whales. The estimation approach is diagramed in Figure 8.10.

Under this approach, the key question was nature and slope of the relationship between sound level near Northstar and distance offshore. If an appreciable positive relationship were found, estimates of the displacement of calling whales at given sound levels could be computed by subtracting estimated 5th quantile distance at a low sound level from that at the given sound level. For example, if the quantile

---

[5] The area considered extended northeast 12 km beyond the CBa DASAR, i.e., to a location 7 km beyond the NE DASAR and 28.6 km from Northstar (see Fig. 8.1 and Fig. 8.21, later). Offshore distances of migrating bowhead whales vary from year to year, but in an average year about half of the bowheads are beyond 28.6 km offshore of Northstar (LGL and Greeneridge 1996; Miller et al. 1999; Treacy 2000). Thus, in a typical year, no more than 2.5% of the migrating bowheads would be expected to travel west inshore of the 5th percentile distance as defined here.

regression line was flat or decreasing up to a sound level of *z* dB and we wished to estimate displacement of the 5th quantile at *w* dB ($w>z$), we would subtract the estimated 5th quantile at *z* from that at *w*.

To estimate the relationship between the 5th percentile of offshore distance and sound level near Northstar, quantile regression (Koenker and Bassett 1978) was employed to fit a smooth function of sound to the lower tail of the offshore distances. Because this relationship was potentially complex and the level of Northstar sound that might induce an effect on calling whales was unknown, we estimated linear, quadratic, and cubic models relating Northstar sound to 5th percentile of offshore distance. The best fitting of the three models was then chosen, and approximate lower 95% confidence bounds on predicted values were constructed.

Northstar sound levels associated with each whale call were calculated over the 5, 15, 30, and 60 minute periods preceding the time of the call. This was done because the duration of sustained sound necessary to induce a calling whale to displace (or to call less often) was unknown. For example, a short burst of loud sound lasting less than 5 minutes might not induce a calling whale to displace or change its calling behavior, but sustained exposure to strong sounds for 60 min or more might cause such an effect. Each summary of Northstar sound was calculated by defining an appropriately sized window of time prior to the call within which observations of the Industrial Sound Index (ISI), as defined earlier, were averaged. For example, to determine the 60-min summary of Northstar sound that should be associated with a call that occurred at 12:00 on 5 Sept, all observations of ISI obtained 400 m from Northstar between 11:00 and 12:00 on 5 Sept were averaged. Because ISI was measured for 1 min out of every 4.37 min, this average would be based on 13 or 14 values. Separate quantile regressions were run to relate offshore distance to each of the four Northstar sound summaries.

Estimated quantile regression coefficients, $\hat{\beta}$, were obtained by minimizing a sum of weighted residuals, where the weights depended on precision of the call location and whether or not the observation was above or below the estimated quantile line. Specifically, let $y_i$ be the ith observed offshore distance and $\mathbf{X}_i$ be the ith vector of industrial sound values associated with $y_i$. For example, in the quadratic model, the vector of predictor variables, $\mathbf{X}_i$, equaled [ 1, ISI, ISI$^2$]. Once an initial guess of $\hat{\beta}$ was constructed, residuals were calculated as $r_i = (y_i - \mathbf{X}_i \hat{\beta})$. Weights associated with the precision of the *i*-th call were calculated as $w_{1i} = n(a_i^{-1}) / \sum_{j=1}^{n} a_j^{-1}$, where *n* was the number of call locations. Weights associated with the quantile were calculated as $w_{2i}=\tau - I(r_i < 0)$, where $I(\cdot)$ was an indicator function taking the value 1 if $r_i < 0$, 0 otherwise, and $\tau=0.05$ for the 5th percentile. The sum of weighted residuals was then calculated as

$$swr = \sum_{i=1}^{n} r_i w_{1i} w_{2i} = \left( n / \sum_{j=1}^{n} a_j^{-1} \right) \sum_{i=1}^{n} r_i a_i^{-1} [\tau - I(r_i < 0)].$$

Final estimates of coefficients were the values that minimized the sum of weighted residuals, i.e.,

$$\hat{\beta}_\tau = \min_\beta \{swr\} = \min_\beta \left\{ \sum_{i=1}^{n} r_i w_{1i} w_{2i} \right\}.$$

Because the inverse of error ellipsoid area was in the minimizing function, observations far from the center of the DASAR array and/or calls with poor precision were down-weighted during the estimation process.

We performed the minimization using the nonlinear optimization routine *nlminb()* available in S-Plus (version 2000). This routine implements a Newton-Raphson type search algorithm to find the minimum sum of weighted residuals.

### Allowance for Interdependence of Calls

Because individual whales could not be identified from their calls, it was impossible to know whether two calls detected at similar times were from independent whales. This caused a potential dependence among distances derived from calls occurring at similar times. As a result, it was necessary to employ statistical inference techniques that do not rely on independence of individual calls.

Our inference technique used bootstrapping (Manly 1997) to construct an approximate lower 95% confidence bound on the 5th percentile line by first determining the amount of elapsed time required before calls were independent, and then randomly resampling independent intervals of time, within which distances were correlated. When a time interval was randomly selected for inclusion in a bootstrap sample, all distance observations occurring in the time interval were included in the bootstrap sample. Due to a general reduction in the number of whale calls detected during the latter half of the study (see Fig. 8.18, later), the set of time intervals occurring after 15 Sept were viewed as different from the set of time intervals occurring before 15 Sept. Because of this, a stratified bootstrap approach was adopted wherein time intervals prior to 15 Sept were resampled separately from time intervals after 15 Sept. The bootstrap approach was justified under the view that the two sets of observed time intervals before and after 15 Sept were random samples of time intervals that could have occurred during their respective periods. Under this view, a random sample with replacement of observed time intervals from each period contains the same amount of correlation and variation as the original sample of intervals.

The time interval to resample during bootstrapping equaled elapsed time necessary for distance measurements to become uncorrelated. This was estimated using Moran's I statistic (Moran 1950) and the observed autocorrelation function (acf). Individual Moran's I statistics at a particular lag time were deemed significantly different from zero if a Bonferroni corrected 95% confidence interval did not contain zero.

Assuming that the elapsed time necessary for offshore distance measurements to become uncorrelated was $t$, the resampling approach that constructed point-wise lower bounds for the true 5% quantile line, with approximate 95% confidence, proceeded as follows:

1. Assuming the first call was detected at time $t_0$, a random time between $t_0$ and $t_0 - t$ was chosen for the start of a grid of time intervals. Let this random time be denoted by $m$.
2. Assuming the total length of time between the first and last whale call was $\Delta t$, a grid of time intervals was defined to be $(m, m+t]$, $(m+t, m+2t]$, …,$(m+(k-1)t, m+kt]$, where $k = \lceil \Delta t/t \rceil$, the smallest integer greater than $\Delta t/t$. The grid of time intervals was then divided into those occurring before 00:00 on 15 Sept (midnight the night of 14-15 Sept) and those that included or occurred after that time. Let the number of intervals occurring before that time be $k_1$ and the number thereafter be $k_2 = k - k_1$.
3. A random sample of size $k_1$ was chosen with replacement from among the $k_1$ time intervals occurring before 15 Sept. A separate random sample of size $k_2$ was chosen with replacement from among the $k_2$ time intervals occurring thereafter.
4. All whale calls in the $k_1+k_2$ randomly chosen time intervals were put into a bootstrap sample and the quantile regression was estimated on this set of bootstrap data. Because sampling of time intervals was done with replacement, any particular interval could have been chosen multiple times. If a time interval was chosen more than once, the whale calls from that interval were included in the bootstrap

sample multiple times. If no whale calls occurred in a particular time interval, no whale calls were included in the bootstrap sample for that interval (i.e., intervals with zeros were included).

5. Steps 1 through 4 were repeated 500 times. The estimated 5th percentile quantile regression line was saved after each repeat.
6. The approximate lower 95% confidence bound was constructed by connecting the lower 5th percentiles of estimated 5th-quantile regression values over the range of sound (ISI) values. To illustrate, 500 predicted 5th quantile offshore-distance values were available at an ISI level of 100 dB after completion of step 5. Those 500 predicted values were sorted and the 5th percentile was plotted at sound level 100 dB. This represented the ~95% lower confidence bound for the 5th quantile of offshore distance at the 100 dB ISI level. The entire lower ~95% confidence bound was constructed by connecting values obtained in similar fashion, i.e., connecting 5th percentile of bootstrap values, for each sound (ISI) level 400 m from Northstar.

Under the estimation approach, no formal hypothesis was tested and no *P*-values were computed. Rather, the observed 5% quantile regression line was estimated and its approximate lower confidence bound was constructed. The minimum displacement of the 5th percentile of offshore call distances was estimated based on any increase in the approximate lower confidence bound evident at high levels of Northstar sound.

Estimates of the displacement of whales for a given sound level (ISI) were computed by subtracting the estimated 5th quantile at a low ("baseline") ISI from that at a given ISI. Approximate confidence bounds on displacement were calculated in a parallel fashion during the bootstrap procedure. A lower ~95% confidence bound for displacement when ISI increased from $z$ to $w$ dB was calculated by subtracting the fitted 5th quantile at $z$ dB from the 5th quantile at $w$ dB at each iteration of the bootstrap procedure. This produced 500 estimates of displacement when ISI levels (as measured 400 m from Northstar) reached $w$ dB. The 5th percentile of these 500 values constituted an ~95% lower bound on displacement at $w$ dB.

## RESULTS

This section is organized with five subsections, concerning results of (1) the ping calibration measurements, (2) near-island sound measurements, (3) DASAR long-term noise measurements, (4) whale call localization, and (5) whale call locations relative to near-island sound levels.

### *Ping Calibration Results*

Ping calibration transmissions were made on 30 and 31 Aug and on 6, 15, 23 and 29 Sept. Not all units were operating for all calibration transmissions, and the number of pings used in the calibration estimations depended on the number of pings received and recorded.

#### *Time Calibration*

A least-squares fit of the ping time error versus GPS time, done separately for each DASAR, gave a well defined slope and intercept for each DASAR. Clock drift for the various DASARs ranged from -3.18 to +1.53 seconds per day. This enabled a simple calculation of the time correction required in order to estimate the GPS time associated with each whale call detected by a given DASAR. We estimate that, after application of the correction factors for clock drift, the GPS times of most whale calls were estimated within 2 s. This allowed unambiguous matching of calls received by one DASAR with those received at corresponding times by other DASARs.

### *Reference Axis Calibration*

There was much greater scatter in reference bearings determined from pings in the same test series than was desired or expected. Pings emitted and received within seconds of each other, with the source (and DASAR) locations being essentially unchanged from ping to ping, could differ in apparent bearing by 20° to 30°. Bearings from the single-frequency bursts (p300 and p400 in Fig. 8.9) were the most variable, even when the signal-to-noise (S/N) ratio was high. The frequency-sweeps provided more consistent bearings, but there were still spreads of 10° or more. Bearing errors are most likely the result of interfering sounds arriving simultaneously from other bearings, especially lateral multipaths. The greater bandwidth of the sweeps minimizes the possible influence of such interference. Figure 8.9A presents results from DASAR SEa as an example, and Figure 8.9B presents results for DASAR NEa. Results from the other DASARs were comparable.

The horizontal axis represents the sample number of each calibration ping received by a given DASAR, in time sequence. Vertical lines separate the different days on which calibration pings were made. The vertical axis is the measured grid bearing of the DASAR reference axis (the difference between GPS grid bearing and measured reference bearing) for each ping. Each symbol represents the bearing derived from one calibration ping. The symbol type represents the type of ping used, and the color of the symbol indicates the minimum signal-to-noise (S/N) ratio measured.

These Figures show the data remaining after editing out the wild pings, i.e., those at angles >30° from the nominal average angle. Most wild points corresponded to tonal pings with low S/N, for which interference effects were greatest. As noted in Figure 8.9A, for DASAR SEa the average of the plotted ping angles is 29.6° with a standard deviation of 9.1°. For other DASARs, the standard deviations ranged from 3.3° to 13.2° (Table 8.1). For some DASARs, there was less spread when only measurements with sweeps were included, and for others there was less spread when all the measurements, pings and sweeps, were included. Generally the data sets with less spread were used for estimating the reference axis directions.

In general, the scatter was greatest for the 400 Hz single-frequency pings. Within that group, the greatest scatter was for pings that had low S/N. However, once the largest outliers were edited out, the scatter among the remainder did not show much dependence on S/N. The sweeps showed less scatter within the local groups of pings and thus individual values tended to be closer to the average. However, there was still variation among results from groups of sweeps made at different times. Put another way, there appear to be unexplained time-variable biases in the groups of ping angles.

Plots were made of the same reference-axis data vs. calendar time and vs. grid bearing to the source of the ping in searches for functional dependencies that might account for some of the variability, and thus increase precision of bearing data. There was no apparent time dependence in the reference-axis values for most DASARs. In a few cases where one or more of the DIFAR channels later failed, there were changes in mean reference-axis value towards the end of the period of operation. All data taken during such "failure imminent" times were ignored. In some DASARs there was just the barest hint of a dependence on bearing to the ping, but this was of the order of a few degrees and very small compared to the overall scatter. Such dependence might have been caused by any of the following:

- transducer tilt
- unbalanced gain in the DIFAR directional channel
- DASAR location error.

TABLE 8.1. Measured reference bearing, standard deviation, and number of pings used in the reference bearing estimation for each of the 2001 DASARs.

| DASAR[†] | Mean or Median | Standard Deviation | No. of Pings Used |
|---|---|---|---|
| CAa | 209.8 | 9.0 | 211 |
| CBa | 243.7 | 7.4 | 140 |
| CBb | 226.2 | 13.2 | 115 |
| CBc | 114.7 | 3.3 | 266 |
| CCa | 172.5 | 7.4 | 81 |
| EAa | 183.2 | 5.0 | 147 |
| EAb | 249.6 | 3.5 | 256 |
| EBa | 211.2 | 5.1 | 130 |
| NEa | 177.0 | 5.9 | 446 |
| NWa | ** | | |
| SEa | 29.6 | 9.1 | 473 |
| SWa | 220.2 | 6.4 | 201 |
| SWb | * | | |
| WAa | 186.4 | 8.7 | 405 |
| WAb | 123.6 | 4.0 | 154 |
| WBa | 36.7 | 5.6 | 811 |

[†] Third character (a-c) distinguishes 1st, 2nd, and 3rd deployments at locations where the DASAR was replaced one or two times during the season.

*=No Pings **=DASAR Failed

In the absence of a clear dependence on any of these factors, it was decided to use the mean or the median of the edited bearings to define the reference axis for each DASAR. The differences between mean and median values were generally less than 2°. Variability in bearings is further addressed in the "Discussion" section. Uncertainty in the positions of calling whales has been allowed for in the statistical analysis of call locations vs. industrial sound through incorporation of a weighting factor related (inversely) to the potential position error for each localized whale call (see "Methods", above).

## *Underwater Sounds near Northstar*

The cabled hydrophone and ASAR signals from the sensors positioned near Seal Island were analyzed to determine the broadband sound level (10-1000 Hz). Figure 8.11 shows the broadband sound pressure level vs. time for the full 28 Aug – 3 Oct 2001 period considered here, as measured via Cabled Hydrophone #2 located 400 m NNW of Seal Island (Fig. 8.2). The apparent spikes are generally due to boats and tugs coming and going from the island. The lowest levels in the graph are indicative of the quietest times in the water near the island.

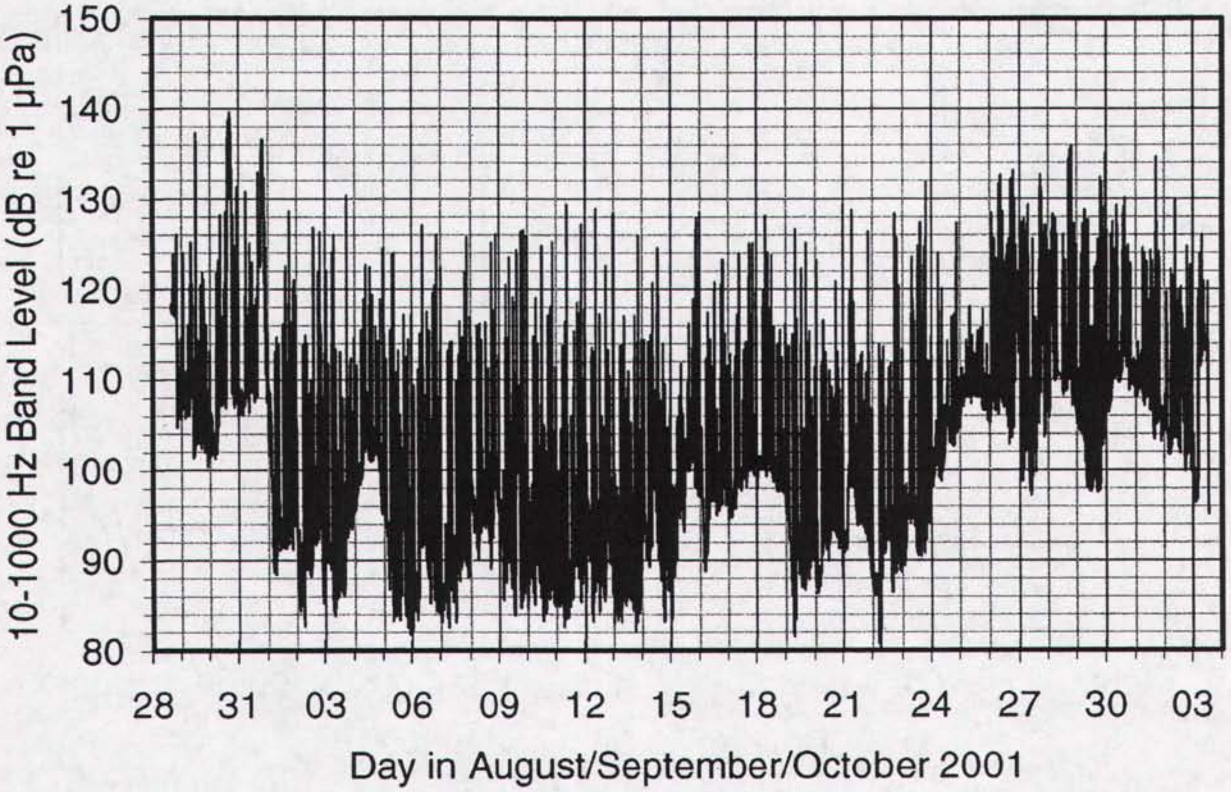


FIGURE 8.11. 10-1000 Hz broadband sound pressure level vs. time 1300 ft (400 m) north-northwest of Seal Island, from cabled hydrophone system #2, 28 Aug to 3 Oct 2001.

Figure 8.12 shows a sample of the same data limited to the two days 2 and 3 Sept. The nature of the spikes is revealed in these graphs. They correspond to the arrival and departure of vessels traveling back and forth from West Dock. Later in the report, the whale call locations will be presented for these same two days as examples of the localization results.

To characterize the sounds near Northstar during the study period in 2001, one-third octave band levels were calculated for Cabled Hydrophone #2 on a systematic basis over the operating life of the unit. Starting on 28 Aug at 14:44:32 and ending on 3 Oct at 13:31:26, 11,486 spectrum analyses were calculated. Each analysis represented the average sounds over a 1-min period starting 4.37 min after the start of the last such period. One-third octave band levels were computed by integrating over the appropriate frequency cells for each standard center frequency from 10 through 800 Hz. For each center frequency, the 11,486 levels were sorted from smallest to largest in order to determine the minimum, 5th-percentile, median, 95th-percentile, and maximum level. Those values, when plotted, resulted in the five statistical spectra shown in Figure 8.13. Note that these are one-third octave band levels, not spectral density levels. The only dominant peak occurs for the one-third octave band centered at 63 Hz, and then only in the 95th-percentile spectrum. The standard U.S. power line frequency of 60 Hz occurs in the band centered at 63-Hz, which extends from about 56.1 to 70.7 Hz. When the sound level was high (95th percentile), a strong component at the power line frequency was con spicuous. The rolloff in level for frequencies below 63 Hz, or below 31.5 Hz for the minimum and 5th-percentile levels, probably comes from a combination of (1) lower levels at the sources on and near the island and (2) waveguide cutoff over the 400-m path from the island to the hydrophone.

Related data from the ASARs deployed near Northstar are presented in Chapter 7.

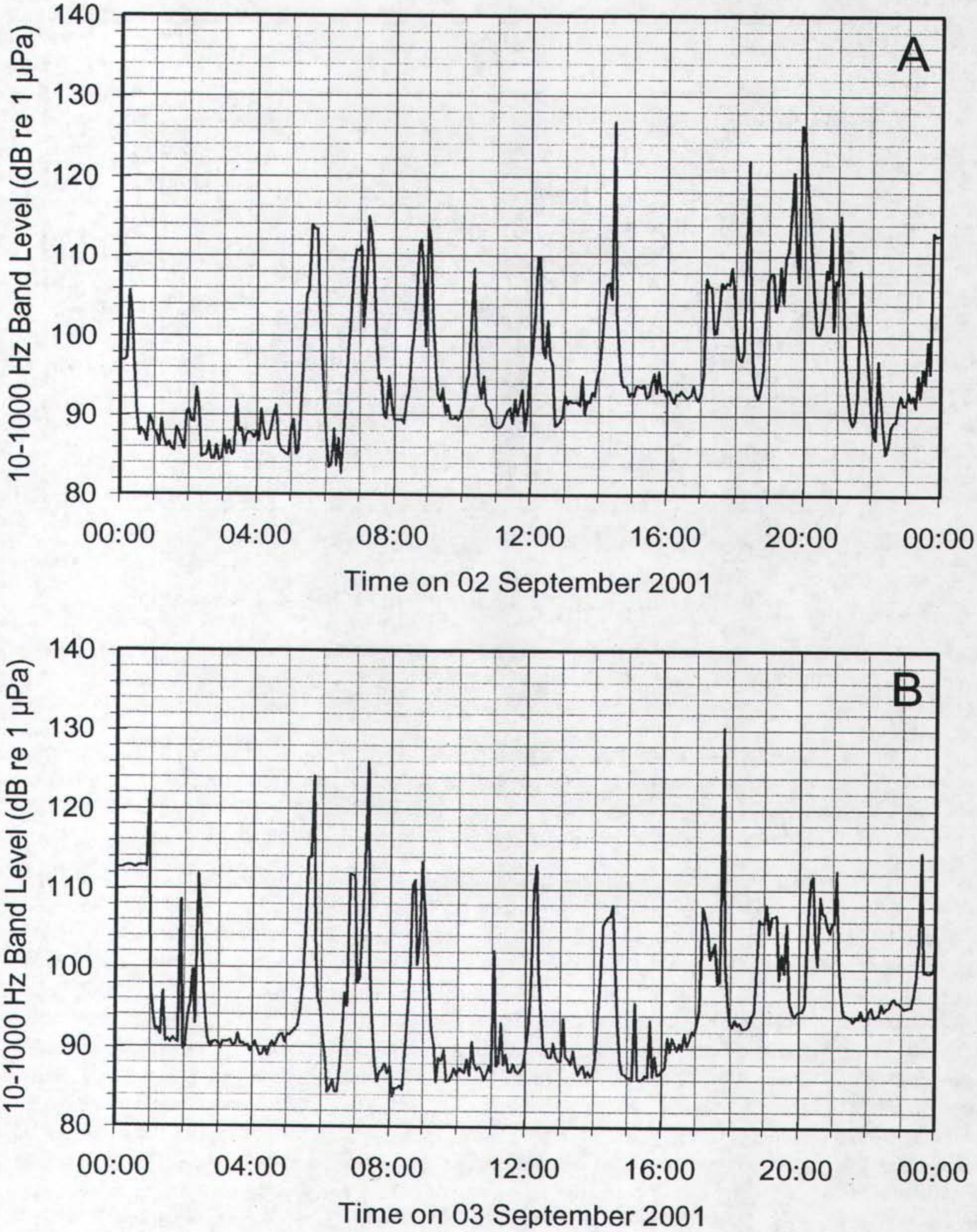


FIGURE 8.12. 10-1000 Hz broadband sound pressure level vs. time 1300 ft (400 m) north-northwest of Seal Island, from cabled hydrophone system #2, for ***(A)*** 2 Sept 2001, and ***(B)*** 3 Sept 2001.

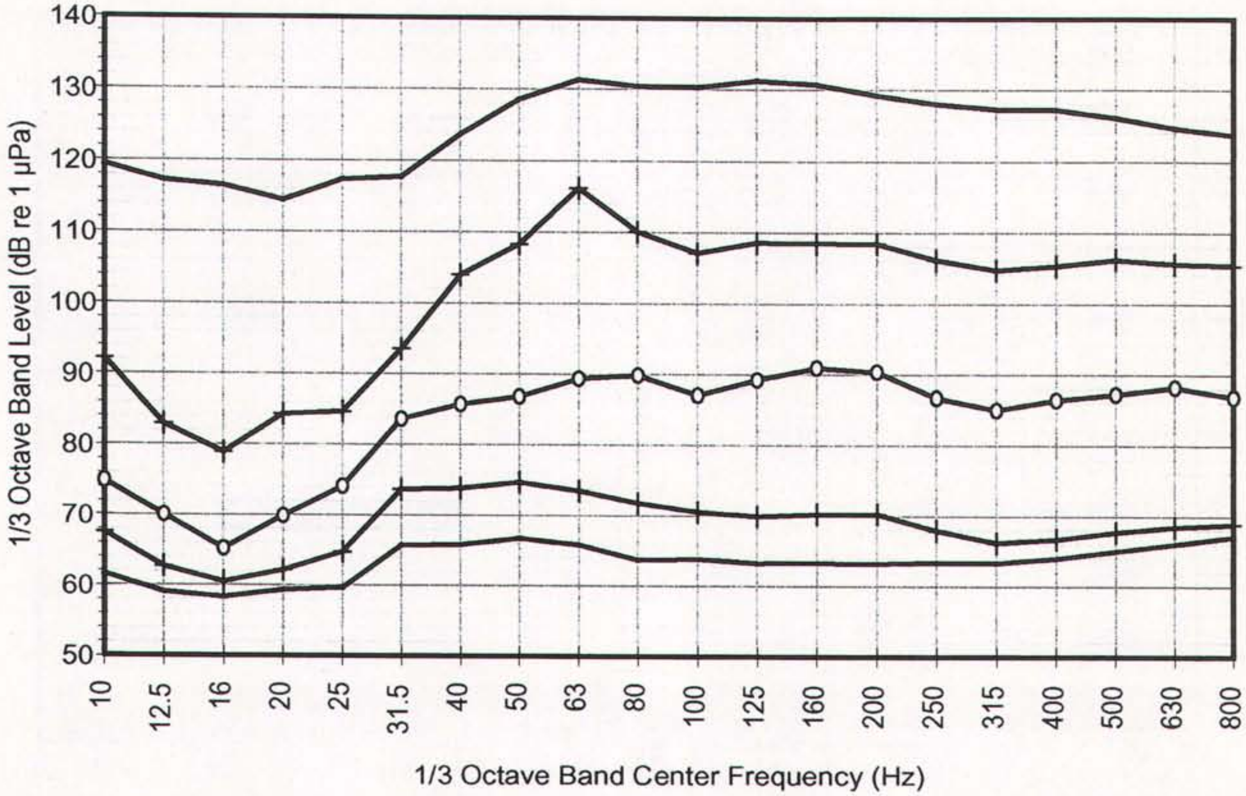


FIGURE 8.13. One-third octave band levels vs. center frequency for the minimum, the 5th-, 50th- and 95th-percentile, and the maximum observed near Northstar via Cable Hydrophone #2 during the period 28 Aug – 3 Oct 2001. Each statistical spectrum is based on 11,486 one-minute measurements.

## *Underwater Sounds at the DASARs*

### *DASAR Function Times*

DASAR health was checked weekly when weather and boat availability allowed. No problems were found on 6 Sept, but no check was possible on 13 Sept because the ACS boats were not available for charter. Problems were found when the next check was made on 15 Sept, but it took a few days before the troubled DASARs could be retrieved, restarted, and replaced. Also, the health checks did not reveal sensor problems, and some DASAR sensors failed during the monitoring period without our knowledge. Most unfortunately, the DASAR at NW (see Fig. 8.1) failed shortly after installation although it wrote to its disk successfully for the duration of the field effort and thus "passed" each health check.

Figure 8.14 shows the dates during which each of the DASARs recorded valid data. For the first nine days after deployment, valid data were acquired from 10 of the 11 DASARs (i.e., from 9 of 10 DASAR locations, given that the co-located CA and CB units were both providing data). From then through 28 Sept, data were acquired from at least six DASARs at almost all times (only 5 for a portion of 26 Sept). After 28 Sept there were additional DASAR failures. It had been intended to retrieve the equipment on 30 Sept. However, bad weather prevented retrieval until 2 and 3 Oct, when all deployed DASARs were retrieved successfully. Boat operations ceased for the season on 4–7 Oct because of formation of new ice, confirming that the decision to retrieve the equipment had been timely.

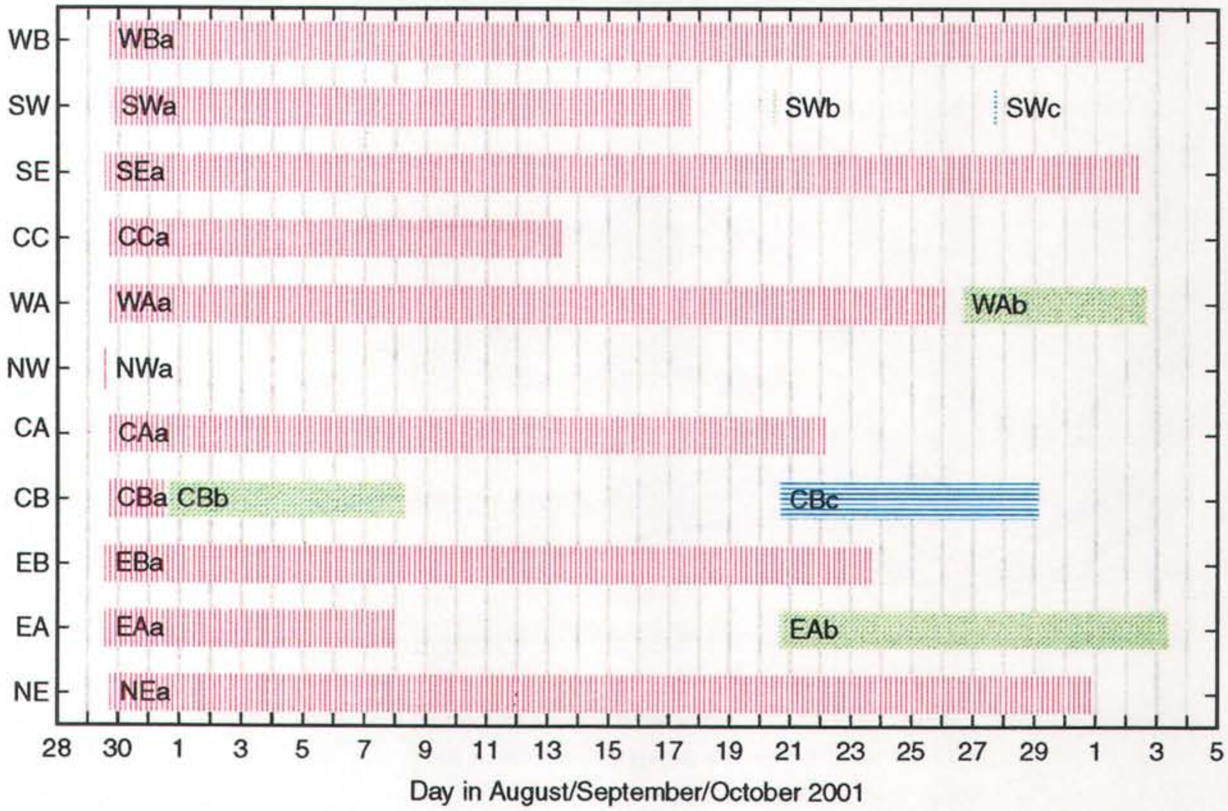


FIGURE 8.14. Successful data collection times for all the DASARs during the 2001 field season. Blanks and gaps are the result of failed sensors or recording breakdowns.

### *DASAR Sound Levels*

The DASAR sounds were recorded continuously and analyzed minute by minute to find and characterize every whale call detected by every DASAR. For background sound measurements, three-minute periods were chosen every 15 minutes for broadband analysis, i.e., to determine the sound pressure level in the 10-500 Hz band. This 15-minute analysis period results in 96 analyses/day, close to the 100 analyses/ day performed with the ASAR data (see Chapter 7). Exceptions were made when the selected 3-min period coincided with the noise from disk writing. In those instances, the 3 min sample was selected at a close time that did not include any disk writing.

The results for three specific DASARs that operated during most or all of the field season are presented in Figure 8.15. Some of the "spikes" in the graphs represent sounds from nearby boats, including approaches by our chartered vessel when it was conducting DASAR health checks and calibrations. However, there are also low-frequency background sounds of unknown origin.

## *Sources and Radii of Detectability for Northstar Sounds*

The sounds received at the DASARs (described above) are a combination of natural ambient and, at times, Northstar-related sounds, in varying proportions. It is of interest to consider how far from the island the island-related sounds might be detectable during times with varying levels of island noise and ambient noise. The important one-third octave bands for industrial noise were determined to be centered

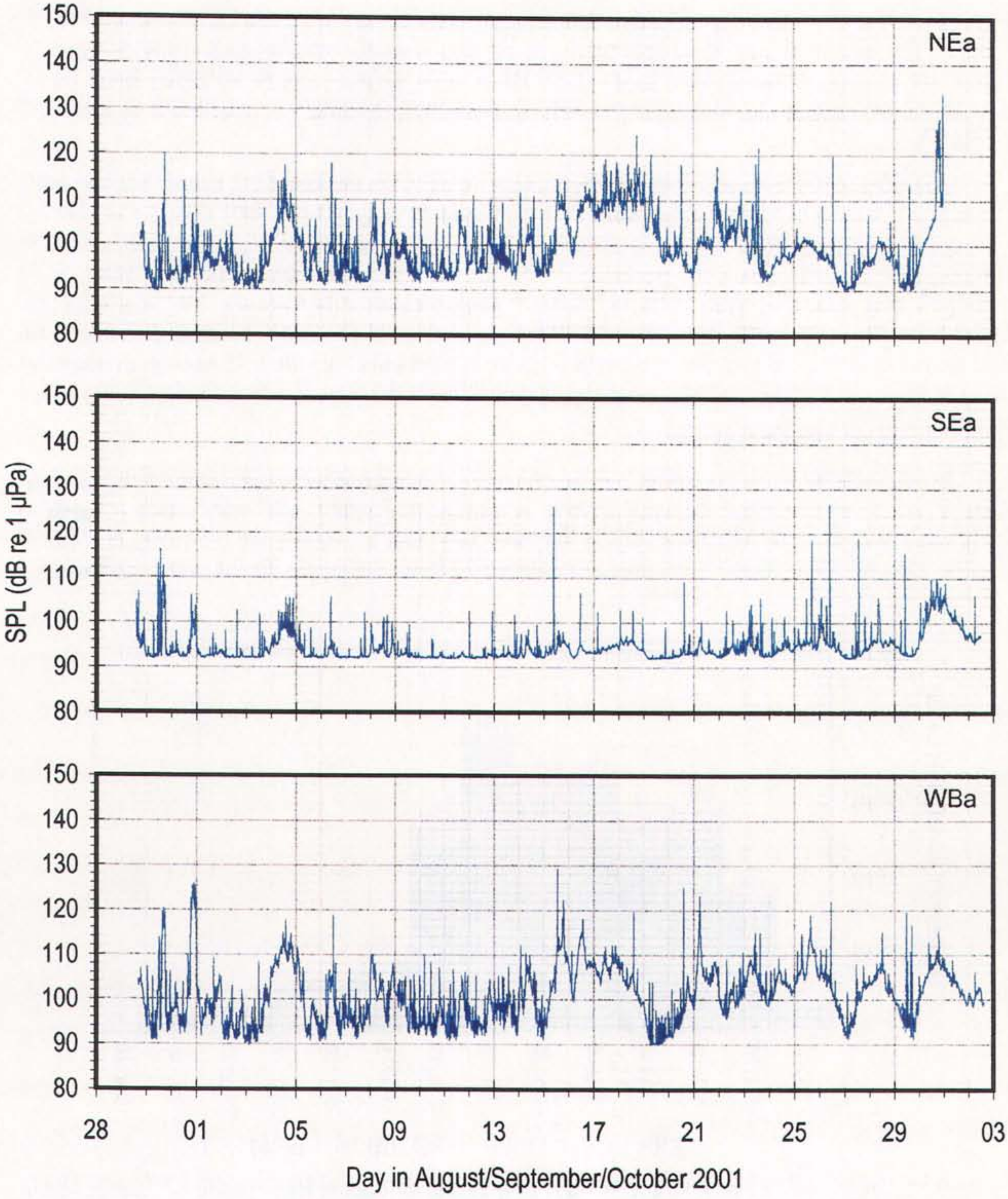


FIGURE 8.15. 10-500 Hz broadband sound pressure levels vs. time from three DASARs: **NEa**, **SEa**, and **WBa**. (See Fig. 8.1 for DASAR location names.) The data do not span exactly the same amount of time because the recorders stopped recording at different times.

at 63, 80 and 160 Hz. Thus, the "Industrial Sound Index" (ISI) was defined as the cumulative sound level in those three bands. During September 2001, the ISI was measured directly via a cabled hydrophone located 400 m north of Northstar. Levels of the ISI at other distances can be estimated based on the approximate attenuation rate of sounds propagating away from Northstar, as determined in Chapter 7 (15 log R).

Data from cabled hydrophone #2 (400 m from the island) were analyzed for 1-minute intervals every 4.37 minutes, leading to 11,847 observations over the period 28 Aug to 3 Oct 2001 (Fig. 8.11). The ISI levels for each of these observations, when compiled into a frequency distribution (Fig. 8.16), had a 5th percentile of 77.8 dB re 1 μPa, a 50th percentile of 95.7 dB, and a 95th percentile of 118.5 dB. These values differ from those plotted in Figure 7.21B (in Chapter 7) partly because of the narrower "ISI" bandwidth considered here. (On average, ISI values were 5.8 dB lower than those determined at the same time for the 10-1000 Hz band.) Also, the two analyses are based on data from somewhat different (though overlapping) ranges of dates, and from hydrophones located at slightly different distances from Northstar.

### *Main Sources of Northstar Sound*

To assess the ISI levels associated with specific types of sound sources, we re-examined the measurements at various distances from particular sources, as obtained in the 2001 open-water season (Chapter 7) and in other seasons. The data from varying distances were used to estimate the ISI values at a 400 m distance. Only the sound energy in the three one-third octave bands comprising the ISI were considered.

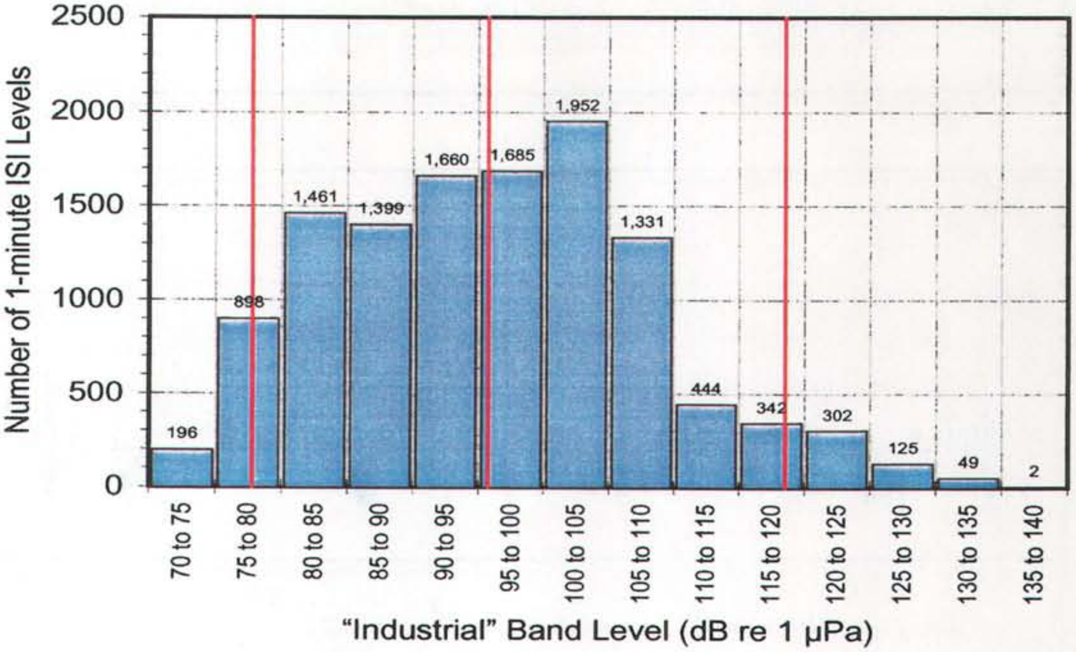


FIGURE 8.16. Histogram of industrial sound index (ISI) values for Cabled Hydrophone #2 located 400 m from Northstar, 28 Aug to 3 Oct 2001. The ISI is the cumulative sound level in three one-third octave bands, centered at 63, 80 and 160 Hz. Each ISI value is a 1-min average, with 11,846 such values being determined for the study period (one every 4.37 minutes). The three vertical lines, from left to right, show the 5th, 50th, and 95th percentiles of these ISI levels (77.8, 95.7 and 118.5 dB re 1 μPa).

Maneuvering by tugs and other vessels resulted in the highest ISI values, as expected from the results in Chapter 7. At a distance of 400 m, their ISI levels were on the order of 122 to 135 dB re 1 μPa, consistent with the highest levels found in the continuous series of data from the cabled hydrophone at 400 m from Northstar (*cf.* Fig. 8.16). The ISI level at 400 m when island machinery was operating but no vessels were maneuvering nearby was notably lower (106 dB). No data are available during drilling in the open-water season, but ISI values 400 m from Northstar during drilling in the ice-covered season were 100 dB or below (Table 8.2). Additional types of sounds that are relevant for the Northstar area include the crew boat and drilling sounds during the summer. Although specific data on these are not yet available, both of these types of sounds were recorded during September 2002 and results on a broadband and ISI basis will be forthcoming in the 90-day report on the 2002 open-water work, to be completed in January 2003.

Another potentially relevant type of sound is helicopter sound, although helicopters supporting Northstar do not fly over the bowhead migration corridor offshore of Northstar. No specific measurements of underwater sound from helicopters have been obtained at Northstar, but sound from Bell 212 helicopters (the type used at Northstar) has been measured elsewhere in the Beaufort Sea under both open-water and broken-ice conditions (Richardson et al. 1995; Patenaude et al. 2002). Levels of helicopter sound in the water can be moderately high directly below a helicopter when it is at low altitude, as when on-approach or just after take-off. For example, Patenaude et al. (2002) measured momentary broadband levels of ~110-125 dB re 1 μPa when a Bell 212 flew directly overhead at altitude 250 ft (75 m), probably corresponding to an ISI of about 105-120 dB. Levels diminished rapidly with increasing altitude and increasing lateral distance, as expected from other studies of aircraft sound transmission into water (e.g., Urick 1972).

Overall, these results concerning specific sound sources indicate that the highest ISI levels found 400 m from Northstar were associated with vessels maneuvering nearby. A helicopter flying directly overhead at low altitude (e.g., immediately after takeoff) would also produce relatively strong sound, but this would be momentary, and would diminish rapidly with increasing distance to the side of the helicopter. ISI values at 400 m from typical machinery operations on Northstar Island are substantially lower. Thus, boats generally accounted for the highest levels of sound near Northstar (Chapter 7). When there were no active boats, the sounds recorded 400 m north of the island were distinctly lower. The 90th-100th percentile ISI values were representative of periods with boats active close to Northstar. The 50th and especially the 5th percentile ISI values (Fig. 8.16) were generally times with little or no boat activity.

TABLE 8.2. Industrial Sound Index (ISI) values for three types of sources at or related to Northstar Island, at a distance of approximately 400 m.

| Sound Source | ISI at distance ~400 m (dB re 1 μPa) |
|---|---|
| **Tugs**[1] | |
| Tugs holding barge at Northstar dock | 135 |
| Arrival of barge towed by two tugs | 130 |
| Tugs maneuvering barge at dock | 122 |
| **Island machinery (summer)**[2] | 106 |
| **Winter drilling**: | |
| 2001[3] | 100 |
| 2002[4] | 89 |

[1] From chapter 7 in the present report.

[2] From Blackwell and Greene (2001).

[3] From chapter 3 in the present report.

[4] From Blackwell (2002).

### *Radii of Detectability of Northstar Sound*

The rate at which island sounds diminish with increasing distance away (generally northward) from the island, toward the area of bowhead migration, is reported in Chapter 7. This "spreading loss" is nominally $15 \log(R/R_0)$, where $R_0$ is some reference distance. Because the cabled hydrophone used to monitor the island-related sounds was 400 m from the edge of the island, 400 m is used as the reference distance. Figure 8.17 shows the 5th, 50th and 95th percentile ISI values 400 m from the island (diamonds), and the expected received levels at other distances based on the $15 \log(R/R_0)$ relationship.

Distances at which the industrial components of the sound would be expected to drop below the natural ambient level and become undetectable can be estimated based on previous ambient noise measurements by Burgess and Greene (1999). Their dataset provided measurements of ambient noise by one-third octave band, allowing us to re-compute the ambient noise within the three one-third octave bands contributing to the ISI. Their data were recorded by autonomous seafloor acoustic recorders (ASARs) deployed for acoustic monitoring during a seismic survey in 1998, and included 4929 observations (not all independent) during times when no airgun sounds or sounds from a nearby boat were being detected. The results were

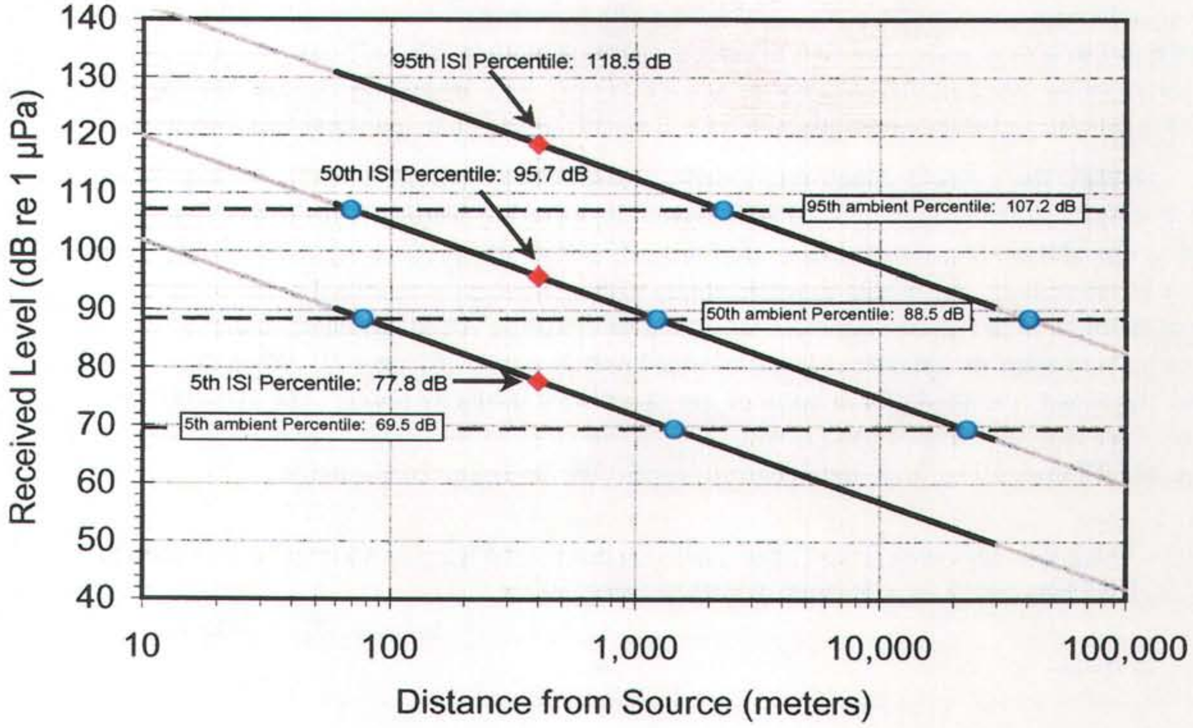


FIGURE 8.17. Estimated maximum detection distances for Northstar industrial sound, late August to early October 2001. Red diamonds show 5th, 50th and 95th percentiles of the industrial sound index (ISI) at a site 400 m from Northstar, based on 1-minute averages computed every 4.37 min using the 2001 C.H.2 data. Sloping lines show estimated ISI levels at other distances, assuming a spreading loss rate of 15 log (R). Gray-shaded extensions of the sloping lines represent expected levels at distances extrapolated beyond the range of 2000-2001 measurements. Horizontal dashed lines represent the 5th, 50th and 95th percentiles values of background sound in the ISI bands as determined with Autonomous Seafloor Acoustic Recorders (ASARs) in 1998; no airgun or boat sounds included (Burgess and Greene 1999). Intersections of the sloping island-sound lines with horizontal ambient sound lines show approximate maximum distances at which island sounds (1-min averages) would be audible underwater with various combinations of island and ambient levels in the ISI bands.

that the 5th percentile level of the ambient noise in the ISI bands was 69.5 dB re 1 μPa, the 50th percentile (median) level was 88.5 dB, and the 95th percentile level was 107.2 dB. These values are less than those quoted in Chapter 7 (Fig. 7.21) because we are here dealing only with the ambient sound in three one-third octaves, whereas the values plotted in Figure 7.21 include a broader bandwidth (20-1000 Hz). The 5th, 50th and 95th percentile levels of ambient noise in the ISI bands have been plotted in Figure 8.17 as horizontal dashed lines, given that ambient noise is postulated not to change with distance from the island.

In Figure 8.17, the intersections of the sloping "received level" lines with the horizontal "ambient noise" lines define the approximate distances where the ISI would diminish below ambient under varying conditions, i.e. distances where industrial sound would become undetectable. Table 8.3 summarizes the distances denoted by the intersections. These distances are larger than those derived in Chapter 7 based on consideration of the full 20-1000 Hz band. This is to be expected, given that the ISI bands considered here contained a higher proportion of the total industrial sound than of the total ambient sound. Thus, the industrial-to-ambient ratio for the ISI bands considered here was higher than for the overall 20-1000 Hz band considered in Chapter 7, with the result that the industrial sound level remained above ambient out to a longer distance when only the ISI bands were considered.

### *Detected Whale Calling Rates and Locations*

Figure 8.18 shows the numbers of bowhead calls detected per hour for the full 2001 field season, from 29 Aug through 3 Oct. A whale call detected at multiple DASARs was counted once. Altogether, 10,738 calls were detected during this 36-day period (the first and last of these 36 days included <24 hours of recording).

It has been characteristic of such calling rate histories in the past that calls occur in clusters (Greene et al. 1998, 2001). Such clustering is manifest in the calling rates shown in Figure 8.18. Interestingly, bowheads were present in the Northstar area by 29-31 Aug again in 2001. The highest hourly call detection rate in 2001 occurred on 13 Sept. The average call detection rate was lower in the latter half of September and the first few days of October than in early September. However, there was a period with a high call detection rate on 29 Sept, and lesser peaks near midnight on 23-24 Sept and 2-3 Oct (Fig. 8.18).

Locations were estimated for 3446 calls—the others were detected at only one DASAR. Some of these estimated locations were so far from the array that their accuracy was highly doubtful. Procedures used to assess the precision of the location estimates, to weight the subsequent statistical analysis based on those estimates of precision, and to limit the analysis to the area that could be monitored effectively, are described in the "Methods" and applied in the next subsection.

TABLE 8.3. Distances (in km) from Northstar Island at which sounds in the ISI band propagating away from Northstar would be expected to diminish below various percentile levels of ambient noise (from Fig. 8.17). All levels are in dB re 1 μPa for the three one-third octave bands centered at 63, 80 and 160 Hz.

| ISI 400 m | Distance (km) where ISI Diminishes to Ambient Noise Level | | |
|---|---|---|---|
| From Northstar | 69.5 dB (5th %ile) | 88.5 dB (50th %ile) | 107.2 dB (95th %ile) |
| 77.8 dB (5th %ile) | 1.42 | 0.077 | Nil |
| 95.7 dB (50th %ile) | 22.3 | 1.2 | 0.068 |
| 118.5 dB (95th %ile) | >50 | 40 | 2.27 |

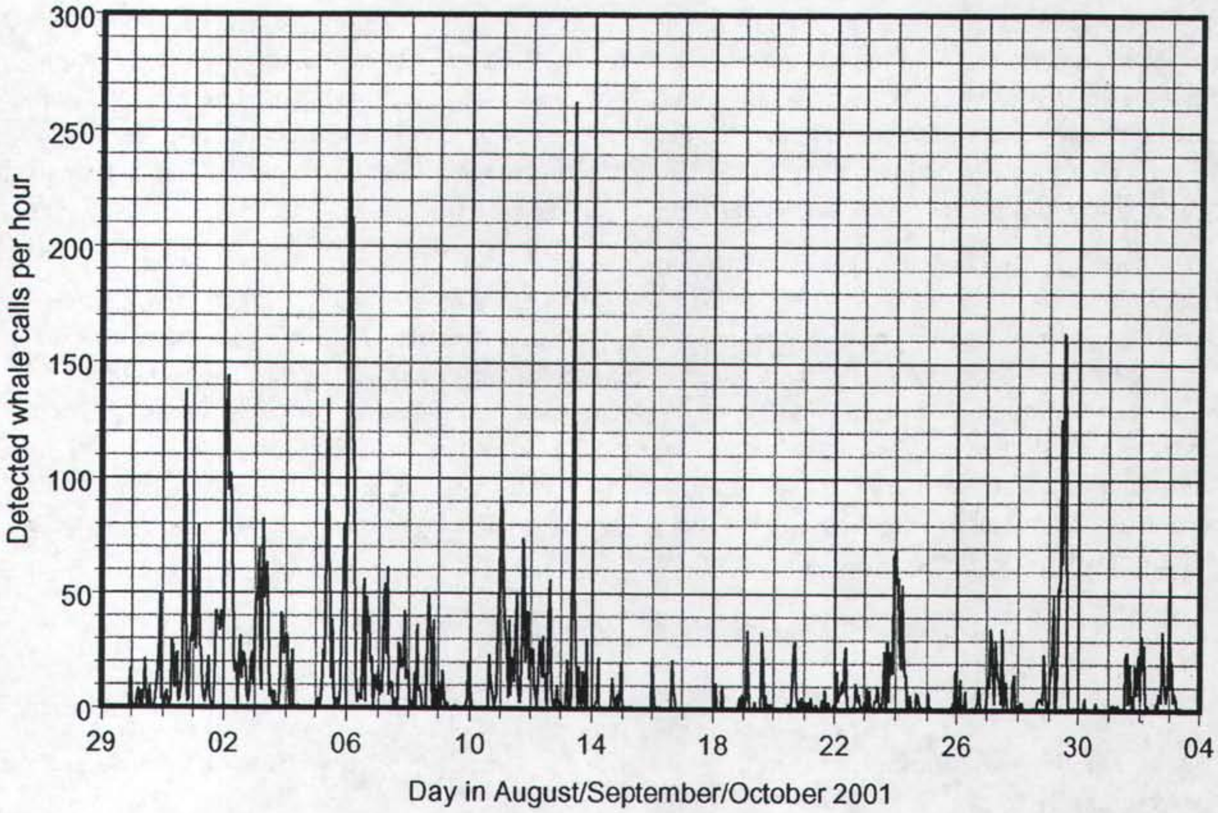


FIGURE 8.18. Numbers of bowhead whale calls detected per hour over the period 29 Aug through 3 Oct 2001. A total of 10,738 calls were detected by one or more DASARs during this period.

Estimated locations of origin for bowhead calls detected on two days, 2 Sept and 3 Sept 2001, are mapped in Figures 8.19 and 8.20. The symbol types discriminate calls whose locations were estimated based on bearings from two (+), three (∇), or more (□) DASARs.

When call locations are displayed in quick succession by 5-min increments of time in a time-lapse video presentation, it is apparent that, after one call was detected, it was common for additional calls to be detected somewhat to the west-northwest during succeeding minutes. For example, when the 2 Sept 2001 data from Figure 8.19 are displayed in a time-lapse sequence, the cluster of call locations extending from ESE to WNW toward and across the array of DASARs is seen to include many such sequences. The cluster of call locations several kilometers northeast of the DASAR array on 2 Sept also included a number of sequences of calls progressing to the WNW. These call sequences presumably represent the same whale calling repeatedly, or calls by different whales within a group in relatively close proximity, or (most likely) a combination of the two.

Figure 8.21 shows the calculated locations for all bowhead calls detected near the DASARs from 29 Aug through 3 Oct 2001. The calls are subdivided (by a dashed black line) into those within vs. those beyond a "12 km Analysis Area". Distance is measured from the CBa DASAR (Fig. 8.1) and the line from there to Northstar. Calculated locations beyond the analysis area are less precise than those within that area. Estimated locations >20 km (>12 mi) away are not plotted, as they are highly uncertain (see Fig. 8.27, below).

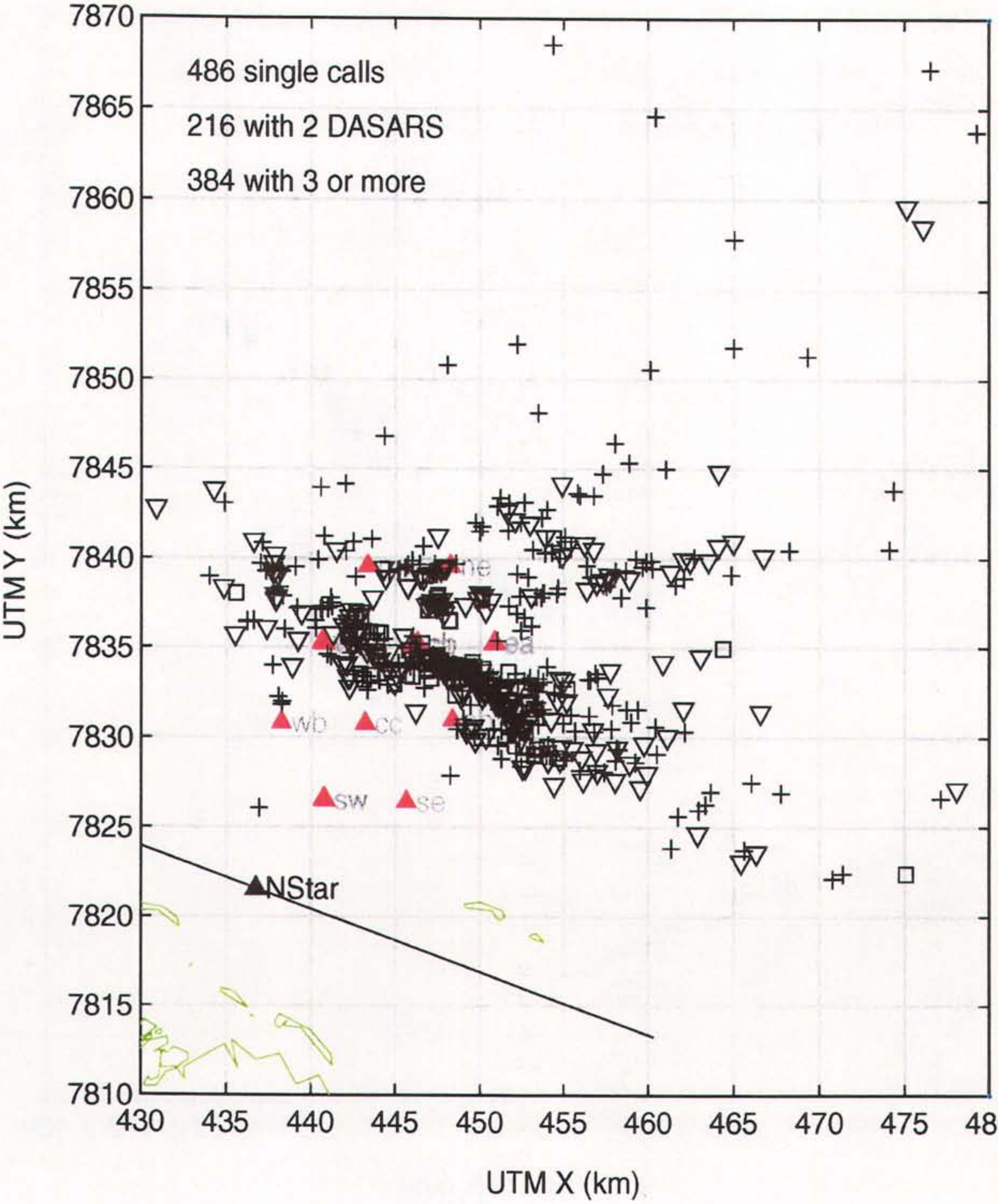


FIGURE 8.19. Whale call localizations for 2 Sept 2001. + = location determined from two bearings; ∇ = location determined from three bearings; □ = location determined from four or more bearings. Filled upright triangles represent DASAR locations. WNW–ESE line through Northstar shows the general direction of bowhead autumn migration parallel to shore, and is used as a baseline for estimating "distance offshore from Northstar".

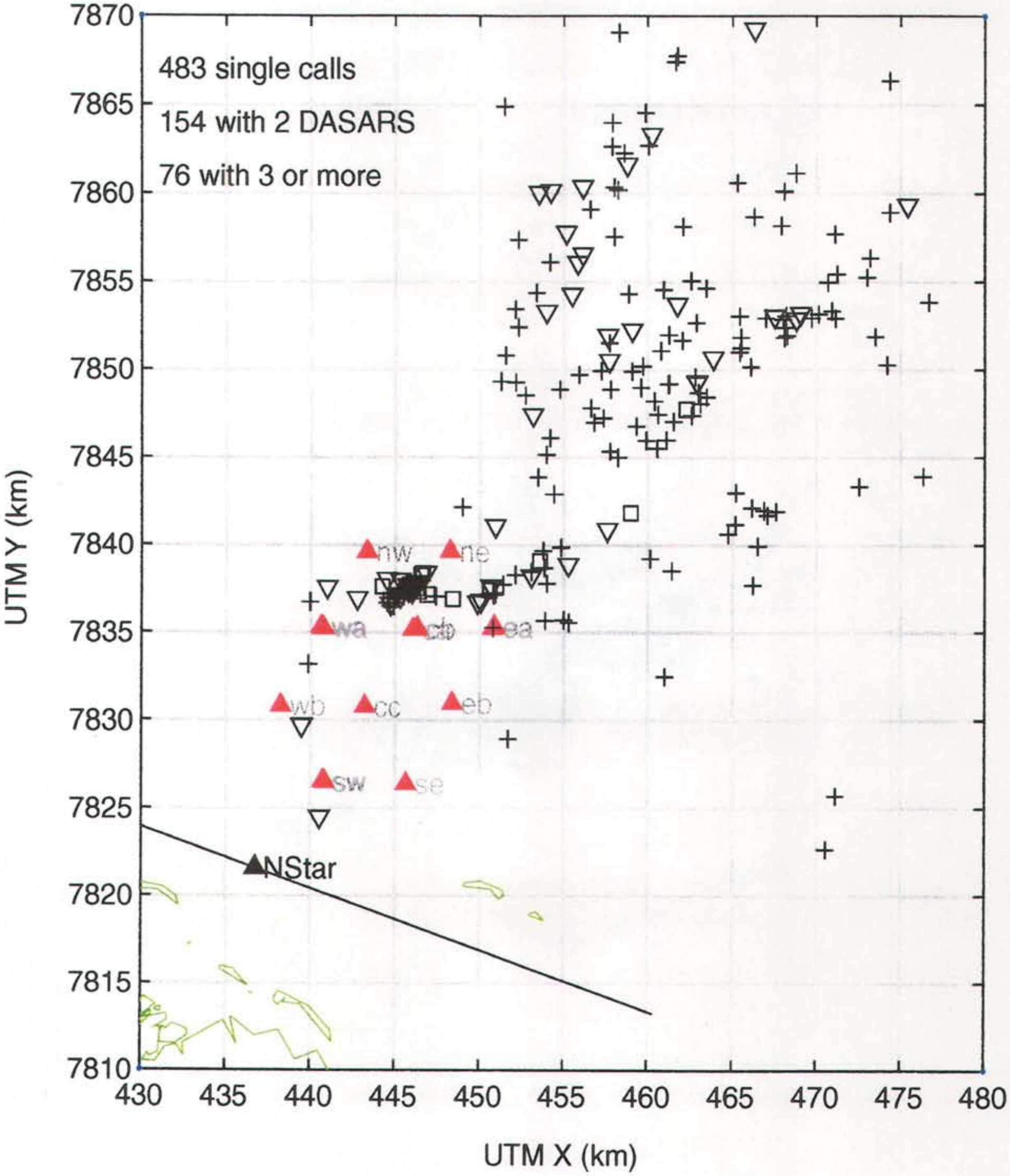


FIGURE 8.20. Whale call localizations for 3 Sept 2002. Plotted as in Figure 8.19.

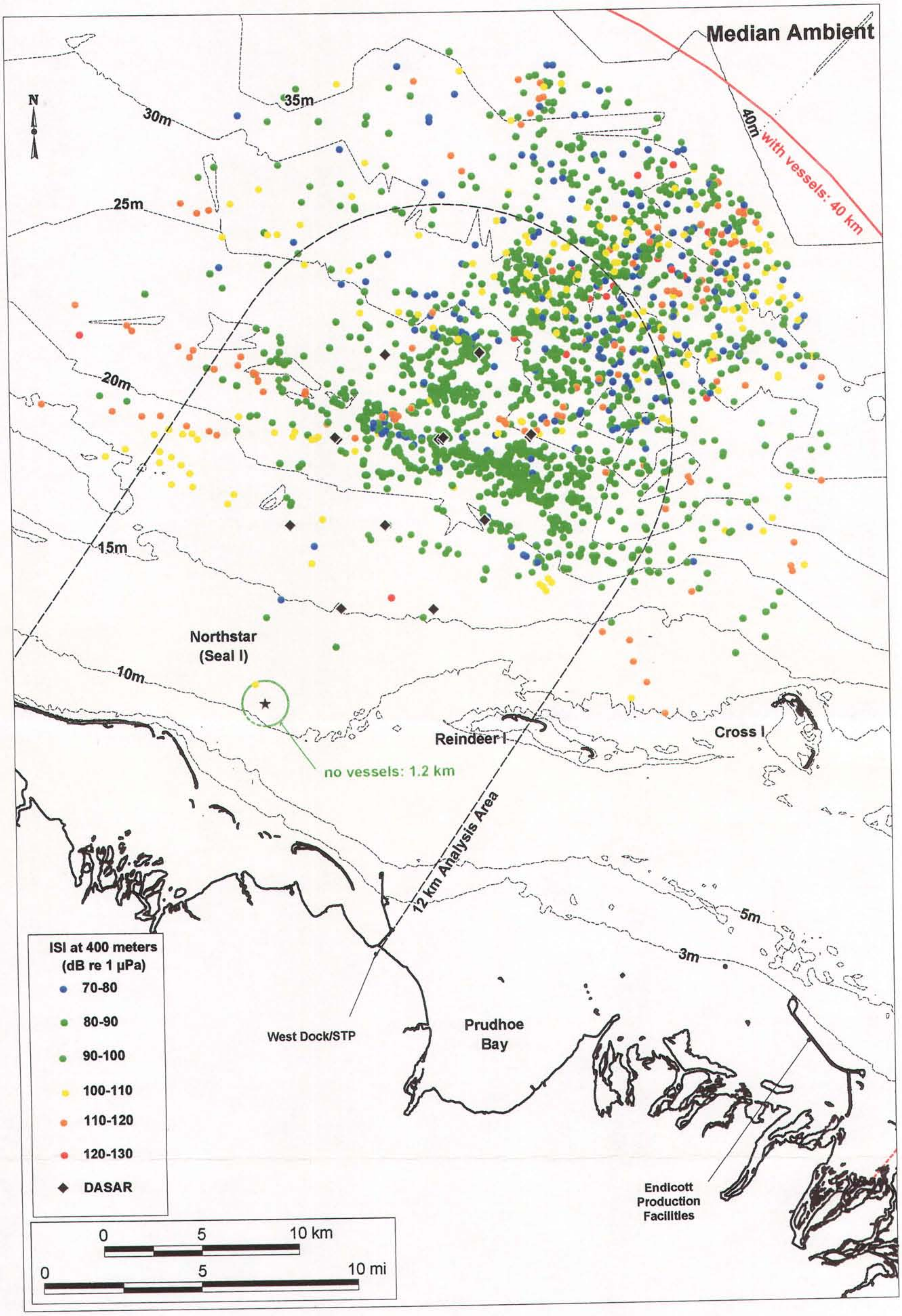


FIGURE 8.21. Estimated whale call locations near Northstar, 29 Aug –3 Oct 2001, color-coded by average ***ISI 400 m from Northstar*** during the 60-min period preceding detection of each call. Also shown, for times with and without vessel activity, are the distances within which island-related sound (1-min ISI) would be expected to diminish to the median ambient noise level in corresponding bands. See text regarding definition of times with and without vessels. Most analyses considered only calls within the "12 km Analysis Zone" outlined by a dashed black line.

Over the full field season, large numbers of bowhead calls were detected at distances ranging from ~13 km seaward of Northstar (near the 20 m depth contour) out to the maximum effective range of the DASAR array (Fig. 8.21). Inshore of the 20 m depth contour, i.e., within ~13 km of Northstar, the number of whale calls diminished sharply. Only a few bowhead calls were localized within 10 km of Northstar, and even fewer within 5 km. As expected, Cross Island was too far east to be within the effective monitoring range. However, assuming that the bowheads were moving parallel to shore, from east-southeast to west-northwest, it appears that the southern edge of the main migration corridor was within 5 km (3 mi) offshore of Cross Island.

Figure 8.21 also shows the approximate distances to which underwater sounds from Northstar and its associated vessels are expected to be detectable during two circumstances: *(1)* times with median (50th percentile) ambient noise and 95th percentile ISI levels near Northstar, indicating considerable vessel activity there (red arc with radius 40 km, in northeast corner of map); *(2)* times with median ambient noise and median ISI levels near Northstar, indicating little or no vessel activity there (green circle with radius 1.2 km). These radii where industrial sounds are expected to be barely detectable under the specified conditions come from the "50th percentile ambient" column of Table 8.3. Corresponding radii would be larger for times with low ambient noise (5th %ile column of Table 8.3), and much smaller for times with high ambient noise (95th %ile column). Appendix C contains maps similar to Figure 8.21, but with estimated detection radii for Northstar sounds under 5th and 95th percentile (rather than median) ambient conditions. In all these cases, Northstar-associated sounds typically would be barely detectable underwater at the illustrated distance, and ~15 dB stronger at 1/10th the indicated distance.

### *Industrial Sound Levels Associated with Each Whale Call*

Later analyses show that call locations were apparently related to the industrial sound averaged over a 60-minute period preceding detection of the call, and less related to averages over 5, 15 or 30 min (see Fig. 8.31–8.34, later). In this section, we summarize the 60-minute-average ISI values associated with the whale calls detected.

ISI levels *as measured 400 m from Northstar* were averaged for 60 minutes ending at the time each whale call was received. A total of 3431 whale calls were used in the location analysis, and each had a corresponding 60-minute ISI level. The distribution of those 60-minute ISI levels was such that the 5th percentile level was 75.6 dB, the 50th percentile level was 88.7 dB, and the 95th percentile level was 113.1 dB (Table 8.4). For the subset of 1259 calls within the 12-km analysis area that met all criteria for inclusion in the analysis, the frequency distribution of 60-min ISI values 400 m from Northstar is shown in Figure 8.22. The 5th percentile level was 77.2 dB, the 50th percentile level was 86.5 dB, and the 95th percentile level was 106.9 dB (Table 8.4). The 90th percentile level, relevant in Figure 8.35 (in "Discussion"), was 100.6 dB. In Figure 8.21, the locations of whale calls localized within and near the 12-km analysis area (out to 20 km) are color-coded to show the 60-min ISI values 400 m from Northstar during the hour preceding detection of each call.

The 60-min ISI levels *as received at the call locations* were also estimated (Fig. 8.23, 8.24). The received level for each of the 1259 whale calls in the 12-km analysis zone and used in the analyses was estimated from the measured value 400 m from Northstar based on the 15 log(R/400) relationship. At most call locations, the estimated received ISI levels were lower than the typical levels of ambient sounds in the same ISI bands (Fig. 8.23). Also, an unknown fraction of the sound energy represented in the ISI as measured at 400 m (especially at the low-noise times) was natural background sound rather than industrial

TABLE 8.4. Percentiles of the Industrial Sound Index (in dB re 1 µPa) from measurements under three conditions. Percentiles for ambient noise in the same band were computed from Burgess and Greene (1999).

| | 5% | 50% | 95% | *n* |
|---|---|---|---|---|
| Ambient from B&G (1999) | 69.5 | 88.5 | 107.2 | 4,929 |
| 1-min ISI at 400 m [a] | 77.8 | 95.7 | 118.5 | 11,846 |
| 60-min ISI at 400 m: all call times | 75.6 | 88.7 | 113.1 | 3,431 |
| 60-min ISI at 400 m for calls in 12-km analysis zone & used [b] | 77.2 | 86.5 | 106.9 | 1,259 |

[s] See Figure 8.16. [b] See Figure 8.22

sound. Thus, levels of industrial sound at the locations of the calling whales would have averaged slightly lower than estimated here, i.e. even further below the typical ambient levels than shown in Figure 8.23. However, some of the calling whales were apparently able to hear industrial sounds associated with Northstar: A minority of the whale calls occurred at locations where the received 60-min ISI level was above the 5th percentile ambient, and a small minority of the calls were at locations where the received level was above the median ambient. We do not know the actual ambient level at the time and location of each whale call. However, these overall data strongly suggest that industrial sound was detectable to a minority of the calling whales. Those for which the estimated received ISI levels were highest (red and orange colors in Fig. 8.24) were the ones most likely to have heard industrial sounds during the hour preceding detection of the whale call.

Figure 8.23 shows that the estimated maximum 60-min ISI levels to which calling whales near Northstar were exposed were 115-120 dB re 1 µPa. Only 3 of 1259 localized calls (0.2%) received ISI levels this high. ISI levels averaged 5.8 dB less than 10-1000 Hz broadband levels. Thus, only 0.2% of the localized calls were associated with estimated received broadband levels of island sound ≥121 dB re 1 µPa, and none involved levels >126 dB. Similarly, only 8 of 1259 calls (0.6%) were associated with estimated received ISI levels ≥105 dB, or received broadband levels ≥111 dB. Only 42 of 1259 calls (3.3%) were associated with estimated received ISI levels ≥95 dB, or received broadband levels ≥101 dB. Furthermore, given that ambient levels are not uncommonly as high as 95 dB on an ISI basis (Fig. 8.23), the island sound was probably below ambient and undetectable for some of those whales.

The actual percentages of the migrating bowheads that were exposed to the above-referenced ISI and broadband levels were probably only about half of the percentages quoted above. The analysis zone extended offshore 28.6 km from Northstar, to the 25-m depth contour. That is near the middle of the migration corridor in an average year (LGL and Greeneridge 1996; Miller et al. 1999; Treacy 2000; see Chapter 9). Thus, it is probable that only about half of the whales were close enough to shore to pass through the analysis zone and to be represented in Figure 8.23.

As previously noted, periods with high ISI values 400 m from Northstar generally were periods with boat activity, whereas periods with average and low ISI values at 400 m represented little or no boat activity. Figure 8.25 shows the estimated received 60-min ISI values at locations of whale calls within the analysis zone for times when the ISI 400 m from Northstar was low, moderate and high. As one would expect, it was primarily at the times with high ISI, as measured near Northstar, that the received ISI values near calling whales were high enough that they would sometimes exceed the ambient level in the ISI band and be detectable to the whale (Fig. 8.25).

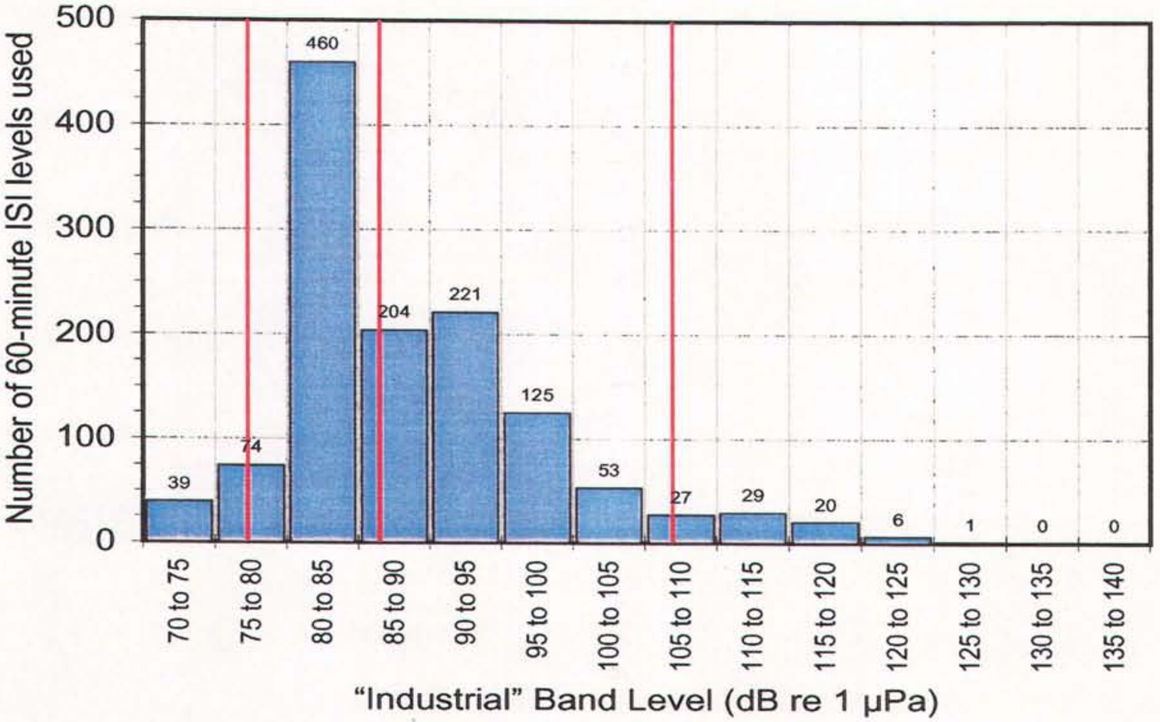


FIGURE 8.22. Histogram of average ISI values ***measured 400 m from Northstar*** during 60-min periods preceding detection of 1259 bowhead whale calls within 12-km Analysis Zone. The 3 vertical lines show the 5th, 50th and 95th percentiles of these ISI levels (77.2, 86.5 and 106.9 dB re 1 μPa, respectively).

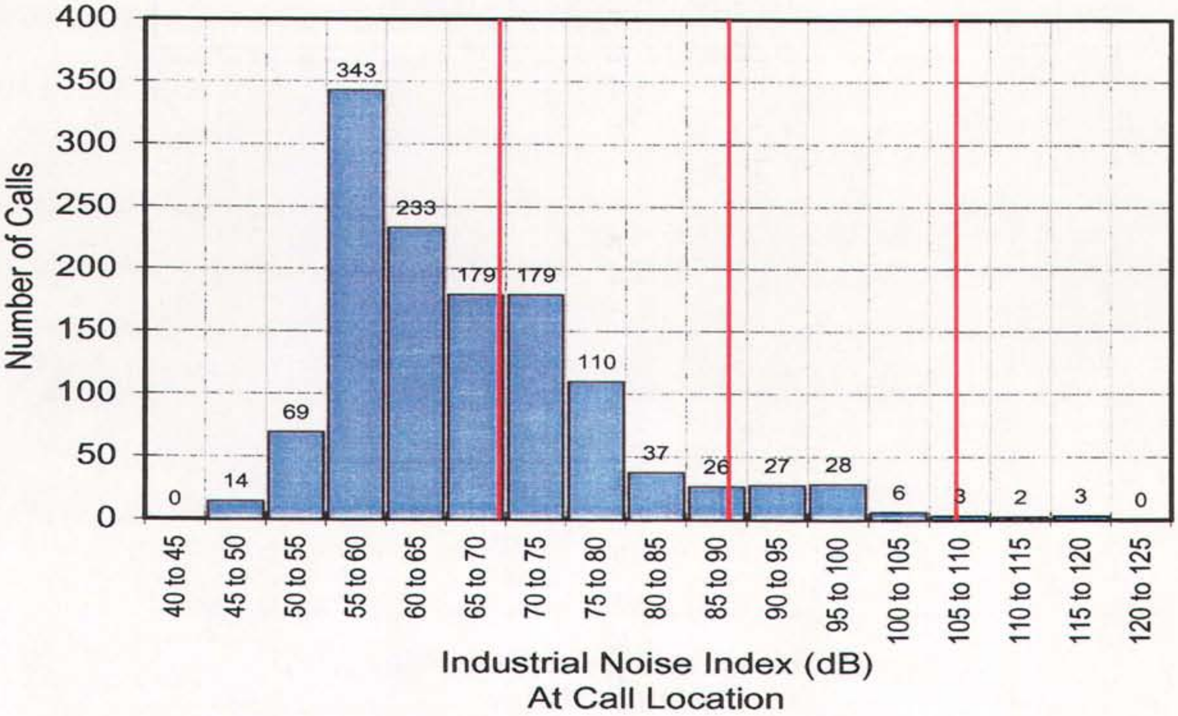


FIGURE 8.23. Histogram of estimated average ISI values ***at whale-call locations*** during the 60-min periods preceding detection of 1259 bowhead whale calls within 12-km Analysis Zone. The 3 vertical lines show the 5th, 50th and 95th percentiles for ambient level in the ISI bands, computed from background-noise data of Burgess and Greene (1999).

This page left intentionally blank

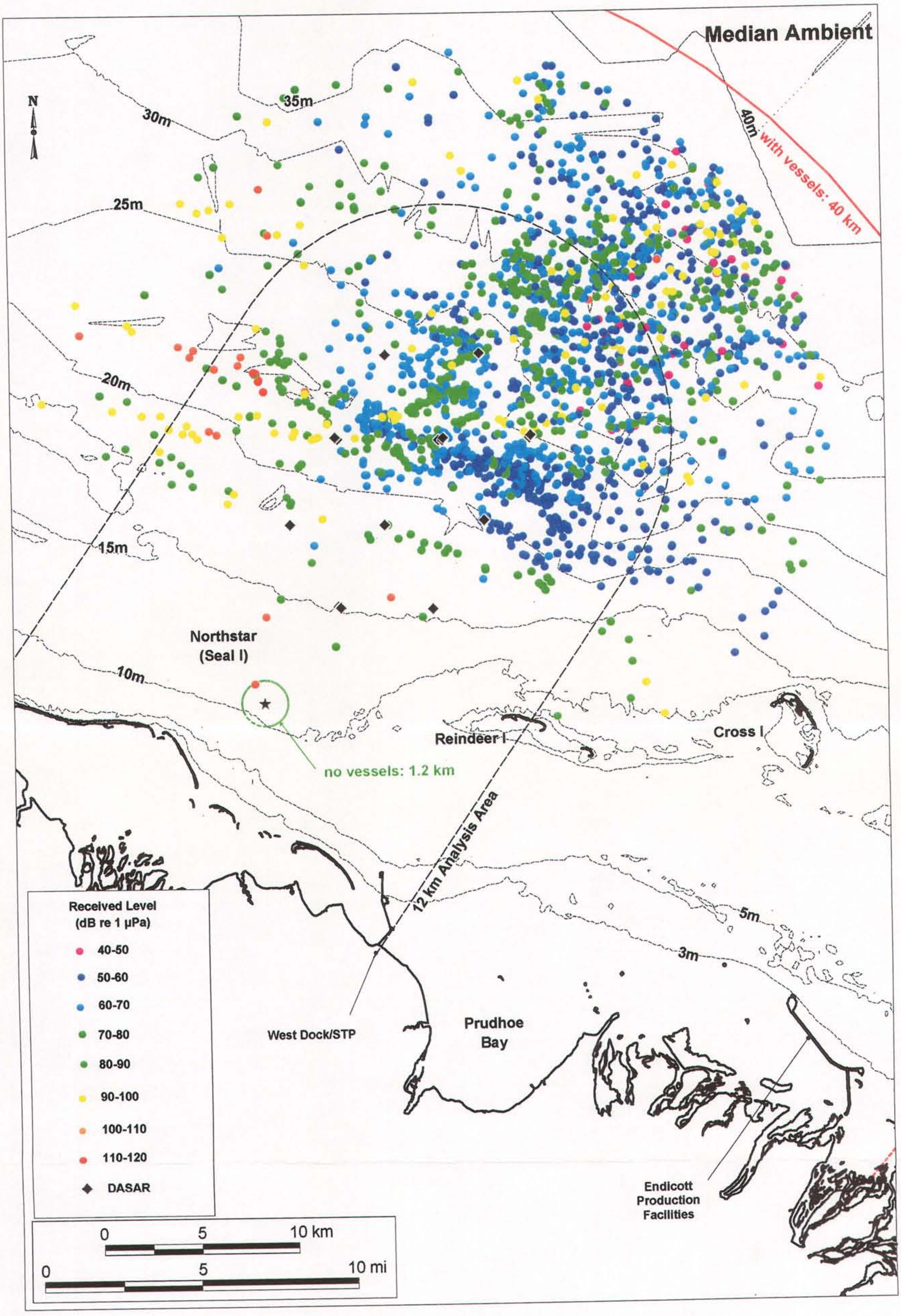


FIGURE 8.24. Estimated whale call locations near Northstar, 29 Aug –3 Oct 2001, color-coded by estimated average ***ISI at call location*** during the 60-min period preceding detection of each call. Also shown, for times with and without vessel activity, are distances within which island-related sound (1-min ISI) would be expected to diminish to the median ambient noise level in corresponding bands. See text regarding definition of times with and without vessels. Most analyses considered only the calls within the "12 km Analysis Zone" outlined by a dashed black line.

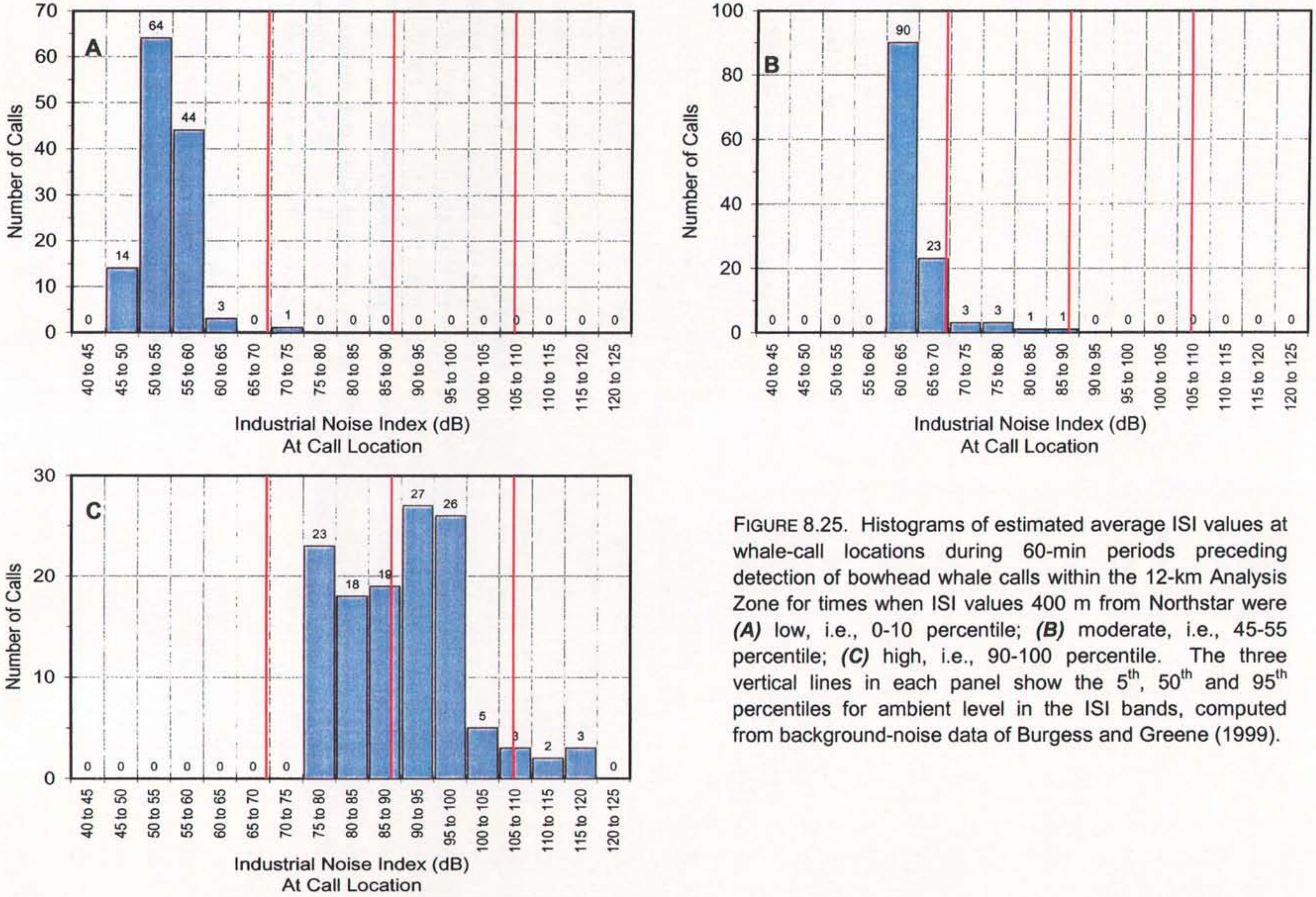


FIGURE 8.25. Histograms of estimated average ISI values at whale-call locations during 60-min periods preceding detection of bowhead whale calls within the 12-km Analysis Zone for times when ISI values 400 m from Northstar were ***(A)*** low, i.e., 0-10 percentile; ***(B)*** moderate, i.e., 45-55 percentile; ***(C)*** high, i.e., 90-100 percentile. The three vertical lines in each panel show the 5th, 50th and 95th percentiles for ambient level in the ISI bands, computed from background-noise data of Burgess and Greene (1999).

## *Statistical Analysis of Localized Calls vs. Underwater Sound*[6]

Average error ellipse sizes for individual whale calls at various locations surrounding the DASAR array are plotted in Figure 8.26. Precision of the whale call locations is shown in Figure 8.27. In general, estimated call locations were within 2 km (1.25 mi) of true call locations with 95% confidence when a call occurred in the central and eastern portions of the DASAR array. Precision of estimated locations declined outside the DASAR array, but remained less than 5 km (3.1 mi) for most locations within 5 km (3.1 mi) from the nearest DASAR. Precision of the DASAR array in localizing calling whales appeared to be higher for calls to the east of the array's center than for calls to the west. Certain locations within the DASAR array had lower precision than others because bearings from nearby DASARS were nearly parallel in those areas. Due to increased error ellipse size outside the DASAR array, calls located beyond ~9 km (5.6 mi) from the CBa DASAR were substantially down-weighted in the quantile regression. As described below, almost all of those >12 km away were excluded entirely.

Figure 8.28 shows histograms of distance from the center DASAR during extremely high (>90th percentile), high (>75th percentile), and low (<25th percentile) background noise conditions, as measured at the NEa DASAR. Extremely high noise conditions occurred when omni-directional noise levels there were greater than 101.2 dB re 1 μPa. High noise conditions occurred when noise levels there were >96.8 dB re 1 μ Pa. Low noise conditions occurred when noise levels at the NEa DASAR were <91.9 dB re 1 μPa. Evidence in Figure 8.28 suggests that the number of detected calls dropped appreciably beyond 12 km (7.45 mi) during high and extremely high noise conditions. In contrast, a substantially higher proportion of the calls detected and localized during low noise conditions were beyond 12 km. To remove the bias that this might cause, calls >12 km from the CBa DASAR were dropped from the analysis, with the following exception: "inshore" calls that occurred >12 km from CBa but <12 km from a line connecting CBa and Northstar Island were retained in the analysis. The resulting "analysis area" is shown by a dashed line in Figure 8.21.

In all, 2871 calls detected from 28 Aug 2001 to 3 Oct 2001were locatable and produced positive definite variance-covariance matrices. After elimination of call locations greater than 12 km from the center DASAR and adding back the inshore calls ($n = 16$), a total of 1259 usable whale calls were available for further analysis (Fig. 8.21). Their locations ranged from ~1 km seaward of the baseline through Northstar (and parallel to shore) to ~28 km offshore. Most of the calls included in the analysis were 10 to 27 km offshore (Fig. 8.29). The cutoff at ~28 km was a result of the exclusion of calls >12 km seaward of the CBa DASAR, or >7 km seaward of the most offshore of the DASARs (NEa). Many of the excluded calls were calculated to be considerably farther offshore (e.g., Fig. 8.19–8.21), but those locations were quite unreliable and were underrepresented at times of high background noise.

Within the cutoff distance, offshore distances were significantly correlated when their associated calls were less than ~24 hours apart, based on Moran's I statistic (Fig. 8.30). If two offshore distance measurements were separated by >24 hours, they were essentially independent. The time period used in the bootstrap resample procedure was $t = 24$ hours.

The 5th percentile offshore distance relative to industrial sound levels near Northstar was determined by fitting linear, quadratic, and cubic quantile regression lines. Four measures of Northstar sound were considered, i.e., sound during the 5-, 15-, 30- and 60-min periods preceding the call in

---

[6] This subsection prepared by Dr. Trent L. McDonald assisted by Ryan Nielson, WEST Inc., Cheyenne, WY.

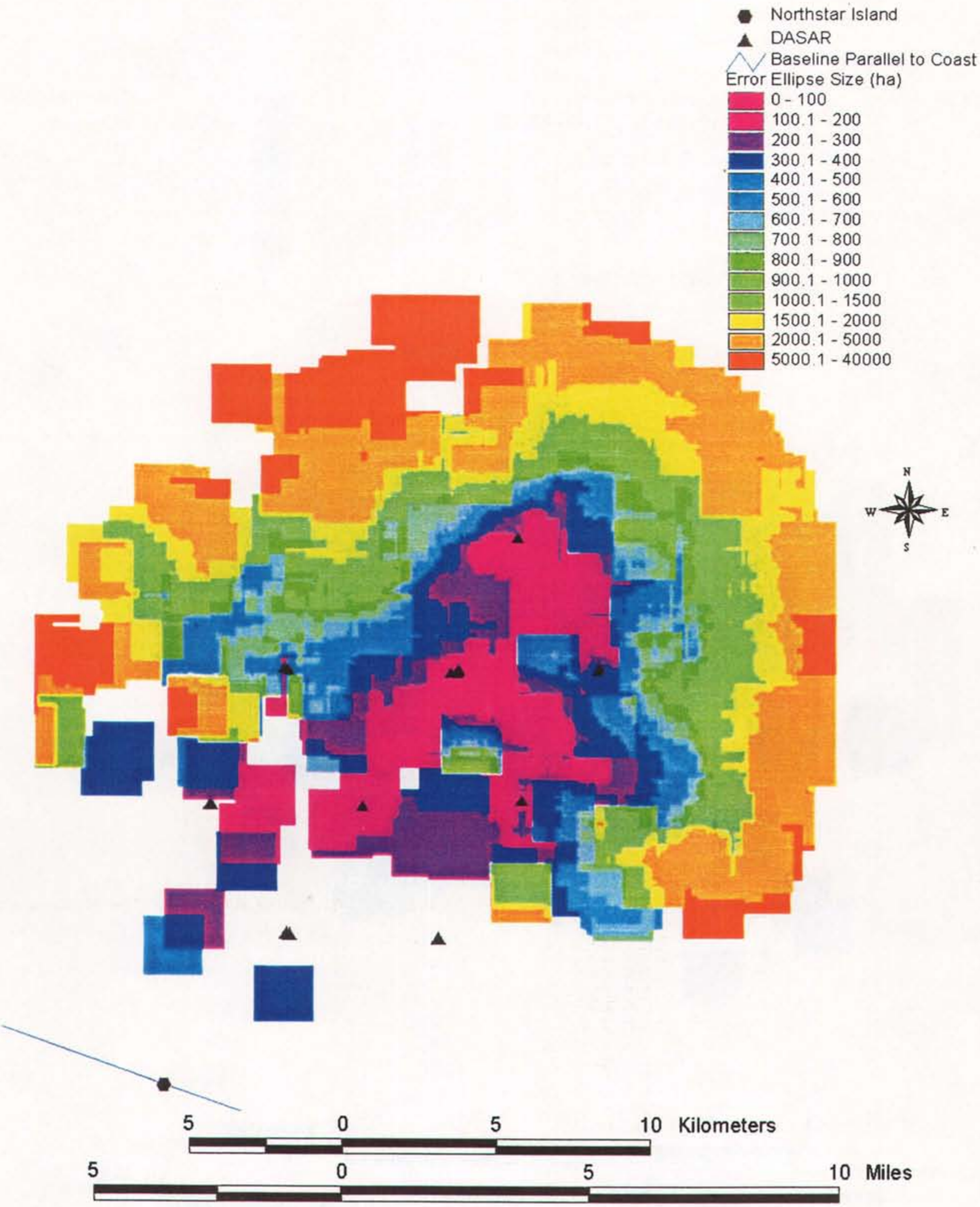


FIGURE 8.26. Average error ellipse size (hectares) for whale calls estimated to be at various locations near Northstar and the DASAR hydrophone array. Error ellipses were 95% confidence ellipses around the true call location.

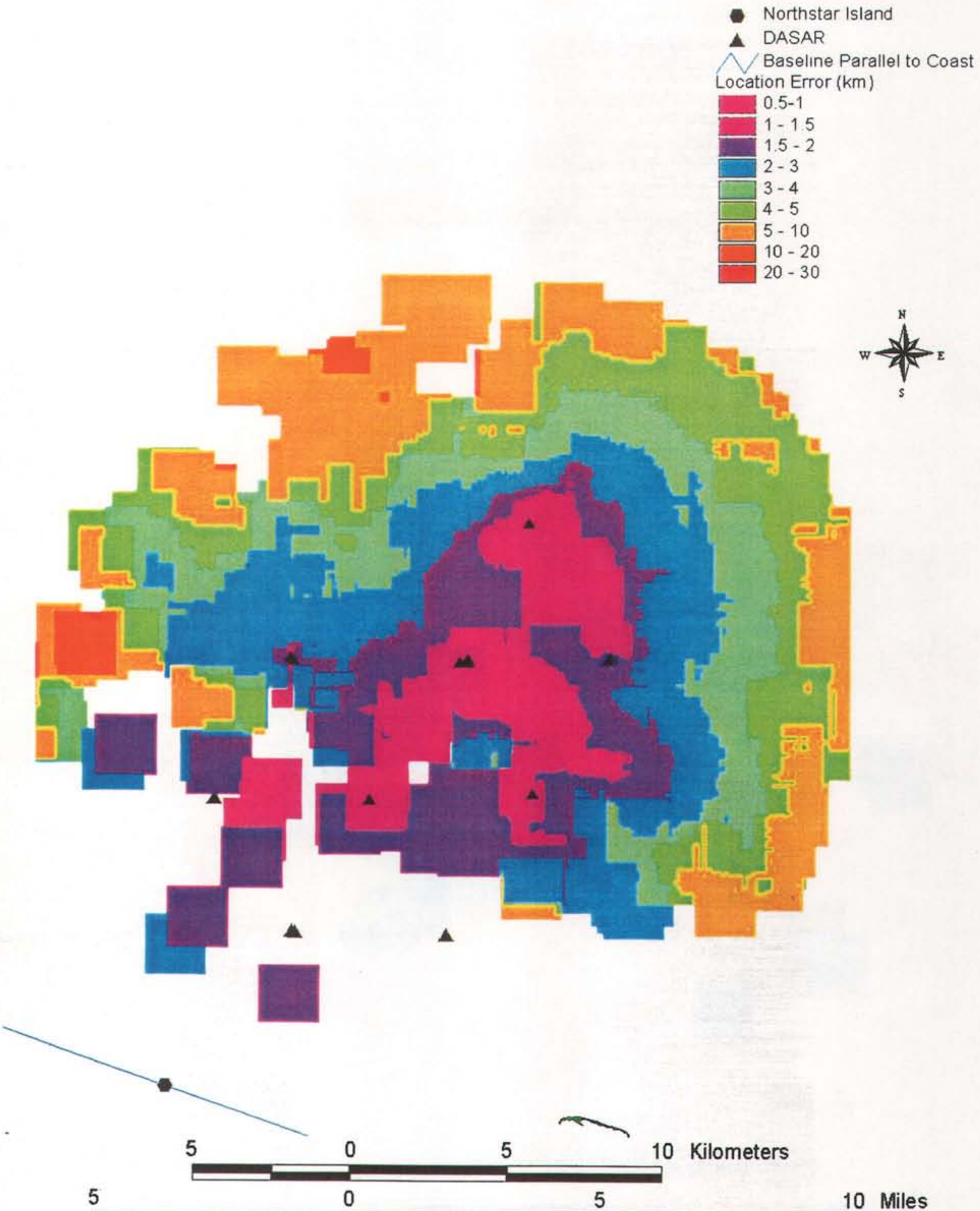


FIGURE 8.27. Average error (km) in estimated location of a calling whale, based on the square root of error ellipse size.

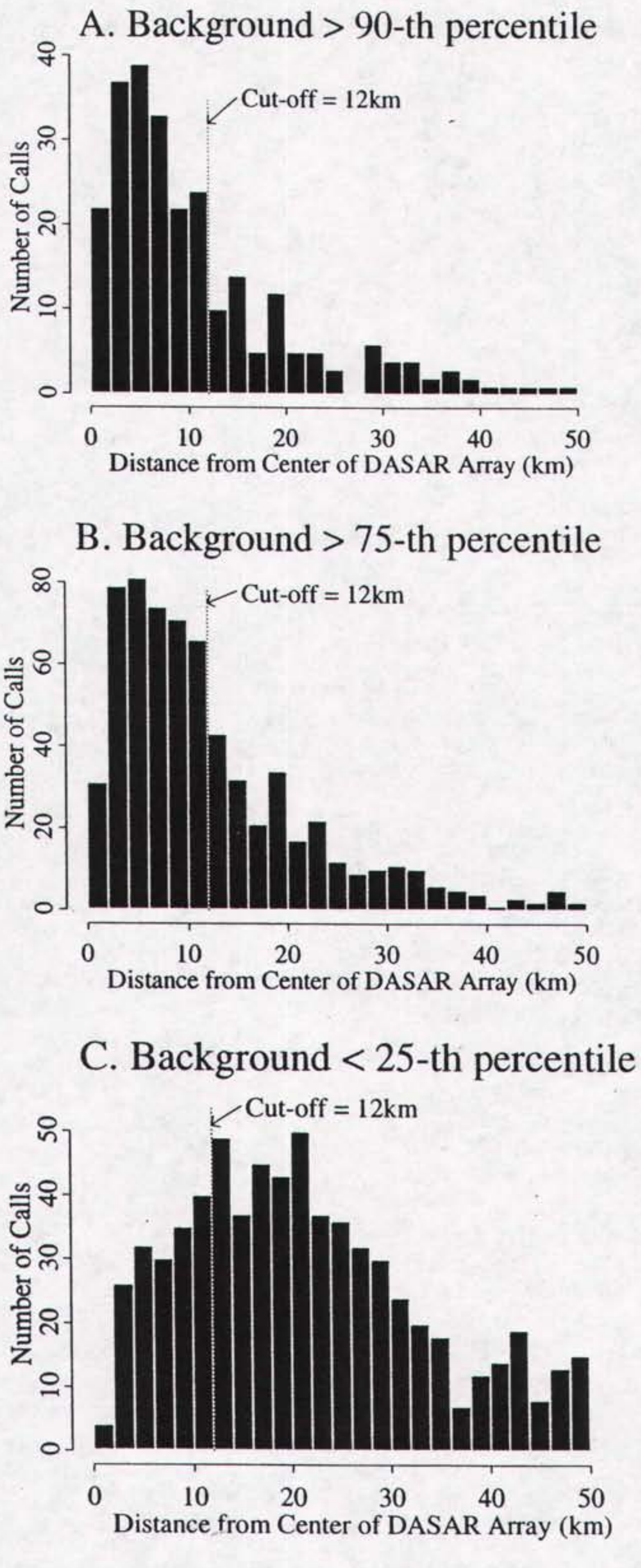


FIGURE 8.28. Frequency distribution of distances from estimated locations of calling whales to the center DASAR during extremely high (top), high (middle), and low (bottom) background noise conditions. A cutoff distance of 12 km was established at "shoulder" evident in the top two distributions.

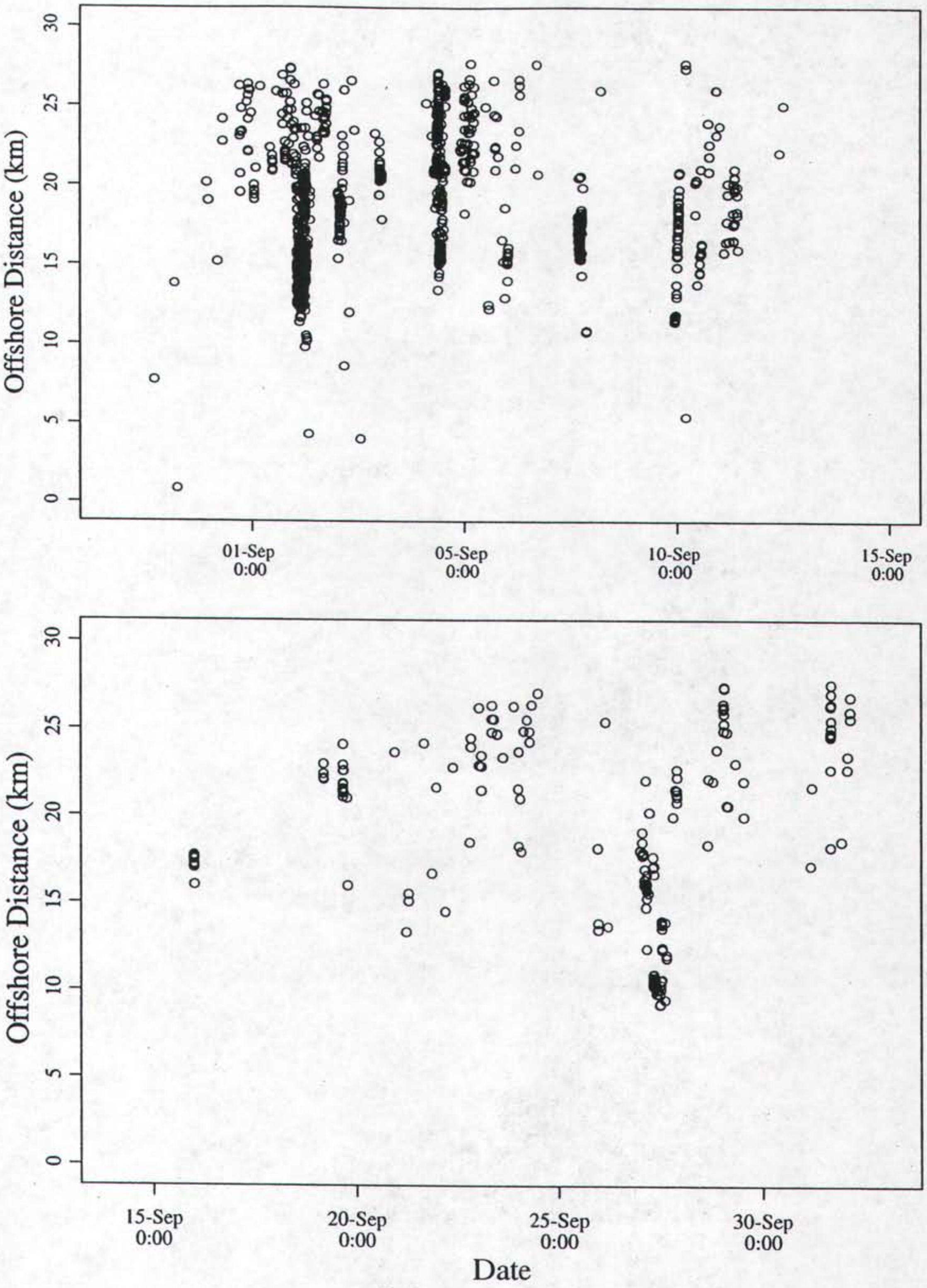


FIGURE 8.29. Offshore distances to whale call locations ($n = 1259$) obtained from 28 Aug to 3 Oct 2001, excluding those beyond the 12 km cutoff distance. Top panel covers the period 28 Aug to 00:00 15 Sept. Bottom panel covers the period 00:00 15 Sept to 3 Oct.

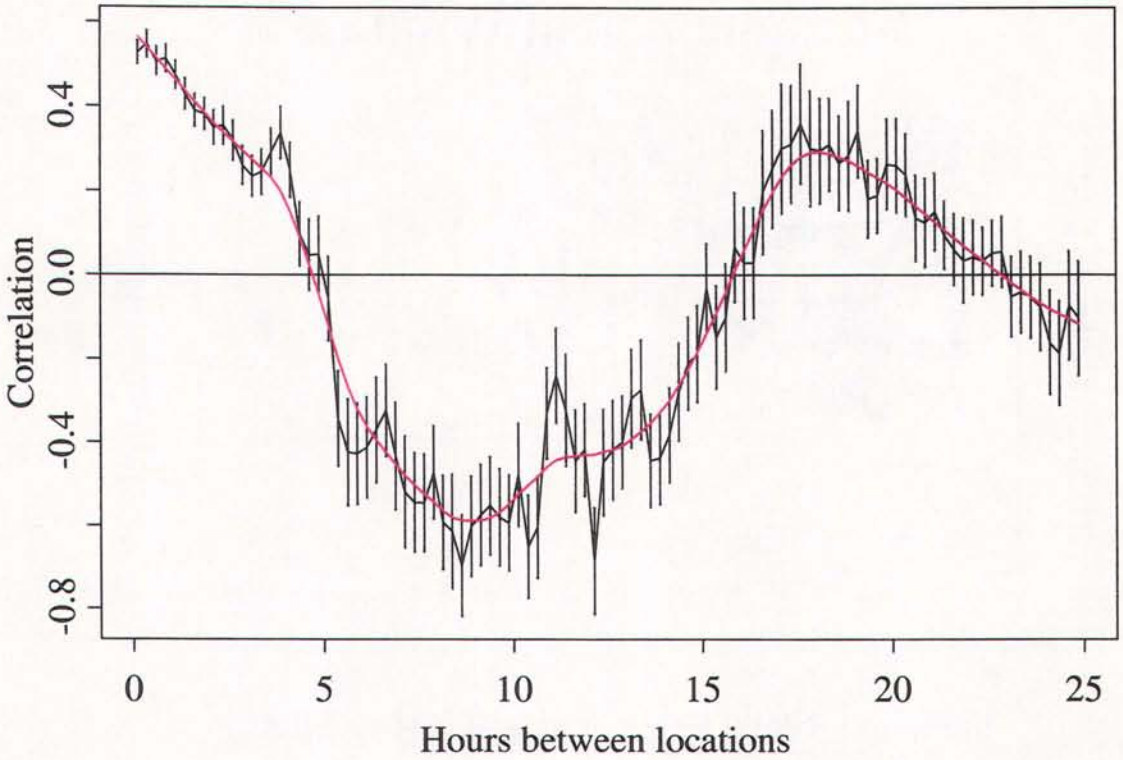


FIGURE 8.30. Moran's I statistics and estimated autocorrelation function for offshore distances of calls detected in the 12-km analysis area. Vertical bars are Bonferroni-corrected 95% confidence intervals on Moran's I. Red line is smoothed estimate of the autocorrelation function.

question. In each case, sound was measured underwater 400 m from Northstar, and included the sound components in three one-third octave bands where industrial sound was predominant (see Methods). A quadratic function of the sound level near Northstar fit the 5th percentile of offshore distances best, based on visual examination of model residuals. Residuals from the analysis based on a 5-min sound window indicated that a linear model fit just as well as a quadratic function; however, the quadratic function fit better for the 15-, 30-, and 60-min windows. For consistency, the quadratic model was adopted for all sound windows.

Figures 8.31 through 8.34 show scatter plots of distance offshore versus underwater sound 400 m from Northstar over the previous 5, 15, 30, and 60 minutes. Included in each Figure is the estimated quadratic 5th quantile regression line and associated approximate 95% lower bound. (See "Discussion" regarding the confidence levels of these lower bounds and our use of the word "approximate" and the equivalent symbol "~".) All four estimated quadratic quantile regression functions had positive curvature (i.e., positive 2nd derivative), and curvature increased with increasing sound-window duration. The quantile regression lines estimated using 15-, 30-, and 60-min sound windows indicated that the relationship between offshore distance and sound level was positive at sound levels greater than ~95 dB. Overall, the 60-min results indicated that distance offshore was related to 400-m ISI level, but the results for shorter intervals were not definitive:

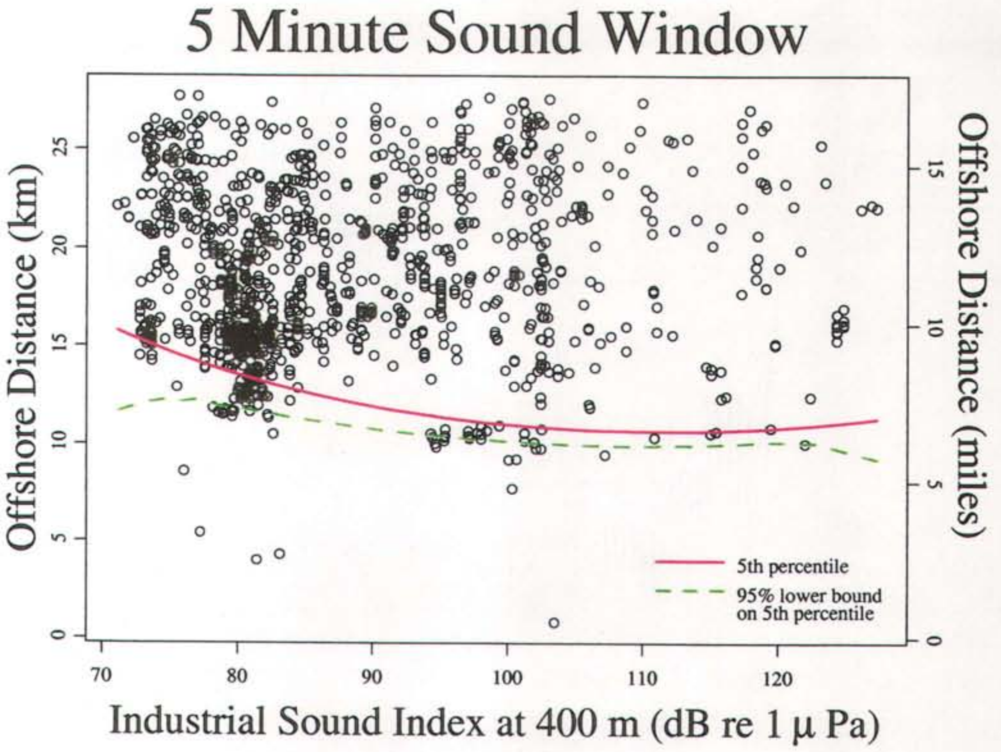


FIGURE 8.31. Offshore distances of bowhead calls detected in the analysis area vs. average industrial sound index (ISI) 400 m north of Northstar in the ***5 minutes*** previous to the call. Quantile regression (solid line) relates 5th percentile of offshore distances for bowhead calls to 5-min ISI. Approximate lower 95% confidence bound (dashed line) for the quantile regression was estimated via a stratified bootstrap method (see Methods). Calls from locations outside the "analysis area", generally >12 km from the center of the DASAR array (Fig. 8.21), were excluded. ISI is total sound level in three 1/3rd–octave bands dominated by industrial components. Offshore distances were measured perpendicular from the baseline through Northstar Island (pictured in Fig. 8.19) to the call location. See "Discussion" for caveats and why we say the lower bound has "approximate 95% confidence".

- The approximate 95% lower bounds for 5-, 15-, and 30-min sound windows were not positively sloped. If a positive relationship existed between the 5th percentile of offshore distance and Northstar sound over intervals up to 30 min, the effect was too small to estimate with acceptable precision, i.e., any such effect was smaller than the random variation in our data. Thus, from these individual analyses, we cannot be ~95% sure that the 5th percentile of whale call distances increased with increasing ISI values measured 400 m from Northstar over intervals up to 30 min.
- In contrast, the approximate 95% lower bound for the quantile regression curve based on 60-min sound data (Fig. 8.34) sloped upward appreciably for 400-m ISI values exceeding ~100 dB. Based on the lower bound for the 60-min sound window, we can state with ~95% confidence (see "Discussion") that the 5th percentile of offshore call distances increased appreciably when 400-m ISI values averaged over 60 min were above 100 dB. The 5th percentile of offshore call distance at ISI levels of ~125 dB could not be estimated with high precision and is subject to caveats, but the increase in 5th percentile distance offshore as 60-min ISI increased from ~100 dB to 125 dB appeared to be larger than random variation in the data.

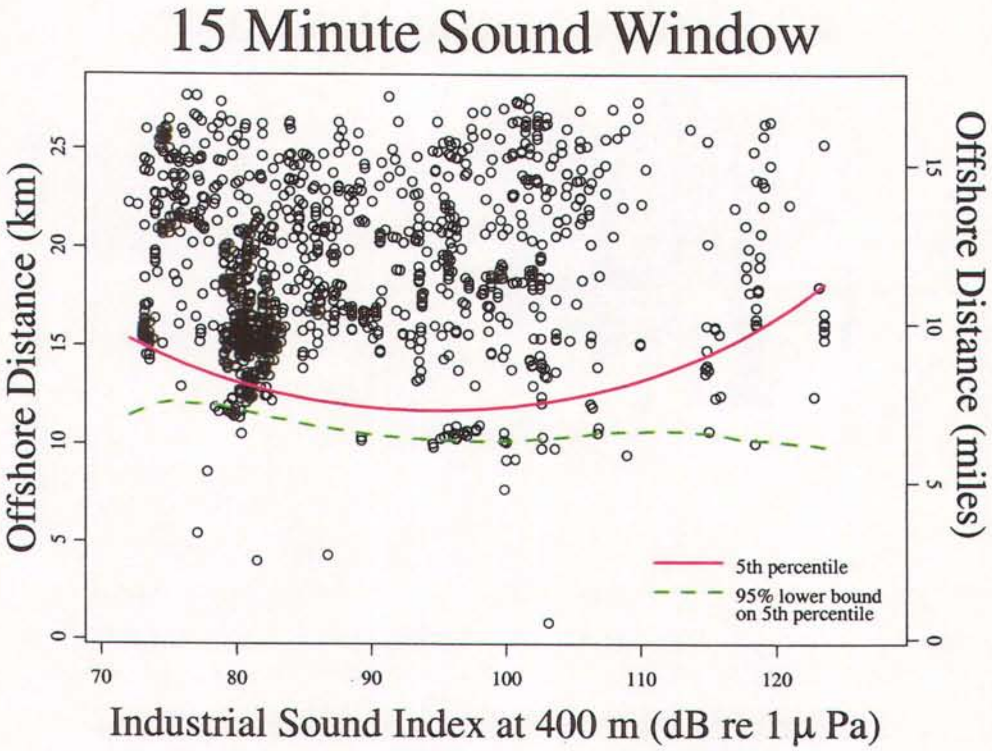


FIGURE 8.32. Offshore distances of bowhead calls detected in the analysis area vs. average industrial sound index (ISI) 400 m north of Northstar in the ***15 minutes*** previous to the call. Otherwise as in Figure 8.31.

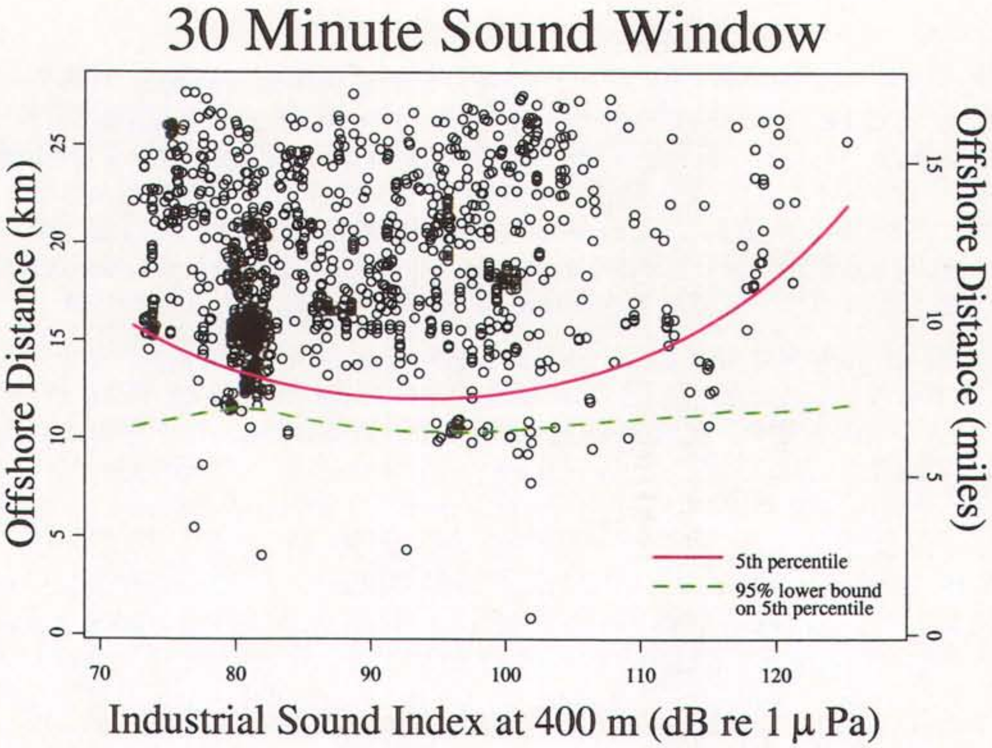


FIGURE 8.33. Offshore distances of bowhead calls detected in the analysis area vs. average industrial sound index (ISI) 400 m north of Northstar in the ***30 minutes*** previous to the call. Otherwise as in Figure 8.31.

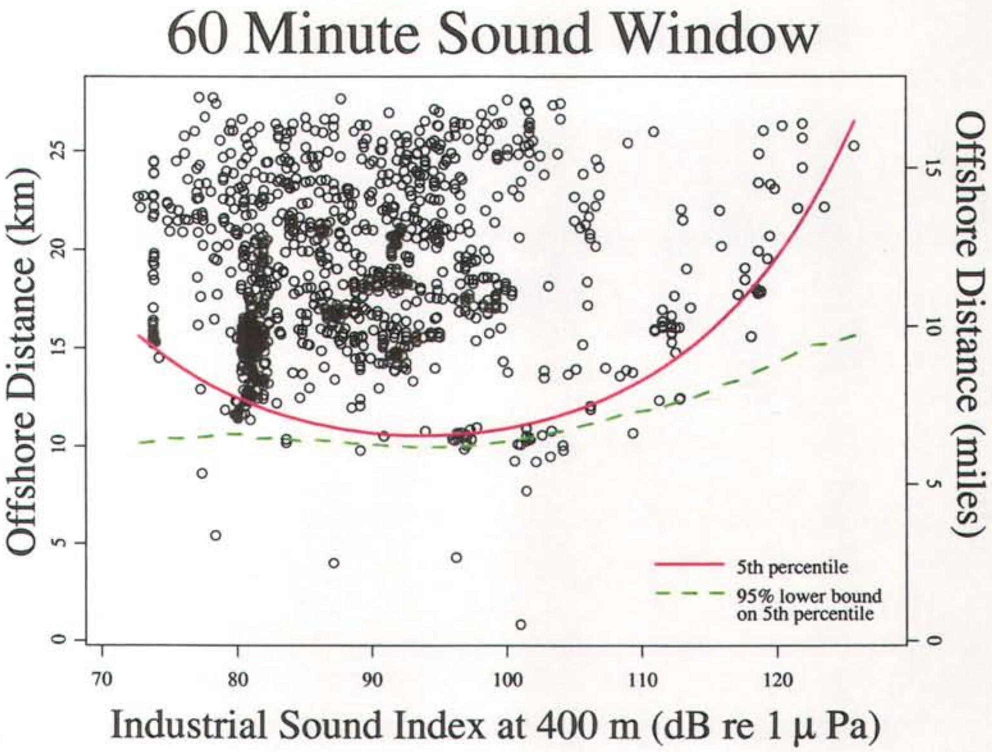


FIGURE 8.34. Offshore distances of bowhead calls detected in the analysis area vs. average industrial sound index (ISI) 400 m north of Northstar in the ***60 minutes*** previous to the call. Otherwise as in Figure 8.31.

In 2000, before collecting any data, we decided on a 1-tailed analysis approach. That is, we assumed that any relationship of the "distances offshore" to Northstar sound would involve increasing distances with increasing sound level. However, the data in Figures 8.31 to 8.34 are consistent with the possibility that the closest bowhead calls tended to become somewhat closer to Northstar as ISI levels increased from low to moderate. This could be indicative of an attraction effect at moderate sound levels (see "Discussion" for further comments on this possibility). Whether this is real or a sampling artifact is not determinable from the present 2001 data. This will be examined further when additional data from 2002 are analyzed.

To estimate the geographic scale of the apparent displacement effect as ISI increased from moderate to high levels, we further examined the model based on a 60-min sound window, for which the displacement effect at high ISI seemed largest. Throughout, it is important to recall that results apply to the bowheads passing within ~28.6 km offshore of Northstar, not the entire width of the bowhead migration corridor. At average (for 60 min) ISI levels of 95 dB re 1 μPa, the 5th percentile of whale call distances was estimated to be 10.58 km (6.57 mi) offshore, and with ~95% confidence, this number was greater than 9.97 km or 6.19 mi. When 60-min ISI levels were <95 dB re 1 μPa, there was no evidence of offshore displacement; the fitted 5th percentile line and its lower bound were slightly descending or nearly horizontal. When average (for 60 min) sound levels near Northstar increased from 95 dB to 105 dB, 115 dB, and 125 dB re 1 μPa, we are ~95% confident that the 5th percentile of offshore whale call distance was displaced farther offshore by more than 0.34 km (0.21 mi), 1.41 km (0.88 mi), and 3.01 km (1.91 mi), respectively. Point estimates for the displacement of the 5th percentiles were 1.26 km (0.78 mi) at 105 dB, 5.26 km (3.27 mi) at 115 dB, and 14.79 km (9.19 mi) for 125 dB. These estimates were based on comparing the fitted 5th percentile of offshore distances at 105, 115 and 125 dB with that at 95 dB.

In interpreting these results, it is important to note that the sound levels used in the analysis are those measured 400 m from the north edge of Northstar Island in three 1/3-octave bands believed to be strongly influenced by industrial sounds. The overall broadband level (e.g., 10-1000 Hz level) at this location averaged 5.8 dB higher than the level for these three bands. In addition, the calling whales localized during this project were all more than 400 m away from Northstar. Consequently, they would have been exposed to lower sound levels than those recorded at the 400-m measurement location, as shown above in Figure 8.24 vs. 8.21, and in Figure 8.23 vs. 8.22. Regardless, over the 28 Aug to 3 Oct 2001 period, higher-than-normal sound levels in the general Northstar area were associated with changes in bowhead distribution and/or calling behavior several kilometers offshore.

## DISCUSSION

This study has demonstrated that the acoustical localization method, as proposed to NMFS and stakeholders during 2000, is a practical method for assessing the extent to which the Northstar Development influences bowhead whales migrating west in the southern (inshore) part of their migration corridor. However, the results reported here are preliminary in the sense that they pertain to only a five-week segment of the bowhead migration within a single year. Also, there is still considerable uncertainty in estimates of the magnitude of the "Northstar effect" on bowhead whales:

- One analysis approach provided evidence of some offshore displacement of the locations at which bowhead calls were detected during times in 2001 when sound level, averaged over 60 min, was fairly high (Fig. 8.34). This apparent effect involved the whales near the southern edge of the bowhead migration corridor. It occurred during a minority of times during the bowhead migration period when underwater sounds emanating from the Northstar area were strongest. From the results of this one analysis, we can state with confidence somewhat less than 95%, but greater than 81.5% (see later), that displacement was greater than zero at high noise times, at least in 2001.
- Three other analysis approaches showed less or no evidence of such a displacement effect in 2001 (Fig. 8.31-8.33). With those approaches, we could not state with approximate 95% confidence that there was a meaningful tendency for offshore displacement at times when Northstar sound was strongest.
- The 2001 data are consistent with the possibility of an attraction effect at times with moderate levels of Northstar sounds as compared with times having low levels. The closest whale calls tended to be closer at times with moderate Northstar sounds than with weaker Northstar sounds. This suggests that the 1-sided analysis concept adopted at the outset of this project should be reconsidered.

Additional data from 2002 are expected to allow us to determine which (if any) of these patterns is evident in another year. The same types of data were collected in September 2002, and analysis of those data is (as of October 2002) about to begin. Combined data from 2001 and 2002 will provide a better basis for assessing the potential effects of Northstar than now possible.

There is much year-to-year variation in the migration corridor of bowheads, ice conditions, and other aspects of the environment. The possible "Northstar effect" evident in the southern part of the bowhead migration corridor at times in 2001 might not occur in a year when the overall migration corridor in the central Alaskan Beaufort Sea is farther offshore. The effect might be different, or absent, in a year when ice has a strong effect on the migration corridor. It also may not be evident in future years if the underwater sounds created by Northstar during oil production in 2002 and later years are weaker and/or less variable than those during construction in 2000-2001.

The following subsections discuss various aspects of the 2001 methods and results in more detail.

## *Ping Calibrations*

The DIFAR ping processing resulted in bearing measurements with more scatter than we had expected. Some possible explanations are discussed below:

*Sensitivity to Reflections.*—The DIFAR process is sensitive to reflections that are asymmetrical in the horizontal plane, i.e., reflected sounds arriving from different azimuths. There will, in general, be reflections off the sea bottom and surface, but those reflected sounds will arrive in the vertical plane of the direct arrival and should not distort the bearing measurement in the absence of transducer tilt. There are no known reflectors such as piles of boulders in the relatively flat, shallow region of the DASAR array—such reflectors could account for lateral sound travel paths. Possible sources of lateral transmission paths include scattering off surface waves near the acoustic path, the presence of ice floes, or even bottom irregularities of the order of a wavelength (3-7 m). The pings that consisted of a sweep across frequency may be more resistant to reflections. The slight delay between arrival of the direct and reflected signals means that the frequencies of the direct and reflected energy arriving at a given instant are not the same, and the bearing-distorting effect of the interfering reflection will be averaged out. Similarly, whale calls generally vary in frequency within the duration of the call, and are probably not subject to as much bearing variability as the single-frequency pings.

*Interfering Noise Sources.*—If there exists in the field an interfering noise source at the same frequency as the ping (or whale call), with significant directionality and with amplitude comparable to the ping (or whale call), it will adversely influence the estimated average bearing to the source of interest. Such directional noise was definitely present at some times, with the predominant background sound usually arriving from the approximate direction of Northstar.

*Possible Alternative Processing.*—There are other possible ways to process the DIFAR information, some of which might result in less bearing variation. In particular, the band pass filter must be as wide as the entire sweep, and at any one time more noise is present than is necessary. The ping could be detected by correlating the known (transmitted) waveform against the DIFAR channel outputs (matched filtering). This could improve the precision of the bearing estimates for the calibration pings with known properties. An especially useful waveform for this technique is called PRN (pseudorandom noise), which can be formed across an arbitrary bandwidth, like 200-400 Hz. This correlation approach would be less applicable to whale calls, whose individual properties are not known *a priori.* Another alternative is frequency-domain processing, where bearings are calculated for the measured sound in each frequency bin of a discrete Fourier transform. The latter approach was used with the year 2000 data (Greene et al. 2001) and gave results comparable to those from the time-domain approach described here.

*Variable Depth Source.*—The ping projector was always operated at a depth of 10 meters, which was convenient and near mid-water given the range of water depths near the DASARs (17-25 m; see Fig. 8.1). Perhaps deeper depths would give better propagation, although 10 m should have been adequate for the wavelengths of the 100-500 Hz calibration pings used here (approx. 3 to 15 m). A deeper source might have resulted in less interference from surface reflections. Averaging the bearings from pings transmitted at different depths from the same location might also improve the accuracy.

## *Underwater Sounds from Northstar*

Figures 8.11 and 8.12 present records of broadband sounds received by a cabled hydrophone 400 m north-northwest of Seal Island. The strong narrow pulses evident in Figure 8.12 appear to correspond to marine vessel operations, including crewboats and tugs-and-barges to and from Northstar Island. Most of the pulses on the two days occur at about the same times each day, consistent with the crewboat operating schedule. More random barge operations account for variability between the two days. Note that these pulses are about 20-25 dB higher relative to the general background level at intervening times. Such pulses were seen in 2000 as well (Greene et al. 2001).

The lowest levels seen, as manifested by the lower envelope of the sound levels vs. time, are indicative of the "normal" background and island sound in the absence of vessels. These levels rise and fall over much longer time periods than do the pulses (Fig. 8.11). On 31 Aug, when CIDS and the last of the sealift vessels departed (see Chapter 7), the lowest sound levels, on a broadband basis, dropped from about 108 dB re 1 µPa to 90-92 dB. The same pattern was evident in data from an ASAR located close to the cabled hydrophone (*cf.* Fig. 7.17 *in* Chapter 7). However, the minimum sound levels rose again on 18 Sept and again on the 25th and later, probably due to storms or winds that raised the sea state and hence the background noise. Thus, even the high sound levels from the CIDS presence and departure, as received by a hydrophone at a distance of about 700 m from the (former) CIDS location, were not as high as the levels due to storms on the 28th and 30th of Sept.

## *Underwater Sounds at the DASARs*

Figure 8.15 presents the 10-500 Hz sound levels for three DASARs, at the NE, SE and WB stations as mapped in Figure 8.1. The DASAR most distant from Seal Island was NE, at range 22 km. The DASARs at SE and WB were two of the closer units, at respective distances of 10 km and 9.5 km. How similar were the sounds at these three locations as compared to the near-island sounds? Examining the envelope of minimum levels, one notes that all three rise on 4 Sept, as did the near-island hydrophone level shown in Figure 8.11. Other maxima in the envelope of minima also correspond to maxima in the levels near the island, such as on 17, 21, 25, 28 and 30 Sept. The pulses in the sound levels at NE and WB have the same boat-related pattern as those in the near-island sound, but the maximum levels are roughly 10 dB lower. This would be expected given that vessels operating near the island were closer to WB and SE than to NE, and were generally larger (and more numerous) than those operating near the DASARs.

The minimum broadband levels recorded by all three DASARs, close to 90 dB, are accounted for by the self-noise of the sensors. Actual minimum levels of underwater sound under near-calm conditions and in the absence of nearby vessels would be expected to be lower.

## *Whale Call Locations*

The patterns of whale call locations shown in Figures 8.19–8.21 are not surprising in relation to previous evidence from aerial surveys (e.g., Treacy 2000) and from the 2000 phase of this project (Greene et al. 2001). The bowhead migration corridor is known to be almost exclusively offshore of Northstar, wide, and variable from time to time. These features are all evident in Figures 8.19–8.21.

As described in the "Results", there was evidence from "call sequences" that many of the whales detected on 2 Sept (Fig. 8.19) were traveling to the west-northwest, parallel to shore. The 2 Sept data, and those from all days combined (Fig. 8.21), show more calls from whales approaching the array from the east than from whales departing to the west. The effect is not as clear in Figure 8.20, but again more calls were localized on the ESE than on the WNW side of a line perpendicular to the migration path and through the DASAR array. These results are consistent with previous evidence that bowhead whale calls are somewhat directional, favoring detection in the area generally ahead of the whale (Clark et al. 1986). However, some caution is needed in interpreting the lower number of localizations to the NW than to the NE and E of the array given that the DASAR at the northwesternmost position was inoperative (Fig. 8.14).

In Figure 8.19 (2 Sept), the call locations were generally near the DASAR array. In Figure 8.20 (3 Sept), most of the call locations are much farther offshore. Many of the estimated whale locations on 3 Sept were far enough offshore or east of the DASARs to be unreliable. (Those more than 20 km from the central axis of the DASAR array are excluded from Figure 8.21, and those more than 12 km away are excluded from the statistical analysis of call locations relative to Northstar sound.) Nonetheless, it is certain that the majority of the detectable calling whales were farther offshore on 3 Sept than on 2 Sept. The graphs of underwater sound levels near Northstar vs. time for the two days (Fig. 8.12A vs. B) show no major difference in the sound environment on the two dates. (See also Figures 8.11 and 7.17 for acoustic data from these vs. other dates.) These results illustrate that notable differences in the position of the bowhead migration corridor can occur from day-to-day without any obvious connection with industrial activities. It was necessary to apply statistical approaches to the data from all dates in order to determine whether any such relationship existed, and to quantify the strength of the relationship.

In 2000, we saw many cases in which the bearings from DASARs to successively-detected calls were consistent with westward travel by a single whale or closely-spaced group. However, in 2000 the whale calls were not localized with sufficient accuracy to allow detailed analysis of call sequences (Greene et al. 2001). In 2001, when calling whales within and near the DASAR array were localized more accurately, it was apparent that many calls occurred in sequences indicative of WNW travel parallel to the coast.

The call sequences progressing across the middle of the DASAR array on 2 Sept, apparently representing whales traveling WNW parallel to shore, showed no indication that bowhead whales were diverting farther offshore as they approached Northstar. However, no specific analysis of the call sequences has been attempted to assess this in a quantitative way. Although a time-lapse presentation of the call positions sometimes shows the general orientation of the traveling whales, it is impossible to be certain that any two specific calls represent the same individual whale or closely-spaced group of whales.

### *Effect of Northstar-Related Sound on Call Locations*

Based on 2001 results, we are reasonably confident (~95%) that, at times with higher-than-average underwater sound near Northstar Island averaged over 60 min, the spatial distribution of bowhead calls near Northstar was affected. By "~95% confident", we mean confidence somewhat less than 95% but greater than 81.5%. We did not find a clear effect when sound was averaged over shorter periods. Nonetheless, as the 60-min measure of sound level increased above a certain threshold value, the southernmost of the whale calls tended to be increasingly far offshore. This result addressed one of the key objectives: "to estimate the effects of Northstar activities on the migration corridor and calling behavior of bowheads by comparing distances of calling whales from Northstar at times with varying levels of industrial sound".

The analysis of the distribution of bowhead calls relative to Northstar sound depended on two main types of data—sound measurements near Northstar and localization of calling bowheads—, and on several decisions as to how these data should be analyzed. These topics are considered briefly here:

During the monitoring period in 2001, continuous data on low-frequency (up to 1000 Hz) underwater sounds were available from several instruments deployed within a few hundred meters offshore of Northstar (Fig. 8.2; see also Fig. 7.1 in Chapter 7). For the present analysis, we used data from a single hydrophone (C.H.2) that operated continuously throughout the period of interest at a location 400 m NNW of Northstar Island. We restricted the acoustic data to three 1/3-octave bands in which the sounds seemed to be dominated by industrial sound. This resulted in a sound index that best represented the variability in industrial sound emissions. However, the numerical value of this index was inevitably lower than the overall sound pressure level in the 10-1000 Hz band—a commonly-used measure of industrial sounds. The mean difference between our industrial sound index and the 10-1000 Hz level was 5.8 dB (± s.d. 2.85 dB). The median difference was 5.4 dB. We found evidence that a sound effect started to become evident at a sound index of about 100 dB re 1 μPa when averaged for an hour. This means that a sound effect started to become evident at a 10-1000 Hz level of ~106 dB. Likewise, we found evidence that the effect became conspicuous at sound index values above ~110 dB, or above ~116 dB re 1 μPa on a 10-1000 Hz basis.

The sound levels mentioned above were at a location only 400 m from the north edge of Northstar Island. The whale calls that were localized were all farther away than that. Sound levels tend to decrease with increasing distance from the source (see Chapter 7). Thus, bowheads were apparently reacting to sounds at received levels lower than those that were directly measured 400 m from Northstar. The estimated received levels of the industrial sound index at whale call locations are shown in Figures 8.23 and 8.24 for locations within the analysis zone. Only about 1% of the calls in the 12-km analysis zone were associated with estimated received sound indices averaging 100 dB re 1 μPa or more over the 60 min preceding detection (Fig. 8.23). Figure 8.23 and associated text show the percentages of calls associated with other received sound indices (and broadband levels).

The accuracy of the call locations determined in this study has been discussed earlier. In general, the bearings determined by the DASARs in 2001 were more accurate than those for 2000, but more variable than hoped or expected. As a result, estimated locations of calling whales were determined with less accuracy than desired, especially for whales that were outside the perimeter of the array of DASARs. The potential negative effects of this inaccuracy on the overall statistical analysis of call locations vs. sound were minimized by two methods. *(1)* After the uncertainty in each call location was estimated using available calibration data, uncertainty was used as a weighting factor in the analysis, with imprecise locations being down-weighted. *(2)* For other reasons (avoidance of a possible bias), it was found necessary to limit the study area to the zone within 12 km east, west and offshore of the center of the DASAR array. This automatically excluded calls at locations distant from the instruments, which constituted most of the calls whose positions were especially uncertain.

We analyzed the distribution of whale calls based on their perpendicular distances offshore from a line drawn through Northstar Island and parallel to the coast. Thus, a call that originated 10 km offshore of this line was considered to be at the same offshore distance whether it was directly offshore of Northstar or as much as 12 km to the east or west. (Calls more than 12 km east or west were excluded, as noted above.) This approach has some advantages and some disadvantages over the simplest alternative, analyzing radial distances from Northstar. For an initial analysis, it seemed most appropriate to determine the extent to which, for calling whales in the general Northstar area, distance-from-shore was related to the sound level. However, in follow-up analyses it might also be useful to test for an effect of sound on radial distances.

There was little evidence of an effect until the sound index 400 m from Northstar (averaged for an hour) exceeded ~100 dB re 1 μPa, i.e., overall 10-1000 Hz band level above ~106 dB. The effect did not become conspicuous until the index at 400 m, averaged over an hour, exceeded ~110 dB (overall 10-1000 Hz band level above ~116 dB). The 60-min sound index 400 m from Northstar exceeded 100 dB for only 10.8% of the whale calls and 38.4% of the time. It exceeded 110 dB for only 4.4% of the calls and 10.7% of the time. Thus it can be assumed that only a minority of the total bowhead population passed at times with any Northstar effect, and only a small fraction passed at times with a conspicuous Northstar effect. Furthermore, at those times, the Northstar effect was restricted to only the southern part of the migration corridor (Fig. 8.34). The number of bowheads potentially affected is discussed in Chapter 9, but it is obvious that this must have been only a small fraction of those passing through the monitoring zone, and an even smaller fraction of the population. The analysis zone extended offshore 28.6 km from Northstar, to the 25-m depth contour. This is near the middle of the migration corridor in an average year (LGL and Greeneridge 1996; Miller et al. 1999; Treacy 2000; see Chapter 9). Thus, it is probable that only about half of the whales were close enough to shore to pass through the analysis zone.

A further consideration is that the bowhead migration past Northstar continues until mid or late October. In 2001, routine vessel operations near Northstar ceased by 7 Oct, when freeze-up was occurring. After that date, there probably were few if any occasions when industrial sound levels were high enough to cause any "Northstar effect". This would further reduce the percentage of the population that might have been affected. Chapter 9 provides additional details concerning numbers of bowhead whales potentially affected, based on the 60-min average sound levels.

Our results show that the strongest sound emissions from the Northstar area were associated with maneuvering by vessels (see Table 8.2 vs. Fig. 8.16, and associated text). Vessels were the predominant sound sources at times when ISI values, as measured 400 m from Northstar, exceeded the 90th percentile ISI level. Vessel noise made some lesser contribution at certain times when ISI values were in the 50th to 90th percentile range, but made little or no contribution at times when ISI values were below the median (50th percentile) ISI. Figure 8.35 shows these three percentile ISI values (as measured 400 m from Northstar) in relation to the number of whale calls that were localized. The apparent displacement effect was evident only when the 60-minute ISI was above its 90th percentile value. If the rightmost 10% of the whale-call data in Figure 8.35 were excluded from consideration, there would be no evidence of an offshore displacement effect. Thus, this apparent effect is attributable largely if not entirely to times when the industrial sounds were dominated by vessel noise. To the extent that there is concern about offshore displacement of bowhead whales near the southern edge of their migration corridor, this could be mitigated by reduced vessel activities during the bowhead migration season.

In September 2002 we obtained more complete records of vessel and other activities at and near Northstar than were available for 2001. Thus, the planned analyses of 2002 data should provide more specific information about the sound levels associated with vessels vs. other Northstar activities, and the activities occurring at any times when an offshore displacement might be evident.

### *Statistical Analysis Issues*

Many of the passing whales are expected to emit a number of calls in succession, and this raises concerns about ***lack of independence*** of the individual calls. In the preliminary analysis of 2000 data described in Greene et al. (2001), we addressed this by subdividing the field season into 15 temporal bins that were assumed to be statistically independent, applying quantile regression separately to each bin, and

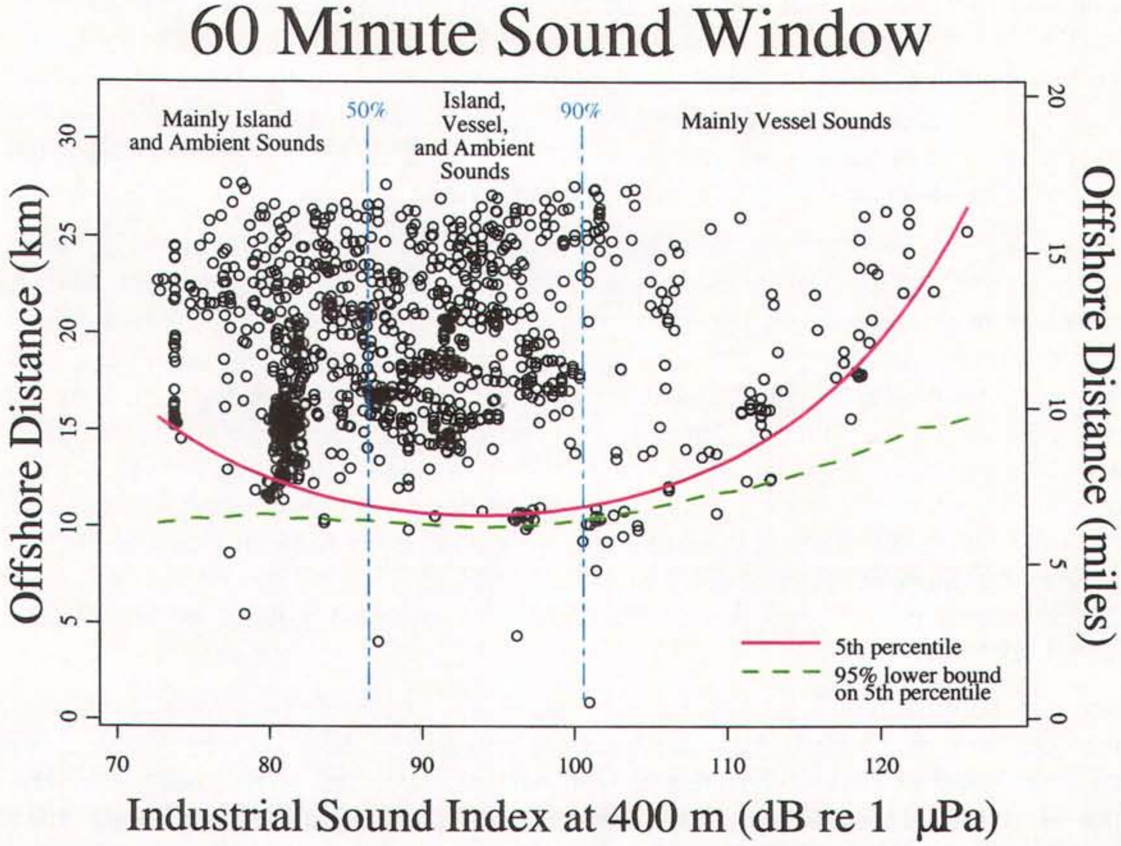


FIGURE 8.35: Offshore distances of bowhead calls detected in the analysis area vs. average industrial sound index (ISI) 400 m north of Northstar in the 60 minutes previous to the call, distinguishing the ISI values associated primarily with vessel sounds. The dashed vertical lines show the 50th and 90th percentile ISI levels (86.5 and 100.6 dB), based on data plotted in Figure 8.22. Otherwise identical to Figure 8.34.

then pooling the results. In the present analysis of 2001 data, we have used an improved approach that tested for autocorrelation in the distance-offshore data, and then applied a bootstrapping (re-sampling) approach. This approach is believed to provide an unbiased estimate of the strength of the relationship between Northstar sound and the distribution of whale calls. It allows for the interdependence of data collected within short time periods, and thus avoids overestimating the strength of the apparent relationship between sound levels and call distribution. After applying these precautions, the analysis based on the 60-min average sound estimated a positive (offshore) displacement of calls at high-noise times with nearly 95% confidence. With the same precautions, the other three analyses based on 5-, 15-, and 30-min average sound did not provide similar evidence of a positive displacement.

As described in the Results, the outcome of the analyses depended on the ***averaging time*** that was used when determining the Northstar sound level. Apparent offshore displacement at times with relatively high sound emissions was evident when sound was averaged for 60 minutes, but was less evident (or not evident) based on shorter averaging times. Prior to collecting the 2001 data, there was no specific basis for judging the averaging time most relevant to bowhead whales. It was reasonable to assume that sounds received by a whale over some substantial period preceding detection of a given whale call would have an influence on the location of the whale when the call was emitted. If the apparent offshore displacement at high-sound times was at least partly the result of an actual offshore displacement of whales, and not solely attributable to a reduced tendency to call when exposed to industrial sound, then it is not surprising that displacement would be most evident when sound is averaged over a relatively long (60-min) time period. Migrating bowhead whales travel at an average speed of ~4 km/h, so any substantial displacement in response to strong sounds would require some time to become evident.

Prior to examining the 2001 data, we decided to consider 5, 15, 30 and 60 min averaging times. In hindsight, it is possible that the apparent displacement observed at times with strongest sounds might have been stronger with an averaging time longer than 60 min. The best-estimate of the displacement distance at the highest-sound times encountered in 2001 exceeded 4 km for ISI values of 115 dB and greater, and was substantially more than 4 km at the few times with ISI values of 120 dB or more (see Fig. 8.34, 8.35). There was much uncertainty in these estimates. However, if the actual average displacement of whales traveling along the southern part of the migration corridor at the highest ISI times was as suggested by 5th-quantile curve shown in Figure 8.35, then it might require more than 60 min for this displacement to manifest itself at a 4 km/h swimming speed. Thus, it is possible (but not certain) that a larger displacement effect than evident in Figure 8.35 might be evident if sound levels were averaged over more than 60 min. This suggests that a maximum averaging time larger than 60 min should be investigated in future analyses of 2002 or combined 2001-2002 data.

There may be some reason for concern about the effects of conducting ***multiple analyses*** with varying averaging times on our lower confidence bounds as estimated for the 5th-quantile distance offshore. Some statisticians would recommend correcting the probability statements that we have made to account for the fact that we conducted four analyses on the same data set. These statisticians might argue that at a specific ISI level, the probability of all four of the 95% lower bounds being simultaneously accurate (i.e., that the true 5th quantile was greater in all four cases) is somewhere between 81.5% and 95%. Other statisticians would recommend no correction of probability statements based on multiple analyses. They might argue that, because the analyses we conducted were planned in advance, we do not need to correct for multiple analyses. If an analysis is planned and the same study could somehow be repeated an infinite (or very large) number of times, each lower bound would be wrong (i.e., the true 5th quantile would be lower) 5% of the time, and together the entire set of tests would be wrong 5% of the time. Still other statisticians have expressed the opinion that no study ever needs to correct for multiple analyses of the same data, whether analyses were planned or not. As noted in the "Methods" section, we choose not to correct individual lower bounds in each of our four planned analyses, primarily to avoid further complications in presentation. Instead, we have termed our lower confidence bounds "approximate 95%" lower bounds and sometimes say we are "nearly 95% confident" in our lower bounds. By "approximate" and "nearly", we mean that the probability (prior to analysis) that the true 5th quantile is greater than the lower bound is somewhat less than 95%, but greater than 81.5% (=100(0.95$^4$)). Users of this report need to be aware of the disagreement among statisticians regarding the most appropriate way to handle situations such as this, and bear it in mind when judging the weight of evidence that this study presents for a displacement of whales.

For 2002, this concern about multiple analyses can be addressed because there is now an *a priori* basis (i.e., the 2001 results) for selecting a 60-min (or longer) analysis time for the primary analysis of 2002 data. In addition, this concern can likely be alleviated for 2002 data by estimating the relationship between the size of any apparent deflection and averaging time.

We made several ***methodological assumptions*** throughout the analysis. For example, bearings were assumed to follow a Von Mises distribution, and we assumed that call locations more than 24 hours apart are independent. Because of the likelihood that one or more methodological assumptions was not wholly satisfied, use of the term "approximate" in reference to confidence levels is further justified. Users of this report need to be aware of the methodological assumptions and bear their validity in mind when judging the weight of evidence that this 2001 study presents for a displacement of whales.

Before collecting any data, we decided on a ***1-tailed analysis approach***. That is, we assumed that any relationship of the "distances offshore" to Northstar sound would involve increasing distances with increasing sound level. The appropriateness of a 1-tailed approach was discussed at the peer/stakeholder review meeting prior to the 2000 field season, and was subsequently mentioned in the monitoring plans for 2000 and 2001-2002 (submitted Aug. 2000 and May 2001), and in previous reports on the 2000 and 2001 monitoring. However, the call location data in Figure 8.35 (and Fig. 8.31 to 8.34) are consistent with the possibility that the closest bowhead calls tended to become somewhat closer to Northstar as ISI levels increased from low to moderate. In saying this, it should also be noted that, for low to moderate sound levels, the lower bounds for the 5th quantile in the analyses based on 30-min and 60-min average sound show little if any negative slope. Nonetheless, these data could be indicative of an attraction effect at moderate sound levels. Whether this phenomenon is real is not determinable from the present 2001 data. This will be examined further when additional data from 2002 are analyzed. In any event, the 2001 results suggest that the 1-sided analysis concept adopted at the outset of this project should be reconsidered for 2002.

### *Possible Attraction to Weak Industrial Sounds*

It would not be entirely surprising if some whales in the southern part of the migration corridor were somewhat attracted toward the relatively weak received levels that they might perceive during times when sound emissions were at moderate levels. Bowheads and other whales have often been shown to exhibit tolerance of industrial sounds that are only slightly above ambient noise levels provided those sounds are not associated with any obvious threat (Chapter 9 *in* Richardson et al. 1995). Minke whales often approach and even swim under stationary or slow-moving vessels (Winn and Perkins 1976; I.W.C. 1982; Leatherwood et al. 1982; Tillman and Donovan 1986). Gray whales, especially in the calving lagoons in winter, are often attracted to quiet, idling, or slow-moving boats, especially in late winter (Swartz and Cummings 1978; Norris et al. 1983; Withrow 1983; Bryant et al. 1984; Dahlheim et al. 1984; Jones and Swartz 1984, 1986).

Attraction to weak, steady sounds has not been demonstrated for bowheads, but the possibility should not be discounted without further consideration of the data. In doing this, it would be very desirable to take account of the industrial-to-ambient ratios at the locations of the calling whales. At times when ISI at 400 m is moderate, i.e., when there is a possible attraction effect, received levels at the locations of even the most inshore whales will often be below the ambient noise and presumably undetectable. It is difficult to see how there could be attraction to Northstar sound in these circumstances. Unfortunately, we do not have precise data on ambient noise levels near each calling whale, so the industrial-to-ambient ratios to which each whale is exposed are not specifically determinable.

### *Limitations of the Acoustical Monitoring Approach*

The acoustical method used in this study has many advantages. As compared with aerial surveys, some of the main advantages are the large number of detections and localizations that it can provide, and its ability to operate autonomously, day or night, and in any weather conditions.

However, this approach also has limitations that need to be recognized when evaluating its suitability for any particular purpose. The acoustical localization approach depends on the calling behavior of bowhead whales, and on the ability of the instrumentation to detect and then to localize the calls. Both calling behavior and the capabilities of the localization system are complex, and several factors are known or suspected to influence each of them. The following list is the same one provided in the report on the initial localization effort at Northstar in 2000 (Greene et al. 2001), updated to take account of new information.

1. Only whales that call can be detected and localized. Any silent whales will be missed. If the proportion of whales that pass by without calling varies from time to time, this could result in biases.
2. The number of calls emitted by whales is not necessarily a direct indication of the number of whales present. Whales may call at a higher rate on one occasion than another.
3. The rate and intensity (source level) at which whales call may be affected by the sounds (anthropogenic or natural ambient) that they hear.
4. There are limits on the distance to which a given call can be detected and localized. With the DIFAR method, a bearing can be obtained to any call that is detected, but localization accuracy diminishes as the number of DASARs detecting a given call decreases, and as the distance of the calling whale from the DASARs increases. Also, the bearings to calling whales provided by the DIFAR sensors in the DASARs have, to date, been less consistent and reliable than had been expected. Considerable improvements in localization accuracy were achieved in 2001 relative to 2000, and a weighting procedure was applied during analysis to reduce the influence of some of the less reliable locations without discarding them altogether. However, the variability in the bearing calibration data was still higher than expected (see Table 8.1 and associated text), and this reduced the overall capability of the system as compared with initial expectations.
5. The source level of a whale call affects the ability of a DASAR (or any hydrophone) to detect the call. The higher the source level, the farther away the call will be detected, other factors being equal. As noted above, source levels might be affected by exposure to anthropogenic or natural background noise.
6. Background noise (anthropogenic plus natural ambient) at the location of a DASAR (or any hydrophone) affects its ability to detect a given whale call. In this study, all DASARs were close enough to Northstar such that, at times of high industrial sound output by or near Northstar, weak calls that would otherwise be detectable by the DASARs might be masked by industrial sounds. Also, natural ambient noise levels vary widely. Results from 2000 showed that there was a strong negative correlation between number of calls detected and background noise level (Greene et al. 2001). Results from 2001 showed that the distances of the localized whale calls from a reference point near the center of the DASAR array depended strongly on background noise level; the number of calls detected dropped off sharply at distances beyond ~12 km at times with high background noise, whereas many calls were detected at longer distances at the quiet times (Fig. 8.28)
7. Given these considerations, one cannot directly determine whether a change in the call detection rate represents a change in (a) the number whales present, (b) their calling rate, or (c) the system's ability to detect the calls. However, considerable information about the effective monitoring radius can be derived, when the detected calls are localized, based on two types of data: the distance at which the number of detected calls starts to decline (e.g., Fig. 8.28), and the signal-to-noise ratios of the calls received from whales at various distances.

   Based on the 2000 study, we noted that it is important to ensure that the array of DASARs extends far enough south to monitor the southernmost portions of the migration corridor even at times when background noise levels are high. In 2001, the DASARs were placed 1.85 km (1.15

mi) south of their 2000 locations. Also, in 2001, another DASAR location was added to the southwest part of the array (WB in Fig. 8.1).

Based on the 2000 study, we also noted that it may be appropriate to restrict the eastern, western and northern edges of the area considered in the statistical analysis to the area where there is a high probability of detecting and localizing whale calls even at times when background noise levels are high. This would reduce bias associated with variations in background noise levels. This was done in 2001. We considered only the calls within the radius where most calls were detectable even at times with high noise levels. This was done at the expense of excluding many of the data. It would be desirable if some approach could be developed to overcome the potential bias without excluding all information on calls localized at the longer distances under quiet conditions. The received levels of the calls might be one type of data that could be used. In 2001, we logged the received level of every call (and the call type) for possible use in future analyses.

8. To assess whether "the distribution of calling whales detected north of Northstar is (or is not) related to the level of industrial sound from Northstar", it is necessary that there be substantial temporal variability in the amount of underwater sound emitted by Northstar activities. We expected that sound emissions would be quite variable during construction and during subsequent times with vessel traffic and/or drilling. Results from 2001 confirmed that there was much variability in underwater sound levels near Northstar during the monitoring period from 28 Aug to 3 Oct 2001. Nonetheless, most of the time the sound levels were below that at which offshore deflection of bowhead whales became evident (Fig. 8.34). Also, our data did not extend into the latter part of the 2001 bowhead migration period, as it was necessary to retrieve the acoustic instrumentation before vessel operations were curtailed by ice. Vessel operations near Northstar ceased by 7 Oct in 2001 (Chapter 6). After that date, underwater sound levels were unmeasured but most if not all the time were probably below the level where deflection of bowheads would occur. There will probably be less variability in underwater sound emissions, and generally lower levels of underwater sound, during "routine" production operations in 2002 and future years. Thus, deflection of bowheads is likely to become less common (and more difficult to document) in future.

9. If there is an offshore deflection or change in calling behavior but it is limited to a small radius around Northstar, the number of call localizations within the impact area might be too small to allow detection of a difference during the high-sound vs. low-sound periods. This would be most likely in a year when the general bowhead migration corridor is farther offshore than average, or a year when sound emissions are relatively low most of the time. In 2001, there was sufficient variability in sound, and a sufficient effect on the bowhead migration, that the statistical technique was able to identify an effect with a high degree of confidence. If no similar effect were found in another year, or in some future application of this methodology elsewhere, the precision of the statistical estimators should be determined for various sizes of hypothesized effects. This would be an update of the *a priori* power analysis given in Appendix D of Greene et al. (2001), taking account of the actual sample size, actual call locations, and updated analysis methodology.

10. There could be a change in the relative numbers of calls detected at different distances offshore even if there were no corresponding change in the distribution of whales. An effect such as that detected in 2001 (Fig. 8.34) indicates that some change in bowhead behavior occurred in response to industrial sound. However, it is not immediately obvious whether this industry effect involved a change in whale distribution, in calling rate, in source levels of the calls, or in some combina-

tion of these parameters. In our description of the results, we have often stated or implied that the effect represents an offshore deflection upon exposure to high sound levels, as this type of effect was predicted based on reactions of bowheads to industrial activities in other situations. However, we acknowledge that the sound effect on locations where calls are detected could be attributable, at least in part, to a sound effect on some other aspect of bowhead behavior. To some degree, it may ultimately be possible to discriminate these potential types of industry effects based on the localization data, sequences of calls, and the received levels (and types) of the calls. This level of refinement has not yet been attempted, but (in 2001) the received levels and types of calls were logged for possible future analysis.

11. Another complication in assessing the disturbance effects of any one activity, in this case Northstar, is the occurrence of other potentially disturbing activities in the area:

    - The Concrete Island Drilling Structure (CIDS) had been cold-stacked 1.1 km northeast of Northstar since August 2000. In August 2001 there was vessel activity around CIDS as it was prepared for its eventual westward departure on 31 Aug 2001 (Chapters 6, 7). The activities at and around CIDS were a confounding factor during the first three days of our 2001 monitoring period (28-31 Aug).

    - Bowhead hunting near Cross Island, located east of Northstar by 28 km (15 n.mi. or 17.5 mi), also might influence whale distribution, calling behavior, or both. The eastern edge portion of our analysis area was 10 km (5.4 n.mi. or 6.2 mi) west of Cross Island (Fig. 8.21, 8.24). However, it is not known how far west of Cross Island any hunting effects might extend. The Nuiqsut hunters were at Cross Island from 3 to 26 Sept in 2001. They hunted intermittently from 4 or 5 Sept to 22 Sept, and landed three whales, on 5, 10 and 22 Sept (M. Galginaitis, pers. comm., April 2002).

    - Activities of the boat we used to deploy, service, calibrate, and retrieve seafloor recorders may have caused intermittent disturbance to some bowheads. We conducted such operations for several hours once or twice per week during the 2001 monitoring period.

Notwithstanding these complications, the acoustical monitoring approach has the great advantage of being able to detect the locations of large numbers of bowhead whales as they pass the Northstar area, and to do so by both day and night, independent of darkness, visibility, or weather. Although this method has limitations and biases, so do other methods that have been suggested for use. Aerial surveys, in particular, also involve a variety of biases in detectability of bowhead whales (Thomas et al. 2002). In addition, sample sizes achievable with aerial surveys are orders of magnitude smaller, and inadequate to address project objectives, as discussed under "Objective 5", below (see also the power analysis in Appendix C of Greene et al. [2001]).

## *Ability of Approach to Meet Objectives*

The objectives of the acoustic monitoring task are listed in the Introduction of this chapter and are discussed one-by-one here. Objectives of the 2001 work were essentially the same as those of the previous 2000 effort. This section is an update of discussion included in Greene et al. (2001), now taking account of the successful monitoring effort in 2001.

### Objective 1

> *"to monitor the year 2001 bowhead migration past Northstar by acoustic localization methods, primarily to document the relative numbers of bowhead calls vs. distance offshore in the southern part of the bowhead migration corridor seaward of Northstar."*

This objective had been partially met based on 2000 data, and was met based on 2001 data. In 2000, bowhead whale calls were recorded successfully, in large numbers, and the results provided data on call detection rates at several locations varying distances from Northstar during about 20 days of the fall migration. Directions to calling whales were measured for all call detections, but these bearings were not sufficiently accurate for reliable localization of the individual calling whales. The bearings (and hence localizations) obtained in 2000 results were substantially less precise than had been anticipated.

The 2001 monitoring program was able to meet Objective 1. All necessary types of data, i.e., call locations and industrial sound levels near Northstar, were collected continuously over a 36-day period including the early and middle portion of the bowhead migration season. Also, the DASARs (and the call data stored in those instruments) were all recovered successfully just prior to freeze up. Localization accuracy was considerably improved in 2001 through improvements in design and reliability of the DASARs, and by implementing a more systematic and comprehensive set of field calibrations of the DASAR clocks and orientations. Despite the improvements, the bearing accuracy (and hence the localization accuracy) of the DASARs during 2001 was still less than had been anticipated, and further improvements are desirable, as previously discussed.

### Objective 2

> *"to document continuously • the characteristics of the sounds propagating away from Northstar, as determined at a close-in monitoring site approximately 300-500 m (1000-1600 ft) offshore from the island, as well as • the characteristics of the background sounds (industrial plus ambient) reaching the recording devices in the southern part of the migration corridor;"*

This objective was not met in 2000 except over the period 25-30 Sept, when a backup ASAR provided continuous hydrophone data from a site ¼ n.mi. (~455 m) NNE of Northstar. This objective was met in 2001.

The problems with the cabled hydrophone system encountered in 2000 were avoided in 2001 by deploying redundant hydrophones and recording systems near Northstar (see Fig. 8.2), and by confirming frequently, throughout the field season, that useful data were being acquired. All data used in this analysis were acquired from one of the two cabled hydrophone systems ("C.H.2"), which operated successfully throughout the period when the DASARs operated. Another cabled hydrophone as well as autonomous seafloor recorders (ASARs) provided redundant information that could have been used if C.H.2 had failed. Figure 7.1 (in Chapter 7) shows the periods of operation of each of these sensors.

Results from the DASARs indicated that sounds from vessels operating near Northstar were sometimes detectable even at the DASARs situated farthest offshore. (The DASAR most distant from Northstar was at the NE location, 22 km (13.7 mi) northeast of Northstar—see Fig. 8.1.) The variability in the sounds received at that NE location and at two of the closer DASARs is documented in Figure 8.15 over the full duration of the 2001 field season.

One remaining instrumentation issue is the fact that the electronic noise floor of the DASARs was sufficiently high that electronic noise masked background sounds at times when they were weak. This had little if any negative effect on the detection of whale calls within the primary study area (within 12 km of the central axis of the DASAR array). However, it did reduce the ability of the DASARs to provide data on the full range of variability in background sounds. We are investigating whether the noise floor of the DASARs can be lowered during future deployments.

### *Objective 3*

> *"to estimate the effects of Northstar activities on the migration corridor and calling behavior of bowheads by comparing the distances of calling whales from Northstar at times with varying levels of industrial sound;"*

This objective had not been met in 2000 because of the imprecision of the directional data and the lack of continuous data on sounds emitted by Northstar. Simultaneous data of both types were needed for a substantial part of the bowhead migration season in order to meet this objective. This objective was met in 2001. Both types of data were collected over a 36-day period extending from the onset of the main bowhead migration period (28 Aug) until freeze-up was imminent. Instrumentation problems that were encountered in 2000 were much reduced in 2001, allowing us to obtain the needed types of data continuously. Localization accuracy was improved in 2001, allowing locations of calls within and near the DASAR array to be determined with sufficient accuracy for use in the analysis. However, the accuracy of the directional data provided by the DASARs during 2001 was still less than had been hoped. We are continuing to seek ways to improve this accuracy during future deployments.

The statistical approach that had been proposed for estimating the effects of Northstar sound on bowhead whales in the southern part of the bowhead migration corridor requires continuous data on sound emissions from Northstar and on locations of whale calls. Data acquisition problems in 2000 prevented application of the statistical approach in that year, but the 2000 results showed that the statistical approach could answer some relevant questions when the instrumentation problems were resolved. Both types of data were obtained in 2001, and this allowed us to estimate the occurrence and magnitude of an apparent offshore displacement of bowheads during the 2001 autumn migration, as related to industrial sound associated with Northstar. Based on 3 of 4 quantile regressions, and bearing in mind the statistical caveats listed above (see "Statistical Analysis Issues"), we could not be ~95% confident that Northstar sound was associated with an apparent offshore displacement at times of high sound emissions. However, based on the 60-min average sound, and again bearing in mind the statistical caveats, we are nearly 95% confident that, at times in 2001 with high sound emissions, Northstar did affect some bowhead whales traveling in the southern part of their migration corridor. Because three analyses did not provide substantial evidence of an apparent displacement, and one analysis did, this conclusion should be considered provisional until the additional data collected during September 2002 are analyzed. Experience in 2000 and 2001 has showed that the number of bowhead calls that can be localized is sufficient for a meaningful analysis. A procedure has been developed to avoid the bias that might otherwise occur as a result of variations in background noise level and detection-radius. Also, a bootstrapping procedure has been developed to deal with the complication that calls detected close to one another in time may not be independent.

### *Objective 4*

> *"to determine whether any individual bowheads or bowhead groups can be tracked acoustically. If so, the tracks will be analyzed to determine whether there is evidence of deflection as the whales approach Northstar and, if so, at what distances and received sound levels;"*

This objective was met to a limited extent with the 2000 and 2001 data. In 2000, the lack of precise, reliable localizations precludes detailed analysis of sequences of calls. However, the observed sequences of call bearings vs. time (Greene et al. 2001) showed several sets of successive points that appeared to represent "tracks in bearing". These data suggested that, when the localization problems encountered in 2000 were solved, it would likely be possible to track some calling bowheads (or closely spaced groups) via the planned acoustical method. Results from 2001 showed apparent temporal sequences of calls progressing WNW toward and through the DASAR array, or passing just offshore of the DASARs. Specific analysis of these call sequences was not pursued in 2001 because the statistical analysis based on individual call locations was able to characterize a Northstar effect on locations of detectable whale calls. Any analysis of call sequences would be complicated by the fact that it is impossible to be certain whether successive calls from locations close to one another are created by the same bowhead (or the same group of bowheads).

### *Objective 5*

> *"to compare the acoustic monitoring results with results from MMS or any other available aerial surveys to further assess the strengths and limitations of acoustic and aerial methods in documenting the bowhead migration corridor past Northstar and in detecting any change (probably small-scale, if at all) in the migration corridor near a site like Northstar;"*

Review and analysis of historical aerial survey data in advance of the 2000 field season showed conclusively that the number of aerial survey sightings that could be acquired near Northstar, even with a dedicated site-specific aerial survey project, would be far from adequate to detect an offshore displacement of the anticipated magnitude if it occurred (LGL et al. 2000). The statistical power analysis done as part of that assessment was repeated as Appendix C of Greene et al. (2001). Conversely, another *a priori* power analysis showed that the acoustic localization approach did have the potential to detect a small-scale (e.g., 5 km or 2.7 n.mi.) displacement of the southern part of the migration corridor if it occurred (Appendix D of Greene et al. 2001). Based on that assessment, BP proposed and the peer/stakeholder group agreed (at its May 2000 meeting) that the acoustical approach to monitoring should be adopted, and that site-specific aerial surveys would not be effective. The same group, at its June 2001 meeting, re-affirmed that the acoustical approach should be applied again during the autumn of 2001.

As implemented in 2001, the acoustic method was able to identify and characterize a small-scale change in the pattern of call detections during the minority of the time when much underwater sound was emitted near Northstar. Results from both 2001 and 2000 showed that bowheads moved past Northstar in approximately their normal migration corridor during much of the 2001 and 2000 season. As usual, the main corridor was well offshore from Northstar, but a small minority of the individuals passed within a few kilometers of Northstar (Fig. 8.21, 8.29). Nonetheless, during parts of the 2001 season when sound emissions near Northstar were well above average, a lower-than-average proportion of the detected calls originated from locations along the southern edge of the migration corridor (Fig. 8.34).

Figure 9.23 in Greene et al. (2001) showed data on the sightings of bowhead whales in the central part of the Alaskan Beaufort Sea during the broad-scale aerial survey program conducted by MMS during the late summer and autumn of 2000 (original 2000 data courtesy of S. Treacy, MMS; see also Treacy 2002). The number of sightings within that area in 2000 (14 sightings) was lower than average. This was probably attributable, in large part, to difficult weather conditions for aerial surveys during much of the 2000 bowhead migration season. MMS survey data from 2001 have not yet been reported. However, there were very few bowhead sightings in the central part of the Alaskan Beaufort Sea during MMS's 2001 aerial survey program, again because of difficult weather conditions for aerial surveys (S. Treacy, MMS, pers. comm., April 2002).

Given the low number of MMS sightings in this region in 2000 and 2001, even a dedicated daily site-specific aerial survey program in the Northstar area (had it been done during those years) probably would have provided fewer than 100 bowhead sightings per year. Furthermore, the 2001 acoustic localization results indicate that there was a Northstar effect on the call distribution only during the small percentage of time when sound levels were highest (Fig. 8.35). Only a small percentage of any aerial survey results would represent whale distribution at times when a Northstar effect was occurring. Thus, the conclusion from the *a priori* statistical power analysis regarding the inability of aerial survey methods (either broad-scale MMS or site-specific) to detect a small-scale displacement undoubtedly applied to 2000 and 2001.

### *Objective 6*

> *"to estimate the number of bowhead whales whose movements and/or calling behavior were affected by the presence of industrial activities at Northstar in autumn 2001."*

This objective was to be addressed primarily by using the acoustical localization data to determine the scale of any deflection of the bowhead migration corridor. This was not possible in 2000 given the data limitations that year. In 2001, we were able to demonstrate that an effect occurred, and that this effect only became evident when sound levels near Northstar exceeded a specific value (about 95 dB re 1 μPa within three 1/3-octave bands dominated by industrial sounds). For the minority of the times when the underwater sound levels near Northstar exceeded that level, the analysis technique provided an estimate of the extent (in kilometers) of the effect, and the dependence of the effect size on the sound level. The analysis also provided an approximate lower confidence bound on the estimated displacement effect at various sound levels.

These results indicate that the general acoustic-localization approach provides a basis for estimating how often an effect occurs, and thus an upper limit on the fraction of the bowhead population that is potentially affected. Also, the approach provides a basis for estimating how far offshore the effect extends at times when it does occur. However, the variability in 2001 results depending on the averaging time that is assumed means that a decision must be made as to the most appropriate averaging time. Also, there are complications in converting the estimated offshore displacement of the "5th percentile whale" under specified sound conditions into an estimate of the number of whales potentially affected. As discussed earlier, the acoustical method does not directly reveal whether the demonstrated effect represents displacement, a change in calling behavior, or some combination of the two. The utility of the 2001 data in estimating the numbers of whales potentially affected by Northstar that year is further discussed in Chapter 9, "Estimated Numbers of Seals and Whales Potentially Affected".

The acoustic monitoring approach has provided an empirical basis for estimating numbers of whales that might have been affected by Northstar in 2001, despite some limitations discussed in Chapter 9. We are not aware of any alternative monitoring method that could have provided this information. In particular, aerial surveys would not have provided sufficient coverage and sightings of bowheads to detect any change in whale distribution during the minority of the time when Northstar-related sounds were strong enough to have a local effect on bowhead distribution. The acoustic localization method was able to document the frequency and scale of such an effect on the distribution of bowhead calls.

## SUMMARY

During the bowhead whale migration in the autumn of 2001, BP implemented an acoustic monitoring program northeast of BP's Northstar oil development at Seal Island. The primary objective was to assess the effects of Northstar construction activities on the migration corridor and calling behavior of bowhead whales by comparing the offshore distances of calling bowheads at times with varying levels of industrial sound. This project was a follow up to a similar effort in 2000. The 2000 work demonstrated that the acoustic localization approach had promise as a method for detecting and quantifying Northstar effects on the whale migration corridor. However, in 2000 equipment problems prevented determining whether (and to what extent) the migration corridor was related to Northstar construction sounds. The results from 2001 provided evidence that the southern edge of the bowhead migration corridor was deflected offshore at times with high levels of underwater sound near Northstar.

During 2001, bowhead whale calls were recorded from 29 Aug until 3 Oct in 2001 by instruments placed on the seafloor at locations 6 to 22 km (4 to 14 mi) offshore of Seal Island (Northstar). Eleven autonomous instruments (DASARs) with the capability of recording directional acoustic information about the calls were installed in an array. The directional information from the array provided intersecting bearings to the sources of sound occurring within several kilometers, thereby measuring the locations of whales when their calls were detected at two or more DASARs. About 400 m (¼ mi) north of Seal Island, near-island sounds were recorded continuously during the same time period. These data have been used in a statistical analysis to investigate the extent to which island sounds influence distances from the island at which calling whales are detected, i.e., to what extent strong levels of Northstar-related industrial sound influence whales to swim farther away from shore than they would in the absence of island sound, or change their calling patterns, or both.

Sounds recorded near the north side of the island ranged from about 80 to as high as 140 dB re 1 $\mu$Pa in the 10-1000 Hz band. The low levels correspond to broadband levels expected at times of low sea states. The high levels occurred when vessels were active near the island. Variations in the minimum levels of sound (below the levels attributed to the vessels) were within the range expected from calm seas to well developed wind-driven waves.

For the first nine days after the DASARs were deployed, valid data were acquired from 10 of the 11 DASARs. From then through 28 Sept, data were acquired from at least six DASARs at almost all times. Some DASARs failed and were repaired and replaced. Other DASARs suffered failures that were not detected. By the end of the 36-day recording period on 2-3 Oct, four DASARs were still collecting useful data and providing information about locations of calling whales. The background sounds at the DASARs, even at 13.7 mi (22 km), included vessel sounds from the vicinity of the island, consistent with the boat-based hydrophone measurements at long distances from the island reported in Chapter 7.

In the 36 days of operation, 10,738 bowhead calls were detected. Of these, source locations were computed for 3446 calls, and 1259 were within an area where calls could be monitored effectively even at times with relatively high levels of background noise. That monitoring area extended out to 28.6 km (~18 mi) offshore of Northstar, and to 12 km (7½ mi) east and west of a line running offshore from Northstar. Aerial survey data show that, in an average year, about half of the bowheads migrate west within that distance of Northstar.

Quantile regression was used to assess whether, for calls within the effective monitoring area, the 5th percentile of whale call distance tended to be farther offshore at times with high than with low sound levels at the hydrophone 400 m (¼ mi) from Northstar. The analysis used a bootstrapping method to take account of the fact that the distances-from-shore of whale calls detected at intervals less than 24 hours apart were interdependent. It also applied a weighting factor that was inversely related to the uncertainty in the call locations.

Four indices of underwater sound near Northstar were considered, representing the sound averaged over the 5 min, 15 min, 30 min, and 60 min previous to detection of each whale call. These sound indices included the sound components within three 1/3-octave bands that were dominated by industrial sound. These bands were centered at 63, 80 and 160 Hz. The level in those three bands (industrial sound index, ISI) averaged about 5.8 dB less than the level in the overall 10-1000 Hz band.

Although all conclusions are subject to various caveats and provisos discussed in Chapter 8, the quantile regression lines estimated using 15-, 30-, and 60-min averages of the ISI indicated that the relationship between offshore distance and sound level was positive when ISI (averaged over 15-60 min) was greater than ~95 dB re 1 µPa. The relationship was strongest for the 60-min average ISI. For that analysis, the approximate 95% lower confidence bound indicates appreciable offshore displacement of call locations when sound levels are high. With ISI up to 95-100 dB re 1 µPa, there was no apparent displacement of the 5th percentile of whale call distances. When average (for 60 min) ISI levels near Northstar increased from 95 dB to 105 dB, 115 dB, and 125 dB re 1 µPa, the 5th percentile of offshore whale call distance was estimated to displace farther offshore by 1.26 km (0.78 mi), 5.26 km (3.27 mi), and 14.79 km (9.19 mi), respectively. With nearly 95% confidence, the 5th percentile of offshore whale call distances increased by more than 0.34 km (0.21 mi), 1.41 km (0.88 mi), and 3.01 km (1.91 mi) when 60-min ISI values increased to 105 dB, 115 dB, and 125 dB, respectively. The apparent displacement effect was evident only when the 60-min ISI was above its 90th percentile value. This apparent effect occurred largely if not entirely at times when the industrial sounds were dominated by vessel rather than sounds from Northstar island itself.

In general, during the early and middle portion of the bowhead migration season in 2001, we are reasonably certain that higher-than-normal sound levels in the Northstar area (averaged over 60 minutes) were associated with an offshore displacement of the southern edge of the bowhead migration corridor and/or a change in bowhead calling behavior in the area within several kilometers offshore of Northstar. The number of whales potentially affected is estimated in the following Chapter. However, analyses based on sound levels averaged over 5, 15 or 30 min showed less or no evidence of a displacement effect in 2001. With those analysis approaches, we could not be ~95% confident that there was a meaningful tendency for offshore displacement at times when Northstar sound was strongest. Also, the 2001 data are consistent with the possibility of an attraction effect at times with moderate levels of Northstar sounds as compared with times having low levels. Again, all conclusions are subject to caveats discussed in Chapter 8. Because three analyses did not provide substantial evidence of apparent displacement at higher-than-normal sound levels, and one analysis did, conclusions about offshore displacement should be considered provisional until the additional data collected during September 2002 are analyzed.

Additional data from 2002 are expected to allow us to determine which (if any) of these patterns are evident in another year. The same types of data were collected in September 2002, and analysis of those data is (as of October 2002) about to begin. Combined data from 2001 and 2002 will provide a better basis for assessing the potential effects of Northstar than now possible.

There is much year-to-year variation in the migration corridor of bowheads, ice conditions, and other aspects of the environment. The possible "Northstar effect" evident in the southern part of the bowhead migration corridor at times in 2001 might not occur in a year when the overall migration corridor in the central Alaskan Beaufort Sea is farther offshore. The effect might be different, or absent, in a year when ice has a strong effect on the migration corridor. It also may not be evident in future years if the underwater sounds created by Northstar during oil production in 2002 and later years are weaker and/or less variable than those during construction in 2000-2001.

## ACKNOWLEDGEMENTS

Alaska Clean Seas crews on their Bay-class boats made the ocean work near Seal Island and at the DASAR array safe and successful. Mark Theriault, Bob Venable, Karl Pulliam, Willy Nye and Greg Ronne were particularly helpful. ACS supervisors and coordinators Barron Rutherford, Eric Olsen, Jim Nevels, Fred McAdams and Walter Henry made the scheduling and personnel assignments work. Jonah

Leavitt of Barrow helped during field preparations and sea work. Dr. Susanna Blackwell and Jennifer Seitz of Greeneridge managed the field operations for health checks and calibration transmissions. Dr. Blackwell also performed the retrieval, refurbishment and replacement of failed DASARs, and compiled Table 8.2. Bob Norman and Quy Nguyen engineered the DASAR re-design and fabrication essential for the success of the instruments in 2001. Bob also helped at Prudhoe Bay with deployment and retrieval. Kristin Otte, Jane Fleischman, Shoshanna Love, Robert Fortune, Jaime Lynch, Jennifer Seitz, Jonah Leavitt and Debbie Martinez of Greeneridge performed the whale call localization analysis. Bob Blaylock, Greeneridge, prepared many of the Figures for this chapter. At WEST, Ryan Nielson assisted with the statistical analysis of whale locations vs. Northstar sounds. Anne Wright and Kathleen Hester, LGL, assisted with report production. Wilson Cullor and Allison Erickson of BP Alaska provided helpful logistical connections for the Prudhoe Bay field work. Dr. Ray Jakubczak, Dave Trudgen, and Dr. Bill Streever of BP Alaska supported the project, and numerous participants in the peer/stakeholder group convened by NMFS provided guidance and support. Dr. Streever and Dr. Jakubczak, plus Mike Williams of LGL, provided helpful comments on the draft chapter. Thanks to all.

## LITERATURE CITED

Blackwell, S.B. 2002. Sound and vibration measurements during oil production and drilling at Northstar in early 2002. p. 2-1 to 2-28 2 *In:* W.J. Richardson and M.T. Williams (eds.), Monitoring of ringed seals, sounds and vibrations during operation of BP's Northstar Oil Development, Alaskan Beaufort Sea, winter and spring 2001-2002: 90-day report. Rep. From LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 86 p.

Bryant, P.J., C.M. Lafferty and S.K. Lafferty. 1984. Reoccupation of Laguna Guerrero Negro, Baja California, Mexico, by gray whales. p. 375-387 *In:* M.L. Jones, S.L. Swartz and S. Leatherwood (eds.), The gray whale *Eschrichtius robustus*. Academic Press, Orlando, FL. 600 p.

Blackwell, S.B. and C.R. Greene, Jr. 2001. Sound measurements, 2000 break-up and open-water seasons. p. 7-1 to 7-55 *In:* W.J. Richardson and M.T. Williams (eds), Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2000. [Draft, April 2001.] LGL Rep. TA2429-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 316 p.

Clark, C.W. 1983. Acoustic communication and behavior of the southern right whale (*Eubalaena australis*). p. 163-198 *In:* R.S. Payne (ed.) Behavior and Communication of Whales. AAAS Selected Sympos. 76. Westview Press, Boulder CO. 643 p.

Clark, C.W., W.T. Ellison and K. Beeman. 1986. An acoustic study of bowhead whales, *Balaena mysticetus*, off Point Barrow, Alaska during the 1984 spring migration. Rep. from Marine Acoustics, Clinton, MA, for North Slope Borough, Barrow, AK. 145 p.

Cummings, W.C. and D.V. Holliday. 1987. Sounds and source levels from bowhead whales off Pt. Barrow, Alaska. **J. Acoust. Soc. Am.** 82(3):814-821.

Dahlheim, M.E., H.D. Fisher and J.D. Schempp. 1984. Sound production by the gray whale and ambient noise levels in Laguna San Ignacio, Baja California Sur, Mexico. p. 511-541 *In:* M.L. Jones, S.L. Swartz and S. Leatherwood (eds.), The gray whale *Eschrichtius robustus*. Academic Press, Orlando, FL. 600 p.

Greene, C.R., Jr., with J.S. Hanna and R.W. Blaylock. 1997. Physical acoustics measurements. p. 3-1 to 3-63 *In*: W.J. Richardson (ed.), Northstar marine mammal monitoring program, 1996: marine mammal and acoustical monitoring of a seismic program in the Alaska Beaufort Sea. LGL Rep. TA2121-2. Rep. from LGL Ltd., King

City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 245 p.

Greene, C.R., Jr., R. Norman and J.S. Hanna, with R.W. Blaylock. 1998. Physical acoustics measurements. p. 3-1 to 3-66 *In*: W.J. Richardson (ed.), Marine mammal and acoustical monitoring of BP Exploration (Alaska's) open-water seismic program in the Alaskan Beaufort Sea, 1997. LGL Rep. TA2150-3. Rep. From LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 318 p.

Greene, C.R., Jr., M.W. McLennan, T.L. McDonald and W.J. Richardson. 2001. Acoustic monitoring of bowhead whale migration, autumn 2000. p. 9-1 to 9-57 *In*: W.J. Richardson and M.T. Williams (eds), Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2000. [Draft, April 2001.] LGL Rep. TA2431-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 316 p.

Hickie, J. and R.A. Davis. 1983. Distribution and movements of bowhead whales and other marine mammals in the Prudhoe Bay region, Alaska 26 September to 13 October 1982. p. 84-117 *In*: B.J. Gallaway (ed.), Biological studies and monitoring at Seal Island, Beaufort Sea, Alaska 1982. Rep. from LGL Ecol. Res. Assoc. Inc., Bryan, TX, for Shell Oil Co., Houston, TX. 150 p.

IWC. 1982. Report of the special meeting on Southern Hemisphere minke whales, Cambridge, 22-26 June 1981. **Rep. Int. Whal. Comm.** 32:697-745.

Johnson, S.R., C.R. Greene, R.A. Davis and W.J. Richardson. 1986. Bowhead whales and underwater noise near the Sandpiper Island drillsite, Alaskan Beaufort Sea, autumn 1985. Rep. from LGL Ltd., King City, Ont., for Shell Western E & P Inc., Anchorage, AK. 130 p.

Jones, M.L. and S.L. Swartz. 1984. Demography and phenology of gray whales and evaluation of whale-watching activities in Laguna San Ignacio, Baja California Sur, Mexico. p. 309-374 *In:* M.L. Jones, S.L. Swartz and S. Leatherwood (eds.), The gray whale Eschrichtius robustus. Academic Press, Orlando, FL. 600 p.

Jones, M.L. and S.L. Swartz. 1986. Demography and phenology of gray whales and evaluation of human activities in Laguna San Ignacio, Baja California Sur, Mexico: 1978-1982. Rep. from Cetacean Res. Assoc., San Diego, CA, for U.S. Mar. Mamm. Comm., Washington, DC. 69 p. NTIS PB86-219078.

Leatherwood, S., F.T. Awbrey and J.A. Thomas. 1982. Minke whale response to a transiting survey vessel. **Rep. Int. Whal. Comm.** 32:795-802.

Koenker, R. and G. Bassett, Jr. 1978. Regression quantiles. **Econometrica** 46:33-50.

Lenth, R.V. 1981. On finding the source of a signal. **Technometrics** 23:149-154.

LGL and Greeneridge. 1996. Northstar marine mammal monitoring program, 1995: baseline surveys and retrospective analyses of marine mammal and ambient noise data from the central Alaskan Beaufort Sea. LGL Rep. TA2101-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK. 104 p.

LGL and Greeneridge. 2000. Technical plan for marine mammal and acoustic monitoring during construction of BP's Northstar oil development in the Alaskan Beaufort Sea, 2000-2001 (revised 30 Aug. 2000). Rep. from LGL Alaska Res. Assoc. Inc. (Anchorage, AK), LGL Ltd. (King City, Ont.) and Greeneridge Sciences Inc. (Santa Barbara, CA) for BP Exploration (Alaska) Inc., Anchorage, AK. 80 p.

Manly, B.F.J. 1997. Randomization, bootstrap and Monte Carlo methods in biology, 2nd ed. Chapman and Hall, London, U.K. 281 p.

Mardia, K.V. 1972. Statistics of direction data. Academic Press, New York, NY. 357 p.

Miller, G.W., R.E. Elliott, W.R. Koski, V.D. Moulton and W.J. Richardson. 1999. Whales. p. 5-1 to 5-109 *In*: W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA2230-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 390 p.

Moore, S.E., D.K. Ljungblad and D.R. Schmidt. 1984. Ambient, industrial and biological sounds recorded in the northern Bearing, eastern Chukchi and Alaska Beaufort Seas during the seasonal migrations of the bowhead whale (*Balaena mysticetus*), 1979-1982. Rep. from SEACO Inc., San Diego, CA, for U.S. Minerals Manage. Serv., Anchorage, AK. 111 p. NTIS PB86-168887.

Moran, P.A.P. 1950. Notes on continuous stochastic phenomena. **Biometrika** 37:17-23.

Norris, K.S., B. Villa-Ramirez, G. Nichols, B. Würsig and K. Miller. 1983. Lagoon entrance and other aggregations of gray whales (*Eschrichtius robustus*). p. 259-293 *In:* R. Payne (ed.), Communication and behavior of whales. AAAS Selected Symp. 76. Westview Press, Boulder, CO. 643 p.

Patenaude, N.J., W.J. Richardson, M.A. Smultea, W.R. Koski, G.W. Miller, B. Würsig and C.R. Greene Jr. 2002. Aircraft sound and disturbance to bowhead and beluga whales during spring migration in the Alaskan Beaufort Sea. **Mar. Mamm. Sci.** 18(2):309-335.

Richardson, W.J., C.R. Greene Jr., C.I. Malme, and D.H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego, CA. 576 p.

Swartz, S.L. and W.C. Cummings. 1978. Gray whales, *Eschrichtius robustus*, in Laguna San Ignacio, Baja California, Mexico. MMC-77/04. Rep. from San Diego Nat. Hist. Mus. for U.S. Mar. Mamm. Comm., Washington, DC. 38 p. NTIS PB-276319.

Thomas, T.A., W.R. Koski and W.J. Richardson. 2002. Correction factors to calculate bowhead whale numbers from aerial surveys of the Beaufort Sea. Chapter 15 *In:* W.J. Richardson and D.H. Thomson (eds.), Bowhead whale feeding in the eastern Alaskan Beaufort Sea, vol. 1. LGL Rep. TA2196-7. Rep. from LGL Ltd., King City, Ont., for U.S. Minerals Manage. Serv., Herndon, VA.

Tillman, M.F. and G.P. Donovan. 1986. Behaviour of whales in relation to management: report of the workshop. **Rep. Int. Whal. Comm., Spec. Iss.** 8:1-56.

Treacy, S.D. 2000. Aerial surveys of endangered whales in the Beaufort Sea, fall 1998-1999. OCS Study MMS 2000-066. U.S. Minerals Manage. Serv., Anchorage, AK. 135 p.

Treacy, S.D. 2002. Aerial surveys of endangered whales in the Beaufort Sea, fall 2000. OCS Study MMS 2002-014. U.S. Minerals Manage. Serv., Anchorage, AK. 111 p.

Urick, R.J. 1972. Noise signature of an aircraft in level flight over a hydrophone in the sea. **J. Acoust. Soc. Am.** 52(3, Pt. 2):993-999.

White, G.C. and R.A. Garrott. 1990. Analysis of wildlife radio-tracking data. Academic Press, New York, NY. 383 p.

Winn, H.E. and P.J. Perkins. 1976. Distribution and sounds of the minke whale, with a review of mysticete sounds. **Cetology** 19:1-12.

Withrow, D.E. 1983. Gray whale research in Scammon's Lagoon (Laguna Ojo de Liebre). **Cetus** 5(1):8-13.

# ESTIMATED NUMBERS OF SEALS AND WHALES POTENTIALLY AFFECTED BY NORTHSTAR ACTIVITIES,

NOV. 2000—OCT. 2001

# CHAPTER 9:

# ESTIMATED NUMBERS OF SEALS AND WHALES POTENTIALLY AFFECTED BY NORTHSTAR ACTIVITIES, NOV. 2000 – OCT. 2001 [1]

by

**Michael T. Williams [a], Valerie D. Moulton [b] and W. John Richardson [c]**

**[a] LGL Alaska Research Associates Inc.**
1101 E. 76th Ave., Suite B, Anchorage, AK 99518
(907) 562-3339; mwilliams@lgl.com

**[b] LGL Ltd., environmental research associates**
388 Kenmount Rd., POB 13248 Stn. A, St. John's, Nfld. A1B 4A5
(709) 754-1992; vmoulton@lgl.com

**[c] LGL Ltd., environmental research associates**
22 Fisher St., POB 280, King City, Ont. L7B 1A6
(905) 833-1244; wjr@lgl.com

for

**BP Exploration (Alaska) Inc.**
Dept of Health, Safety & Environment
900 East Benson Blvd. P.O. 196612
Anchorage, AK 99519-6612

LGL Report TA2563-7

Revised October 2002

---

[1] Chapter 9 *In:* W.J. Richardson and M.T. Williams (eds.). 2001. Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2001. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD.

## INTRODUCTION

BP continued construction of the Northstar Development from November 2000 through October 2001, and began drilling the first wells for below-ground injection and oil production. Re-construction of ice roads began in November 2000 and was completed by early March 2001. Drilling occurred from mid-December to mid-June. On-ice activities continued into early June 2001, followed by breakup and the use of helicopters for transportation until the open-water season. No drilling occurred during the open-water season. Production facilities arrived by sealift in August, and sealift vessels departed during late August. There was frequent vessel traffic between Prudhoe Bay and Northstar throughout the open-water season. Installation of production facilities continued on the island during early-mid autumn. Oil production began on 31 October 2001, at the end of the period covered by this report. Chapters 2 and 6 provide more details concerning BP's activities during the ice-covered and open-water periods, respectively.

Estimates of the number of seals and whales that might be affected by Northstar activities were discussed by NMFS (2000) in the preamble to the regulations issued in May 2000 with regard to "taking" of seals and whales by Northstar activities. The Letter of Authorization (LoA) issued by NMFS on 18 September 2000 under those regulations set limits on the type and level of "taking" that was authorized. Specifically, the LoA stated that

> (i) During the ice-covered period, up to 125 ringed seals and 5 bearded seals may be incidentally harassed annually;
>
> (ii) During the ice-covered period, up to 5 ringed seals may be incidentally killed annually; and
>
> (iii) During the open-water period, up to 22 ringed seals, 1 spotted seal, 5 bearded seals, 717 bowhead whales (maximum of 1533 bowheads in 2 out of 5 seasons, or 3585 in 5 years), 5 gray whales, and 45 beluga whales may be incidentally harassed annually.

The LoA also called for BP to conduct monitoring work as had been proposed by BP in the revised monitoring plan submitted to NMFS in September 2000. One of the primary purposes of the monitoring was to assess the actual numbers of seals and whales affected by BP's Northstar activities, and to compare those estimates with the numbers authorized in the LoA.

The monitoring work planned for the period Nov 2000 through Oct 2001 was done, and the results have been described earlier in this report. Chapters 3–5 describe the three types of monitoring conducted during the 2000-2001 ice-covered season, and Chapters 7–8 describe the two types of monitoring during the 2001 open-water season.

***Monitoring during the ice-covered season*** of 2000-2001 included

- on-ice measurements of sounds (underwater and in-air) and vibrations in the ice during March 2001 (Chapter 3),
- dog-based searches for ringed seal breathing holes and lairs, including installation of temperature sensors and data loggers, during Nov–Dec 2000, March 2001, and May 2001 (Chapter 4), and
- fixed-wing aerial surveys of seals during May-June 2001 (Chapter 5).

BP's searches for ringed seal breathing holes and lairs, as described in Chapter 4, went beyond the scope proposed in the monitoring plan in order to address NMFS statements in the LoA and its covering letter:

1. *"...NMFS has implemented a requirement for BP to monitor ice road construction again this year using trained dogs and handlers... NMFS believes that there is a need*

> *for at least one more year of data on potential impacts to ringed seals during the winter resulting from ice road construction...* Any *ice-roads or other construction activities that are initiated, after January 1, 2001, in previously undisturbed areas in waters deeper than 3 meters (10 ft), must be surveyed, using trained dogs, in order to identify and avoid structures by a minimum of 150 m (492 ft).*"

***Monitoring during the open-water season*** of 2001 included

- in-air and underwater acoustic measurements during August 2001, with some continued measurements in September (Chapter 7), and
- acoustic monitoring of calling bowhead whales during the autumn migration (Chapter 8).

On-ice searches for ringed seal structures (Chapter 4) and acoustic monitoring of calling bowhead whales (Chapter 8) were more successful in 2001 than in 2000. This was a result of improvements in methodology and in implementation of planned procedures. This, in turn, provided a better ability to estimate numbers of seals and whales affected in 2001 than in 2000.

The next section of this chapter estimates the number of seals potentially affected by activities associated with BP's Northstar development during the ice-covered period of Nov 2000 through mid-June 2001. A subsequent section estimates numbers of seals and whales potentially affected during the break-up and open-water periods in 2001 (mid-June through October). In addition, this chapter discusses potential impacts of Northstar activities on subsistence hunting for seals and whales near the development area.

## 2000-2001 ICE-COVERED SEASON

During the ice-covered season, the only species of seal or whale that occurs regularly in the area of landfast ice surrounding Northstar is the ringed seal. An occasional bearded seal can occur in the landfast ice in some years. Bowhead and beluga whales are absent from the Beaufort Sea in winter, and in spring their eastward migrations are far offshore in areas covered by pack ice with leads.

### *Searches for Ringed Seal Structures in the Sea Ice*

In November/December 2000, trained dogs were used to search a 75.3 km$^2$ area for ringed seal structures in and near the area where Northstar construction activities were planned to occur later in the winter (see Fig. 4.1 in Chapter 4). In March and May 2001, the status of previously located structures was re-examined and the entire study area (slightly expanded to 84.5 km$^2$—see Fig. 4.2) was searched again for any new structures. This expanded monitoring was not listed in the August 2000 version of BP's technical plan for marine mammal and acoustic monitoring of Northstar, but was generally required by NMFS in the monitoring requirements section of the LoA and in the associated covering letter.

These searches on the sea ice involved use of dogs to locate ringed seal structures, partial excavation of structures with shovels to determine their status and physical characteristics, marking of structures with wooden stakes, installation of temperature sensors within some structures, and use of vehicles (see Chapter 4). All of these activities could have affected ringed seals. Effects could include increased probability of abandonment of structures, reduced use of structures, displacement of seals to marginal habitat, and increased predation by polar bears and/or foxes responding to new olfactory cues (dog and human) or visual cues (wooden stakes and vehicle tracks) at the structure location.

### *Number of Structures Located by Dogs*

In Nov/Dec 2000, 35 structures were located in the study area (see Fig. 4.6). Three of these 35 structures had already been abandoned before the initial survey; 32 structures were active. All of the structures were partially excavated to determine structure type and status (see Chapter 4).

Of the 32 structures active in November–December, nine breathing holes and two resting lairs were still being used in March 2001. Also, two lairs that were frozen in December at the completion of our first search were reoccupied in March 2001. All of the 11 active structures were potentially disturbed again in March 2001.

We found 63 new structures in March 2001 (see Fig. 4.8). All of the structures were partially excavated to determine structure type and status. One structure was abandoned in March when we first located it. Therefore, 64 structures (includes two reoccupied structures) were disturbed by our activities on the ice in March 2001.

In May 2001, we attempted to revisit all of the previously-located structures to determine whether ringed seals had continued using the structures in the same or a different manner, or had stopped using the structures. Of the 98 structures examined in March 2001, 45 structures (28 breathing holes and 17 lairs) were still being used in May 2001. None of the abandoned structures in March were reoccupied in May.

We found 81 new structures in May 2001 (see Fig. 4.9). Thirty-six of the structures were partially excavated to determine structure type and status, and the remainder of the structures were naturally open to the surface. One structure was abandoned in May when we first located it. The status of another structure was unknown, as the dogs were unable to locate it amongst the rubble ice. Therefore, 80 new structures were disturbed by our activities on the ice in May 2001.

We assume that all structures located by dogs, with the exception of those abandoned before being located, were potentially disturbed by dog searches. This results in a total of 176 structures that were potentially disturbed: 32 active structures located in Nov/Dec 2000, 64 new active structures (including two reoccupied structures) in March 2001, and 80 new or potentially active structures located in May 2001. Structures that were located initially in Nov/Dec 2000 and subsequently revisited in March and May 2001 were counted once, not twice, in the tally of 176 active structures potentially disturbed. These numbers do not correspond precisely to those listed at some places in Chapter 4. The values reported here include structures found in areas searched in March and May that were not searched in Nov/Dec, and also include additional structures found when the dogs ventured just outside the borders of the officially designated study area. The present values represent the total number of structures investigated using the methodology requested by NMFS and described in detail in Chapter 4.

### *Number of Seals Potentially Affected by Structure Searches and Investigations*

It is highly unlikely that all 176 of the active or potentially active structures found and investigated were affected negatively by dog searches. For example, Frost and Burns (1989) reported 18% of structures that were disturbed by investigators were abandoned.

Also, the total number of active structures found (176) does not represent the actual number of ringed seals affected by dog searches as ringed seals simultaneously maintain and use more than one structure in the landfast ice. The ratio of structures to seals varies geographically (Smith and Hammill 1981; Hammill and Smith 1990) and has not been documented adequately for the central Alaskan Beaufort Sea. The "holes per seal" ratio has been estimated as 3.4 : 1 in Barrow Strait, Northwest Territories (Hammill and Smith 1990), and 4.8 : 1 off Baffin Island (Smith and Hammill 1981). If these ratios are used to calculate the number of seals associated with the 180 structures found during the present dog searches, the estimated number of seals is 52.9 and 37.5 seals, respectively. Based on these calculations the dog searches may have affected between 38 and 53 ringed seals.

## *Fixed-wing Aerial Surveys*

Overflights by the survey aircraft at altitudes of 91 m (300 ft) ASL were expected to elicit behavioral responses by a minority of the seals on the ice (Richardson et al. 1995; Born et al. 1999). This was in fact observed; the majority of seals showed no apparent reaction to the aircraft (see Table 5.7 in Chapter 5). Behavioral responses from the seals that apparently reacted to the aircraft ranged from very slight (looking up at the aircraft) to diving into the water. None of these behavioral reactions are expected to have serious consequences for the individual seals involved. In any event, a Letter of Confirmation (481-1626) from NMFS to LGL authorized the limited disturbance of seals that was expected to occur during the aerial surveys. Any such disturbance does not fall under the provisions of the LoA issued to BP.

This section applies several methods to estimate the numbers of seals that may have reacted to aircraft overflights during the 2001 aerial surveys.

Overall, 36 ringed seals were observed diving down holes or cracks in the ice during the 2001 aerial surveys. This represents 1.5% of the 2440 ringed seals sighted in both fast and pack ice whose behavior was recorded (see Table 5.7). If we apply this percentage to the ringed seals with "unknown" behavior (264 seals), then there were an additional 4 potential dives, for a total of 40.

These 40 ringed seals represent a minimal estimate of the number of dives that may have occurred in response to the aircraft. Some of the unseen seals in the relatively narrow (271 m wide) unsurveyed area directly under the aircraft presumably dived in response to the aircraft. The unsurveyed area underneath the aircraft totaled 1587 km$^2$ (0.271 km × 5855 km). If we apply the overall observed density for ringed seals on the landfast ice during the 2001 surveys (0.49 seals/km$^2$), we estimate that 778 seals may have been located underneath the aircraft. Assuming that the percentage of seals that dove was the same underneath the aircraft as in the observed areas to the sides of the aircraft (1.5%), an additional 12 seals may have dived. However, it is likely that a higher proportion of the seals underneath the aircraft dived. If we assume that seals under the aircraft were twice as likely to dive as compared with those to the side, the estimated number of seals below the aircraft that dived is doubled to 24 seals. Combining the previous estimate of 40 seals with the possible 24 seals that dived below the aircraft, we estimate that at least 64 seals dove in response to the survey aircraft.

Additional seals were encountered but not recorded as the aircraft flew over the ice while in transit between successive transects. Approximately 90% of the over-ice distance flown consisted of flights along transect lines. The remaining 10% consisted of brief between-transect flight segments, averaging ~4 km long. Half of these between-transect segments were over land or grounded ice near the south edge of the survey area, and were unsuitable as ringed seal habitat. Thus, the 64 instances when seals along transects dived should be increased by a factor of about 5% to allow for unrecorded seals overflown during the between-transect segments at the northern end of transects. This results in a total of about 67 dives observed or presumed to have occurred in response to the aircraft.

Furthermore, observers probably missed some seals that were hauled out (detection bias). Frost et al. (1988) estimated that a factor of ×1.22 should be applied to correct for detection bias. This results in a total estimate of about 82 dives. We do not consider the additional seals that simply "looked" at the aircraft as it passed (see Table 5.7) to have been disturbed.

The actual number of ringed seal dives in response to the aircraft was probably somewhat higher than 82, but the extent of underestimation is unknown:

- A few seals may have dived at a distance far enough ahead of the aircraft that the observers did not sight them.
- A few seals may have dived in response to the aircraft in the few seconds after the aircraft passed, in some cases behind the field of view of the observer
- It is possible that a few unseen seals beyond the transect-width (more than 546 m to the side of the aircraft flight path) dived in response to the aircraft.
- Observers likely missed some seals hauled out (Frost et al. 1988), and a small proportion of these seals may have dived.

An unknown but probably small proportion of the observed dives might have occurred for some reason other than the aircraft overflight. However, for purposes of this analysis, we assume that all observed dives were in response to the aircraft.

The total number of individual ringed seals that dived may have been somewhat less than the 82+ estimated above. The 82+ value is an estimate of the total instances of diving in response to the aircraft. Each transect was surveyed twice, and some of the between-transect segments may have been covered more than two times. Thus, some of the same seals may have reacted to the aircraft on two different days or possibly, in a very few cases, more than two days. However, it is unlikely that diving into the water from the ice on one or two days would have significant negative consequences for the seal.

In total, 3 bearded seals were seen in 2001; none of these were observed diving. Two of the bearded seals were recorded as having "looked" in response to the aircraft and the remaining seal did not respond overtly.

## *Acoustic Monitoring*

Measurements of sounds and vibrations produced by various construction activities were recorded at a variety of distances from the sources on the island (see Chapter 3). These measurements were made along two transects extending 6.1 km east and 7.3 km northwest onto the landfast ice from points of origin at Northstar Island (Fig. 3.1). The near-island part of the eastern transect was sampled on two different days. A rolligon was used to deploy an ice-augur (for drilling a hole through the ice) and a Hägglunds was used to deploy the recording equipment at recording stations along the eastern and northern transects (Chapter 3).

It is possible that some seal structures were encountered during travel along the acoustic transects, and that some seals may have been exposed to sounds and vibrations from activities associated with the acoustic measurements. However, no seals or seal structures were observed during acoustic monitoring activities. Also, 10 of 16 acoustic measurement stations were located within 3.5 km (2.2 mi) of Northstar and thus within the dog search zone considered previously and in the next section. Therefore, the majority of the seals potentially disturbed by the limited on-ice activity required by acoustic monitoring are included in the total number of seals potentially affected by the more intensive activities associated with construction of Northstar or the searches for seal structures.

## *Possible Displacement from Northstar Development Area*

It was not expected that there would be any injuries or mortality to seals as a result of the activities at and near Northstar. Two dead pups were found within the study area described in Chapter 4, but there was no evidence of predation or of industrial activity near those two sites. Drilling and the limited construction activities at Northstar might have displaced some seals from the area, or at least caused some seals to cease using one or more of their breathing holes or lairs. However, the overall density of seals seen during aerial surveys of the Development Area was (if anything) higher than that elsewhere in the immediate area (Chapter 5).

### *Definition of Zones*

For purposes of estimating the numbers of seals potentially affected by Northstar activities, we defined three zones of progressively increasing size around Northstar:

*(1)* The "***Northstar development zone***", as it existed in the winter-spring of 2000-2001, was defined as the area covered by artificially thickened ice roads and Northstar Island, plus the equipment testing areas around Northstar Island (see area shaded dark gray in Fig. 9.1).

*(2)* The "***potential impact zone***" was defined following the criteria outlined in BP's Petition for Regulations (BPXA 1999); we assumed that seals within 0.64 km of the primary ice road and pipeline corridor, and 1.85 km of the artificial island, could potentially be affected. We assumed that seals within 0.64 km of the equipment testing areas could also potentially be affected. These areas are shaded medium-gray in Figure 9.1. Those areas plus the "Northstar development zone" are hereafter referred to as the "potential impact zone". This zone totaled 49.2 $km^2$ (19.0 $mi^2$) and included water depths ranging from 0 to 15 m (0 to 49 ft). There was a substantial amount of overlap among the buffers around the three major industrial components of Northstar (primary ice road, island activities, and pipeline corridor). Any area within the 0.64 or 1.85 km buffer around more than one industrial component was counted only once in determining the total potential impact zone.

It is possible that seals near the island might have been affected during helicopter landings and takeoffs at the island. The low-altitude portion of the helicopter route, as depicted in Figure 6.1 (Chapter 6), was largely included in the potential impact zone and was therefore not treated separately. Helicopter altitudes were normally maintained at 1000 ft while en route. Low-altitude operations near Northstar during take-offs and landings were largely confined to a small triangle-shaped area east, west and south of the island. That area overlapped entirely with an "emergency equipment testing area" included within the development and potential impact zones, as depicted by the hourglass-shaped area in Figure 9.1.

It is recognized that sounds from Northstar activities were at times detectable outside the boundaries of the "Potential Impact Zone". Those boundaries were selected based on the best available information (prior to the start of the present monitoring work) about the size of the area where displacement or other substantial effects would be likely to occur. It was assumed, based on previous studies, that seals would tolerate some level of noise and disturbance from distant industrial activities. Results from on-ice and aerial monitoring during the present study (Chapters 4, 5) indicate that the distance categories applied in defining the "potential impact zone" are, if anything, overestimates of actual impact distances. As a result, ***our estimates of numbers of seals within the "potential impact zone" no doubt overestimate the numbers of seals significantly affected by Northstar.***

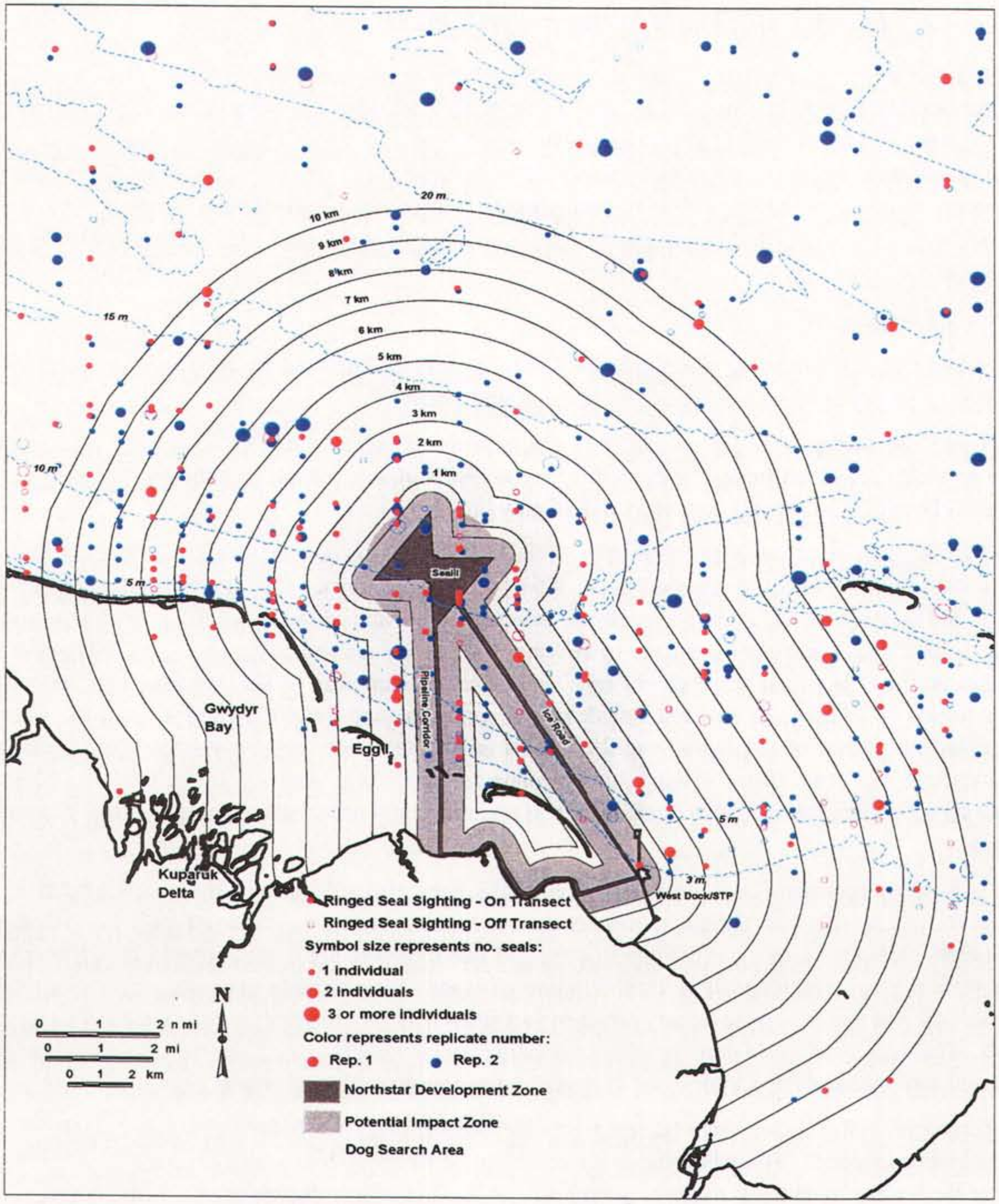


FIGURE 9.1. Distribution of ringed seal sightings within 10 km of the edges of the Northstar Development Zone (dark gray shading) during two aerial survey replicates in 2001 (28 May – 4 June and 4–8 June). The "Northstar development zone" consists of the ice roads, pipeline, artificial island, and equipment test area. The 1-km bins are measured from the edge of that area. The "potential impact zone" (see text) is indicated with medium gray shading (but also includes the "Northstar development zone"), and the area with dog-assisted searches for seals ("dog search zone") is shown with light gray shading. The dog search zone includes parts of the potential impact zone in water >1.5 m deep. 1 km = 0.62 mile = 0.54 n.mi.

*(3)* The "***dog search zone***", where we used dogs to search for seal structures, was also identified as a potentially-impacted zone of a different type. This area is shaded light gray in Figure 9.1 and also includes parts of the "potential impact zone" where the summer water depth was more than 1.5 m or 5 ft (Fig. 9.1). The total area for this zone is 90.9 $km^2$ (35.1 $mi^2$). This value slightly exceeds the area of the dog-search zone as described in Chapter 4 because we include here all areas searched by dogs, whereas Chapter 4 considers only the area within specified distances of industrial activities that was searched systematically.

There was a substantial amount of overlap between the potential impact zone and the area where dog searches were conducted. Any area searched by dogs within the potential impact zone was counted only once in determining the total dog search zone.

### *Seals in the "Potential Impact Zone"*

In this section, we estimate the number of seals that might have occurred within the potential impact zone if the Northstar Development had not been constructed. The estimate is compared to observed densities of ringed seals in that area. The expected number in the absence of industrial activities was based on aerial surveys of otherwise-similar non-industrial areas, or surveys of the Northstar area in non-industrial years. In these comparisons, we used average densities from BP/LGL aerial surveys in various zones in 1997-2001 (Miller et al. 1998; Link et al. 1999; Moulton et al. 2000, 2001, Chapter 5 of this study).

When calculating the number of ringed seals expected within the potential impact zone in the absence of industrial activity, we considered the area at a distance of 4-10 km from the Northstar Development Zone as our "reference" area. We limited the reference area to these nearby locations in case there were characteristics (independent of industry) of the Northstar area that made it either more or less "favorable" to ringed seals. We also had to control for water depth, because ringed seal density in our overall study area is often highest in waters 10-15 m deep. We would expect higher densities in some areas 4-10 km from Northstar than within the potential impact zone even in the absence of industrial activity; the 4-10 km zone includes some deeper water than occurs anywhere in the potential impact zone (Fig. 9.1). Because of inter-annual variation in ringed seal density, we used both individual-year densities for 1997-2001 and the five-year average densities.

To calculate the number of ringed seals expected to occur within the potential impact zone in the absence of avoidance, we applied densities from four water depth categories (0-3 m, 3-5 m, 5-10 m, 10-15 m) within the 4-10 km "reference" zone. These four densities (in seals/$km^2$) were multiplied by the corresponding four stratum areas within the potential impact zone (totaling 49.2 $km^2$) to give the expected numbers of ringed seals within that zone, i.e., within 0.64 km of the ice road to the island, along the pipeline, and within the emergency equipment testing area; and within 1.85 km from the artificial island. This was done separately based on 1997, 1998, 1999, 2000, 2001, and average 1997-2001 data from the BP/LGL surveys. Based on the 1997-2001 surveys of the 4-10 km "reference" zone, the expected "uncorrected" numbers of seals in the potential impact zone in the absence of any avoidance ranged from 16 to 21, depending on the year. The estimate based on 2001 survey data was 21 seals (Table 9.1).

These initial estimates are not corrected for the proportions of the seals that would be missed by aerial surveyors because of "detection bias" or "availability bias". ("Detection bias" refers to the fact that aerial surveyors do not see every seal that is on the ice and potentially sightable. "Availability bias" refers to the fact that seals are not always hauled out above the ice and snow, and thus "available" to be seen by aerial surveyors.) Instead, the estimates quoted above represent the average number of seals that one would expect to see during a single aerial survey of the entire potential impact zone, i.e., assuming 100% on-transect coverage.

TABLE 9.1. Expected numbers of ringed seals within "Potential Impact Zone" in the absence of any Northstar impact, along with observed densities within that zone during 1997-2001. Expected numbers are based on seal densities observed during aerial surveys of a reference area 4-10 km from Northstar. Potential impact zone included actual development zone plus other areas within 0.64 km of the primary ice road, pipeline, and equipment test area, and within 1.85 km of Northstar (=Seal) Island (Fig. 9.1).

| | | Expected Number of Seals Within the Potential Impact Zone | | |
|---|---|---|---|---|
| BP/LGL Survey | Expected Density[a] (seals/km$^2$) | Uncorrected | Corrected Total[b] | Observed Density[c] (seals/km$^2$) |
| 1997 | 0.41 | 20 | 57 | 0.35 |
| 1998 | 0.38 | 19 | 54 | 0.45 |
| 1999 | 0.32 | 16 | 45 | 0.28 |
| 2000 | 0.43 | 21 | 60 | 0.37 |
| 2001 | 0.42 | 21 | 59 | 0.66 |
| Average 1997-2001 | 0.39 | 19 | 55 | 0.42 |

[a] These average uncorrected densities are based on data from the zone 4-10 km away from the 2001 development zone, controlling for water depth by weighting density based on the proportions of the potential impact zone within the various depth strata.

[b] "Uncorrected" multiplied by the 1.22 correction factor for seals hauled out but not seen by observers (Frost et al. 1988), and by the 2.33 correction factor for seals not hauled out (Kelly and Quakenbush 1990).

[c] This observed uncorrected density is based on the actual area surveyed each year and not on the entire potential impact zone.

We adjusted the above estimates to allow for seals hauled out but not sighted by observers (×1.22, based on Frost et al. 1988), and for the proportion of ringed seals not hauled out during the survey coverage (×2.33, based on Kelly and Quakenbush 1990). These calculations increased the estimated numbers of seals present within the potential impact zone by a combined factor of ×2.84, within the limits of rounding error (Table 9.1). For example, based on the 2001 survey data, the actual numbers of seals expected to occur within the potential impact zone in the absence of any avoidance effect increased from the uncorrected estimates of 21 seals to a corrected estimate of 59 seals.

Aerial surveyors saw eight ringed seals (seven sightings) in the Northstar development zone during late spring in 2001, and they saw numerous additional seals within the potential impact area (Fig. 9.1). The observed density of ringed seals within the potential impact zone in 2001 was actually higher (0.66 seals/km$^2$) than the expected density (0.42 seals/km$^2$) based on densities observed 4-10 km away in 2001 (Table 9.1). If we use the observed density to calculate number of seals within the potential impact zone, this results in an uncorrected estimate of 33 seals and a corrected estimate of 92 seals. Also, more seals were sighted in the potential impact zone in 2001, after a winter and spring of construction activities, drilling, etc., than in the same area in 1997, 1998 or 1999 when no or less intensive activities had occurred. (There was no appreciable year-to-year change in density in the "reference" area 4-10 km away.)

### *Seals in the "Dog Search Zone"*

A corresponding procedure was used to estimate numbers of seals expected to occur within the larger "dog search zone" if seal densities there were the same as those in the reference area 4-10 km from the development zone. As already mentioned, the dog search zone includes the potential impact zone (minus areas with water depth <1.5 m) plus an additional area outside the potential impact zone. The expected uncorrected numbers in the "dog search zone" (area 90.9 km$^2$) ranged from 39 to 53 seals, depending on year. The uncorrected estimate based on 2001 survey data was 52 seals; the corrected estimate was 146 seals (Table 9.2).

Aerial surveyors saw 135 ringed seals in the dog search zone during surveys on various dates in late spring in 2001 (Fig. 9.1). The observed density of ringed seals there in 2001 was actually higher (0.86 seals/km$^2$) than that expected (0.57 seals/km$^2$) based on densities 4-10 km away in 2001 (Table 9.2). If we use observed density to calculate number of seals within the dog search zone, this results in an uncorrected estimate of 78 seals and a corrected estimate of 222 seals. Also, more seals were sighted in the dog search zone in 2001, after a winter and spring of BP construction activities, drilling, etc., plus the dog searches, than in the same area in 1997, 1998 or 1999 when no or less intensive activities had occurred. (There was no appreciable year-to-year change in density in the "reference" area 4-10 km away.)

In addition to seals observed during aerial surveys, 180 ringed seal structures were located during dog-assisted searches within the area shown by the light gray shading in Figure 9.1 (including the parts of the potential impact zone that were >1.5 m deep; see Fig. 3.10 for structure locations). Of these structures, 118 were active during May 2001. During May 2001, eight active structures were found within areas where the ice had been artificially thickened to support Northstar on-ice activities (see Fig. 2.1 in Chapter 2). (The thickened area was smaller than the overall Northstar Development Zone.) If much displacement occurred, we would have expected no structures within the artificially thickened areas. The structures that were active near Northstar in May 2001, and the basking seals seen there by on-ice and aerial surveyors during May/early June, were present after the most intensive on-ice construction activities were completed.

TABLE 9.2. Expected numbers of ringed seals within the zone where dog search impacts were considered possible in 2001, along with observed densities within that zone during 1997-2001. Expected numbers are based on seal densities observed during aerial surveys of a reference area 4-10 km from Northstar. Dog search zone includes the potential impact zone minus areas where water depth was <1.5 m.

| | | Expected Number of Seals Within the Dog Search Zone | | |
|---|---|---|---|---|
| BP/LGL Survey | Expected Density[a] (seals/km$^2$) | Uncorrected | Corrected Total[b] | Observed Density[c] (seals/km$^2$) |
| 1997 | 0.53 | 48 | 137 | 0.53 |
| 1998 | 0.52 | 47 | 134 | 0.43 |
| 1999 | 0.42 | 39 | 110 | 0.24 |
| 2000 | 0.58 | 53 | 150 | 0.54 |
| 2001 | 0.57 | 52 | 146 | 0.86 |
| Average 1997-2001 | 0.52 | 48 | 135 | 0.52 |

[a] These average uncorrected densities are based on data from the zone 4-10 km away from the 2001 development zone, controlling for water depth by weighting density based on the proportions of the dog search zone within the various depth strata.

[b] "Uncorrected" multiplied by the 1.22 correction factor for seals hauled out but not seen by observers (Frost et al. 1988), and by the 2.33 correction factor for seals not hauled out (Kelly and Quakenbush 1990).

[c] This observed uncorrected density is based on the actual area surveyed each year and not on the entire dog search zone.

### *Overall Findings*

The available data suggest that ringed seals did not avoid the area around Northstar in 2001. However, these results should be treated with caution as the geographical area very close to Northstar facilities (e.g. within 0.64 km) is small, and there is uncertainty (as much as 600 m—see Chapter 5) in the locations of individual seals recorded during aerial surveys. It is possible that a small number of ringed seals were displaced from the immediate area around Northstar, although there is little evidence of this.

Seal densities based upon aerial survey results indicate that there was no major avoidance effect on ringed seals near Northstar in the winter of 2001. If there had been a strong avoidance effect, we would expect fewer seals within the potential impact zone during 2001 than in 1997, 1998, and 1999, and fewer than predicted based on densities 4-10 km away. No such reductions in density were found in 2001. In fact, the density in the potential impact zone was higher than that predicted from the observations 4-10 km away. Similarly, there was little evidence of reduced densities near Northstar in 2000 after a winter of intensive construction activity (Williams et al. 2001a,b).

The high rate of turnover in active structures between Nov/Dec 2000 and May 2001 (Chapter 4), and similar results from the previous winter (Williams et al. 2001a), might be indicative of localized avoidance effects. However, in the absence of data on turnover from December to May in a distant "reference" area, or in winters without industrial activities, it is uncertain that the high turnover observed in 2001 (and 2000) was attributable to Northstar. Also, the presence of numerous seals (and structures) within the potential impact zone, and some within the Northstar Development proper, indicates that any displacement effect was localized if it occurred at all.

Aerial surveys alone do not indicate whether individual seals seen near Northstar in late May and early June 2000 had been resident at the same locations during the winter/early spring period when on-ice industrial activities were most intensive. However, the 11 structures that remained active from Nov/Dec 2000 through May 2001 suggest that some seals remained within the area at least until 22 May 2001. Results described in Chapter 4 show that, within the ~3.5 km radius where dog-assisted searches for seal structures were done, the abandonment rate as evident in May 2001 was, if anything, *lower* close to Northstar facilities than somewhat farther away. Also, any reduction in number of active seal structures per unit area was limited to no more than 0.5 – 1 km (0.3 – 0.6 mi) from Northstar facilities.

The multivariate analyses included in Chapter 5 provide further evidence that the density of seals near Northstar in spring 2001 was not reduced compared to that farther away after allowance for the effects of weather, ice deformation, meltwater, and other environmental and temporal parameters that are known to influence haulout by seals. Indeed, the multivariate analysis indicated that densities close to Northstar were *higher* than those farther away, other factors being equal. Likewise in 2000, the multivariate analyses suggested that number of seal sightings was not significantly related to distance from Northstar after allowance for other potentially confounding factors (Moulton et al. 2001).

## *Combined Impact of Northstar Activities during Ice-Covered Season*

BP's updated petition for regulations (as submitted on 1 October 1999) estimated that, on average, about 91 ringed seals might be expected to occur within the potential impact zone around Northstar construction activities during the ice-covered season in the absence of any avoidance. An upper limit of 125 seals was predicted during construction. The impact-area assumed in the Petition was larger than the here-defined potential impact zone for the 2000-2001 ice-covered season. The reduction in the potential impact zone is a result of the reduced level of construction activity during the winter of 2000-2001 as compared to 1999-2000. A further reduction in the activities and thus the size of the potential impact zone is anticipated during future winters (drilling and production operations) as compared with 2000-2001 (construction and drilling). The Petition estimated that, after production began, 77 ringed seals would be in the (smaller) impact zone during the ice-covered season, with an upper limit of 105 seals. It was expected that one to five bearded seals might also occur within 2-4 km of the Northstar facilities during construction during any one winter/spring season. The LoA also allows for the possibility that up to 5 ringed seals might be incidentally killed annually.

There was no evidence, and no reason to suspect, that any ringed seals or other marine mammals were killed or injured by Northstar-related activities during the reporting period. There were no Northstar related activities that could have exposed ringed seals or other marine mammals to underwater sounds with received levels 180 dB re 1 μPa or above.

Based on observed ringed seal densities from the 2001 spring seal surveys (corrected for observer and availability bias) in a reference area 4-10 km away from the Northstar development zone, we calculated that 59 ringed seals would have been expected in the "potential impact zone" in the absence of Northstar construction. This number corresponds to a raw survey density of 0.42 seals/km$^2$. In fact, the observed raw density in the potential impact zone was 0.66 seals/km$^2$ (Table 9.1), corresponding to ***a corrected estimate of 92 ringed seals within the potential impact zone.***

Thus, the estimated number of ringed seals within the potential impact zone in spring 2001 (92) was higher than the best estimates that had been predicted (in BP's Petition) for the periods of construction and operations (91 and 43 seals, respectively) but lower than the maximal estimate of 125 seals. The fact that this number of seals remained in the area despite construction and drilling activities suggests that these seals were not appreciably disturbed. The ringed seals were distributed throughout the "potential impact zone", which extended as much as 1.85 km (1 n.mi.) from Northstar Island, and 0.64 km from the primary ice road and pipeline corridor (Fig. 9.1). Some ringed seals were present in the central parts of the construction area in May and early June 2001. There was no indication that any fewer seals were present than would have been present in the absence of Northstar activities; if anything, more seals than expected were present in the potential impact zone.

The number of ringed seals potentially affected by the dog-assisted searches is difficult to estimate. Based on published hole-to-seal ratios, the dog searches may have affected 38-53 seals in May. We also searched for seals earlier in the winter during months for which hole-to-seal ratios have not been determined (Nov/Dec and early March). Provisionally, we could assume that 38-53 seals were potentially affected during each search period. Therefore, as many as 114 to 159 seals might have been affected if there were 100% turnover of seals from one survey period to the next – a highly unlikely assumption. As few as 38-53 might have been involved if there were no turnover and if published seal-to-hole ratios in other regions are applicable here.

Based on aerial survey data 4-10 km from Northstar and correction factors for missed seals, Table 9.2 estimates that there would be ~146 ringed seals within the dog-search zone during the spring of 2001 in the absence of any Northstar effect. (That figure is based on an observed density of 0.57 seals/km$^2$ in areas 4-10 km away from Northstar). In fact, the observed raw density in the dog search zone was 0.86 seals/km$^2$ (Table 9.2), corresponding to ***a corrected estimate of 222 ringed seals within the dog search zone***. Thus, aerial survey results (after upward adjustment using published correction factors for missed seals) suggested that there were considerably more seals in the dog-search zone than estimated from the number of seal structures found by dogs (adjusted downward using published hole : seal ratios).

Based on aerial surveys and correction factors for missed seals, Table 9.1 estimates that there were about 92 ringed seals within the potential impact zone, almost all of which were also within the dog-search zone. If there were at least 222 seals within the dog search zone as suggested by aerial surveys (Table 9.2), then ***at least 130 additional ringed seals may have been affected by dog-assisted searches*** over and above the number that might have been affected by Northstar activities alone (222 – 92 = 130).

No bearded seals were sighted within 10 km of Northstar during the 2001 aerial surveys (see Chapter 5). There is no indication that any bearded seals were affected by Northstar activities during the ice-covered season of 2001.

***Approximately 82 ringed seals, but (probably) no bearded seals, dived in response to aircraft overflights*** during the spring seal survey in 2001. The great majority of these seals were distant from Northstar and thus different individuals than those potentially affected by industrial or monitoring activities near Northstar. This behavioral reaction is not expected to have any substantial deleterious impact on seals. NMFS has stated that any disturbance of seals during this aerial survey falls under the provisions of the General Authorization for "Level B" harassment during scientific research on non-endangered species [MMPA §104(c)(3)(C); 50 C.F.R. §216.45; NMFS letter of confirmation 481-1626].

## 2000 BREAK-UP AND OPEN-WATER SEASONS

Potential sources of disturbance to marine mammals from the Northstar project during the open-water season of 2001 consisted primarily of helicopter and vessel traffic (see Chapter 6). Helicopter flights to and from Northstar were especially frequent during break-up and freeze-up, and less so during the open-water period. Vessel traffic included local vessel movements between the Prudhoe Bay area and Northstar throughout the open-water period; and arrival, offloading, and departure of the sealift during August. In addition, during the 2001 open-water period there was continued activity on Northstar Island itself, but (in contrast to 2000) no impact pile driving.

### *Estimated Number of Seals Present*

#### *Break-Up Period*

As noted above, there was little evidence that seals near Northstar were affected by Northstar activities during winter or spring, and there is no reason to believe that effects would be greater during the subsequent break-up period. If any seals were affected during break-up in some subtle way, it is probable that some or all of these would be some of the same individuals already counted as present and potentially affected during the latter stages of the ice covered season.

BP's Petition for Regulations (BPXA 1999) assumed that seals within 1 km (0.6 mi) of the island might be affected by construction and other activities on the island. The area of water within 1 km of the island is 3.11 $km^2$. During aerial surveys in the 28 May – 8 June 2001 period, the observed average density of seals hauled out on the landfast ice depended on the specific area considered, but was 0.66 $seals/km^2$ within the "Potential Impact Zone" (Table 9.1). When correction factors are applied to allow for seals present on the ice but not seen (×1.22) and below the surface of the ice (×2.33), the estimated actual density of seals was 1.88 $seals/km^2$. Thus, an estimated 6 seals would be present within 1 km of the island (1.88 $seals/km^2 \times 3.11\ km^2$). The Petition for Regulations assumed that, during the break-up and open-water seasons, there could be complete turnover in the seals present on a weekly basis. If so, and assuming that break-up lasted six weeks (early June to mid-July), the total number of seals potentially present might be about 36 (6 seals × 6 weeks).

### *Open-Water Period*

For the 2000 season, we estimated the number of seals exposed to and potentially affected by Northstar activities assuming that

- seals within 1 km of the island might be affected;
- the density of seals within that area would be no more than 2× the density observed during boat-based surveys for seals within the general Prudhoe Bay area in 1996-2000 (0.19 seals/km$^2$ × 2 = 0.38 seals/km$^2$); and
- seals within the affected area are replaced once for each of fifteen 7-day intervals during the open water period.

The first of these points assumes that seals in open water are not significantly affected by passing vessels (or helicopters) that they could occasionally encounter in areas >1 km from Northstar.

Based on the above assumptions, an estimated 18 seals might be present and potentially affected, i.e., 3.11 km$^2$ x 0.38 seals/km$^2$ x 15 weeks. Ringed seals constituted 94% of the seals identified in the area during the open-water seasons of 1996-2000, with 4.3% being bearded seals and 1.5% spotted seals. Thus, of the estimated 18 seals, about 17 would be ringed seals, one might be a bearded seal, and probably none would be spotted seals.

There is no specific evidence that any of the seals occurring near Northstar during the 2001 open-water season were disturbed or otherwise affected by BP's activities. We assume that simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a potentially significant manner, do not constitute harassment or "taking".

### *Combined Break-Up and Open-Water Periods*

Overall, on the order of 54 seals (36 + 18) might have been present within 1 km of Northstar Island at some time during the break-up and open water periods during 2001, given the assumptions listed above. This total assumes complete turnover of the seals each week for 21 weeks. ***The actual number of different individuals present would probably be lower, and there is no indication that these seals were deleteriously affected.*** BP's petition for regulations predicted that the total numbers of seals that might be exposed to Northstar activities during the break-up and open-water periods might be about 22 ringed seals, 5 bearded seals, and 1 spotted seal. The actual estimates derived above for 2001 are 53 ringed seals, 1 bearded seal, and probably no spotted seals. The higher "actual" than predicted figure for ringed seals results primarily from the longer break-up and open-water season assumed here than in the petition, and the higher density of seals assumed here for the break-up period.

## *Estimated Number of Whales Potentially Affected*

### *Bowhead Whales*

Task 7 of the Northstar monitoring program, as described in Chapter 8, was designed to determine (with certain limitations) whether bowhead whales were displaced offshore by Northstar construction activities and, if so, to what geographical extent. This was to be done based on acoustic localization of calling bowheads. If the southernmost calling bowheads detected by the acoustic monitoring system tended to be farther offshore when Northstar operations were noisy than when they were quieter, this was to be taken as evidence of an effect. The geographic scale of any documented effect, as a function of Northstar sound level, would provide a basis for estimating the number of whales affected.

In ***2000***, calling bowheads were monitored acoustically during 2-28 Sept, but technical problems reduced the accuracy of the call localizations and prevented measuring underwater sounds near Northstar until late in the season (Greene et al. 2001). In the absence of these data, the number of bowheads that might have been affected by Northstar activities in 2000 was estimated by an alternative method based on *(1)* the distance from Northstar within which received levels of underwater sounds might exceed 115 dB re 1 μPa, estimated to be 4 km; and *(2)* historical data concerning the proportion of the bowhead population expected to approach within 4 km of Northstar. With that approach, we estimated that as many as 202 bowheads might be affected by Northstar in an average year. The estimate was ~727 bowheads if the migration corridor in 2000 was as close to shore as in 1997, the year when bowheads were closer to shore than in any other year in the 1979-2000 period (Williams et al. 2001b). The 202 estimate, and especially the 727 estimate, were probably overestimates of the actual number of bowheads that, in 2000, would have received a sound level of ≥115 dB re 1 μPa if they had not deflected away from Northstar. In 2000, the received sound levels dropped below 115 dB well within 4 km of Northstar much of the time (Blackwell and Greene 2001). Also, the limited available aerial survey data from 2000 suggested that the bowhead migration corridor in the general Prudhoe Bay/Northstar region was not unusually close to shore in 2000 (Treacy 2002).[2]

In ***2001***, the acoustic monitoring approach was attempted again, this time with improved instrumentation and procedures. The required types of data were obtained continuously from 28 August to 3 October 2001 (see Chapter 8). Thus, for 2001, the originally planned procedures can be used to estimate the number of bowheads that were apparently affected by Northstar.

The geographic distribution of bowhead calls in the area out to 28.6 km seaward of Northstar was unrelated to the amount of underwater sound being emitted by Northstar until the sound level exceeded a certain value. Above that level, there was evidence that the southernmost calls tended to be increasingly far offshore with increasing sound levels, as measured by the 60-min average sound level. For details, see Figure 8.34 and associated text in Chapter 8. The sound level was measured at a fixed location 400 m NNW of Northstar. The sound level above which an effect on the distribution of calls began to become evident was 100 dB re 1 μPa when measured in three specific 1/3-octave bands that were dominated by Northstar (as opposed to natural ambient) sound. (The sound level in these three "industrial bands" averaged about 5.8 dB less than that in the overall 10-1000 Hz band.)

There was uncertainty about the strength of the relationship between sound level and distribution of whale calls. This relationship depended on the duration over which sound level was averaged (Chapter 8). The largest apparent effect was found with 60-min averaging, and those results are the ones used below. It is possible that a larger effect might have been evident if a longer averaging time had been used. (We plan to investigate that possibility based on the corresponding data collected during the 2002 monitoring program.) Conversely, alternative analysis approaches involving shorter averaging times, when applied to the 2001 data, showed little or no evidence of an offshore displacement at the times of highest noise. The 2001 data were also consistent with the possibility of an attraction effect at times of

---

[2] For the "West" portion of the Alaskan Beaufort as a whole, including Northstar, bowhead sightings in 2000 tended to be closer to shore than in most other years (see Table 7 *in* Treacy 2002). However, the low mean and median distance-from-shore values in 2000 were caused by numerous sightings close to shore in the extreme western part of the Beaufort Sea, west of Harrison Bay. The few sightings in 2000 in the Prudhoe Bay/Northstar area were at relatively "normal" distances offshore, as were the larger number of sightings in the "East" region east of Prudhoe Bay (see Figures 7-10 *in* Treacy 2002).

moderate Northstar sound relative to times with weaker sound. These issues are discussed in Chapter 8. In summary, there is uncertainty about the strength and geographic extent of the apparent displacement effect in 2001. We expect the uncertainties to be reduced when similar data collected in September 2002 are analyzed. In the meantime, our estimates of the maximum number of bowheads that might have been affected in 2001 are based on the analysis of whale calls vs. sounds averaged over 60-min periods. This approach provides the largest estimates of the number of whales potentially affected.

Overall, 89.2% of the whale calls were detected when the sound level in the three "industrial bands", averaged over the 60-min period immediately prior to detection of the call, was <100 dB. Assuming that the number of calls was in proportion to the number of passing whales, then ~89.2% of the bowhead population passed Northstar when there was no evidence of any Northstar effect on the distribution of calls.

Conversely, 10.8% of the population is assumed to have passed when the "offshore distances" of whale calls near the southern edge of the migration corridor tended to be at least slightly farther offshore than evident with lower levels of industry sound. We assume that, in 2001, the Bering-Chukchi-Beaufort bowhead population consisted of 10,550 whales. This figure is calculated based on the best estimate of the population size in 1993 (8200 whales) and the best estimate of the annual rate of increase of the population (3.2%) (Angliss et al. 2001).[3] Therefore, about 1140 whales (0.108 × 10,550) passed Northstar during the 10.8% of the time when the noise level (averaged over 60 min) was high enough to have at least a slight effect on whales near the southern edge of the migration corridor. However, the number of whales potentially affected was much less than 1140, as most of these 1140 whales would not be near the southern edge of the migration corridor. The remainder of this subsection discusses how many of these ~1140 bowheads might have been affected by Northstar.

Of the 10.8% of the calls detected when the sound level was >100 dB,

- 6.35% occurred when "industrial sound levels" near Northstar (60-min average) were 100-110 dB; this suggests that about 670 whales passed Northstar at such times;
- 3.89% occurred with sound levels 110-120 dB, suggesting that ~410 whales passed at such times;
- 0.56% occurred with sound levels >120 dB, suggesting that ~60 whales passed at those times.

The offshore distances of the whale calls received with various levels of Northstar sound are shown in Figure 8.34 (in Chapter 8). Only the area out to 28.6 km offshore of Northstar is considered. The fitted parabolic curve in Figure 8.34 shows the estimated offshore "deflection" of the 5th percentile whale call at various sound levels, averaged over 60-min. There was only a very slight effect at 100-110 dB (5th percentile deflected by an estimated 1.3 km at 105 dB). The effect was greater at 110-120 dB (5th percentile deflected ~5.3 km at 115 dB), and a substantially greater above 120 dB (~15 km at 125 dB).

The aforementioned estimates of deflection distance for the 5th percentile whale calls are based on whale calls detected within the area out to 28.6 km offshore of Northstar – the zone where acoustic monitoring was effective even at times with high levels of background noise. Historical aerial survey

---

[3] Preliminary estimates taking account of results from the 2001 ice-based bowhead census at Barrow suggest that the 2001 population size was ~9860, with an annual rate of increase of 3.3% (George et al. 2002). However, the 9860 figure is subject to revision based on ongoing data analysis. For this reason, and to take a precautionary approach, we use the higher estimated population size based on the earlier data.

data (MMS plus LGL; 1979-2000) indicate that, in the general Prudhoe Bay area (Flaxman Island to Thetis Island), about 52% of the bowheads detected by aerial surveys pass within 28.6 km of Northstar in an average year. Based on the MMS aerial surveys in 2001, the median distance from shore was neither unusually low nor unusually high; however, sample size in 2001 was low due to poor flying conditions (S. Treacy, MMS, pers. comm.). Thus, it is reasonable to assume that about 5% ÷ 2 = 2.5% of the whales passing Northstar under each individual noise condition with 60-minute sound level >100 dB might have been "deflected" by at least the amounts described in the previous paragraph.

Whales slightly farther offshore than the 5th percentile whale call (or the 2.5th percentile whale) would be exposed to somewhat lower sound levels than those at the 5th/2.5th percentile distance-from-Northstar. These whales that were exposed to lower sound levels presumably would be less affected, i.e., deflected by lesser amounts, assuming that the observed "Northstar effect" is a result of offshore deflection. Chapter 8 has not attempted to quantify how much deflection is evident in (for example) the 10th percentile call (=5th percentile whale), the 15th percentile call (=7.5th percentile whale), etc. In future it might be useful to fit curves to the 10th, 15th, etc., percentile distances-from-Northstar as well as to the 5th percentile, especially when a larger sample size is available. This could show how much farther offshore, beyond the 5th percentile distance, the apparent displacement effect extends. That information, in turn, would help in estimating the number of whales affected.

We provisionally conclude, based on inspection of Figure 8.34, that the "Northstar effect" on the offshore-distances of the detectable whale calls probably did not involve more than the southernmost

- 20% of the calls within the acoustic monitoring zone (and presumably 10% of ~670 passing whales) under the 100-110 dB condition,
- 50% of the calls (and 25% of ~410 passing whales) under the 110-120 dB condition, and
- 100% of the few calls (and 50% of ~60 passing whales) under the >120 dB condition.

Given this, we estimate that it is unlikely that more than ~200 bowhead whales were affected by Northstar in 2001, i.e. (0.10 × 670) + (0.25 × 410) + (0.5 × 60) = 200.

The majority of these (maximum) 200 whales would be farther offshore than shown in Figure 8.34 by the line fitted to the "5th percentile" whale calls, and would be exposed to lower sound levels than those associated with the "5th percentile whale calls". Thus, for most of the (maximum) 200 whales, the offshore "deflection" is expected to be less than the average distances quoted above, i.e., <1.3 km, <5.3 km, and <15 km when sounds 400 m from Northstar, averaged over 60 min, were (respectively) 105, 115, and 125 dB re 1 µPa in three 1/3rd octaves dominated by industrial sounds.

In estimating that a maximum of 200 bowheads might have been affected by Northstar in 2001, it is important to note that the confidence limits around this estimate are inevitably broad and not specifically defined. Figure 8.34 documents the approximate lower 95% confidence bound for the curve fitted to the 5th percentile of the offshore call distances (2.5th percentile whale). Text associated with that Figure describes the corresponding approximate lower confidence bound for the estimated offshore displacement at "industrial sound levels" of 105, 115, and 125 dB.

The above estimation process assumes that whales traveling past Northstar after 3 October (when monitoring ended) encountered the same range of sounds as those passing up to 3 October. However, vessel activity near Northstar had essentially ended by 7 October as freeze-up occurred. Chapter 8 shows that times when there were apparent displacement effects were times when "Northstar sounds" were dominated by vessel sounds, not sounds from the island itself (Fig. 8.35). Thus, there probably were few if any occasions after 7 October when sound levels were high enough to cause appreciable deflection. The proportion of the bowhead migration that occurred after 7 October in 2001 is unknown. The last bowhead sightings during the MMS's 2001 aerial surveys were on 2 October, but aerial survey coverage thereafter was limited (S. Treacy, MMS, pers. comm.). Bowhead migration through the Prudhoe Bay area commonly continues until mid- to late October. These considerations are a further reason for expecting that the actual number of bowheads affected by Northstar activities in 2001 was less than 200.

Although we have often described the apparent "Northstar effect" on the distribution of whale calls as being indicative of deflection offshore, it is possible that the effect represents a change in the calling behavior of the whales close to shore rather than an actual offshore deflection. These possibilities cannot be distinguished with confidence at the present time (see Chapter 8). In either case, i.e., deflection or altered calling behavior, there was apparently a change in the behavior of some whales as a result of exposure to Northstar activities. Our estimate of the number of whales involved (maximum 200) is only a small proportion of the bowhead population. It is likely that the effects on these individual bowheads were limited to short-term changes in behavior with no long-term consequences for the individuals or population. Potential implications for subsistence hunting are addressed below.

### *Gray Whales*

BPXA (1999) estimated that no more than five gray whales would be disturbed by Northstar construction activities in one open-water season. There are no specific data on the numbers of gray whales (if any) that were present near Northstar in 2001. Gray whales are uncommon in the Prudhoe Bay area, with no more than a few sightings in any one year, and usually no sightings (Miller et al. 1999; Treacy 2000, 2002). The only gray whale sightings during the MMS aerial surveys in 2001 were far to the west, near Point Barrow (S. Treacy, MMS, pers. comm.). It is most likely that no gray whales were affected by activities at Northstar in 2001.

### *Beluga Whales*

There are no specific data on the numbers of beluga whales (if any) disturbed or otherwise affected by Northstar construction activities in 2001. During MMS aerial surveys in 2001, all beluga sightings (aside from a few near Barrow) were far offshore, near or beyond the shelf-break (S. Treacy, MMS, pers. comm.).

Williams et al. (2001b), following procedures similar to those of Miller et al. (1999), used historical aerial survey data to estimate the number of belugas that might approach the Northstar site in the absence of any disturbance:

- Aerial survey data from 1979 to 2000, including both MMS and LGL surveys, were used to estimate the proportion of belugas migrating through waters ≤4 km seaward of Northstar. Of the belugas traveling through the surveyed waters (generally inshore of the 100-m contour), the overall percentage seen ≤4 km offshore of Northstar during 1979-2000 was **0.62%** (8 of 1289 belugas). The maximum percentage for any one year was for 1996, when 6 of 153 (**3.9%**) were ≤4 km offshore of Northstar. These figures are based on beluga sightings within the area 147°00' to 150°30'W.
- Most beluga whales migrate far offshore; the proportion migrating through the surveyed area is unknown but was assumed by Miller et al. (1999) to be ≤20%, which is probably an overestimate.
- The disturbance radius for belugas exposed to construction and operational activities, although not well defined, is apparently considerably less than that for bowheads (Richardson et al. 1995). BPXA (1999) assumed that the potential radius of disturbance was ~1 km around the island.

(There are no Northstar-specific data that could be used to obtain a better estimate than this ~1 km figure.) Based on the assumed 1 km radius, we would expect that no more than **20%** of the belugas migrating ≤4 km seaward of Northstar would approach within 1 km of the Northstar island in the absence of any industrial activity there.

- The current size of the Beaufort Sea population of beluga whales is **~39,258** animals.

From these values, the number of belugas that might approach within 1 km of Northstar (in the absence of industrial activities) during a given open water season is ~10 belugas based on the average distribution: 0.0062 × 0.2 × 0.2 × 39,258. A maximum estimate (based on the 1996 sighting data) is ~60 belugas: 0.039 × 0.2 × 0.2 × 39,258.

It is possible that the average disturbance radius in 2001 was higher than the assumed 1 km, given the frequent vessel activity around the island in August (including the sealift) and the continued vessel activity in September. If the disturbance radius were 2 km rather than 1 km, the "probable" and "maximum" estimates would become ~20 and ~120 belugas, respectively.

## EFFECT ON ACCESSIBILITY TO HUNTERS

Residents of the village of Nuiqsut are the primary subsistence users in the Northstar project area. The subsistence harvest during winter and spring is mainly ringed seals. During the open-water period both ringed and bearded seals are taken commonly. Bowhead whales are hunted from camps on Cross Island, east of Northstar, during September. Beluga whales are rarely taken by Nuiqsut hunters.

### *Seals*

Nuiqsut hunters may hunt seals year-round; however during recent years, most of the seal harvest has been in the early summer in open water (Thomas Napageak, pers. comm.). The most important seal hunting area for Nuiqsut hunters is off the Colville Delta, extending as far west as Fish Creek and as far east as Pingok Island (149°40'W). Seal hunting occurs in this area by snow machine before ice break-up, and by boat during summer. Pingok Island, the closest edge of the main hunting area, is ~27 km (17 mi) west of Northstar.

Construction of an artificial island, pipeline, and ice roads in the winter of 1999-2000, and continued construction and drilling during the winter of 2000-2001, would have had negligible impact on the availability of seals to hunters, given the distance of Northstar from areas where Nuiqsut residents usually hunt seals. No hunters were observed near the Northstar development during LGL's intermittent monitoring work in November 2000 through early June 2001. In winter and spring, a small number of ringed seals may have been displaced from the immediate location of the development area. However, if this occurred, the effect was sufficiently limited and localized as to be undetectable by aerial surveys (Chapter 5) and barely evident from data on seal structures found by dogs (Chapter 4). Any seals that were displaced probably moved only a short distance and remained in the area. Any localized displacement of ringed seals during the ice-covered period would not affect their availability to subsistence hunters at that time of year.

Similarly, any disturbance caused by flying over seals during the aerial surveys described in this chapter and (in more detail) in Chapter 5 had little potential to influence seal hunting activities by residents of Nuiqsut. The western edge of the survey area is 13.7 km (8.5 mi) east of Pingok Island, the eastern edge of the preferred hunting area. No hunters were observed on the ice during any of the flights during the present 2001 surveys or during the 1997-2000 surveys (G. Miller, LGL, pers. comm.; M. Williams and V. Moulton, pers. obs.).

## *Bowhead Whales*

Nuiqsut hunters establish hunting camps on Cross Island during early September each year in order to hunt for bowhead whales. Cross Island is located 28 km (15 n.mi. or 17.5 mi) east of Northstar. Most bowheads that are taken by Nuiqsut hunters are struck east or north of Cross Island (Long 1996). In recent years, Nuiqsut hunters have had a quota of four whales. The number of whales landed has ranged from two to four per year during 1995 to 2001.

Four bowheads were landed in 2000, on dates ranging from 2 to 9 Sept. The 2000 hunt was completed successfully at an earlier date than normal despite the ongoing Northstar operations west of Cross Island. In 2001, three bowheads were landed, on 5, 10 and 22 Sept. The Nuiqsut hunters indicated that the 2001 hunt was more difficult than the 2000 hunt (M. Galginaitis, Applied Sociocultural Research, pers. comm., April 2002). This was partly because of more difficult ice and weather conditions in 2001. However, the hunters reported that the whales also were more difficult to find, more skittish, and generally more difficult to hunt in 2001. They suggested that this could be attributable to industrial activities, vessel traffic, or perhaps killer whales to the east of Cross Island (M. Galginaitis, pers. comm.).

BP expected that Northstar construction activities occurring during the 2000 and 2001 bowhead migration seasons would emit only relatively low levels of sound (BPXA 1999). Consequently, BP did not anticipate that any offshore deflection of migrating bowheads that might occur as a result of Northstar activities would extend far enough east to affect whales in the area where they are hunted by Nuiqsut hunters. Actual sound emissions were often higher than expected because of the prolonged operations by self-propelled barges (functioning as docks) at Northstar during the late summer and autumn of 2000 (Blackwell and Greene 2001) and frequent operations by a variety of other vessels in both 2000 and 2001. Even so, in 2000, broadband sound levels diminished below 115 dB re 1 μPa within an average distance of 3.8 km (2.1 n.mi.) – similar to the 3.2 km (1.7 n.mi.) that was predicted by BPXA (1999). During August 2001, levels of underwater sound were sometimes higher than recorded in 2000 (Chapter 7). However, much of this higher-level sound was associated with the sealift to Northstar in August, before the start of the main migration period of bowheads. After the departure of the sealift vessels (and CIDS) in late August, levels of industrial sound were notably lower. Nonetheless, even in September 2001, it was common for some tonal components from vessels or other anthropogenic sources to be faintly detectable at the DASAR positioned farthest offshore: 22 km or 12 n.mi. northeast of Northstar (see Fig. 8.15A *in* Chapter 8). Although scientific studies have not documented that bowheads would react to the weak sounds detectable that far away from vessels, it is probable that bowheads would hear any low-frequency sound that we could detect via hydrophones. Also, it has been demonstrated that bowheads (and other cetaceans) are more responsive to fluctuating sounds from boats than they are to more consistent sounds (Richardson et al. 1985, 1995).

The acoustic localization system deployed offshore of Northstar was not designed to monitor bowhead calls reliably as far away as the Cross Island area. However, it did provide much information on the positions and distances-from-shore for bowhead calls detected west of Cross Island but (predominantly) east of Northstar (see Fig. 8.21 or 8.24 *in* Chapter 8). Most calling bowheads were at least 10 km offshore of a line parallel to the coast and through Northstar, and the densest concentration of calls was 15 km or more offshore of that line (Fig. 8.21, 8.29). These acoustic data are not entirely comparable to aerial survey data available from previous years. However, historical aerial survey data do confirm that most bowheads have been sighted 15 km or more offshore of a similar baseline when passing through the general Prudhoe Bay area (e.g., LGL and Greeneridge 1996).

The acoustic localization data revealed an apparent "Northstar effect" on the distribution of whale calls during the 10.8% of the time when Northstar sounds (averaged over 60 min) were strongest. This effect was wholly or largely attributable to sounds from maneuvering vessels rather than Northstar island itself (Chapter 8). The effect was most evident during the 4.45% of the time when sound levels in the "industrial bands", averaged over 60 min, were >110 dB re 1 μPa at a location 400 m from Northstar. That level is equivalent, on average, to >116 dB in the overall 10-1000 Hz band. During the infrequent times of highest noise (>120 dB in the industrial bands; >126 dB overall), the spatial scale of the effect was larger but quite imprecisely quantified because of low sample size under these highest-noise conditions. The limited results at these noisiest times are consistent with the possibility that, on these infrequent occasions, effects on bowheads, either displacement or effects on calling patterns, extended 15+ km (Fig. 8.34). Because the sound levels associated with an effect of that size occurred infrequently (<1% of the time), this alone could not account for reports that "skittish" behavior was common among bowheads off Cross Island in 2001. Indeed, the acoustic monitoring data suggest that, in 2001, a maximum of 200 bowheads (≤2% of 10,550) were measurably affected by Northstar. Furthermore, the approximate confidence bounds around this 15+ km value are very wide. The approximate 90% confidence bounds range from 3 to 22 km based on the 60-min average sound, and are even wider (encompassing zero) if based on shorter averaging times.

If an effect does extend to 15+ km at the infrequent times with highest noise levels at Northstar, the "Northstar effect" on bowheads might extend a substantial part of the way to Cross Island. It is not known whether this effect ever reached to (or beyond) Cross Island during the infrequent times in 2001 with the highest noise levels. If so, it was attributable largely if not wholly to maneuvering vessels, not to sounds from the island itself.

## SUMMARY

A Letter of Authorization (LoA) issued by NMFS to BP authorized the "taking" of small numbers of seals and whales incidental to Northstar construction activities (Table 9.3). The numbers of seals and whales present and potentially affected by Northstar construction activities during the ice-covered, break-up, and open-water periods in November 2000 through October 2001 have been estimated based on information in previous chapters of this report (Table 9.3). The ice-covered and open-water seasons are not discrete, and the intervening "break-up" period has been combined with the open-water season in estimating the "numbers potentially affected". The following paragraphs summarize the basis for the estimates in Table 9.3.

### *Seals*

During the 2000-2001 ***ice-covered season***, no evidence linking industrial activities to the two observed ringed seal deaths was evident, nor was it expected.

A total of 180 ringed seal structures were found during dog-assisted searches conducted in November/December 2000, March 2001, and May 2001. We estimated that at least 38 to 53 individual seals may have been associated with the structures found by the dogs, based on published structure : seal ratios from other geographic areas. However, the aerial surveys suggested that, during the spring of 2001, ~222 seals may have been present within the area that had been searched by dogs, assuming that the combined ×2.84 correction factor for seals present but missed by aerial surveys was correct. The actual number of seals potentially affected by the dog searches is uncertain. However, the fact that, during spring, the seal density was higher within the area that had been searched by dogs than in otherwise-similar neighboring areas suggests that the dog searches did not have a major impact on the seals.

TABLE 9.3. Authorized annual takes incidental to Northstar construction activities, and estimated numbers of seals and whales present and potentially affected during November 2000 – October 2001.

| | Authorized Annual Harassment Takes | | | # Present &/or Potentially Affected | | |
|---|---|---|---|---|---|---|
| | Ice-Covered Season | Open-Water Seasons | Total | Ice-Covered Season | Break-up & Open-Water Seasons | Total |
| Ringed Seal | 125 [a] | 22 | 147 | 92 [b,c,d] | 53 [b] | 145 [b] |
| Bearded Seal | 5 | 5 | 10 | - | 1 | 1 |
| Spotted Seal | - | 1 | 1 | - | - | 0 |
| Bowhead Whale | - | 717 [e] | 717 [e] | - | ≤200 | ≤200 |
| Gray Whale | - | 5 | 5 | - | ~0 | ~0 |
| Beluga Whale | - | 45 | 45 | - | 10-20 | 10-20 |

[a] In addition, the LoA authorized up to 5 ringed seals to be incidentally killed annually during the ice-covered period. In fact, there was no evidence of any seal deaths as a result of Northstar activities.

[b] Northstar construction probably had little or no effect on most of these seals, as discussed in text.

[c] Excludes an estimated 82 seals that dove in response to the passing aircraft during spring seal surveys; possible disturbance to seals during those surveys was authorized separately by NMFS under provisions of the General Authorization for research on non-endangered species, MMPA §104(c)(3)( C)and 50 C.F.R. §216.45.

[d] Excludes the uncertain number of seals potentially disturbed by the dog-assisted searches required by the LoA. This could have involved as few as 38-53 seals (some of which were among the 92 in the potential impact zone), or as many as 222 seals (including ~130 outside the potential impact zone and thus additional to the estimated 92 in that area).

[e] Up to 717 bowheads annually, with maxima of 1533 bowheads in 2 out of 5 seasons, and 3585 in 5 years.

We estimated that there were approximately 82 occasions when ringed seals (and no occasions when bearded seals) dived into the water in response to aircraft overflights during the aerial surveys in spring 2001. Only a small minority of the seals reacted by diving; most seals showed no apparent response to the aircraft. Seals that dived into the water once or twice in response to aircraft overflights are unlikely to have suffered deleterious effects.

About 59 ringed seals were expected to occur within the area potentially impacted by BP's Northstar development if there had been no industrial activities there during 2001. This estimate is based on the density of seals 4-10 km (2.5-6.2 mi) from the potential impact zone in comparable water depths, corrected for availability and detection biases. In fact, the observed density and the estimated number of seals within the potential impact zone in 2001 were higher than the expected density based on the reference area 4-10 km away. The potential impact zone to which these estimates apply was defined as extending from 0.64 km to 1.85 km (0.4 to 1.15 mi) from various types of industrial activities that occurred during the winter of 2000-2001.

During aerial surveys, eight seals (7 sightings) were observed in the Northstar Development Zone, including artificially-thickened ice roads and an equipment testing area around Northstar Island. These results, along with the presence of 118 active structures near Northstar during the follow-up dog-assisted search in May 2001, indicate that effects of industrial activities were likely minor and localized.

During the ***break-up and open-water seasons***, no evidence of seal injuries or fatalities was evident, nor was it expected. No impact pile driving occurred during the break-up season (or at any other time) in 2001. Approximately 54 different seals (53 ringed seals and 1 bearded seal) are estimated to have occurred within a 1 km (0.62 mi) radius around Northstar (=Seal) Island at some time during the break-up and open-water seasons. This estimate is based on the densities of seals observed during the 2001 aerial surveys (applied to the break-up season) and during vessel-based surveys during 1996-2000 (applied to the open-water season). The estimate takes account of correction factors for missed animals, and assumes weekly turnover of individuals during the break-up and open-water periods. It is unlikely that these seals were affected deleteriously by Northstar activities.

For the ***year as a whole*** (ice-covered and open-water seasons combined), an estimated 145 ringed seals, 1 bearded seal, and probably no spotted seals were present near BP's Northstar activities. These figures are slightly less than the corresponding "takes" authorized by the LoA issued by NMFS to BP (Table 9.3). Furthermore, most of these seals do not seem to have been negatively affected by Northstar activities, and it would appear that very few of them should be counted as "takes". These totals exclude the ~82 seals that dived in response to aircraft overflights during the spring aerial surveys; those incidents were separately authorized via a Letter of Confirmation issued by NFMS to LGL. These totals also exclude the uncertain number of ringed seals in the area searched by dogs. The overall results suggest that any effects of Northstar construction and the associated monitoring on seals were minor, short-term, and localized, with no consequences for the seal populations.

## *Whales*

For ***bowhead whales***, acoustic localization data indicated that whales in the southern part of the migration corridor (closest to Northstar) may have been affected by vessel or Northstar operations during the 10.8% of the time when levels of underwater sound from these activities were highest. At these times, the main components of "Northstar sound" were from maneuvering vessels, not from the island itself. An estimated 1140 bowheads passed Northstar at such times, and an estimated maximum of 200 of these whales (≤2% of the population) were potentially affected by vessel or Northstar operations. This effect consisted of either an offshore displacement of whales traveling near the southern edge of the migration corridor or some change in their calling behavior or both. Most of the affected whales passed Northstar at times when the effect was quite subtle and limited to the southern edge of the migration corridor. However, a small number (<1% of the population) may have been displaced (or otherwise affected) by 15 km (9.3 mi) or more. The LoA authorized the "taking by harassment" of up to 717 bowheads annually, or as many as 1533 as long as this larger number applied to no more than 2 of 5 years. The possible occurrence of a "Northstar effect" on a maximum of 200 bowheads is well within the provisions of the LoA.

There was no specific information on numbers of ***gray or beluga whales*** (if any) that may have been close enough to Northstar to be disturbed by construction operations in 2001. For belugas, the estimated numbers that might approach within an assumed 1-2 km (0.6-1.2 mi) disturbance radius are 10-20 (most probable estimate) and 60-120 (maximum estimate). The LoA authorized the "taking by harassment" of up to 5 gray whales and 45 belugas.

## *Availability for Subsistence*

There was no indication of any effects of the Northstar development on availability of seals to subsistence hunters during the 2001 ice-covered, break-up, or open-water periods. Any localized displacement of ringed seals that may have occurred would not have affected their availability to subsistence hunters.

The bowhead hunt at Cross Island was more protracted and apparently more difficult in 2001 than in some other recent years; 3 whales from the quota of 4 were landed. The difficulties in the hunt were partly because of weather and ice problems, but in addition the whales were described as being skittish and difficult to hunt in 2001. Based on the acoustic monitoring results, Northstar activities during late summer and autumn of 2001 are not expected to have affected the availability of most bowhead whales to subsistence hunters. However, a fraction of the estimated maximum of 200 bowheads suspected to have been displaced offshore or otherwise affected by Northstar might have been less accessible to hunters if the Northstar effect extended eastward somewhat farther than specifically documented during the monitoring work. If there was any such an effect, it was attributable largely if not entirely to sound from vessels rather than sound from the island itself.

## ACKNOWLEDGEMENTS

We thank Drs. Bill Streever and Ray Jakubczak of BP, plus Wilson Cullor, Allison Erickson and Dave Trudgen, of the BP Environmental Studies Group, for their support during this project. We also thank the authors of all other chapters of this report, who provided the data used in estimating numbers of seals and whales potentially affected. In particular, we thank Drs. Susanna Blackwell and Charles Greene (Greeneridge Sciences) and Dr. Trent McDonald (WEST) for providing the necessary acoustic data and associated analyses. Drs. Streever and Jakubczak commented on earlier drafts of this report. Ted Elliott of LGL assisted with data management and analysis.

## LITERATURE CITED

Angliss, R.P., D.P. DeMaster and A.L. Lopez. 2001. Alaska marine mammal stock assessments, 2001. NOAA Tech. Memo. NMFS-AFSC-124. Nat. Mar. Fish. Serv., Nat. Mar. Mamm. Lab., Seattle, WA. 206 p.

Blackwell, S.B. and C.R. Greene Jr. 2001. Sound measurements, 2000 break-up and open-water seasons. p. 7-1 to 7-55 *In*: W.J. Richardson and M.T. Williams (eds.), Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2000. [Draft, April 2001.] LGL Rep. TA2429-2. Rep. from LGL Ltd., King City, Ont., and Greenridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 316 p.

BPXA. 1999. Petition for regulations pursuant to section 101 (a) (5) of the Marine Mammal Protection Act covering taking of marine mammals incidental to offshore oil and gas development and production in the Beaufort Sea, Sept. 1999 ed. Submitted by BP Explor. (Alaska) Inc., Anchorage, AK, to Nat. Mar. Fish. Serv. [Silver Spring, MD]. Prepared by LGL Alaska Res. Assoc., Anchorage, AK. 121 p.

Born, E.W., F.F. Riget, R. Dietz and D. Andriashek. 1999. Escape responses of hauled out ringed seals (Phoca hispida) to aircraft disturbance. **Polar Biol.** 21(3):171-178.

Frost, K.J., and J.J. Burns. 1989. Winter ecology of ringed seals (*Phoca hispida*) in Alaska. Outer Cont. Shelf Environ. Assess. Progr., Final Rep., NOAA Proj. RU-232, Anchorage, AK (1989). 108 p. Contract NA-81-RAC-00045.

Frost, K.J., L.F. Lowry, J.R. Gilbert and J.J. Burns. 1988. Ringed seal monitoring: relationships of distribution and abundance to habitat attributes and industrial activities. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 61 (1989):345-445. NTIS PB89-234645.

George, J.C., J. Zeh, R. Suydam and C. Clark. 2002. Population size of the Bering-Chukchi-Beaufort Seas stock of bowhead whales, *Balaena mysticetus*, based on the 2001 census off Point Barrow, Alaska. SC/54/BRG5. Intern. Whal. Comm., Cambridge, U.K.

Greene, C.R. Jr., M.W. McLennan, T.L. McDonald and W.J. Richardson. 2001. Acoustic monitoring of bowhead whale migration, autumn 2000. p. 9-1 to 9-57 *In*: W.J. Richardson and M.T. Williams (eds.), Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2000. [Draft, April 2001.] LGL Rep. TA2429-2. Rep. from LGL Ltd., King City, Ont., and

Greenridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 316 p.

Hammill, M.O. and T.G. Smith. 1990. Application of removal sampling to estimate the density of ringed seals (*Phoca hispida*) in Barrow Strait, Northwest Territories. **Can. J. Fish. Aquatic Sci.** 47(2):244-250.

Kelly, B.P., and L.T. Quakenbush. 1990. Spatiotemporal use of lairs by ringed seals (*Phoca hispida*). **Can. J. Zool.** 68(12):2503-2512.

LGL and Greeneridge. 1996. Northstar marine mammal monitoring program, 1995: baseline surveys and retrospective analyses of marine mammal and ambient noise data from the central Alaskan Beaufort Sea. LGL Rep. TA2101-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK. 104 p.

Link, M.R., T.L. Olson and M.T. Williams. 1999. Ringed seal distribution and abundance near potential oil development sites in the central Alaskan Beaufort Sea, spring 1998. LGL Rep. P-430. Rep. from LGL Alaska Res. Assoc. Inc., Anchorage, AK, for BP Explor. (Alaska) Inc., Anchorage, AK. 58 p.

Long, F., Jr. 1996. History of subsistence whaling by Nuiqsut. p. 73-76 *In:* Proc. 1995 Arctic Synthesis Meeting, Anchorage, AK, Oct. 1995. OCS Study MMS 95-0065. U.S. Minerals Manage. Serv., Anchorage, AK. 206 p. + Appendices.

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. LGL Rep. TA2160-3. Rep. from LGL Ltd., King City, Ont., for BP Explor. (Alaska) Inc., Anchorage, AK. 36 p.

Miller, G.W., R.E. Elliott, W.R. Koski, V.D. Moulton and W.J. Richardson. 1999. Whales. p. 5-1 to 5-109 *In:* W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA2230-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 390 p.

Moulton, V.D., T.L. McDonald, W.J. Richardson, R.E. Elliott and M.T. Williams. 2000. Fixed-wing aerial surveys of seals near BP's Northstar and Liberty sites in 1999 (and 1997-99 combined). p. 3-1 to 3-71 *In*: W.J. Richardson and M.T. Williams (eds.), Monitoring of ringed seals during construction of ice roads for BP's Northstar oil development, Alaskan Beaufort Sea, 1999. LGL Rep. TA2349-3. Final Rep. from LGL Ltd., King City, Ont., and LGL Alaska Res. Assoc. Inc., Anchorage, AK, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 153 p.

Moulton, V.D., R.E. Elliott, T.L. McDonald and W.J. Richardson. 2001. Fixed-wing aerial surveys of seals near BP's Northstar and Liberty sites in 2000 (and 1997-2000) combined). p. 5-1 to 5-66 *In*: W.J. Richardson and M.T. Williams (eds.), Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2000. [Draft, April 2001.] LGL Rep. TA2428-3. Rep. from LGL Ltd., King City, Ont., and Greenridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 316 p.

NMFS. 2000. Taking marine mammals incidental to construction and operation of offshore oil and gas facilities in the Beaufort Sea/Final rule. **Fed. Regist.** 65(102, 25 May):34014-34032.

Richardson, W.J., M.A. Fraker, B. Würsig and R.S. Wells. 1985. Behaviour of bowhead whales *Balaena mysticetus* summering in the Beaufort Sea: reactions to industrial activities. **Biol. Conserv.** 32(3):195-230.

Richardson, W.J., C.R. Greene Jr., C.I. Malme and D.H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego, CA. 576 p.

Smith, T.G. and M.O. Hammill. 1981. Ecology of the ringed seal, *Phoca hispida*, in its fast ice breeding habitat. **Can. J. Zool.** 59(6):966-981.

Treacy, S.D. 2000. Aerial surveys of endangered whales in the Beaufort Sea, fall 1998-1999. OCS Study MMS 2000-066. U.S. Minerals Manage. Serv., Anchorage, AK. 135 p.

Treacy, S.D. 2002. Aerial surveys of endangered whales in the Beaufort Sea, fall 2000. OCS Study MMS 2002-014. U.S. Minerals Manage. Serv., Anchorage, AK. 111 p.

Williams, M.T., J.A. Coltrane and C.J. Perham. 2001a. On-ice location of ringed seal structures near Northstar, December 1999 and May 2000. p. 4-1 to 4-22 *In:* W.J. Richardson and M.T. Williams (eds.), Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2000. [Draft, April 2001.] LGL Rep. P485-2. Rep. from LGL Ltd., King City, Ont., and Greenridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 316 p.

Williams, M.T., W.J. Richardson, J.W. Lawson and V.D. Moulton. 2001b. Estimated numbers of seals and whales potentially affected by Northstar activities, Nov. 1999 – Oct. 2000. p. 10-1 to 10-23 *In:* W.J. Richardson and M.T. Williams (eds.), Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2000. [Draft, April 2001.] LGL Rep. TA2432-8. Rep. from LGL Ltd., King City, Ont., and Greenridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 316 p.

# APPENDICES

APPENDIX A: Data on Ringed Seal Structures Located Within the Northstar Development Area, 2000-2001.

APPENDIX B: Incidental Sightings of Polar Bears During Monitoring Activities for BP's Northstar Oil Development, Alaskan Beaufort Sea, 2001.

APPENDIX C: Estimated Whale Call Locations Near Northstar, 29 Aug – 3 Oct 2001.

APPENDIX A: Data on ringed seal structures located within the Northstar Development Area, Central Beaufort Sea, Alaska, November/December 2000, March 2001, and May 2001. Latitudes and longitudes are in NAD 27 datum.

| Structure Number | Map ID Number | Original Structure Type | Fianl Structure Type | N Latitude | W Longitude | Date Located | Original Status | March Recheck Status | May Final Check | Structure Abandoned | Snow Depth (cm) | Estimated Distance from Activities (m) | Bin # | Nearest Infrastructure | Ice Deformation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 00BH01 | A01 | Breathing Hole | Breathing Hole | 70.45214 | -148.62628 | 24-Nov-00 | open | frozen | frozen | Y | 7.65 cm | 120 | 1 | Primary Ice Road | 5% |
| 00BH02 | A02 | Breathing Hole | Breathing Hole | 70.42843 | -148.5709 | 25-Nov-00 | open | frozen | frozen | Y | 5.08 cm | 260 | 1 | Primary Ice Road | 5% |
| 00BH03 | A03 | Breathing Hole | Breathing Hole | 70.43539 | -148.57511 | 25-Nov-00 | open | open | open | N | 15.24 cm | 490 | 1 | Primary Ice Road | 10% |
| 00BH04 | A04 | Breathing Hole | Breathing Hole | 70.49522 | -148.70443 | 26-Nov-00 | open | frozen | frozen | Y | - | 450 | 1 | Primary Ice Road | 20% |
| 00BH05 | A05 | Breathing Hole | Breathing Hole | 70.46177 | -148.62255 | 27-Nov-00 | open | open | open | N | - | 550 | 2 | Primary Ice Road | 0-5% |
| 00BH06 | A06 | Breathing Hole | Breathing Hole | 70.46396 | -148.61774 | 27-Nov-00 | open | open | open | N | - | 830 | 2 | Primary Ice Road | 0-5% |
| 00BH07 | A07 | Breathing Hole | Breathing Hole | 70.43978 | -148.65456 | 28-Nov-00 | open | frozen | frozen | Y | - | 1740 | 4 | Primary Ice Road | 0-5% |
| 00BH08 | A08 | Breathing Hole | Breathing Hole | 70.44238 | -148.65906 | 28-Nov-00 | open | open | open | N | - | 1740 | 4 | Primary Ice Road | 0-5% |
| 00BH09 | A09 | Breathing Hole | Breathing Hole | 70.45738 | -148.6894 | 28-Nov-00 | frozen | frozen | frozen | Y[1] | - | 40 | 1 | Pipeline Ice Road | 0-5% |
| 00BH10 | A10 | Breathing Hole | Breathing Hole | 70.46798 | -148.69926 | 28-Nov-00 | open | frozen | frozen | Y | - | 280 | 1 | Pipeline Ice Road | 5% |
| 00BH11 | A11 | Breathing Hole | Breathing Hole | 70.48091 | -148.71713 | 28-Nov-00 | open | open | frozen | Y | - | 890 | 2 | Pipeline Ice Road | 5-10% |
| 00BH12 | A12 | Breathing Hole | Breathing Hole | 70.48091 | -148.71713 | 28-Nov-00 | open | frozen | frozen | Y | - | 890 | 2 | Pipeline Ice Road | 5-10% |
| 00BH13 | A13 | Breathing Hole | Breathing Hole | 70.47641 | -148.72052 | 29-Nov-00 | open | open | open | N | - | 1040 | 3 | Pipeline Ice Road | 0-2% |
| 00BH14 | A14 | Breathing Hole | Breathing Hole | 70.4727 | -148.72735 | 28-Nov-00 | open | frozen | frozen | Y | - | 1310 | 3 | Pipeline Ice Road | 0-2% |
| 00BH15 | A15 | Breathing Hole | Breathing Hole | 70.48122 | -148.72604 | 29-Nov-00 | open | frozen | unknown | U | - | 1220 | 3 | Pipeline Ice Road | 5-10% |
| 00BH16 | A16 | Breathing Hole | Breathing Hole | 70.50311 | -148.77967 | 30-Nov-00 | open | frozen | frozen | Y | - | 3320 | 7 | Northstar Island | 10% |
| 00BH17 | A17 | Breathing Hole | Breathing Hole | 70.50461 | -148.75673 | 30-Nov-00 | open | frozen | frozen | Y | - | 2630 | 6 | Northstar Island | 20% |
| 00BH18 | A18 | Breathing Hole | Breathing Hole | 70.49551 | -148.69862 | 30-Nov-00 | open | frozen | frozen | Y | - | 390 | 1 | Northstar Island | 20-30% |

| Structure Number | Map ID Number | Original Structure Type | Fianl Structure Type | N Latitude | W Longitude | Date Located | Original Status | March Recheck Status | May Final Check | Structure Abandoned | Snow Depth (cm) | Estimated Distance from Activities (m) | Bin # | Nearest Infrastructure | Ice Deformation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 00BH19 | A19 | Breathing Hole | Breathing Hole | 70.48197 | -148.60141 | 12/1/2000 | open | frozen | frozen | Y | - | 2400 | 5 | Primary Ice Road | 0-2% |
| 00BH20 | A20 | Breathing Hole | Breathing Hole | 70.49647 | -148.62222 | 12/1/2000 | open | frozen | frozen | Y | - | 2650 | 6 | Northstar Island | 50% |
| 00BH21 | A21 | Breathing Hole | Breathing Hole | 70.51681 | -148.68944 | 12/2/2000 | open | frozen | frozen | Y | - | 2740 | 6 | Northstar Island | 5-10% |
| 00BH22 | A22 | Breathing Hole | Breathing Hole | 70.50351 | -148.6536 | 12/3/2000 | open | frozen | frozen | Y | - | 1920 | 4 | Northstar Island | 10% |
| 00BH23 | A23 | Breathing Hole | Breathing Hole | 70.43281 | -148.54915 | 12/3/2000 | open | open | frozen | Y | - | 1210 | 3 | Primary Ice Road | 0-5% |
| 00BH24 | A24 | Breathing Hole | Breathing Hole | 70.45085 | -148.56129 | 12/7/2000 | open | open | open | N | - | 1870 | 4 | Primary Ice Road | - |
| 00BH25 | A25 | Breathing Hole | Breathing Hole | 70.44336 | -148.55389 | 12/7/2000 | open | frozen | frozen | Y | - | 1670 | 4 | Primary Ice Road | 0-2% |
| 00BH26 | A26 | Breathing Hole | Breathing Hole | 70.43011 | -148.53363 | 12/7/2000 | open | frozen | frozen | Y | - | 1540 | 4 | Primary Ice Road | - |
| 00BH27 | A27 | Breathing Hole | Breathing Hole | 70.43598 | -148.67094 | 12/8/2000 | open | open | open | N | 50 cm | 650 | 2 | Pipeline Ice Road | 5-10% |
| 00BH28 | A28 | Breathing Hole | Breathing Hole | 70.46414 | -148.59854 | 12/8/2000 | open | open | open | N | - | 1450 | 3 | Primary Ice Road | - |
| 00LA01 | A29 | Lair | Lair | 70.42047 | -148.56433 | 24-Nov-00 | open | frozen | frozen | Y | - | 2 | 1 | Primary Ice Road | - |
| 00LA02 | A30 | Lair | Lair | 70.46257 | -148.64232 | 24-Nov-00 | open | frozen | frozen | Y | - | 30 | 1 | Primary Ice Road | 5% |
| 00LA03 | A31 | Lair | Lair | 70.43547 | -148.57673 | 25-Nov-00 | open | frozen | frozen | Y | 25.4 cm | 540 | 2 | Primary Ice Road | 5-10% |
| 00LA04 | A32 | Lair | Lair | 70.45615 | -148.57663 | 1-Dec-00 | frozen | open | open | - | - | 1630 | 4 | Primary Ice Road | 0-2% |
| 00LA05 | A33 | Lair | Lair | 70.49073 | -148.61114 | 12/1/2000 | frozen | open | open | - | - | 2600 | 6 | Primary Ice Road | - |
| 00LA06 | A34 | Lair | Lair | 70.42546 | -148.52779 | 12/3/2000 | open | frozen | frozen | Y | - | 1450 | 3 | Primary Ice Road | 0-5% |
| 00LA07 | A35 | Lair | Lair | 70.45326 | -148.65536 | 12/8/2000 | open | frozen | frozen | Y | 2 cm | 990 | 2 | Primary Ice Road | - |
| 01BH01 | B01 | Breathing Hole | Breathing Hole | 70.43121 | -148.64487 | 2-Mar-01 | open | n/a | frozen | Y | 25 cm | 2000 | 4 | Primary Ice Road | 0% |
| 01BH02 | B02 | Breathing Hole | Breathing Hole | 70.43645 | -148.63929 | 2-Mar-01 | open | n/a | frozen | Y | - | 1500 | 3 | Primary Ice Road | 0% |

| Structure Number | Map ID Number | Original Structure Type | Fianl Structure Type | N Latitude | W Longitude | Date Located | Original Status | March Recheck Status | May Final Check | Structure Abandoned | Snow Depth (cm) | Estimated Distance from Activities (m) | Bin # | Nearest Infrastructure | Ice Deformation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01BH03 | B03 | Breathing Hole | Breathing Hole | 70.48682 | -148.64364 | 2-Mar-01 | open | n/a | open | N | - | 1300 | 3 | Primary Ice Road | 20% |
| 01BH04 | B04 | Breathing Hole | Breathing Hole | 70.49591 | -148.62209 | 2-Mar-01 | open | n/a | frozen | Y | - | 2500 | 5 | Primary Ice Road | 30% |
| 01BH05 | B05 | Breathing Hole | Breathing Hole | 70.4936 | -148.61047 | 2-Mar-01 | open | n/a | frozen | Y | - | 2800 | 6 | Primary Ice Road | 20% |
| 01BH06 | B06 | Breathing Hole | Haulout Hole | 70.42618 | -148.62455 | 3-Mar-01 | open | n/a | open | N | - | 1600 | 4 | Primary Ice Road | 0-5% |
| 01BH07 | B07 | Breathing Hole | Breathing Hole | 70.45853 | -148.66896 | 3-Mar-01 | open | n/a | frozen | Y | - | 1300 | 3 | Primary Ice Road | - |
| 01BH08 | B08 | Breathing Hole | Breathing Hole | 70.4618 | -148.66684 | 3-Mar-01 | open | n/a | frozen | Y | - | 900 | 2 | Primary Ice Road | 0-5% |
| 01BH09 | B09 | Breathing Hole | Pupping Lair | 70.46919 | -148.65802 | 3-Mar-01 | open | n/a | open | N | - | 200 | 1 | Primary Ice Road | 0% |
| 01BH10 | B10 | Breathing Hole | Breathing Hole | 70.49866 | -148.66254 | 3-Mar-01 | open | n/a | frozen | Y | - | 1400 | 3 | Primary Ice Road | 50% |
| 01BH11 | B11 | Breathing Hole | Breathing Hole | 70.512 | -148.63237 | 3-Mar-01 | open | n/a | frozen | Y | - | 3100 | 7 | Northstar Island | 10-20% |
| 01BH12 | B12 | Breathing Hole | Breathing Hole | 70.48248 | -148.76691 | 3-Mar-01 | open | n/a | frozen | Y | - | 3400 | 7 | Northstar Island | 5-10% |
| 01BH13 | B13 | Breathing Hole | Resting Lair | 70.52204 | -148.68443 | 4-Mar-01 | open | n/a | frozen | Y | - | 3300 | 7 | Northstar Island | 10-15% |
| 01BH15 | B15 | Breathing Hole | Lair | 70.4907 | -148.67509 | 4-Mar-01 | open | n/a | open | N | - | 600 | 2 | Primary Ice Road | 20% |
| 01BH16 | B16 | Breathing Hole | Breathing Hole | 70.44701 | -148.57529 | 5-Mar-01 | frozen | n/a | unknown | - | - | 1400 | 3 | Primary Ice Road | 0% |
| 01BH17 | B17 | Breathing Hole | Lair | 70.45371 | -148.57045 | 5-Mar-01 | open | n/a | open | N | - | 1700 | 4 | Primary Ice Road | 0% |
| 01BH18 | B18 | Breathing Hole | Haulout Hole | 70.43333 | -148.62164 | 5-Mar-01 | open | n/a | open | N | - | 1100 | 3 | Primary Ice Road | 0% |
| 01BH19 | B19 | Breathing Hole | Breathing Hole | 70.45861 | -148.61165 | 5-Mar-01 | open | n/a | frozen | Y | - | 800 | 2 | Primary Ice Road | 0% |
| 01BH20 | B20 | Breathing Hole | Breathing Hole | 70.44336 | -148.58923 | 8-Mar-01 | open | n/a | frozen | Y | - | 600 | 2 | Primary Ice Road | 0% |
| 01BH21 | B21 | Breathing Hole | Haulout Hole | 70.45295 | -148.5894 | 8-Mar-01 | open | n/a | frozen | Y | - | 1100 | 3 | Primary Ice Road | 5% |
| 01BH22 | B22 | Breathing Hole | Breathing Hole | 70.50227 | -148.7475 | 8-Mar-01 | open | n/a | open | N | - | 2200 | 5 | Northstar Island | 50% |
| 01BH25 | B25 | Breathing Hole | Breathing Hole | 70.47182 | -148.76351 | 10-Mar-01 | open | n/a | open | N | - | 2600 | 6 | Pipeline Ice Road | 5% |

| Structure Number | Map ID Number | Original Structure Type | Fianl Structure Type | N Latitude | W Longitude | Date Located | Original Status | March Recheck Status | May Final Check | Structure Abandoned | Snow Depth (cm) | Estimated Distance from Activities (m) | Bin # | Nearest Infrastructure | Ice Deformation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01BH26 | B26 | Breathing Hole | Breathing Hole | 70.47335 | -148.76599 | 10-Mar-01 | open | n/a | open | N | - | 2700 | 6 | Pipeline Ice Road | 5% |
| 01BH27 | B27 | Breathing Hole | Breathing Hole | 70.48686 | -148.76466 | 10-Mar-01 | open | n/a | open | N | - | 2500 | 5 | Northstar Island | 0% |
| 01BH29 | B29 | Breathing Hole | Breathing Hole | 70.49844 | -148.71422 | 11-Mar-01 | open | n/a | frozen | Y | - | 1000 | 2 | Northstar Island | 40% |
| 01BH30 | B30 | Breathing Hole | Haulout Hole | 70.50649 | -148.71382 | 11-Mar-01 | open | n/a | open | N | - | 1700 | 4 | Northstar Island | 2% |
| 01BH31 | B31 | Breathing Hole | Breathing Hole | 70.51188 | -148.71206 | 11-Mar-01 | open | n/a | frozen | Y | - | 2300 | 5 | Northstar Island | 0% |
| 01BH32 | B32 | Breathing Hole | Breathing Hole | 70.46203 | -148.55699 | 12-Mar-01 | open | n/a | frozen | Y | - | 3100 | 7 | Primary Ice Road | 0% |
| 01BH33 | B33 | Breathing Hole | Haulout Hole | 70.50566 | -148.67212 | 12-Mar-01 | open | n/a | open | N | - | 1700 | 4 | Northstar Island | 2% |
| 01BH34 | B34 | Breathing Hole | Haulout Hole | 70.51086 | -148.66563 | 12-Mar-01 | open | n/a | open | N | - | 2300 | 5 | Northstar Island | 30% |
| 01BH35 | B35 | Breathing Hole | Breathing Hole | 70.49967 | -148.69776 | 12-Mar-01 | open | n/a | open | N | - | 800 | 2 | Northstar Island | 70% |
| 01BH36 | B36 | Breathing Hole | Breathing Hole | 70.48111 | -148.6798 | 13-Mar-01 | open | n/a | frozen | Y | - | 200 | 1 | Primary Ice Road | 0% |
| 01BH37 | B37 | Breathing Hole | Breathing Hole | 70.47967 | -148.7792 | 13-Mar-01 | open | n/a | open | N | - | 3200 | 7 | Pipeline Ice Road | 2% |
| 01BH38 | B38 | Breathing Hole | Breathing Hole | 70.4805 | -148.72918 | 13-Mar-01 | open | n/a | frozen | Y | - | 1300 | 3 | Pipeline Ice Road | 30% |
| 01BH39 | B39 | Breathing Hole | Breathing Hole | 70.48283 | -148.72045 | 13-Mar-01 | open | n/a | frozen | Y | - | 1000 | 2 | Pipeline Ice Road | 20% |
| 01BH40 | B40 | Breathing Hole | Breathing Hole | 70.50796 | -148.64585 | 13-Mar-01 | open | n/a | open | N | - | 2500 | 5 | Northstar Island | 2% |
| 01LA01 | B41 | Lair | Lair | 70.42006 | -148.5891 | 2-Mar-01 | open | n/a | open | N | - | 800 | 2 | Primary Ice Road | 10% |
| 01LA02 | B42 | Lair | Lair | 70.48024 | -148.6438 | 2-Mar-01 | open | n/a | open | N | - | 900 | 2 | Primary Ice Road | 5% |
| 01LA03 | B43 | Lair | Lair | 70.49111 | -148.66056 | 3-Mar-01 | open | n/a | open | N | - | 1100 | 3 | Primary Ice Road | 20% |
| 01LA04 | B44 | Lair | Pupping Lair | 70.50296 | -148.65622 | 3-Mar-01 | open | n/a | frozen | Y | - | 1800 | 4 | Northstar Island | 40% |
| 01LA05 | B45 | Lair | Breathing Hole | 70.48045 | -148.69852 | 4-Mar-01 | open | n/a | open | N | - | 200 | 1 | Pipeline Ice Road | 0% |
| 01LA06 | B46 | Lair | Lair | 70.46408 | -148.73148 | 4-Mar-01 | open | n/a | frozen | Y | - | 1500 | 3 | Pipeline Ice Road | 0% |

| Structure Number | Map ID Number | Original Structure Type | Fianl Structure Type | N Latitude | W Longitude | Date Located | Original Status | March Recheck Status | May Final Check | Structure Abandoned | Snow Depth (cm) | Estimated Distance from Activities (m) | Bin # | Nearest Infrastructure | Ice Deformation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01LA07 | B47 | Lair | Lair | 70.47986 | -148.72692 | 4-Mar-01 | open | n/a | frozen | Y | - | 1260 | 3 | Pipeline Ice Road | - |
| 01LA08 | B48 | Lair | Lair | 70.51687 | -148.71073 | 4-Mar-01 | open | n/a | open | N | - | 2800 | 6 | Northstar Island | 20% |
| 01LA12 | B52 | Lair | Lair | 70.50629 | -148.75103 | 8-Mar-01 | open | n/a | open | N | - | 2500 | 5 | Northstar Island | - |
| 01LA13 | B53 | Lair | Lair | 70.4966 | -148.7609 | 10-Mar-01 | open | n/a | open | N | - | 2400 | 5 | Northstar Island | 10% |
| 01LA14 | B54 | Lair | Lair | 70.5051 | -148.7679 | 10-Mar-01 | open | n/a | open | N | - | 3000 | 6 | Northstar Island | 3% |
| 01LA15 | B55 | Lair | Lair | 70.47008 | -148.71196 | 1-Mar-01 | open | n/a | open | N | - | 750 | 2 | Pipeline Ice Road | 2% |
| 01LA16 | B56 | Lair | Lair | 70.49589 | -148.7096 | 11-Mar-01 | open | n/a | open | N | - | 600 | 2 | Northstar Island | 90% |
| 01LA19 | B59 | Lair | Lair | 70.50069 | -148.78341 | 11-Mar-01 | open | n/a | unknown | U | - | 3300 | 7 | Northstar Island | 5% |
| 01LA20 | B60 | Lair | Lair | 70.45887 | -148.68819 | 13-Mar-01 | open | n/a | open | N | - | 100 | 1 | Pipeline Ice Road | 0% |
| 01LA21 | B61 | Lair | Lair | 70.46233 | -148.68737 | 13-Mar-01 | open | n/a | open | N | - | 140 | 1 | Pipeline Ice Road | 0% |
| 01LA22 | B62 | Lair | Pupping Lair | 70.47975 | -148.73126 | 13-Mar-01 | open | n/a | open | N | - | 1420 | 3 | Pipeline Ice Road | 10% |
| 01LA23 | B63 | Lair | Lair | 70.47975 | -148.73129 | 13-Mar-01 | open | n/a | frozen | Y | - | 1420 | 3 | Pipeline Ice Road | 10% |
| 01BH43 | C03 | Breathing hole | Haulout Hole | 70.48515 | -148.66692 | 6-May-01 | open | n/a | open | N | - | 580 | 2 | Primary Ice Road | 5-10% |
| 01BH45 | C05 | Breathing hole | Haulout Hole | 70.48334 | -148.72574 | 8-May-01 | open | n/a | open | N | 15 cm | 1200 | 3 | Pipeline Ice Road | 20% |
| 01BH46 | C06 | Breathing Hole | Breathing Hole | 70.51041 | -148.73425 | 8-May-01 | open | n/a | unknown | U | - | 2500 | 5 | Northstar Island | - |
| 01BH48 | C08 | Breathing hole | Haulout Hole | 70.48372 | -148.70777 | 8-May-01 | open | n/a | open | N | 20 cm | 530 | 2 | Pipeline Ice Road | - |
| 01BH49 | C09 | Breathing Hole | Breathing Hole | 70.48316 | -148.76657 | 9-May-01 | open | n/a | open | N | 16 cm | 2700 | 6 | Pipeline Ice Road | - |
| 01BH53 | C13 | Breathing Hole | Breathing Hole | 70.45363 | -148.67127 | 10-May-01 | open | n/a | open | N | - | 700 | 2 | Pipeline Ice Road | - |
| 01BH54 | C14 | Breathing hole | Haulout Hole | 70.48209 | -148.67787 | 10-May-01 | open | n/a | open | N | - | 40 | 1 | Primary Ice Road | - |
| 01BH55 | C15 | Breathing hole | Haulout Hole | 70.47634 | -148.66707 | 10-May-01 | open | n/a | open | N | 15 cm | 30 | 1 | Primary Ice Road | - |

| Structure Number | Map ID Number | Original Structure Type | Fianl Structure Type | N Latitude | W Longitude | Date Located | Original Status | March Recheck Status | May Final Check | Structure Abandoned | Snow Depth (cm) | Estimated Distance from Activities (m) | Bin # | Nearest Infrastructure | Ice Deformation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01BH56 | C16 | Breathing hole | Haulout Hole | 70.43885 | -148.60886 | 10-May-01 | open | n/a | open | N | 22 cm | 360 | 1 | Primary Ice Road | - |
| 01BH57 | C17 | Breathing Hole | Breathing Hole | 70.46797 | -148.64062 | 10-May-01 | open | n/a | open | N | - | 330 | 1 | Primary Ice Road | - |
| 01BH58 | C18 | Breathing hole | Haulout Hole | 70.48997 | -148.63556 | 10-May-01 | open | n/a | open | N | 19 cm | 1800 | 4 | Primary Ice Road | 10% |
| 01BH59 | C19 | Breathing hole | Haulout Hole | 70.41583 | -148.54283 | 11-May-01 | open | n/a | open | N | - | 420 | 1 | Primary Ice Road | 5% |
| 01BH60 | C20 | Breathing Hole | Breathing Hole | 70.46187 | -148.58095 | 12-May-01 | open | n/a | unknown | U | 18 cm | 1900 | 4 | Primary Ice Road | - |
| 01BH61 | C21 | Breathing Hole | Breathing Hole | 70.48978 | -148.69812 | 13-May-01 | open | n/a | unknown | U | - | 100 | 1 | Northstar Island | 0% |
| 01BH62 | C22 | Breathing hole | Haulout Hole | 70.41552 | -148.57136 | 13-May-01 | open | n/a | open | N | - | 510 | 2 | Primary Ice Road | - |
| 01BH63 | C23 | Breathing hole | Haulout Hole | 70.43684 | -148.54158 | 13-May-01 | open | n/a | open | N | - | 1700 | 4 | Primary Ice Road | 5% |
| 01BH65 | C25 | Breathing hole | Haulout Hole | 70.50221 | -148.66735 | 14-May-01 | open | n/a | open | N | 35 cm | 1500 | 3 | Northstar Island | 20% |
| 01BH66 | C26 | Breathing hole | Haulout Hole | 70.48132 | -148.72222 | 14-May-01 | open | n/a | open | N | - | 1080 | 3 | Pipeline Ice Road | - |
| 01BH69 | C29 | Breathing hole | Haulout Hole | 70.50309 | -148.72587 | 15-May-01 | open | n/a | open | N | 0 | 1600 | 4 | Northstar Island | 0-5% |
| 01BH71 | C31 | Breathing Hole | Breathing Hole | 70.45703 | -148.71286 | 16-May-01 | open | n/a | open | - | - | 800 | 2 | Pipeline Ice Road | - |
| 01BH73 | C33 | Breathing hole | Haulout Hole | 70.4634 | -148.73631 | 16-May-01 | open | n/a | open | - | 35 cm | 1700 | 4 | Pipeline Ice Road | 0% |
| 01BH74 | C34 | Breathing hole | Haulout Hole | 70.47505 | -148.59456 | 17-May-01 | open | n/a | open | - | - | 2300 | 5 | Primary Ice Road | 0% |
| 01BH75 | C35 | Breathing hole | Haulout Hole | 70.48063 | -148.59647 | 17-May-01 | open | n/a | open | - | - | 2600 | 6 | Primary Ice Road | 0% |
| 01BH76 | C36 | Breathing hole | Haulout Hole | 70.43783 | -148.58957 | 17-May-01 | open | n/a | open | - | 9 cm | 310 | 1 | Primary Ice Road | 0% |
| 01BH77 | C37 | Breathing hole | Haulout Hole | 70.46555 | -148.64744 | 18-May-01 | open | n/a | open | - | 33 cm | 90 | 1 | Primary Ice Road | 0% |
| 01BH78 | C38 | Breathing hole | Haulout Hole | 70.47145 | -148.69192 | 19-May-01 | open | n/a | open | - | 12 cm | 120 | 1 | Pipeline Ice Road | 0% |
| 01BH79 | C39 | Breathing hole | Haulout Hole | 70.44203 | -148.67095 | 19-May-01 | open | n/a | open | - | 15 cm | 790 | 2 | Primary Ice Road | 0% |
| 01BH80 | C40 | Breathing hole | Haulout Hole | 70.44243 | -148.65335 | 19-May-01 | open | n/a | open | - | 20 cm | 1450 | 3 | Primary Ice Road | - |

| Structure Number | Map ID Number | Original Structure Type | Fiani Structure Type | N Latitude | W Longitude | Date Located | Original Status | March Recheck Status | May Final Check | Structure Abandoned | Snow Depth (cm) | Estimated Distance from Activities (m) | Bin # | Nearest Infrastructure | Ice Deformation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01BH81 | C41 | Breathing hole | Haulout Hole | 70.43513 | -148.61533 | 19-May-01 | open | n/a | open | - | 26 cm | 670 | 2 | Primary Ice Road | 1% |
| 01BH82 | C42 | Breathing hole | Haulout Hole | 70.4817 | -148.61032 | 20-May-01 | open | n/a | open | - | - | 2100 | 5 | Primary Ice Road | 0% |
| 01BH83 | C43 | Breathing hole | Haulout Hole | 70.5033 | -148.71612 | 21-May-01 | open | n/a | open | - | 5 cm | 1400 | 3 | Northstar Island | 3% |
| 01BH84 | C44 | Breathing hole | Haulout Hole | 70.49814 | -148.67519 | 21-May-01 | open | n/a | open | - | 15 cm | 900 | 2 | Northstar Island | 19% |
| 01BH85 | C45 | Breathing hole | Haulout Hole | 70.45343 | -148.65517 | 21-May-01 | open | n/a | open | - | - | 980 | 2 | Primary Ice Road | 2% |
| 01HO50 | C46 | Lair | Lair | 70.41608 | -148.53612 | 7-May-01 | frozen | n/a | frozen | - | - | 650 | 2 | Primary Ice Road | - |
| 01LA24 | C47 | Lair | Lair | 70.4137 | -148.53055 | 4-May-01 | open | n/a | open | N | - | 680 | 2 | Primary Ice Road | - |
| 01LA25 | C48 | Lair | Lair | 70.4757 | -148.74549 | 4-May-01 | open | n/a | open | N | - | 2000 | 4 | Pipeline Ice Road | - |
| 01LA26 | C49 | Lair | Lair | 70.49327 | -148.63925 | 4-May-01 | open | n/a | open | N | 65cm | 2000 | 4 | Northstar Island | - |
| 01LA27 | C50 | Lair | Lair | 70.4988 | -148.64067 | 4-May-01 | open | n/a | frozen | Y | - | 2100 | 5 | Northstar Island | 40% |
| 01LA29 | C52 | Lair | Lair | 70.46174 | -148.66712 | 5-May-01 | open | n/a | frozen | Y | 27 cm | 870 | 2 | Primary Ice Road | - |
| 01LA30 | C53 | Lair | Pupping Lair | 70.42659 | -148.6085 | 5-May-01 | open | n/a | open | N | - | 1060 | 3 | Primary Ice Road | 10% |
| 01LA31 | C54 | Lair | Lair | 70.42663 | -148.60865 | 5-May-01 | open | n/a | frozen | Y | 75cm | 1070 | 3 | Primary Ice Road | - |
| 01LA32 | C55 | Lair | Lair | 70.46301 | -148.62167 | 5-May-01 | open | n/a | open | N | 60cm | 650 | 2 | Primary Ice Road | - |
| 01LA33 | C56 | Lair | Lair | 70.46408 | -148.73139 | 8-May-01 | open | n/a | open | N | - | 1500 | 3 | Pipeline Ice Road | 0-5% |
| 01LA34 | C57 | Lair | Lair | 70.49029 | -148.73123 | 8-May-01 | open | n/a | open | N | - | 1300 | 3 | Northstar Island | 10-20% |
| 01LA35 | C58 | Lair | Lair | 70.51431 | -148.68728 | 9-May-01 | open | n/a | open | N | 65 cm | 2500 | 5 | Northstar Island | 20% |
| 01LA36 | C59 | Lair | Pupping Lair | 70.49953 | -148.68946 | 9-May-01 | open | n/a | open | N | 92 cm | 900 | 2 | Northstar Island | 40% |
| 01LA37 | C60 | Lair | Lair | 70.49056 | -148.68259 | 9-May-01 | open | n/a | open | N | 68 cm | 350 | 1 | Northstar Island | 5% |
| 01LA38 | C61 | Lair | Lair | 70.48718 | -148.69046 | 9-May-01 | open | n/a | open | N | 45 cm | 130 | 1 | Pipeline Ice Road | 5% |

| Structure Number | Map ID Number | Original Structure Type | Fianl Structure Type | N Latitude | W Longitude | Date Located | Original Status | March Recheck Status | May Final Check | Structure Abandoned | Snow Depth (cm) | Estimated Distance from Activities (m) | Bin # | Nearest Infrastructure | Ice Deformation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01LA40 | C63 | Lair | Pupping Lair | 70.43391 | -148.65837 | 10-May-01 | open | n/a | open | N | - | 1100 | 3 | Pipeline Ice Road | 10% |
| 01LA41 | C64 | Lair | Haulout Hole | 70.48264 | -148.67584 | 10-May-01 | open | n/a | open | N | 48 cm | 70 | 1 | Primary Ice Road | 5% |
| 01LA42 | C65 | Lair | Lair | 70.45285 | -148.62976 | 10-May-01 | open | n/a | open | N | 35 cm | 200 | 1 | Primary Ice Road | 0-5% |
| 01LA44 | C66 | Lair | Lair | 70.46473 | -148.69171 | 14-May-01 | open | n/a | unknown | U | - | 10 | 1 | Pipeline Ice Road | - |
| 01LA45 | C67 | Lair | Lair | 70.50294 | -148.66593 | 14-May-01 | open | n/a | unknown | U | - | 1600 | 4 | Northstar Island | - |
| 01LA47 | C69 | lair | Lair | 70.49847 | -148.72778 | 15-May-01 | open | n/a | open | N | 50 cm | 1200 | 3 | Northstar Island | 30% |
| 01LA48 | C70 | Lair | Haulout Hole | 70.50036 | -148.73969 | 15-May-01 | open | n/a | open | - | - | 1900 | 4 | Northstar Island | - |
| 01LA50 | C72 | Lair | Pupping Lair | 70.47466 | -148.74153 | 16-May-01 | open | n/a | open | - | 39 cm | 1800 | 4 | Pipeline Ice Road | 5% |
| 01LA51 | C73 | Lair | Pupping Lair | 70.51459 | -148.70028 | 16-May-01 | open | n/a | open | - | 120 cm | 2500 | 5 | Northstar Island | 20% |
| 01LA52 | C74 | Lair | Lair | 70.44978 | -148.52786 | 17-May-01 | unknown | n/a | unknown | - | - | 2900 | 6 | Primary Ice Road | - |
| 01LA53 | C75 | Lair | Haulout Hole | 70.49467 | -148.60662 | 17-May-01 | open | n/a | open | - | - | 3200 | 7 | Northstar Island | - |
| 01LA54 | C76 | Lair | Lair | 70.51346 | -148.63657 | 17-May-01 | open | n/a | open | - | 90 cm | 3200 | 7 | Northstar Island | 5% |
| 01LA55 | C77 | Lair | Haulout Hole | 70.48488 | -148.61235 | 17-May-01 | open | n/a | open | - | 35 cm | 2100 | 5 | Primary Ice Road | 1% |
| 01LA56 | C78 | Lair | Pupping Lair | 70.46452 | -148.59802 | 17-May-01 | open | n/a | open | - | 48 cm | 1700 | 4 | Primary Ice Road | 0% |
| 01LA57 | C79 | Lair | Lair | 70.44883 | -148.58392 | 17-May-01 | open | n/a | open | - | 37 cm | 1200 | 3 | Primary Ice Road | 0% |
| 01LA58 | C80 | Lair | Pupping Lair | 70.42211 | -148.57461 | 18-May-01 | open | n/a | open | - | 69 cm | 120 | 1 | Primary Ice Road | 0% |
| 01LA59 | C81 | Lair | Haulout Hole | 70.46962 | -148.67029 | 19-May-01 | open | n/a | open | - | 23 cm | 400 | 1 | Primary Ice Road | 0% |
| 01UNK01 | C82 | unknown | Unknown | 70.48915 | -148.64645 | 10-May-01 | - | n/a | unknown | - | - | 1400 | 3 | Primary Ice Road | - |
| 01BH14 | B14[a] | Breathing Hole | Breathing Hole | 70.44687 | -148.73301 | 4-Mar-01 | open | n/a | open | N | - | 1600 | 3 | Pipeline ice road | 5% |
| 01BH23 | B23[a] | Breathing Hole | Breathing Hole | 70.4551 | -148.76756 | 10-Mar-01 | open | n/a | open | N | - | 2900 | 6 | Pipeline ice road | 10-15% |

| Structure Number | Map ID Number | Original Structure Type | Fianl Structure Type | N Latitude | W Longitude | Date Located | Original Status | March Recheck Status | May Final Check | Structure Abandoned | Snow Depth (cm) | Estimated Distance from Activities (m) | Bin # | Nearest Infrastructure | Ice Deformation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01BH24 | B24[a] | Breathing Hole | Lair | 70.45982 | -148.76915 | 10-Mar-01 | open | n/a | open | N | - | 2900 | 6 | Pipeline ice road | 5% |
| 01BH28 | B28[a] | Breathing Hole | Breathing Hole | 70.44172 | -148.71613 | 11-Mar-01 | open | n/a | open | N | - | 1000 | 2 | Pipeline ice road | 5% |
| 01LA09 | B49[a] | Lair | Lair | 70.4439 | -148.72968 | 7-Mar-01 | open | n/a | open | N | - | 1500 | 3 | Pipeline ice road | 10% |
| 01LA10 | B50[b] | Lair | Pupping Lair | 70.47064 | -148.80698 | 7-Mar-01 | open | n/a | frozen | Y | - | 4300 | 8 | Pipeline ice road | 5% |
| 01LA11 | B51[a] | Lair | Lair | 70.46422 | -148.76405 | 7-Mar-01 | open | n/a | frozen | Y | - | 2700 | 6 | Pipeline ice road | - |
| 01LA17 | B57[b] | Lair | Lair | 70.47812 | -148.80152 | 11-Mar-01 | open | n/a | frozen | Y | - | 4100 | 8 | Northstar Northstar Island | 2% |
| 01LA18 | B58[b] | Lair | Lair | 70.48619 | -148.79457 | 11-Mar-01 | open | n/a | open | N | - | 3700 | 8 | Northstar Northstar Island | 50% |
| 01 BH41 | C01[a] | Breathing hole | Haulout Hole | 70.47533 | -148.7849 | 4-May-01 | open | n/a | open | N | - | 3400 | 7 | Pipeline ice road | 0-5% |
| 01BH42 | C02[a] | Breathing hole | Haulout Hole | 70.46154 | -148.76111 | 5-May-01 | open | n/a | frozen | Y | - | 2600 | 6 | Pipeline ice road | 10% |
| 01BH44 | C04[a] | Breathing Hole | Haulout Hole | 70.45134 | -148.73211 | 8-May-01 | open | n/a | open | N | 20 cm | 1600 | 3 | Pipeline ice road | - |
| 01BH47 | C07[b] | Breathing hole | Haulout Hole | 70.52356 | -148.74949 | 8-May-01 | open | n/a | open | N | 12 cm | 4000 | 8 | Northstar Northstar Island | 10% |
| 01BH50 | C10[a] | Breathing Hole | Breathing Hole | 70.46826 | -148.78782 | 9-May-01 | open | n/a | open | N | - | 3600 | 8 | Pipeline ice road | 10% |
| 01BH51 | C11[a] | Breathing Hole | Breathing Hole | 70.46965 | -148.79109 | 9-May-01 | open | n/a | open | N | 30 cm | 3700 | 8 | Pipeline ice road | - |
| 01BH52 | C12[a] | Breathing hole | Haulout Hole | 70.48325 | -148.78788 | 9-May-01 | open | n/a | open | N | - | 3500 | 7 | Northstar Northstar Island | - |
| 01BH64 | C24[b] | Breathing hole | Haulout Hole | 70.42657 | -148.51469 | 13-May-01 | open | n/a | open | N | - | 1930 | 4 | Primary ice road | - |
| 01BH67 | C27[a] | Breathing hole | Haulout Hole | 70.44404 | -148.71994 | 15-May-01 | open | n/a | open | N | - | 1100 | 3 | Pipeline ice road | - |
| 01BH68 | C28[a] | Breathing hole | Haulout Hole | 70.45622 | -148.15983 | 15-May-01 | open | n/a | open | N | - | 2400 | 5 | Pipeline ice road | - |
| 01BH70 | C30[b] | Breathing hole | Haulout Hole | 70.52283 | -148.71963 | 15-May-01 | open | n/a | open | N | 28 cm | 3100 | 7 | Northstar Northstar Island | 10% |
| 01BH72 | C32[a] | Breathing hole | Haulout Hole | 70.44493 | -148.7613 | 16-May-01 | open | n/a | open | Y | 12 cm | 2700 | 6 | Pipeline ice road | - |
| 01LA28 | C51[a] | Lair | Lair | 70.45786 | -148.761 | 5-May-01 | open | n/a | open | N | - | 2600 | 6 | Pipeline ice road | - |

| Structure Number | Map ID Number | Original Structure Type | Fianl Structure Type | N Latitude | W Longitude | Date Located | Original Status | March Recheck Status | May Final Check | Structure Abandoned | Snow Depth (cm) | Estimated Distance from Activities (m) | Bin # | Nearest Infrastructure | Ice Deformation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01LA39 | C62 [a] | Lair | Lair | 70.47116 | -148.78767 | 9-May-01 | open | n/a | open | N | - | 3500 | 7 | Pipeline ice road | 20% |
| 01LA46 | C68 [a] | Lair | Lair | 70.45539 | -148.72752 | 15-May-01 | open | n/a | open | N | - | 1400 | 3 | Pipeline ice road | - |
| 01LA49 | C71 [a] | Lair | Pupping Lair | 70.44775 | -148.74366 | 16-May-01 | open | n/a | open | Y | 63 cm | 1900 | 4 | Pipeline ice road | 2% |

[1] Structure abandoned prior to this study

[a] Structure within Monitoring Zone Addition

[b] Structure outside of study area

# APPENDIX B: INCIDENTAL SIGHTINGS OF POLAR BEARS DURING MONITORING ACTIVITIES FOR BP'S NORTHSTAR OIL DEVELOPMENT, ALASKAN BEAUFORT SEA, 2001[1,2]

## *Introduction*

BP Exploration (Alaska) Inc. (BP) is producing crude oil from the Northstar Unit, located just northwest of Prudhoe Bay, between 3 and 13 km (1.9 and 8.1 miles) offshore from Point Storkersen. The unit is adjacent to the Prudhoe Bay industrial complex, and is approximately 87 km (54 mi) northeast of Nuiqsut, a Native Alaskan (Inupiat) community. The Northstar drilling and production island was built in early 2000 on the submerged remnants of Seal Island. Seal Island was an artificial island constructed in 1982, used for exploration drilling during the 1980s, and subsequently abandoned. The main facilities required for Northstar include a gravel island work surface for drilling and oil production, and two pipelines connecting the island to the existing infrastructure in Prudhoe Bay. One pipeline transports crude oil to shore, and the other transports natural gas to the island for field injection and use in power generation. A camp and supporting infrastructure for personnel are also required on the island.

The Northstar island and pipelines were constructed during the winter of late 1999 and 2000. Construction activities included: ice road construction, gravel hauling, pipeline installation through a trench in the ice, emplacing and capping the sheet pile retaining wall, installing well conductor pipes, foundation blocks, concrete slope protection, utility and permanent living quarter modules, and the drilling rig with a grind and inject module. Industrial activities were less intensive during 2001, the period covered in this report. During the winter of 2001, one primary offshore ice road was built from West Dock to the island. A second offshore ice road was built along the pipeline alignment (however, it was not maintained after limited gravel backfilling was completed in mid April 2001), and a third road was built along the shoreline. Activities on and around the island during the winter and spring included general transportation on the ice roads, emergency equipment testing, drilling, and gravel backfilling at nine locations along the pipeline alignment (Perham and Williams 2001). During the spring break-up and open-water season of 2001, BP transported equipment modules to Northstar by sealift, and installed them on the island. In addition, there were frequent transits of helicopters, crew boats, tugs, barges and other vessels between the Prudhoe Bay area and Northstar (Williams 2002). Drilling was suspended during the 2001 open-water season. Ice road construction and drilling occurred again in November and December 2001.

BP, the National Marine Fisheries Service (NMFS), and various other stakeholders anticipated that some seals and whales could be disturbed in a manner that might be considered "takes" under the Marine Mammal Protection Act (MMPA), during construction and subsequent operation of Northstar. Consequently, BP requested that NMFS issue incidental take authorizations under section 101 (a) (5) of the MMPA to authorize "taking" of small numbers of whales and seals. Such authorizations normally require that monitoring studies be conducted to assess the amount and nature of any taking that did occur, and to

---

[1] By **Valerie D. Moulton** (LGL Ltd. environ. res. assoc., King City, Ont.) and **Michael T. Williams** (LGL Alaska Res. Assoc. Inc., Anchorage, AK). E-mail: vmoulton@lgl.com; mwilliams@lgl.com.

[2] This is a re-formated and slightly revised copy of LGL Report TA2570-2 submitted to the U.S. Fish & Wildlife Service (USFWS), Anchorage, AK, on 27 March 2002 to satisfy one requirement of a Letter of Authorization issued by the USFWS to BP Exploration (Alaska) Inc. authorizing incidental (unintentional) takes of polar bears during Northstar industrial and monitoring activities.

help determine whether the activities had an unmitigated effect on the accessibility of whales or seals to subsistence hunters. BP proposed that it would conduct several types of monitoring during both the ice-covered season and the open-water season. The three tasks that were conducted during the ice-covered season in winter and spring included (Richardson and Williams 2001):

- Fixed-wing aerial surveys of seals hauled out on the ice in spring (*Task 1*),
- On-ice searches for ringed seal breathing holes and lairs near Northstar (*Task 3*), and
- Sound measurements to document sounds and vibrations from Northstar activities (*Task 4*).

The two tasks that were conducted during the open-water season included (Richardson 2002):

- Sound measurements, concentrating on potentially noisy activities whose sounds were not measured in detail during 2000 (*Task 5*), and
- Acoustic monitoring of the 2001 bowhead migration past Northstar (*Task 7*).

Some disturbance and (potentially) localized displacement effects on polar bears (*Ursus maritimus*) near Northstar were a possibility in 2001 as a result of industrial and monitoring activities. However, the tasks designed to monitor the effects of on-ice industrial activities on seals and whales provided an opportunity to document sightings of polar bears in the area.

### Business Rationale

Incidental (unintentional) takes of polar bears during Northstar industrial and monitoring activities were authorized by Letters of Authorization (LoA). A LoA for Northstar activities was issued on 10 September 1999 and reinstated on 23 February 2000. The period covered in the LoA was extended on 3 May 2000, and again on 3 January 2001 to include activities at the Northstar site until 31 December 2001. The LoA was issued by the U.S. Fish & Wildlife Service (FWS) under Section 101(a)(5) of the Marine Mammal Protection Act and 50 CFR 18, subpart J—"Taking of Marine Mammals Incidental to Oil and Gas Exploration, Development, and Production Activities in the Beaufort Sea and Adjacent Northern Coast of Alaska".

The types of industrial activity as well as the monitoring tasks conducted in 2001 are described below, followed by information on the sightings of polar bears during marine mammal and acoustical monitoring activities. Sightings of polar bears by BP personnel (with the exception of two sightings during acoustical monitoring) are not reported here as this information has already been presented to FWS in the form of individual Polar Bear Sighting Reports (A. Erickson, BP, pers. comm.).

## Northstar Industrial Activities

More detailed information about industrial activities during the ice-covered season and open-water season can be found in Perham and Williams (2001) and Williams (2002), respectively.

### Ice-covered Season, January to Spring 2001

Construction of the Northstar ice-roads for the winter of 2000-2001 began in November 2000 and was completed in March 2001. The primary ice road running northwest from West Dock to Northstar Island, used for general traffic, was completed in mid March 2001. A second ice road was built in January and February from Northstar Island south along the pipeline alignment to the mainland. A third ice road was constructed along the shoreline on the grounded ice.

Ice cutting and supplementary gravel placement along the pipeline alignment was initiated in March 2001 and completed in mid April 2001. At each gravel placement location, these two activities (i.e., cutting and backfilling) occurred in sequence. The ice road along the pipeline alignment was not maintained after gravel backfilling was completed.

Major construction activities included completing the assembly of the drilling rig, construction of a pipe rack, and dock improvements. Module construction included completing the permanent living quarters and the grind and inject modules, as well as the foundation blocks for the modules housing the processing plant, compressor, and garage. Installation of the emergency diesel generator and mini-injection effluent skid also occurred.

Equipment testing occurred throughout the ice-covered season. The ARKTOS vehicles used as emergency escape vehicles were tested in mid-April 2001 (see shaded area around Northstar in Fig.1). The well rig engines and emergency diesel generators were tested in mid March 2001. An on-ice equipment exercise was conducted on 1 and 2 June 2001 to test several types of equipment during softening ice conditions.

A total of five wells were drilled during the ice-covered season; one of these wells was only partially drilled and later was abandoned. Oil production began in November 2001.

### *Open-water Season 2001*

Two Bell 212 helicopters were used as transportation to and from Northstar Island during break-up. During the open-water season, two crew boats (18.5 m or 61.5 ft in length), the *Hawk* and *Arctic Express*, were the primary method of transportation, but helicopter flights continued on a less frequent basis. Helicopter flights began on 9 June 2001 from the West Dock base of operations and Deadhorse airport to Northstar and return. The crew boat began transits on 23 July 2001 between West Dock and Northstar. Eight round-trip trips were scheduled daily during summer and autumn operations. Crew boat operations ceased on 7 October 2001 as sea ice formed. During the open-water period in 2001, there were 824 round-trips by the crew boat and 69 round-trips by barge (ranged in length from 45 to 130 m [150 to 430 ft]) between West Dock and the island. Alaska Clean Seas vessels were deployed around Northstar for training and fuel transfers on 23 days during the open-water season.

A sealift carrying production facilities, gas-turbine compressors, and other major facilities arrived in the Northstar area from southern Alaska on 10 August. The sealift included three barges and several tugboats. The modules, gas-turbine system and other facilities were off-loaded from the sealift barge to the island during the 12-20 August period using a Scheuerle trailer model MPEK 5200. During this period there was much maneuvering of the sealift barges by tugs (ranged in length from 14 to 41 m [46 to 136 ft]).

Tugs and barges periodically traveled to Northstar. Eight vessels were used for transport of diesel fuel, 17 vessels were used for cargo transport, and 11 vessels were used for spill response activities in and around Northstar.

The "emergency" generator in the utility module was used until 24 October 2001. The gas-turbine system brought to the island during August was integrated into the existing modules and became operational on 24 October 2001.

The Northstar drill rig, which had been installed in 2000 and operated during the winter and spring, was shut down from 13 June 2001 to October 2001, and drilling did not resume until November 2001. The grind and injection module injected seawater and miscellaneous wastes into the disposal well throughout the open water and broken-ice periods in 2001.

### *Ice-covered Season, November to December 2001*

During the 2001-2002 winter season, construction of the Northstar ice road began on 11 November 2001. The ice road to Northstar (~12 km in length) originates near Point McIntyre and extends to the island, similar to the main ice road created the previous year. Ice road construction was completed in 2002. The ice road was built in support of general vehicle traffic for ongoing drilling and oil production operations on Northstar.

## *Monitoring Methods*

Three monitoring tasks were implemented during the ice-covered season and two were implemented during the open-water season. There was potential for takes of polar bears as a result of some of these monitoring activities. However, monitoring (especially the aerial surveys) also permitted the collection of valuable information on polar bear distribution and abundance in the Northstar area.

### *Fixed-Wing Aerial Survey of Seals (Task 1)*

LGL conducted aerial surveys for seals (primarily ringed seals, *Phoca hispida*, but also bearded seals, *Erignathus barbatus*) in the Northstar area from 28 May to 8 June 2001 (Moulton et al. 2001a). These surveys were designed to monitor the effects of industrial activity at Northstar on ringed seal distribution and abundance. The 2001 surveys were the fifth year of such surveys; results from 1997, 1998, 1999, and 2000 were described by Miller et al. (1998), Link et al. (1999), and Moulton et al. (2000, 2001b). 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 haulout, when ringed seals are most easily counted from the air.

Two "replicates" of aerial survey transects were flown between longitudes 147°06'W and 149°04.5'W, an east-west extent of about 75 km (46 mi). Each survey replicate consisted of 80 north-south transects spaced 0.9 km apart. Each transect extended from the Beaufort Sea shoreline to roughly 37 km offshore or to the edge of the landfast ice if it was encountered and recognizable <37 km offshore. Survey replicate 1 was flown on 28 May - 4 June 2001 and replicate 2 was flown on 4-8 June 2001. In total, 5154 linear kilometers (3203 mi) of surveys were flown by LGL during the 10-day survey period. The surveys were flown over the landfast ice in an Aero Commander at an altitude of 91 m (300 ft) above sea level and a ground speed of 222 km/h (120 knots). Overflights by the survey aircraft had the potential to disturb polar bears.

### *On-Ice Monitoring Near the Northstar Development (Task 3)*

In March and again in May 2001[3], trained dogs were used to locate ringed seal structures in an 84.5 $km^2$ (32.6 $mi^2$) study area surrounding the Northstar Development area. This area was derived from the centerline of the ice roads and the edge of the island and extended approximately 3 km laterally. Summaries of the monitoring procedures are presented below. The objectives of these surveys were (1) to detect any seal structures, breathing holes or lairs in areas where seals might be harmed by on-ice industrial activities, and (2) to help characterize the responses of ringed seals to the Northstar Development through detecting the presence and fate of seal structures near the development area. On-ice dog searches may have displaced or potentially attracted polar bears from/to the area. Polar bears may have been attracted to seal structures excavated by biologists because of new olfactory cues (dog and human) or visual cues (wooden stakes and vehicle tracks).

---

[3] The Northstar area was also searched from 24 November to 8 December 2000 (prior to intense industrial activities for the winter of 2000/2001).

During the 2-13 March period, trained dogs were used to locate ringed seal structures within an area extending 3 km from Northstar and the associated ice roads (Williams et al. 2001). Surveys were conducted by biologists (either on snow machine or foot, depending on ice conditions) using two trained Labrador retriever dogs. All seal structures that were found were marked with stakes and some structures were excavated to obtain structure measurements and/or to deploy a temperature sensor used to detect presence of seals. An additional search for seal structures was conducted from 4-21 May 2001 within the same area searched in March 2001. Both the March and May surveys were conducted in an attempt to document abandonment rate of ringed seal structures relative to Northstar industrial activities and to locate additional structures created since the original search (in December 2000) or missed during the previous search (Williams et al. 2001).

### *Sound and Vibration Measurements (Task 4)*

On 6, 8 and 9 March 2001, Greeneridge Sciences made made digital audio recordings of underwater and airborne sounds, and of iceborne vibrations, at 14 locations up to 7.3 km (4.6 mi) east and northwest of Northstar Island to document sound levels during drilling (Blackwell and Greene 2001). Typically, the acoustic field crew traveled in a Hägglunds all-terrain vehicle and used a Blue Bird rolligon-type vehicle with low-pressure tires equipped with a powered ice auger to drill holes through which underwater recordings were made.

It is possible that these monitoring activities may have displaced or potentially attracted polar bears from/to the area. However, the short duration and limited scale of this work had little potential (relative to the overall seal monitoring and Northstar activities) to influence polar bears.

### *Sound Measurements (Task 5)*

Boat-based recordings of underwater and airborne sounds during the arrival and offloading of three sealift barges at Northstar were obtained on 10, 12 and 13 August 2001 (Blackwell and Greene 2002). Four types of sound measurements were made: the arrival of the barge train, tug noises as barges were maneuvered at the dock, overall island sounds from distances up to 20 km from Northstar, and noises produced by the Concrete Island Drilling Structure (CIDS). In addition, an Autonomous Seafloor Acoustic Recorder (ASAR), placed about 320 m (1050 ft) from the north shore of Northstar, recorded underwater island sounds continuously for 23 days in August 2001.

These acoustic-monitoring activities likely had little potential (relative to the overall Northstar activities in August) to influence polar bears.

### *Acoustic Monitoring of Bowhead Migration (Task 7)*

Details of field techniques employed to obtain acoustical measurements of whale vocalizations near Northstar are presented in Greene and McLennan (2002). There was little chance the activities associated with this monitoring task would affect polar bears. It is possible that the boats used to deploy and retrieve acoustic equipment may have disturbed bears in the area. Boats used during this monitoring task were the "Bay" boats operated by Alaska Clean Seas (ACS). Two cabled hydrophones and two ASARs were installed and operated about 300-550 m (984-1804 ft) north of Northstar during 30 July through 3 October 2001. On 28 August, 11 directional autonomous seafloor acoustic recorders (DASARs) were deployed. Periodically between 6 September and 3 October, boats were used to install, retrieve, or calibrate acoustical equipment.

## *Results*

### *Fixed-Wing Aerial Survey of Seals (Task 1)*

Sixteen polar bear sightings were made during six of the nine days that surveys were flown (Table B.1). These sightings are mapped in Figure B.1, along with the aerial survey flight lines flown during the surveys. One or two of the polar bear sightings may have been repeated sightings of the same individuals on different days. Most sightings were located near the fast-ice edge, one polar bear was sighted near Cross Island, and another bear was seen near Reindeer Island.

There were sixteen sightings of probable sites where polar bears had killed prey (Table B.1, Fig. B.1). The kill sites occurred in water depths of approximately 15-25 m (49-82 ft). These sites were recognized primarily by blood on the ice and by polar bear tracks. Ringed seals, by far the most abundant phocids seen during the aerial surveys, are the primary prey of polar bears and were the likely source of the blood.

Polar bear tracks were concentrated in the northern portion of the study area, primarily beyond the 15-m depth contour, during both survey replicates (Fig. B.2).

### *On-Ice Monitoring Near the Northstar Development (Task 3)*

During the on-ice surveys conducted in March and May 2001, LGL biologists identified no signs of polar bears.

TABLE B.1. Incidental sightings of polar bears and probable sites where polar bears killed prey during fixed-wing aerial surveys for seals, 28 May – 8 June 2001.

| Date | Local Time | Sighting | No. | Latitude (Deg. N) | Longitude (Deg. W) | Comment |
|---|---|---|---|---|---|---|
| 28-May | 13:14:43 | Polar Bear | 1 | 70.69 | 148.75 | Large bear running east and looking at the plane. |
| 28-May | 13:32:50 | Polar Bear | 2 | 70.68 | 148.65 | Mother and cub running northeast. |
| 28-May | 14:51:19 | Polar Bear | 1 | 70.49 | 147.95 | Polar bear north of island. |
| 29-May | 13:27:03 | Polar Bear | 2 | 70.78 | 149.00 | Pilot saw bears. |
| 01-Jun | 12:37:14 | Polar Bear | 1 | 70.48 | 147.77 | Single male; walking slowly westward. |
| 01-Jun | 15:48:46 | Polar Bear | 2 | 70.69 | 148.43 | Mom and cub running north. |
| 01-Jun | 12:09:19 | Polar Bear | 1 | 70.63 | 147.98 | Polar bear seen between transects. |
| 05-Jun | 15:47:45 | Polar Bear | 1 | 70.63 | 148.30 | One large bear sitting on the ice. |
| 07-Jun | 14:03:24 | Polar Bear | 2 | 70.51 | 148.37 | Mother and cub (?) walking north and looking at plane. |
| 07-Jun | 14:21:31 | Polar Bear | 2 | 70.64 | 148.27 | Mother and cub running north. |
| 08-Jun | 13:36:51 | Polar Bear | 1 | 70.50 | 147.62 | Polar was entering an apparent lair. |
| 28-May | 14:23:10 | PB Kill | 1 | 70.68 | 148.15 | Off transect; between transects 17 and 19. |
| 01-Jun | 12:02:06 | PB Kill | 1 | 70.48 | 148.08 | |
| 01-Jun | 12:13:11 | PB Kill | 1 | 70.51 | 147.98 | |
| 01-Jun | 12:37:51 | PB Kill | 1 | 70.46 | 147.77 | Near ridge of ice. |
| 01-Jun | 14:00:36 | PB Kill | 1 | 70.24 | 147.17 | Big area of blood; seal or caribou kill? |
| 01-Jun | 14:30:03 | PB Kill | 1 | 70.80 | 149.03 | Along a crack; polar bear tracks sighted as well. |
| 01-Jun | 15:20:39 | PB Kill | 1 | 70.69 | 148.62 | |
| 01-Jun | 16:48:42 | PB Kill | 1 | 70.57 | 147.93 | Near rubble ice. |
| 04-Jun | 16:25:37 | PB Kill | 1 | 70.51 | 147.85 | |
| 04-Jun | 17:12:29 | PB Kill | 1 | 70.60 | 148.25 | On flat ice. |
| 04-Jun | 17:13:11 | PB Kill | 2 | 70.63 | 148.25 | Two areas of blood. |
| 05-Jun | 15:53:14 | PB Kill | 1 | 70.60 | 148.40 | Old site. |
| 05-Jun | 17:01:19 | PB Kill | 1 | 70.61 | 148.90 | Big mess. |
| 07-Jun | 13:32:11 | PB Kill | 1 | 70.69 | 148.58 | Lots of blood spread over large area. |
| 08-Jun | 12:53:51 | PB Kill | 1 | 70.60 | 147.93 | Off transect. |

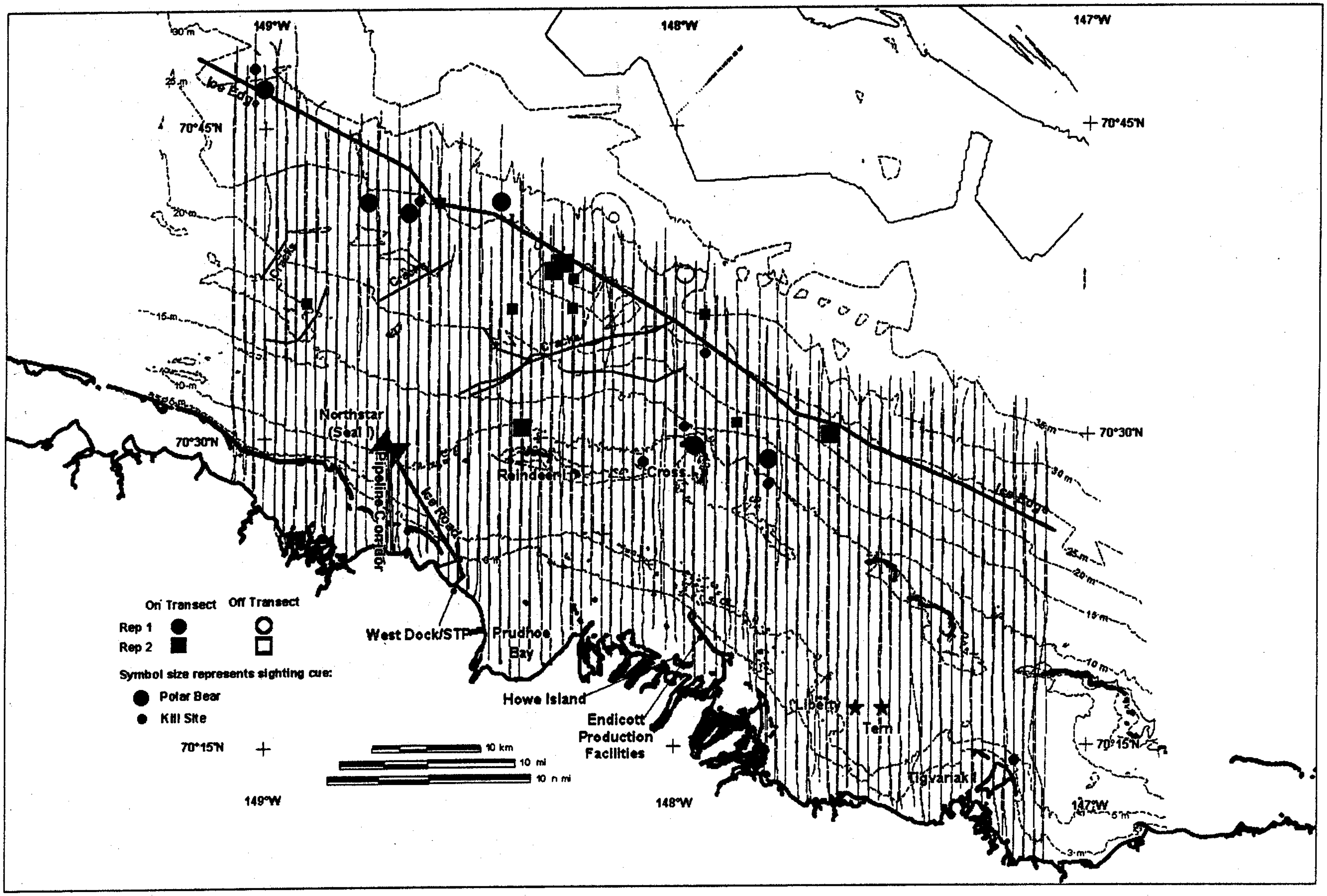


FIGURE B.1. Sightings of polar bears and probable polar bear kill sites recorded during marine mammal monitoring of BP's Northstar site in 2001. Also shown are the transects flown during the ringed seal aerial surveys in spring 2001. Areas of open water (leads) and pack ice occurred north of the landfast ice edge.

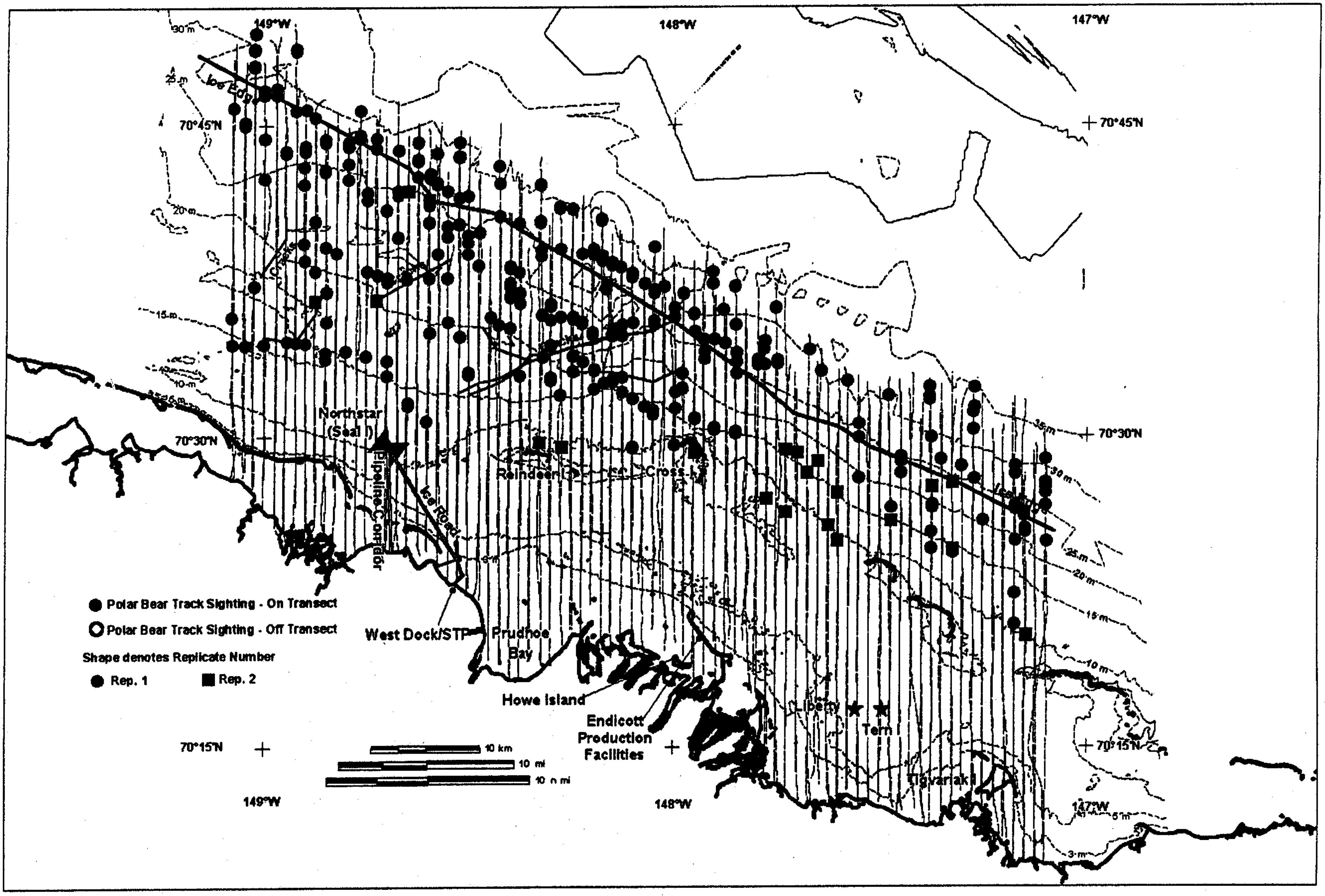


FIGURE B.2. Sightings of polar bear tracks recorded during marine mammal monitoring of BP's Northstar site in 2001. Also shown are the transects flown during the ringed seal aerial survey in spring 2001. Areas of open water (leads) and pack ice occurred north of the landfast ice edge.

### *Sound and Vibration Measurements (Task 4)*

No signs of polar bears were identified by acoustical surveyors during monitoring in March 2001.

### *Sound Measurements (Task 5)*

LGL or Greeneridge personnel did not observe any polar bears when obtaining acoustic recordings on 10, 12 and 13 August 2001.

### *Acoustic Monitoring of Bowhead Migration (Task 7)*

Greeneridge personnel observed a polar bear on 30 August 2001 while they were on an ACS vessel. Another polar bear was sighted on 29 September 2001 near West Dock; Greeneridge personnel were aboard an ACS vessel. BP personnel reported both of these sighting to FWS. LGL or Greeneridge personnel identified no other signs of polar bears during acoustic monitoring of Northstar.

## *Discussion*

Overall, there were at least 18 incidents that could be interpreted as incidental takes of polar bears during the marine mammal monitoring activities associated with the Northstar development in 2001. Sixteen polar bears were overflown during the fixed-wing survey and two polar bears were sighted during acoustical monitoring at Northstar.

The fixed-wing aerial survey (Task 1) provided the best opportunity to sight polar bears. However, the design of these surveys 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 it very difficult to assess polar bear 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. In our view, none of the 16 polar bears sighted during the fixed-wing aerial surveys were disturbed to the extent that there could be a long-term deleterious effect on those individual bears. It was difficult to discern if polar bears were reacting to the plane; however, three bears were observed looking at the aircraft. Seven polar bears were observed running, three were observed walking, and one bear was observed sitting on the ice. The polar bears that either ran or walked in apparent response to overflights by our survey aircraft may have been temporarily displaced from an area. We do not consider bears that simply looked at the aircraft as being overly disturbed.

The polar bears sighted on 30 August and 29 September 2001 while Greeneridge personnel were aboard an ACS vessel were likely not affected by monitoring activities. However, these bears may have been attracted to the Northstar development.

During 2001, the nearest known polar bear den to Northstar was located on Cottle Island, approximately 15 km west of Northstar (G. York, USGS, pers. comm.).

## *Acknowledgements*

We thank Ted Elliott of LGL Ltd. for creating the maps. Dr. Bill Streever (BP) reviewed this report and we appreciate his comments.

## *Literature Cited*

Blackwell, S.B. and C.R. Greene Jr. 2001. Sound and vibration measurements during winter drilling at Northstar in early 2001. p. 2-1 to 2-23 *In:* W.J. Richardson and M.T. Williams (eds.), *q.v.* LGL Rep. TA2571-1. [Superseded by Chapter 3 in this volume.]

Blackwell, S.B. and C.R. Greene Jr. 2002. Sound measurements, 2001 open-water season. p. 2-1 to 2-34 *In:* W.J. Richardson (ed.), *q.v.* LGL Rep. TA2572-1. [Superseded by Chapter 7 in this volume.]

Greene, C.R. Jr., and M.W. McLennan. 2002. Acoustic monitoring of 2001 bowhead whale migration. p. 3-1 to 3-30 *In:* W.J. Richardson (ed.), *q.v.* LGL Rep. TA2573-1. [Superseded by Chapter 8 in this volume.]

Link, M.R, T.L. Olson and M.T. Williams. 1999. Ringed seal distribution and abundance near potential oil development sites in the central Alaskan Beaufort Sea, spring 1998. LGL Rep. P-430. Rep. from LGL Alaska Research Assoc. Inc., for BP Explor. (Alaska) Inc., Anchorage, AK. 58 p.

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. LGL Rep. TA2160-3. Rep. from LGL Ltd., King City, Ont., for BP Explor. (Alaska) Inc., Anchorage, AK. 36 p.

Moulton, V.D., R.E. Elliott and M.T. Williams. 2001a. Fixed-wing aerial surveys of seals near BP's Northstar and Liberty sites, 2001. p. 4-1 to 4-31 *In:* W.J. Richardson and M.T. Williams (eds.), *q.v.* LGL Rep. TA2570-1. [Superseded by Chapter 5 in this volume.]

Moulton, V.D., R.E. Elliott, T.L. McDonald and W.J. Richardson. 2001b. Fixed-wing aerial surveys of seals near BP's Northstar and Liberty sites in 2000 (and 1997-2000 combined). p. 5-1 to 5-66 *In*: W.J. Richardson and M.T. Williams (eds.), Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, 2000. [Draft, April 2001.] Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 316 p. LGL Rep. TA2428-3.

Moulton, V.D., T.L. McDonald, W.J. Richardson, R.E. Elliott and M.T. Williams. 2000. Fixed-wing aerial surveys of seals near BP's Northstar and Liberty sites in 1999 (and 1997-1999 combined). p. 3-1 to 3-71 *In*: W.J. Richardson and M.T. Williams (eds.), Monitoring of ringed seals during construction of ice roads for BP's Northstar oil development, Alaskan Beaufort Sea, 1999. Final Rep. from LGL Ltd., King City, Ont., and LGL Alaska Res. Assoc. Inc., Anchorage, AK, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. xiv + 153 p. LGL Rep. TA2349-3.

Perham, C.J. and M.T Williams. 2001. Introduction and description of BP's on-ice activities, late 2000 to mid-2001. p. 1-1 to 1-13 *In:* W.J. Richardson and M.T. Williams (eds.), *q.v.* LGL Rep. TA2563-1. [Superseded by Chapter 2 in this volume.]

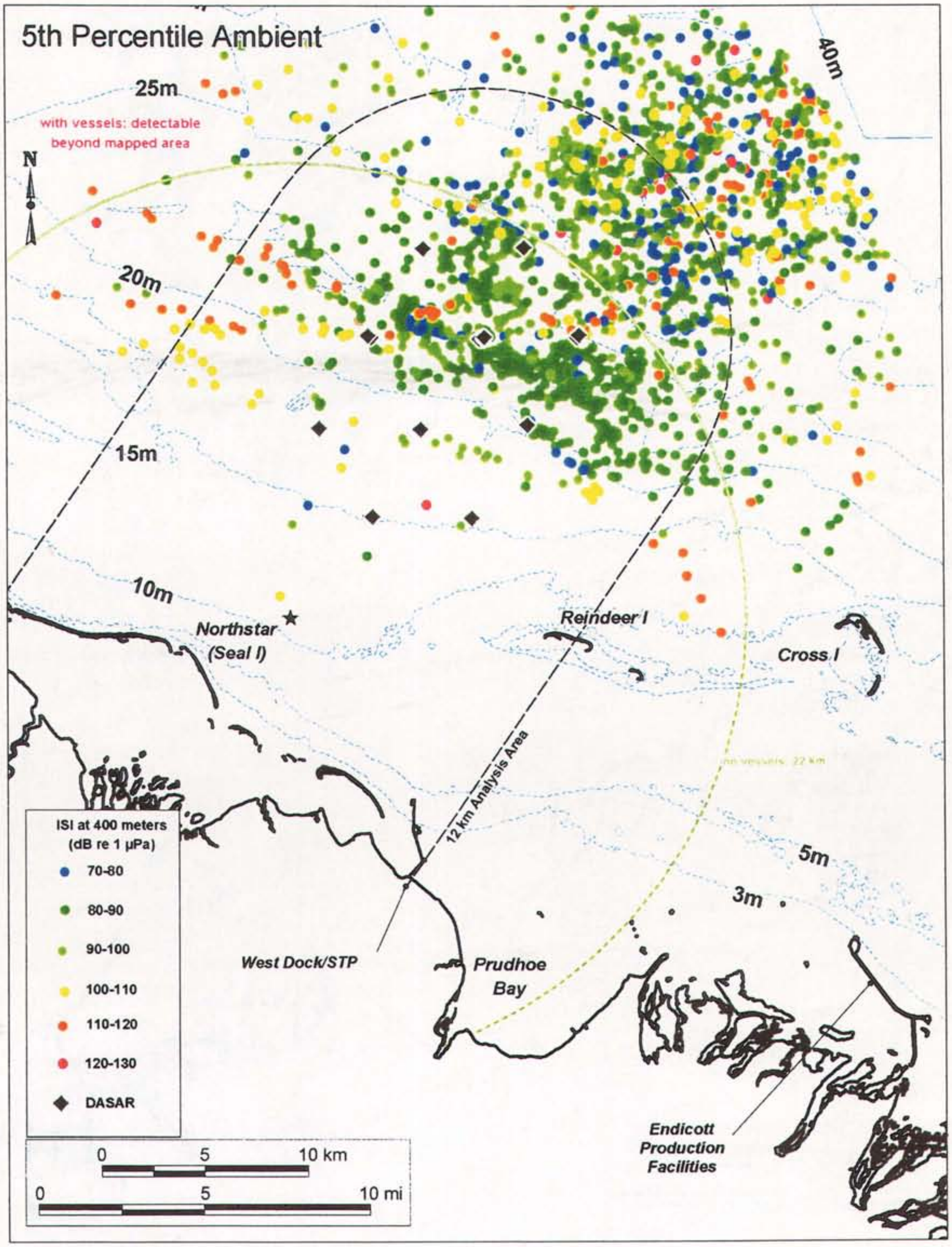
Richardson, W.J. (ed.) 2002. Monitoring of industrial sounds and whale calls during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, summer and autumn 2001: 90-day report. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 74 p. [Superseded by Chapters 1 and 6-9 in this volume.]

Richardson, W.J. and M.T. Williams (eds.). 2001. Monitoring of ringed seals, sounds and vibrations during construction of BP's Northstar Oil Development, Alaskan Beaufort Sea, winter and spring 2000-2001: 90-day report. Rep. from LGL Ltd., King City, Ont., and and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 117 p. [Superseded by Chapters 1-5 plus 9 in this volume.]

Williams, M.T. 2002. Introduction and description of BP activities. p. 1-1 to 1-10 *In:* W.J. Richardson (ed.), *q.v.* LGL Rep. TA2563-3. [Superseded by Chapter 6 in this volume.]

Williams, M.T., T.G. Smith, C.J. Perham and J.A. Coltrane. 2001. Location of ringed seal structures in the sea ice near Northstar, winter 2000 and spring 2001. p. 3-1 to 3-24 *In:* W.J. Richardson and M.T. Williams (eds.), *q.v.* LGL Rep. P557-1. [Superseded by Chapter 4 in this volume.]

APPENDIX C.1. Estimated whale call locations near Northstar, 29 Aug – 3 Oct 2001, color-coded by average ISI value 400 m from Northstar during the 60-min period preceding detection of each call. Also shown, for times with and without vessel activity, are the distances within which island-related sound (1-min ISI) would be expected to diminish to the ***5th-percentile*** ambient noise level in corresponding bands. See Chapter 8 regarding definition of times with and without vessels.



APPENDIX C.2. Estimated whale call locations near Northstar, 29 Aug – 3 Oct 2001, color-coded by average ISI value 400 m from Northstar during the 60-min period preceding detection of each call. Also shown, for times with and without vessel activity, are the distances within which island-related sound (1-min ISI) would be expected to diminish to the ***95th-percentile*** ambient noise level in corresponding bands. See Chapter 8 regarding definition of times with and without vessels.