Monitoring of Industrial Sounds, Seals, and Bowhead Whales Near BP's Northstar Oil Development, Alaskan Beaufort Sea: Comprehensive Report for 2005–2009

by

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MONITORING OF INDUSTRIAL SOUNDS, SEALS, AND BOWHEAD WHALES NEAR BP'S NORTHSTAR OIL DEVELOPMENT, ALASKAN BEAUFORT SEA: COMPREHENSIVE REPORT FOR 2005–2009

edited by

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TABLE OF CONTENTS

APPENDICES A – G (ON CD-ROM ONLY):
Northstar Technical Reports Completed Since 2005 [1]

A. **Final Comprehensive Report, 1999–2004** (Richardson [ed.] 2008; LGL Rep. P1004) – Revised March 2009 [Chapters 1–14; electronic Appendices excluded]
B. **2005 Annual Summary Report** (Richardson [ed.] 2006; LGL Rep. TA4209) – Revised August 2006
C. **2006 Annual Summary Report** (Richardson [ed.] 2007; LGL Rep. TA4441) – March 2007
D. **2007 Annual Summary Report** (Aerts & Richardson [eds.] 2008; LGL Rep. P1005b) – March 2008
E. **2008 Annual Summary Report** (Aerts & Richardson [eds.] 2009; LGL Rep. P1081) – March 2009.
F. **2009 Annual Summary Report** (Aerts & Richardson [eds.] 2010; LGL Rep. P1132) – March 2010
G. [reserved]

APPENDICES H – O (ON CD-ROM ONLY):
Journal Publications and Manuscripts Completed Since 2005 [1]

Papers on Physical Acoustics

H. Underwater and in-air sounds from a small hovercraft (Blackwell, S.B. and C.R. Greene Jr. 2005. ***J. Acoust. Soc. Am.*** 118(6): 3646-3652)

I. Sounds from an oil production island in the Beaufort Sea in summer: characteristics and contribution of vessels (Blackwell, S.B. and C.R. Greene Jr. 2006. ***J. Acoust. Soc. Am.*** 119(1): 182-196)

J. Sounds and vibrations in the frozen Beaufort Sea during gravel island construction (Greene, C.R., Jr., S.B. Blackwell, and M.W. McLennan. 2008. ***J. Acoust. Soc. Am.*** 123(2): 687-695)

Papers on Seals

K. Effects of an offshore oil development on local abundance and distribution of ringed seals (*Phoca hispida*) of the Alaskan Beaufort Sea (Moulton, V.D., W.J. Richardson, R.E. Elliott, T.L. McDonald, C. Nations and M.T. Williams. 2005. ***Mar. Mamm. Sci.*** 21(2): 217-242)

L. Ringed seal (*Phoca hispida*) use of subnivean structures in the Alaskan Beaufort Sea during development of an oil production facility (Williams, M.T., C.S. Nations, T.G. Smith, V.D. Moulton and C. Perham. 2006. ***Aquat. Mamm.*** 32(3): 311-324).

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[1] Copies of eight additional Northstar technical reports issued before 2005 and of five additional journal papers published before 2005 can be found (as Appendices) on the CD-ROM accompanying the Comprehensive Report on work in 1999–2004.

Papers on Cetaceans

ACRONYMS AND ABBREVIATIONS

~	approximately
ACS	Alaska Clean Seas
AEWC	Alaska Eskimo Whaling Commission
AIC	Akaike's Information Criterion
α	in Chapter 5: vector mean bearing (see Fig. 5.2 *in* Chapter 5) in Chapter 6: statistical significance criterion, here usually set to $P = 0.05$.
ANIMIDA	Arctic Nearshore Impact Monitoring in the Development Area
APE	American Piledriving Equipment
ASAR	Autonomous Seafloor Acoustic Recorder
BPXA	BP Exploration (Alaska) Inc.
BWASP	Bowhead Whale Aerial Survey Program
CAA	Conflict Avoidance Agreement
cANIMIDA	Continuation of Arctic Nearshore Impact Monitoring in the Development Area
cm	centimeter (=0.394 inch)
C.F.R.	Code of Federal Regulations
CH	Cabled hydrophone
CI	Confidence Interval
cm	centimeter
DASAR	Directional Autonomous Seafloor Acoustic Recorder
dB	decibel, a logarithmic measure of sound strength
dBA	"A-weighted" decibel scale, for in-air sounds
df	degrees of freedom
DIFAR	Directional Frequency and Recording – a directional sonobuoy
EB / C	DASAR location "EB" (2001–2007) = "C" (2008–2009), 14.9 km (9.2 mi) northeast of Northstar
EIS	Environmental Impact Statement
FLIR	Forward Looking Infra-Red
ft	foot or feet (1 foot = 0.305 m)
FWS	Fish & Wildlife Service
GPS	Global Positioning System
GSC	Geological Survey of Canada
ha	hectare
hp	horsepower (1 hp ≅ 0.75 kW)
hr	hour
HT	Horvitz-Thompson (see Chapter 6)
Hz	hertz, or "cycles per second"; standard measure of sound frequency
in	inch (=2.54 cm)
IHA	Incidental Harassment Authorization
ISI	Industrial Sound Index
ISI_5band	Industrial Sound Index defined as the combined sound level in 5 specific one-third octave bands, centered at 31.5–80 Hz; total bandwidth 28–90 Hz)
ISI_tone	Industrial Sound Index quantifying the presence of tones in a sample of sound
ISI_transient	Industrial Sound Index quantifying the presence of transient sounds (e.g., from a boat) in a sample of sound

ITC	International Transducer Corp.
L	mean vector length (0 – 1 scale): a measure of variability in bearings (see Fig. 5.2 *in* Chapter 5)
LoA	Letter of Authorization
kg	kilogram (= 2.20 lb)
kHz	kilohertz (= 1000 Hz)
km	kilometer (1 km = 3281 ft, 0.62 land miles, or 0.54 n.mi)
knot	nautical mile per hour (1 knot = 1.15 mph or 1.853 km/h or 0.52 m/s)
kW	kilowatt (1 kW ≅ 1.34 hp)
lb	pound (= 0.454 kg)
LoA	Letter of Authorization
m	meter (1 m = 1.09 yards or 3.28 ft)
MHz	Megahertz (=1,000,000 Hz)
mi	land or statute mile (1 mi = 1.61 km or 0.87 n.mi.)
min	minute
MMPA	Marine Mammal Protection Act
MMS	Minerals Management Service, U.S. Dept. of the Interior
NMFS	National Marine Fisheries Service, NOAA, U.S. Dept. of Commerce
n.mi.	nautical mile (1 n.mi. = 1.15 land miles or 1.853 km)
NMML	National Marine Mammal Laboratory (a branch of NMFS)
NOAA	National Oceanic & Atmospheric Administration, U.S. Dept. of Commerce
NRC	National Research Council, (U.S.) National Academy of Sciences
NSB	North Slope Borough
NWCA	Nuiqsut Whaling Captains Association
OBC	Ocean Bottom Cable (a seismic survey technique)
OCS	Outer Continental Shelf
OCSEAP	Outer Continental Shelf Environmental Assessment Program
ODS	Oooguruk Drillsite (Pioneer Natural Resources), offshore from Colville Delta
O/I	offshore / inshore ratio (see Fig. 5.3 in Chapter 5)
OWA	Oil / Whalers Agreement
P	calculated significance level
Pa	Pascal (a unit of pressure which equals 1 Newton/m^2)
PLQ	permanent living quarters
q.v.	*quod vide* = which see
RC	River-class (tugboat)
RL	received level
rms	root mean square (a type of average)
rpm	revolutions per minute
§	Section
s	second
SAC	Science Advisory Committee, North Slope Borough
S.D.	standard deviation
sec	second (usually abbreviated herein as “s”)
SEL	Sound Exposure Level (an energy-based measure)
SID	Spy Island Drillsite (Eni US Operating Co.)
SNR	Signal-to-Noise Ratio

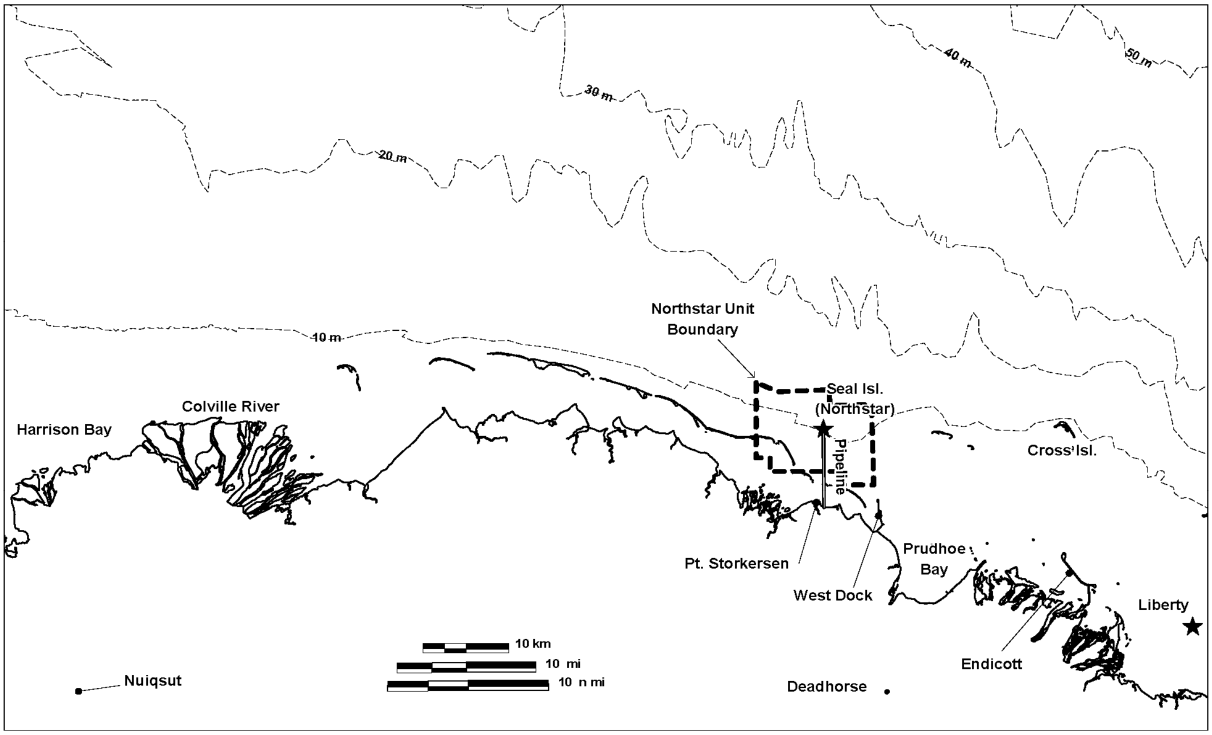
SPL	Sound Pressure Level
SPLTS	Sound Pressure Level Time Series
SPSDL	Sound Pressure Spectrum Density Level
SPTS	Sound Pressure Time Series
SSDC	Single Steel (or Steel Sided) Drilling Caisson; = SDC, Steel Drilling Caisson
TK	Traditional Knowledge
μPa	micropascal, a measure of pressure
USCG	U.S. Coast Guard
USGS	U.S. Geological Survey
USFWS	U.S. Fish & Wildlife Service
yd	yard (= 0.9144 m)

EXECUTIVE SUMMARY

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 on 31 October 2001. The Northstar Development includes production facilities on a gravel island 5 km (3 mi) offshore of the natural barrier islands 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 power generation and field injection. The main activities on the island include oil production, gas injection, and power generation. Also present are a drilling rig, and facilities for waste grind and injection. The production facilities include gas turbine engines to operate power generators and gas compressors. Transportation between the mainland and Northstar is primarily via ice roads in winter, hovercraft and vessels in summer, and helicopters during the transitional seasons. Vessel and helicopter use diminished after BP began using a hovercraft in 2003. The Northstar Development is, to date, the only offshore oil production facility in the Beaufort Sea north of the barrier islands.

This "comprehensive report" was prepared to meet BP's reporting obligations under incidental take regulations and associated Letters of Authorization (LoA) issued by the National Marine Fisheries Service (NMFS). The current regulations are valid for the period 6 April 2006 through 6 April 2011, and a Comprehensive Report is required 240 days prior to expiry of those regulations, i.e., by 9 August 2010. A previous Comprehensive Report addressed BP's activities and monitoring work at Northstar up to 2004. The present report concentrates on BP's Northstar activities and the associated marine mammal and acoustic monitoring projects from 2005 through 2009. However, monitoring work prior to 2004 is summarized, and planned activities at Northstar in 2010 are described.



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

BP's business rationale for the marine mammal and acoustical studies was driven both by corporate values and by regulatory requirements. BP supports studies that objectively assess environmental effects that may result from BP operations. In addition, the monitoring work met BP's obligations under the regulations and LoAs issued by NMFS, and additional BP obligations under a North Slope Borough (NSB) zoning ordinance.

For the 2005 to 2009 period, four major types of monitoring were conducted by BP at and near Northstar:

1. Underwater noise measurements near Northstar, primarily during the bowhead whale migration period in late summer/early autumn;
2. Counts of seals near Northstar, mainly in the late spring/early summer basking period;
3. Acoustic monitoring of the bowhead whale migration in late summer/early autumn;
4. Summarize the subsistence hunt for bowheads at Cross Island, 27 km (17 mi) east of Northstar, and whaler perceptions of industry effects on the hunt.

Additional types of monitoring had been done prior to 2005, including acoustic measurements in winter and detailed studies of seal use of the Northstar area.

The following nine sections of this Executive Summary are summaries of Chapters 2 to 8 of the present report, plus lists of "Key Findings" and "Lessons Learned". The Appendices (on CD-ROM) include complete copies of the related annual reports released since 2005 and of journal papers derived from the Northstar monitoring work published since 2005. All Appendices are in PDF format. These Appendices provide supplementary details in support of various chapters in the printed report.

BP's Activities at Northstar, 2005–2009

In 1999 BP Exploration (Alaska) Inc. (BP) began construction of an offshore island for future oil production on submerged remnants of Seal Island, a man-made island originally constructed in 1982. The new oil development was called Northstar. BP's construction and initial production activities at Northstar, through 2004, were described in an earlier Comprehensive Report. ***Chapter 2*** of this report, by R. Rodrigues and L.A.M. Aerts of LGL Alaska, describes continuing oil production in 2005–2009, along with associated support and maintenance work. A brief description of ongoing and proposed activities in 2010 is also included. This chapter was prepared to meet the regulatory requirement for a description of BP's Northstar activities during the 5-year period covered by the current "Northstar regulations", at 50 C.F.R. §216.200–210, and by annual Letters of Authorization issued by the National Marine Fisheries Service to BP under those regulations.

As in previous years ice roads were constructed to facilitate on-ice transportation during winter and early spring. Ice-road construction began in Nov. or Dec. and the road was generally functional from Jan. until mid- to late May. Standard buses, vans, and pick-up trucks were the primary vehicles used for transportation of personnel and equipment to and from Northstar during that period. Several types of tracked vehicles were also used early and late during the ice-covered period. During the open-water periods, a hovercraft and Bell 212 helicopter were the primary means of transportation of personnel. Crew vessels were also used occasionally and barges were used to transport equipment, supplies, and fuel.

Drilling into oil-bearing strata occurred during the winter months each year but did not occur during break-up or open-water periods. However, well maintenance activities using the drill rig to lower cables down the hole occurred above the formation depth in the 2005 and 2006 open-water seasons.

Four or more aerial surveys were conducted each month to inspect the pipeline between Northstar and shore for leaks or spills. An automated system was also used continuously to detect any pipeline spills. No reportable conditions were recorded using either monitoring method. A number of small spills of various types of material on the island were reported each year. These materials were all cleaned up. No clean up after flare events was required during the reporting period.

Maintenance activities to repair the shoreline protection system (concrete blocks and fabric barrier) occurred during the latter part of the ice-covered period and extended into the open-water period in 2005–2007. Equipment used included a Manitowoc 888 crane, Volvo 150D loader, John Deere 650H excavator, Ingersoll-Rand zoom-boom, air compressors, Chinook 800 and Tioga heaters, and generators.

Repair activities in 2008 involved placement of boulders along the northeast corner of the island during the ice-covered period and some minor repair activities during the subsequent open-water period. Boulders were hauled to Northstar in March and April via the ice road. A Caterpillar 966 loader, Caterpillar 345B excavator, and John Deere 850 dozer were used for boulder placement. In 2009 repairs to the block system and fabric barrier similar to those in 2005–2007 were necessary on the northwest side of the island. Repair techniques and equipment used were similar to those used in 2005–2007.

In 2010 BP began an expansion project in the SE corner of Northstar to accommodate a new operations center scheduled to arrive in 2012. Removal of the drill rig, for which some dredging activity may be necessary, and construction of a water intake system are also planned for 2010.

BP continued acoustic studies each fall to monitor sounds from Northstar and calling bowhead whales during their westward migration. In 2008 BP also deployed sensors on the bottom at three sites to increase knowledge about wave and ice forces affecting the Northstar protection barrier. Retrieval and re-installation of the sensors is planned once a year for 3 to 5 years. In addition to BP's activities, various other industry and agency activities occurred near Northstar during the 2005–2009 reporting period.

Seal Sightings, 2005–2009

During the planning stages of the Northstar project, BP and stakeholders had concerns regarding the potential for activities associated with construction and oil production to result in disturbance to seals and other marine mammals. Authorizations issued to BP for potential "taking" of seals during construction and operation of Northstar required studies and monitoring to assess effects on seals and on subsistence hunting. To satisfy the requirements, BP conducted several studies prior to and during construction and operation of Northstar. Systematic fixed-wing aerial surveys were used to study the distribution and abundance of seals around Northstar. The fixed-wing surveys in 1997–1999 provided three years of pre-development "baseline" data, and surveys in 2000–2002 provided three years data with construction and then oil production activity. To complement the aerial survey program on a finer scale, specially-trained dogs were used to find seal holes and lairs, and to monitor the fate of structures in relation to distance from industrial activities during the ice-covered seasons of 1999–2000 (initial construction) and 2000–2001 (later stages of construction). After these intensive studies were completed, NMFS and stakeholders concurred with BP's conclusion that it was not necessary to continue the types of intensive seal studies that had been done through 2002. However, BP continued to observe and count seals near Northstar to provide assurance that seal use of the area was similar in subsequent years to that found up to 2002.

Chapter 3 of this report, by R. Rodrigues and L.A.M. Aerts of LGL Alaska, describes the results of seal observations from Northstar during 2005–2009. Northstar Environmental Specialists observed and counted seals from the top of the 33 m (109 ft) high process module. The observation period varied among years. Results from the 15 May through 15 July period are reported here to maintain consistency in observation periods for comparisons among years, although 2005 was an exception in that observations did not begin until 3 June. The total number of seals recorded varied considerably from year to year, ranging from three seals in 2007 to 811 in 2009, with no consistent trend across the five years of observations. Relatively few seals were observed in 2006 and 2007 compared to other years, and more seals were recorded in 2009 than all other years combined. The numbers of seals seen during a given day's observation period were highly variable ranging from zero to 124. Seal sighting rates in 2006 and 2007 were relatively low during all half-monthly periods of observation. For the years when the largest numbers of seals were recorded (2005, 2008 and 2009), relatively few seals were recorded in the latter half of June 2005 and in the first half of July 2008. The relatively high number of seals seen per day in July 2005 resulted from a single sighting of 124 seals on an ice floe on 11 July. The larger numbers of seals were generally recorded in groups congregated on ice floes that remained as the sea ice melted. The observations confirm that ringed seals continue to haul out on ice and bask within approx. 1 km (0.6 mi) of Northstar during the late spring and early summer. Numbers that do so vary from year to year, probably as a function of ice conditions.

Underwater Sounds Near Northstar

The objective of ***Chapter 4***, by S.B. Blackwell and colleagues of Greeneridge Sciences Inc., is to report on the levels, characteristics, and range-dependence of underwater sounds produced by industrial activities related to Northstar Island during the open-water seasons of 2001–2009, with emphasis on the period 2005–2009 (which was not covered in the previous Comprehensive Report). Directional Autonomous Seafloor Acoustic Recorders (DASARs) were deployed close to Northstar (~450 m or ¼ mi from the island's north shore) and in an array offshore of the island. In 2001–2004, offshore DASARs were deployed at 10 sites 6.5–21.5 km (4.0–13.4 mi) northeast of Northstar, with 5 km DASAR spacing. In 2005–2007 smaller arrays were deployed with DASARs at 3 or 4 of the same locations used in 2001–2004. In 2008 and 2009, a large array was again deployed, with DASARs in 10 locations 8.6–38.4 km (5.3–23.9 mi) from Northstar and with 7 km DASAR spacing.

Underwater sounds received at a near-island DASAR and a subset of offshore DASARs were analyzed as broadband signals (10–450 Hz) and as one-third octave and narrowband levels over the entire DASAR deployment period each year (~4 weeks, from late August to late September). In addition, three "Industrial Sound Indices" (ISIs) were defined to quantify three different characteristics of industrial sounds: the presence of low frequencies (*ISI_5band*), the presence of tones from machinery (*ISI_tone*), and the presence of transient sounds such as those from vessels (*ISI_transient*). A subset of the 2009 sound data—those collected near Northstar and at one offshore DASAR—are used in the assessment of the effects of industrial sounds on the distribution of bowhead whale calls in 2009 (see Chapter 6).

Median levels of broadband underwater sound near Northstar varied in the range 98.7–105.5 dB re 1 μPa in 2005–2009, compared to 100.5–103.5 dB in 2001–2004. At an offshore location where data were acquired every year from 2001 through 2009 (location EB / C, 14.9 km or 9.2 mi from Northstar), median levels varied in the range 95.4–103.1 dB in 2005–2009, compared to 93.1–96.5 dB in 2001–2004. Median broadband levels of sound near Northstar, calculated over the entire season, were always higher than in the offshore array (location EB / C), by 2.4–7.9 dB in 2005–2009. Spectral composition of Northstar sounds included tones at 30 Hz and 60 Hz every year (2005–2009). The presence of tones in the spectral density levels received at the near-island DASAR was a distinguishing characteristic of Northstar sound. These tones were not found consistently in the recordings from the offshore DASARs.

Based on comparisons of the three industrial sound indices across years, there was a trend towards a smaller contribution of industrial sounds in 2005–2009 compared to 2001–2004: fewer samples containing transients (vessels), fewer samples containing tones, and lower *ISI_tone* levels.

Activities by vessels operating near Northstar produced some of the highest amplitude underwater sounds. During maneuvering by tugs at the island, received levels at the near-island recorder reached 135 dB re 1 μPa and were detectable, in below-average ambient sound conditions, as far offshore as DASAR location E, ~21.5 km (13.4 mi) from Northstar. Sounds from helicopters (tones and their harmonics from the main rotor and tail rotor) were detected near the seafloor for short periods, but only during departures from the island, when the helicopter's flight path was close (< 600 m) to the location of the recorder.

Thousands of airgun pulses were detected on DASAR records during the 2008 and 2009 study periods; these were from seismic exploration unrelated to Northstar. At the most offshore DASAR location (J), ~147,000 and ~65,000 airgun pulses were detected during 29 and 33 days in 2008 and 2009, respectively, with median received SPLs of 105 dB and 98 dB re 1 μPa. At offshore DASAR location C, ~17,000 airgun pulses were detected during 33 days in 2009, with median received SPL 88 dB re 1 μPa.

Acoustic Monitoring of Bowhead whales

One key objective of the Northstar monitoring is to characterize the westward migration of bowhead whales past Northstar during late summer/autumn, and the possible effects of sound from Northstar on that migration. Since 2001, that has been done primarily by detecting and localizing calls from bowheads in waters offshore of Northstar. The specific objectives of ***Chapter 5***, by K.H. Kim and colleagues of Greeneridge Sciences and LGL, are to report on the detection, classification, and localization of bowhead whale calls recorded by the array of directional autonomous seafloor acoustic recorders (DASARs) deployed offshore of Northstar during the autumn migration of bowhead whales in 2005–2009, and to put those results into broader context by summarizing corresponding data from 2001–2004. Specifically, this chapter provides information on year-to-year and within-season variation in the numbers, types, and distribution of calls detected offshore of Northstar, and in their bearings from a location where acoustic data were acquired every late summer/early autumn season from 2001 to 2009.

The number of bowhead whale calls detected via the DASAR arrays and the associated call detection rates varied substantially from year to year and from day to day within each season. Some variation can be attributed to methodological differences among years, especially the different DASAR array configurations in 2001–2004 (10 DASAR locations) vs. 2005–2007 (3–4) vs. 2008–2008 (10, but extending farther offshore). Other sources of variation were the presence of nearshore pack ice in some years (2005, 2006), and differences in mean wind speed (high in 2005, 2007). High winds increase ambient noise levels and tend to reduce call detection rates. Based on data from one location monitored in all 9 years, call detection rates were highest in 2003, 2004 and 2008, intermediate in 2001, 2002, 2007 and 2009, and low in 2005 and 2006. The 2008 season had the highest number of call detections in the history of the study with 85,669 calls detected, resulting in an average of 2914 detected calls/day, and a peak hourly call detection rate of 627 calls in one hour on 20 Sept. 2008.

Percentage use of different call types varied from year to year, but of the four types of simple calls (upsweep, downsweep, constant, and undulations), the upsweep was most common. It comprised 26% of all calls detected in 2001–2009. The four types of simple calls comprised (on average) 84% of calls detected in 2001–2008. In 2009, only 51% of calls were simple (51%); 49% were complex.

Bearings to bowhead calls and the percentage distribution of these bearings were estimated with respect to a consistent location 14.9 km (9.2 mi) offshore of Northstar (EB / C) where there was a DASAR during all nine seasons 2001–2009. In 8 of 9 seasons, the average bearing of whale calls was northeast or east-northeast of this site. In the other year (2005), the bearings were highly variable. The bearings in 2009 were predominantly to the northeast, similar to those in 2001 — both were years when the whale migration corridor was relatively far offshore. In contrast, the majority of the calls detected at location EB / C in 2002–2004, 2007, and 2008 were to the east of that location.

Localized whale calls provided much information about the distribution of calling bowhead whales over the inner and middle part of the continental shelf offshore of Northstar. The localization data, in conjunction with bearings from EB / C, indicated that 2001 and to a lesser degree 2002 and 2009 were years when the migration corridor was relatively far offshore, whereas 2003, 2004, and 2008 were years when the southern part of that corridor was close to shore. The localization data documented pronounced within-season (day to day) shifts in the offshore distances of whale calls. Localization data also showed spatial concentrations of calls, with some concentrations aligned parallel to shore but others aligned in different configurations of unknown significance. Analysis of 2008 data indicated that bowhead whale calls show at least slight directionality (stronger ahead than behind the whale).

Effects on Distribution of Calling Bowheads

Chapter 6, by Trent L. McDonald and colleagues of WEST Inc., LGL, and Greeneridge Sciences, describes an analysis designed to detect effects of underwater sound produced by Northstar Island and its support vessels on the distribution of calling bowhead whales (*Balaena mysticetus*) during their westward autumn migration in 2009. This analysis builds on past analyses of similar 2001–2004 data. Underwater sound levels were measured both near the source and offshore near the southern edge of the migration corridor. Locations of calling whales were determined by a seafloor array of directional acoustic recorders. Weighted quantile regression (QR) was used to relate the 5th quantile of offshore distance (a measure of the southern edge of the call distribution) to varying levels of industrial sounds near and offshore of Northstar, and to measures of airgun pulses from distant seismic exploration. Weights in the primary QR were inversely proportional to estimated location uncertainty and probability of including a call in our data set. To overcome lack of independence among calls, block permutation of uncorrelated call clusters was used to assign significance levels to coefficients in the QR model. Normal within-season variation in the migration corridor's apparent southern edge was accommodated by considering day–night changes, distance of the call east or west of Northstar, and date as covariates. Occurrence and received levels of weak airgun pulses from seismic surveys occurring intermittently >200 km (>320 mi) to the east and north were also considered as covariates. Data were collected from 26 August to 28 September 2009, during which time there were 11,263 usable calls.

Based on the primary analysis, the apparent southern edge of the distribution of calling whales was significantly ($P = 0.011$) closer to shore when underwater sound measured near the southern edge of the overall 2009 call distribution included transients in the 10–450 Hz band during the 75 minute period just prior to the call. The southern edge of the distribution of calling whales was an estimated 1.82 km or 1.13 mi (95% confidence interval 0.72 to 2.77 km) closer to shore when transients were detected offshore than without. That measure of industry sound was a better predictor of the southern edge of the call distribution than was any measure of sound near Northstar itself, and the analysis was structured to allow only one such variable to enter the model. In addition, when received levels of airgun pulses from seismic exploration far to the east of Northstar were above background, the apparent southern edge of the call distribution was another 0.68 km or 0.42 mi (95% CI 0.37 to 0.93 km; $P < 0.001$) closer to shore for every 1 dB increase in received airgun pulse level.

Sensitivity analyses revealed that the measure of Northstar sound most closely associated with the southern edge of call distribution, and possibly even the direction of the apparent effect, depended on analysis decisions and assumptions, including the order in which variables were considered and decisions about case weighting. With one exception, alternative methods of model selection and weighting (like the primary analysis) estimated the southern edge of the call distribution to be *closer* to shore when sound variables associated with Northstar were elevated. However, the specific measure of industrial sound most closely related to call distribution varied among analyses.

Although not specifically designed to characterize effects of airgun pulses on bowhead whale behavior, the primary analysis and all but one sensitivity analysis suggested that the calls nearest to shore tended to be *closer* to shore with increasing received levels of airgun sound arriving from the east. This trend is especially noteworthy as the seismic operation to the east was in Canadian waters, hundreds of kilometers away.

The results for 2009 differ from those obtained during 2001–2004, when the southern edge of the call distribution tended to be farther offshore when anthropogenic sounds, as measured near Northstar, were elevated. Also, sensitivity analyses showed that 2001–2004 results were largely insensitive to weighting and other analysis decisions, although fewer covariates were considered and the order of model selection was not tested in 2001–2004 studies. Reasons for the differences between 2009 and 2001–2004 (and among alternative 2009 analyses) are speculative. In any case, for 2009, we could not conclusively identify one specific relationship between offshore distances of bowhead whale calls and industrial sound.

Subsistence Whaling at Cross Island

The North Slope Borough's Science Advisory Committee (NSB SAC) recommended in 2005 that local and traditional knowledge of Nuiqsut whalers be incorporated into reports concerning BP's Northstar marine mammal and acoustic monitoring program. ***Chapter*** *7*, by Michael S. Galginaitis of Applied Sociocultural Research, does so in large part by summarizing data acquired during the Minerals Management Service (MMS) project "Annual assessment of subsistence bowhead whaling near Cross Island" (2001–present). Those data were supplemented by interviews with the whalers in 2005–2009 focusing on specific aspects of the 2001–2009 whaling seasons relevant to BP's Northstar monitoring program. The interviews concentrated on whalers' encounters or concerns with non-whaling vessels, and the whalers' observations of the general offshore distribution of bowhead whales, whale feeding behavior (if any), and "skittish" behavior. The emphasis in this chapter is on the period 2005–2009, with prior years being discussed only where especially pertinent.

Historically, Cross Island was used periodically as a base for subsistence whaling during the first half of the 20th century (prehistoric use is not well documented). After a hiatus in mid-century, whaling in the general area resumed in 1973 when Nuiqsut was resettled, and a bowhead whale was taken that year near the Canning River. For several years after 1973, relatively few crews from Nuiqsut whaled, and they had infrequent success. Subsequently Cross Island came to be used increasingly as a base, and both the number of crews and hunting success increased, especially in the 1990s. However, in certain years, there were difficulties that the whalers attributed variously to weather, ice conditions, or interference by marine seismic surveys and offshore exploratory drilling operations. At times, whales were perceived as having been deflected offshore by industrial activities east of Cross Island, or to be "spooky" and difficult to approach. Stakeholder discussions of these issues resulted in 1986 in the "Oil/Whaler Agreement" to mitigate and minimize such effects. This mechanism continued (after a lapse of several years with no offshore oil and gas exploration in the Alaskan Beaufort Sea) under the label "Conflict Avoidance Agreement" (CAA). The CAAs, combined with BP Standard Operating Procedures and agency stipulations, have been largely successful in preventing or mitigating Northstar effects on Cross Island whaling.

The variability among the 2001–2009 whaling seasons that was documented by the MMS project was primarily due to differences in ice and wind conditions, differences in the distribution (distance from Cross Island) and apparent local abundance of whales, and variable behavior ("normal" or "skittish") of whales. Year-to-year differences in effort expended by whalers ("boat hours") were fairly well quantified. However, the relationships between variable whaling effort and variability in ice and wind conditions, whale distribution, or whale behavior were not as clear-cut. The ice conditions that occurred during the nine seasons sometimes prevented access to whales altogether but otherwise seemed to have no net effect. Adverse weather conditions hinder whaling, but the shortest seasons were those that were measurably the worst in terms of weather. Perhaps the least ambiguous factor associated with the effort expended per landed whale was the distance of whales from Cross Island, i.e., the distance from Cross Island where whalers found whales. The two were directly related: the greater the distance, the greater the effort. That result is hardly surprising.

Of the anthropogenic activities considered in this chapter, vessel traffic probably had the greatest direct or perceived adverse effects on Cross Island subsistence whaling during 2001–2009, even though precise effects would be difficult to demonstrate in a rigorous way. Vessel effects were almost totally related to non-oil-industry commercial vessel traffic that operates outside the provisions of the CAA. The CAA has effectively managed most industry-whaler potential conflicts, at least in the area of industry-whaler vessel interaction. The problematic vessel interactions, most prominently those of 2005, were all with non-oil-industry vessels not subject to the CAA.

Potential Effects on Marine Mammals and Subsistence

Letters of Authorization (LoA) issued by NMFS to BP annually in 2000–05 and in 2006–09 authorized the "taking" of small numbers of seals and whales incidental to Northstar activities. ***Chapter 8***, by W.J. Richardson et al. of LGL and WEST, summarizes this topic, as required by the regulations and LoAs.

For 2000–04, estimates of numbers of seals potentially affected were made annually, with the most recent estimates being for Nov. 2003–Oct. 2004. In that period, an estimated 61 ringed seals, 1 bearded seal, and probably no spotted seals were close enough to Northstar activities for there to be a possibility of disturbance. Those estimates took account of monitoring results showing no more than highly localized effects on seals. The overwintering seals that were potentially affected probably were limited to those excluded from physically-disturbed areas, including the artificial island and ice road plus a 100 m (328 ft) buffer zone. Estimated numbers of seals potentially affected were less than the numbers of "takes" authorized by the LoAs issued by NMFS to BP. Furthermore, most seals counted as "potentially affected" probably did not incur biologically significant effects. In the present 2005–2009 reporting period, no intensive monitoring was required or done, but ongoing counts of seals visible from Northstar show that ringed seals continue to occupy the area within *ca.* 1 km (0.6 mi) in variable numbers. The overall results suggest that any effects of Northstar production activities on seals are minor, short-term, and localized, with no consequences for the seal populations. The Northstar location is not an area where seal hunting was common before Northstar was built. Insofar as we know, there has been no subsistence hunting of seals there since Northstar was constructed, and availability of seals for subsistence harvest probably was not affected.

Acoustic localization data indicated that, during late summer and early autumn of 2001–2004, some bowhead whales in the southern part of the migration corridor (closest to Northstar) were affected by vessel or Northstar operations. The southern edge of the distribution of calling whales tended to be slightly but (statistically) significantly farther offshore, by an estimated 0.76–2.35 km (0.47–1.5 mi) in the various years, at times with higher levels of underwater sound from Northstar. At these times, most "Northstar sound" was from vessels supporting Northstar, not the island itself. Results from 2009 are equivocal as to how the southern edge of the distribution of calling whales was related to measures of Northstar sound; there were some indications in 2009 that (with elevated underwater noise levels) the closest calls tended to be slightly *closer to*, not farther from, Northstar. In all years, the small shift in the southern edge of the distribution of calling whales was probably partly attributable to a noise-related change in calling behavior rather than actual deflection. Based on guidance in recent reviews as to what effects are biologically significant, migrating bowheads whose paths are deflected offshore (or inshore) by no more than a few kilometers, or whose calling behavior is altered temporarily, would not be expected to incur biologically significant effects. Thus, numbers of bowheads (if any) that were truly "harassed" by Northstar would be, at most, low and presumably well within provisions of the Northstar regulations and associated LoAs. Those authorized up to 765 harassment "takes" annually (or 1533 in 2 years or 3585 in 5 years) during the most recent years when a specific number of "takes" was authorized.

The bowhead monitoring results do not explicitly show how far east the slight "deflection effect" extended, and in particular, whether it extended east into waters where Nuiqsut whalers commonly hunt bowheads. However, during 2005–2009, the Nuiqsut whalers struck 3 or 4 bowheads (of their annual quota of 4) during each autumn except 2005, and the whalers did not attribute their problems in 2005 to Northstar.

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 Northstar drilling, production or ancillary operations in 2005–09. Gray whale sightings have been infrequent this far to the east, and it is likely that no gray whales were affected by Northstar activities. For belugas, estimated numbers that might approach within an assumed 1–2 km (0.6–1.2 mi) disturbance radius are 10–20 in an average year.

Key Findings

BP's Activities at Northstar

- Oil production and gas injection have been ongoing almost continuously since 31 Oct. 2001.
- General types of transportation during 2005–2009 were similar to those used during earlier construction periods including standard vehicles on ice roads during winter, tracked vehicles prior to completion of the ice road and again during spring break up, crew vessels (infrequent since 2004), hovercraft (primarily from late spring to freeze up), and helicopters.
- Drilling into the oil-bearing strata occurred during the ice-covered period but did not occur during summer months from 13 June until 18 inches (0.47 m) of continuous ice had formed to 1.5 mi (2.4 km) in all directions from Northstar.
- Periodic aerial monitoring and continual remote monitoring did not detect any oil leaks or spills from the sub-sea pipeline.
- Maintenance activities initiated in 2003 to repair the block system around the island were ongoing through 2009 and into 2010.
- Acoustic studies initiated in 2000 to document underwater and in-air sounds from Northstar and to monitor the westward bowhead whale migration were ongoing through 2009

Seal Sightings

- During Northstar construction and initial production operations up to 2004, seals did not appear to be affected by island construction and activities on the island, including impact pipe driving.

- During spring 2005–2009 seals, were again observed within 950 m (0.6 mi) from Northstar when production was ongoing.
- Differences among years (2005–2009) in the numbers of seals observed were likely due largely to varying ice conditions.
- The highest seal counts were generally recorded from mid-June to mid-July when seals aggregated on ice floes.

Underwater Sounds Near Northstar

- Median levels of broadband (10–450 Hz) underwater sound, as recorded in 2005–2009, were in the range 98.7–105.5 dB re 1 µPa when measured ~450 m from Northstar and 95.4–103.1 dB at a location (EB / C) 14.9 km (9.2 mi) away.
- Levels of ambient sound underwater were strongly related to wind speed.
- Industrial sounds tended to contribute less of the sound in the 10–450 Hz band during 2005–2009 compared to 2001–2004: fewer sound samples containing transients (sounds from vessels) or prominent tones, and levels of sound from tones tended to be lower.
- Vessels produced some of the highest amplitude sounds associated with the Northstar Development.
- Sounds from helicopters were detected near the seafloor for short periods, but only when the helicopter's flight path was close to the location of the recorder.

Acoustic Monitoring of Bowhead Whales

- The number and detection rate of bowhead whale calls at monitoring locations on the inner- and middle shelf varied substantially within each season due to variation in ambient noise levels, the effect of nearshore pack ice and other unknown factors on the location of the whale migration corridor that day, seasonal progression of the migration, day/night effects, and (probably) day-to-day variations in numbers of bowheads passing Northstar.
- The number and detection rate of bowhead calls also varied substantially from year to year due to methodological considerations (differences in DASAR array configuration), variation in seasonal average wind speed, and the effects of ice and other unknown factors on the location of the whale migration corridor.
- Simple call types comprised, on average, 84% of calls detected in 2001–2008, when the upsweep was most common, but only 51% of calls detected in 2009 (i.e., 49% of calls detected in 2009 were complex calls).
- In 8 out of 9 seasons during the 2001–2009 period, bearings to whale calls detected at a site 14.9 km (9.2 mi) offshore of Northstar were predominantly to the northeast or east-northeast of that location; 2005 was the exception with highly variable bearings.
- Localized whale calls indicate that the migration corridor was relatively far offshore in 2001 and to a lesser degree in 2002 and 2009, and close to shore in 2003, 2004, and 2008. Localized calls were spatially concentrated for largely unknown reasons.
- Analysis of 2008 data demonstrated that bowhead whale calls are directional (stronger ahead of than behind the whale). This explains, at least in part, why fewer calls are detected west of the Northstar array than east of it.

Northstar Effects on Distribution of Calling Bowheads

- In five autumn migration seasons (2001 to 2004 and 2009), locations of calling whales were examined relative to fluctuations in the sound emitted by Northstar and its support vessels. Simple inspection of maps of whale calls detected at times with higher vs. lower sound levels showed no conspicuous difference in the distributions of bowhead calls in relation to sound.
- Nonetheless, each year from 2001 to 2004, the southern edge of the distribution of bowhead calls tended to be slightly but statistically significantly farther offshore when the underwater sound level near Northstar increased above baseline values.
- In 2009, there again appeared to be an effect of fluctuating Northstar sound (especially as measured offshore) on the southern edge of the migration corridor, but the direction of the apparent effect depended on how the analysis was conducted. For 2009, unlike 2001–2004, we could not conclusively identify one specific relationship between offshore distances of bowhead whale calls and industrial sound.
- In 2009, when airgun pulses from a seismic operation far to the east were received above background levels, the southern edge of the call distribution was estimated to be an additional 0.68 km (0.42 mi) closer to shore for every 1 dB increase in received airgun pulse level.

The 2005–2009 Subsistence Whaling Seasons

- The 2001–2009 whaling seasons, and more generally the 2001–2009 seasons, all differed in terms of ice and wind conditions, whale distribution, whale behavior, hunting effort, and hunting success. The most consistent relationship was between the distance from Cross Island where hunters encountered whales and hunting effort (measured as boat hours per whale struck or landed). The further the whales from Cross Island, the greater the effort expended per whale struck.
- Years of low success (1 or 2 whales landed) were due to adverse conditions throughout most or all of a given season. In 2005 there was almost no access to whales because ice conditions confined whaling boats inshore of the barrier islands, while the whale migration was seaward of the barrier islands. In 2009, whales were encountered relatively far from Cross Island, in relatively low numbers, and wind and sea state conditions were generally marginal and made sighting whales on most days very difficult. The presence of commercial (non-oil industry) vessel traffic may also have contributed to low whaler success in these years.
- Years of greater whaler success (3 or 4 whales landed) often included periods of adverse whaling conditions, but also included favorable periods of varying lengths. The closer to Cross Island that whales were encountered, the less the hunting effort required per whale struck.
- Of the potential anthropogenic effects addressed in this study, vessel traffic likely had the greatest direct or perceived adverse effects on Cross Island subsistence whaling during 2005–2009 (and 2001–2009). However, precise effects are difficult to demonstrate in a rigorous way.
- Vessel traffic that interacted with the hunt was almost entirely commercial traffic not associated with the oil industry and operated outside of the provisions of the Conflict Avoidance Agreement between the whalers and the oil industry.

Lessons Learned (or Re-Learned)

This section is a list of some of the “lessons learned” during the Northstar monitoring work over the past decade. Many of these points were (or should have been) well known in advance, but were reinforced by experience during the project.

Acoustic Field Methodology

- Grappling is both a cost-effective and an extremely reliable method for instrument retrieval in the shallow waters offshore of Northstar as compared to popular approaches such as the use of acoustic releases.
- A 7-km spacing between DASARs is sufficiently close for detecting bowhead whale calls on multiple units for localization, allowing greater coverage of the whale migration corridor than achieved with closer spacing.
- Instrument mounting frames that prevent the DASAR from moving or turning on the seafloor (e.g., square base instead of circular base; base that digs into the mud for stability) are important to obtain uninterrupted data sets of high quality.
- Because of bottom currents near the Beaufort seafloor, shrouds are necessary to shield the DASAR sensors, and these shrouds must be acoustically transparent.
- Redundancy of some specific instruments is a high priority if they provide data critical for interpretation or critical for maintenance of a long-term time series.

Analysis and Interpretation — Physical Acoustics

- Direct measurements of received sound levels at different distances from a source are often used to estimate source level. Even so, determining a "source level" requires compromises, assumptions, and strict definition as to what is meant by "source level". This is especially true when dealing with shallow water propagation and with sounds that originate in air, on land, or in the seafloor.
- To interpret sounds from and biological responses to an industrial activity, information about the industry activities may be needed from many individuals who are not part of the science team. Finding cooperative individuals who are good sources for information is challenging.
- Because acoustic terminology is confusing to the lay reader and can be ambiguous even among acousticians, it is important to use precise language and standardized methods when reporting sound levels.

Analysis and Interpretation — Bioacoustics

- Although passive acoustic detection and localization of whale calls increases sample size compared to visual methods and, hence, increases the statistical power of analyses, acoustic methods have their own limitations: dependence on vocalizing by animals, inconsistent detection range, challenges in managing and analyzing large quantities of acoustic data, lack of statistical independence of calls spaced closely in time or space, etc.
- As a corollary to the above, a change in the distribution of calls may or may not mean that the distribution of the animals has changed.
- Call directionality can affect the interpretation of a given distribution of call locations.

- The precision of call localizations computed via triangulation varies tremendously with distance from the recorders and this needs to be considered in analyses. Differential precision of locations can sometimes be accounted for by using a weighting factor or by limiting the study area to an area where precision is high and more or less constant.

Statistics

- Relatively subtle effects can be uncovered using multivariate analysis to allow for natural and confounding effects before assessing the response of interest. However, caution and special procedures are needed if there is lack of independence among some units of observation, or if some potential predictor variables are correlated, or if there are interactions among predictors.
- Block bootstrapping is a useful statistical technique for controlling problematic effects of dependencies on P-values and confidence intervals.
- Quantile regression is a useful and under-utilized technique for explaining changes in the shape of a distribution that might not be experiencing changes in central tendency.
- Probability of detecting and localizing a call varies with distance, background sound level, and direction (due to directionality of calls). Differential probability of detection and localization can have ill effects on statistical inferences, if left unaccounted for. It can be accounted for by limiting the size of the study area or developing a weighting factor similar to the approach used in line transect analyses.
- It is necessary to account for whale call localization uncertainties in analyses of spatial distribution, but how best to do so remains under debate.
- Many options and decisions are involved in a complex analysis, and every knowledgeable analyst or reviewer has different ideas about the best approach. In this situation, it is important to determine, via sensitivity analyses, whether alternative analysis approaches lead to differences in the final results.

Nuiqsut Subsistence Whaling

- Anthropogenic activities reported or perceived by the whalers to have most significantly affected Nuiqsut subsistence whaling in the past have been to the east of the whaling activities. Northstar is west of the area where almost all Nuiqsut subsistence whaling activities occurred during 2001–2009. The whalers did not perceive Northstar to have had any significant effects on Cross Island whaling during 2001–2009, although noise and potential oil spills are still of concern.
- Northstar is located in an area historically used for subsistence whaling, especially when ice and/or fog prevent access to whales northeast of Cross Island. One whale was struck and killed near the present location of Northstar in 1997 under those precise conditions. Whalers currently avoid the Northstar area, due to noise and visual impact of the development there. This did not significantly affect the success of the 2001–2009 whaling seasons, but could reduce success in a year with conditions similar to those of 1997.
- Any anthropogenic activities, whether related to the oil industry or not, with the potential to displace whales further from Cross Island, or to disturb their behavior, have the potential to significantly reduce the success of the hunt. Such activities are more likely to produce significant effects on subsistence whaling if they occur to the east of Cross Island than if they (like Northstar) are to the west.

CHAPTER 1:

INTRODUCTION [1]

by

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BACKGROUND

BP Exploration (Alaska) Inc. began constructing the Northstar offshore oil production facility during early 2000, and began producing crude oil from Northstar on 31 October 2001. The Northstar unit extends from 3.2 to 12.9 km (2 to 8 miles) offshore from Point Storkersen, northwest of the Prudhoe Bay industrial complex (Fig. 1.1). The production facilities are on an artificial gravel island about 5 km (3 mi) offshore of the natural barrier islands. Northstar is 87 km (54 mi) northeast of Nuiqsut, the closest Inupiat community, and it is 27 km (17 mi) east of Cross Island, where the Nuiqsut subsistence whalers are based for their autumn hunt for bowhead whales.

The Northstar production facilities (Fig. 1.2) were built on the remnants of Seal Island, an artificial island constructed in 1982 by another oil company. Seal Island was used for exploration drilling during the 1980s, and subsequently abandoned until rebuilt by BP in early 2000. 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 and power generation. In winter and early spring, the island is connected to the shore by an ice road from West Dock. The facilities on the island include prefabricated modules for living quarters, utilities, and warehouse/shop. Also present are a drilling rig, facilities for grinding and injecting wastes, and facilities for oil production and gas injection. The production facilities include gas turbine engines to operate power generators and gas compressors. Transportation between the mainland and Northstar is primarily via the ice road in winter, conventional vessels and (since 2003) a hovercraft in summer, and helicopters during the transitional seasons and (to a lesser extent) in summer.

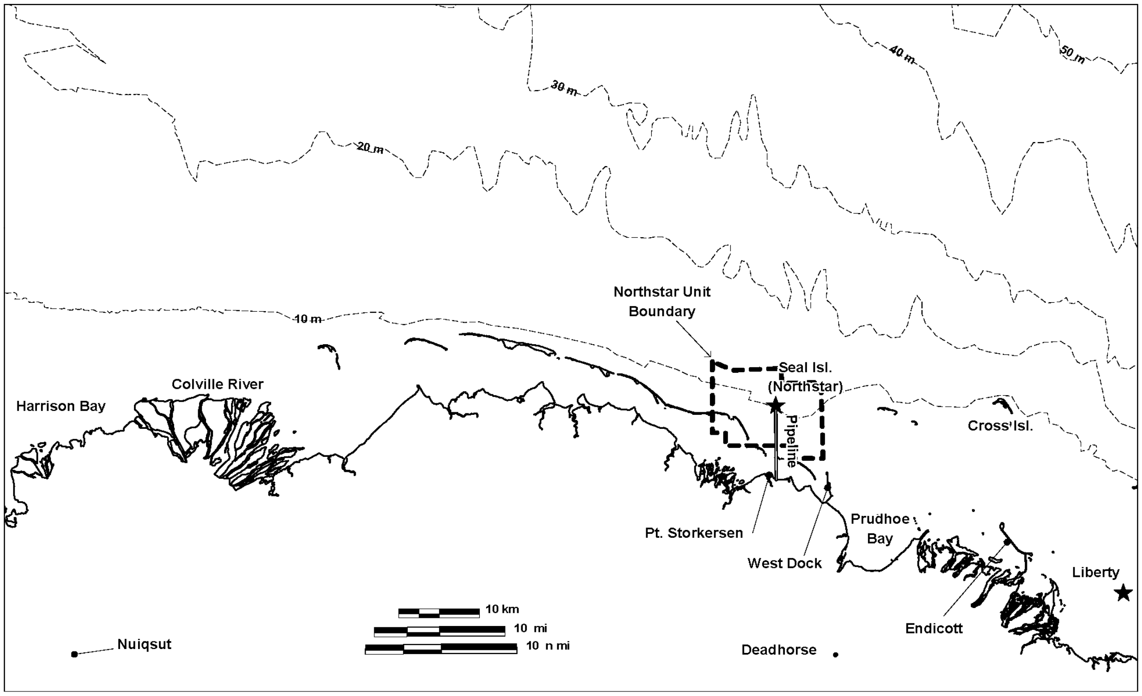

FIGURE 1.1. Location of the Northstar Development in the central Alaskan Beaufort Sea.

FIGURE 1.2. The Northstar Development, as it appeared in 2009, looking from north to south (photo: Wm. C. Burgess, Greeneridge Sciences Inc.)

Oil production, intermittent drilling and well maintenance have continued at Northstar from late 2001, when production began, to the present. Chapter 2 of a previous Comprehensive Report (Richardson [ed.] 2008) provided a detailed description and chronology of the construction and initial operations at Northstar, through early 2005, with photographs of several key facilities and activities. Chapter 2 of the present report describes BP's Northstar activities from the winter of 2004–05 to the present time.

This report as a whole describes BP's Northstar activities and the associated marine mammal and acoustic monitoring projects during the 2005 through 2009 period. It has been prepared to meet the reporting requirements of the regulations issued by the National Marine Fisheries Service (NMFS) in March 2006 concerning effects of Northstar on marine mammals during the period 6 April 2006 through 6 April 2011 (50 CFR 216.206). Those regulations require that BP provide "a final comprehensive report on all marine mammal monitoring and research conducted during the period of these regulations … at least 240 days prior to expiration of these regulations…" (i.e., in August 2010) if renewal of the regulations is being requested. Although the current regulations require BP to report in August 2010 on activities and monitoring subsequent to issuance of the regulations in April 2006, this report also describes BP's Northstar activities during 2005 and early 2006 in some detail. Because the previous 5-year regulations expired in May 2005, the previous Comprehensive Report did not provide much information about BP's activities or monitoring after early 2005. This report includes the intervening period in 2005–06. It does not address BP's activities or monitoring studies prior to May 2005 in the same detail as it addresses the more recent activities and monitoring, but it does include frequent references to the earlier work to provide context and a better understanding of the overall monitoring results.

The contents and organization of this comprehensive report, and its relationship to previous reports and journal publications concerning the Northstar monitoring work, are further summarized later in this Chapter.

BP BUSINESS RATIONALE FOR THE NORTHSTAR MONITORING PROGRAM

BP's business rationale for the marine mammal and acoustical studies summarized in this report, and in the previous Comprehensive Report on work up to 2004, 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. BP recognizes the need for industry to take a proactive role in conservation and biodiversity issues (BPXA 2003). This drives the design and implementation of studies intended to understand and minimize the effects of BP operations. In addition, monitoring and reporting were required to satisfy BP's commitments under incidental "take" authorizations issued by NMFS to BP, and under a North Slope Borough (NSB) zoning ordinance.

During the present reporting period from 2005 to date, four main types of monitoring work were conducted each year. These satisfied NMFS and NSB requirements for acoustical measurements, whale and seal monitoring, and documentation of the subsistence whale hunt at Cross Island (near Northstar). This monitoring work was required by • the incidental take authorizations issued by NMFS and • BP's agreements with the NSB. Those authorizations and agreements also required BP to provide reports describing BP's activities and monitoring studies:

- The general requirements administered by NMFS flow from the provisions of the Marine Mammal Protection Act (MMPA), which prohibits "taking" of whales and seals, including disturbance, unless a specific authorization for incidental "taking" has been issued by NMFS. BP requested and received the appropriate authorizations from NMFS. Those authorizations required monitoring and reporting on an annual basis and, toward the end of the 5-year period, in the form of this Comprehensive Report.
- The zoning ordinance issued by the NSB to BP for construction of Northstar also included requirements for some types of monitoring, particularly of bowhead whales (see below).
- The NSB's Science Advisory Committee (SAC) reviewed BP's monitoring program in early 2005, and recommended that the program incorporate local and traditional knowledge of subsistence whalers from Nuiqsut. They hunt for bowhead whales near Cross Island, 27 km (17 mi) east of Northstar, each autumn. That element was added to the monitoring program in 2005 and has continued in each subsequent year.

The NSB's zoning ordinance for Northstar (Ordinance Serial No. 75-6-38) called for a monitoring program that includes

- "documentation of the noise put into the water by island activities (in particular frequency spectrums and received levels at various distances from the island…;
- "distribution of fall migrating bowhead whales within something like 15–20 miles of the island. The monitoring should exist for as many years as needed to clearly show that there is no impact; and
- "design of the monitoring program and draft of the final report shall be subjected to peer review. Peer reviewers shall include representatives of the NSB and AEWC [Alaska Eskimo Whaling

> Commission]. The monitoring program and report shall be modified in accord with peer reviewer's comments."

The acoustical, marine mammal and subsistence studies described in this and prior reports, along with resulting papers in scientific journals, meet the requirements of the authorizations issued by NMFS, the NSB zoning ordinance, and other agreements with the NSB relating to the SAC review.

CHRONOLOGY OF MARINE MAMMAL AUTHORIZATIONS

Well before the start of Northstar construction, BP, 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 MMPA. Disturbance of seals and whales by certain operations of the offshore oil industry had been documented previously (Richardson et al. 1995). Consequently, in August 1998, BP requested that NMFS issue an Incidental Harassment Authorization (IHA) under section 101 (a) (5) (D) of the MMPA, to authorize disturbance to small numbers of seals and whales during initial construction activities that were then planned for 1999. Also, in November 1998, BP requested that NMFS promulgate regulations allowing for the issuance of Letters of Authorization (LoA) under section 101 (a) (5) (A) of the MMPA to allow "taking" of small numbers of seals and whales during a subsequent five-year period of construction and initial operations. An interim IHA was issued on 15 March 1999.

The Regulations that had been requested by BP were issued by NMFS on 25 May 2000 and were effective for 5 years (NMFS 2000). A series of five LoAs were issued under those regulations (Table 1.1). Those LoAs authorized potential "taking" of whales and seals incidental to construction, production, and maintenance operations during various periods up to 25 May 2005, the end of the 5-year period. BP's activities and monitoring work during that period were described in a previous Comprehensive Report, several versions of which were issued over the period from July 2004 through March 2009 (see Richardson [ed.] 2008).

On 30 August 2004, BP requested that NMFS renew the authorization to "take" whales and seals by harassment during continued Northstar operations over a second 5-year period, from 26 May 2005 through 25 May 2010 (NMFS 2004). BP also requested that NMFS issue an LoA effective 26 May 2005 to cover any "taking" during the initial portion of this second 5-yr period. Renewed regulations were issued on 7 March 2006 (NMFS 2006), and the first LoA under those regulations was issued on 7 July 2006. That and three subsequent LoAs (Table 1.1) provided the appropriate incidental take authorizations for periods up to 6 July 2010. On 30 April 2010, BP requested that NMFS issue a fifth and final LoA under the existing regulations to extend the incidental take authorization to 6 April 2011 when the current regulations expire.

During the interim period after expiry of the initial regulations on 25 May 2005 and prior to issuance of the renewed regulations on 7 March 2006, Northstar operations, monitoring and mitigation continued in a manner consistent

- with the provisions of the initial regulations, and
- with decisions reached at the 2005 Beaufort Sea open-water peer review meeting (convened by NMFS in May 2005) regarding monitoring and mitigation to be done in the ensuing months.

The present Comprehensive Report describes BP's activities (Chapter 2) and monitoring studies (Chapters 3–7) during that interim period as well as during the period since 7 March 2006 while the current regulations have been in place.

TABLE 1.1. Overview of BP requests to NMFS seeking IHAs, Regulations and LoAs to allow "taking" of small numbers of marine mammals incidental to BP's activities at Northstar, and summary of the authorizations issued by NMFS.

Date	BP Request or Regulatory Activity
Aug. 1998	BP applied for an IHA from NMFS
Nov. 1998	***BP requested NMFS to promulgate regulations allowing for issuance of LoAs***
15 March 1999	NMFS issued interim IHA for construction phase
25 May 2000	**NMFS issued Regulations, effective from 25 May 2000 to 25 May 2005**
18 Sept. 2000	First LoA issued to BP for Northstar construction, effective until expired 30 Nov. 2001
14 Dec. 2001	Second LoA issued to BP, effective until 30 Nov. 2002
9 Dec. 2002	Third LoA issued to BP, effective until 30 Nov. 2003
4 Dec. 2003	Fourth LoA issued to BP, effective until 3 Dec. 2004
30 Aug. 2004	***BP requested renewal of the Regulations and LoA***
6 Dec. 2004	Fifth LoA issued to BP, effective until 25 May 2005
7 March 2006	**NMFS renewed Regulations, effective from 6 April 2006 to 6 April 2011**
7 July 2006	NMFS issued initial LoA under the new Regulations, effective until 6 July 2007
7 July 2007	Second LoA issued to BP, effective until 6 July 2008
1 July 2008	Third LoA issued to BP, effective from 7 July 2008 until 6 July 2009
18 June 2008	Fourth LoA issued to BP, effective from 7 July 2009 until 6 July 2010
28 Oct. 2009	***BP requested renewal of the Regulations and LoA***
30 April 2010	Fifth LoA requested by BP, for the period until 6 April 2011

On 28 October 2009, BP submitted a request that NMFS renew the regulations for a third 5-year period, i.e., from April 2011 through April 2016. Submittal of the current draft comprehensive report satisfies one of the requirements for renewal of the current regulations.

NORTHSTAR MONITORING TASKS

Incidental take authorizations normally require studies or monitoring to assess the nature, amount, and geographic extent of any "taking" that did occur, and associated effects on any subsistence hunting (Swartz and Hofman 1991; NMFS 1996). BP's 1998 petition for regulations, supplemented by a 1999 update of that petition and subsequent detailed monitoring plans, proposed several types of monitoring studies during both the ice-covered and the open-water seasons. The study design and results of some or all the projects were reviewed by a peer-review and stakeholder group convened by NMFS at least once each year from 1998 through 2009. An updated monitoring plan was submitted when BP petitioned NMFS for renewal of the 5-year regulations after the initial regulations expired in May 2005. Updates to that monitoring plan have been included in the requests for LoAs submitted each year since 2006.

Monitoring in 1999 to 2004

The monitoring studies conducted in the early years of the Northstar project (Table 1.2) were designed to assess whether effects on seals and whales were limited to behavioral disturbance and/or localized displacement, the nature and extent of such effects, whether effects on these mammals and their populations were negligible, and whether there were 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. Monitoring of marine mammals under the provisions of

TABLE 1.2. Summary of results of individual studies comprising the Northstar marine mammal and acoustic monitoring program, 1999–2004.

1. Fixed-wing aerial surveys of ringed seals (LGL)	Observed ringed seal densities on landfast ice in spring ranged from 0.39 to 0.83 seals/km^2 during 6 years (1997–2002). Multivariate analysis showed no evidence that construction, drilling, or production activities at Northstar affected ringed seal abundance or distribution. The results provided high statistical power to detect such an effect had it occurred.
2. Studies of seal structures in sea ice (LGL)	
(a) Use of avalanche probes to locate ringed seal breathing holes	The study confirmed that this method was not useful for detecting seal structures.
(b) Ringed seal utilization of holes and lairs found through use of trained dogs.	The proportion of seal structures abandoned during the course of the winter and spring was not related to distance from Northstar or the ice road.
(c) Persistence of structure use as determined by temperature sensors	Temperature sensors were used to determine dates of abandonment of breathing holes and lairs. Statistical analysis showed no reduction in length of time a structure was used for structures close to Northstar activities.
3. Helicopter survey of seal breathing holes (LGL)	Surveyors concluded that the temporal window to perform this type of survey was quite narrow and unpredictable, and this survey method was not practical for detecting active and abandoned structures reliably.
4. Acoustic measurements during winter (Greeneridge Sciences)	Sound levels at Northstar during winter were highest during initial construction (2000), intermediate during drilling, and lowest during production. Broadband underwater sounds were detectable above background levels to variable distances, typically a few kilometers. Broadband in-air sounds were sometimes detectable to 5–10 km, but this distance was often much reduced by wind.
5. Sound measurements during July, Aug., Sept. (Greeneridge Sciences)	Vessels (crew boats, tugs, and self-propelled barges) were the main contributors to underwater sound near Northstar, and were at times detectable above background levels as much as 30 km offshore. Island sounds during construction, and especially during drilling and production, were weaker than vessel sounds, and generally not detectable above background beyond 2–4 km in either water or air. Island sound levels showed more variation during construction than during drilling and production.
6. Island-based visual monitoring (LGL)	The only observed reactions of ringed seals to Northstar activities (including impact pipe-driving) during break-up and open-water seasons were minor reactions to some helicopter flights.
7. Bowhead migration monitoring (Greeneridge Sciences, LGL, and WEST)	At times in autumn 2001 to 2004 when higher-than-average levels of underwater sound (much of it from support vessels) emanated from Northstar, the southern edge of the distribution of calling bowhead whales near Northstar tended to be slightly farther offshore. The 2001–2004 acoustic data did not allow us to determine whether this tendency represented noise-induced offshore deflection, a noise-induced change in calling rate, or a combination of the two. However, there were indications of Northstar sound effects on certain attributes of the whale calls themselves.

the NMFS incidental take authorization process began in 1999, and has continued during each successive year. Initial baseline studies of seals in the Northstar area began in 1997, before any incidental take authorizations were in place.

Some of the key aspects of the monitoring were use of innovative, adaptive techniques, and use of statistically powerful study designs. For example, during the ice-covered season, one method used to study ringed seals involved intensive, replicated, fixed-wing aerial surveys of basking seals. This approach was applied in six consecutive spring seasons, including three years prior to Northstar construction (1997–99) as well as three subsequent years (2000–02) (Moulton et al. 2002, 2005). Another of the techniques used to study seals was the intensive application of specially trained dogs to find seal holes and lairs, and monitor their fate over the course of the winter, in relation to distance from industrial activities. This approach was applied during the winters of 1999–2000 and 2000–01 (Williams et al. 2006). To ensure compliance with NMFS requirements concerning exposure of seals to strong sounds, a specific study of sounds from pile-driving, exposure of seals to those sounds, and reactions of the seals was undertaken (Blackwell et al. 2004b).

For the open-water season, BP proposed a novel acoustic localization method to monitor the bowhead migration. This approach was approved by NMFS and the stakeholders, developed in 2000, and applied successfully in 2001, 2002, 2003, and 2004 (Greene et al. 2004; Blackwell et al. 2007; McDonald et al. in review). Directional Autonomous Seafloor Acoustic Recorders (DASARs) were developed and widely applied to localize calling bowhead whales. In modified forms, acoustic localization continued in 2005–2009, as documented in the present report.

The results from the 2001–2004 acoustic localization study of the bowhead migration past Northstar were described in detail in several chapters of the previous Comprehensive Report (Richardson [ed.] 2008), in a descriptive paper by Blackwell et al. (2007), and in other forthcoming papers. As summarized in the last section of Table 1.2, at times in autumn 2001 to 2004 when higher-than-average levels of underwater sound (much of it from support vessels) emanated from Northstar, the southern edge of the distribution of calling bowhead whales near Northstar tended to be slightly but significantly farther offshore. The 2001–2004 acoustic data did not allow us to determine whether this tendency represented noise-induced offshore deflection, a noise-induced change in calling rate, or a combination of the two. However, there were indications of Northstar sound effects on certain attributes of the whale calls themselves.

In addition to these and other biological studies, extensive physical acoustic measurements have been obtained during both the ice-covered season (winter–spring; Blackwell et al. 2004a; Greene et al. 2008) and the open-water season (summer–autumn; Blackwell and Greene 2005, 2006). Acoustic data were needed as a basis for evaluating the results of seal and whale studies in the context of their exposure to Northstar sounds.

The objectives, methods, results and significance of these early studies at Northstar were described in detail in the aforementioned published papers, the first Comprehensive Report (Richardson [ed.] 2008), and in earlier reports included as electronic Appendices to the first Comprehensive Report. Those studies in 1999 to 2004 (plus aerial surveys of seals as far back as 1997) are briefly summarized in Table 1.2.

Monitoring in 2005 to 2009

The 5-year regulations issued by NMFS for the April 2006 through April 2011 period require that BP implement the monitoring required by the individual LoAs issued under those regulations. However, the regulations do not specify the particular types of monitoring to be done (NMFS 2006). The specific requirements are set out in the annual LoAs and in BP's agreements with the NSB.

1. Underwater and In-Air Noise Measurements

Underwater sounds near Northstar during construction, drilling, and production were documented during the previous 5-year period (2000–2004). This included measurements under the ice in winter/spring and in open water during summer/early autumn. In-air sounds and (during the ice-covered season) iceborne vibrations were often measured simultaneously with underwater sounds. Also, during the 2001–2004 autumn migration seasons for bowhead whales, the characteristics and variability of underwater sounds approximately 450 m (¼ mi) seaward of Northstar were monitored essentially continuously.

In the present 2005–2009 reporting period, the LoAs required BP to continue to measure sounds produced by activities associated with oil-production. Each year, underwater sounds ~450 m (¼ mi) seaward of Northstar were again monitored essentially continuously for ~1 month during the late summer/early autumn period (the early and middle portion of the bowhead whale migration season). The objectives included

- identifying and characterizing any new or altered types of underwater sounds to which bowhead whales could be exposed,
- determining whether Northstar sounds were consistent or changing from year to year, and
- providing acoustic data needed to assess whether the bowhead whale migration was affected by fluctuating levels of Northstar sound.

This consistent annual monitoring of underwater sounds near Northstar showed that some new sound types became evident in certain periods. Chapter 4 of this report summarizes the underwater sound data from the near-Northstar station during each year in the current 2005–2009 reporting period, and compares those results with corresponding data from 2001–2004.

Near-continuous measurements of underwater sound were also obtained during the same ~1 month period each year at a series of sites that were (in 2008–2009) as much as 38 km (24 mi) offshore of Northstar. Acoustic data from the offshore stations provided additional information on attenuation of Northstar sound as a function of distance from the island. Also, the offshore acoustic data from 2009 were used in evaluating potential effects of industrial sound on migrating bowheads (see Chapter 6).

Measurements of in-air sounds were generally not required or conducted during the current reporting period. However, the LoAs required that BP document levels, characteristics, and transmission of airborne sound if expected levels at the water's edge could exceed 90 dBA (re 20 µPa) and if the specific sound source had not been measured in previous years. In March–April 2008, heavy construction equipment was used to deposit boulders onto the slope around the island for ice-protection purposes, and measurements of airborne sound were obtained (see Appendix A *in* Aerts and Richardson 2009). Most if not all in-air sounds generated by boulder placement were below 90 dB re 20 µPa.

2. Ringed Seals

Intensive aerial surveys and on-ice studies during the 1997 to 2002 period demonstrated that Northstar had very little effect on the distribution or numbers of seals around Northstar during winter and spring. There was also no discernible tendency for earlier abandonment of seal holes and lairs near Northstar vs. farther from Northstar. The distance from Northstar facilities within which seals were displaced was limited to no more than 100–200 m, and was essentially coincident with the area where ice and snow conditions were physically altered.

Based on these results, NMFS, peer reviewers and stakeholders agreed that detailed monitoring of seals was not required after 2002. Incidental sightings of seals by Northstar personnel were tabulated for the 2003–2004 period and summarized in Chapter 3 of the previous Comprehensive Report, but this did not constitute formal monitoring. For the 2005–2009 period, the LoAs did not include a specific requirement for routine monitoring of seals. However, BP proposed that personnel based on Northstar Island would, during the spring/early summer period when ringed seals haul out on the ice, conduct near-daily (weather permitting) systematic counts of seals visible from a high vantage point at Northstar. This was expected to provide a basis for recognizing any major change in seal use of the area. Results of these counts during the five years from 2005 to 2009 were reported in "Annual Summary Reports", included as Appendices B–F on the CD-ROM accompanying this report. Those counts are also included and summarized in Chapter 3 of the present report.

The LoAs issued to BP by NMFS for recent years have required on-ice dog-assisted searches for seal structures and associated mitigation if BP's ice-road or other construction activities moved onto previously undisturbed landfast ice after 1 March, i.e., during the season when ringed seals give birth to pups in lairs under the snow. Since 2002, BP has avoided on-ice activities in such areas during late winter. Consequently, on-ice searches for seals were neither necessary nor done during those winters.

The LoAs have also required BP to monitor, during all daylight hours, a 190 dB re 1 μPa (rms) safety zone for seals around the island if BP's activities might produce underwater sound pressure levels (SPLs) exceeding that level. Impact pile (or pipe) driving in water bordering the island is the one potential BP activity that might create such sound levels (see Blackwell et al. 2004b). However, BP has not conducted impact pile or pipe driving in water around Northstar during the reporting period, so no monitoring of this type was required or conducted.

3. Acoustic Monitoring of Bowhead Whale Migration

One of the key components of the monitoring required by both NMFS and the NSB from the start of the Northstar project has been monitoring of the autumn bowhead migration past Northstar. The main concern is the possibility that migrating bowheads might be deflected offshore or otherwise affected as a result of exposure to underwater sounds from Northstar activities. The recent LoAs specified that BP would, in a manner consistent with recommendations at the 2006 open-water peer-review meeting, monitor the bowhead migration past Northstar by acoustic localization methods (primarily DASARs) to document relative numbers of bowhead calls vs. distance offshore in the southern part of the migration corridor.

The 2001–2004 acoustic localization study of the bowhead migration past Northstar showed that, at times in autumn 2001 to 2004 with higher-than-average levels of underwater sound from Northstar, the southern edge of the distribution of calling bowhead whales near Northstar tended to be slightly farther offshore. The acoustic data do not allow us to distinguish whether this was a noise-induced offshore deflection, a noise-induced change in calling rate, or a combination of the two, but in any case, it represented a noise-induced change in bowhead behavior.

The NSB's Science Advisory Committee, after reviewing the results obtained up to 2004, agreed with a proposal by BP that it would be appropriate to scale back the bowhead monitoring program for three years (2005–2007), with the possibility of then conducting a more intensive monitoring effort again for at least one year (2008). In the meantime, a reduced acoustic monitoring program was to be conducted each year, along with additional analyses of the large acoustic dataset from 2001–2004. The annual open-water peer-review meetings in 2005 and subsequent years supported this conclusion.

During the 2005–2007 period, a smaller array of DASARs was deployed at 3 or 4 offshore locations, including one location that was used in every year of the study from 2001 to 2007 (and again in 2008–2009). The smaller array used in 2005–2009 allowed counting of whale calls, determining call types, and characterizing the approximate location of the migration corridor by analyses of bearings to the calls. (It also provided data on industrial and background sound levels offshore of Northstar.) Results of the bowhead monitoring in 2005–2007 were described in the "Annual Summary Reports" (included as Appendices B–D) and are summarized in Chapter 5 of this report.

In early 2008, it was agreed among BP, NMFS and NSB that the monitoring program should be expanded for one season, as had been envisaged by the SAC review in 2005. The primary objective of the 2008 monitoring was again to assess the effects of Northstar production activities, especially their underwater sounds, on the southern part of the distribution of calling bowhead whales during their autumn migration. There was a desire to extend the monitoring capability farther offshore, so the DASAR array was modified. It again included instruments at 10 offshore locations (as in 2001–2004), but in 2008 the DASARs were farther apart (7 rather than 5 km) and extended to 38 km (24 mi) offshore rather than the maximum 21.5 km (13.4 mi) that had applied in 2001–2004. The 2008 program provided a very large dataset; more bowhead calls were detected than in any other year (see the "Annual Summary Report" in Appendix E, and Chapter 5 of this report). However, several marine seismic programs were active in the Beaufort Sea at times during the 2008 field season, and large numbers of airgun pulses were also detected by the DASAR array seaward of Northstar. Given that seismic programs are known to affect the distribution of migrating bowhead whales as observed both visually and acoustically (e.g., Miller et al. 1999; Greene et al. 1999a,b), it was decided (in consultation with NMFS and NSB) that the extensive airgun activity in 2008 would make it difficult to detect and characterize any Northstar effect on the distribution of calling whales. Consequently, the 2008 data were not analyzed in detail to test for a Northstar effect.

Instead, during the late summer/early autumn of 2009, the extensive array of 10 DASARs extending to 38 km offshore was deployed again. In 2009, less seismic survey activity was expected. A moderate number of bowhead calls (relative to other years) were detected that season. There was some seismic survey activity in 2009 as well, but it was less frequent and more distant than in 2008 (see "Annual Summary Report" in Appendix F, and Chapter 5 of this report). Consequently, it was decided to go ahead with a comprehensive analysis of the 2009 bowhead call data to assess possible effects of fluctuating Northstar sounds on the distribution of calls. In 2009, for the first time, various measurements of industrial sound (both Northstar-related and airgun) as received offshore were used as covariates in the analysis, along with the measurements of sound emanating from the Northstar area. The results of this analysis of the 2009 data are described in Chapter 6 of the present report. The 2009 results are quite different from those of 2001–2004, and the data suggest that this was at least partly because of the confounding influence of the distant seismic surveys in 2009.

4. Subsistence Hunt for Bowheads and Whaler Perceptions of Industry Effects

The NSB's Science Advisory Committee, in its 2005 review of BP's Northstar monitoring work, recommended that local and traditional knowledge of Nuiqsut whalers be incorporated into reports concerning BP's Northstar monitoring. This has been done since 2005 by the participation of Michael S. Galginaitis (MSG) of Applied Sociocultural Research, Anchorage, in the BP monitoring program. Each autumn, generally in September, the Nuiqsut whalers are based at Cross Island, about 27 km (17 mi) east of Nuiqsut (Fig. 1.1), and hunt bowheads from there. MSG has (with support from the Minerals Management Service, MMS) observed and characterized the bowhead hunts at Cross Island during every autumn migration season since 2001. His work on the island has included providing the whalers with GPS data loggers to document the routes that they took when scouting for bowheads.

From 2005 onward, MSG has — in the BP monitoring reports — summarized information about each year's bowhead hunt, and about whaler perceptions of that year's whale migration, weather and ice conditions, bowhead feeding activity or skittish behavior (if observed), and interactions between vessel traffic and the hunt. MSG's initial review and summary, including available information for years prior to 2005, appeared in the first Comprehensive Report (Galginaitis 2008). Corresponding information for each year from 2006 to 2009 was included in MSG's chapters in BP's "Annual Summary Reports" for those years (see Appendices C–F). Chapter 7 of the current Comprehensive Report summarizes the results for all nine years (2001–2009) that MSG has spent on Cross Island during the autumn whaling season.

This effort to incorporate information about the hunt and about whaler perceptions into the BP monitoring program addresses the NSB-SAC's recommendation on this topic. It is not a specific requirement of the LoAs issued by NMFS.

REPORTS AND PUBLICATIONS ON NORTHSTAR MONITORING

The present comprehensive report describes BP's Northstar activities and the associated Northstar monitoring work from 2005 to 2009, with frequent references to monitoring work in prior years as well. This report summarizes BP's activities, acoustical measurement work, and seal and whale studies. It also summarizes the subsistence hunts for bowhead whales near Cross Island, and whaler impressions of the bowhead migrations and any industrial effects on the hunt.

The main body of this report includes eight chapters, some with Annexes of supporting material:

- Chapter 1 of the report is this general introduction.
- Chapter 2, by R. Rodrigues and L. Aerts of LGL Alaska, describes BP's activities during 2005–2009, with a brief summary of previous Northstar activities and of planned activities in early–mid 2010.
- Chapter 3, also by R. Rodrigues and L. Aerts, summarizes sightings of seals by Northstar personnel during 2005–2009, primarily during the late winter and break-up periods, with additional details in Annexes.
- Chapter 4, by S.B. Blackwell and colleagues from Greeneridge Sciences Inc., describes the underwater sounds associated with Northstar during the late summer / early autumn period when bowhead whales migrate past Northstar, including data from seafloor recorders (DASARs) ~450 m (¼ mi) seaward of Northstar and from recorders farther offshore. There is some emphasis on data from 2005–2009, but 2001–2004 data are also summarized for comparative purposes.

- Chapter 5, by K.H. Kim and colleagues from Greeneridge and LGL, describes the acoustic monitoring of bowhead whales seaward of Northstar, based on detection of calling bowhead whales by the seafloor recorders deployed in 2005–2009 and also in 2001–2004. An Annex to Chapter 5 includes the manuscript of a paper documenting slight directionality in bowhead whale calls. The calls are shown to be (on average) stronger ahead than behind the whales, as determined by analysis of 2008 data from the DASARs offshore of Northstar.

- Chapter 6, by T.L. McDonald and colleagues from WEST Inc., LGL and Greeneridge, analyzes the whale call data from 2009 to assess Northstar effects on the distribution of bowhead calls near the southern edge of the bowhead migration corridor. This analysis takes account of fluctuating underwater sounds measured near Northstar and offshore, variable airgun sound, and various natural environmental variables. The statistical approach is a further development of methods developed for analysis of the 2001–2004 data on bowhead calls (McDonald et al. 2008 and in review; Richardson et al. 2008).

- Chapter 7, by M.S. Galginaitis of Applied Sociocultural Research, concerns the subsistence hunts for bowheads passing Cross Island and the perceptions of the subsistence whalers regarding the characteristics of each year's bowhead migration and the possible influences of industrial activities on the whales and the hunt.

- Chapter 8, by W.J. Richardson and colleagues of LGL Ltd. and WEST, summarizes the numbers of seals and whales potentially affected by Northstar activities, principally in 2005–2009, insofar as can be determined. It also discusses the potential implications for access by subsistence hunters to hunted species of marine mammals.

Six previous related reports describing BP's Northstar activities and the associated marine mammal and acoustical monitoring are included on the accompanying CD-ROM as Appendices A–F. Appendix A is the final version of the main text (14 chapters) of the previous Comprehensive Report on Northstar activities and monitoring in 1999–2004 (Richardson [ed.] 2008). Appendices B–F are BP's "Annual Summary Reports" concerning Northstar activities and monitoring in 2005–2009, respectively (Richardson [ed.] 2006, 2007; Aerts and Richardson 2008, 2009, 2010). The annual summary reports document BP's activities, seal sightings, acoustical measurements, and acoustical monitoring of calling bowhead whales, along with subsistence whaling activities at Cross Island, for each of the five years summarized in this Comprehensive Report. For individual years, more details about some of the topics can be found in the annual summary reports than in the present report.

Also included, as Appendices H–O, are copies of eight refereed papers or manuscripts published or completed since 2005 based on the aforementioned studies. Each of these provides supporting information relevant to one or more of the chapters in this report. Six of these are papers that have been published since 2005 (Blackwell and Greene 2005, 2006; Moulton et al. 2005; Williams et al. 2006; Blackwell et al. 2007; Greene et al. 2008). A paper in manuscript form (McDonald et al. – Appendix O) is currently "in review" by a journal, and another manuscript (Moulton et al. – Appendix M) is currently being revised for resubmission. A ninth paper (Blackwell et al., in review) is included in printed form as an Annex to Chapter 5 in this report.

Several additional papers based on our early work at Northstar were published prior to 2005; most of those were included on the CD-ROM that accompanied the first Comprehensive Report (Richardson [ed.] 2008). Table 1.3 lists the authors, title, and status of each journal publication and manuscript, completed or currently planned, based on the Northstar studies.

TABLE 1.3. Authors and titles of publications and manuscripts resulting from the Northstar marine mammal and acoustic studies program, 1999–2010. Papers included as part of this report, either on CD-ROM or in Annex 5.1, are shown in blue. CR#1 means "First Comprehensive Report", Richardson (ed., 2008). Author and title lists for "in preparation" manuscripts are tentative.

Authors	Title	Status
Acoustical Studies		
Blackwell, S.B., C.R. Greene Jr., and W.J. Richardson (2004)	Drilling and operational sounds from an oil production island in the ice-covered Beaufort Sea.	***J. Acoust. Soc. Am***. 116(5): 3199-3211 (Appendix J *to* CR#1)
Blackwell, S.B., and C.R. Greene Jr. (2005)	Underwater and in-air sounds from a small hovercraft	***J. Acoust. Soc. Am.*** 118(6): 3646-3652 (included as Appendix H)
Blackwell, S.B., and C.R. Greene Jr. (2006)	Sounds from an oil production island in the Beaufort Sea in summer: characteristics and contribution of vessels	***J. Acoust. Soc. Am.*** 119(1): 182-196 (included as Appendix I)
Greene, C.R., Jr., S.B. Blackwell and M.W. McLennan (2008)	Sounds and vibrations in the frozen Beaufort Sea during gravel island construction	***J. Acoust. Soc. Am.*** 123(2): 687-695 (included as Appendix J)
Bowhead Whale Studies		
Greene, C.R., Jr., M.W. McLennan, R.G. Norman, T.L. McDonald, R.S. Jakubczak, and W.J. Richardson (2004)	Directional frequency and recording (DIFAR) sensors in seafloor recorders to locate calling bowhead whales during their fall migration	***J. Acoust. Soc. Am.*** 116(2): 799-813 (Appendix S *to* CR#1)
Blackwell, S.B., W.J. Richardson, C.R. Greene Jr., and B. Streever (2007)	Bowhead whale (*Balaena mysticetus*) migration and calling behaviour in the Alaskan Beaufort Sea, autumn 2001–04: an acoustic localization study	***Arctic*** 60(3): 255-270 (included as Appendix N)
Streever, B., R.A. Angliss, R. Suydam, M. Ahmaogak, C. Bailey, S.B. Blackwell, J.C. George, and 6 others (2008)	Progress through collaboration: a case study examining effects of industrial sounds on bowhead whales.	***Bioacoustics*** 17(1-3): 345-347
McDonald, T.L., W.J. Richardson, C.R. Greene Jr., S.B. Blackwell, C.S. Nations, R.M. Nielson, and B. Streever	Detecting changes in the distribution of calling bowhead whales exposed to fluctuating anthropogenic sounds	MS (submitted): included as Appendix O
Blackwell, S.B., T.L. McDonald, K.H. Kim, L.A.M. Aerts, W.J. Richardson, C.R. Greene Jr., and B. Streever	Directionality in the calls of bowhead whales	MS (submitted): included as Annex 5.2 to Chapter 5 of this report
Richardson, W.J., T.L. McDonald, C.R. Greene Jr., S.B. Blackwell and B. Streever	Distribution of calling bowhead whales near an oil production island with variable underwater sound, 2001–2004	MS (in preparation); based on Chapter 10 of CR#1

…***continued***

TABLE 1.3. *Concluded*.

Author	**Title**	**Status**
Blackwell, S.B., T.L. McDonald, R.M. Nielson, C.S. Nations, C.R. Greene Jr., W.J. Richardson, and B. Streever	Effects of an oil production island in the Beaufort Sea on the calling behaviour of bowhead whales	MS (in preparation); based on Chapter 12 of CR#1
Seal Studies		
Harris, R.E., G.W. Miller, and W. John Richardson (2001)	Seal responses to airgun sounds during summer seismic surveys in the Alaskan Beaufort Sea[2]	***Mar. Mamm. Sci.*** 17(4): 795-812
Moulton, V.D., W.J. Richardson, T.L. McDonald, R.E. Elliott, and M.T. Williams (2002)	Factors influencing local abundance and haulout behaviour of ringed seals (*Phoca hispida*) on landfast ice of the Alaskan Beaufort Sea	***Can. J. Zool.*** 80(11): 1900-1917 (Appendix K *to* CR#1).
Moulton, V.D., W.J. Richardson, M.T. Williams, and S.B. Blackwell (2003)	Ringed seal densities and noise near an icebound artificial island with construction and drilling	***Acoust. Res. Let. Online*** 4(4): 112-117 (Appendix L *to* CR#1)
Blackwell, S.B., J.W. Lawson, and M.T. Williams (2004)	Tolerance by ringed seals *(Phoca hispida)* to impact pipe-driving and construction sounds at an oil production island	***J. Acoust. Soc. Am.*** 115(5): 2346-2357 (Appendix P *to* CR#1)
Moulton, V.D., W.J. Richardson, R.E. Elliott, T.L. McDonald, C. Nations, and M.T. Williams (2005)	Effects of an offshore oil development on local abundance and distribution of ringed seals *(Phoca hispida)* of the Alaskan Beaufort Sea	***Mar. Mamm. Sci.*** 21(2): 217-242 (included as Appendix K)
Williams, M.T., C.S. Nations, T.G. Smith, V.D. Moulton, and C.J. Perham (2006)	Ringed seal (*Phoca hispida*) use of subnivean structures in the Alaskan Beaufort Sea during development of an oil production facility	***Aquat. Mamm.*** 32(3): 311-324 (included as Appendix L)
Moulton, V.D., M.T. Williams, S.B. Blackwell, W.J. Richardson, R.E. Elliott, and B. Streever	Zone of displacement for ringed seals (*Pusa hispida*) wintering around offshore oil production operations in the Alaskan Beaufort Sea	MS (in preparation); included as Appendix M.

In summary, this volume and its associated Appendices is a comprehensive report on the marine mammal studies and acoustical measurements done in association with BP's Northstar Development during 2005–2009, with considerable reference to earlier Northstar monitoring work. The report also includes descriptions of BP's activities, principally those in 2005–2009 and those planned for 2010. Many of the marine mammal and acoustical results from individual years or on specific topics have been reported previously in annual reports and journal papers. Those documents are included in electronic form as Appendices to this report, or (for documents completed before 2005) on the CD-ROM accompanying the previous Comprehensive Report.

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[2] This paper concerns a BP seismic survey conducted (in part) at the Northstar site.

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Also, we thank the many participants in the advisory groups that have provided valuable comments and suggestions over the years. Peer / stakeholder groups convened each year by the National Marine Fisheries Service discussed the plans for and results of the monitoring studies. Participants in this group have varied from meeting to meeting, but included representatives of NMFS, the Alaska Eskimo Whaling Commission, the North Slope Borough, and the Minerals Management Service, plus numerous individual researchers with expertise on topics related to some of the work described in this report. Also, we thank the NSB and its Science Advisory Committee for their detailed review and constructive comments on the Northstar monitoring program during early 2005. The SAC members were Dr. J. Kelley (chair); Drs. T. Albert, C. Clark, W. Ellison, G. Givens and J. Zeh; and *ex officio* members C. George and R. Suydam. Our thanks to all.

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CHAPTER 2:
BP'S ACTIVITIES AT NORTHSTAR, 2005–2009 [1]

by

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ABSTRACT

In 1999 BP Exploration (Alaska) Inc. (BP) began construction of an offshore island for future oil production on submerged remnants of Seal Island, a man-made island originally constructed in 1982. The new oil development was called Northstar. BP's construction and initial production activities at Northstar, through 2004, were described in an earlier Comprehensive Report. This chapter describes continuing oil production in 2005–2009, along with associated support and maintenance work. A brief description of ongoing and proposed activities in 2010 is also included. This chapter was prepared to meet the regulatory requirement for a description of BP's Northstar activities during the 5-year period covered by the current "Northstar regulations", at 50 C.F.R. §216.200–210, and by annual Letters of Authorization issued by the National Marine Fisheries Service to BP under those regulations.

As in previous years ice roads were constructed to facilitate on-ice transportation during winter and early spring. Ice-road construction began in Nov. or Dec. and the road was generally functional from Jan. until mid- to late May. Standard buses, vans, and pick-up trucks were the primary vehicles used for transportation of personnel and equipment to and from Northstar during that period. Several types of tracked vehicles were also used early and late during the ice-covered period. During the open-water periods, a hovercraft and Bell 212 helicopter were the primary means of transportation of personnel. Crew vessels were also used occasionally and barges were used to transport equipment, supplies, and fuel.

Drilling into oil-bearing strata occurred during the winter months each year but did not occur during break-up or open-water periods. However, well maintenance activities using the drill rig to lower cables down the hole occurred above the formation depth in the 2005 and 2006 open-water seasons.

Four or more aerial surveys were conducted each month to inspect the pipeline between Northstar and shore for leaks or spills. An automated system was also used continuously to detect any pipeline spills. No reportable conditions were recorded using either monitoring method. A number of small spills of various types of material on the island were reported each year. These materials were all cleaned up. No clean up after flare events was required during the reporting period.

Maintenance activities to repair the shoreline protection system (concrete blocks and fabric barrier) occurred during the latter part of the ice-covered period and extended into the open-water period in 2005–2007. Equipment used included a Manitowoc 888 crane, Volvo 150D loader, John Deere 650H excavator, Ingersoll-Rand zoom-boom, air compressors, Chinook 800 and Tioga heaters, and generators.

Repair activities in 2008 involved placement of boulders along the northeast corner of the island during the ice-covered period and some minor repair activities during the subsequent open-water period. Boulders were hauled to Northstar in March and April via the ice road. A Caterpillar 966 loader, Caterpillar 345B excavator, and John Deere 850 dozer were used for boulder placement. In 2009 repairs to the block system and fabric barrier similar to those in 2005–2007 were necessary on the northwest side of the island. Repair techniques and equipment used were similar to those used in 2005–2007.

In 2010 BP began an expansion project in the SE corner of Northstar to accommodate a new operations center scheduled to arrive in 2012. Removal of the drill rig, for which some dredging activity may be necessary, and construction of a water intake system are also planned for 2010.

BP continued acoustic studies each fall to monitor sounds from Northstar and calling bowhead whales during their westward migration. In 2008 BP also deployed sensors on the bottom at three sites to increase knowledge about wave and ice forces affecting the Northstar protection barrier. Retrieval and re-installation of the sensors is planned once a year for 3 to 5 years. In addition to BP's activities, various other industry and agency activities occurred near Northstar during the 2005–2009 reporting period.

INTRODUCTION

BP Exploration (Alaska) Inc.'s activities at its oil production facility at Northstar Island from 1999 through the end of the 2004 open-water period were described in detail in an earlier report (Rodrigues and Williams 2006). That report also briefly described BP's activities during the winter of 2004–2005. The present chapter provides a detailed description of BP's Northstar activities for the period 1 Nov. 2004 through the 2009 open-water period ending on 31 Oct. 2009. To make the text less cumbersome, the period addressed in this chapter is often referred to as the 2005–2009 reporting period.[3] At the request of the National Marine Fisheries Service (NMFS), a brief summary of BP's current construction and maintenance activities during the 2010 ice-covered period is presented along with a summary of activities proposed for the 2010 open-water period.

Objectives

Before construction and oil production began, BP requested authorizations from the NMFS to allow "taking" of small numbers of whales and seals incidental to activities at Northstar. The annual authorizations issued by NMFS for 2005–2009 required BP to provide summaries of BP's activities at Northstar, including "…dates and locations of ice-road construction; on-ice activities; vessel/hovercraft operations; oil spills; emergency training; and major repair or maintenance activities that might alter the ambient sounds in a way that might have detectable effects on marine mammals, principally bowhead whales". Descriptions of BP's activities each year from 2005 through 2009 were provided in BP's "Annual Summary Reports" for those years, which are included as Appendices B–F on the CD-ROM accompanying this report. This chapter summarizes those activities for the combined 2005–2009 period, as required to meet the reporting requirements of the incidental take regulations issued by NMFS.

Construction and Initial Production Operations, 2000–2004

Although BP's Northstar activities in 2000–2004 have been reported previously (Rodrigues and Williams 2006) and are outside the primary period covered by this report, they are summarized here to provide context for the subsequent description of BP's activities at Northstar in 2005 to 2009.

In 2000 BP built Northstar Island on the submerged remnants of Seal Island, a man-made island originally constructed in 1982, as a platform for future drilling and oil production. On-ice work began in late fall 1999 and early 2000 when two ice roads were constructed, one from the mainland in the Kuparuk River Delta to Seal Island for gravel hauling, and a second ice road from Seal Island along a pipeline right-of-way to the mainland at Pt. Storkersen. Gravel was hauled and deposited into a hole in the ice at the location of the abandoned Seal Island beginning in Feb. 2000. In March, vibratory and impact pile drivers were used to install a sheetpile wall around the entire working surface of the island to stabilize the island and provide protection for future facilities. In late winter 2000, two 10-inch (25.4-cm) pipelines were buried below the seafloor between the island and mainland and additional construction work began on the newly-built Northstar Island. Helicopter and vessel-based monitoring was undertaken to collect bathymetric data and information on strudel scour and ice gouges, which could present potential risk of damage to the subsea pipelines.

Construction activities continued at Northstar during the subsequent 2000 open-water season with installation of well conductor pipes and well insulator pipes using vibratory and impact pile drivers, and

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[3] Yearly reporting periods (e.g., 1 Nov. 2004 through 31 Oct. 2005) are often identified in this chapter by reference to the year of the open-water season within that period. Thus, the 1 Nov. 2004 through 31 Oct. 2005 reporting period may be referred to as the 2005 reporting period.

modules and equipment were delivered via sealift barges. Continuing construction activities included grading of the island slopes, placement of filter fabric and concrete slope protection, and placement of foundation blocks for modules, pipe racks, and the drilling rig. Equipment used during these initial construction activities included a Caterpillar front-end loader, American crane model 11320, Manitowoc 888 crane, APE model 200A vibratory pile driver, DELMAG D62-22 impact pile driver, Hitachi backhoe, Caterpillar D8 bulldozer, mechanics box truck, and Polaris 6-wheelers. Crew vessels, barges and helicopters were used to transport personnel and equipment to and from Northstar Island during open-water seasons. Other vessel activity included spill training exercises by Alaska Clean Seas (ACS).

Ice roads were again constructed during the ice-covered period in late 2000 and early 2001, and in subsequent ice-covered periods. Blue Bird rolligon-type vehicles with power augers and pumps, along with tanker trucks hauling fresh water, were used for ice road construction. Once adequate thickness was achieved, ice roads were maintained with snow blowers, front-end loaders, D-3 and D-4 Caterpillar bulldozers, and Caterpillar 14G and 16H graders. Helicopters were also used at the beginning and end of the ice-covered periods when ice roads were not operational. Standard vehicles including buses, vans and pickups were used when ice roads were operational. Major construction activities during the 2000–2001 ice-covered period included assembly of the drilling rig, pipe rack, permanent living quarters, grind and inject module, and dock improvements.

Drilling of the underground disposal well began in Dec. 2000 and drilling of production wells continued to mid-June 2001 when it was suspended to meet regulatory requirements. Drilling into oil-bearing strata is authorized only during the ice-covered period and not during break-up or the open-water period. Drilling into the formation cannot begin in the late fall/early winter until a minimum of 18 inches (0.47 m) of continuous ice has formed out to 1.5 miles (2.4 km) in all directions from Northstar, and drilling is required to end by 13 June each year (see NMFS 2001, p. 65932).

The main oil production equipment arrived and was installed during the 2001 open-water period and the pipeline monitoring program was continued. Oil production and gas injection at Northstar began on 31 Oct. 2001. Both have continued from then to the present with almost no interruption.

Power generation on Northstar Island was converted from diesel generators to gas turbine generators during the 2001–2002 ice-covered period, and drilling occurred from Nov. 2001 to early June 2002. Drilling activity above reservoir depths, continued monitoring of the subsea pipeline, and spill response training occurred during the 2002 open-water period.

A number of activities initially begun during earlier years, some of which were seasonal, were ongoing during 2003 and 2004. Drilling into the oil-bearing formation occurred only during the ice-covered period as described above. Other activities during the ice-covered periods included various tests of equipment and oil spill exercises. Ice roads were constructed during each ice-covered period using techniques similar to those of previous years to facilitate transportation of personnel and equipment. Crew vessels were again used to transport personnel and equipment during the 2003 open water season, but a small hovercraft also operated in 2003. The hovercraft was used more than crew boats in 2004. Helicopters were also used for transportation and barge traffic occurred during the 2003 and 2004 open-water periods as in previous years. Berm reconstruction around the perimeter of Northstar Island and repairs to the concrete block slope protection system were undertaken during the 2003 open-water season and were continued in 2004. Other maintenance activities during the 2003 open-water period included a well cellar retrofit project, modification to the hovercraft landing area, and installation of thermosiphons along some on-island pipelines to prevent thawing and uneven settlement of gravel.

Many of the Northstar and Northstar-related activities that were conducted in 2002–2004 continued in subsequent years. The following sections of this chapter describe BP's activities at and in support of Northstar from 2005 to date.

TRANSPORTATION

Numerous types of vehicles were used to transport personnel and equipment to and from Northstar during the previous reporting period (1999–2004) depending in part on the time of year. The same or similar types of vehicles were used during the current 2005–2009 reporting period.

During the ice-covered period (defined as the period from 1 Nov. through 15 June of the subsequent year) most access to Northstar was via an ~12 km (7.4 mi) ice road constructed from West Dock to Northstar Island (Fig. 2.1). Construction of the ice road began in Nov. or Dec. each year, and the road was generally operational from Dec. or Jan. until mid- to late May. Methods used to construct the ice road are discussed in detail in the previous Comprehensive Report describing BP's monitoring activities at Northstar through 2004 (Rodrigues and Williams 2006), and in the various annual reports. Standard buses, vans, and pick-ups are the primary types of vehicles used for transportation of personnel, supplies, and materials to Northstar when the ice road is operational. Several types of tracked vehicles including Hägglunds, Tucker, and Mattrak-equipped standard vehicles may also operate at the beginning and end of the ice-covered period when the ice road is not useable by conventional vehicles.

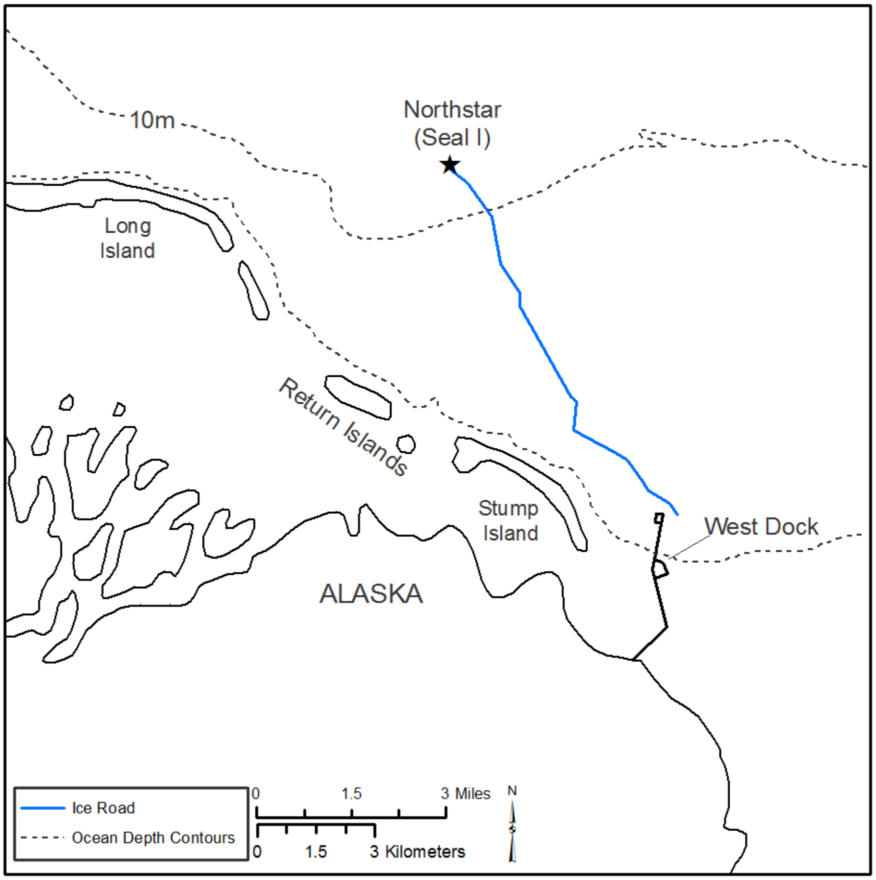

FIGURE 2.1. Transportation corridor to Northstar Island during ice-covered periods showing possible ice road route. Routes may vary among years due to local ice conditions.

During the open-water period (defined as 16 June through 31 Oct.) Bell 212 helicopters, a Griffon 2000 TD hovercraft, barges and *Bay*-class boats were used for transportation of personnel and equipment to and from Northstar. Helicopters and the hovercraft may also be used during the ice-covered period if necessary or most practical. The hovercraft generally traveled along the ice road in the spring until the ice started to move and break up (Fig. 2.1). Thereafter the hovercraft route changed as needed depending on weather and ice conditions.

BP also maintains ARKTOS articulated vehicles on Northstar Island to be used in case of emergency evacuation. Two ARKTOS vehicle were available on Northstar until 2008 when BP added a third ARKTOS vehicle to increase emergency evacuation capacity and allow for additional personnel to be on the island.

Bell 212 Helicopter

Bell 212 helicopters (Fig. 2.2) may be used at any time of the year for Northstar transportation needs. Helicopter routes to and from Northstar were negotiated with the U.S. Fish and Wildlife Service (USFWS) and the NMFS during early planning of Northstar operations. Various Letters of Authorization (LoAs) issued to BP by NMFS stated that helicopter flights to support Northstar operations were limited to a corridor from Northstar to the mainland and, except when taking off, landing or when limited by bad weather, must maintain a minimum altitude of 305 m (1000 ft).

Most helicopter activity during the 2005–2009 reporting period occurred during freeze-up in fall before the ice road was operational (Table 2.1). Helicopter activity resumed in the spring after the ice road was no longer operational although activity was generally reduced compared to that of the fall period. Little helicopter activity occurred during winter months. The amount of Northstar helicopter activity varied annually during the reporting period with lowest levels in 2004/05 and highest levels in 2005/06.

FIGURE 2.2. Bell 212 helicopter used for transportation of personnel to and from Northstar.

TABLE 2.1. Monthly and total annual Bell 212 helicopter round trips to Northstar, 2005–2009.

Month	**2004/05**	**2005/06**	**2006/07**	**2007/08**	**2008/09**
November	48	193	189	131	40
December	19	153	116	81	13
January	16	18	6	8	1
February	5	0	0	0	0
March	0	0	4	0	0
April	0	0	0	0	0
May	0	66	9	0	8
June	41	69	27	9	182
July	12	26	17	11	24
August	1	33	3	13	13
September	9	13	42	28	46
October	70	155	112	60	35
Total	**221**	**726**	**525**	**341**	**362**

Griffon 2000 TD Hovercraft

The Griffon 2000 TD hovercraft (Fig. 2.3) was first used in 2003 for transportation of personnel to and from Northstar. The hovercraft may be used during both the ice-covered and the open-water periods although no hovercraft activity occurred during March and April of 2005–2009 (Table 2.2). The hovercraft is powered by a 355 hp air-cooled Deutz diesel engine and is 11.9 m (39 ft) in length (Blackwell and Greene 2005). The hovercraft is capable of carrying a payload of 2268 kg (5000 lb). Most hovercraft activity during the 2005–2009 reporting period occurred from the summer open-water period through fall and diminished rapidly as the ice road became operational. Much less hovercraft activity occurred from Jan. through May when conventional vehicles (mainly pick-ups, vans, and buses) were used to transport personnel. The level of hovercraft use was similar from 2005/06 through 2008/09, but was much lower in 2004/05 (Table 2.2).

FIGURE 2.3. Griffon 2000 TD hovercraft at the landing area on Northstar Island.

TABLE 2.2. Monthly and total annual round trips to Northstar by the Griffon 2000 TD hovercraft, 2005–2009.

Month	2004/05	2005/06	2006/07	2007/08	2008/09
November	22	0	75	23	72.5
December	61	83	326	101.5	104
January	37	7	3	149.5	159
February	0	0	0	37	3
March	0	0	0	0	0
April	0	0	0	0	0
May	14	82	61	47.5	94.5
June	84	124	205	131.5	161.5
July	37	124	97	122.5	90.5
August	45	114	100	135	79.5
September	41	162	36	84	83
October	27	113	18	40	64.5
Total	**368**	**809**	**921**	**871.5**	**912**

Tracked Vehicles

Hägglunds tracked vehicles (model 206 SUSV; Fig. 2.4) with personnel carriers were used to transport personnel and materials between West Dock and Northstar during periods when the ice road did not permit standard vehicle traffic. These situations occurred mainly in the months just prior to completion of the ice road in early winter, and again during spring break-up when meltwater accumulating on the ice road prevented standard vehicles from safely transiting to and from the island. A Hägglunds is powered by a turbocharged diesel engine capable of 143 hp at 4600 rpm; total weight of the two cars is ~4536 kg (10,000 lb). Average transport speeds were typically 8–16 km/hr (5–10 mile/hr). The maximum allowable payloads were 380 kg (838 lb) for the 4-person front car and 1250 kg (2756 lb) for the 8-person personnel carrier.

The Hägglunds made 25, 70, and 37 round trips between West Dock and Northstar Island during the 2004/05, 2005/06, and 2006/07 ice-covered periods, respectively (Table 2.3). Hägglunds vehicles were apparently used more extensively during earlier phases of the Northstar development (2001–2003) when they were used 14 times a day on average, mainly prior to the completion of the ice-road.

A ***Tucker tracked vehicle*** and Mattrak-equipped vehicle also made occasional round trips to Northstar Island during 2004/05–2006/07, and thereafter the Tucker largely replaced the Hägglunds. Tucker model 1600 Tucker-Terra vehicles (Fig. 2.5) were used more frequently during the 2007/08 and 2008/09 ice-covered periods (Table 2.3). Tucker vehicles are powered by a Cummins 6-Qsb 173 hp diesel engine; weight of the Tucker ranges between ~4536 and 7257 kg (10,000–16,000 lb). Passenger capacity on the Tucker vehicles is 15 persons. Tucker tracked vehicles made a total of 111.5 and 127.5 round trips between West Dock and Northstar during the 2007/08 and 2008/09 ice-covered seasons, respectively. Most Tucker activity (83% in 2008 and 90% in 2009) occurred in Jan. with few round trips in Dec. and the Feb.–May period. Hägglund and Mattrak vehicles made only occasional round trips to Northstar Island during the 2007/08 and 2008/09 ice-covered seasons. Tracked vehicles were used much more often in 2008 and 2009 than in 2005–2007 (Table 2.3).

FIGURE 2.4. Hägglunds tracked vehicle and personnel carrier.

TABLE 2.3. Round trips between West Dock and Northstar Island by Hägglunds (2004/05–2006/07) and Tucker (2007/08–2008/09) tracked vehicles operating on the ice.

Year	Round Trips
2004/05	25
2005/06	70
2006/07	37
2007/08	111.5
2008/09	127.5

Vessel Activity

Tugs with barges and smaller ACS **Bay-*class boats*** (in addition to helicopters and hovercraft) were used to meet Northstar transportation needs during the open-water periods. Barges for transport of fuel and cargo to Northstar are typically ~46–61 m (160–200 ft) in length and tugs are ~20 m (65 ft). *Bay*-class boats are ~13 m (~42 ft) in length and normally are used as oil spill response vessels.

During 2005–2009, most (~80%) of the Northstar-related barge traffic occurred during Aug. and Sept., with the highest amount of barge traffic occurring in Aug. (Table 2.4). However, barge trips were about equally frequent during Aug. and Sept. in 2006 and 2009. The amount of barge traffic was similar each year in 2007–2009, but higher in 2006 and lower in 2005.

FIGURE 2.5. Tucker tracked vehicle used for transport of personnel during early winter and during spring break-up.

TABLE 2.4. Number of tug/barge round trips to Northstar during the open-water periods, 2005–2009.

Year	July	August	September	October	Total
2005	3	10	7	1	**21**
2006	10	25	25	4	**64**
2007	3	32	4	1	**40**
2008	5	26	12	2	**45**
2009	8	15.5	16	5	**44.5**
Total	**29**	**108.5**	**64**	**13**	**214.5**

Bay-class boats (Fig. 2.6) were used to transport personnel to and from Northstar when weather conditions prevented the use of the hovercraft. Over the entire 2005–2009 period, *Bay*-class boat activity was greater in Sept. than other months although this was not the case each year (Table 2.5). In 2006 more Northstar-related *Bay*-class boat activity occurred in Aug. than in other months. As with barge traffic, ~80% of *Bay*-class boat traffic occurred in Aug. and Sept. Within the 2005–2009 period, the amount of *Bay*-class boat activity was greater in 2006 and 2007 than in other years and was lowest in 2005. In addition to the trips to Northstar, each year a few trips extended seaward of Northstar in support of acoustic and (in 2009) visual monitoring of the bowhead whale migration (see *Acoustic Studies of Calling Bowhead Whales* below).

ARKTOS Evacuation Craft

Two ARKTOS articulating evacuation craft (Fig. 2.7) were available at Northstar as emergency evacuation vehicles until 2008 when a third ARKTOS was added. Each ARKTOS is powered by two Cummins 260 hp diesel engines and weighs 29,484 kg (65,000 lb). Each ARKTOS is 15 m (50 ft) in length and 3.9 m (13 ft) high with a beam of 3.8 m (12 ft 9 in). In water the ARKTOS craft are propelled by two 14-inch-diameter water jets. The maximum speed is 16 km/hr (10 mph) on land or ice and 6 knots

FIGURE 2.6. ACS *Bay*-class boat "*Harrison Bay*".

TABLE 2.5. Number of *Bay*–class boat round trips to Northstar during the open-water periods, 2005–2009.

Year	July	August	September	October	Total
2005	0	2	10	2	**14**
2006	1	69	33	3	**106**
2007	22	41	71	3	**137**
2008	15	8	16	16	**55**
2009	15	17	32	1	**65**
Total	**53**	**137**	**162**	**25**	**377**

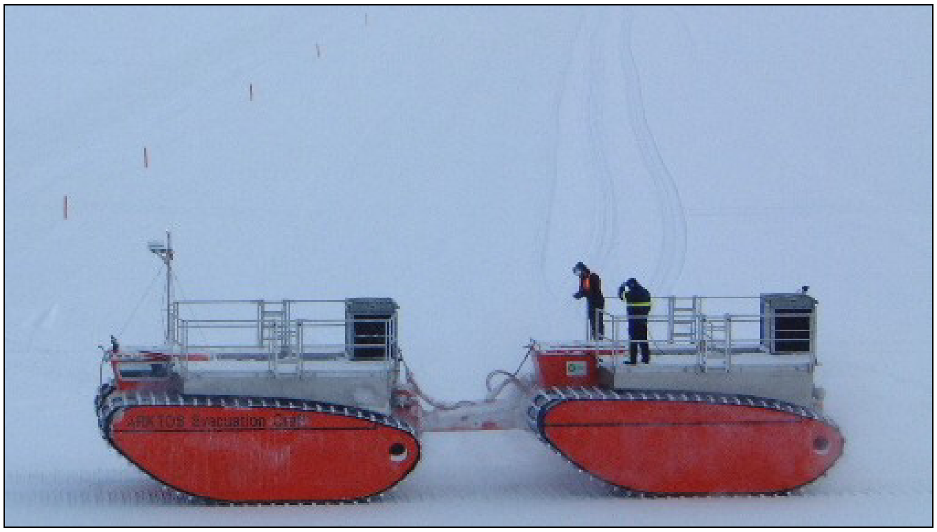

FIGURE 2.7. ARKTOS emergency evacuation craft.

in water. Each ARKTOS is capable of carrying 52 people, 24 in the front section and 28 in the rear section. Training exercises with the ARKTOS craft were conducted periodically during both the ice-covered and open-water periods, as noted below under "Training Activities".

PRODUCTION ACTIVITIES

Power Generation

Five gas turbines are located at Northstar Island including three Solar® generators for power generation and two GE LM-2500 high pressure compressors for gas injection. Each Solar® generator is a 13,000 hp (9700 kW) gas turbine, rated at 10,780 rpm and operating at 9500 rpm. Only two of the three gas-turbine generators operate at any given time. Preventative maintenance on these generators occurs twice per month at which time the inactive generator is activated. A diesel backup generator that is operated for one hr on a bi-monthly basis is available for emergency situations. Each high pressure compressor is a 30,000 hp (22,370 kW) gas turbine, rated at 10,000 rpm and running between 9000 and 9400 rpm; speed varies with the gas injection rate. One of the two compressors operates continually with the second compressor operating at a reduced rate. There is also a low-pressure compressor driven by a 5000 hp (3730 kW) electric motor running at a constant speed of 3600 rpm.

Drilling and Pipe Driving

Nabors drill rig 33E, which had been on the island since 2000, was used for ongoing drilling operations during the ice-covered period each year during the 2005–2009 reporting period (Table 2.6). Drilling into the oil-bearing strata did not occur during the summer months. Well maintenance activities using the drill rig to lower cables with equipment down the hole occurred above the formation during the open-water period in 2005 and 2006.

Pile drivers were used occasionally in order to install well conductor pipe. Vibratory pipe driving using an APE 200 vibratory pile driver and impact pipe driving using a DELMAG D–100 impact pile driver occurred on 8–9 May 2006 during installation of conductor pipes at two Northstar well sites (wells NS-33 and NS-36). Vibratory pile driving also occurred in Feb. and in July–Aug. 2008 during placement of thermosiphons, which were part of the thaw protection system.

Oil Spill Inspections

Each month four or more aerial surveys were conducted to inspect the pipeline for leaks or spills. Aerial surveys were conducted primarily from a Twin Otter (DHC-6) with a CASA 212 aircraft as a backup. Forward-looking infrared (FLIR) devices were used on an as-needed basis. In addition, LEOS technology (Leck Erkennung und Ortangs System, also known as Leak and Location System) and Ed Farmer Mass-Pack leak detection system were used continuously to detect oil spills. No reportable conditions were recorded using any of these methods.

Reportable Spills

Reportable spills occurred at various times throughout the reporting period during both the ice-covered and open-water periods. Overall more reportable spills occurred during the ice-covered than open-water periods (Table 2.7). These spills generally involved small amounts (often <1 gallon) of various types of material, some of which was in containment and recovered, and others which were cleaned up. Equipment used for clean up included waste bags and drums, absorbent pads, various scrapers and hand tools, sorbents, loader with bucket, bobcat, acid neutralizers, and air-actuated drum vacuum. The largest reported spills included

- 318 gal of drilling mud on 9 Dec. 2006,
- 1022 gal of drilling mud on 17 Feb. 2007,
- 1590 gal of diesel on 12 Aug. 2007, and
- 500 gal of tri-ethylene glycol on 9 Jan. 2008.

Most spilled material was contained on Northstar Island and very little reached the Beaufort Sea. Material spilled into the Beaufort Sea, either onto ice or in water, included

- 1 gallon of hydraulic fluid on 3–4 Jan. 2006,
- 3 gal of power steering fluid on 31 Dec. 2007,
- 0.25 gal of hydraulic fluid on 9 Aug. 2008, and
- an unknown amount of fuel released from a water jetting pump for divers on 26 May 2009.

All materials spilled on the island or in the Beaufort Sea (on ice or in water) were cleaned up. See Annexes 2.1–2.5 for complete lists of reported spills, as listed in Annual Summary Reports since 2005.

Gas flaring is used to eliminate waste gas that cannot be used or transported, and as a safety measure to prevent over pressurization. Flaring can result in deposition of residual hydrocarbons, and BP conducts inspections after flare events. A design problem in the early years of operation (2002–2004) resulted in unusual flare events that necessitated some clean up activity (Rodrigues and Williams 2006). The problems were related to malfunction of a low-pressure compressor and were resolved in 2004. No clean up activities were necessary after Northstar flaring events from 2005 through 2009.

TABLE 2.6. Date and description of drilling and pile driving activity at Northstar, 2005–2009.

Year	Dates	Activity
2004/05	9 Jan.–14 May	Drilling activity plus rig set-up and break-down
2005/06	7 Dec. 2005–12 May 2006	Well drilling and maintenance at six sites
	8-9 May	Vibratory and impact pile driving for conductor pipe installation
2006/07	17 Nov. 2006–1 May 2007	Well drilling at two sites
2007/08	18 Jan.–12 May	Well drilling at two sites
	15–19 Feb., 24 Jul.–10 Aug.	Vibratory pile driving for placement of thermosiphons
2008/09	Jan. through May	Well drilling at one site

TABLE 2.7. Number and types of reported spills during ice-covered and open-water periods at Northstar Island, 2005–2009.

Year	Ice-covered	Open-water	Material
2004/05	8	5	methanol, corrosion inhibitor, diesel, oxygen scavenger, propylene glycol, lubricants, crude oil and produced water
2005/06	17	3	corrosion inhibitor, scale inhibitor, diesel fuel, hydraulic fluid, anti-foulant, drilling mud, sulfuric acid, hydrochloric acid, sewage and lube oil
2006/07	21	4	drilling mud, corrosion inhibitor, sewage, motor oil, diesel, hydraulic fluid, lube oil, and propylene glycol and hydrochloric acid
2007/08	6	4	corrosion inhibitor, power steering fluid, tri-ethylene glycol, sewage and hydraulic fluid
2008/09	13	15	Lubricant, hydraulic oil, tri-ethelene glycol, corrosion inhibitor, wastewater, glycol, produced water, diesel, sewage

Training Activities

Various training activities occurred during both the ice-covered and open-water periods each year of the reporting period. Training sessions for the spill response team were generally given every Monday evening, and the fire brigade underwent weekly training on Saturday evenings. These training sessions included a combination of classroom instruction and field activities including activation of fire fighting equipment and deployment and charging of fire hoses. Oil spill response training activities occurred in the field on floating ice during 2007 and 2009, and during each open-water season.

Training involving activation of the ARKTOS emergency evacuation vehicles also occurred periodically during the reporting period. The ARKTOS vehicles were serviced and used during training activities in the following periods: 18 to 24 Aug. 2005, 10 July 2006, 7 May 2007, and 1 July 2008. These activities occurred on the island, in adjacent marine waters, and on floating ice. No training activities with the ARKTOS were conducted in 2009.

CONSTRUCTION AND MAINTENANCE ACTIVITIES

Maintenance activities to repair the block system and fabric barrier around Northstar occurred at various times before 2005 and were continued in 2005 and subsequently.

In ***2005***, maintenance activities began on 28 May 2005 and were completed during the subsequent open-water period on 26 June 2005. Divers were used for underwater work throughout the duration of the procedure. Initial repair activities included melting ice using high pressure washers and a hot water sled. Blocks were removed and sandbags were positioned in areas where gravel had been washed away. A new fabric barrier was placed over the sandbags and the blocks were replaced and shackled together. Equipment used included a Manitowoc 888 crane, Volvo 150D loader, John Deere 650H excavator, Ingersoll-Rand zoom-boom, air compressors, Chinook 800 and Tioga heaters, and generators. A hot oil unit composed of 2 pumps and 3 holding tanks with a total capacity of 135 gallons was used to heat fluids.

In ***2006*** and ***2007***, similar maintenance activities on the block system and fabric barrier continued at various times from May through Aug.

The ***2008*** repair activities involved placement of boulders along the northeast corner of the island during the ice-covered season from 7 March to 24 April and some minor repair activities during the open-water season in Aug. Most of the damage to the slope armor protection around Northstar was the consequence of combined wave and ice interactions, e.g., through local pressure of large blocks of ice rubble moving onto the slope of the island. During a heavy storm in Oct. 2006, the lower blocks along the northeast corner of the island were removed from the protection barrier by ice impacts. Rather than replacing these lower concrete blocks, BP planned to install large boulders at this location, and this was completed in 2008.

The boulders were transported with four side-dump trucks (C-500 trucks with 50 ft flatbed trailer) from a quarry in the Brooks Range to Northstar. A total of 812 round trips were made during March–April 2008 using the ice road for transport from West Dock to the island. Boulder placement was conducted with a Caterpillar 966 loader, a Caterpillar 345B excavator, and a John Deere 850 dozer. Measurements of airborne sound from the placement activities were obtained in accordance with the 2008/09 LoA. Results from these in-air sound measurements suggest that most, if not all, in-air sounds generated by rock dumping activity were below 90 dB re 20 μPa (Appendix A *in* Aerts and Richardson 2009, included on CD-ROM as Appendix E).

Following inspection of the slope protection, minor below-water repairs were conducted during Aug. 2008 by a dive crew. This work, consisting primarily of replacing small sections of damaged or missing blocks and re-linking missing shackles, was performed during ~5 days in early Aug. In addition, two swales (one on the north side and one on the southeast corner of the island) were identified for repair. Each of those repair sections would have benefited from below-water repair but that was not done in 2008 due to safety concerns related to storm potential in late Aug. However, some repair work was done from the surface:

- At the southeast corner, the proximity of the rock berm precluded access to the below-water slope. The repair techniques were similar to those applied during previous years, and consisted primarily of removing the blocks from the swale, placing new fabric on the slope, installing geotextile bags to buttress the damaged area, covering the bags with fabric and geogrid, and replacing the blocks. The repaired area was entirely above water.
- On the north side, the area to be repaired extended into shallow water. The objective of the repair was to minimize further loss of gravel from the lower slope during the 2008 fall storm season. The work was conducted from 15 to 24 Aug. Figure 2.8 shows before and after photos of the repair areas on the north side and southeast corner.

In ***2009***, repairs to the block system and fabric barrier around Northstar similar to the repairs in 2005–2007 were necessary. The 2009 activities included bench block repair work on the NNW, NW and WNW sides of the island with divers and a bench repair crew. The repair techniques were similar to those applied during previous years, and consisted primarily of removing the blocks from the swale, placing new fabric on the slope, installing geotextile bags to buttress the damaged area, covering the bags with fabric and geogrid, and replacing the blocks (Fig. 2.9). This work started in the last week of April with the cutting of ice to prepare a moat via which the divers could access the water, and was completed on 18 June prior to break-up of the sea ice. Equipment was similar to that used in previous years.

Following inspection of the slope protection, minor below-water repairs were conducted by a dive crew. This work, consisting primarily of replacing small sections of damaged or missing blocks and re-linking missing shackles, occurred from 27 July to 5 Aug. 2009.

The ***2010*** season is outside the period being addressed specifically in this report. However, here we briefly describe BP's construction/maintenance activities during the latter part of the 2010 ice-covered season and activities proposed for the 2010 open-water season. In early 2010, BP began an expansion project on the southeast corner of Northstar to accommodate a new operations center, which will be sea-lifted to the island in 2012. Maxi hauls (tractor/trailer dump trucks) were used to haul gravel to the island via the ice road from ~6 March to 7 May 2010. Concrete block removal around the southeast corner began on 11 March and installation of sheetpiles using an APE model 200A vibratory impact hammer began on 1 April 2010. Most of the sheetpile installation (660 of 679 sheetpiles) was completed by 1 July. A vibratory compactor will be used in Aug. and Sept. to compress gravel placed in the newly-created expansion area.

The southeast corner expansion project will include installation of a new water intake system, which is a sump from which sea water will be pumped to the island's reverse osmosis system to produce potable water. The sump will be the water source for the island, including water for fire protection and for the production process. Z-piles (sheetpiles that are Z-shaped rather than flattened) will be used to construct the walls of the new sea-water intake system. Z-pile installation using a vibratory hammer is scheduled to occur in Sept. 2010.

FIGURE 2.8. Before and after the 2008 repairs at the north side swale area (A=before; B=after) and at the southeast side swale area (C=before; D=after).

Demobilization of the Nabors drill rig began on 8 July 2010. A Manitowok model 555 crane will be used to load drill rig components onto barges for transport to West Dock. About 8 to 12 barge trips will be required to remove the rig from Northstar. Transportation of the rig will be coordinated with regular barge traffic that occurs annually bringing supplies and equipment to Northstar. The rig will likely be transported on back hauls by the same barges and dedicated barge traffic for rig transportation will likely not be necessary.

Dredging of the Northstar dock area may be necessary depending on the level of silt deposition. A crane with a clam-shell bucket located on the island will be used if dredging is necessary. A crane mounted on a barge will be used for dredging the outer portion of the dock area if necessary.

BP'S MONITORING ACTIVITIES

As summarized in Chapter 1, a variety of acoustic and biological monitoring studies were conducted near Northstar prior to 2005, but in the present reporting period from 2005 to 2009 the monitoring work was more narrowly focused. Acoustic measurements and acoustic monitoring of calling bowhead whales continued each year from 2005 to 2009, and this required boat operations near and offshore of Northstar on a few days each year, as summarized below. In addition, wave, current, and ice sensors were deployed by boat offshore of Northstar in 2008, and re-visited in 2009 (see below). Seal monitoring in the 2005–2009 period involved observations from Northstar island, without an supporting

FIGURE 2.9. Block system and fabric repair (above left and right) and diver repair work (bottom left and right) at Northstar Island in 2009.

aircraft or vessel operations, so that work is not further mentioned in this chapter; the seal monitoring is summarized in Chapter 3.

Acoustic Studies

Underwater and in-air acoustic measurements were conducted near and offshore of Northstar beginning in the early stages of development. The objectives of these studies were

- to document the characteristics and propagation of sounds from various Northstar-related activities during both the ice-covered season and the open-water season, and
- to monitor the westward migration of bowhead whales during late summer and early autumn by detecting and localizing calling bowhead whales.

Extensive acoustic studies of both these types were done during 2000–2004. These acoustic studies were summarized in the first Comprehensive Report concerning work done up to 2004 (Richardson [ed.] 2008, included on CD-ROM as Appendix A), with additional details in the associated annual reports and peer-reviewed technical papers (see Chapter 1).

Acoustic monitoring continued during each open-water season within the current reporting period to document the sounds from Northstar and its support vessels, and to characterize the bowhead whale migration each late summer/autumn based on monitoring of calling bowhead whales. *Bay*-class boats were used to deploy Directional Autonomous Seafloor Acoustic Recorders (DASARs) at various locations offshore of Northstar. Deployments generally occurred in late Aug. and the DASARs were retrieved in late Sept. or early Oct. each year from 2005 through 2009. The results of this acoustic monitoring are reported in Chapters 4–6 of this report, with additional details in the Annual Summary Reports that are included on CD-ROM as Appendices B–F.

The acoustic monitoring work differed somewhat between 2005–2007 and 2008–2009. Each year in the ***2005–2007*** period, two (in 2007) or three (in 2005 and 2006) closely-spaced DASARs were deployed in late Aug. about 450 m (¼ mile) northeast of Northstar to monitor sounds from Northstar. In addition, DASARs were deployed at 3 or 4 widely-spaced locations 9.3–21.5 km (5.8–13.4 mi) northeast of Northstar[4], primarily to detect bowhead whale calls and to determine their bearings from a standard location 14.9 km (9.2 mi) offshore where a DASAR was deployed every year since 2001. In ***2008*** and ***2009***, three DASARs were again deployed about 450 m (¼ mile) northeast of Northstar, but in those years a more extensive array of DASARS was deployed at 10 locations 8.5–38.5 km (5.3–24 mi) offshore to provide detailed data on whale call locations and other ancillary data. Chapter 4 describes the DASAR deployments in detail.

Deploying, maintaining and retrieving the DASARs involved, as noted above, use of a *Bay*-class vessel on 3–6 days in each year from 2005 to 2009 [5]. After initial deployment from that vessel, the vessel traveled to locations around each DASAR to conduct DASAR health checks and calibration work that involved projecting relatively low-intensity underwater sounds (~150 dB re 1 µPa·m in the case of the calibration sounds). The calibrations were repeated near the end of each field period, and in 2008 and 2009 were also done once in the middle of the deployment period.

In conjunction with boat-based DASAR work in 2009, an *Acousonde*™ (a small, self-contained, autonomous underwater acoustic recorder with omnidirectional hydrophones) was deployed close to Northstar on three dates to obtain near real-time information on the presence of pop-sounds, which were first detected in 2008 (see Chapter 4). The *Acousonde* is described at www.acousonde.com (see also Fig. 4.4 *in* Chapter 4). An *Acousonde* was operated for about 8 hours on each of 25 Aug. and 12 and 26 Sept. Another attempt to detect the presence of pop sounds was made earlier in the season with a hydrophone listening system deployed from ACS boat *Gwydyr Bay* on 16 July. Results of these pop sound measurements are reported in Chapter 4 of this report and in Chapter 3 of the 2009 Annual Summary Report (Blackwell et al. 2010, *in* Appendix F on CD-ROM).

Boat-based visual monitoring seeking to detect bowheads migrating through the middle of the DASAR array was attempted on 19 Sept. 2009 from the ACS boat *Mikkelsen Bay*. Two additional attempts at visual observations were made on 20 and 24 Sept. 2009, but both times the weather offshore of Northstar was too rough to conduct reliable visual observations. Results from these visual observations were reported by Kim et al. (2010), *in* Appendix F on CD-ROM.

Monitoring of Waves, Currents, and Ice

To increase knowledge about the wave and ice forces to which the Northstar protection barrier is subjected, wave, current, and ice thickness sensors (Nortek AWAC AST) and ASL ice profilers were

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[4] The four DASARs deployed offshore in 2005–2007 were 9.3–15 km (5.8–9.3 mi) northeast of Northstar in 2005, 11.5–16.6 km (7.1–10.3 mi) in 2006, and 11.4–21.4 km (7.1–13.3 mi) in 2007.

[5] Boat operations seaward of Northstar in support of DASAR deployments, health checks, calibrations, and retrieval occurred as follows: **2005:** 30 Aug., 4 and 25 Sept., and 2 and 3 Oct.; **2006:** 29 Aug. and 5, 7, 24 and 25 Sept.; **2007:** 28 Aug., 30 Sept. and 3 Oct.; **2008:** 26, 27 and 29 Aug., and 10, 24 and 25 Sept.; and **2009:** 25 and 26 Aug. and 12, 26 and 28 Sept. (see Annual Summary Reports in Appendices B–F for details).

deployed on bottom-mounted platforms at three locations ~1 mile offshore from Northstar Isl. (70°29.973 N, 148°44.960 W; 70°29.993 N, 148°41.981 W; 70°29.986 N, 148°38.997 W) on 9 Aug. 2008. Data are being recorded year-round and stored on an internal hard drive. Retrieval and re-installation of the equipment is planned to occur at least once a year for 3 to 5 years. Two of the three bottom-mounted platforms were retrieved on 26 Aug. 2009. The third platform could not be retrieved and remained on site. The transmit frequency of the ultrasound-based AWAC sensors is 1 MHz, with 8.5-min ping series every 15 min at a ping rate (duty cycle) of 2 per second, sometimes expressed as 2 Hz. At 1 MHz, attenuation is very rapid and the maximum propagation distance is ~30 to 50 m. The ice profilers provide data complementing the ice thickness data from the AWAC sensors. They transmit high frequency energy (420 kHz) with a range up to ~225 m. The ice profilers transmit 17-min ping series every 40 min at a ping rate of 2 per second. The operating frequencies of these sensors are far above the upper end of the functional hearing range of all marine mammal species (i.e., 180 kHz; Southall et al. 2007).

NON-NORTHSTAR ACTIVITIES

Several types of monitoring studies unrelated to BP's activities at Northstar occurred in offshore areas near or in the general vicinity of Northstar Island. These included aerial surveys, vessel-based surveys, and acoustic monitoring, each of which is discussed briefly below. Reports on some of these monitoring studies are available and reports for others will be forthcoming. Some of these monitoring studies were in support of offshore development activities by Pioneer Natural Resources Alaska Inc. (Pioneer) and Eni US Operating Co. Inc. (Eni), which occurred at two sites west of Northstar during the reporting period. Other monitoring studies were conducted in relation to offshore seismic exploration by Eni, Shell, and BP. Barges and crew vessels were used to support these development and exploration activities, and activities associated with villages and government facilities along the Beaufort Sea coast.

Offshore Exploration and Development Activities

In 2006, Pioneer began construction of a gravel island, Oooguruk Drillsite (ODS), offshore of the Colville River Delta. This island was subsequently used for drilling and oil production. A subsea flowline was installed in Feb. 2007 and oil production at ODS began in June 2008. A brief discussion of the ODS development and associated vessel and helicopter activities was reported by Rodrigues et al. (2010).

In 2008, Eni began construction of a gravel island west of Northstar, the Spy Island Drillsite (SID), for future oil development. Island construction was ongoing during the 2009 open-water period.

Offshore seismic exploration was conducted in the Alaskan Beaufort Sea by Shell during open-water seasons from 2006 through 2008. Exploration activities were confined to shallow hazards surveys in 2006 due to heavy ice conditions that year. Deep seismic surveys along with shallow hazards surveys were conducted by Shell in 2007 and 2008. The surveys occurred on or near Shell lease holdings in eastern Harrison Bay ~40 km (25 mi) west of Northstar, and in the Camden Bay area ~80 km (50 mi) east of Northstar. Larger airgun arrays were used during the deep seismic surveys in 2007–2008 than during shallow hazards surveys. These activities and associated marine mammal monitoring were discussed in annual 90-day reports (Patterson et al. 2007; Funk et al. 2008; Ireland et al. 2009).

In 2008 ocean bottom cable (OBC) seismic surveys were conducted by Eni in eastern Harrison Bay (Hauser et al. 2008) and by BP in Foggy Island Bay (Aerts et al. 2008). The Eni and BP OBC surveys occurred ~40 km (25 mi) west and east of Northstar, respectively. Airgun sources used during the OBC surveys were intermediate in size between the larger airgun arrays used by during deep seismic surveys and smaller arrays used during shallow hazards surveys.

In 2008, ExxonMobil began limited barge traffic from West Dock eastward to Point Thomson in support of development activities. This activity was continued in the open-water period of 2009.

Various other types of barge activity occurred in the Beaufort Sea in support of government facilities at Point Lonely and Bullen Point, and for the villages of Barrow and Kaktovik. Several barges (and other vessels) also transited the Alaskan Beaufort Sea annually enroute to or returning from Canada.

Aerial Surveys

The USFWS conducted low-level, aerial surveys for polar bears along the Beaufort Sea coast and barrier islands from Barrow to the Canadian border during the late fall of 2005 and 2006 using a twin-engine TurboCommander aircraft. During each 2-day survey, the aircraft passed briefly through the Northstar area.

The Minerals Management Service (MMS), in cooperation with the National Marine Mammal Laboratory in recent years, has conducted the Bowhead Whale Aerial Survey Program (BWASP) during the bowhead fall migration annually since 1979. (In the early years, before formation of MMS, BWASP was sponsored by the Bureau of Land Management.) These surveys are conducted along north/south (approximately) tracklines from Barrow into Canadian waters, including the Northstar area, with adjacent tracklines being spaced an average of about 18.5 km (12 mi) apart. The survey season, in most recent years, has extended from late Aug. to mid-Oct. Information on the BWASP surveys is available online at http://www.afsc.noaa.gov/NMML/cetacean/bwasp/flights_BWASP.php.

The Bowhead Whale Feeding Ecology Study (BOWFEST) was initiated in the Barrow area in 2007 and was ongoing in 2009 (Rugh 2010). BOWFEST is a multiyear MMS-funded study that focuses on late summer oceanography and prey densities relative to whale distribution over continental shelf waters within 160 km (100 mi) north and east of Point Barrow. BOWFEST involves both aerial and vessel-based activities, but that work does not approach the Northstar area.

Aerial surveys in support of offshore seismic surveys were conducted by Shell during the open-water seasons of 2006–2008. Pioneer and Eni cooperated with Shell in sponsoring the aerial surveys done during 2008. The surveyed area varied among years and dates but included locations from eastern Harrison Bay to Kaktovik including, at times, the Northstar area during the bowhead migration season. Results of these surveys were presented in 90-day reports each year (Patterson et al. 2007; Funk et al. 2008, Ireland et al. 2009).

Pioneer also conducted aerial surveys offshore of the Colville River Delta in 2006 and 2007 in support of their Oooguruk development. Results of these surveys were reported by Reiser et al. (2008) and Williams et al. (2008).

Vessel-based Surveys

Vessel-based monitoring in support of offshore seismic survey activity was conducted by Shell at several locations from eastern Harrison Bay to Camden Bay during 2006 through 2008 (Patterson et al. 2007; Funk et al. 2008, Ireland et al. 2009) with a limited effort in 2009. Eni also conducted vessel-based monitoring in support of OBC seismic exploration offshore of the Colville River Delta in 2008 (Hauser et al. 2008), as did BP in Foggy Island Bay (Aerts et al. 2008).

In 2005 and 2006, MMS funded boat-based surveys to collect water, sediment, tissue, and plankton samples for physical and chemical analyses (Neff et al. 2009). This work occurred at various locations from the Northstar area east to Barter Island. In 2005, the surveys were conducted from 26 July to 14 Aug., with sampling in the Northstar area on 4, 10, and 11 Aug. In 2006, the surveys were conducted from 24 July to 12 Aug., with sampling in the Northstar area on six days from 31 July to 10 Aug. 2006.

Acoustic Monitoring

Shell conducted underwater acoustic monitoring with arrays of DASARs deployed offshore at five sites widely spaced from eastern Harrison Bay to the Kaktovik area during 2007 through 2009 (e.g., Blackwell et al. 2009), with preliminary work in 2006 (Greene et al. 2007). This work was supported in part by Eni and Pioneer in 2008. The seafloor recorders documented ambient and industrial sounds plus bowhead whale calls, and provided the data needed to localize bowhead calls. This work was ongoing in 2009 and a report on the recent work will be forthcoming.

In 2008, Pioneer and Eni also collected data on underwater sounds produced from vessels, on-island activities, and seismic exploration activities. A report on these underwater acoustic studies will be forthcoming.

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ANNEXES 2.1 – 2.5: REPORTABLE SPILLS

ANNEX 2.1. Reported spills at Northstar during the 2005 open-water season. Specific information on eight spills during the 2004–2005 ice-covered period was not available.

Date	Description/Source	Gal. Out of Containment	Gal. In Containment
16 June 2005	Lube oil from compressor seal leak	0.1	0.9
21 June 2005	Hydraulic fluid from excavator fitting	1.5	0
4 Sept. 2005	Diesel from TEG reboiler	0.5	0
6 Sept. 2005	Crude and produced water from test header valve	1	0
25 Sept. 2005	Corrosion inhibitor inside plant	0	0.06

ANNEX 2.2. Reported spills at Northstar during the 2005/06 reporting period.

Date	Description/Source	Material	Gallons Out of Containment	Gallons in Containment
26 Nov. 2005	Leak in pipe connec-tion from lift station	Sewage	10	100
8 Dec. 2005	Pin hole leak in weld	Scale Inhibitor	0	0.25
20 Dec. 2005	O-ring failure	Anti-foulant	0	2
26 Dec. 2005	Loose ring on top of tote	Corrosion inhibitor	0.004	
3 Jan. 2006	Broken hose fitting on dozer	Hydraulic oil	0.5	
4 Jan. 2006	Broken hose fitting on dozer	Hydraulic oil	0.75	
24 Jan. 2006	Mud spilled onto floor during process drilling	Drilling mud	0.2	167.8
31 Jan. 2006	Battery fell off pallet	Sulfuric acid	0.01	
5 Feb. 2006	Valve misalignment between pits	Drilling mud	0	5
26 Feb. 2006	Incorrect installation of fuel line	Diesel fuel	0	180
3 Apr. 2006	Acid release during transport	Hydrochloric acid	1	
6 Apr. 2006	Cracked weld due to pump vibration	Hydrochloric acid	0	1
27 Apr. 2006	Mud line valve failure	Drilling mud	55	55
5 May 2006	Release during fueling operation	Diesel fuel	2	
15 May 2006	Cap not secured	Corrosion inhibitor	0.01	
15 May 2006	Leak from trencher fuel tank	Diesel fuel	0.06	
20 May 2006	Loose fitting	Hydraulic oil	0.03	
26 June 2006	Pump failure during transfer of scale inhibitor	Scale inhibitor	0	0.25
29 Aug. 2006	Leak in chemical injection line at DS-11	Corrosion inhibitor	0	0.125
19 Sept. 2006	Oil filter on loader failed	Lube oil	3	1

ANNEX 2.3. Reported spills at Northstar during the 2006/07 reporting period.

Date	Location	Material	Quantity Released	Clean Up Action
18 Nov. 2006	Northstar Pad	Drilling Mud	3.79	Material was scraped and placed in cuttings bin.
19 Nov. 2006	Northstar Process 33 m (109 ft) level	Corrosion Inhibitor	0.95	Absorbed and placed in oily waste bags.
9 Dec. 2006	Drilling rig roof and ground north of rig	Drilling Mud	317.97	Scraped area and put into storage bin for future onsite disposal.
27 Dec. 2006	Between process module and overhead pipe rack	Sewage	18.93	Shovels were used to scrape frozen treated effluent and material was taken to the Northstar G & I (Grind & Inject) facility.
18 Jan. 2007	Northstar well row	Corrosion Inhibitor	1.89	Sorbents were used to clean piping and gravel under the well house grating.
21 Jan. 2007	Well row in front of NS-14	Methanol	0.95	All material captured in containment.
1 Feb. 2007	NS-16 well house	Corrosion Inhibitor	0.12	Contaminated gravel cleaned up.
5 Feb. 2007	Ice road 9.1 m (30 ft) east of Northstar	Motor Oil	3.79	Most captured in 5-gal bucket; pads used to absorb ~0.47 l (1 pt) of remaining fluid.
5 Feb. 2007	Ice road 30.5 m (100 ft) west of Northstar	Diesel	3.79	Diesel-contaminated ice removed to bin and sent to G & I facility.
17 Feb. 2007	Pit #3, service module rig N33E, Well NS-33	Drilling Mud	1022.06	Free liquids sucked and transferred to G & I facility. Mops and sorbents used to wipe remaining drilling mud from the rig floors and walls.
14 Mar. 2007	Pad between warehouse and process building	Sewage	7.57	Shovels and chipping bars used to remove affected snow and ice. Material stored for later processing in G & I facility.
22 Mar. 2007	22.9 m (75 ft) east of southeast access ramp to island	Hydraulic Fluid	<0.00	Shovel used to scrape contaminated snow. Sorbents used to wipe backhoe.
11 Apr. 2007	Southeast access ramp to island	Lube oil	2.84	Loader with bucket used to scrape affected ice; shovels used to place contaminated materials into bins for processing.
20 Apr. 2007	Sea ice at southeast side of island	Hydraulic Fluid	7.57	Loader and bobcat used to scrape contaminated snow and ice for transfer to G & I facility.
22 Apr. 2007	Sea ice at southeast corner of island	Propylene Glycol	1.89	Sorbents, bobcat, and small hand tools used to clean and scrape affected area.
25 Apr. 2007	NS-18 well head corrosion inhibitor system	Corrosion Inhibitor	0.23	Absorbents and small hand tools used to scrape contaminated gravel.
4 May 2007	Sea ice 18.3-22.9 m (20-25 yd) northeast of Northstar	Hydraulic Fluid	0.95	Removed ~0.76 m^3 (1 yd^3) of contaminated snow.
18 May 2007	Sea ice ~61 m (200 ft) southeast of island	Hydraulic fluid	0.95	Shovels used to scrape contaminated snow and ice. Sorbents used to soak materials on surface of water.

ANNEX 2.3. Continued.

Date	Location	Material	Quantity Released	Clean Up Action
20 May 2007	On pad northwest of warehouse and adjacent sea ice	Diesel	0.38	Shovels used to scrape contaminated snow, ice, and gravel.
20 May 2007	Sea ice ~22.9 m (75 ft) west of bench.	Hydraulic Fluid	0.04	Sorbents used to soak sheen and shovels used to scrape contaminated snow and ice.
1 June 2007	Sea ice at east side of island	Hydraulic fluid	0.47	Shovels used to scrape contaminated snow.
9 Aug. 2007	NS-05	Hydrochloric Acid	0.11	Acid was neutralized then soaked up with sorbents.
10 Aug. 2007	NS-11 well head	Corrosion Inhibitor	1.89	Sorbents used to soak up material.
12 Aug. 2007	NS-29 well cellar	Diesel	37.85 1589.87	Liquids recovered using air actuated drum vacuum. Remaining fluids soaked up with sorbents.
17 Oct. 2007	Process module	Corrosion Inhibitor	0.95	Sorbents and oily waste bags.

ANNEX 2.4. Reported spills at Northstar during the 2007/08 reporting period.

Date	Location	Material Released	Volume Released (Gallons)	Did Release reach Beaufort	Clean Up Action
15 Nov. 2007	Process Module	Corrosion Inhibitor	0.05	No	Spilled material was collected with sorbents
31 Dec. 2007	Northstar Ice Road	Power Steering Fluid	3	Yes	Contaminated snow and ice was scraped up with shovels and placed into oily waste bags. These bags were transported to Northstar island for disposal.
1 Jan. 2008	NS-20 Well Cellar	Corrosion Inhibitor	0.035	No	Sorbent was used to collect material (100% spilled to lined well cellar).
9 Jan. 2008	Process Module	Tri-ethylene Glycol (TEG)	500	No	Majority of spilled material was captured in drums (480 gallons). The amount that reached the module floor was cleaned up with sorbents.
13 Apr. 2008	Northstar Utility Module & Underlying Pad	Sewage	200	No	Majority of spilled material was captured in containment (180 gallons). The amount outside the containment was allowed to freeze on pad, and was then chipped up and taken to the disposal well.
17 May 2008	Process Module	Corrosion Inhibitor	4	No	100% of the material spilled to containment - easily collected for disposal
24 June 2008	Gravel pad between utility module & 38 man camp	Sewage	2	No	Impacted area was disinfected with 10:1 Chlorox bleach solution. Disinfected liquids were then wiped off of concrete footing with sorbents.
9 Aug. 2008	Seawater in front of Northstar Dock	Hydraulic Fluid	0.25	Yes	Sorbent materials were used to clean affected areas of backhoe and barge surfaces. Sorbent boom was used sweeping back and forth inside containment boom to recover sheen in water.
18 Aug. 2008	North Process Module	Corrosion Inhibitor	0.004	No	Fluids collected (100% spilled to containment) using sorbent materials.

ANNEX 2.5. Reported spills at Northstar during the 2008/09 reporting period.

Date	Material Released	Did Release reach Beaufort Sea or Sea Ice
11 Jan 2009	Oil leak on high pressure compressor	No
17 Feb. 2009	Hydraulic spill from snowblower	No
3 Apr. 2009	Tri-ethylene glycol leak	No
22 Apr. 2009	5-Gal container leaked inside hazchem storage building	No
3 May 2009	Corrosion inhibitor release	No
6 May 2009	Wastewater spill from utility floor drain sump	No
17 May 2009	Arktos 3A vehicle hydraulic leak	No
19 May 2009	Glycol leak from ruptured radiator hose	No
23 May 2009	Small leak of produced water and condensate	No
23 May 2009	Motor oil leak from oil line to cab heater	No
24 May 2009	Fitting failure on pipe lift	No
26 May 2009	Fuel release from water jetting pump for divers	Yes
5 June 2009	Leak from triplex bleed hose	No
20 June 2009	Lube oil release from low pressure compressor	No
16 July 2009	Hydraulic leak at NS-13 well control panel	No
5 Sept. 2009	Hydraulic leak	No
7 Sept. 2009	Hydraulic leak	No
9 Sept. 2009	Wash water from tank cleaning leaked from hose into secondary containment	No
28 Sept. 2009	Leak from NS-27 wellhead hydraulic control panel	No
2 Oct. 2009	Gas release from needle valve	No
2 Oct. 2009	Hydraulic leak at NS-18 well control panel	No
3 Oct. 2009	Hydraulic leak at NS-19 well control panel	No
27 Oct. 2009	Hydraulic leak on man lift	No
28 Oct. 2009	Gray water leaking from soffit area under PLQ	No
29 Oct. 2009	Hydraulic fluid leak from Volvo loader	No
12 Nov. 2009	Leak on corrosion inhibitor level indicator valve union	No
7 Dec. 2009	Sewage discharge line failure	No
13 Dec. 2009	Hydraulic tubing valve failure at NS-30 panel	No

CHAPTER 3:

SEAL SIGHTINGS, 2005–2009 [1]

by

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ABSTRACT

During the planning stages of the Northstar project, BP and stakeholders had concerns regarding the potential for activities associated with construction and oil production to result in disturbance to seals and other marine mammals. Authorizations issued to BP for potential "taking" of seals during construction and operation of Northstar required studies and monitoring to assess effects on seals and on subsistence hunting. To satisfy the requirements, BP conducted several studies prior to and during construction and operation of Northstar. Systematic fixed-wing aerial surveys were used to study the distribution and abundance of seals around Northstar. The fixed-wing surveys in 1997–1999 provided three years of pre-development "baseline" data, and surveys in 2000–2002 provided three years data with construction and then oil production activity. To complement the aerial survey program on a finer scale, specially-trained dogs were used to find seal holes and lairs, and to monitor the fate of structures in relation to distance from industrial activities during the ice-covered seasons of 1999–2000 (initial construction) and 2000–2001 (later stages of construction). After these intensive studies were completed, NMFS and stakeholders concurred with BP's conclusion that it was not necessary to continue the types of intensive seal studies that had been done through 2002. However, BP continued to observe and count seals near Northstar to provide assurance that seal use of the area was similar in subsequent years to that found up to 2002.

This chapter reports on the results of seal observations from Northstar during 2005–2009. Northstar Environmental Specialists observed and counted seals from the top of the 33 m (109 ft) high process module. The observation period varied among years. Results from the 15 May through 15 July period are reported here to maintain consistency in observation periods for comparisons among years, although 2005 was an exception in that observations did not begin until 3 June. The total number of seals recorded varied considerably from year to year, ranging from three seals in 2007 to 811 in 2009, with no consistent trend across the five years of observations. Relatively few seals were observed in 2006 and 2007 compared to other years, and more seals were recorded in 2009 than all other years combined. The numbers of seals seen during a given day's observation period were highly variable ranging from zero to 124. Seal sighting rates in 2006 and 2007 were relatively low during all half-monthly periods of observation. For the years when the largest numbers of seals were recorded (2005, 2008 and 2009), relatively few seals were recorded in the latter half of June 2005 and in the first half of July 2008. The relatively high number of seals seen per day in July 2005 resulted from a single sighting of 124 seals on an ice floe on 11 July. The larger numbers of seals were generally recorded in groups congregated on ice floes that remained as the sea ice melted. The observations confirm that ringed seals continue to haul out on ice and bask within approx. 1 km (0.6 mi) of Northstar during the late spring and early summer. Numbers that do so vary from year to year, probably as a function of ice conditions.

INTRODUCTION

Three species of seals occur in the Northstar region. The ringed seal *Phoca hispida* (=*Pusa hispida*) is an abundant year-around resident of the area, although some individuals may migrate away in winter. The bearded seal *Erignathus barbatus* is a somewhat less abundant summer resident, but a few individuals may remain (mainly offshore in the pack ice) during winter. The spotted seal *Phoca largha* is a migratory species that occurs in the region during summer in small numbers, but is not present in winter. All three species are protected under the U.S. Marine Mammal Protection Act (MMPA). All three species (but especially ringed and bearded seals) are hunted in the Beaufort Sea by Inupiat subsistence hunters (Lentfer [ed.] 1988).

During the planning stages of the Northstar project, BP and stakeholders had concerns regarding the potential for activities associated with construction and oil production to result in disturbance to seals and other marine mammals. Ringed seals occupy the Beaufort Sea throughout the year and maintain breathing holes in the ice during winter months. It was suspected that noise and activities at or near Northstar would be detectable to ringed seals during both the ice-covered and ice-free seasons. However, the potential for disturbance to seals might be greater during winter: Ringed seal movements are more confined during winter due to their reliance on breathing holes, whereas seal movements are unrestricted during the open-water periods. Prior to construction, BP anticipated that disturbance to seals would be considered "Level B" harassment under the MMPA. Consequently, BP requested that the National Marine Fisheries Service (NMFS) issue incidental take authorizations to BP, authorizing "harassment takes" of small numbers of seals as a result of disturbance associated with construction and (subsequently) production activities at Northstar. Chapter 1 summarizes the sequence of authorizations that were issued by NMFS, initially an Incidental Harassment Authorization and subsequently a set of Regulations under which Letters of Authorization could be issued annually.

The authorizations issued to BP for potential "taking" of seals during construction and operation of Northstar required studies and monitoring to assess the nature and the geographic and numerical extent of any effects on seals and on subsistence hunting. The studies done before and during the early years of Northstar construction and production were designed to address the effects on seals. BP's studies included (1) acoustic measurements of underwater and in-air sounds and iceborne vibrations, (2) fixed-wing aerial surveys to document local distribution and abundance of basking seals on ice during spring before and after onset of industrial activities, and (3) dog-based studies of ringed seal utilization of ice holes and lairs as a function of distance from Northstar. These studies provided much new information about, respectively, industrial sounds and vibrations that might affect seals, seal distribution and haulout patterns in spring, and the dynamics of spring seal occupancy of "structures" in the sea ice (Richardson [ed.] 2008). These studies also provided data relevant in assessing the potential for seals to be affected sufficiently to have implications for subsistence hunting. It was later determined that little or no subsistence hunting for seals occurs near Northstar.

Acoustic measurements were undertaken in 2000 to 2002 to document the levels, characteristics, and range-dependence of sounds and vibrations produced by Northstar-related activities during both the ice-covered season and the open-water season. Measurements were made during initial construction activities in early 2000 (Greene and McLennan 2000; Greene et al. 2008), and during subsequent construction, drilling and production operations in 2001 and 2002 (Blackwell and Greene 2002; Blackwell et al. 2004).

Systematic fixed-wing aerial surveys were used to study the distribution and abundance of seals around the Northstar. The surveys began in 1997 to provide pre-development "baseline" data (Miller et al. 1998). The surveys were continued each year from 1997 through 2002, collectively providing three years of pre-development data (1997–99) and three years with construction and then oil production activity (2000–02). The results of the aerial surveys were described in a series of annual reports included as Appendices to Richardson (ed., 2008) and in peer-reviewed articles by Moulton et al. (2002, 2003, 2005). The results of the aerial surveys suggested that Northstar's effects on seal distribution and abundance during spring were essentially undetectable even with unusually intensive aerial surveys followed by analyses that had high statistical power.

To complement the aerial survey program on a finer scale, specially-trained dogs were used to find seal holes and lairs, and to monitor the fate of structures in relation to distance from industrial activities during the ice-covered seasons of 1999–2000 (initial construction) and 2000–2001 (later stages of construction). Use and densities of seal structures at distances beyond 100–200 m from Northstar facilities did not appear to be affected by Northstar construction activities (Williams et al. 2006a,b).

After these intensive studies were completed, NMFS and stakeholders concurred with BP's conclusion that it was not necessary to continue the types of intensive seal studies that had been done up to 2002. However, BP continued to report seal observations near Northstar in annual reports in order to provide assurance that seal use of the area was similar in subsequent years to that found up to 2002. These observations were obtained in mainly spring and early summer, when seals bask on sea ice. In 2002–03 and 2003–04, BP requested that personnel working at Northstar report seal observations, which were compiled in monthly reports for those years (Annex 3.1 *in* Williams et al. 2006b). These opportunistic sightings were made at or near Northstar and along the ice road during Oct. and Nov., and Apr. through June 2002–2004. Beginning in spring 2005, BP arranged for personnel at Northstar to make more systematic near-daily (weather permitting) seal observations from the roof of the process module on Northstar Island during spring and early summer. The results of those observations from 2005 through 2009 were reported annually by BP (see Chapter 1 in each of Richardson [ed.] 2006, 2007; Aerts and Richardson [eds.] 2008, 2009, 2010; included as Appendices B–F on the CD-ROM accompanying this report). Those results are summarized below.

METHODS

Northstar Environmental Specialists, on behalf of BP, observed and counted seals from the top of the 33 m (109 ft) high process module. The observation period varied among years. In 2005 the period extended from 3 June through 22 Aug. In 2006, it began and ended earlier, extending from 1 May through 20 July. In 2007, observations extended from 6 May through 31 July. No seals were observed after 15 July in 2005 through 2007, so in 2008 and 2009 observations were confined to the period from 15 May through 15 July. Only results from the 15 May through 15 July period are reported here to permit (with the exception of 2005) comparisons among years. As noted above, during 2005 observations did not begin until 3 June.

The protocol for systematic seal counts was developed in 2005 and, aside from the date range with observations, most aspects have remained the same through 2009. The protocol included the following:

- Count the number of basking seals from 15 May to 15 July on a near-daily basis.
- Counts were usually done between 11:00 and 19:00 local time for at least five days per week, when practicable.
- Counts were restricted to periods with cloud ceiling >91 m (300 ft).

- Counts were made through a 360° field of view from the roof of the Northstar process module, considering areas within a radius of ~950 m (3116 ft) covering an area of ~281 ha (695 acres).
- An inclinometer was used to determine distance of a sighting from the observation platform. From the platform, a 2° depression angle corresponded to a distance of ~950 m or 3116 ft.
- Observers scanned with the unaided eye, and used binoculars to confirm suspected seal sightings.
- Observers recorded date and time of observation period, sky conditions, temperature (°F), number of seal sightings, and relevant comments.

RESULTS

The number of days with observations during the 15 May to 15 July period ranged from a low of 42 in 2005 to a high of 61 in 2009 (Table 3.1; Annexes 3.1–3.5). The observations likely included many repeat sighting of individual seals on different days. The total number of seals sighted varied annually ranging from three seal sightings in 2007 to 811 in 2009, with no consistent trend across the five years of observations. The annual totals did not appear to be a function of observation effort. For example, there was little difference in observation effort in 2007 (57 days) when seal sightings were least common compared to 2009 (61 days) when the highest total number of seals was recorded. Relatively few seals were observed in 2006 and 2007 compared to other years, and more seals were recorded in 2009 than all other years combined.

TABLE 3.1. Summary of seal data collected from Northstar in the period 15 May to 15 July during 2005 to 2009. Source: Aerts (2010).

Year	Total # of seals	Total obs. days	Mean # seals/day	Max. # observed on any day	Standard deviation
2005	229	42	5.5	124	19.4
2006	54	49	1.1	4	1.2
2007	3	57	0.1	1	0.2
2008	415	54	7.7	63	15.1
2009	811	61	13.3	87	25.7

The numbers of seals seen during a given day's observation period were highly variable ranging from zero to 124. Seal sighting rates in 2006 and 2007 were relatively low during all half-monthly observation time periods. The highest numbers of seals were reported during the last half of June and the first half of July, although the trend was not consistent among years (Fig. 3.1). For the years when the largest numbers of seals were recorded (2005, 2008 and 2009), relatively few seals were recorded in the latter half of June 2005 and in the first half of July 2008. The relatively high number of seals seen per day in July 2005 resulted from a single sighting of 124 seals on an ice floe on 11 July.

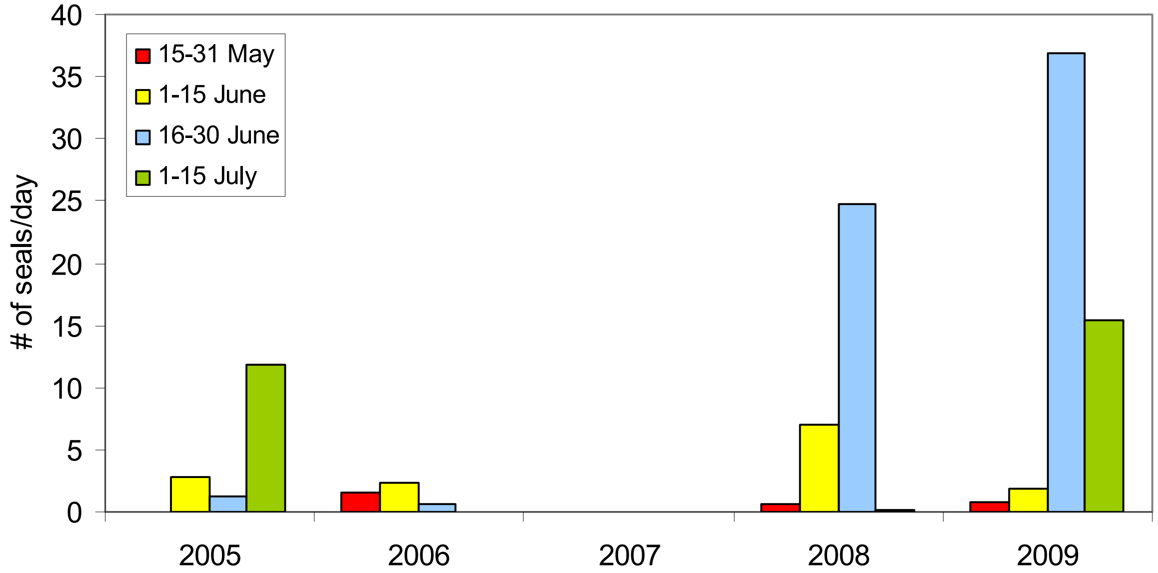

FIGURE 3.1. Average number of seals observed per day from Northstar Island, by half-month, from 15 May to 15 July during 2005 through 2009. In 2005 observations started 3 June and data were not available for the 15 May–2 June period. Other "missing" bars (1–15 July 2006 and 2008, and all periods in 2007) indicate zero or near zero seal sighting rates. Source: Aerts (2010).

DISCUSSION

The numbers of seals seen during different dates within specific years varied widely, as indicated by the fairly wide standard deviations in daily counts (Table 3.1). In 2005 through 2007, during observation periods in which seals were observed, the number of seals sighted was usually low, ranging from one to four seals (Annex 3.1). The relatively high average number seen per day in July 2005 resulted from a sighting of 124 seals on ice floes on 11 July. Seventeen and 30 seals were reported on 8 and 10 July 2005, respectively, but no more than four seals were observed on any other day in 2005. The highest seal count during any observation period in 2006 was four, and in 2007 the highest count was one.

In contrast to 2005–2007, relatively large numbers of seals were seen (and were seen more consistently) in 2008 and 2009. In 2008, ten or more seals were recorded during 11 days and more than 30 seals were recorded on six days. In 2009, 30 or more seals were recorded during 13 days and 50 or more seals were recorded on eight days. Reasons for the consistently higher numbers of seals present in late June and July 2008 and 2009 are not known with certainty, but may be related to differences in local ice conditions or other environmental variables among years. The larger numbers of seals were generally recorded in groups congregated on ice floes that remained as the sea ice melted (Annexes 3.1, 3.4, 3.5).

Based on the observations during each of the five years summarized here, it was concluded that there was no evidence (and no reason to suspect) that any seals were injured or killed by Northstar-related activities (see Chapter 1 *in* Richardson [ed.] 2006, 2007; Aerts and Richardson [eds.] 2008, 2009, 2010). A dead seal pup was reported an estimated ½ mile (0.8 km) from the island on 19 June 2009 (Annex 3.5), but there was no reason to attribute its death to Northstar activities.

The seal observation program at Northstar in 2005–2009 was intended to verify continuing use of the region near Northstar by seals, and to serve as a "warning system" if there were any pronounced changes in seal use of the area. The observations confirm that ringed seals continue to haul out on ice and bask within approx. 1 km (0.6 mi) of Northstar during the late spring and early summer. Numbers that do so vary from year to year, probably as a function of ice conditions.

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Dr. Bill Streever of the BP Environmental Studies Group has supported this project since 2001 and provided comments on earlier related reports that are incorporated here. The protocol for seal observations by Northstar personnel was developed by Mike Williams. Seal observations were conducted by Phil Hubbard, Hunter Ervin, and Joe Serra. Dr. W. John Richardson and Sheyna Wisdom of LGL reviewed drafts of this chapter, and Anne Wright of LGL assisted with chapter layout.

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ANNEX 3.1. Numbers of seals recorded by Northstar observers, 3 June through 22 Aug. 2005. Dates are Mo/Day/Yr. Sky codes OO= overcast, PS= partly sunny, PC= partly cloudy, CC= clear. RS = ringed seal.

Date	Time	Sky	Temp (ºF)	Species	Number	Comments
6/3/2005	11:30	OO	32F	RS	2	NW and W of Island
6/4/2005	11:00	PS	33F	RS	2	NE and W of Island
6/5/2005	13:00	PS	32F	RS	3	NW, NE, and W of Island
6/6/2005	11:30	OO	28F	RS	3	NW, NE, and W of Island
6/7/2005	13:30	PS	34F	RS	3	NW, NE, and W of Island
6/9/2005	12:05	PS	40F	RS	4	2 on NE (1 In Construction Moat) 2 on NW
6/10/2005	12:00	OO	34F	RS	3	1 on NE, 2 on NW
6/11/2005	12:30	OO	35F	RS	3	1 on NE, 2 on NW (Same places as prior days)
6/12/2005	12:15	OO	33F	RS	3	1 on NE, 2 on NW (Same places as prior days)
6/13/2005	13:00	OO	35F	RS	3	1 on NE, (Same places as prior days)
6/14/2005	13:00	OO (FOG)	36F	RS	2	1 on NE, 1 on NW
6/15/2005	13:30	CC	35F	RS	2	1 on NE, 1 on NW
6/16/2005	13:00	OO	35F	RS	1	1 on NW
6/17/2005	13:30	CC	36F	RS	2	1 on NE, 1 on NW
6/18/2005	13:45	CC	35F	RS	2	1 on NE, 1 on NW
6/19/2005	12:45	OO	34F	RS	2	1 on SW Approx 100' Small Pup. Raises head when hovercraft passes but then back to normal basking. 1 on NW side
6/20/2005	13:30	CC	36F	RS	1	1 Pup on SW
6/21/2005	13:00	OO	38F	RS	0	
6/22/2005	13:45	OO	31F	RS	2	1 Pup on SW. 1 on SE
6/23/2005	12:30	OO (FOG)	32F	RS	4	1 Pup on SW. 1 on SE. 1 on W. 1 on NW
6/24/2005	13:30	CC	36F	RS	2	1 Pup on SW. 1 on SE
6/25/2005	13:30	CC	36F	RS	1	1 Pup on SW
6/26/2005	13:30	OO	38F	RS	1	Ceiling<300',1 Pup on SW
6/27/2005	13:30	CC	43F	RS	0	
6/28/2005	13:30	CC	47F	RS	0	
6/29/2005	13:00	CC	46F	RS	0	
6/30/2005	13:20	OO	44F	RS	0	
7/1/2005	13:30	CC	48F	RS	0	
7/2/2005	13:50	OO	35F	RS	2	Rain & Light snow today Small area of open water S of the island Seals were observed swimming
7/3/2005	13:50	OO	32F	RS	2	Small area of open water S of the island Seals were observed swimming
7/4/2005	13:30	OO	35F	RS	0	Rain
7/5/2005	13:40	OO	41F	RS	0	Rain
7/6/2005	13:30	OO	33F	RS	0	Thick Fog, Low Ceiling (<300') During Observation
7/7/2005	13:30	CC	38F	RS	0	

ANNEX 3.1. Concluded.

Date	Time	Sky	Temp (ºF)	Species	Number	Comments
7/8/2005	14:30	OO	34F	RS	17	10 Sighted basking on an ice flow passing on the N/E, 7 Sighted basking on an ice flow passing on the S/W Winds blowing from W @ 17 - 25 mph lots of moving ice.
7/9/2005	13:00	OO	35F	RS	0	
7/10/2005	12:30	OO	37F	RS	30	30 Sighted basking on an ice flow passing on the South / West. Ice has been flowing back and forth all day
7/11/2005	12:30	OO	38F	RS	124	40 Sighted basking on an ice flow passing on the East, 6 Sighted basking on an ice flow passing on the North, 40 Sighted basking on an ice flow passing on the West, 38 Sighted basking on an ice flow passing on the South/West The ice was flowing past in la
7/12/2005	12:30	OO	38F	RS	0	
7/13/2005	13:30	CC	39F	RS	2	South East on ice flow basking
7/14/2005	13:00	OO	41F	RS	0	
7/15/2005	14:00	OO	41F	RS	1	Swimming South of the island
7/16/2005	13:30	OO	37F	RS	0	
7/17/2005	13:30	OO	35F	RS	0	Mostly open water with small ice chunks floating by
7/18/2005	14:00	OO	38F	RS	0	Mostly open water with small ice chunks floating by
7/19/2005	13:30	CC	32F	RS	0	Mostly open water with small ice chunks floating by
7/20/2005	12:00	CC	38	RS	0	
7/30/2005	15:00	OO	41F		0	Mostly open water with small ice chunks floating by
8/1/2005	12:30	PC	40F		0	Mostly open water with small ice chunks floating by
8/5/2005	9:00	OO	45F		0	Open Water
8/9/2005	10:00	PC	55F		0	Open Water
8/13/2005	13:00	OO	55F		0	Mostly open water with small ice chunks floating by
8/16/2005	13:00	OO	37F		0	Mostly open water with small ice chunks floating by
8/18/2005	15:00	OO	41F		0	Open Water
8/19/2005	8:00	OO	33F		0	Open Water
8/22/2005	10:00	OO	41F		0	Open Water

ANNEX 3.2. Numbers of seals recorded by Northstar observers, 1 May through 20 July 2006. Dates are Mo/Day/Yr. Sky codes OO= overcast, PS= partly sunny, PC= partly cloudy, CC= clear. RS = ringed seal.

Date	Time	Sky	Temp (ºF)	Species	Number	Comments
5/1/2006	14:45	OO	12	RS	1	2.2 Ice Road
5/4/2006	14:45	PC	13		0	
5/5/2006	11:00	OO	12		0	
5/7/2006	13:30	OO	21		0	
5/8/2006	12:30	OO	26	RS	1	Long Way off NE
5/11/2006	13:00	OO	38	RS	1	1.2 Ice Road
5/12/2006	13:00	OO	29		0	
5/13/2006	13:30	OO	28		0	
5/14/2006	13:00	PC	35	RS	1	SW of Island
5/15/2006	13:30	PC	34		2	1 NE, 1 SW of Island
5/16/2006	12:00	OO	27		0	
5/17/2006	14:00	OO	30		0	
5/18/2006	13:30	OO	27	RS	1	1 SW of Island
5/19/2006	13:00	PC	32		0	
5/20/2006	13:00	PC	32	RS	1	1 SW of Island
5/21/2006	12:00	OO	35	RS	3	1 NE, 1NW, 1 SW of Island
5/22/2006	13:00	OO	35	RS	2	1 NE, 1 SW of Island
5/23/2006	13:00	OO	39	RS	2	1 NE, 1 SW of Island
5/24/2006	14:00	PC	43	RS	2	1 NE, 1 SW of Island
5/30/2006	13:00	OO	30	RS	4	1 SE, 1 SW, 1 W, 1 NW of Island
6/2/2006	13:00	PC	36	RS	3	1 SW, 1 W, 1 NW of Island
6/3/2006	13:30	OO	28	RS	3	1 SW, 1 W, 1 NW of Island
6/4/2006	12:30	OO	28	RS	3	1 SW, 1 W, 1 NW of Island
6/6/2006	14:00	PC	43	RS	3	2 W, 1 SW
6/8/2006	14:00	PC	50	RS	4	2W, 1SW, 1SE of Island
6/9/2006	13:30	CC	52	RS	2	1NW, 1SW
6/10/2006	18:00	OO	53		0	
6/11/2006	18:00	OO	54	RS	1	1SW
6/12/2006	14:00	OO	42	RS	3	1SW, 1W, 1NW of Island
6/13/2006	14:00	CC	53	RS	2	1SW, 1 NW
6/14/2006	13:30	OO	43	RS	1	1SW
6/15/2006	14:00	OO	38	RS	3	1SW, 1W, 1NW of Island
6/16/2006	14:00	OO	35		0	
6/17/2006	14:00	OO	38	RS	1	1 NW
6/18/2006	13:30	OO	40	RS	1	1 SW
6/19/2006	14:00	OO	42	RS	1	1 SW
6/20/2006	14:00	OO	44	RS	1	1 SW
6/21/2006	13:30	OO	40	RS	1	1 SW
6/22/2006	13:30	PC	45	RS	1	1 SW
6/23/2006	14:00	PC	45		0	
6/24/2006	14:00	OO	42		0	
6/25/2006	12:30	CC	50	RS	1	1 SW
6/26/2006	12:30	CC	48		0	
6/27/2006	13:30			RS	1	
6/28/2006					0	

ANNEX 3.2. Concluded.

Date	Time	Sky	Temp (ºF)	Species	Number	Comments
6/29/2006					0	
6/30/2006					1	
7/6/2006	15:00	OO/FG	33		0	
7/7/2006	14:00	OO	41		0	
7/8/2006	14:30	OO	41		0	
7/9/2006	14:00	OO	37		0	
7/10/2006	14:00	PC	39		0	
7/11/2006	14:30	CC	41		0	
7/12/2006	13:00	OO/FG	42		0	
7/13/2006	14:30	OO/FG	38		0	
7/14/2006	15:00	OO/FG	47		0	
7/15/2006	15:00	OO/FG	59		0	
7/16/2006	15:30	OO	55		0	
7/17/2006	14:30	OO	53		0	
7/18/2006	15:00	OO/FG	60		0	
7/19/2006	13:00	OO	51		0	
7/20/2006	10:00	PC	37		0	

ANNEX 3.3. Numbers of seals recorded by Northstar observers, 15 May through 31 July 2007. Dates are Mo/Day/Yr. Sky codes OO= overcast, PS= partly sunny, PC= partly cloudy, CC= clear. RS = ringed seal.

Date	Time	Sky	Temp (ºF)	Species	Number	Comments
5/15/2007	13:00	SKC	18	N/A	0	There were a couple of seals sighted along the Nstar Ice Road
5/16/2007	13:00	SKC	23	N/A	0	
5/17/2007	13:00	OVC	23	N/A	0	
5/18/2007	13:30	OVC	20	N/A	0	
5/19/2007	13:30	OVC	30	N/A	0	
5/20/2007	13:30	OVC	23	N/A	0	
5/21/2007	12:00	OVC	25	N/A	0	
5/22/2007	12:30	OVC	23	N/A	0	
5/23/2007	13:00	OVC	23	N/A	0	
5/24/2007	10:00	OVC	23	N/A	0	
5/25/2007	8:30	OVC	28	N/A	0	
5/26/2007	12:30	OVC	28	N/A	0	
5/27/2007	13:30	OVC	30	N/A	0	
5/28/2007	13:00	OVC	29	N/A	0	
5/29/2007	15:30	OVC	28	N/A	0	
5/30/2007	12:00	OVC	31	N/A	0	
5/31/2007	10:30	OVC	26	N/A	0	
6/1/2007	10:30	OVC	28	N/A	0	
6/2/2007	8:30	OVC	30	N/A	0	
6/3/2007	7:30	PS	31	N/A	0	
6/4/2007	15:00	PS	38	N/A	0	
6/5/2007	15:00	PS	39	N/A	0	
6/6/2007	15:00	CC	47	N/A	0	
6/7/2007	13:00	CC	40	N/A	0	
6/8/2007	13:30	CC	39	N/A	0	
6/9/2007	14:00	CC	35	N/A	0	
6/10/2007	13:00	CC	34	N/A	0	
6/11/2007	13:30	PC	22	N/A	0	
6/12/2007	14:00	OO	33	N/A	0	
6/13/2007	13:00	OO	33	N/A	0	
6/14/2007	15:00	OO	34	RS	1	Approximately 1 mile SW of island
6/15/2007	11:30	CC	34	N/A	0	
6/16/2007	12:30	CC	33	N/A	0	
6/17/2007	12:30	CC	33	N/A	0	
6/18/2007	9:00	OO	32	N/A	0	NO VIS
6/19/2007	15:30	CC	41	N/A	0	
6/20/2007	11:00	CC	39	N/A	0	
6/21/2007	14:00	CC	66	N/A	0	
6/22/2007	13:00	PC	45	N/A	0	
6/23/2007	14:30	CC	41	N/A	0	
6/24/2007	13:00	CC	43	N/A	0	
6/25/2007	16:00	CC	41	N/A	0	
6/26/2007	13:00	OO	38	N/A	0	
6/27/2007	13:00	OO	Unk.	RS	1	SW

ANNEX 3.3. Concluded.

Date	Time	Sky	Temp (ºF)	Species	Number	Comments
6/28/2007	9:30	OO	37	N/A	0	
6/29/2007	16:00	OO	39	N/A	0	
6/30/2007	8:15	OO	35	N/A	0	
7/1/2007	11:20	OO	39	N/A	0	
7/2/2007	14:10	OO	44	N/A	0	
7/3/2007	13:30	CC	51	N/A	0	
7/4/2007	12:00	CC	50	N/A	0	
7/5/2007	11:30	CC	44	N/A	0	Lots of ice
7/6/2007	13:00	CC	38	N/A	0	Lots of ice
7/7/2007	13:00	PC W/FOG	42	N/A	0	Mix of open water and large ice
7/8/2007	13:30	PC W/FOG	35	N/A	0	Mix of open water and large ice
7/9/2007	13:50	OO W/FOG	35	N/A	0	Mostly open water with small ice chunks floating
7/10/2007	12:00	OO W/FOG	36	N/A	0	Mostly open water with small ice chunks floating
7/11/2007	14:00	OO W/FOG	34	N/A	0	Open water
7/12/2007	13:00	PC W/FOG	39	N/A	0	Open water
7/13/2007	12:30	OO W/FOG	47	N/A	0	Open water. Ceiling below 300'
7/14/2007	13:00	OO W/FOG	41	N/A	0	Mostly open water. Ceiling below 300'
7/15/2007	14:00	OO W/FOG	39	RS	1	Swimming off south westcorner of island. Mostly open water with medium to small chunks of ice floating by to the west
7/16/2007	13:00		43F	N/A	0	Mostly open water with small ice chunks floating
7/17/2007	14:00	CC	50	N/A	0	Mostly open water with small ice chunks floating
7/18/2007						No Observation made
7/19/2007	15:00	OO W/FOG	43	N/A	0	Open water
7/20/2007	14:00	OO	45	N/A	0	Open water
7/21/2007	14:00	OO	45	N/A	0	Open water
7/22/2007	14:00	OO	42	N/A	0	Open water
7/23/2007	14:00	OO	47	N/A	0	Open water
7/24/2007	14:00	OO	49	N/A	0	Open water
7/25/2007	14:00	OO	50	N/A	0	Open water
7/26/2007	14:00	PC	54	N/A	0	Open water
7/27/2007	14:00	PC	52	N/A	0	Open water
7/28/2007	14:00	OO	50	N/A	0	Open water
7/29/2007	14:00	OO	50	N/A	0	Open water
7/30/2007	14:00	PC	54	N/A	0	Open water
7/31/2007	14:00	OO	46	N/A	0	Open water

ANNEX 3.4. Numbers of seals recorded by Northstar observers, 15 May through 15 July 2008. Dates are Mo/Day/Yr. Sky codes OO= overcast, PS= partly sunny, PC= partly cloudy, CC= clear. RS = ringed seal.

Date	Time	Sky	Temp (ºF)	Species	Number	Comments
5/15/2008	13:00	PC	33	N/A	0	
5/16/2008	13:30	CC	41	N/A	0	
5/17/2008				N/A	0	Too much fog
5/18/2008				N/A	0	Too much fog
5/19/2008	14:15	PC	31	N/A	0	Solid Ice
5/20/2008	11:00	PS	32	N/A	0	Solid Ice
5/21/2008	11:00	PC	32	N/A	0	Solid Ice
5/22/2008	15:30	CC	33	N/A	0	Solid Ice
5/23/2008	8:00	CC	29	N/A	0	Solid Ice
5/24/2008	15:45	CC	43	N/A	0	Solid Ice
5/25/2008	13:00	OO	36	N/A	0	Solid Ice
5/26/2008	10:00	PC	37	RS	1	North of Island on Sea Ice
5/27/2008	10:30	PC	38	N/A	0	Solid Ice
5/28/2008	13:00	PC	31	N/A	0	Solid Ice
5/29/2008	12:15	CC	35	N/A	0	Noticed Seals to the South of Island (3)
5/30/2008	13:15	OO	35	N/A	0	Noticed Seals to the South of Island (2)
5/31/2008	12:50	OO	35	RS	10	Noticed Seals outside Protocol (3)
6/2/2008	14:00	PC	34	RS	7	Solid Ice
6/3/2008	17:30	PS	37	RS	8	Went out around Noon and the fog was lower then 300 feet
6/4/2008	14:30	PS	35	RS	12	Solid Ice/Lots more surface water
6/5/2008		OO	37			Too much fog, lower than 300ft
6/6/2008	12:45	PC	37	RS		Outside perimeter 1
6/7/2008	15:00	OO	38			Fog was lower than 300ft
6/8/2008	14:30	OO	32			Fog was lower than 300ft
6/9/2008	13:30	OO	34			Fog was lower than 300ft
6/10/2008	14:00	OO	36			Fog was lower than 300ft
6/11/2008	13:30	CC	36	RS	5	Outside perimeter 2
6/12/2008	13:00	CC	35	RS	8	North end
6/13/2008	13:00	CC	37	RS	3	Outside perimeter 6, all on North end
6/14/2008	16:15	CC	41	RS	2	Outside perimeter 4, all on North end
6/15/2008	12:30	PC	42	RS	11	Outside perimeter 8,all on North end and West side
6/16/2008	12:30	OO	37			Fog was lower than 300ft
6/17/2008	13:00	PS	41	RS	7	Outside perimeter 6,all on North end and West side
6/18/2008	14:30	PC	32	RS	6	Outside perimeter 3,all on North end and West side
6/19/2008	18:00	PC	48	RS	4	Nothing noticed outside perimeter Ice is very rotten and dirty
6/20/2008	14:00	OO	46	RS	27	Nothing noticed outside perimeter Ice is very rotten and dirty

ANNEX 3.4. Concluded.

Date	Time	Sky	Temp (ºF)	Species	Number	Comments
6/21/2008	13:00	CC	42	RS	34	Nothing noticed outside perimeter Ice is very rotten and dirty
6/22/2008	12:00	PC	36	RS	38	Nothing noticed outside perimeter Ice is very rotten and dirty
6/23/2008	17:00	PC	38	RS	28	Ice is very rotten and a lead is opening to the North
6/24/2008	18:00	PS	38	RS	38	Lots of standing water
6/25/2008	18:00	PS	40	RS	55	Ice is very rotten and a lead is opening to the North and Ice is moving in large pans
6/26/2008	17:30	PS	40	RS	46	Ice is very rotten and a lead is opening to the North and Ice is moving in large pans
6/27/2008	17:00	OO	40		0	Fog was lower than 300ft
6/28/2008	15:00	OO	46		0	Fog was lower than 300ft
6/29/2008	17:00	PS	44	RS	63	Lots of Open Water Seals on Ice Pans to SW and NE
6/30/2008	14:00	PS	42		0	Lots of Open water and no seals sighted
7/1/2008	14:15	PS	39		0	Open water 360 degrees around the Island with floating Ice
7/2/2008	16:00	OO	40		0	Fog was lower than 300ft-Lots of Open Water
7/3/2008	15:45	PS	39		0	Open water 360 degrees around the Island with floating Ice
7/4/2008	15:30	PS	44		1	Open water 360 degrees around the Island with floating Ice
7/5/2008	14:00	PS	45		0	Open water 360 degrees around the Island with floating Ice
7/6/2008	13:00	CC	48		0	Open water 360 degrees around the Island some floating ice
7/7/2008	14:30	CC	50		0	Open water 360 degrees around the Island some floating ice
7/8/2008	16:00	PC	49		0	Open water 360 degrees around the Island some floating ice
7/9/2008	13:15	PC	48		0	Open water 360 degrees around the Island some floating ice
7/10/2008	14:00	PC	46		0	Open water 360 degrees around the Island some floating ice
7/11/2008	14:30	PC	45		0	Open water 360 degrees around the Island some floating ice
7/12/2008	13:30	PC	44		1	Seal floating around south west side
7/13/2008	11:00	PC	46		0	Open water 360 degrees around the Island some floating ice
7/14/2008	12:30	PC	47		0	Open water 360 degrees around the Island some floating ice
7/15/2008	13:00	PC	53		0	Open water

ANNEX 3.5. Numbers of seals recorded by Northstar observers, 15 May through 15 July 2009. Dates are Mo/Day/Yr. Sky codes OO= overcast, PS= partly sunny, PC= partly cloudy, CC= clear. RS = ringed seal.

Date	Time	Sky	Temp (ºF)	Species	Number	Comments
5/15/2009	10:00	OO	23	N/A	0	Soild Ice
5/16/2009	15:30	OO	20	N/A	0	Soild Ice
5/17/2009	11:00	CC	27	N/A	0	Soild Ice
5/18/2009	10:00	PC	41	RS	1	In our man made moat from the bench repair project.
5/19/2009	10:20	CC	40	RS	1	Soild Ice
5/20/2009	9:45	CC	33	N/A	0	Soild Ice
5/21/2009	14:30	PC	28	N/A	0	Soild Ice
5/22/2009	7:00	CC	30	N/A	0	Soild Ice
5/23/2009	7:30	PC	29	RS	1	In our man made moat from the bench repair project.
5/24/2009	14:40	PC	30	N/A	0	Soild Ice
5/25/2009	8:20	PC	31	N/A	0	Soild Ice
5/26/2009	14:30	PC	32	RS	1	In our man made moat from the bench repair project.
5/27/2009	10:20	PC	31	N/A	0	Soild Ice
5/28/2009	7:40	PC	29	N/A	0	Soild Ice
5/29/2009	14:00	PC	31	RS	2	Soild Ice/1 to the South and 1 to the North
5/30/2009	14:30	OO	31	RS	3	Solid Ice/ 2 to the South and 1 to the North
5/31/2009	13:00	PS	38	RS	5	Solid Ice/ 3 to the South and 2 to the North
6/1/2009	12:30	PS	43	RS	5	Solid Ice/ 3 to the South and 2 to the North
6/2/2009	13:00	PS	39	RS	3	Solid Ice/ 2 to the South and 1 to the North
6/3/2009	13:00	PS	29	RS	1	Solid Ice/ 1 to the North
6/4/2009	15:00	PS	37	RS	1	Solid Ice/ 1 to the North
6/5/2009	14:00	OO	33	N/A	0	Soild Ice
6/6/2009	12:30	PC	34	N/A	0	Soild Ice
6/7/2009	18:30	PC	37	RS	2	2 to the South
6/8/2009	11:30	PS	36	RS	1	1 to the South West Corner
6/9/2009	16:30	CC	34	RS	5	3 to the North and 2 to the south West corner
6/10/2009	14:30	OO	33	RS	2	1 to the south west corner 1 to the south east
6/11/2009	16:00	OO	36	N/A	0	Too Much Fog
6/12/2009	13:30	OO	36	RS	3	1 to the north, 2 to the south west
6/13/2009	16:00	OO	34	N/A	0	Too Much Fog
6/14/2009	13:30	OO	36	N/A	0	Lots of water holes on top of ice
6/15/2009	13:00	PC	39	RS	5	4 To the west 1 to the north
6/16/2009	15:00	OO	33	RS	1	South of island
6/17/2009	16:20	OO	36	RS	3	2 to the north, 1 to south
6/18/2009	15:50	PC	41	RS	3	2 to the north, 1 to south

ANNEX 3.5. Concluded.

Date	Time	Sky	Temp (ºF)	Species	Number	Comments
6/19/2009	14:00	PC	36	RS	6	2 to the north, 2 to south, and 1 East (1 Dead Pup to the South 1/2 mile off Island)
6/20/2009	13:00	OO	29	RS	35	10 to the SE, 10 to the NE, 10 to the NW, and 5 to the SW
6/21/2009	14:00	OO	32	RS	36	10 to the SE, 10 to the NE, 10 to the NW, and 6 to the SW
6/22/2009	14:00	OO	32	N/A	0	Too Much Fog
6/23/2009	12:30	OO	33	RS	65	18 to the NE, 22 to the NW, 4 to the SW, and 21 to the SE
6/24/2009	14:30	OO	34	RS	52	13 to the NE, 15 to the NW, 4 to the SW, and 20 to the SE
6/25/2009	14:00	OO	35f	RS	63	18 to the NE, 20 to the NW, 4 to the SW, and 21 to the SE
6/26/2009	16:00	OO	36	RS	82	26 to the NE, 31 to the NW, 4 to the SW, and 21 to the SE
6/27/2009	14:30	PS	37	RS	87	26 to the NW, 31 to the SE, 3 to the SW, and 27 to the SE
6/28/2009	14:00	PS	38	RS	50	13 to the NE, 15 to the NW, 4 to the SW, and 18 to the SE
6/29/2009	15:30	PS		RS	2	To the N. Lot of Fog
6/30/2009	1230	CC	38	RS	68	10 to the NE, 33 to the NW, and 21 to the SE
7/1/2009	12:00	PC	39	RS	71	
7/2/2009	19:00	CC	39	RS	49	
7/3/2009	16:00	OO	39	RS	46	
7/4/2009	14:00	PC	36	N/A	0	Moving Ice
7/5/2009	9:00	CC	43	RS	49	Slow Moving Ice
7/6/2009	13:00	PS	40	N/A	0	Moving Ice
7/7/2009	11:00	OO	40	N/A	0	Open Water
7/8/2009				N/A		No Personnel on island to make observation
7/9/2009	15:00	OO	42	RS	1	Swimming next to Island, all open water.
7/10/2009	13:00	OO	41	N/A	0	Open Water, some ice chunks floating
7/11/2009	14:00	OO	47	N/A	0	Open Water
7/12/2009	15:15	CC	48	N/A	0	Open Water
7/13/2009	13:00	CC	45	N/A	0	Open Water
7/14/2009	14:00	CC	47	N/A	0	Moderate seas
7/15/2009	14:15	CC	41	N/A	0	Heavy seas

CHAPTER 4:
UNDERWATER SOUNDS NEAR NORTHSTAR DURING LATE SUMMER AND AUTUMN OF 2005–2009 [1]

by

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ABSTRACT

The objective of this chapter is to report on the levels, characteristics, and range-dependence of underwater sounds produced by industrial activities related to Northstar Island during the open-water seasons of 2001–2009, with emphasis on the period 2005–2009 (which was not covered in the previous Comprehensive Report). Directional Autonomous Seafloor Acoustic Recorders (DASARs) were deployed close to Northstar (~450 m or ¼ mi from the island's north shore) and in an array offshore of the island. In 2001–2004, offshore DASARs were deployed at 10 sites 6.5–21.5 km (4.0–13.4 mi) northeast of Northstar, with 5 km DASAR spacing. In 2005–2007 smaller arrays were deployed with DASARs at 3 or 4 of the same locations used in 2001–2004. In 2008 and 2009, a large array was again deployed, with DASARs in 10 locations 8.6–38.4 km (5.3–23.9 mi) from Northstar and with 7 km DASAR spacing.

Underwater sounds received at a near-island DASAR and a subset of offshore DASARs were analyzed as broadband signals (10–450 Hz) and as one-third octave and narrowband levels over the entire DASAR deployment period each year (~4 weeks, from late August to late September). In addition, three "Industrial Sound Indices" (ISIs) were defined to quantify three different characteristics of industrial sounds: the presence of low frequencies (*ISI_5band*), the presence of tones from machinery (*ISI_tone*), and the presence of transient sounds such as those from vessels (*ISI_transient*). A subset of the 2009 sound data—those collected near Northstar and at one offshore DASAR—are used in the assessment of the effects of industrial sounds on the distribution of bowhead whale calls in 2009 (see Chapter 6).

Median levels of broadband underwater sound near Northstar varied in the range 98.7–105.5 dB re 1 μPa in 2005–2009, compared to 100.5–103.5 dB in 2001–2004. At an offshore location where data were acquired every year from 2001 through 2009 (location EB / C, 14.9 km or 9.2 mi from Northstar), median levels varied in the range 95.4–103.1 dB in 2005–2009, compared to 93.1–96.5 dB in 2001–2004. Median broadband levels of sound near Northstar, calculated over the entire season, were always higher than in the offshore array (location EB / C), by 2.4–7.9 dB in 2005–2009. Spectral composition of Northstar sounds included tones at 30 Hz and 60 Hz every year (2005–2009). The presence of tones in the spectral density levels received at the near-island DASAR was a distinguishing characteristic of Northstar sound. These tones were not found consistently in the recordings from the offshore DASARs.

Based on comparisons of the three industrial sound indices across years, there was a trend towards a smaller contribution of industrial sounds in 2005–2009 compared to 2001–2004: fewer samples containing transients (vessels), fewer samples containing tones, and lower *ISI_tone* levels.

Activities by vessels operating near Northstar produced some of the highest amplitude underwater sounds. During maneuvering by tugs at the island, received levels at the near-island recorder reached 135 dB re 1 μPa and were detectable, in below-average ambient sound conditions, as far offshore as DASAR location E, ~21.5 km (13.4 mi) from Northstar. Sounds from helicopters (tones and their harmonics from the main rotor and tail rotor) were detected near the seafloor for short periods, but only during departures from the island, when the helicopter's flight path was close (< 600 m) to the location of the recorder.

Thousands of airgun pulses were detected on DASAR records during the 2008 and 2009 study periods; these were from seismic exploration unrelated to Northstar. At the most offshore DASAR location (J), ~147,000 and ~65,000 airgun pulses were detected during 29 and 33 days in 2008 and 2009, respectively, with median received SPLs of 105 dB and 98 dB re 1 μPa. At offshore DASAR location C, ~17,000 airgun pulses were detected during 33 days in 2009, with median received SPL 88 dB re 1 μPa.

INTRODUCTION

Background

Northstar is an oil production island located ~5 km offshore of the barrier islands northwest of Prudhoe Bay, in nearshore waters of the Alaskan Beaufort Sea (position 70.49ºN, 148.70ºW). The island is man-made, constructed of gravel, and located in shallow water (12 m). BP Exploration (Alaska) Inc. began construction during the winter of 1999–2000 on the eroded remnants of an artificial island built in the 1980s for exploratory drilling (Seal Island). The first oil was produced on 31 October 2001, peak production was reached in 2003–2004 (~80,000 barrels / day), and current production (March 2010) is about 22,000 barrels / day.

Concern over the short-term and long-term effects of anthropogenic sounds on the ocean environment has been growing in recent years (Richardson et al. 1995; NRC 2003). Shipping traffic and coastal industrial development have contributed to an increase in average levels of underwater sound in several ocean regions since the 1950s (Ross 1976, 1993; Andrew et al. 2002; NRC 2003). Ice cover for most of the year has, in the past, limited boat traffic in the Arctic. However, the diminishing extent of the summer ice cover (e.g., Johannessen et al. 1999; Wang and Overland 2009) and the quest for new oilfields has resulted in increased human activity in the Beaufort Sea and elsewhere in the Arctic.

At the start of the Northstar project in the late 1990s, a few studies had reported on the underwater sounds produced by man-made oil exploration islands in the Arctic during summer (e.g., Davis et al. 1985; Johnson et al. 1986; see Richardson et al. 1995 for a review). Some of these data came from the original exploratory drilling operation at Seal Island, where the Northstar production facilities were subsequently built. Measurements of underwater and airborne sound during oil production from offshore facilities operating in the Arctic during summer (open-water season) were also lacking until recently. Gales (1982) had reported on sounds from drilling and production operations in temperate waters, but facilities used there differed from those used in the Arctic. These early studies indicated that sound levels during construction and drilling were lower when emanating from gravel islands than from other types of offshore platforms used in the Arctic (e.g., caissons, drillships). Reasons for this difference probably have to do with the different construction or emplacement procedures and the various ways in which sounds are coupled to the water. Sound measurements made underwater, in air, and in the ice during Northstar construction in 2000–2001 and during initial drilling and production operations have added to the literature on the subject (Blackwell et al. 2004a,b; Blackwell and Greene 2005, 2006; Greene et al. 2008). Overall, these measurements have confirmed that Northstar Island itself is relatively quiet, and that most of the sounds emanating from the Northstar operation in summer can be attributed to the vessels associated with the island for transport of goods or personnel.

Objectives and Approach

To help assess possible effects of Northstar on marine mammals (mainly bowhead whales, *Balaena mysticetus*, and ringed seals, *Phoca hispida*), underwater measurements of island sounds were needed during all phases of the Northstar project, from construction to production. Also, acoustical measurements were required on an annual basis to satisfy the provisions of ***(1)*** the NSB zoning ordinance for Northstar, and ***(2)*** Letters of Authorization (LoA) issued by NMFS to BP with respect to possible disturbance of whales and seals during Northstar construction and production (see Chapter 1).

The objective of the present chapter is to report on the levels, characteristics, and range-dependence of underwater sounds produced by Northstar-related industrial activities during the open-water seasons (late August to late September) of 2001–2009, with emphasis on the period 2005–2009 that was not covered in the previous Comprehensive Report (Richardson [ed.] 2008). In particular, we aim to describe island-related sounds (from construction, drilling, oil production activities and vessel traffic) as recorded close to the island,

~450 m from the island's north shore. In addition, we aim to investigate how far from the island these sounds propagate towards and into the southern part of the autumn migration corridor of the bowhead whale. The approach relies on continuous underwater recordings at fixed sites over periods of several weeks every year, obtained by deploying instrumentation on the seafloor.

This report is required to summarize monitoring work that has been done at Northstar during the period 2005–2009 (see Chapter 1). However, data from previous years (2001–2004) are often included for the sake of comparison. In particular, data from 2001 are often mentioned because that was a construction year with different sound-producing equipment than later years.

BP's Activities near Northstar

Following is a short summary of some of the activities at Northstar since 2001. Although this report focuses mainly on 2005–2009, activities in earlier years are also mentioned here as differences in activities during 2005–2009 vs. some earlier years are important in explaining differences in the sounds measured during the various years. Note that only the BP activities that took place during times in late summer/early autumn when acoustic recorders were deployed and that have the potential to produce sounds are included in this summary. Chapter 2 includes a more complete chronology of BP's activities at Northstar. Numerous activities that are not mentioned here took place either during the ice-covered season or in early summer, before our monitoring begins in late August, as BP aims to minimize noise-producing activities during the autumn migration of bowhead whales (see Chapter 2).

Northstar construction started in early 2000, during the ice-covered season. The island was still under construction during the open-water season in 2001, when three sealift barges brought modular buildings and oil production equipment to Northstar in August; installation on the island continued until late September. There were a number of tugs present, including ocean-class (7200 hp), point-class (2100 hp), and river-class (1095 hp) tugs. Self-propelled barges (440 hp each) had been used as moveable docks for transfer of island personnel as well as goods, but were replaced with floating docks on the island's eastern and western shores during 2001. The island's primary power was provided by diesel-powered generators.

From late 2001 (after the whale migration season) to the present day, oil production and gas injection have occurred at Northstar essentially continuously. By the 2002 open-water season, the diesel-powered generators had been replaced with generators powered by Solar gas turbines, and two gas compressors had been installed for re-injection of gas into the oil reservoir. Drilling for new wells took place nearly continuously until late October 2002 (concurrent with oil production) using a top-drive drill-rig on the island. Information on vessel traffic, which is an important contributor to the sound field around Northstar during the open-water season, will be presented in more detail in the section ***Specific Island-Related Sources***.

METHODS

Recorders (DASARs)

The data presented in this chapter are based on recordings obtained with **D**irectional **A**utonomous **S**eafloor **A**coustic **R**ecorders (DASARs, Greene et al. 2004). Two different DASAR models were used during the period covered in this report. The two DASAR models are functionally equivalent, with some minor differences in the specific mechanical configuration and electronic equipment (see p. 2-5 in Blackwell et al. 2010a). In 2001–2007 DASARs of the initial design (model "A") were used; these DASARs are described in Greene et al. (2004) and Blackwell et al. (2007a). DASARs of the model "C08" were built in 2008 and used during the 2008 and 2009 field seasons. A photograph and schematic representation of a DASAR-C08 are shown in Figure 4.1. A DASAR-C08 consists of a pressure housing (17.8 cm high and

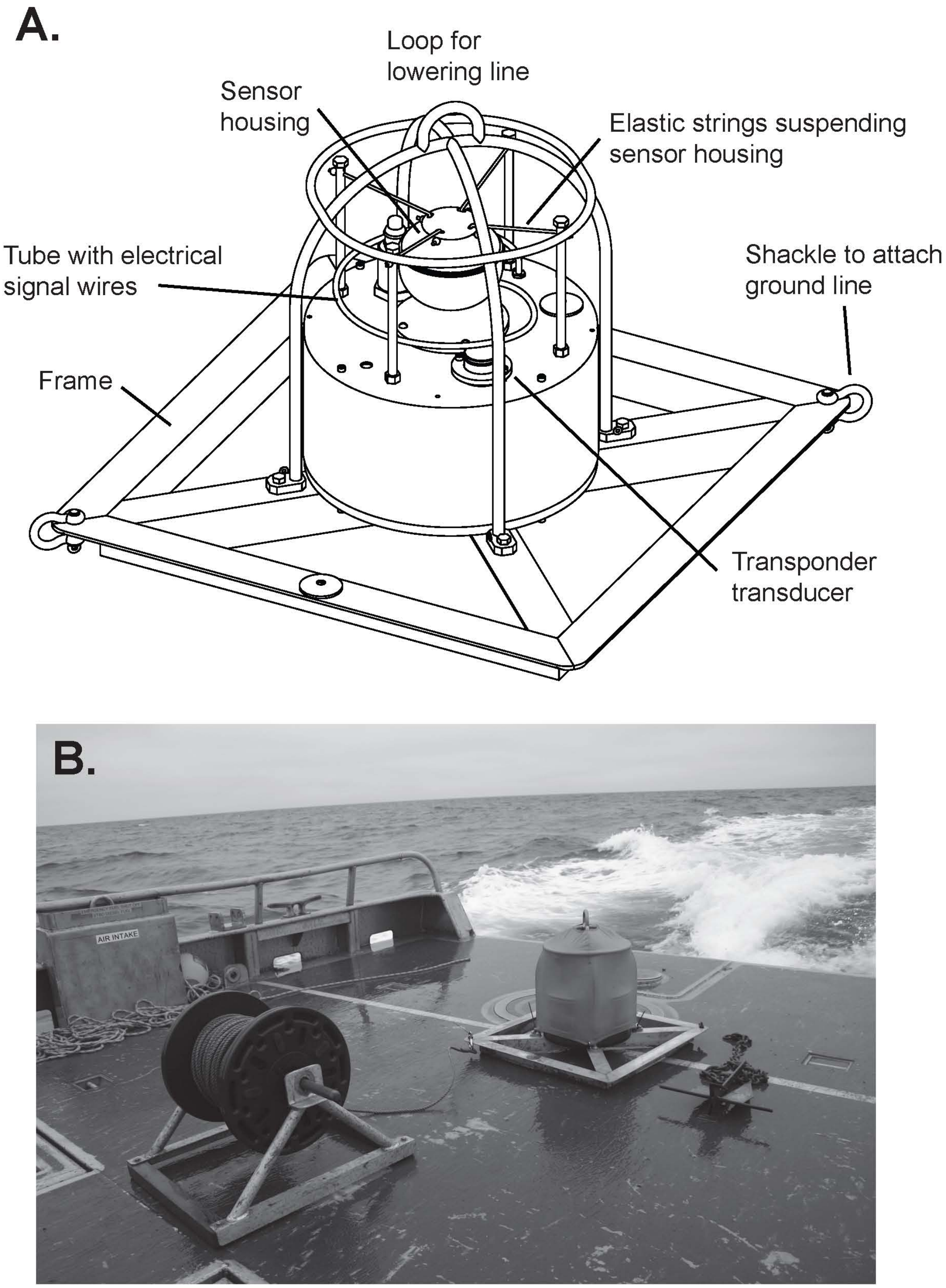

FIGURE 4.1. Directional Autonomous Seafloor Acoustic Recorder (DASAR). ***(A)*** Schematic diagram of the components of a DASAR (model C08) recorder. ***(B)*** A DASAR about to be deployed off the stern of an ACS *Bay* vessel. The ground line is on the reel (left) and the Danforth anchor and chain (right) are ready to be shackled to the ground line once the latter has been laid out on the seafloor. The DASAR is deployed first and the anchor last.

32.4 cm in diameter, or ~7" and 12.75", respectively) containing the recording electronics and alkaline batteries. A sensor suspended elastically about 12.7 cm (5") above the pressure housing includes two particle motion sensors mounted orthogonally in the horizontal plane for sensing direction. It also includes a flexural pressure transducer for the omni-directional sensor. The pressure housing is bolted to a square frame with 66 cm (26") sides. A spandex "sock" stretched over the tubular "cage" surrounding the pressure housing (see Fig. 4.1B) protects the sensors from motion in water currents. The total in-air weight is ~32.2 kg (71 lb) and the in-water weight is ~15 kg (33 lb).

DASARs record sound at a 1 kHz sampling rate (1000 samples/s) on each of three data channels: (1) an omnidirectional channel, (2) a "cosine channel" on the primary horizontal axis, and (3) a "sine channel" on the horizontal axis perpendicular to the cosine channel. Each channel has maximum sensitivity in its primary direction, and the sensitivity falls off with the cosine of the angle away from the axis. The recorder includes a signal digitizer with 16-bit quantization. The samples are buffered for about 45 min, then written to an internal 60 GB hard drive (25.4 GB for DASAR-As), which takes about 20 s. Allowing for anti-aliasing, the 1 kHz sampling rate and the 60 GB hard drives used in 2008–2009 allow for a data bandwidth of 450 Hz and up to 116 days of continuous recording (45 days in 2001–2007).

The directional capability of DASARs is used to triangulate the positions of whale calls (see Chapter 5). However, in this chapter only data from the omnidirectional channel (an acoustic pressure sensor) are presented.

The hydrophones in DASARs of both models were procured with individual sensitivity information, relative to frequency, provided by the manufacturer. For DASAR-As this means that reported sound pressure levels are expected to be correct within ± 1.5 dB across the range of reported frequencies. DASAR-C08s used in 2008–2009 were calibrated more accurately. Two DASAR-C08s were taken to the U.S. Navy's sound transducer calibration facility TRANSDEC in San Diego in 2008. The two DASAR-C08s calibrated at TRANSDEC were then used as secondary standards for calibrating the remaining DASAR-C08s. The hydrophone sensitivity varies with frequency. The manufacturer's specifications for the hydrophones listed a sensitivity of –134 dB re 1 V/μPa at 100 Hz for the DASAR-As and –149 dB re 1 V/μPa at 100 Hz for the DASAR-C08s. For the latter, the results of the TRANSDEC calibration confirmed this value. The hydrophone recorder electronics overloaded (saturated) when the instantaneous sound pressure exceeded 136 dB and 151 dB re 1 μPa at 100 Hz, respectively, for the DASAR-As and DASAR-C08s. This happened occasionally with received airgun pulses or vessels passing right over the recorder.

Field Work

Deployments and Retrievals

Every year from 2001 to 2009, recorders were deployed in late August and retrieved in late September or early October. Table 4.1 gives dates of the beginning and end of data collection each year. Season length was in the range 18–36 days. Weather, sea state, ice conditions, and the prognosis for deteriorating conditions in late September/early October influenced the specific dates of DASAR deployment and retrieval.

TABLE 4.1. Deployment dates for DASARs in 2001–2009. Begin and end times (local) of data collection are rounded to the nearest multiple of 15 min. End times of data collection exclude problematic DASARs that stopped recording early. The season lengths shown represent minima, calculated using the latest deployment times and / or earliest retrieval times.

	Data collection begins	Data collection ends	Season length (days)
2001	~29 Aug. 12:00	1–3 Oct.	32.5
2002	30 Aug. 11:15–31 Aug. 15:00	23 Sept. 10:00(1)	22.8
2003	29 Aug. 01:00(2)	28 Sept. 09:30–15:00	30.4
2004	30 Aug. 19:00	26 Sept. 09:00–1 Oct. 16:00	26.6
2005	4 Sept. 10:00(3)	3 Oct. 09:15–11:15	29.0
2006	7 Sept. 11:00–12:00(4)	25 Sept. 09:00–13:00	17.9
2007	28 Aug. 12:00	3 Oct. 15:30–19:15	36.1
2008	27 Aug. 00:00	25 Sept. 08:30–16:15	29.4
2009	26 Aug. 00:00	28 Sept. 09:00–15:45	33.4

(1) In 2002, a storm tipped over the DASARs at the specified time, even though recording continued until retrieval on 3 and 4 Oct. (2) In 2003, WB, SE, and SW started recording on 29 Aug. at 15:00. (3) In 2005, near-island DASARs started recording on 30 Aug. at 21:00. (4) In 2006, near-island DASARs started recording on 29 Aug. at 12:00.

DASARs were configured for deployment by connecting one end of the instrument's aluminum frame to a 110-m line and a 2-kg Danforth anchor (see Fig. 4.1). After deploying the DASAR with a lowering line, the ground line was laid out straight on the seafloor and the anchor was dropped when the end of the ground line was reached. The GPS locations of both the DASAR and anchor were recorded during deployment. For retrieval at the end of the season, a triple grapnel anchor assembly[2] was towed perpendicular to the 110-m line and across it. Once the ground line was snagged by the grappling hooks, all the gear was brought back onboard the ship.

DASARs were deployed in two main areas:

(1) **Near Northstar**, about 450 m northeast of the island's north shore—these DASARs will hereafter be referred to as "near-island DASARs". The near-island recorders have been deployed in approximately the same locations in all years of the study (2001–2009). Three (or more) recorders were deployed in close proximity (about 150 m between adjacent recorders) to ensure that suitable near-island acoustic data would be acquired if 1 or even 2 units malfunctioned. Water depth at the deployment locations was about 13 m (43 ft). These DASARs are referred to as NSa, NSb, and NSc.

(2) As an **offshore array**, at distances 6.5–38.4 km (4–23.9 mi) northeast of Northstar, depending on the years—these DASARs will hereafter be referred to as "array DASARs" or "offshore DASARs". Figure 4.2 shows a map with the DASAR deployment locations used in all years. The deployment pattern for these DASARs has gone through three phases, summarized in Table 4.2: • **2001–2004**, when DASARs were deployed in two overlapping hexagons (10 locations forming 10 equilateral triangles with 5 km sides), at distances 6.5–21.5 km (4–13.4 mi) from Northstar. • **2005–2007**, when a smaller array was deployed (3 or 4 locations), in some of the same locations as in 2001–2004. Deployment locations varied among these three

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[2] This assembly consisted of a 6-m chain and three grapnel anchors, with one anchor near the middle of the chain, one at the end, and the third between the other two.

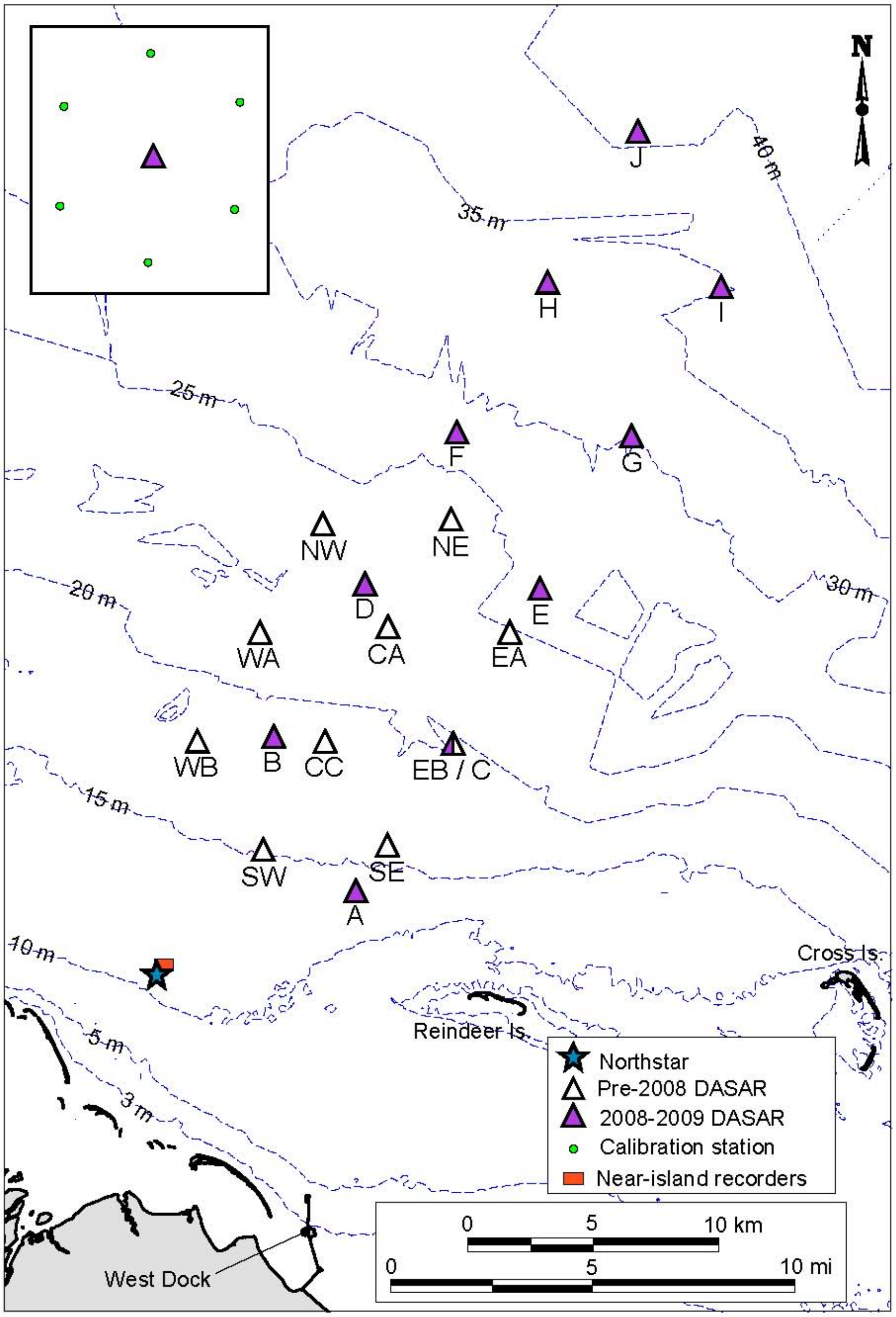

FIGURE 4.2. DASAR locations in 2001–2009, in relation to Northstar (blue star). All locations shown with open triangles were used in 2001–2004, whereas a subset of these locations was used in 2005–2007 (see Table 4.2). All locations shown with purple triangles were used in 2008 and 2009. Note that location EB / C was used in all years. The locations of the near-island DASARs (red rectangle) are shown just north of Northstar. The inset shows how calibration stations (green dots) were positioned around each DASAR. The distance between a DASAR and its calibration stations was ~2.9 km in 2001–2007 (with 5 km between adjacent DASARs) and ~4.0 km in 2008 and 2009 (with 7 km between adjacent DASARs).

TABLE 4.2. Deployment locations for DASARs in 2001–2009, water depths at these locations, and their distances to Northstar (N*). Water depths are approximate as they varied slightly from year to year. At some locations, duplicate DASARs were deployed in certain years (for example CA in 2001–2004, EB / C in 2006–2009). Near-island recorders (N*, top line) were always deployed at least in triplicate. The near-island recorders were cabled hydrophones in 2001, 2002, and the first half of the 2003 field season, and DASARs during the second half of the 2003 season and in 2004–2009. See Figure 4.2 for a map of the deployment locations and Table 4.1 for deployment dates. √ = complete record obtained. √ * = incomplete record because of DASAR malfunction. √ ** = DASAR deployed but no data collected.

	Water Depth (m / ft)	Dist. to N* (km / mi)	2001	2002	2003	2004	2005	2006	2007	2008	2009
N*	13 / 43	0.45 / 0.28	√	√	√	√	√	√	√	√	√
SW	17 / 56	6.5 / 4.0	√ *	√ *	√	√ *	-	-	-	-	-
SE	18 / 59	10.6 / 6.6	√	√	√	√	-	-	-	-	-
WB	19 / 62	9.3 / 5.8	√	√	√	√	√	-	-	-	-
CC	20 / 66	11.4 / 7.1	√ *	√	√	√	√	√	√	-	-
EB = C	23 / 75	14.9 / 9.2	√ *	√	√	√	√	√	√	√	√
WA	22 / 72	14.1 / 8.8	√	√	√	√	-	-	-	-	-
CA	24 / 79	16.6 / 10.3	√ *	√	√	√	-	√	√	-	-
EA	24 / 79	19.5 / 12.1	√ *	√	√ *	√	-	-	-	-	-
NE	24 / 79	21.5 / 13.4	√	√	√	√	-	-	√	-	-
NW	24 / 79	19.0 / 11.8	√ **	√	√	√	-	-	-	-	-
A	15 / 49	8.6 / 5.3	-	-	-	-	-	-	-	√	√
B	18 / 59	10.5 / 6.5	-	-	-	-	-	-	-	√	√
D	23 / 75	17.5 / 10.9	-	-	-	-	-	-	-	√	√
E	25 / 82	21.5 / 13.4	-	-	-	-	-	-	-	√	√
F	28 / 92	24.5 / 15.2	-	-	-	-	-	-	-	√	√
G	30 / 98	28.4 / 17.7	-	-	-	-	-	-	-	√	√
H	35 / 115	31.5 / 19.6	-	-	-	-	-	-	-	√	√
I	35 / 115	35.2 / 21.9	-	-	-	-	-	-	-	√	√
J	38 / 125	38.4 / 23.9	-	-	-	-	-	-	-	√	√

years because they were influenced by the location of the nearshore pack-ice in 2005 and 2006. • **2008–2009**, when a large array was deployed 8.6–38.4 km (5.3–23.9 mi) offshore, with 10 locations forming 8 equilateral triangles with 7 km sides, organized as two parallel rows, tilted to the east by 30° from true north (Fig. 4.2).

One deployment location in the offshore array has remained the same in all years of the study: location EB, called C since 2008, 14.9 km (9.2 mi) northeast of Northstar (Fig. 4.2, Table 4.2). This DASAR location serves as a reference for sound levels and whale calls throughout all years of the study.

Health checks were performed on the DASARs after deployment to test whether they were functioning as expected. This was done by placing a surface-deployed transducer (a pole-mounted Benthos DRI-267A Dive Ranger Interrogator) in the water at the recorded GPS location of each DASAR. The transducer interrogated an acoustic transponder (Benthos UAT-376, operational range 25–32 kHz) in each recorder, which responded on one channel if it was recording and on another channel if it was not.

DASAR Clock Calibrations

Each field season, clock and bearing calibrations were performed after deployment and before retrieval on all DASARs. In some years, additional calibrations were performed on one or more intermediate dates. Clock calibrations are conducted because each DASAR's clock has a small but significant drift. The rate of drift needs to be quantified in order to maintain an accurate time base over the course of the deployment (Greene et al. 2004). Bearing calibrations are conducted because, during initial deployment, a DASAR's orientation on the seafloor is random with respect to true north. Directional calibration is therefore necessary in order to obtain correct bearings to whale calls detected by the DASARs (see Chapter 5). The calibration procedure in the field applies to both clock and bearing calibration analyses conducted after the DASARs are retrieved. However, only the data from the omnidirectional sensor are presented in this chapter, so only clock calibrations are relevant here. (Bearing calibration procedures are described in Chapter 5.) Calibrations are performed by projecting test sounds underwater at known times and known locations, and recording these sounds on the DASARs. Six calibration stations were used around each DASAR (see insert in Fig. 4.2), with shared calibration stations between adjacent DASARs. After processing (see below), the collected data allowed us to synchronize all the DASAR clocks and to determine each DASAR's orientation on the seafloor.

Equipment used for calibrations included a J-9 sound projector, an amplifier, a laptop computer to generate the projected waveform, and a GPS to control the timing of the sound source. A spectrogram of the waveform used is shown in Figure 4.3. The signal consisted of a 2-s tone at 400 Hz, a 2-s linear sweep from 400 to 200 Hz, a 2-s linear sweep from 200 to 400 Hz, a 2-s linear sweep from 400 to 200 Hz, and 4 s of pseudo-random noise (m-sequence with 255 chips, repeated once every second on a 255 Hz carrier frequency). The first 8 s segment of this signal was used in 2001–2008; the final 4 s segment was added in 2009. The source level of the projected sound was ~150 dB re 1 μPa @ 1 m. During calibration a waveform transmission was initiated every 15 s, for a total duration of about 2 min (i.e., 8–9 transmissions).

Investigation of Unknown Sounds at Northstar

Since 2001, three different recurring sounds of unknown origin have been identified on DASAR records. The first (2003) and third (2008–2009) were mainly identified on the records of the near-island recorders; the second (2006) was also detected on offshore DASARs. Characteristics of these three recurring sounds are presented in the ***Results*** section. The current section describes fieldwork performed to investigate the origin and received levels of the unknown sound of 2008–2009. Of the three unknown sounds, it was the only one with received levels (near the source) potentially above 180 dB re 1 μPa, so it was the only one that required additional investigation according to the provisions of LoAs issued by NMFS to BP.

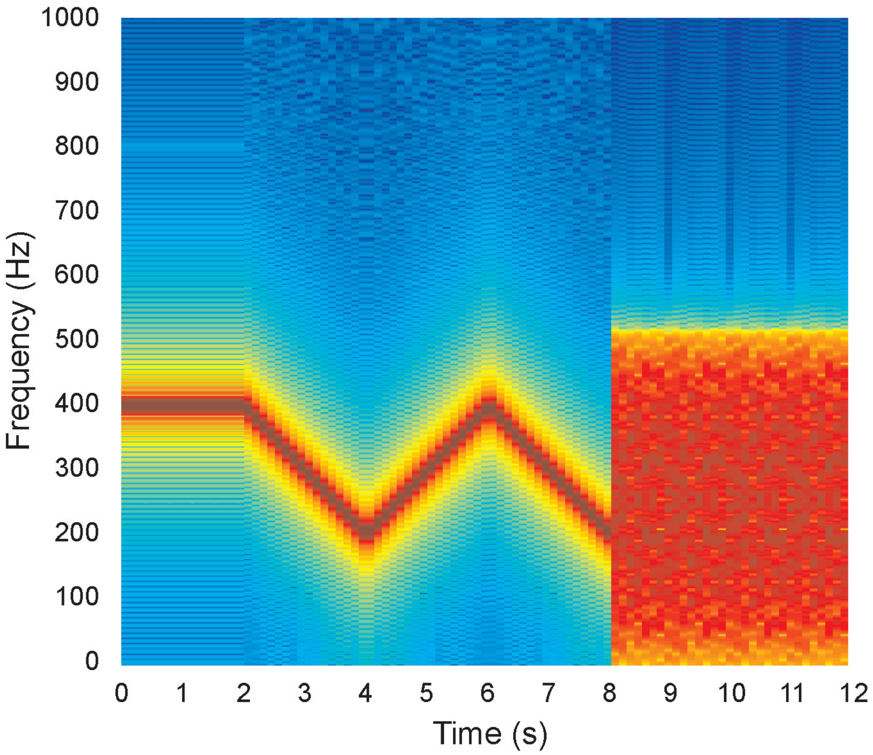

FIGURE 4.3. Spectrogram of the calibration waveform as used in 2009. See text for more information.

In Sept. 2008 an unidentified popping sound was detected on recordings from the near-island DASARs (Blackwell et al. 2009). Bearings extracted from the records of the near-island DASARs pointed to the northeastern side of Northstar as the most likely source location of the pops. Based on the available information, it was possible that the source level of some pops could reach 180 dB re 1 µPa or higher at 1 m. According to the LoAs, BP is required to implement additional marine mammal monitoring if sound pressure levels (SPLs) may exceed 180 dB re 1 µPa in waters beyond the Northstar facility where cetaceans might occur[3]. Therefore, BP informed regulatory agencies about the pops and their potential sound levels at Northstar, and agreed to undertake additional efforts at the start of the 2009 open-water season. These efforts were to (1) determine if the pops were still present in 2009 and, if so, (2) attempt to localize their source.

In spring 2009 (11 June and 16 July) two attempts were made to use hydrophones to listen for pops either from shore (Fig. 4.4A,B) or from a vessel. These attempts are summarized in Blackwell et al. (2010a,b). No popping sounds were heard.

On 25 Aug., 12 Sept., and 26 Sept., in conjunction with DASAR deployments or calibrations, an *Acousonde*™[4] autonomous recorder ("tag") was deployed close to the bottom near the island, with the goal of obtaining recordings of popping sounds. The tag was attached to a small weighted frame and placed on the seafloor (Fig. 4.4C,D). On the three dates, the tag was deployed for ~7 hours, ~8 hr, and ~10 hr, respectively, in locations about 135 m, 35 m, and 45 m northeast of the island's northeastern corner, respectively.

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[3] Note that since the source of the pops is unknown, it is unclear whether they qualify as "industrial sounds".

[4] Information on the *Acousonde*™ can be found on the website http://www.acousonde.com.

FIGURE 4.4: Pop sound investigation. ***(A)*** and ***(B)*** Listening for pops with a cabled hydrophone deployed in the moat along the western shore of Northstar, 11 June 2009. ***(C)*** and ***(D)*** Deployment of the *Acousonde* (the black and red cylinder within the metal stand) on 25 Aug. 2009. On that date, the *Acousonde* was deployed ~135 m northeast of the northeastern corner of Northstar and retrieved after ~ 7 hours.

The tag recorded continuously at a sampling rate of 27.33 kHz (27,330 samples/s), and provided acoustic data in the range 20 Hz–9.3 kHz.

Data Analyses

After retrieval, DASARs were opened and dismantled. The sampling program was shut down, and the hard drives were removed and hand-carried back to Greeneridge Sciences, where backup copies were made. Data were transferred to computers running MATLAB™ and custom analysis software, and were equalized prior to processing. Equalization is a calibration procedure that compensates for the fact that the sensitivity curve of a DASAR sensor is not flat across all frequencies (see Blackwell et al. 2006). Equalization permits computing calibrated sound pressure levels, both on a spectral density basis and in various frequency bands (e.g., 10–450 Hz or by one-third octave).

Various analyses were performed on the data. Details on each of these analyses are explained in the following sections:

- Calibration of DASAR clocks;
- Broadband, narrowband, and one-third octave band levels of sound;

- Industrial sound indices (ISIs), used to characterize industrial components of the sounds emanating from Northstar and its attending vessels;
- Analyses of impulsive sounds, such as airgun pulses and "pop" sounds detected close to Northstar in 2008–2009;

DASAR Clock Calibrations

The sample clock utilized in the DASAR hardware design is quite accurate. However, as with all crystal oscillators, there is an inherent tradeoff between precision and power. Low power consumption is desirable for long-term deployments and fortunately, in the Arctic, clock imprecision is readily correctable because the relatively stable water temperature near the seafloor results in a near-constant rate of clock drift. Under such conditions, the DASAR clocks will incur a linear drift that, over 30 to 40 days of deployment, can reach ± one minute.

Figure 4.5A shows a spectrogram of a group of eight calibration signals received by an offshore DASAR. In this example, there are few interfering background sounds and the calibration signals of interest are readily detected in the spectrogram, and further clarified using a matched filter (Fig. 4.5B). The matched filter is especially useful when calibration signals are obscured by background noise, and was used for the first time in 2008. The calibration analysis accounts for the travel time of the sound propagating between the calibration source and the DASAR and determines what the true time of arrival at the DASAR should be. The time error (the difference between true time and DASAR clock time) is then characterized as a linear function, shown in Figure 4.5C, and used to correct the time measured by the DASAR clock to true time. For the DASAR in Figure 4.5C, the estimated initial time offset is 3.18 s, and the estimated clock drift is -2.02 s/day. Bearing calibration procedures are explained in more detail in Chapter 5.

Broadband, Narrowband, and One-third Octave Band Levels

For each DASAR, narrowband spectral densities (1 Hz cell spacing, 1.7 Hz bandwidth) were determined for a one-min period every 4.37 min (262 s). This provided ~330 spectral measurements per 24-hour day for frequencies in the 10–450 Hz range. To derive each of these one-min spectra, standard signal-analysis procedures were applied. A series of 119 one-second-long data segments, overlapped by 50% and thus spanning one min, were analyzed. The 119 resulting 1-Hz spectra were averaged to derive a single averaged spectrum documenting narrowband levels for the one-min period.

One-third octave band and broadband levels were derived from the narrowband spectral densities. The bandwidth of a one-third octave band is 23% of its center frequency (see Richardson et al. 1995, p. 24, for a review). Standard center frequencies for adjacent one-third octave bands used here include 10 Hz, 12.5, 16, 20, 25, 31.5, 40, 50, 63, 80, 100, 125, 160, 200, 250, 315 and 400 Hz. One-third octave data are commonly used when considering the audibility of sounds to animals (or humans) because the effective filter bandwidth of mammalian hearing is roughly one-third octave (Richardson et al. 1995). One-third octave band levels were calculated by summing the mean-square pressures at all frequencies within the one-third octave band in question, providing a measurement of the sound level in each band, averaged over a one-min period, for each 4.37-min interval. Broadband levels were also derived from the narrowband data by summing the mean square pressures of all frequencies within the 10–450 Hz frequency range. These narrowband, one-third octave, and broadband data at 4.37-min intervals provided a continual time-series record of the levels of low-frequency underwater sounds at each of the DASARs analyzed.

The narrowband and one-third octave data were also summarized over entire deployment periods to derive "statistical spectra" showing, for each frequency or one-third octave band, the levels exceeded during various percentages of the 1-min samples. For each of the 1-Hz frequency bins in the spectra, the values were sorted from smallest to largest, and the minimum, 5th-percentile, 50th-percentile, 95th-percentile, and

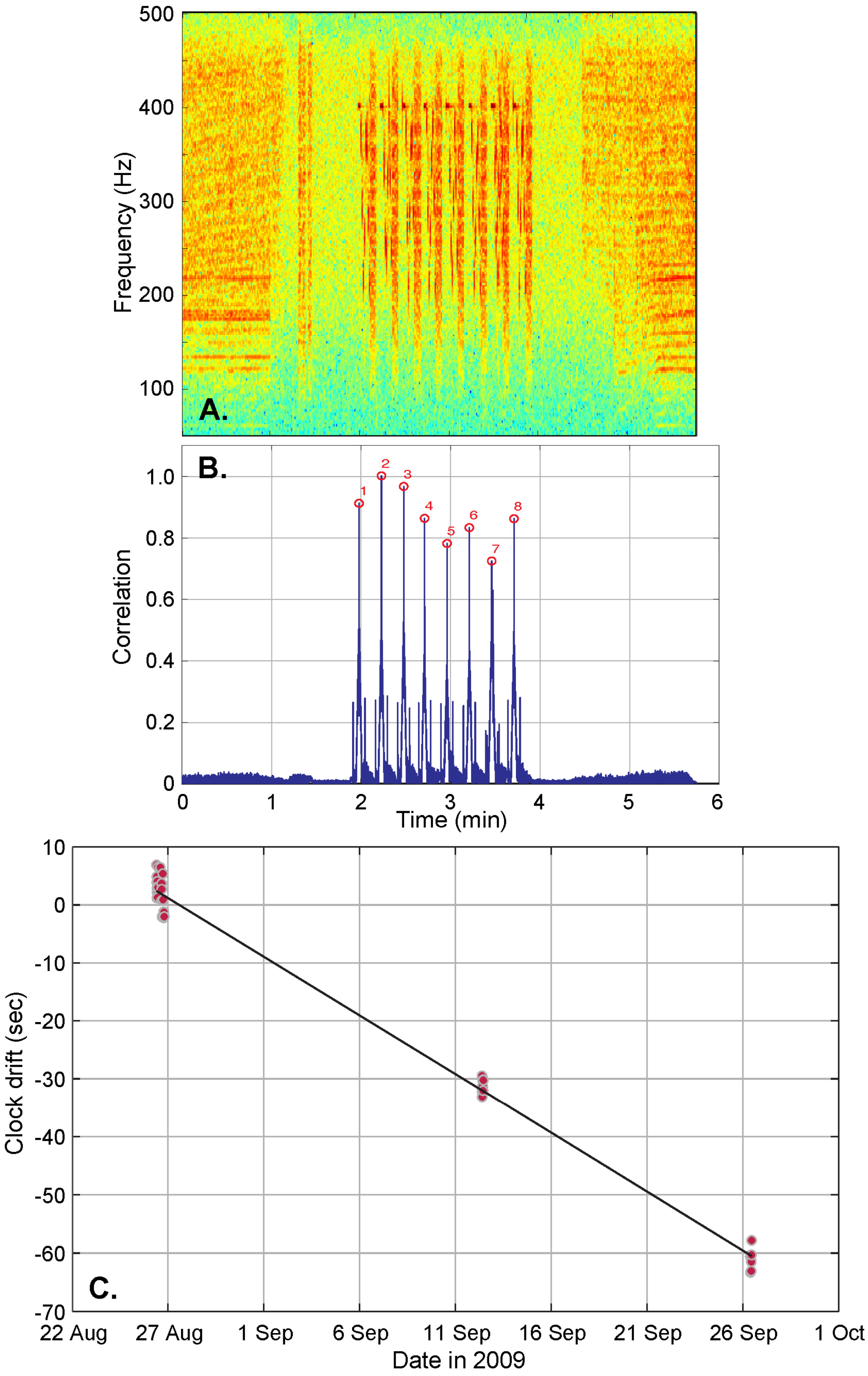

FIGURE 4.5. Calibration of DASAR clocks. ***(A)*** Spectrogram of eight calibration signals projected on 26 Aug. 2009 in conditions of relatively low background noise. Vessel noise is visible before and after the calibration period. ***(B)*** Matched filter output, coincident with above spectrogram, showing detections of the calibration signals. ***(C)*** Clock drift for array DASAR "C" determined by plotting time error as a function of date and time. These calibration transmissions were performed on 26 Aug., 12 Sept., and 26 Sept. 2009 (red dots).

maximum values for that frequency bin were determined. The same procedure was applied to one-third octave band data. This provided a summary of the range of spectral density values or one-third octave band levels over an entire season. It therefore allowed general comparisons between years by identifying, for example, prominent tones or the dominant frequency ranges of industrial sounds.

Industrial Sound Indices (ISIs)

For purposes of this study, where the main interest lies in understanding the relationship between sounds generated by Northstar and the distribution and behavior of migrating bowhead whales, it is important to understand the contribution of industrial components to the overall underwater sound. For that reason, industrial sound indices (ISIs) were developed to represent the most important components of the sounds emanating from Northstar or its attending vessels. These components are the ***low frequency sounds***, which are typical of industrial sounds and are represented by *ISI_5band*; the ***presence of tones***, which are typical of engines and other machinery and are represented by *ISI_tone;* and the ***presence of transient sounds***, such as those produced by passing vessels, as represented by *ISI_transient*.

***ISI_5band*[5].—**This ISI was constructed by summing the mean square sound pressure levels (SPL) in the one-third octave bands centered at 31.5, 40, 50, 63, and 80 Hz. Collectively, those bands span the frequency range 28 to 90 Hz. These one-third octave bands are known to be dominated by industrial components. One-third octave bands that appeared to be substantially influenced by natural sound components (at least in 2001–2002, the years being considered when *ISI_5band* was first defined) were not included when calculating *ISI_5band* (Blackwell 2003; Richardson and Williams [eds.] 2003). Total mean-square sound pressure in the five one-third octave bands considered was computed as

$$ISI\_5band = 10 \times \log_{10} \times \left(10^{\frac{dB_{31.5}}{10}} + 10^{\frac{dB_{40}}{10}} + 10^{\frac{dB_{50}}{10}} + 10^{\frac{dB_{63}}{10}} + 10^{\frac{dB_{80}}{10}} \right);$$

where $dB_{31.5}$, dB_{40}, dB_{50}, dB_{63}, and dB_{80} are mean square SPLs in the five relevant one-third octaves (Richardson et al. 1995, p. 30). The result is equivalent to the sound pressure in the (approx.) 28 to 90 Hz band.

***ISI_tone.*—**This index was designed to quantify tones present in the sound spectrum. Tones are produced by machinery and are, therefore, typically characteristic of industrial or vessel sound. The 1-min spectra (10–450 Hz) computed every 4.37 min from the near-island and offshore recorders were examined for the presence of tones. A tone was defined as present when the spectral density value for a given frequency was at least 5 dB above the average level of the two frequency bins below and the two frequency bins above the frequency being examined. The average of those 4 "nearby" frequency bins constituted the "background"[6]. The amount by which each tone exceeded its corresponding background was recorded. The *ISI_tone* measure for a given 1-min sample was the sum of the powers (pressure, in μPa^2) of these differences, for all the tones identified by the ≥5 dB criterion, converted back to dB re 1 μPa. The value of *ISI_tone* is therefore either 0 or ≥5 dB.

***ISI_transient.*—**This index was designed to quantify transient sounds that build up slowly (over minutes) and then decline, such as those from a passing vessel. The *ISI_transient* level is calculated by computing a running average of *ISI_5band* levels (one sample every 4.37 min) with a time constant of 4 hr, centered on the time of interest. This running average is mainly determined by background levels prevailing

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[5] Called simply "ISI" in the early years of the study (2001–2004).

[6] For example, say the frequency of interest is 20 Hz. The "background" will be calculated from the values of the bins centered at 18 Hz, 19 Hz, 21 Hz, and 22 Hz.

over the 4-hr period. If an individual 1-min level (i.e., in the 28–90 Hz band) is at least 5 dB above the corresponding 4-hr background value, then the amount by which it exceeds the background level is recorded and reported as the value of *ISI_transient* for the corresponding time. The value of *ISI_transient* is therefore either 0 or ≥5 dB.

Analyses of Impulsive Sounds

In some years of the study (principally 2008 and 2009), DASAR records included many impulsive sounds. These were primarily of two types: airgun pulses, from seismic exploration taking place in the Beaufort Sea up to hundreds of km away in certain years, and "pop" sounds, an unknown type of sound occurring close to Northstar in 2008 and 2009.

Airgun pulses have energy distributed over our entire analysis band of 10–450 Hz. They are therefore a source of interference in the sound records and should be quantified. In addition, bowhead whales have been shown to react to sounds from airguns (Richardson et al. 1986, 1999; Ljungblad et al. 1988, and others). Although airgun sounds detected in this study were not associated with activities at or for Northstar, it was suspected that they might influence bowhead whales offshore of Northstar and thus confound interpretation of Northstar effects on the whales. Thus, there was a need for data on the airgun sounds.

To obtain a quantitative assessment of the number and properties of airgun pulses detected via the offshore array, we used an automated pulse detector (developed by Dr. Aaron Thode, Scripps Institution of Oceanography) in 2008 and 2009, two years with heavy airgun activity. The automated pulse detector was run on the records of DASAR location J in 2008 and locations C and J in 2009. This automated process took place in three stages: pulse detection, interval estimation, and level measurement. The first two stages (pulse detection and interval estimation) are described in detail in Annex 4.1 at the end of this chapter. Once pulses were identified, the software calculated the following five parameters (see Greene 1997; McCauley et al. 1998, 2000; Blackwell et al. 2004b) for each detected pulse: (1) *peak pressure*, i.e., the maximum of the received instantaneous sound pressures at the 1 ms sampling intervals (in dB re 1 μPa); (2) *pulse duration*, defined as the time interval between the arrival of 5% and 95% of the total pulse energy (in s); (3) pulse *sound pressure level* (SPL), averaged over the pulse duration (dB re 1 μPa); (4) pulse *sound exposure level* (SEL), a measure related to the energy in the pulse, defined as the squared instantaneous sound pressure integrated over the pulse duration (dB re 1 $\mu Pa^2 \cdot s$); and (5) *background level*, as determined over 0.5–1 s immediately preceding the pulse.

Pops were detected on the records of the near-island recorders in 2008 and 2009. Pops were also detected at DASAR A, the southernmost DASAR in the offshore array. Bearings from the near-island recorders to selected pops were directed predominantly southward and southwestward from those recorders, i.e., pointing towards Northstar (Blackwell et al. 2009). Therefore, it was important to characterize these popping sounds as well as possible, and to identify (or narrow down) the source location.

After retrieving the *Acousonde* tag deployed on 25 Aug., 12 Sept., and 26 Sept. 2009, the records were downloaded to a computer. The data were high-pass filtered with a 50 Hz cutoff frequency (below the pops' frequency band) to remove 30 Hz mechanical noise, which was suspected to originate from the *Acousonde* deployment frame (see Fig. 4.4C,D). A peak detector with an instantaneous pressure threshold of 7 Pa (136.9 dB re 1 μPa) was applied to the time series data from each deployment, to identify the locations in the records where pops occurred. Although a lower detection threshold would detect more putative pops, the aforementioned threshold was chosen because it addressed the main goals of this investigation, i.e., to establish the presence of pops and identify source levels of the strongest ones.

For each peak exceeding the aforementioned 7 Pa threshold, the peak pressure, pulse duration, pulse SPL and pulse SEL were determined, as described above for airgun pulses. In addition, the same peak detector, utilizing various threshold levels including 7 Pa as with the *Acousonde*, was applied to the entire 2008 and 2009 recording from near-island DASAR NSb. This would allow us to compare presence and variability of pops across years and to confirm hypotheses concerning the mechanism behind the pop source.

Helicopter Sounds

During the BP Liberty OBC seismic survey in July 2008 (Aerts et al. 2008), sounds from helicopters were detected on the ocean bottom cables used as seismic receivers. Over deep water away from shore, underwater sounds from helicopters are generally detectable only within an area close to the path of the helicopter (Snell's law, see Richardson et al. 1995, p. 80). However, in the Liberty area, the shallow water and proximity to shore provided possible bottom-reflected and bottom-refracted paths for sound transmission. In those situations, underwater sound from helicopters is often detectable farther from the helicopter's path. BP decided to further investigate the extent to which the helicopters that travel to and from Northstar introduce sound into the water surrounding the island. Bell 212 helicopters are used for travel to and from Northstar (see Chapter 2). The presence of tones from these helicopters was investigated in the record of one of the near-island DASARs during the 2008 field season. The Bell 212 helicopter is known to produce tones at 10.8 Hz from the main rotor and at 55 Hz from the tail rotor (Patenaude et al. 2002). Harmonics of both frequencies also occur. Patenaude et al. (2002) detected tones up to the 13th harmonic (140 Hz) for the main rotor and up to the 6th harmonic (330 Hz) for the tail rotor.

Records of helicopter landings and takeoffs at Northstar during the period 26 Aug.–25 Sept. 2008 were used to identify the times on the sound records at which helicopter sounds might be detected. The calibrated near-island DASAR sound records were used to produce spectrograms for 10-min periods centered on recorded arrival and departure times. There were 27 round trips by helicopters to Northstar during the 26 Aug.–25 Sept. period. Of these, spectrograms were made of about half (13 arrivals, 13 departures). The spectrograms were used to visually identify the presence of tones at ~11 Hz, 55 Hz, and their harmonics, and (if present) to determine the exact time span over which they occurred in the records. (The recorded helicopter arrival and departure times are approximate.) Spectral density levels were then computed over 10 s samples at the times identified on the spectrograms and centered on the strongest part of the helicopter sounds.

RESULTS AND DISCUSSION

The overall study objective is to assess the effects of Northstar activities, as manifested primarily in underwater sounds, on the distribution and behavior of calling bowhead whales. An important component of this assessment is to understand what sounds are produced by the Northstar operation (island and attending vessels) and received by migrating whales, as they represent the "dose" of sound to which we expect some bowhead whales may react. The current chapter summarizes the analyses of sounds recorded near Northstar and in the offshore DASAR array during the late summer and early autumn of 2001–2009, but with an emphasis on 2005–2009, a period that was not covered in the previous comprehensive report (Richardson [ed.] 2008). This nine-year period covers much of the construction of the island, the drilling of the wells, and the transition to a production operation. Northstar sounds will be examined from different perspectives, such as the presence of transient sound sources or tones from machinery. In addition, the contributions of specific sound sources, such as vessels or helicopters, will be assessed and matched to observed changes in the sound records, when possible.

Since 2001, the offshore array of DASARs has included recorders deployed, at various times, in at least 19 different locations at distances 6.5–38.4 km (4–23.9 mi) from Northstar, and it would therefore be impractical to report on the sounds at all of these locations in a summary chapter such as this one. Instead, we have focused on DASAR EB / C as the representative array DASAR, for at least three reasons: • it is the only DASAR location from which recordings have been made during each field season since 2001; • it was close to the 5th quantile of the offshore distances to whale calls as localized in 2009, which is relevant to the studies presented in Chapter 6 on the effects of Northstar sounds on bowhead call distribution; and • it is close enough to Northstar that some of the sounds produced at or near the island can still be detected there. In certain sections, data from one of the other offshore DASARs will be presented to illustrate particular points.

The results are presented in the following six sections:

1. Broadband sound levels as recorded near Northstar and in the offshore array, 2001–2009;
2. Percentile one-third octave band and spectral density levels near Northstar and in the offshore array, i.e., frequency composition of the sounds described in (1), presented for 2001 and 2005–2009;
3. Industrial sound indices (ISIs) of sounds recorded near Northstar and offshore, including *ISI_5band*, *ISI_tone,* and *ISI_transient*, presented for 2001–2009;
4. Sounds from two specific island-related sources: vessels and helicopters;
5. Sounds from unknown sources, including those detected in 2003, 2006, and 2008–2009 ("pops");
6. Airgun pulses recorded by offshore DASARs in 2008 and 2009; these pulses originated from seismic exploration activities not related to Northstar.

Broadband Sound Levels near Northstar and Offshore

Figure 4.6 compares broadband levels, as recorded ~450 m northeast of the island, over nine seasons (late Aug. to late Sept. or early Oct.) of monitoring (2001–2009). The two most important features of these sound pressure time series (SPTS) will be discussed: the general shape of the SPTS and the presence / density of "spikes" (see below).

The shape of the SPTS, and in particular the lower edge of an "envelope" around the plotted SPTS, is mainly determined by wind, which is related to sea state and therefore background levels. This relationship is illustrated in Figure 4.7, showing the minimum hourly broadband level at a near-island DASAR in 2006, and the concurrent mean hourly wind speed as recorded by the Northstar weather station. Most of the time, there is a close match between the two lines. An exception occurred during 13–15 Sept. 2006, when sound levels were lower than expected based on wind alone. It is possible that the wind on those days was from a direction that led the near-island recorder to be on the lee side the island, but this was not verified (the wind direction sensor was broken on those days).

The vertical "spikes" that are visible on the SPTSs in Figure 4.6 correspond to short-duration (generally a few minutes) increases in the received levels of sound at the near-island DASAR. Most of the time these sound spikes are caused by vessels arriving at or departing from the island (Blackwell and Greene 2006), and are therefore referred to as "vessel spikes". The frequency of occurrence of vessel spikes has been quite variable over the years. It was highest in 2001, during island construction (Fig. 4.6). In September 2001 there were high levels of activity by tugs and barges bringing construction-related gear and materials to the island. There was also a crew boat, which made up to two dozen round trips per day to Northstar, delivering personnel and supplies. After 2001 the number of vessel spikes decreased, but is generally related to the construction activities—in recent years often repair or upkeep—that occur at the island any particular season. After the 2003 field season, the crew boat was replaced with a hovercraft. The amount of time that a passing hovercraft is audible from a fixed location underwater is on the order of seconds, certainly less than a min (Blackwell and Greene 2005). Consequently, the hovercraft does not create a sound spike on the SPTS at the near-island recorders (as shown in Fig. 4.6), in part because of how those data are analyzed (see section ***Vessels*** in ***Specific Island-Related Sources*** below). The replacement of the crew boat by a hovercraft has contributed to a decrease in the frequency of occurrence of vessel spikes starting in 2004.

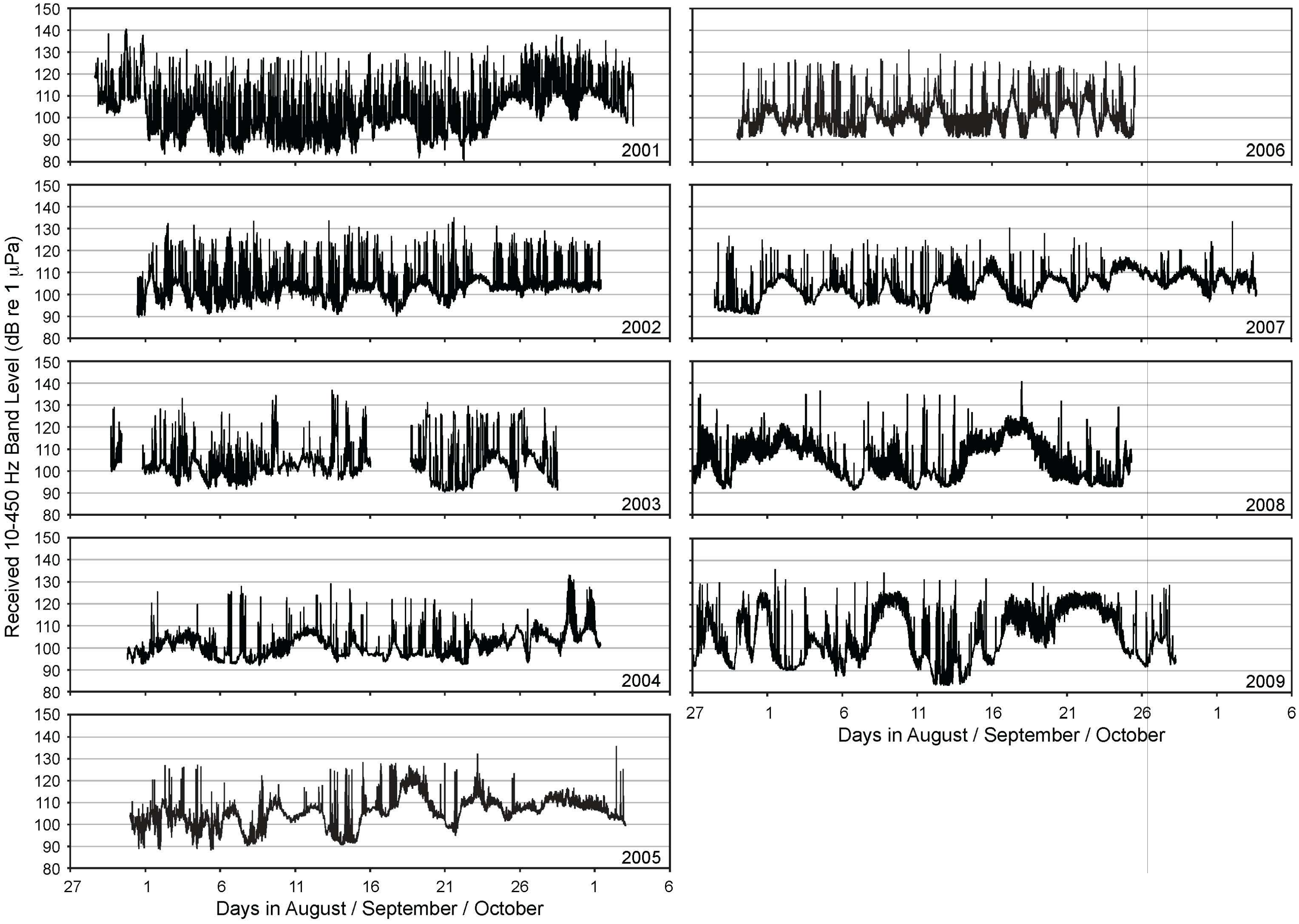

FIGURE 4.6. Sound pressure time series (10–450 Hz band; 1-min averages) for the entire 2001–2009 late summer / early autumn field seasons, as recorded ~450 m north to northeast of Northstar. The recorders were a cabled hydrophone in 2001, 2002, and the first part of 2003, and a DASAR for the second part of 2003 and 2004–2009.

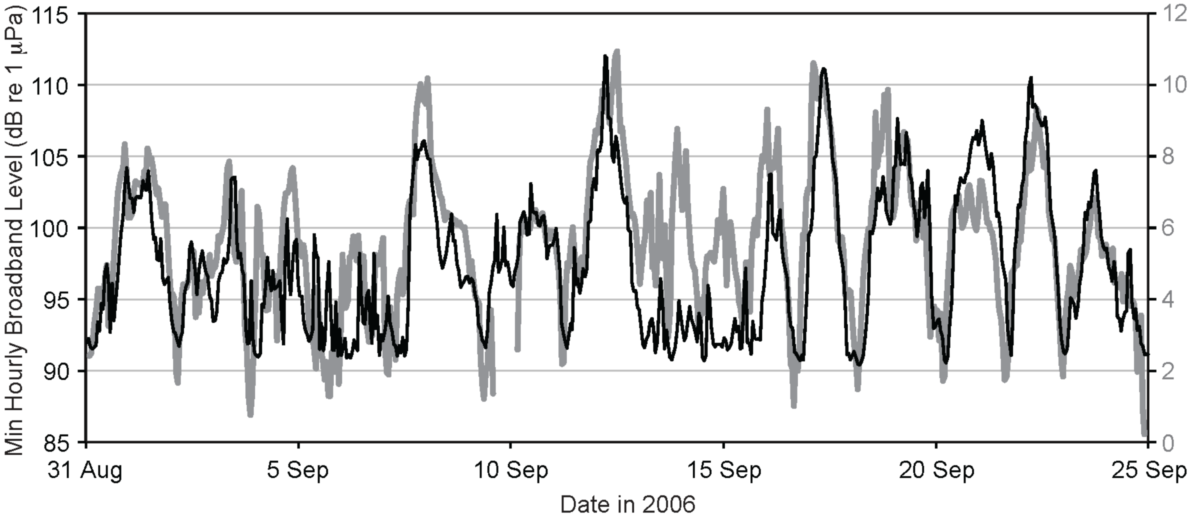

FIGURE 4.7. Comparison of the minimum hourly broadband level (black line) and the mean hourly wind speed (gray line) in 2006. Broadband levels were recorded by near-island DASAR NSc, 465 m (1525 ft) northeast of the island, and the wind speed was recorded by the Northstar weather station.

Figure 4.8 summarizes mean wind speed (31 Aug.–30 Sept.) in each year since 2001, as recorded by the Northstar[7] (2001–2006) or Prudhoe Bay (2007–2009) weather station. Over the nine years shown, mean wind speed varied in the range 4–10 m/s (8.9–22.4 mph). In other words, mean wind speed in the windiest year (2007) was 2.5× that in the year with the lowest mean wind speed (2001). (This comparison ignores any possible differences due to the fact that the wind speed data come from two different weather stations.) Insofar as the SPTS data are affected by wind and waves, these annual differences in mean wind speed should affect received levels of sound at the near-island recorder (see Table 4.3, below) and especially at the offshore recorders (where the industrial contribution is reduced).

Figure 4.9 compares broadband levels over nine seasons of monitoring (2001–2009), as recorded at the offshore DASAR location EB / C. Just as Figure 4.6 shows broadband levels recorded ~450 m from Northstar, Figure 4.9 shows broadband levels ~14.8 km (9.2 mi) offshore of the island. For any particular year, there were two main differences between Figures 4.6 and 4.9: the overall levels of sound and the number of vessel spikes.

On average, broadband levels of sound were lower at location EB / C than near Northstar. When ambient sound levels were low, as in calm weather, received levels of sound were generally higher close to Northstar than at location EB / C because of the sounds emanating from the island. When ambient sound levels were high, as during stormy weather, received levels of sound were still generally higher near Northstar, most likely because waves pounding and breaking on the shores of the island in relatively shallow water (12 m = 39 ft at Northstar) produce more sound than rough weather in open and somewhat deeper water (for example, 38 m = 125 ft deep at location J). This is shown in Figure 4.10, which compares broadband levels at the near-island recorder and at the offshore DASAR farthest from the island (location J) in 2009. Both DASARs display the same general sea state-driven trends of fluctuations in received levels over the season. If we ignore "vessel spikes", the minimum and maximum levels at the near-island DASAR were

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[7] The Northstar weather station was dismantled after the 2006 open-water season. The Northstar and Prudhoe Bay weather stations were located about 12 km apart.

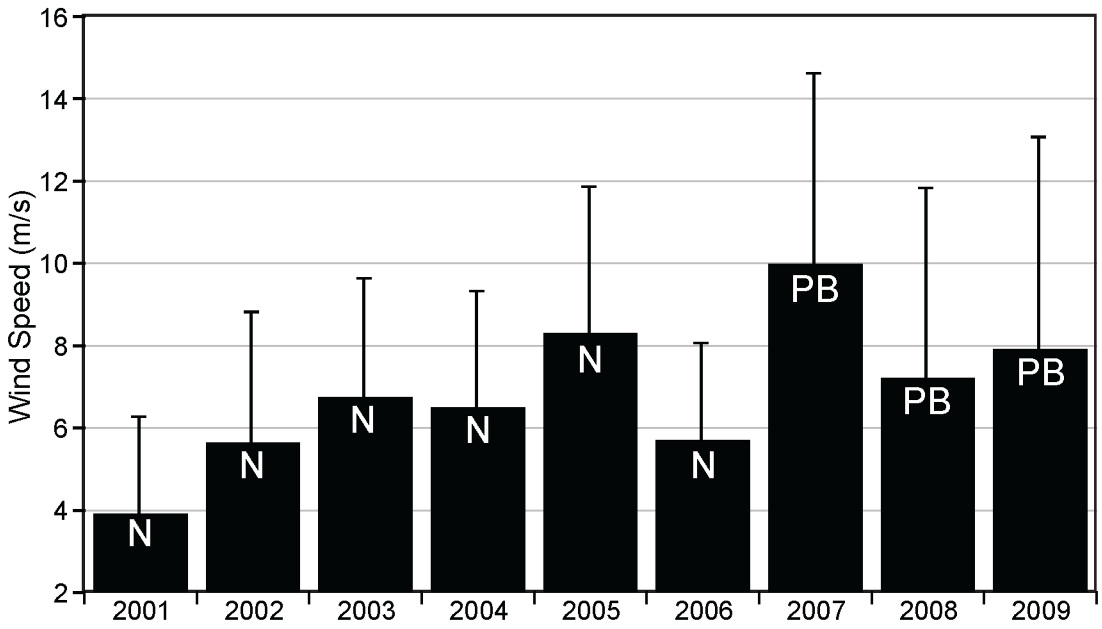

FIGURE 4.8. Mean wind speed for the period 31 Aug.–30 Sept. in 2001–2009, plus one standard deviation. Data for 2001–2006 were collected by the Northstar (N) weather station, and data for 2007–2009 were collected by the Prudhoe Bay (PB) weather station.

about 10 dB and 15 dB higher, respectively, than the corresponding times at DASAR J. Note that occasionally (e.g., 5–6 or 12–14 Sept.) received levels at the near-island DASAR were lower than concurrent measurements at the offshore DASAR.

In Figure 4.9, spikes caused by the vessel carrying the acoustic crew during servicing of the array are shown with diamonds. If those spikes are ignored, the SPTSs in Figure 4.9 (offshore) show very few vessel spikes compared to Figure 4.6 (near-island). Many fewer vessel spikes rise above the broadband level of background noise at location EB / C than near Northstar. This shows that sound from most vessels transiting to/from Northstar is either undetectable or at least not very prominent by the time it reaches (if it reaches) location EB / C (more on this later, see section ***Vessels*** in ***Specific Island-Related Sources*** below).

For each year, percentile levels of broadband sound (maximum, 95th, 50th, and 5th percentile, and minimum) were computed over the entire field season for the near-island DASAR and for DASAR EB / C. These values are summarized in Table 4.3.

The maximum levels in Table 4.3 (lines A and B) are mainly determined by the presence of vessels. A vessel such as a tug that travels close to a DASAR could overload the sensor, so these maximum values could be underestimated. Maximum values were generally higher at the near-island DASAR, but not always (as in 2002 and 2005). Also, because these maximum values can be determined by a single event (e.g., passage of a vessel), they have limited usefulness.

At the near-island recorder, median (=50th percentile, line E in Table 4.3) values of broadband sound were lowest in 2006, a year with comparatively low mean wind speeds (see Fig. 4.8 and Table 4.3, line O; 2001 and 2002 were lower). Median values of broadband sound were highest in 2005 and 2007, the two years with the highest mean wind speeds (Fig. 4.8, Table 4.3). The low mean wind speeds in 2001 did not result in a low median level of broadband sound because of the intense construction activities at that time (see Fig. 4.6). Nevertheless, minimum levels of broadband sound (Table 4.3, line J) were lowest in 2001. The range

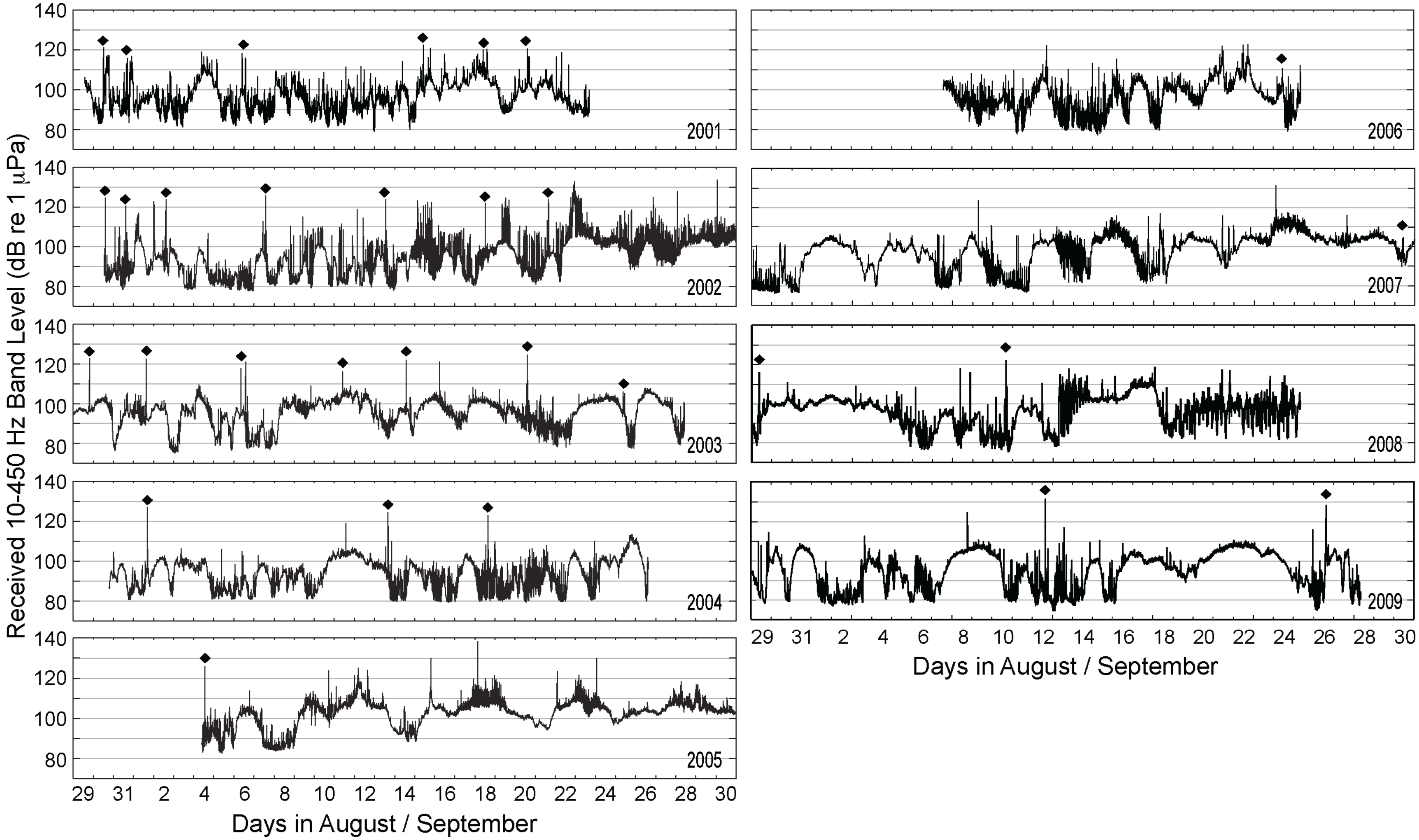

FIGURE 4.9. Sound pressure time series (10–450 Hz band; 1-min averages) for the entire 2001–2009 late summer / early autumn field seasons, as recorded at a DASAR location 14.8 km (9.2 mi) northeast of Northstar. This DASAR location was called EB in 2001–2007 and C in 2008–2009 (Fig. 4.2). Diamonds indicate sound spikes created by the field crew's vessel during servicing of the array of DASARs.

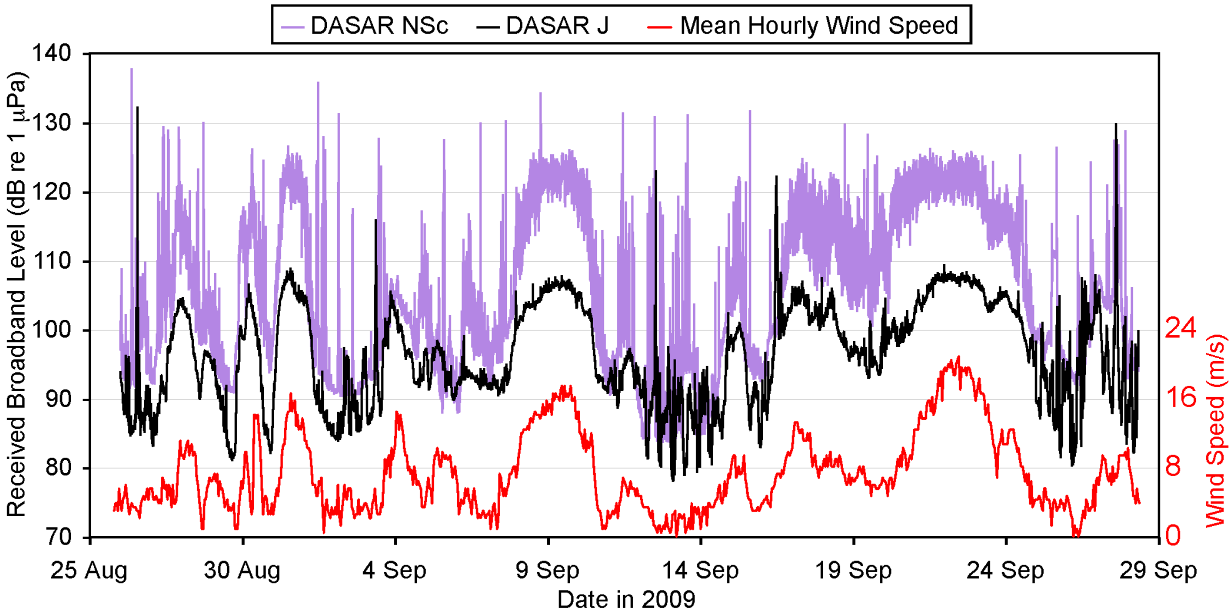

FIGURE 4.10. Broadband levels (10–450 Hz band; 1-min averages) as a function of time for near-island DASAR NSc (450 m or 1480 ft from Northstar, purple line) and offshore DASAR J (38.4 km or 23.9 mi from Northstar, black line) in 2009. Red line shows mean hourly wind speed measured at the Prudhoe Bay weather station.

between the minimum and maximum percentile each year is shown in Table 4.3, line M. This range expresses the amount of variability in the levels of sounds measured near the island. For the near-island recorder this variability was lowest in 2004 (41.4 dB) and highest in 2001 (59.8 dB).

At offshore DASAR EB / C, median values of broadband sound (line F) were highest in 2005 and 2007, the two years with the highest mean wind speeds—as they were for the near-island recorder. With the exception of the maximum values mentioned above, percentile values were always lower at DASAR EB / C than at the near-island DASAR, but by varying amounts. For example, the minimum levels (lines J and K) were quite similar at the two DASAR locations in 2001, a construction year (difference=1.9 dB), but differed between the two locations by at least 15 dB in 2003, 2007, and 2008. The range between minimum and maximum broadband levels (lines M and N) was always greater at the offshore DASAR, except in 2001, when it was greater at the near-island recorder.

Table 4.3 also shows the difference between the near-island and offshore median broadband levels (line G) as well as minimum levels (line L) each year. Not surprisingly, for almost all years, the difference between minima was greater than the difference between medians, the one exception being 2001. In other words, the difference in sound levels received near Northstar and in the offshore array was greater in quiet conditions, simply because Northstar is always present.

Statistical Spectra of Near-island and Offshore Sounds

To characterize the frequency composition of sounds recorded by DASARs over an entire field season, percentile distributions of one-third octave band levels and spectral density levels were calculated for the near-island DASAR and DASAR EB / C. In all cases, the measurements were averages over 1 min. Our previous reports have presented five statistical spectra: the maximum, the 95th, 50th, and 5th percentiles, and the minimum. Here we summarize a subset of these results, presenting several years in each plot to allow

TABLE 4.3. Percentile levels, in dB re 1 µPa, of broadband (10–450 Hz; 1 min averages) underwater sound recorded near Northstar Island and at DASAR location EB / C during late summer and early autumn, 2001–2009. Values for the near-island DASAR are shown in black font, values for DASAR EB / C are shown in *blue italics font*, and differences between the two are shown in **bold font**. "Range" is the difference between maximum and minimum for each recorder location and year. The hydrophones were at similar distances north of Northstar in the various years: 410–550 m (1345–1804 ft) for the near-island recorders, and ~14.8 km (9.2 mi) for the DASARs at location EB / C.

		2001	2002	2003	2004	2005	2006	2007	2008	2009
	Near-island [a]:	CH #2	CH #2	CH #2 & NS	NSa	NSb	NSc	NSb	NSc	NSc
	14.8 km offshore:	*EB*	*EB*	*EB*	*EB*	*EB*	*EB*	*EB*	*C*	*C*
A	Max	140.5	135.0	136.8	133.1	135.8	131.4	133.3	141.1	137.9
B		*122.4*	*135.4*	*124.5*	*126.8*	*138.4*	*122.9*	*131.5*	*130.9*	*133.1*
C	95th %ile	122.7	117.3	123.0	110.1	118.2	111.4	112.5	119.4	123.0
D		*108.5*	*107.7*	*104.1*	*103.9*	*110.8*	*108.4*	*108.8*	*108.6*	*107.4*
E	50th %ile	101.8	103.5	102.3	100.5	105.5	98.7	104.0	103.6	103.9
F		*95.5*	*95.2*	*96.5*	*93.1*	*103.1*	*95.4*	*100.4*	*97.0*	*96.0*
G	**Difference:**	**6.3**	**8.3**	**5.8**	**7.5**	**2.4**	**3.3**	**3.6**	**6.6**	**7.9**
H	5th %ile	87.3	94.8	93.0	93.7	92.4	91.7	93.4	93.2	89.9
I		*85.2*	*81.1*	*80.2*	*81.1*	*87.2*	*81.8*	*79.2*	*80.2*	*79.6*
J	Min	80.8	89.7	90.4	92.0	88.0	89.8	90.9	91.0	83.6
K		*78.9*	*77.6*	*74.9*	*79.1*	*82.5*	*76.8*	*75.9*	*74.9*	*74.6*
L	**Difference:**	**1.9**	**12.1**	**15.5**	**13.0**	**5.5**	**13.0**	**15.0**	**16.1**	**9.0**
M	Range	59.8	45.3	46.4	41.4	44.5	41.6	42.4	50.0	54.3
N		*43.5*	*57.8*	*49.6*	*47.8*	*55.9*	*46.1*	*55.6*	*56.0*	*58.5*
O	Mean wind speed (m/s) [b]	3.9 (N)	5.6 (N)	6.7 (N)	6.5 (N)	8.3 (N)	5.7 (N)	10.0 (PB)	7.2 (PB)	7.9 (PB)

[a] For the near-island DASARs: in 2001 (1–21 Sept.) and 2002 (31 Aug.–23 Sept.), data were collected by cabled hydrophone (CH) #2. In 2003, data were recorded both by CH #2 (29 Aug.–16 Sept.) and DASAR NS (18–28 Sept.). In 2004, 2005, 2006, 2007, and 2008 data were recorded, respectively, by DASAR NSa (30 Aug.–1 Oct.), DASAR NSb (1 Sept.–2 Oct.), DASAR NSc (30 Aug.–25 Sept.), DASAR NSb (28 Aug.–3 Oct.), and DASAR NSc (27 Aug.–25 Sept.). In 2009, data were recorded by DASAR NSc (26 Aug.–28 Sept.).

[b] Mean wind speed is given in meters per second (m/s); multiply values by 2.24 to get mph. Letter given in parentheses is the location of the weather station: N = Northstar, PB = Prudhoe Bay.

comparisons between years, and presenting near-Northstar and offshore (DASAR EB / C) data side-by-side to allow for comparisons between those locations.

Figure 4.11 shows the one-third octave results in this format. For each DASAR location, three percentiles are displayed: the 95th percentile (Fig. 4.11A, D), median (Fig. 4.11B, E) and minimum (Fig. 4.11C, F). Data from 2005–2009 are shown, together with data from 2001 as a reference; the latter stages of Northstar construction were occurring in 2001, whereas Northstar was in production during 2005–2009. Maximum levels were omitted from these plots because they can be determined by a single vessel pass or other noisy activity, so they have limited value for whole-season comparisons.

The minimum levels for the near-island recorder (Fig. 4.11C) are useful because they show the frequency composition of island sounds when sea state was low and, therefore, the contribution of ambient sounds to the records was minimal. For every year shown in Figure 4.11C, there is a "hump" at the one-third octave bands centered at 31.5 Hz, 40 Hz, 50 Hz, and 63 Hz, even though in 2001 levels remained high for one-third octave bands at center frequencies above 63 Hz. The sounds at these frequencies are largely of anthropogenic origin. Recognition of this in 2001 led to the definition of the industrial sound index *ISI_5band* as a summary of the sound level at 28 to 90 Hz (Blackwell 2003). The "hump" at these frequencies is absent from the minimum levels recorded offshore (Fig. 4.11F). Also, minimum levels recorded near Northstar (Fig. 4.11C), across all years and frequencies, show more overall variability than those recorded offshore (Fig. 4.11F): differences of ~26 dB versus ~12 dB between the lowest and highest one-third octave band values on each plot.

Figure 4.11 illustrates the considerable variation between years in whole-season levels, which are in part related to the mean wind speed during each season (see Fig. 4.8). For the years shown in Figure 4.11, the inter-year variability reached 30 dB at the near-island DASAR (95th percentile, one-third octave band centered at 16 Hz, difference between 2009 and 2001) and 22 dB at the offshore DASAR (95th percentile, one-third octave band centered at 12.5 Hz, difference between 2005 and 2008). Differences between 2001 and later years are also apparent. During the construction year (2001), minimum, median, and 95th percentile levels at low frequencies were all lower than they were when Northstar transitioned into production mode. In other words, in the left-hand plots (Fig. 4.11A, B, C) for center frequencies ≤25 Hz, the gray line (2001) is always the lowest line.

Figure 4.12 shows the corresponding spectral density levels: the near-island recorder on the left and offshore DASAR EB / C on the right. As discussed for one-third octave bands above, the minimum spectra for the near-island recorder (Fig. 4.12C) are useful because they show the spectral composition of sounds from the island when ambient levels were low. Figure 4.12C shows the presence of peaks (tones) at 30 Hz, 60 Hz, and some multiples thereof, in every year shown. Some of these peaks (30 Hz and 60 Hz for example) are also visible in the median plot (Fig. 4.12B). A 20 Hz peak was only evident in 2001, along with several other tones or peaks, and 2001 was also the only year with distinct tones in the 95th percentile plot (Fig. 4.12A). This is likely related to the numerous construction activities that year. In addition, because mean wind speed was low in 2001 (see Fig. 4.8) construction sounds were less masked by stormy weather than they were in later years. In contrast, percentile spectral density levels at offshore DASAR EB / C (Fig. 4.12D, E, and F) are characterized by a lack of tones at the low frequencies (<100 Hz) where such tones are most prevalent at Northstar.

Industrial Sound Indices (ISIs)

The three industrial sound indices (ISIs) that have been defined in this project have been used in previous analyses of bowhead call distribution and calling behavior relative to Northstar (Richardson [ed.] 2008), and similar analyses for 2009 are presented in this report (Chapter 6). Therefore, it was important to understand the properties of the ISIs and their relationship to standard measurements of the underwater sounds.

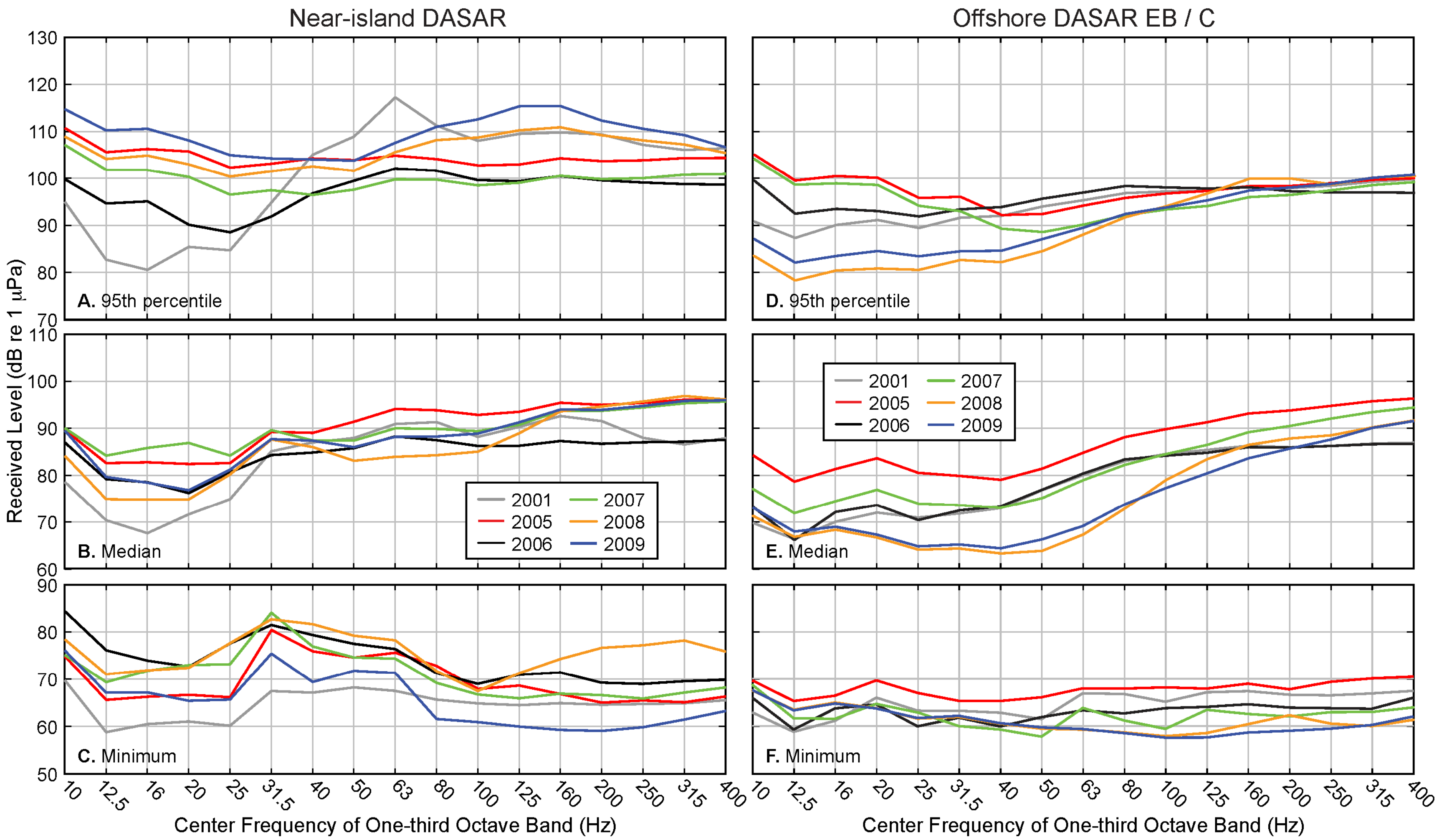

FIGURE 4.11. Selected percentile one-third octave band levels of sound recorded by the near-island DASAR (left) and offshore DASAR EB / C (right) over the entire DASAR deployment period (see Table 4.1) in six years: 2001 (gray line), 2005 (red), 2006 (black), 2007 (green), 2008 (orange) and 2009 (blue). Northstar was in a construction phase in 2001 and in production in 2005–2009. ***(A)*** and ***(D)*** 95th percentile levels. ***(B)*** and ***(E)*** Median levels (50th percentile). ***(C)*** and ***(F)*** Minimum levels.

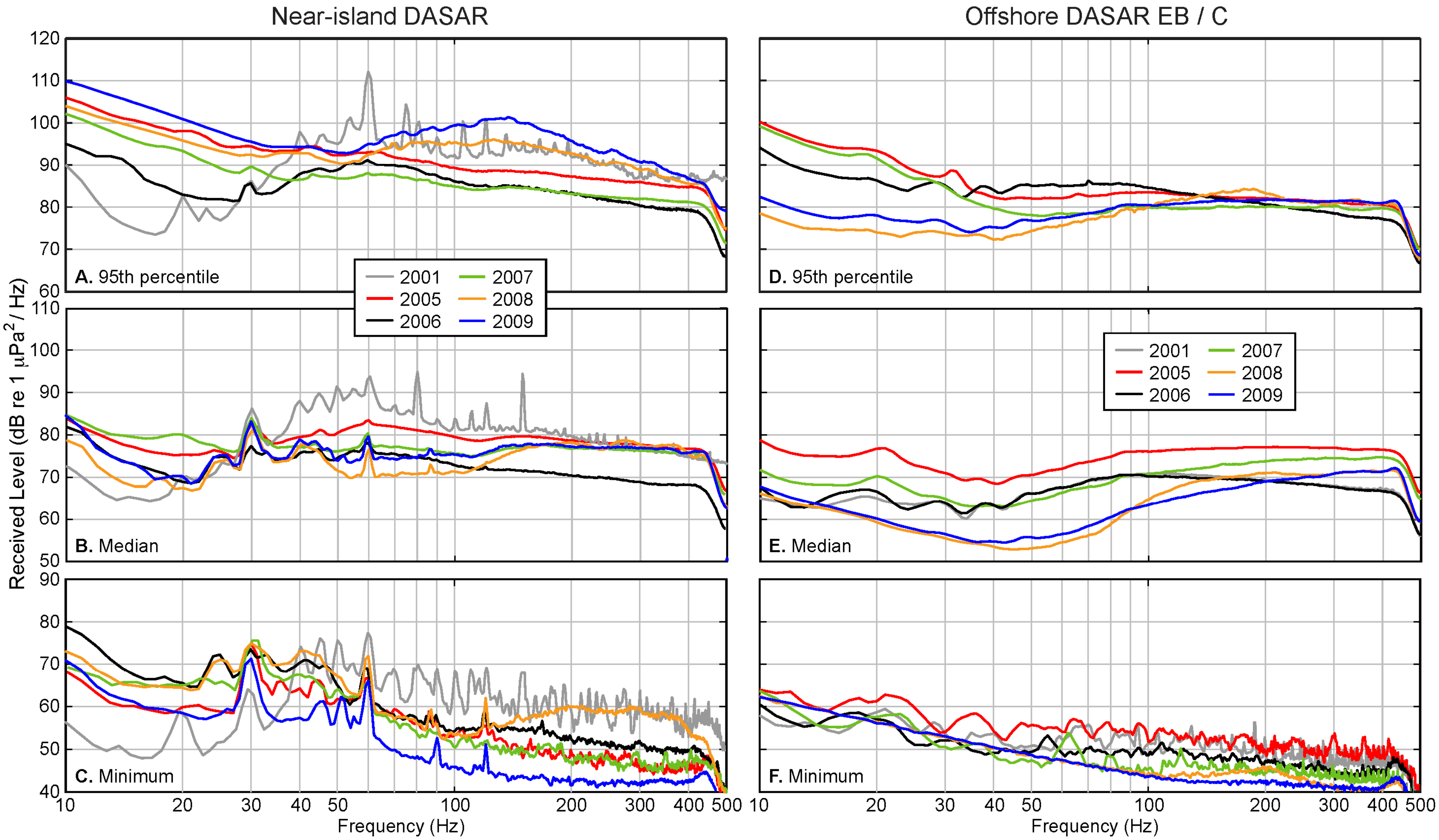

FIGURE 4.12. Selected percentile spectral density levels for sounds recorded by the near-island DASAR (left) and offshore DASAR EB / C (right) over the entire DASAR deployment period (see Table 4.1) in six years: 2001 (gray line), 2005 (red), 2006 (black), 2007 (green), 2008 (orange) and 2009 (blue). Northstar was in a construction phase in 2001 and in production in 2005–2009. ***(A)*** and ***(D)*** 95th percentile levels. ***(B)*** and ***(E)*** Median levels (50th percentile). ***(C)*** and ***(F)*** Minimum levels.

ISI_5band

ISI_5band is an Industrial Sound Index (ISI) that was designed to represent the occurrence of low frequencies—typical of industrial activities—in the sounds emanating from Northstar. *ISI_5band* was calculated by adding together the mean square sound pressures in the one-third octave bands centered at 31.5, 40, 50, 63 and 80 Hz, which collectively span the 28 to 90 Hz frequency range. Each measurement was for a 1-min interval every 4.37 min. Generally, *ISI_5band* was closely related to the overall 10–450 Hz level, but *ISI_5band* was always at least a few decibels lower. This is an expected consequence of the fact that *ISI_5band* excludes sound components at frequencies 10–28 Hz and 90–450 Hz, which are included in the corresponding 10–450 Hz broadband data. Figure 4.13 illustrates this by comparing whole-season broadband and *ISI_5band* levels for two example years: 2006, when the median difference between broadband and *ISI_5band* level was small (4.5 dB over the entire DASAR deployment period), and 2008, when the difference was more than two times greater (11.0 dB). Overall median broadband and *ISI_5band* levels are shown in Table 4.4 for all years from 2001 to 2009, at both the near-island recorder and offshore DASAR location EB / C. These median values were calculated over the entire DASAR deployment period in each year. Table 4.5 contains the same type of information as Table 4.4, but each line is averaged for two periods: 2001–2004 and 2005–2009.

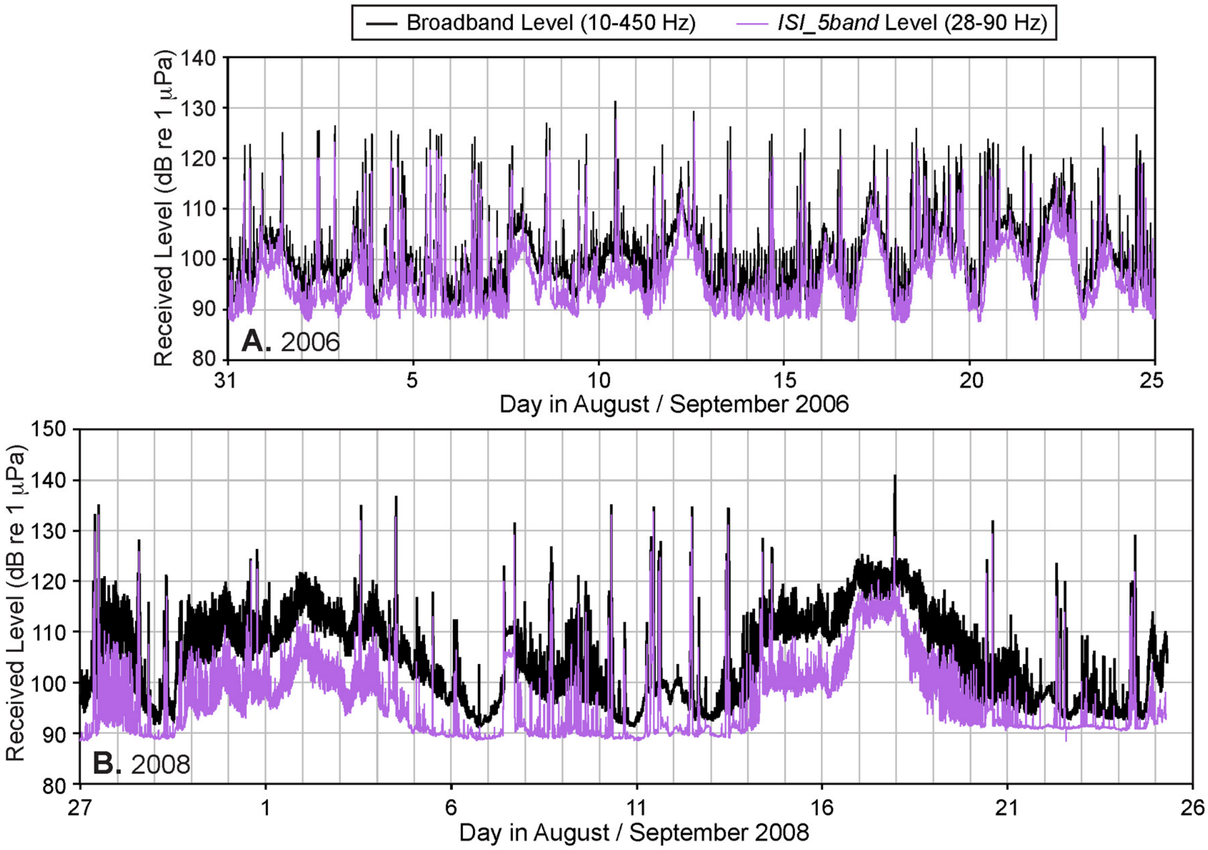

FIGURE 4.13. Received broadband (black line) and *ISI_5band* (purple line) sound levels at the near-island DASAR in ***(A)*** 2006 and ***(B)*** 2008 (DASAR NSc in both cases). The x-axis scales are the same on both plots; the DASAR deployment season was longer in 2008 than in 2006.

TABLE 4.4. Median levels, in dB re 1 µPa, of broadband (10–450 Hz) and *ISI_5band* (28–90 Hz) underwater sound recorded near Northstar Island and at DASAR location EB / C during late summer and early autumn, 2001–2009. For each year and recorder location, the difference between the two is also shown (broadband level – *ISI_5band* level) in **bold font**. The bottom lines (G and H) of the table show, for each year, the difference in broadband (BB) and *ISI_5band* levels at Northstar and location EB / C, respectively. The hydrophones were at similar distances north of Northstar in the various years: 410–550 m (1345–1804 ft) for the near-island recorders, and ~14.8 km (9.2 mi) for the DASARs at location EB / C.

		2001	2002	2003	2004	2005	2006	2007	2008	2009
	Near-island DASAR:									
A	- broadband level	101.8	103.5	102.3	100.5	105.5	98.7	104.0	103.6	103.9
B	- *ISI_5band* level	97.7	98.7	95.9	97.1	99.3	94.2	96.2	92.6	95.0
C	Difference (BB & ISI levels):	**4.2**	**4.8**	**6.3**	**3.4**	**6.2**	**4.5**	**7.8**	**11.0**	**8.9**
	Offshore DASAR EB / C:									
D	- broadband level	95.5	95.2	96.5	93.1	103.1	95.4	100.4	97.0	96.0
E	- *ISI_5band* level	86.3	80.0	80.8	78.3	90.9	89.6	86.1	75.6	76.8
F	Difference (BB & ISI levels):	**9.3**	**15.2**	**15.7**	**14.8**	**12.2**	**5.8**	**14.3**	**21.4**	**19.2**
	Near-island vs. Offshore									
G	Difference in BB levels at Northstar vs. EB / C:	6.3	8.3	5.8	7.5	2.5	3.3	3.6	6.6	7.9
H	Difference in ISI levels at Northstar vs. EB / C:	11.4	18.7	15.1	18.8	8.4	4.6	10.1	17.0	18.2

The difference between median broadband levels and median *ISI_5band* levels varied in the range 3.4–11.0 dB at the near-island recorder over all years shown (Table 4.4, line C). The average of these values for 2001–2004 (4.7 dB) was 3.0 dB lower than the average for 2005–2009 (7.7 dB, Table 4.5, line C). Overall, this indicates that the contribution of the 28–90 Hz frequency range (the "industrial" frequency range) has decreased between the two periods. This is supported by the 2 dB drop in the average *ISI_5band* level between the two periods (97.3 dB to 95.5 dB, Table 4.5, line B), despite a slight increase in broadband levels over the same period (102 dB to 103.2 dB, Table 4.5, line A). In addition, the differences in broadband levels and *ISI_5band* levels between the two DASAR locations (near-island and EB / C) have decreased from 2001–2004 to 2005–2009 (Table 4.5, lines G and H). In other words, sound levels close to Northstar were more similar to those at location EB / C in later years than in 2001–2004.

Similar to the trend seen at the near-island DASAR, broadband levels at location EB / C increased on average from 2001–2004 to 2005–2009 (95.1 dB to 98.4 dB, Table 4.5, line D). However, unlike what was described for the near-island recorder, *ISI_5band* levels also increased, by 2.5 dB (81.3 dB to 83.8 dB, Table 4.5, line E).

At DASAR location EB / C, the difference between median broadband levels and median *ISI_5band* levels was in the range 5.8–21.4 dB in 2001–2009 (Table 4.4, line F). This difference (line F) was higher every year than was the broadband vs. *ISI_5band* difference at the near-island recorder (line C). The main reason for this is that near Northstar the 28–90 Hz band level is elevated by Northstar-related sound, thereby reducing the difference between broadband levels and *ISI_5band* levels. The average difference between median broadband levels and median *ISI_5band* levels at offshore DASAR EB / C (Table 4.5, line F) was

TABLE 4.5. Averages for 2001–04 and 2005–09 of the annual median broadband and *ISI_5band* levels presented in Table 4.4. Broadband levels are for the frequency range 10–450 Hz, whereas *ISI_5band* values are for the frequency range 28–90 Hz. All levels are in dB re 1 μPa. The near-island DASAR and DASAR location EB / C were ~450 m and ~14.8 km (9.2 mi) northeast of Northstar Island, respectively. See Table 4.4 for more information.

		2001–04	2005–09
	Near-island DASAR:		
A	- broadband level	102.0	103.2
B	- *ISI_5band* level	97.3	95.5
C	Difference (BB – ISI levels):	**4.7**	**7.7**
	Offshore DASAR EB / C:		
D	- broadband level	95.1	98.4
E	- *ISI_5band* level	81.3	83.8
F	Difference (BB – ISI levels):	**13.7**	**14.6**
	Near-island vs. Offshore		
G	Difference in BB levels at Northstar vs. EB / C:	7.0	4.8
H	Difference in ISI levels at Northstar vs. EB / C:	16.0	11.7

similar in 2001–2004 (13.7 dB) and 2005–2009 (14.6 dB). This difference (Table 4.4, line F) was particularly high at DASAR location EB / C in 2008 and 2009 (21.4 dB and 19.2 dB, respectively). We have no definite explanation for this observation, but it could be related to the presence of airgun pulses on array DASAR records in those two years (see section Airgun Sounds below). Airgun pulses contain energy both below and above the *ISI_5band* frequency range. If airgun pulses contributed relatively more energy outside the 28–90 Hz band than inside that band, then the difference between broadband and *ISI_5band* levels would be increased in the years with many airgun pulses.

For each year, the difference in median broadband levels between the near-island recorder and DASAR location EB / C was in the range 2.5–8.3 dB (Table 4.4, line G), with the levels at Northstar always being the higher of the two. The corresponding difference in median *ISI_5band* levels was greater, 4.6–18.8 dB (Table 4.4, line H). These comparisons support the notion that *ISI_5band* does include a disproportionate amount of sound from industrial operations and, therefore, is a better index of industrial sound than the 10–450 Hz broadband levels would be.

The difference between median broadband and *ISI_5band* levels at the near-island recorder (Table 4.4, line C) was particularly high in 2008 (11.0 dB) and 2009 (8.9 dB), and to some extent in 2007 (7.8 dB), compared to the values in 2001–2006 (3.4–6.3 dB). At least for 2008 and 2009, this is likely due to the presence of "pops" close to Northstar. "Pops" are sounds of unknown origin that were first detected on the near-island recorders in 2008, and then identified again in 2009. In both years, many thousands of pops were detected on the near-island recorders (see section ***Unknown Sound of 2008–2009*** below and Blackwell et al. 2010b). Pops are broadband impulsive sounds with most of their energy above the 28–90 Hz frequency range (see Fig. 4.25, later), so the presence of pops would lead to a greater difference between broadband and *ISI_5band* values for a given sample. This hypothesis was tested using 2008 data (Blackwell et al. 2009). The difference between broadband values and *ISI_5band* values was computed for a day with many pops (28 Aug. 2008, 00:00–12:00 local time) and another day with few pops (13 Sept. 2008, 00:00–12:00). The two days had similar wind speeds. The results lent support to the hypothesis: the mean difference ± one S.D. between broadband levels and *ISI_*5band *levels* was 13.3 ± 2.4 dB on 28 Aug. 2008, compared to 4.9 ± 2.1 dB on 13 Sept. 2008.

ISI_tone

ISI_tone characterizes the presence and amplitude of tones, which are typical of rotating or vibrating machinery. Most types of large equipment used at Northstar, such as generators, engines of various sorts, vibratory pile-drivers, compactors, etc., are likely to produce tones (Spence 2006). Tones are also produced by vessels such as the tugs used to transport equipment to Northstar (Blackwell and Greene 2006).

Figure 4.14 quantifies the presence and amplitude of tones at the near-island DASAR over 9 years, 2001–2009, and at DASAR location C (EB) in 2008 and 2009. For each year, it shows the overall percentage of 1-min samples with detected tones (according to the *ISI_tone* definition, see section ***ISI_tone*** in ***Methods***). For the near-island DASAR, this percentage was highest in 2001, with nearly 80% of samples containing tones, and lowest in 2006, with less than 15% of samples containing tones. If presence of tones in the samples is correlated with the presence of industrial activities at Northstar, then the following pattern emerges:

- intense activity in 2001 (79% of samples containing tones);
- drop in 2002 (39%), followed by an increase in activities in 2003 and 2004 (57–60%);
- drop in 2005 and 2006 (less than 20%);

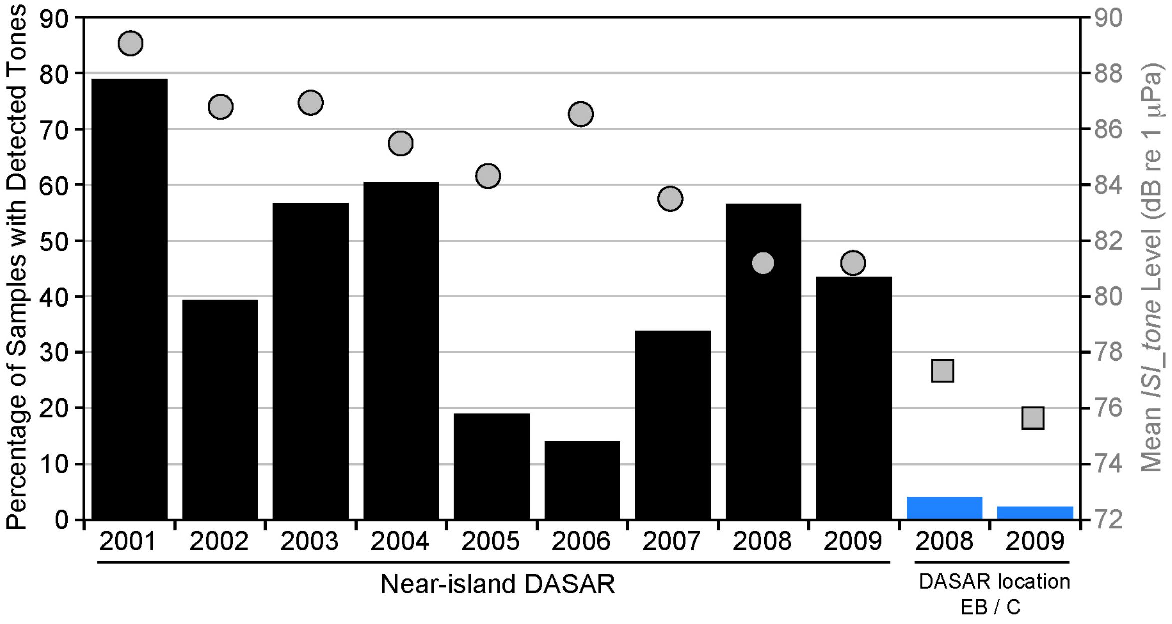

FIGURE 4.14. Measures of *ISI_tone* as recorded at the near-island DASAR, 2001–2009, and at DASAR location C (=EB) in 2008 and 2009. The bars show the percentage of samples (1-min samples every 4.37 min) with detected tones (scale on left side). Bars are black for the near-island recorder and blue for DASAR location C. Gray symbols show the mean yearly *ISI_tone* level (scale on right side), as calculated using only non-zero samples (i.e., sound samples that did contain tones). Gray circles show mean values at the near-island recorder; gray squares show values for DASAR location C. Both *ISI_tone* measures shown in this Figure were calculated over the entire DASAR deployment period each year.

- increase in 2007 (34%) and 2008 (57%);
- decrease in 2009 (43%).

However, Figure 4.14 also shows that the mean *ISI_tone* level over the entire season (calculated by excluding samples with no tones detected) has decreased progressively from 2001 to 2009, with the exception of an increase in 2006. This shows that, despite variations among years in how much of the time tone-producing equipment was being used at or near Northstar, *while* this equipment was being used, the total amount of "tone power" decreased from 2001 to 2009. In other words, either fewer pieces of equipment were being used or those that were being used were quieter.

The rightmost part of Figure 4.14 shows the equivalent data for DASAR location C in 2008 and 2009 (this was location EB in 2001–2007). This location was 14.9 km (9.2 mi) northeast of Northstar. Only 4% and 2% of broadband samples contained any tones (according to the *ISI_tone* definition) in 2008 and 2009, respectively. For samples that did contain tones, mean *ISI_tone* levels at DASAR C were 77 dB and 76 dB re 1 μPa in 2008 and 2009, respectively. These values are 4–13 dB below values at the near-island recorder. It is likely that most of the tones detected at DASAR location C were produced by vessels passing through the array. An attempt to detect tones created by island power generation in the offshore array (Blackwell et al. 2009) showed that the strongest power frequency tone from the island (60 Hz) could not be detected 8.6 km (5.3 mi) away even during times of lowest ambient levels. It is possible that tones from vessels operating at Northstar, for example tugs pushing or maneuvering loaded barges, could propagate to the DASAR array, but we have not done specific analyses to address that question.

Figure 4.15 shows *ISI_tone* levels at the near-island DASAR in 2001–2009. As shown in Figure 4.14, the preponderance of tones during the 2001 season is apparent, but other more subtle differences are visible in this Figure. For example, in 2006 (and other years), most of the tone detections line up vertically, corresponding to well-defined time periods during which tone-producing machinery was being used and produced a range of *ISI_tone* values (in the range 60–120 dB re 1 μPa). In 2007 (and other years) the tone detections also tend to line up horizontally, with many *ISI_tone* levels close to 85 dB, indicating that the machinery producing those tones was being used continuously for extended periods of time, lasting from a few to many days.

Figure 4.16 shows *ISI_tone* levels at DASAR location C in 2008 and 2009. The presence of tones is mostly limited to relatively short periods, most of which correspond to days during which the acoustic team's ACS *Bay* vessel was in the offshore array performing calibrations or health checks. These days are shown in gray shading in Figure 4.16. During calibrations, a 2-s long tone at 400 Hz (see Fig. 4.3, time 0–2 s) is projected underwater, at the rate of about 9 times per calibration station. So even though vessels themselves produce tones, most of the dots in Figure 4.16 during the shaded days are likely produced by calibration transmissions.

ISI_transient

ISI_transient evaluates the presence of broadband transient sounds in the sound record. The most likely source of a transient spike in the sound record is a passing vessel, but it could also be a piece of equipment that is turned on for a period of minutes to hours. (If the sound source is on for many hours, then the *ISI_transient* algorithm would only detect the start of the activity.) Figure 4.17 shows *ISI_5band* levels (gray line) for an example day, 11 Sept. 2009. It also shows a running 4-hr average of *ISI_5band* levels (thick red line). When the *ISI_5band* level at a particular time exceeds the 4-hr running average (centered on the same time) by at least 5 dB, then *ISI_transient* ≠ 0. The black dots in Figure 4.17 show the corresponding *ISI_transient* values (to be read on the right y-axis). Figure 4.17 shows one or more *ISI_transient* identifications (i.e., *ISI_transient* ≥ 5 dB) whenever a "spike" occurred in the sound pressure time series.

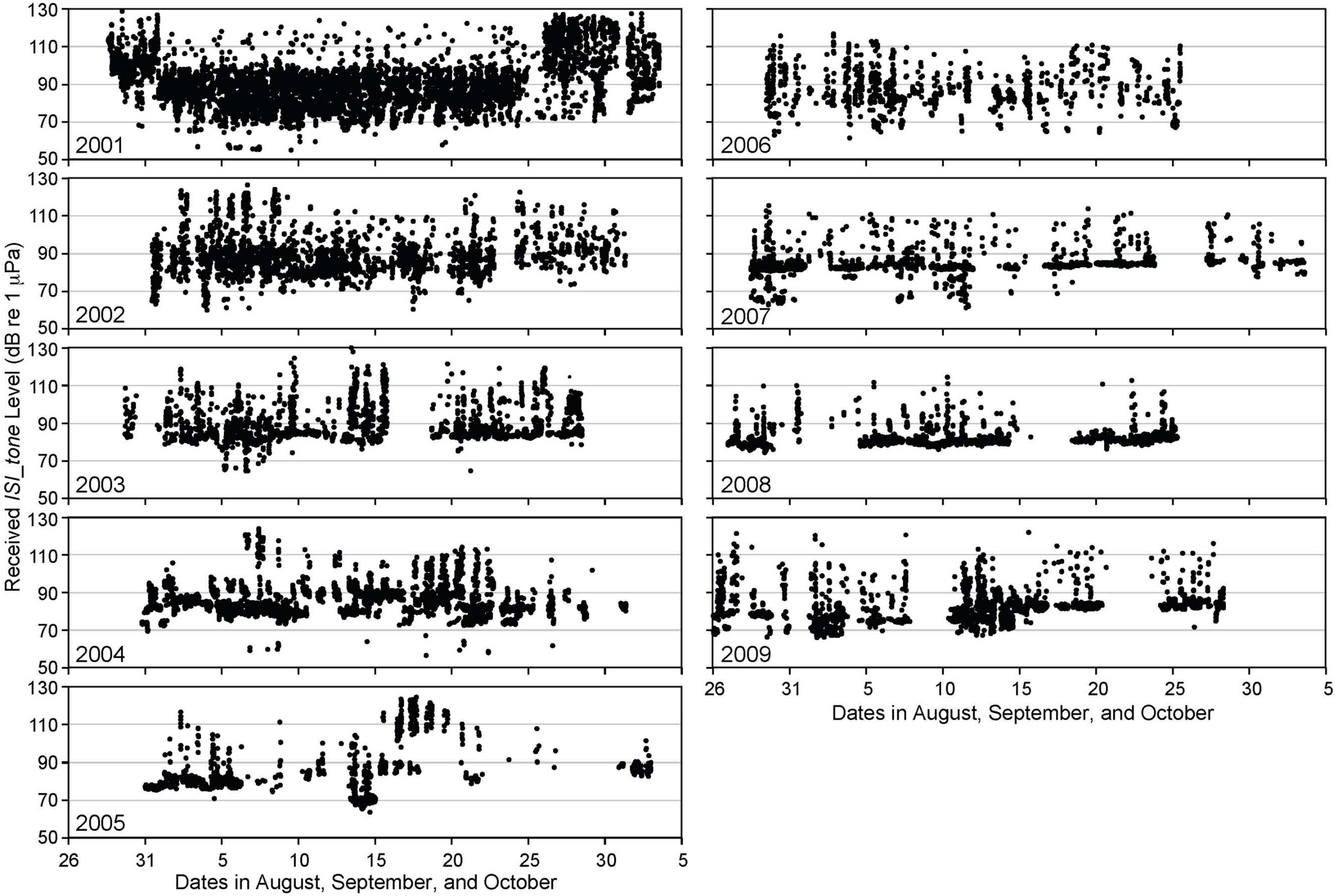

FIGURE 4.15. *ISI_tone* levels (in dB re 1 μPa) at the near-island DASAR in 2001–2009.

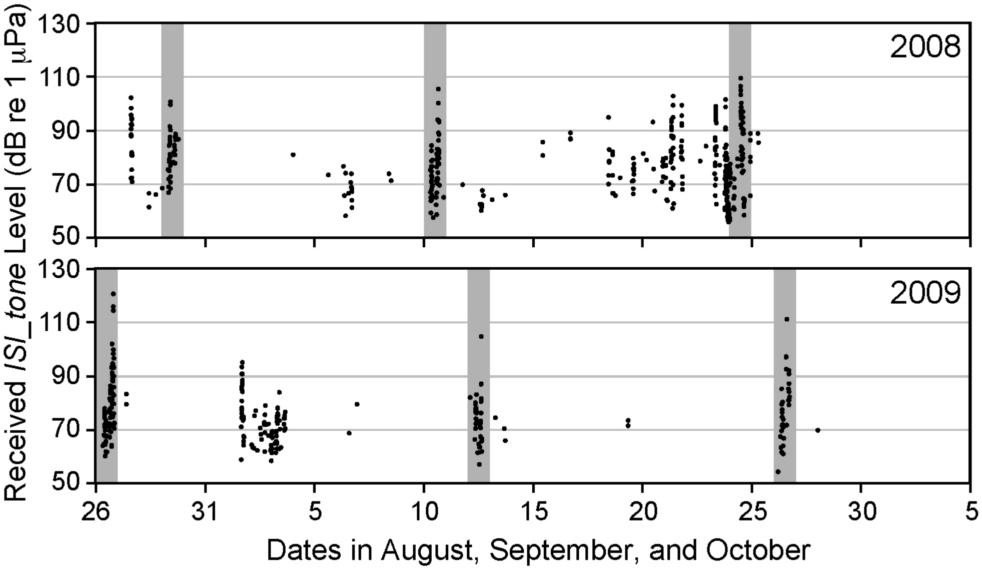

FIGURE 4.16. *ISI_tone* levels (in dB re 1 μPa) at DASAR location C in 2008 and 2009. Days during which an ACS *Bay* vessel was in the offshore array to perform calibrations or health checks on the DASARs are shown in gray shading.

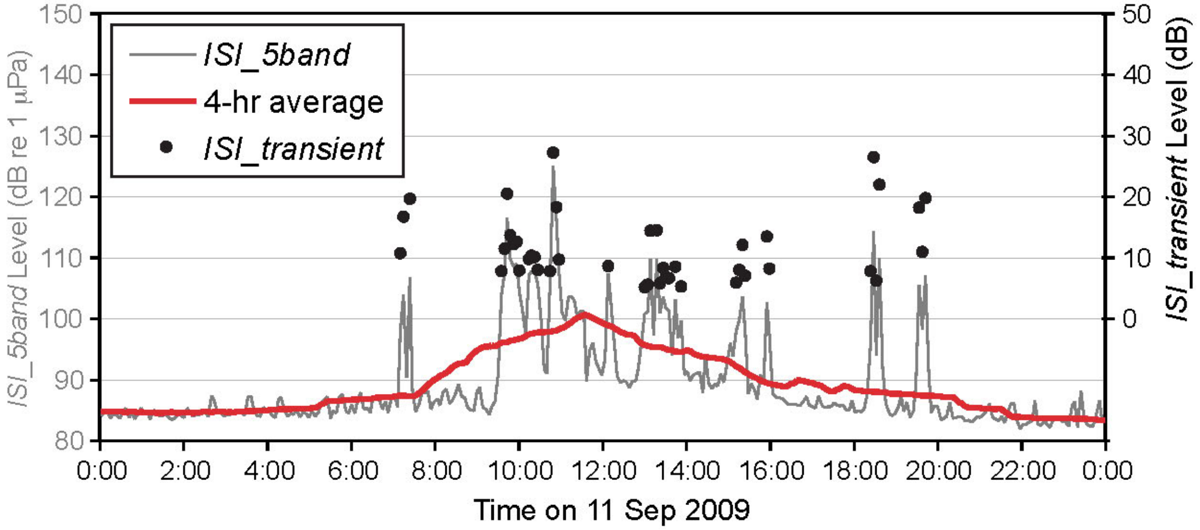

FIGURE 4.17. Computation of *ISI_transient* for sounds recorded at near-island DASAR NSc on 11 Sept. 2009. The gray line shows the value of *ISI_5band* as a function of time (1-min sample every 4.37 min, value of *ISI_5band* to be read on left y-axis). The red line shows the 4-hour moving average of *ISI_5band* levels. A transient sound source is defined as occurring (with the value of *ISI_transient* to be read on the right y-axis) if the value of *ISI_5band* at time *t* is ≥5 dB above the moving average centered on *t*.

According to vessel records, the sound spikes occurring at about 07:00, 18:30, and 19:30 can be attributed to ACS *Bay* boats making three round-trips to the island, and the spikes occurring between 9:30 and 11:00 (including the highest sound spike of the day) can be attributed to a tug and barge.

Figure 4.18 quantifies the presence and amplitude of transients at the near-island DASAR over 9 years, 2001–2009, and at DASAR location C (EB) in 2008 and 2009. For each year, it shows the overall percentage of samples (one sample analyzed every 4.37 min) with a detected transient (according to the *ISI_transient* definition, see above paragraph and section ***ISI_transient*** in ***Methods***). For the near-island DASAR, this percentage was highest in 2001 (as it was for tones), with about 16% of samples including a transient. It was lowest in 2004 and 2007 with less than 3.5% of samples including a transient sound. If we disregard 2001, the frequency of transient sound sources at Northstar has fluctuated on a three-year cycle, with few commonalities relative to the year-to-year pattern in frequency of tones (*cf.* Fig. 4.14). The mean *ISI_transient* value each year (gray symbols in Fig. 4.18) did not show any specific pattern over the years.

The rightmost part of Figure 4.18 shows the equivalent data for DASAR location C in 2008 and 2009 (this was location EB in 2001–2007). In those years, the percentage of samples with detected transients and the mean *ISI_transient* value at DASAR C were similar to the values recorded during the same years at the near-island DASAR. This is in contrast with what was shown for *ISI_tone* (Fig. 4.14), for which values at the near-island DASAR were noticeably higher than values at DASAR C. We know that there are at times sources of tones and transient sounds within the DASAR array independent of Northstar. However, a comparison of Figures 4.14 and 4.18 suggests that transient sounds at Northstar, such as a barge being maneuvered at the island and thereby creating strong, broadband cavitation sounds, are more likely to propagate into the DASAR array than are tones. The main reason for this is probably the relative amplitude of the signal, which is generally much lower for individual tones than for the broadband cavitation sound produced by a maneuvering vessel.

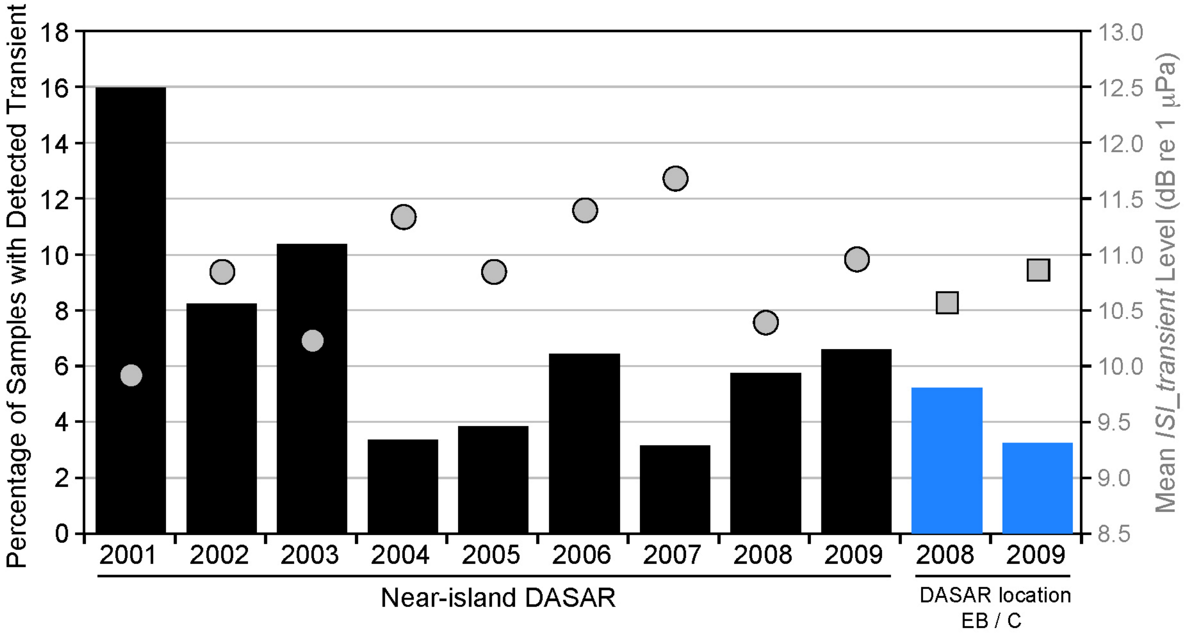

FIGURE 4.18. Measures of *ISI_transient* as recorded at the near-island DASAR, 2001–2009, and at DASAR location C (EB) in 2008 and 2009. The bars (scale on left side) show the percentage of samples (1-min samples every 4.37 min) with detected transients. The bars are black for the near-island recorder and blue for DASAR location C. Gray symbols (scale to be read on right side) show the mean yearly *ISI_transient* level, as calculated using only non-zero samples (i.e., sound samples which did contain a transient). Gray circles show values for the near-island recorder; gray squares show values for DASAR location C. Both *ISI_transient* measures shown in this Figure were calculated over the entire DASAR deployment period each year.

Figure 4.19 shows *ISI_transient* values at the near-island DASAR in 2001–2009. As shown in Figure 4.18, the preponderance of transients during the 2001 season is apparent. Figure 4.20 shows *ISI_transient* values at DASAR location C in 2008 and 2009. Transient sounds were detected more commonly than tones at location C (compare Fig. 4.16 vs. 4.20). In September 2008 there was ongoing seismic exploration at locations roughly 75–115 km west (3–12 Sept.) and east (13–28 Sept.) of the DASAR array. The activities associated with those operations (including vessel traffic) probably account for some of the detected tones (Fig. 4.16) and transients (Fig. 4.20). Note that on 12 Sept. 2009 calibrations and health checks had to be interrupted because of whaling activities (Blackwell et al. 2010b; Galginaitis 2010). The number of transients detected on that day was noticeably lower than on other calibration days in Figure 4.20.

Specific Island-Related Sources

Vessels

Vessels transport goods and personnel to Northstar. From the beginning of island construction (2000) until the 2003 open-water season, personnel transfers were performed using a crew boat. By 2004, the crew boat had been replaced by a hovercraft, whose underwater "sound signature" is considerably smaller. The hovercraft sounds are shorter in duration and lower in amplitude (see Blackwell and Greene 2005) than are the sounds of a conventional vessel. During the present reporting period (2005 to date), most personnel transfers during the open-water season have been done with a hovercraft, although an ACS "*Bay*" boat or Bell 212 helicopter is used when sea state precludes use of the hovercraft (see Chapter 2). Goods and heavy equipment are brought to the island using tugs and barges.

From an underwater sound viewpoint, vessels traveling to Northstar can be split into two categories: those that produce a visible "sound spike" on the near-island recordings (tugs, self-propelled barges, and ACS vessels) and those that do not (the hovercraft). When one examines the raw sound pressure time series of the near-island recorder, brief segments of hovercraft sound can be identified. However, when the data are subsequently analyzed by averaging 1 min of data every 4.37 min (see ***Methods***), the sounds produced by the hovercraft are short enough in duration that they essentially are averaged out and do not produce a "vessel spike".

Figure 4.21 shows the daily mean number of round trips to Northstar by various vessels during the 2003–2009 DASAR deployment periods. These vessels include the crewboat (until 2003), the hovercraft (first used in 2003), barges accompanied by tugs, and ACS vessels. We have no detailed information on ACS vessels before 2004, or on the crewboat or tugs and barges before 2003. However, in 2002 the crew boat alone had eight scheduled daily round trips to the island, and in 2001, a dozen or more (Blackwell and Greene 2006). Chapter 2 also presents information on the number of trips by tugs and barges, ACS vessels, and the hovercraft for every month of the year. The daily mean number of trips by spike-producing vessels (crewboat, tug and barge, and ACS vessels) was 6 in 2003 (excluding ACS vessels), 1.1 in 2004, 0.8 in 2005, 2 in 2006, 2.5 in 2007, 0.8 in 2008, and 1.7 in 2009. These averages were calculated each year over the deployment duration of the near-island recorders.

Generally speaking, there was a close relationship between the number of vessel spikes that could be identified in the sound pressure time series (10–450 Hz) of the near-island recorder (such as in Figure 4.6) and official records of vessel trips to the island. The percentage of documented arrivals and departures at Northstar by tugs and ACS vessels that could be matched to a spike on the sound pressure time series of the near-island recorder was as follows: 81% in 2005, >85% in 2006, 75% in 2007, >95% in 2008, and 80% in 2009. This comparison relies on the accuracy of the official Northstar vessel-traffic records, which may not be totally complete. It is also possible that a vessel arriving on Northstar's southern or southwestern side would not produce a noticeable sound-spike in the record from a near-island recorder located north and northeast of Northstar since the island could have an acoustic shielding effect.

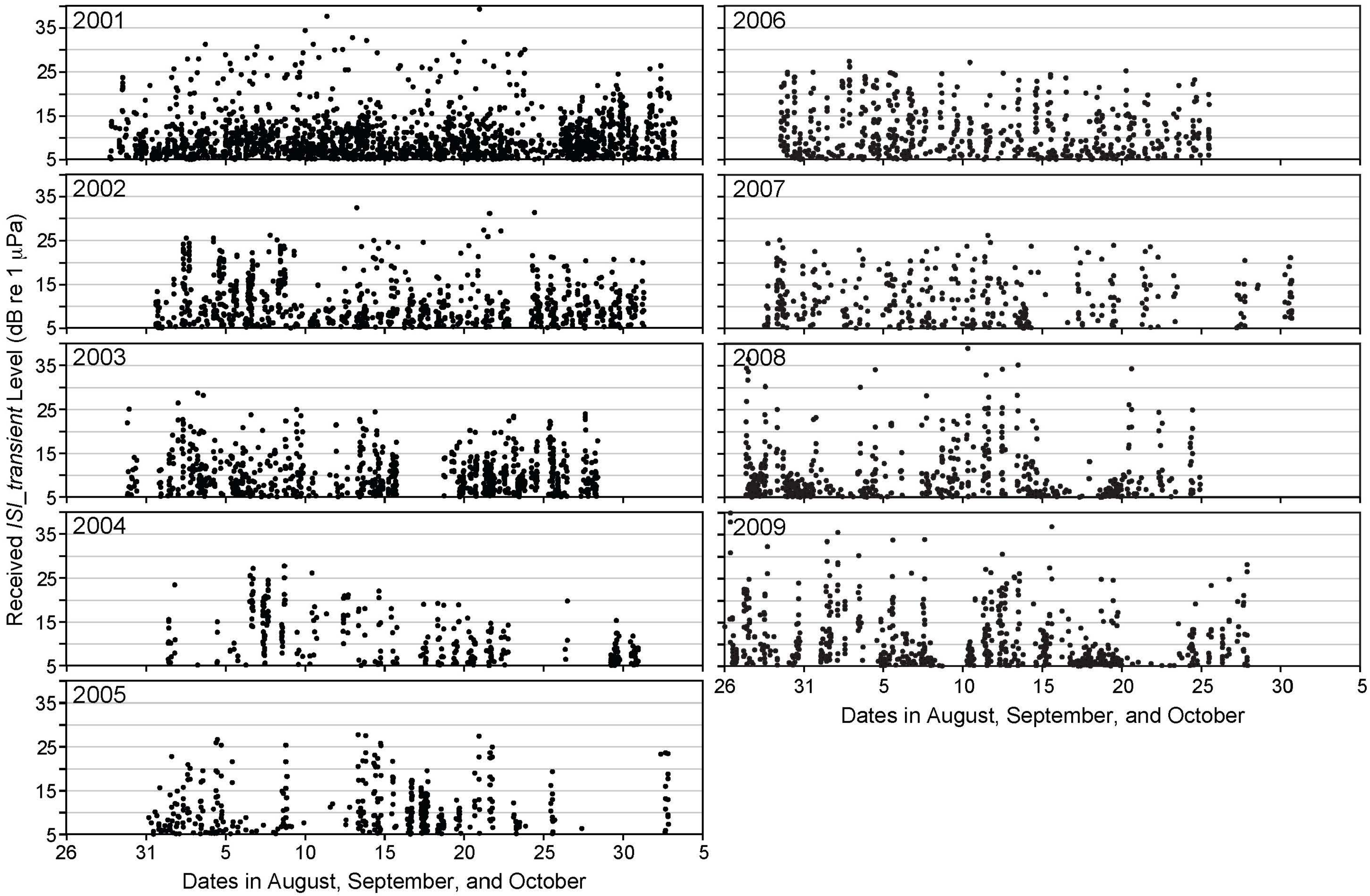

FIGURE 4.19. *ISI_transient* levels (in dB re 1 µPa) at the near-island DASAR in 2001–2009.

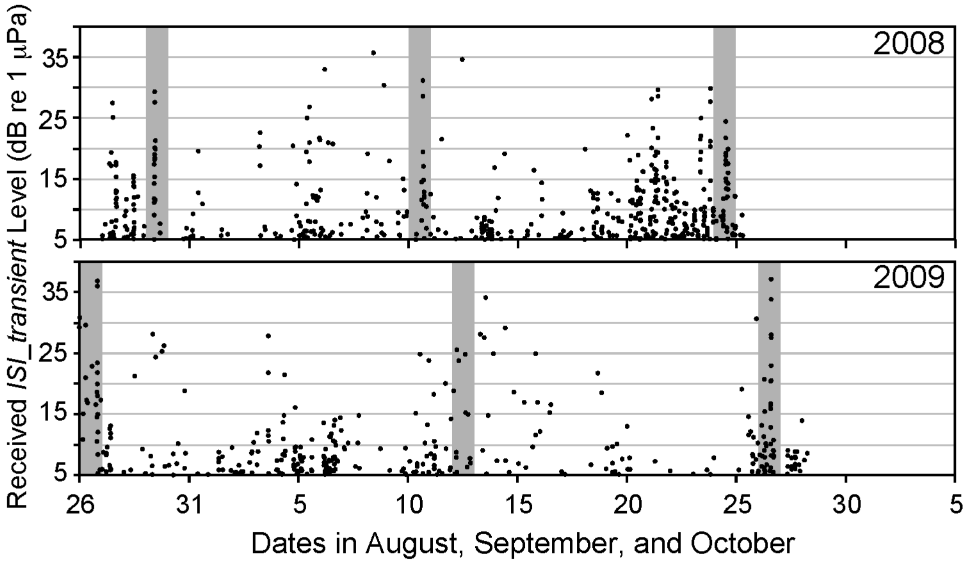

FIGURE 4.20. *ISI_transient* levels (in dB re 1 µPa) at DASAR location C in 2008 and 2009. Days during which an ACS *Bay* vessel was in the offshore array to perform calibrations or health checks on the DASARs are shown in gray shading.

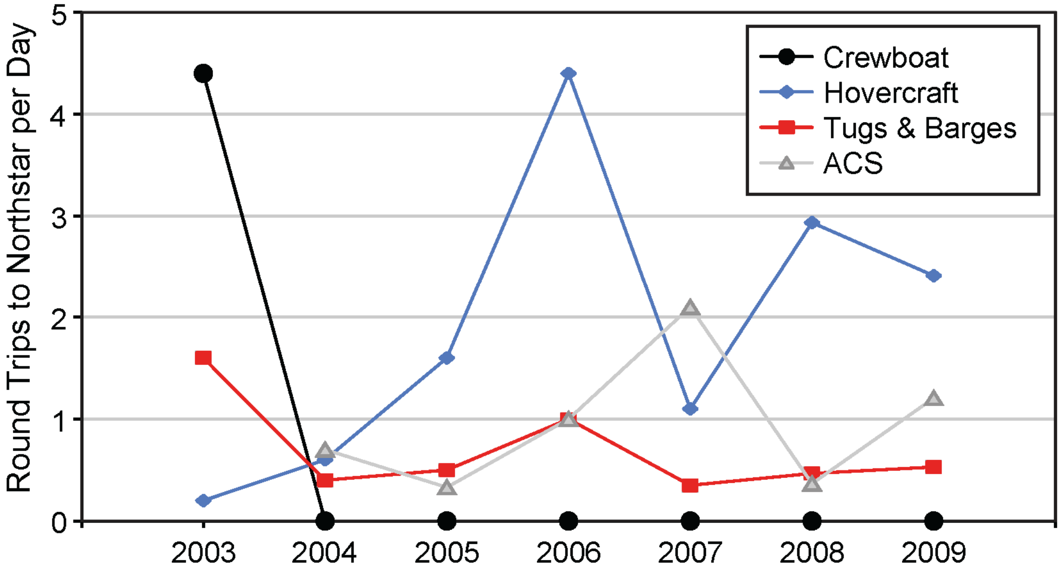

FIGURE 4.21. Daily mean number of round trips to Northstar in 2003–2009 by the crewboat (not used after 2003), the hovercraft, tugs and barges, and ACS vessels (no information for 2003). Each year, these numbers were calculated over the DASAR deployment duration, which varies from year to year, but is generally late Aug. to late Sept.

Vessels are an important source of sound at Northstar. Of the various sounds produced by the "Northstar operation", some of the highest amplitude ones are produced by vessels (Blackwell and Greene 2006). Using data collected in 2008 and 2009, we assessed how far the broadband vessel spikes created at Northstar were detectable on DASAR sound records offshore (see Blackwell et al. 2009, 2010b, for corresponding Figures and explanations). In both years we chose days with average to low wind speeds and well-defined vessel activities at Northstar—namely, tug and barge arrivals and departures at Northstar, and maneuvering at the island. There were three round trips on 11 and 12 Sept. 2008 and one on 25 Sept. 2009. In both years these activities produced some of the largest vessel spikes of the season at the near-island DASAR, reaching a maximum level of about 135 dB re 1 µPa in 2008 and 126 dB in 2009. Thus, the amplitudes from these activities as recorded at the near-island DASAR happened to be about 10 dB higher in 2008 than in 2009. In all four cases, the spikes produced and recorded near the island were also detectable on the sound pressure time series at DASAR location A, 8.6 km (5.3 mi) from Northstar. Spikes were detectable at DASAR C (14.9 km or 9.2 mi from Northstar) in the 2008 data, but barely in 2009. In the 2008 data, spikes were also detected at DASAR E (21.5 km or 13.4 mi from Northstar). These results lead to the conclusion that, on a day with low to average levels of background sound, the larger vessel spikes produced at Northstar can be detected to a distance of at least 21 km from Northstar. Measurements made north of Northstar in 2000–2001 showed that, in low ambient sound conditions, some vessels were audible 30 km from the island (Blackwell and Greene 2006). Besides varying with background level, the range of audibility will depend on the source level, which can vary substantially between vessels. In 2000 and 2001 self-propelled barges and Ocean-class tugs were present, both of which have comparatively high source levels. That may have contributed to the higher maximum detection distances in 2000–2001.

In the analysis of the 2008 data (Blackwell et al. 2009), received levels of sound at various offshore DASARs during tug and barge activities at Northstar were plotted as a function of distance from the source, after subtraction of background sounds. Six equations were obtained, all with spreading loss terms that fell within the range of 22–24.8 dB / tenfold change in distance. If we apply this spreading loss to the 2009 example (in which peak levels at the near-island DASAR were 126 dB re 1 µPa, about 10 dB lower than in 2008), then median background levels of 95 dB would be reached somewhat short of DASAR C, 14.9 km from Northstar.

Helicopters

The contribution of airborne sounds from aircraft to the underwater sound field is complex, but it is well known both on a theoretical basis and from empirical measurements (see section 4.7 in Richardson et al. 1995 for a review). During transmission of sound from air into water, a large proportion of the acoustic energy is reflected back into the air. In the case of an overhead sound source, such as an aircraft, most (but not all) of the sound at angles greater than 13° from the vertical is reflected and does not penetrate the water. The area of maximum sound transmission into the water below an aircraft (at least when the water is calm) can be visualized as a 26° cone with the aircraft at the apex (p. 81 in Richardson et al. 1995). As the aircraft's altitude increases, the base of the cone grows larger and the duration of detectability underwater increases, but the sound pressure levels reaching the water's surface decrease because of the greater distance. Levels received underwater close to the path of the aircraft diminish with increasing depth, and the sound is detectable for longer just below the surface than at deeper depths (e.g., Patenaude et al. 2002).

Based on the angular width of the cone described above, we can calculate the radius of the area below the helicopter into which there will be measurable transmission of sound from the air into the water on a near-calm day. The helicopters' minimum flying altitude to and from Northstar is about 300 m (1000 ft). Since the helicopters land at Northstar, their flying altitude near the island is generally less than 300 m. At 300 m height, the radius of the base of the 26° cone is about 70 m. The underwater area that is directly ensonified by the passage of the aircraft can, therefore, be thought of as a strip centered under the aircraft and 140 m wide (for 300 m flying altitude). In practice, this area is usually wider because ocean surface waves provide suitable angles for additional sound to penetrate the water. Particularly in shallow water, there is some "indirect" lateral propagation of sound in the water from repeated reflections between the surface and the bottom, and some helicopter sound is present in the water outside the cone or strip described above. However, at a given horizontal distance from a helicopter, its sound is much less prominent in the water than in the air.

The presence and received levels of sounds from helicopters were investigated using data collected in 2008 (Blackwell et al. 2009). Helicopters were recorded as arriving at and departing from Northstar 54 times during the period 26 Aug.–25 Sept. 2008. For 26 of these times (~50%, 13 arrivals and 13 departures), acoustic data from DASAR NSc were examined for the presence of helicopter-specific tones. No underwater tones were detected that could be attributed to any of the 13 arrivals. Out of 13 departures, underwater tones were detected in nine cases. With prevailing wind directions being from E to NE, helicopters usually approach Northstar from the SW and take-off toward the NE. With DASAR NSc being located NE from Northstar, it is logical that sounds from helicopters would be more likely to be detected during departures than arrivals. Figure 4.22A and B show two spectrograms of the type that were used to identify the presence of tones, while Figure 4.22C and D show the corresponding spectral density plots. Tones from the tail rotor (55 Hz and harmonics) were strongest (~82–106 dB re 1 μPa), but main rotor tones (10.8 Hz and harmonics) were also detected. All of these tones were weak and could not easily be heard on the near-island acoustic record by listening with headphones. Tones were generally evident for 20–50 s with weaker tones sometimes extending for another 10–50 s. Overall, our analyses are consistent with the theoretical considerations and earlier empirical data summarized in the preceding two paragraphs, i.e., sounds from a helicopter overflight are generally of short duration underwater and generally can only be detected in areas close to the helicopter's flight path.

Sounds from Unknown Sources

Unknown Sound of 2003

A sound-type of unknown origin was detected via near-island recorders during the 2003 field season and is illustrated in Figure 4.23. Figure 4.23A shows that, at about 13:30 on 21 Sept. 2003, there was a steep increase in sound levels beyond the boat spike maxima, reaching a plateau at about 125 dB re 1 μPa and remaining at that level for 2.5 hours. At 16:30 levels started to decrease and returned to ~92 dB. During the period 19–29 Sept., such "plateaus" occurred 8 times and contained 82% of all 1-min sound samples above 120 dB re 1 μPa. The fairly constant portion of the "plateau" was always close to 125 dB re 1 μPa and lasted from 40 min to 5.3 hr. Another example of this sound source is shown in Figure 4.23B, with a sharp increase in SPLs at ~11:30, continuous levels near 125 dB re 1 μPa for 70 min, and a decrease to more variable spikes at ~13:30.

A spectrogram of the sound source is shown in Figure 4.23C, and power spectral density levels for four different occurrences of the sound are shown in Figure 4.23D. The source produced most of its sound energy below 60 Hz but included characteristic peaks at frequencies close to 139, 162, 189, 233, and 285 Hz. Three of the four examples were very similar; the fourth was different by the presence of a stronger peak at 130 Hz and a frequency offset in the peaks above 100 Hz as compared with the other examples. Strikingly, all examples were characterized by lack of a low-frequency cut-off (Fig. 4.23C,D). Very low frequencies cannot be transmitted in the shallow water surrounding Northstar, but Figure 4.23C,D shows that the unknown sound as received at the near-island DASAR extended down to very low frequencies. The absence of a low-frequency cut-off suggests that sounds from the unknown source were not transmitted through the water but rather propagated through the seafloor. The spectrogram (Fig. 4.23C) emphasizes the broadband nature of the source (up to 300 Hz and higher). The well-defined "scalloped" frequency peaks evident in Figure 4.23D show up as horizontal bands in Figure 4.23C. The nearly constant SPL of this source is also evident.

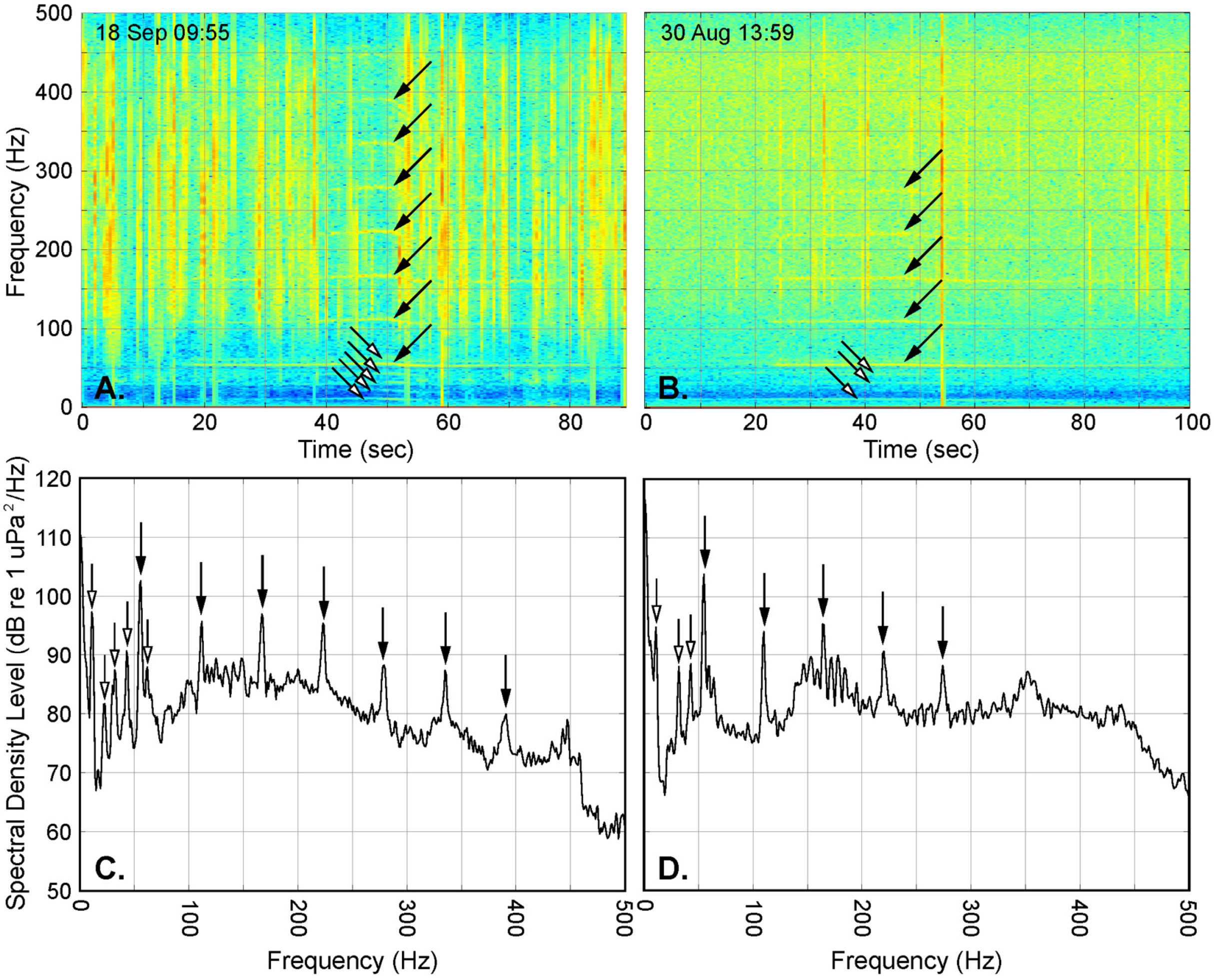

FIGURE 4.22. Spectrograms (A and B) and spectral density plots (C and D) of two helicopter departures from Northstar, on 18 Sept. 2008 at ~09:55 (A and C) and on 30 Aug. 2008 at ~13:59 (B and D), as recorded by near-island DASAR NSc. Black arrows point to tail rotor tones, and white arrows point to main rotor tones. Some pops (vertical lines) are visible on the spectrograms.

This unidentified sound was recorded not only by the near-island DASAR (NS) but also by an ASAR (# 9909) deployed on the bottom close to Northstar. ASARs are non-directional recorders that were used in some years as back-ups to the near-island recorders (see Blackwell et al. 2006). In addition, the 130 Hz tone that was present in one of the samples (see Fig. 4.23D) was detectable offshore at the array DASARs SW, WA, WB and CC (see Fig. 4.2 for the locations of these recorders). Bearings to this 130 Hz tone were calculated for the five DASARs. These converged near Northstar, confirming that at least the tone was an island-related industrial activity. The SPL of the tone was ~117 dB re 1 μPa at DASAR NS and ~83 dB at DASAR SW (6.5 km from Northstar), i.e., a difference of ~34 dB. This corresponds to a transmission loss rate of ~32 dB/tenfold change in distance. Other frequency components of the unknown sound did not sufficiently exceed background levels in the array to be detectable that far offshore.

The source of this sound was never confirmed. However, it originated at or near Northstar, and based on its characteristics, there was a suspicion that it was related to turbulent flow in a pipe (see Blackwell et al. 2006).

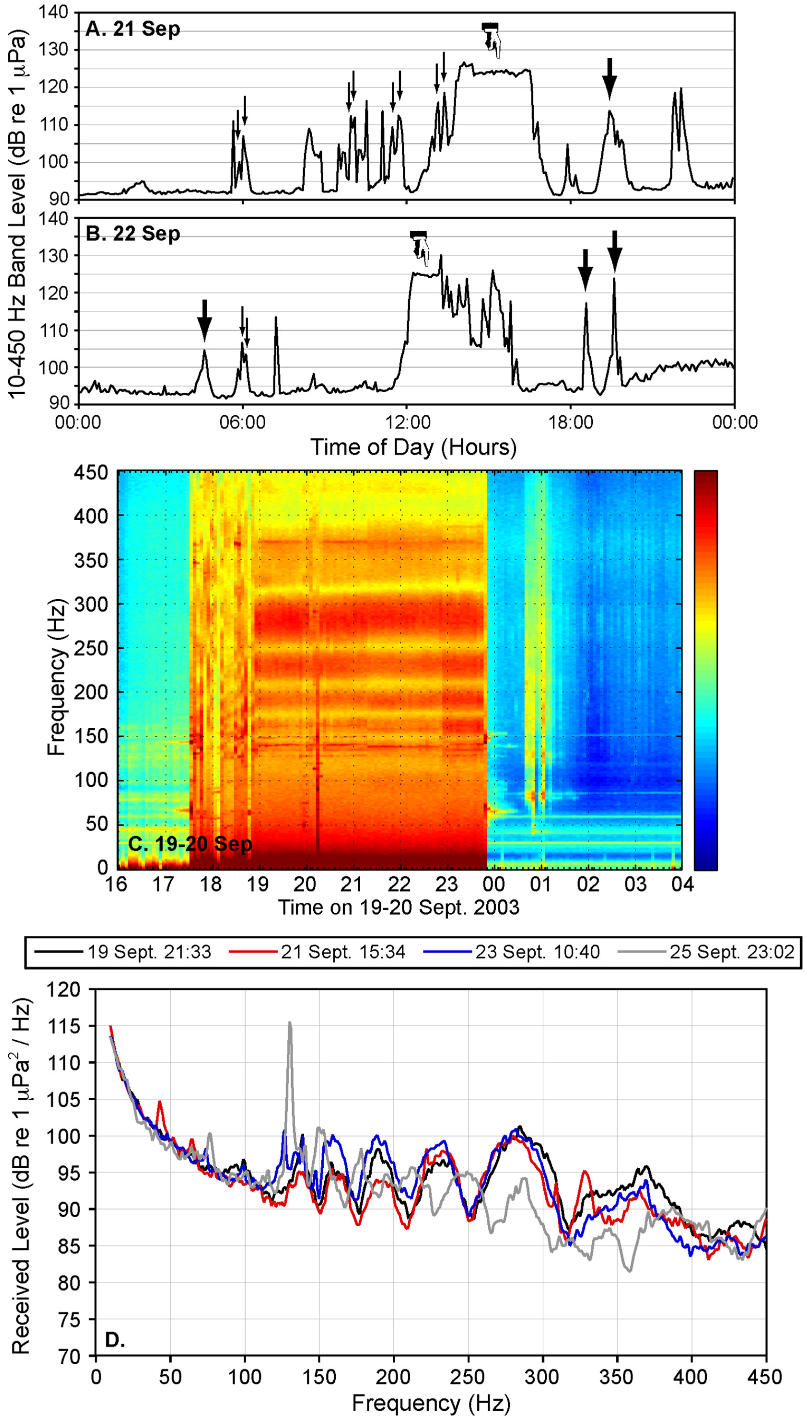

FIGURE 4.23. Unknown sound of 2003. ***(A)*** Sound pressure time series (SPTS) as recorded by a near-island DASAR (NS) on 21 Sept. 2003. DASAR NS was deployed about 550 m north of Northstar. Small and thick arrows show arrivals and departures at Northstar by the crew boat and tugs, respectively. The finger symbol points to times of occurrence of the unknown sound. ***(B)*** SPTS as recorded by a near-island DASAR (NS) on 22 Sept. 2003. Same symbols as in (A). ***(C)*** Twelve-hour spectrogram of sound recorded by near-island DASAR NS on 19–20 Sept. 2003. On this spectrogram the unknown sound occurred from about 17:30 to midnight. ***(D)*** Sound pressure density spectra for four samples of the unknown sound, as recorded by near-island DASAR NS. Each spectrum is based on a 1-min sample of sound.

Unknown Sound of 2006

Another sound-type of unknown origin appeared during the 2006 field season on the records of both near-island and offshore DASARs and is illustrated in Figure 4.24. On spectrograms (Fig. 4.24A,B), this unknown sound had the characteristic shape of an upside-down "V" and was not believed to be produced by whales or other animals. To human ears, it sounded like an outboard engine being revved up and down over several seconds. Over 2711 of these sounds were identified during the 2006 field season (7–25 Sept. for offshore DASARs). The sound was identified every day from 8 Sept. 2006 until DASAR retrieval, and they became so numerous that towards the end of the season the call analysts stopped counting them. The triangulated positions of 233 of these sounds showed them to originate north and northeast of Northstar (Fig. 2.14 in Blackwell et al. 2007b), up to 20 km and more from the island. In other words, Northstar was not the source of these sounds. The unknown sound of 2006 occurred at all times of day and night, with peaks at 00:00–2:00 and 13:00–14:00 local time (Fig. 4.24C). The unknown sound was not very strong and did not propagate well, which could happen if the source was shallow. Indeed, over 95% of the detections by 2 or 3 DASARs came from DASARs within 200 m of each other (such as the near-island DASARs or duplicate recorders at station EB). Whatever the source of this sound, it apparently was not from Northstar.

Unknown Sound of 2008–2009 ("pops")

A previously unidentified "popping" sound appeared on the records of the near-island recorders in 2008 and was also present in 2009. Pops were impulsive in nature and of short duration, on average 0.05 ± 0.03 s (mean ± S.D.). Pops contained most of their energy in the 150–450 Hz range, with some variation among pops. Figure 4.25 shows spectral and temporal characteristics of pops as recorded at one of the near-island recorders. Figure 4.22A,B shows additional examples.

Based on the data collected during the 2008 field season, the locations for the source(s) of the pops were estimated utilizing the bearing measurement capabilities of three nearshore DASARs (Blackwell et al. 2009). This suggested that the pops were likely generated within or close to the perimeter of Northstar, possibly offshore of the northeast corner of the island. Thus, an *Acousonde*^{TM}[8] acoustic data logger was deployed on three different days in close proximity to Northstar, 35–135 m from the NE corner of the island. Acoustic data collected during these three *Acousonde* deployments in 2009 (on 25 Aug., 12, and 26 Sept.) were analyzed for the presence of pops. Similarly, the acoustic records of a near-island DASAR (NSb) in 2008 and 2009 were analyzed in their entirety (~29 and ~33 days, respectively) for the presence of pops. A peak detector with a 7 Pa threshold (i.e., set to detect acoustic transients with peak pressure ≥136.9 dB re 1 µPa) was used on all acoustic records and the results of these analyses are summarized in Table 4.6.

One of the principal goals of the pop investigation was to estimate the highest received levels in the water close to Northstar, if one assumed that the sound source was located near Northstar's northeastern corner. Received SPL (rms) and instantaneous peak values for the largest pop in each acoustic record are presented in Table 4.6. To estimate the received level of a pop at a given location, one requires a model for acoustic transmission loss between the source of the pop and the receiver (*Acousonde* or DASAR NSb). An attempt was made to associate pops on the *Acousonde* records with the same pops on DASAR NSb in 2009, in order to derive a simple transmission loss model based upon direct measurement of transmission loss between the two receivers. However, on 25 Aug. (the first *Acousonde* deployment), DASAR NSb had not yet begun recording. On 12 and 26 Sept. (the second and third *Acousonde* deployments), no pops were detected on DASAR NSb at about the same times (with allowance for sound travel time) as they occurred on the *Acousonde* records, even after lowering the threshold level of the peak detector. Thus, a 15log(R)

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[8] Information on the *Acousonde*^{TM} can be found on the website http://www.acousonde.com

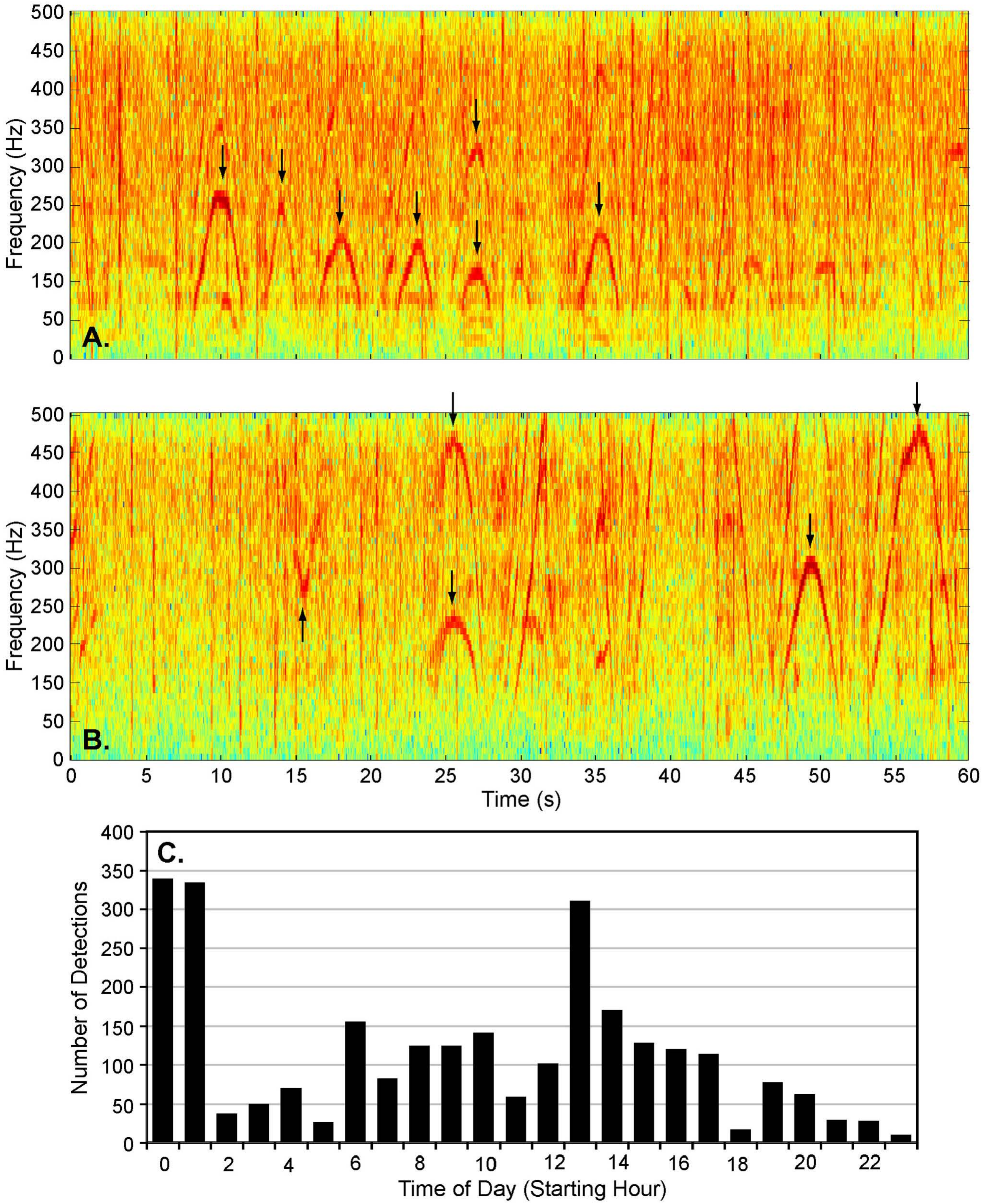

FIGURE 4.24. Unknown sound of 2006. ***(A)*** Spectrogram of one minute of sound data recorded at DASAR CA on 15 Sept. 2006 at 16:40 local time. ***(B)*** Spectrogram of one minute of sound data recorded at DASAR EB on 15 Sept. 2006 at 01:23. The downward pointing arrows show examples of the unknown sound. The upward pointing arrow shows an example of a bowhead call (∪-shaped undulation). ***(C)*** Number of detections of the unknown sound as a function of the time of day. The total number of unknown-sounds tallied is 2711.

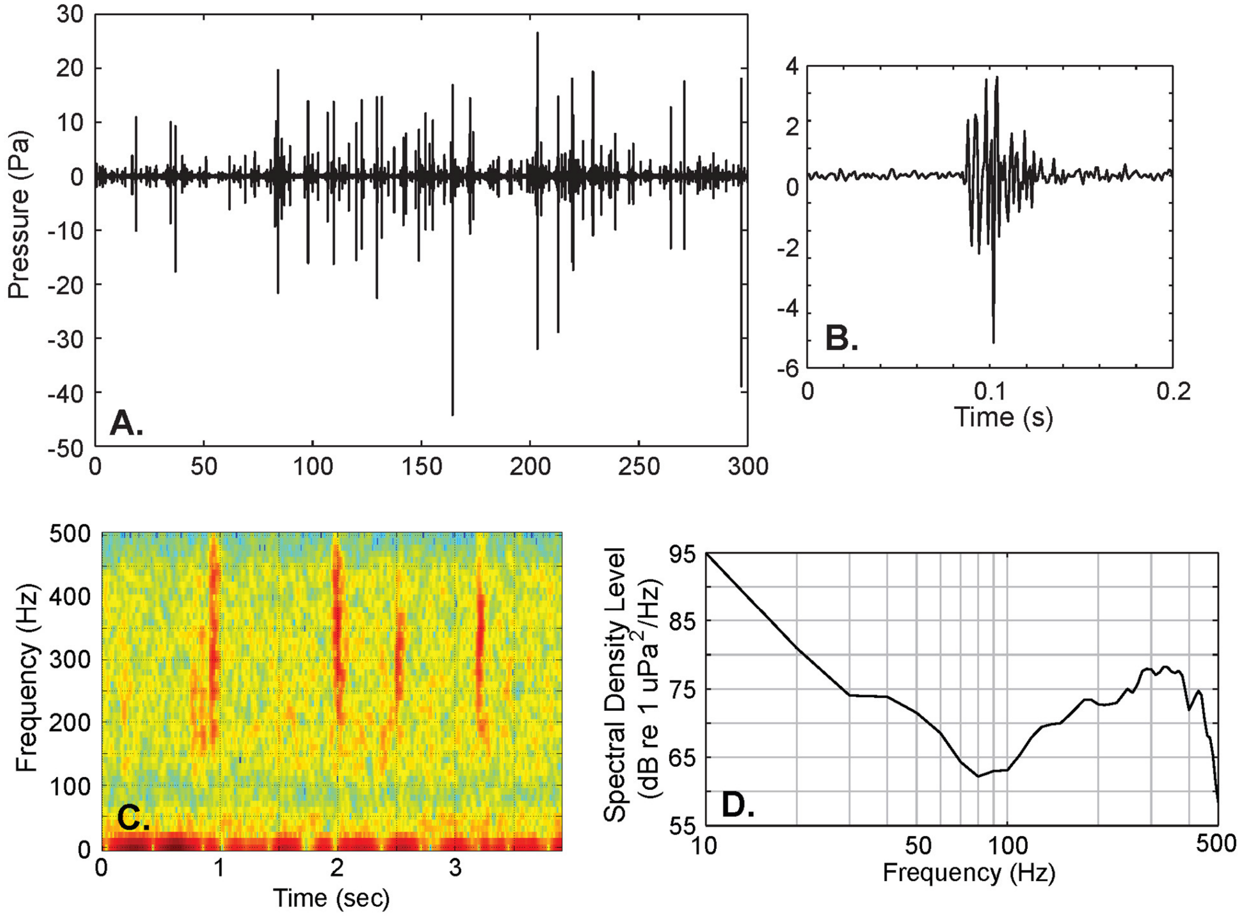

FIGURE 4.25. Unknown sound of 2008–2009 (pops). ***(A)*** Sound pressure time series (duration ~5 min) from a near-island DASAR showing approximately 100 pops. ***(B)*** Sound pressure time series of a single pop lasting about 0.045 s (note expanded time scale). ***(C)*** Spectrogram showing the frequency composition of four consecutive pops. Note that the high levels at frequencies below ~50 Hz are not related to the pops, but constitute background noise. ***(D)*** Spectral density plot, again showing that most of the pops' energy was in the 150–450 Hz range.

transmission loss model, determined empirically for sound sources in the vicinity of Northstar (Blackwell and Greene 2006), was used to estimate the highest potential received SPL at Northstar's northeastern corner. Assuming the pops originated at or near Northstar, the estimated SPL in the water at Northstar's NE corner was in the range 157–183 dB re 1 µPa (Table 4.6). The cases in which this estimate exceeded 180 dB were for DASAR NSb in 2008 (182.6 dB re 1 µPa, duration 44 ms) and 2009 (180.5 dB, duration 56 ms). However, none of the remaining pops detected on DASAR NSb's acoustic records (52,247 and 131,351 pops in 2008 and 2009, respectively) resulted in an estimate above 180 dB. The 15log(R) transmission loss model was derived from measurements taken in deeper water off Northstar, so it is theoretically possible that these calculated received levels at Northstar's NE corner are underestimated, since even greater transmission loss might be expected in the shallower waters at the island's edge.

Another goal of this investigation was to locate and identify, if possible, the source of the pops. We compared the number of pops detected on the *Acousonde* and DASAR NSb records during the same periods on 12 and 26 Sept. 2009. Only one pop was identified on each of these two days on the *Acousonde* records

TABLE 4.6. Putative "pop" sounds identified by a peak detector applied to *Acousonde*™ and DASAR acoustic records from 2008 and 2009. The highest SPL and highest instantaneous peak values are given for the strongest pop in each acoustic record. The estimated SPL at Northstar's NE corner is calculated using the SPL (rms) for the largest pop in each record, the distance between the recorder and the NE corner of the island, and a 15log(R) transmission loss. See text for more information.

	Acousonde data (2009)			DASAR data	
	25 Aug.	12 Sept.	26 Sept.	2008	2009
Distance from recorder to NE corner of Northstar (m)	135	35	45	348	351
# of hours of data analyzed	6.1	7.4	9.6	704.7	801.4
# of pops exceeding 7 Pa threshold	32	1	1	52,248	131,352
Analyses Of Largest Single Pop In Each Acoustic Record:					
Time (local) of pop with highest sound levels	14:01:35	11:56:19	17:21:55	17 Sept. 08 10:47:45	31 Sept. 09 18:58:24
Highest SPL (dB re 1 μPa)	138.0	135.2	132.0	144.5	142.3
Highest instantaneous peak (dB re 1 μPa)	145.6	142.5	137.3	149.0	149.3
Estimated SPL at Northstar's NE corner (dB re 1 μPa) assuming 15log(R)	170.0	158.4	156.8	182.6	180.5
Number of pops with SPL >180 dB at Northstar's NE corner (extrapolated SPL)	0	0	0	1	1
Duration of pulses with SPL >180 dB at Northstar's NE corner (ms)	0	0	0	44	54

(Table 4.6). On 12 Sept. the peak detector identified a number of potential pops on the record of DASAR NSb, but on further investigation all of these were found to be related to vessel noise. On 26 Sept. no pops were detected on NSb. Therefore, this comparison yielded little additional information as to the location and identity of the pops.

Based on analysis of the 2008 data (Blackwell et al. 2009), there was some preliminary evidence that pops were more prevalent on days with higher wind speeds, which would support the hypothesis that they were produced by the movements of an underwater structure. By applying the peak detector to the entire acoustic record from DASAR NSb in 2008 and 2009, we obtained data to address this question. Figure 4.26 shows peak pressure levels from pops for the entire 2008 and 2009 seasons, together with mean hourly wind speeds obtained from the Prudhoe Bay weather station. Even though the relationship was not quantified, there appears to be a strong positive association between wind speed and the presence and amplitude of pops in both years. This may explain why so few pops were detected on the *Acousonde* records in Sept. 2009: both days (12 and 26 Sept.) experienced some of the lowest wind speeds of the season.

The specific source for the "pops" has not been identified, but available evidence suggests that it may be an underwater structure near Northstar that moves as a function of waves or current.

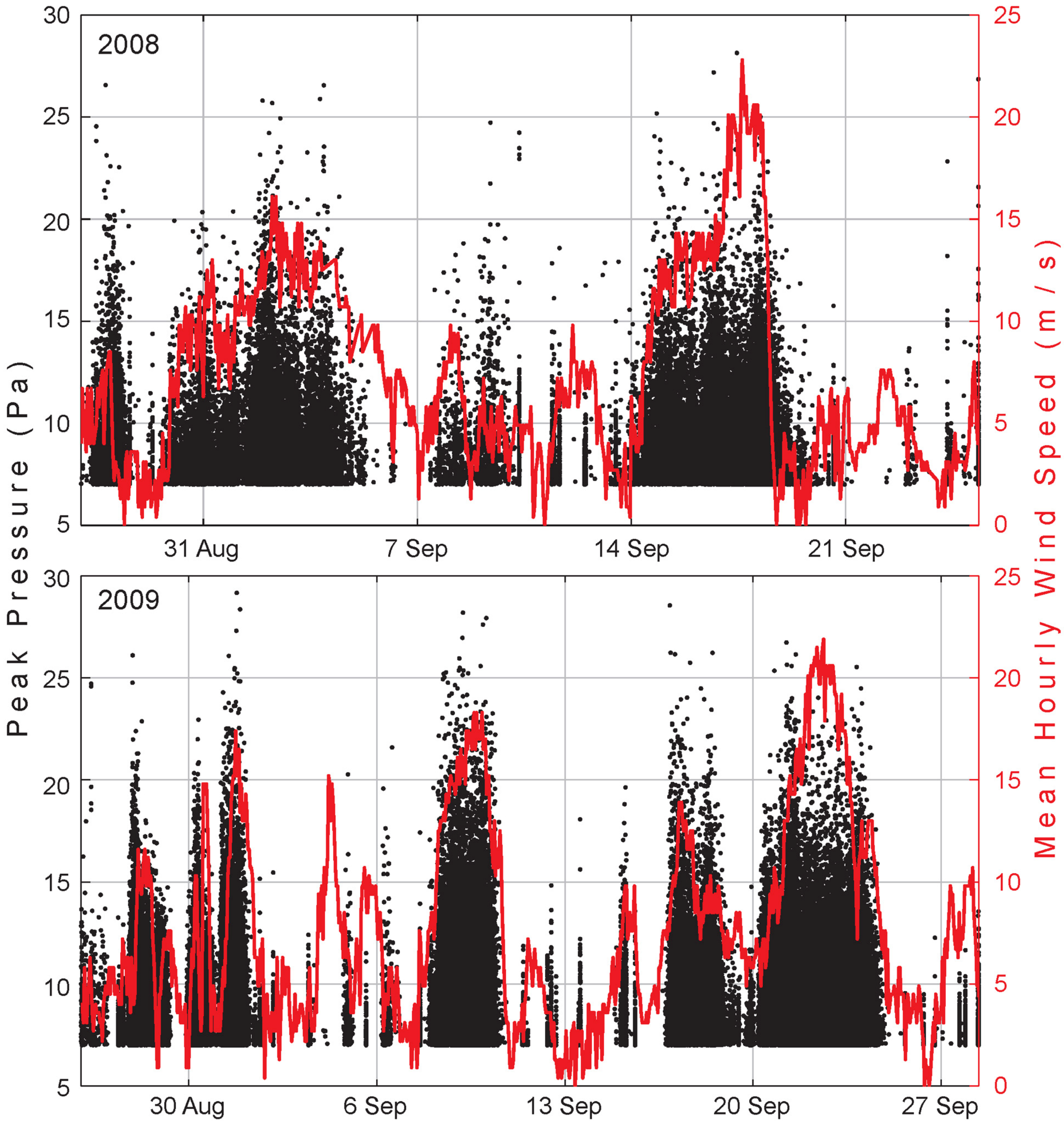

FIGURE 4.26. Presence and received levels of pops (black dots), the unknown sound of 2008–2009, on records of near-island DASAR NSb in 2008 (top) and 2009 (bottom) in relation to mean hourly wind speed (red line). A peak pressure of 7 Pa (136.9 dB re 1 μPa) corresponds to the threshold level of the peak detector. Wind speed was measured at the Prudhoe Bay weather station so is only roughly indicative of wind speed near DASAR NSb.

Airgun Sounds

Until 2008, airgun pulses were occasionally detected on DASAR records but were generally ignored (and therefore not tallied). However, during the 2008 and 2009 field seasons thousands of airgun pulses were evident on DASAR records. Because airgun pulses have energy distributed over our entire analysis band (10–450 Hz) and because bowheads are known to react to certain levels of sound from airgun pulses (Richardson et al. 1986,

TABLE 4.7. Summary statistics for airgun pulses detected in 2008 and 2009 and analyzed by 10-min periods: total number of airgun pulses detected, number of "clipped" (overloaded) pulses, number of 10-min periods with at least one detected airgun pulse, median SPL, 95th percentile of maximum SPL, median SEL, and 95th percentile of maximum instantaneous peak. The "clipped" pulses are not included in the total sample size. All dB units are re 1 μPa except for (*) which are dB re 1 $\mu Pa^2 \cdot s$.

	DASAR J 2008	DASAR J 2009	DASAR C 2009
Sample size	146,967	64,692	16,662
# "clipped" pulses	43	0	0
# 10-min periods with at least one airgun pulse	3020	1938	849
Median SPL (excluding background)	105 dB	98 dB	88 dB
95th percentile of max SPL	127 dB	112 dB	114 dB
Median SEL	107 dB *	100 dB *	86 dB *
95th percentile of max instantaneous peak	140 dB	125 dB	130 dB

1999; Ljungblad et al. 1988; etc.), records collected at some DASARs in 2008 and 2009 were analyzed using an automated pulse detector (see Annex 4.1). In addition, measures of airgun pulses detected at DASAR C in 2009 were included in the analysis of the effects of Northstar (and other sounds) on bowhead whales, presented in Chapter 6. In this chapter we present results from the automated airgun pulse detector from three situations: DASAR J (farthest offshore) in 2008, DASAR J in 2009, and DASAR C in 2009. The two years of data at DASAR J allow us to compare the numbers of pulses received and the levels received at the deepest DASAR site, where the highest number of pulses and the highest received levels are expected. Comparing DASAR locations J and C in 2009 allows us to assess the reduction in numbers and amplitudes of pulses in an important region for the analysis of Chapter 6[9] compared to a location farther offshore (see Chapter 6).

In both 2008 and 2009, the occurrence of airgun pulses on the DASAR records increased with distance from shore, i.e., airgun pulses were least common at DASAR A and most common at DASAR J (e.g., Table 3.2 *in* Blackwell et al. 2009). If airgun pulses were detected by the near-island DASARs, they were very rare—a manual search in 2009 yielded one possible airgun pulse at a barely detectable level. The main seismic operations in 2008 were conducted by Shell and were located roughly 75–115 km to the east and west of DASAR J (Ireland et al. 2009). In 2009, there were two main operations, one hundreds of km to the north of the DASAR array in deep water (Geological Survey of Canada / United States Geological Survey, see Mosher et al. 2009) and another in Canadian waters a few hundred km to the east (BP Canada, B. Streever, BPXA, pers. comm.).

The number of airgun pulses detected in 2009 was 16,662 at DASAR C and 64,692 at DASAR J over a 33-d period (26 Aug.–27 Sept.; Table 4.7). At DASAR J in 2008 it was 146,967 pulses in 29 days (27 Aug.–24 Sept.). The number of pulses recognized here for 2008 is higher than that (90,582) mentioned for the same period by Blackwell et al. (2009). The reason for this is that the algorithm used by the pulse detector for finding airgun pulses was improved by incorporating bearing information, which led to a higher number of pulses being detected than were found during the run performed in January 2009. The actual numbers of airgun pulses received in the DASAR array during both years were likely higher than these numbers. During the automated search for pulses, the threshold signal to noise ratio (SNR) required by the algorithm before a

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[9] DASAR C was at about the same offshore distance as the 5th quantile of the distribution of offshore distances to bowhead whale calls in the late summer/fall of 2009. The 5th quantile of offshore distance is a key variable analyzed in Chapter 6 (for 2009) and in our earlier analyses of the 2001–2004 autumn migrations (Richardson [ed.] 2008).

pulse is identified was set at 8 dB (see Appendix 4.1), a high-enough level that non-airgun sounds were excluded, but weak airgun pulses were also excluded.

Figure 4.27 shows the bearings to airgun pulses as received at DASARs C (14.9 km or 9.2 mi from Northstar) and J (38.4 km or 23.9 mi from Northstar) in 2009. As noted above, many more airgun pulses were detected at DASAR J than at C (about 4×, see Table 4.7). In addition, pulses from the north (350°–40°) were more common at DASAR J, where they comprised ~27% of the detected pulses, than at DASAR C, where they comprised only about 1.3%. Pulses from the east (70°–95°) comprised about 86% and 67%, of the detected pulses at DASARs C and J, respectively.

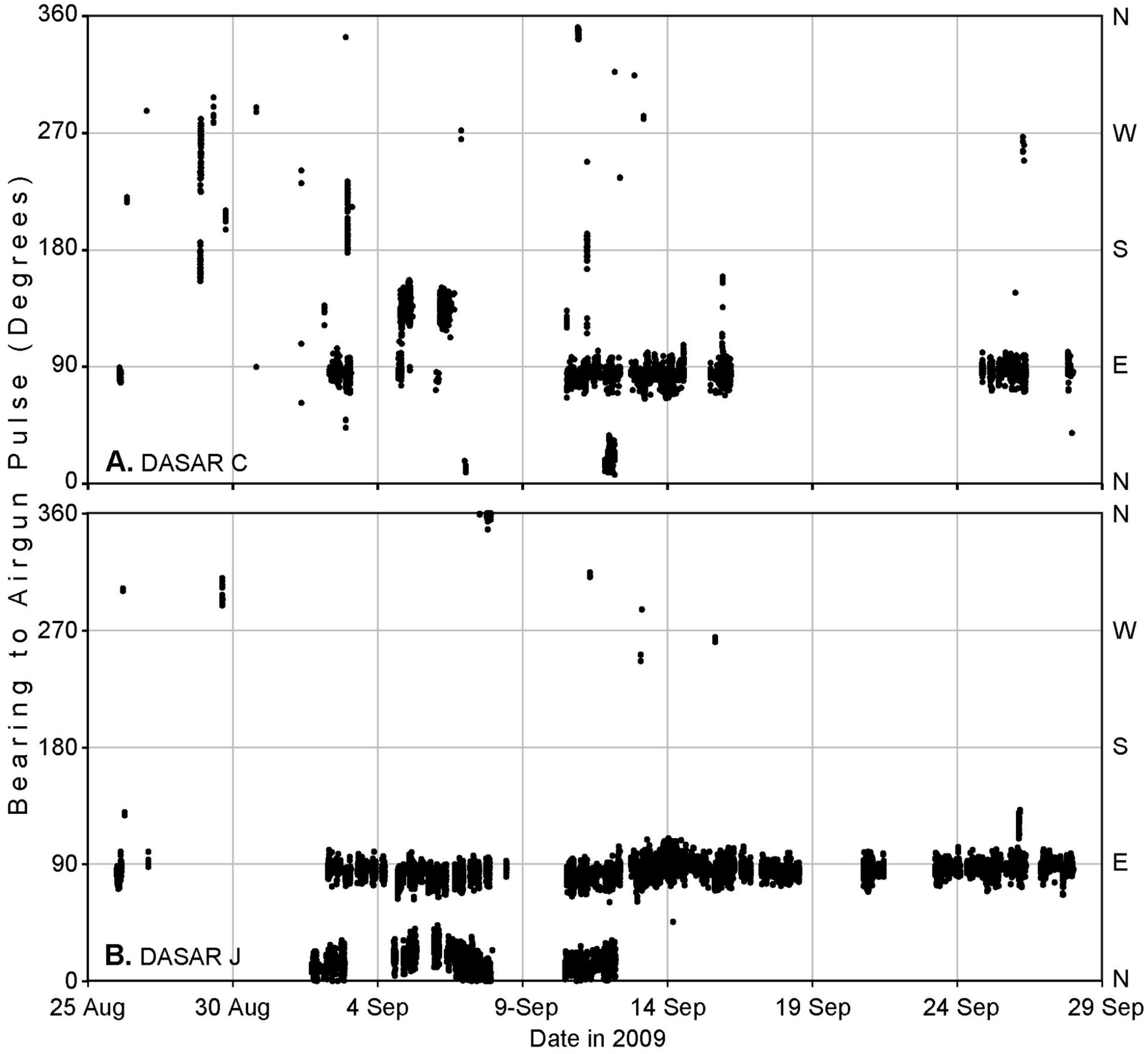

FIGURE 4.27. Bearings to airgun pulse sounds detected in 2009 by ***(A)*** DASAR C (14.9 km or 9.2 mi from Northstar) and ***(B)*** DASAR J (38.4 km or 23.9 mi from Northstar). Bearings are expressed in degrees relative to true north, with 0° and 360° = N, 90° = E, 180° = S, and 270° = W.

Figure 4.28 shows received levels of airgun pulses at DASAR location J in 2008 (top), J in 2009 (middle), and C in 2009 (bottom). For each 10-min period with detected airgun pulses, Figure 4.27 shows (1) the median received sound pressure level (black dot) and (2) the 95th percentile of the maximum instantaneous peak values (red triangle). The number of pulses detected per 10-min period (considering only 10-min periods that included airgun pulses) was on average 49 ± S.D. 22 pulses for J in 2008, 33 ± 17 pulses for J in 2009, and 20 ± 14 pulses for C in 2009. In 2008, 72% of all 10-min periods included in the 29 days analyzed (27 Aug.–24 Sept.) contained one or more airgun pulses. In 2009 this percentage was lower: 41% and 18% of all 10-min periods included in the 33 days analyzed (26 Aug.–27 Sept.) contained one or more airgun pulses at DASAR J and C, respectively.

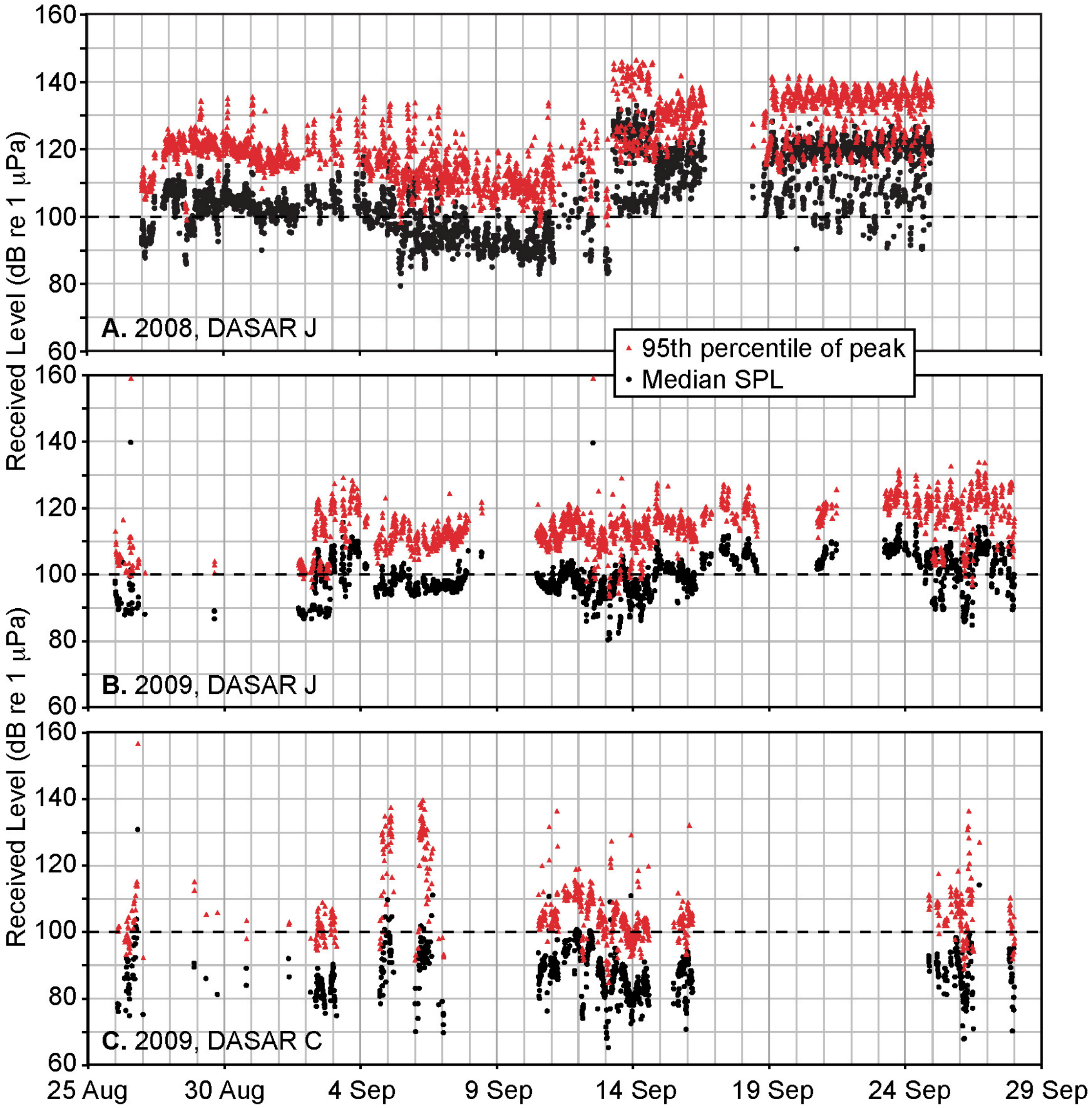

FIGURE 4.28. Levels of airgun pulse sounds, as received at ***(A)*** DASAR J (farthest offshore) in 2008 (27 Aug.–24 Sept.), ***(B)*** DASAR J in 2009 (26 Aug.–27 Sept.), and ***(C)*** DASAR C in 2009 (26 Aug.–27 Sept.). Each plotted symbol represents airgun pulse data summarized over a 10-min period. Median received sound pressure levels (SPLs) for the 10-min periods are shown with black dots, and the 95th percentile of instantaneous peak pressures for a given 10-min period is shown as a red triangle. The dashed black line is set at 100 dB re 1 µPa in each plot to aid in comparisons.

Table 4.7 (above) summarizes received SPLs, SELs, and instantaneous peak levels of airgun pulses detected at DASAR J in 2008 and 2009, and DASAR C in 2009. Overall, received airgun pulse levels were higher in 2008 than in 2009 at DASAR J, with median SPLs and SELs both ~7 dB higher in 2008. Received levels were also more variable in 2008, as is shown in Figure 4.27 and by the fact that the 95th percentile of max SPL at DASAR J was 15 dB higher in 2008 than 2009 (Table 4.7). In 2009, median received levels were ~10 dB lower at DASAR C compared to J.

SUMMARY BULLETS

- The main factor influencing broadband (10–450 Hz) levels of underwater sound near Northstar and in the offshore array during late summer/early autumn was wind speed. Annual median levels of broadband sound ~450 m from Northstar (depth 13 m) varied in the range 98.7–105.5 dB re 1 µPa over the 2001–2009 period. At the offshore location EB / C, ~15 km (9 mi) offshore of Northstar (depth 23 m), annual median levels were in the range 93.1–103.1 dB. Median broadband levels of sound near Northstar, calculated over the entire season, were always higher than in the offshore array (location EB / C), by 2.4–8.3 dB in 2001–2009. This difference was lowest in 2005 and highest in 2002.
- Average mean wind speed during DASAR deployments was lower in 2001–2004 (5.7 m/s) compared to 2005–2009 (7.8 m/s). Whole-season broadband levels showed the same increasing trend between the two periods, both at the near-island recorder (102.0 dB re 1 µPa to 103.2 dB) and at DASAR EB / C (95.1 dB to 98.4 dB).
- Spectral composition of Northstar sounds included tones at 30 Hz and 60 Hz every year in the 2005–2009 period. Tones at other frequencies were present in some years but not all. The presence of tones in the spectral density levels of the near-island DASAR was a distinguishing characteristic of Northstar sound—the minimum percentile spectral density level for offshore DASAR EB / C was devoid of any tones. Compared to offshore location EB / C, sounds produced by Northstar could also be identified by their elevated levels in the frequency range 28–90 Hz.
- *ISI_5band* is an Industrial Sound Index (ISI) that was designed to represent the amount of underwater sound at low frequencies—the 28–90 Hz range, which is typical of industrial activities—in the sounds emanating from Northstar. Near Northstar, mean *ISI_5band* levels decreased between 2001–2004 (97.3 dB) and 2005–2009 (95.5 dB), whereas at offshore array EB / C they increased between the same periods (81.3 dB to 83.8 dB, respectively). Near Northstar, median annual *ISI_5band* levels were ~3.4–6.3 dB below broadband levels in 2001–2004 (mean=4.7 dB), and 4.5–11 dB below broadband levels in 2005–2009 (mean=7.7 dB). In other words, the difference between broadband levels and *ISI_5band* levels increased between the two time periods, indicating a smaller contribution of industrial sounds in the latter period. In the offshore array (location EB / C), where the contribution of industrial sounds should be even smaller, median *ISI_5band* levels were 9.3–21.4 dB below broadband levels in 2001–2009, with similar mean values in 2001–2004 (13.7 dB) and 2005–2009 (14.6 dB).
- *ISI_tone* is an ISI that characterizes the presence and amplitude of tones within the underwater sound. Tones are typical of rotating or vibrating machinery. *ISI_transient* evaluates the presence of broadband transient sounds, such as those produced by vessels. The year 2001, a construction year at Northstar, had the highest proportion of analyzed samples containing either tones or transient sounds, and also the highest mean *ISI_tone* value over the entire season as compared with any other

year. Compared to 2001–2004, the period 2005–2009 showed a trend towards fewer samples containing tones, fewer samples containing transients, and lower mean *ISI_tone* levels. These trends also support the notion that there was less industrial contribution to underwater sound at Northstar in the latter years.

- Vessel trips to and from Northstar by tugs and barges, ACS vessels, and the crewboat (before 2004) were identifiable as "spikes" on the sound pressure time series at one of the near-island recorders. These spikes were by far most numerous in 2001, a construction year, and decreased noticeably starting in 2004, when the crew boat was replaced by a hovercraft. The hovercraft has a much smaller acoustic footprint (lower amplitude and shorter duration of the underwater sound it produces) and its trips to Northstar were not readily identifiable on the near-island recorder's sound pressure time series. During the period 2005–2009, the highest average number of round trips to Northstar per day by spike-producing vessels was in 2007 (2.5 round trips / day) and the lowest in 2005 and 2008 (0.8 trips / day).
- The underwater sounds with highest amplitudes at Northstar are produced by vessels, in particular tugs maneuvering barges at the island. During this activity, received levels at the near-island recorder (~500–600 m away from the activity; 10–450 Hz bandwidth) routinely exceed 115 dB re 1 µPa and can reach 135 dB. In calm to average weather conditions the higher levels (135 dB) remained above background levels at least to DASAR location E, ~21.5 km (13.4 mi) from Northstar.
- The underwater sounds produced by helicopters arriving at Northstar and departing from the island were investigated. Only departures could be detected on the record of a near-island recorder. During 75% of investigated departures, faint tones and harmonics were detected from the main rotor and tail rotor (fundamental frequencies ~11 Hz and 55 Hz, respectively). These tones were evident on spectrograms for durations less than 2 min and often less than 1 min. Overall, underwater sounds from helicopters were detected near the bottom (depth ~12 m) for short periods, and only in areas close to the helicopter's flight path.
- Three types of sounds of unknown origin are described—one from 2003, one from 2006, and another that was present in both 2008 and 2009. As of the date of writing of this report (July 2010), the specific sources of these sounds have not been identified. The "pops" detected in 2008–2009 are probably the most significant because they are impulsive with source levels that are potentially relatively high, and have been present close to Northstar during the two most recent years of monitoring. The occurrence and amplitude of pops were related to wind speed.
- Thousands of airgun pulses were detected on DASAR records in 2008 and 2009, from seismic exploration that was not related to Northstar. At the most offshore DASAR location (J), 38.4 km (24 mi) offshore of Northstar in 38 m of water, ~147,000 and ~65,000 airgun pulses were detected in 2008 and 2009, respectively, with median received SPLs of 105 dB and 98 dB re 1 µPa. In 2009, numbers and levels of pulses were somewhat lower at DASAR C, ~15 km offshore of Northstar in 23 m of water, than they were at DASAR J.

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ANNEX 4.1: AUTOMATIC PULSE DETECTION SOFTWARE

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The process of automatically detecting and measuring acoustic properties of airgun signals took place in three stages: pulse detection, interval estimation, and finally level measurement. The first two stages are described below. The components of the third stage are listed in the *Airgun Pulses* section of Chapter 2.

The first stage of the program seeks to identify any transient pulse that occurs in the acoustic data. To accomplish this, the program first creates a succession of spectrograms of FFT (Fast Fourier Transform) length 256 samples (0.256 s), overlap 50%. It then creates a set of "detection functions" by integrating the FFT output over a set of overlapping 37 Hz frequency bands between 10 and 450 Hz. The units of the detection function are in terms of sound exposure level (SEL), or $\mu Pa^2 \cdot s$. The time integration is simply over the FFT window length of 0.256 s. When a new FFT sample arrives, the detection functions are updated. For a given detection function, if the new value of the function does not exceed a threshold value, then it is assigned to a "background" or "equalization" function with weight alpha:

Equalization function (new) = (1– alpha) · Equalization function (old) + alpha · (new FFT sample)

The value of alpha is set so that the contribution of a new sample will decay away in 25 s. Thus the equalization function becomes a long-term average of the "smoothed" background noise level.

As a new FFT sample enters the system, the new value of each detection function, divided by the current value of the corresponding equalization function, is compared to a threshold of 8 dB (6.3 ratio on a linear scale). If the new value exceeds the threshold, then the presence of a possible detection is flagged, and the equalization function is not updated. As new detection function samples are computed, one will eventually fall below the threshold and the end of the detection is flagged for that detection function. Once all detection functions fall below threshold, the elapsed time of the transient is computed. If the duration is greater than 100 ms, the event is logged for further analysis, along with values of the minimum and maximum frequencies of the event, and the azimuth from which the pulse is arriving. If the detection lasts longer than 5 s, the program forces the detection to end and resets the equalization function. To prevent momentary dips in the detection function from triggering a new detection, a new detection cannot begin until 20 ms have elapsed since the last detection.

The next stage seeks to assign an "interval" or "repetition rate" to each detected transient. To that end the program marches through each detected pulse. For each pulse, the program looks 40 s into the future and past for the presence of any other pulses that arrived within 15° of the azimuth logged for the current pulse. These "candidate" detections, if they exist, provide a set of possible intervals to test. Each candidate interval is tested by searching ten time intervals into the future, and ten time intervals into the past, relative to the current pulse under consideration. If a pulse is present within 1.0*sqrt(K) s of where an interval would be expected, where K is the number of pulse intervals being projected both forward and backward in time, that candidate interval is awarded a "hit". If eight or more out of the 20 interval times are "hits", then the current pulse is assigned that candidate interval. Thus, if the pulse is part of a regular series of pulses it will be assigned a number that is equal to the timing between pulses, or some integer multiple thereof.

If a pulse has been associated with an interval then it is labeled an airgun pulse and various metrics are computed. First, the number of times the time series attains the maximum value permitted by the A/D converter is checked. If this count exceeds five the signal is flagged as "clipped" and no further metrics are computed. Next, a high-resolution estimate of the pulse duration is obtained by running the time series through a calibration filter, which removes the frequency-dependent response of the hydrophone, flattening the response. Next, the rms value of 0.75 s of signal just before the start of the detection is collected. This rms "noise" value is subtracted from the cumulative sum of the square of the signal across the entire detection window, creating an "equalized cumulative sum". The points where the equalized cumulative sum reaches 5% and 95% of its maximum value are defined as the high-resolution start and end of the transient detection. From this duration the sound pressure level (SPL) and SEL of the pulse can be computed. The SPL is averaged over the pulse duration and is in units of dB re 1 μPa. The SEL is defined as the squared instantaneous sound pressure integrated over the pulse duration and is in units of dB re 1 $\mu Pa^2 \cdot s$. The frequency window used to compute the metrics lies roughly between 10 Hz and 450 Hz. The instantaneous maximum (or the algebraic minimum) of the pulse pressure within the duration is saved as the instantaneous peak pressure. All "signal" and "noise" metrics are written to a file for further analysis, as well as the arrival bearing and interval for each pulse.

CHAPTER 5:
ACOUSTIC MONITORING OF BOWHEAD WHALE MIGRATION NEAR NORTHSTAR, AUTUMN 2005–2009[1]

by

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ABSTRACT

One key objective of the Northstar monitoring is to characterize the westward migration of bowhead whales past Northstar during late summer/autumn, and the possible effects of sound from Northstar on that migration. Since 2001, that has been done primarily by detecting and localizing calls from bowheads in waters offshore of Northstar. The specific objectives of this chapter are to report on the detection, classification, and localization of bowhead whale calls recorded by an array of directional autonomous seafloor acoustic recorders (DASARs) deployed offshore of Northstar during the autumn migration of bowhead whales in 2005–2009, and to put those results into broader context by summarizing corresponding data from 2001–2004. Specifically, this chapter provides information on year-to-year and within-season variation in the numbers, types, and distribution of calls detected offshore of Northstar, and in their bearings from a location where acoustic data were acquired every late summer/early autumn season from 2001 to 2009.

The number of bowhead whale calls detected via the DASAR arrays and the associated call detection rates varied substantially from year to year and from day to day within each season. Some variation can be attributed to methodological differences among years, especially the different DASAR array configurations in 2001–2004 (10 DASAR locations) vs. 2005–2007 (3–4) vs. 2008–2008 (10, but extending farther offshore). Other sources of variation were the presence of nearshore pack ice in some years (2005, 2006), and differences in mean wind speed (high in 2005, 2007). High winds increase ambient noise levels and tend to reduce call detection rates. Based on data from one location monitored in all 9 years, call detection rates were highest in 2003, 2004 and 2008, intermediate in 2001, 2002, 2007 and 2009, and low in 2005 and 2006. The 2008 season had the highest number of call detections in the history of the study with 85,669 calls detected, resulting in an average of 2914 detected calls/day, and a peak hourly call detection rate of 627 calls in one hour on 20 Sept. 2008.

Percentage use of different call types varied from year to year, but of the four types of simple calls (upsweep, downsweep, constant, and undulations), the upsweep was most common. It comprised 26% of all calls detected in 2001–2009. The four types of simple calls comprised (on average) 84% of calls detected in 2001–2008. In 2009, only 51% of calls were simple (51%); 49% were complex.

Bearings to bowhead calls and the percentage distribution of these bearings were estimated with respect to a consistent location 14.9 km (9.2 mi) offshore of Northstar (EB / C) where there was a DASAR during all nine seasons 2001–2009. In 8 of 9 seasons, the average bearing of whale calls was northeast or east-northeast of this site. In the other year (2005), the bearings were highly variable. The bearings in 2009 were predominantly to the northeast, similar to those in 2001 — both were years when the whale migration corridor was relatively far offshore. In contrast, the majority of the calls detected at location EB / C in 2002–2004, 2007, and 2008 were to the east of that location.

Localized whale calls provided much information about the distribution of calling bowhead whales over the inner and middle part of the continental shelf offshore of Northstar. The localization data, in conjunction with bearings from EB / C, indicated that 2001 and to a lesser degree 2002 and 2009 were years when the migration corridor was relatively far offshore, whereas 2003, 2004, and 2008 were years when the southern part of that corridor was close to shore. The localization data documented pronounced within-season (day to day) shifts in the offshore distances of whale calls. Localization data also showed spatial concentrations of calls, with some concentrations aligned parallel to shore but others aligned in different configurations of unknown significance. Analysis of 2008 data indicated that bowhead whale calls show at least slight directionality (stronger ahead than behind the whale).

INTRODUCTION

Each autumn, the Bering Sea stock of bowhead whales, *Balaena mysticetus*, migrate from the central and eastern Beaufort Sea and Amundsen Gulf to the Chukchi Sea and then the Bering Sea. Off northern Alaska, most of the whales travel over the continental shelf, roughly 20–60 km offshore and in waters 20–50 m deep (Moore et al. 1989a; Moore and Reeves 1993; Treacy et al. 2006). From late August through late October, swimming westward en route to the Chukchi Sea, whales pass Alaska's Prudhoe Bay oilfields (Moore and Reeves 1993). Prior to the start of this study in 2000, the primary method for monitoring the westward migration of bowhead whales off northern Alaska had been via broad-scale aerial surveys. The Minerals Management Service's BWASP (Bowhead Whale Aerial Survey Program) had been conducted in a systematic way each autumn since 1982 (Ljungblad et al. 1988; Moore 2000; Treacy et al. 2006), supplemented in some years by more intensive but less wide-ranging site-specific aerial surveys around various oil industry activities (e.g., Miller et al. 1999; Schick and Urban 2000). It was known that large numbers of bowhead whale calls can be detected in the Alaskan Beaufort Sea during autumn migration (Moore et al. 1989b; Greene et al. 1999), but prior to this study, acoustical monitoring had not been used very extensively in studying the autumn migration of bowhead whales. In contrast, by 2000 acoustical monitoring was an important component of the periodic censuses of bowhead whales passing Point Barrow in spring (e.g., Clark et al. 1996; Clark and Ellison 2000; George et al. 2004).

The overall aim of this study is to assess the effects of Northstar activities, as manifested in underwater sounds, on the distribution and behavior of calling bowhead whales in late summer and early autumn. An acoustical approach is used to locate calling bowhead whales near Northstar (Greene et al. 2004; Blackwell et al. 2007b), and a dose-response analysis is used to determine whether the distribution of calling whales is related to fluctuations in Northstar sounds. Statistical analyses of the 2001 to 2004 data showed that, with increased levels of certain types of Northstar sounds, there was a northeastward (offshore) shift in the locations of whale calls in the southern (inshore) part of the whale migration corridor (McDonald et al. 2008; Richardson et al. 2008). This shift could be the result of whales in the southern part of the migration corridor deflecting away from the island or changing their calling rates in response to increased sounds, or some combination of the two. The effect might also be at least partly related to changes in whale headings, given newfound evidence of directionality in bowhead whale calls (see Annex 5.2). Because estimated locations of calling bowhead whales constitute the primary data on whale distribution used in this study, understanding the nature of whale calls is important in interpreting the results.

This chapter presents the results from detecting and analyzing bowhead whale calls recorded by an array of directional autonomous seafloor acoustic recorders (DASARs) deployed offshore of Northstar during the late summer/early autumn of 2001–2009. The 2001–2004 results have been reported previously (Blackwell et al. 2007b; Richardson [ed.] 2008), and the emphasis here is on the 2005–2009 data. However, key results from 2001–2004 are also summarized here for comparison with data from the more recent years. This chapter provides information on annual variation in the number, types, and distribution of calls detected offshore of Northstar, and in their bearings from a specific location where acoustic data were acquired every autumn from 2001 to 2009. Chapter 6 presents further detailed analyses of the 2009 data seeking to identify and characterize any change in the distribution of calls that is related to Northstar sounds.

After describing the study's instrumentation and the methods used to calibrate the recorders, four facets of the Northstar whale call analyses—whale call (1) detection, (2) classification, (3) bearing analyses, and (4) localization—are presented in the ***Methods*** and subsequent ***Results*** sections.

METHODS

As described in Chapter 4, this study is based on recordings of underwater sounds at an array of locations offshore of Northstar during the late summer/autumn period in 2001–2009. At each location, one or more directional recorders (DASARs) were deployed, providing the ability to detect bowhead whale calls and determine their bearings. The offshore DASARs were deployed in three general configurations (see Fig. 4.2 *in* Chapter 4). In 2001–2004, DASARs were deployed in an array with recorders at 10 sites spaced 5 km (3.1 mi) from one another and located 6.5–21.5 km (4.0–13.4 mi) seaward of Northstar. In 2005–2007, DASARs were deployed in a smaller array at 3 or 4 sites, also spaced 5 km apart, at locations 9.3–21.5 km (5.8–13.4 mi) seaward of Northstar (exact locations varied among years). In 2008–2009, DASARs were again deployed in a large array with recorders at 10 sites spaced 7 km (4.4 mi) apart and located 8.6–38.4 km (5.3–23.9 mi) km offshore. All three configurations included a DASAR at a location 14.9 km (9.2 mi) seaward of Northstar at a water depth of 23 m (75 ft) that we referred to as “EB” up to 2007 and as “C” in 2008–2009. This DASAR location is hereafter referred to as EB / C.

Instrumentation and Bearing Calibrations

Chapter 4 comprehensively described the DASARs (see section ***Recorders (DASARs)*** in ***Methods***) and their deployment and subsequent retrievals (see section ***Field Work*** in ***Methods***). The reader is also referred to Figure 4.2 for a map of the study area depicting the DASAR locations for 2001–2009. DASAR clock calibrations were also discussed in the ***Methods*** section of Chapter 4.

In addition to time calibrations, bearing calibrations were conducted in order to determine the DASARs’ orientation on the seafloor and, thus, the geographic bearing to a recorded whale call. (Upon deployment, the DASAR’s orientation, in relation to true North, is unknown.) The specific procedures used to determine the DASAR orientations and bearings to calls are detailed in Annex 5.1.

Whale Call Detection

Analysis of whale calls was done manually by trained staff, though with computer assistance to store and present the acoustic records, and to extract information about the whale calls once they were manually identified. Detection and classification of each whale call was done by examining spectrograms of the acoustic data, one minute at a time, and listening to recordings of each call or suspected call (see Fig. 5.1). The sounds recorded during a given 1-min interval by all the DASARs offshore of Northstar were analyzed by a single analyst before that analyst moved on to the next 1-min period. Using a computer mouse, analysts delimited the time- and frequency-range of each call by positioning a rectangle on the spectrogram. The software then calculated several parameters including the call’s bearing from that DASAR, duration, signal-to-noise ratio, etc. Most calls were detected by more than one DASAR, and the aforementioned parameters were determined separately for each DASAR that detected a given call. The call type was also determined by the analyst (see next subsection), but that classification was done only once regardless of the number of DASARs that detected the call. Reception of the call at more than one DASAR allowed for triangulation of the call’s estimated position, according to a method described in Greene et al. (2004) and summarized below.

The lead analysts performed regular checks for consistency among analysts. Ensuring this consistency began by training new analysts and re-training experienced analysts before the start of each analysis season. New analysts' work was then monitored on a daily basis, and all analysts' work was spot-checked on a twice-weekly basis with verbal follow-up if necessary. In addition, lead analysts carefully edited completed log sheets by verifying work accuracy against output files, reviewing analysts' notes, and following-up on any questions. To further aid in the data analysis, lead analysts also provided updates on new information,

FIGURE 5.1. Eight of the 30 workstations at Greeneridge Sciences where analysts identify and localize whale calls. In the left photograph, note 10 spectrograms on the screen of the closest analyst, representing the 10 DASARs of the offshore array in 2008.

including posting of visual examples. In rare cases, lead analysts reassigned work that needed to be re-analyzed.

The presence of the acoustic research vessel was accounted for in post-processing of the whale calls. On days when the acoustic research vessel went into the area of the DASAR array to service the DASARs, calls were excluded from the analyses in some years. The vessel was defined to be "in the area of the array" when it crossed an imaginary line 2 km north of Northstar on its outbound journey and when it re-crossed the line, plus 2 hours, on its return to port. In 2002–2007, the calls detected between those times were not included, and call detection statistics for those days were, therefore, "incomplete". In 2001, 2008, and 2009, all calls were counted, regardless of the presence or absence of the acoustic vessel.

Whale Call Classification

Based on the spectrograms and on listening to the call with headphones, analysts classified calls into two main categories, ***simple calls*** and ***complex calls***. The call classification was based on descriptions by Clark and Johnson (1984) and Würsig and Clark (1993):

- ***Simple calls*** were frequency-modulated (FM) tonal calls or "moans" in the 50–300 Hz range. We distinguished (1) ascending-frequency or up calls, "/"; (2) descending-frequency or down calls, "\"; (3) constant-frequency calls, "–"; and (4) inflected calls with u-shaped ("∪") or n-shaped ("∩") frequency patterns.
- ***Complex calls*** were infinitely varied and included pulsed sounds, squeals, growls with abundant harmonic content, and combinations of two or more simple and complex segments. Subcategories of complex calls could not be discerned consistently, so all subcategories were pooled.

In addition to sounds from bowhead whales, acoustic records included sounds produced by other marine mammals, such as bearded seals (*Erignathus barbatus*), Pacific walruses (*Odobenus rosmarus divergens*), and gray whales (*Eschrichtius robustus*). Some of these were classified and tabulated by the analyses, while calls by less frequently encountered marine mammals were noted in separate logs.

Bearing Analyses

During the whale call detection and classification process, the bearing from each DASAR to each detected call was determined automatically, using information from the bearing calibrations. After all the calls were classified and bearings from DASARs to calls were determined, two parameters were calculated based on the bearings from DASAR EB / C to all whale calls detected by that DASAR: the vector mean bearing and the mean vector length (Batschelet 1981). Figure 5.2 shows how to calculate these two parameters using example bearings to nine different calls. The vector mean bearing (α) indicates the average direction from a given DASAR (here "EB / C") to the calls it received that year, while the mean vector length (L) is a measure of the variation of the individual bearings around the vector mean direction. For example, if all the bearings to calls were the same (e.g., 45°), then the vector mean bearing would be 45° and the mean vector length would be 1. If the bearings were spread evenly in all directions (e.g., 4 bearings at 0°, 90°, 180°, and 270°), then the vector mean bearing would be indeterminate and the mean vector length would be 0.

The proportion of calls "offshore" versus "inshore" (O/I ratio) was also calculated for DASAR EB / C and compared with values from previous years at that location. "Offshore" and "inshore" were defined in relation to the orientation of a line through EB / C and parallel to the general trend of the coast in the longitude range 146°–150.5°W (see Miller et al. 1999). That part of the coast has an approximate orientation of 108° to 288° True. Offshore calls were defined as those whose bearings from DASAR EB / C were between 288° and 107.9° True (including 360° or equivalently 0°, true north), i.e., offshore of the line. Similarly, inshore calls were defined as those with bearings from EB / C between 108° through 180º (south) to 287.9° (Fig. 5.3).

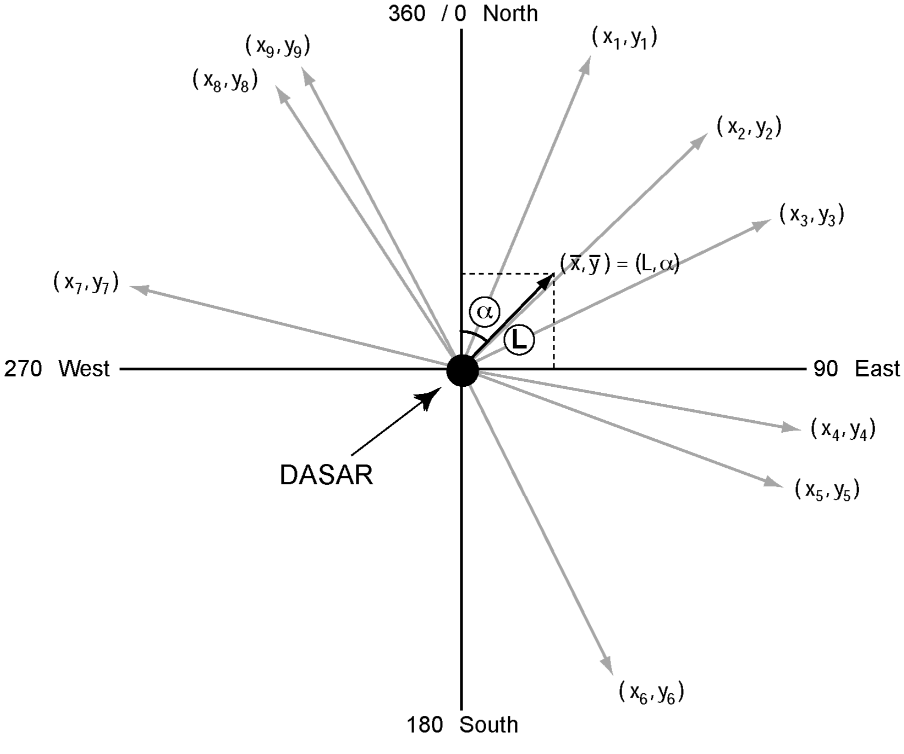


FIGURE 5.2. Average bearing calculation. The gray arrows are example bearings from a DASAR. Mean bearing angle $\alpha = \arctan(\bar{x}, \bar{y})$, where $\bar{x}$ and $\bar{y}$ are the average cos and sin, respectively, of all bearings obtained at one DASAR during a season. Mean vector length, $L = \sqrt{\bar{x}^2 + \bar{y}^2}$, is a measure of the variation of individual bearings around the vector mean direction.

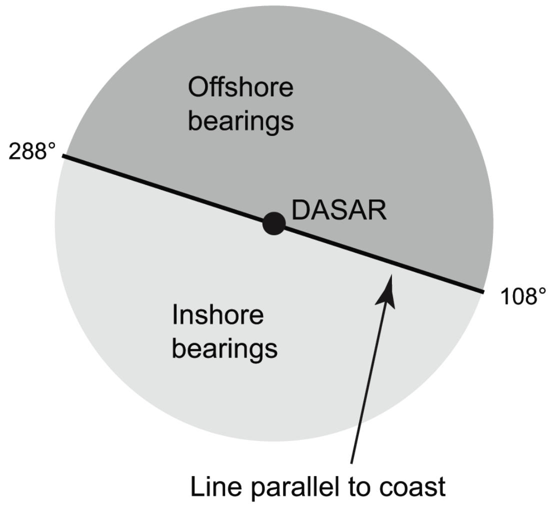


FIGURE 5.3. Definition of the "offshore" and "inshore" sectors in relation to the general orientation of the coastline and DASAR EB / C's location (filled circle in center).

Whale Call Localization

If a call was detected by at least two DASARs, the bearings to that call were combined to estimate its position using triangulation coupled with a maximum likelihood estimate for its location (Lenth 1981). The statistical problem consists of estimating a two-dimensional location parameter (in this case, latitude and longitude) where the data consist of directional bearings, and their associated errors, from several known positions. Ideally, each bearing would intersect all other bearings at a single point. In practice, errors arise that depend on the distance between a DASAR and its detected call as well as the angle of intersection. In addition, there are errors inherent to the bearing estimate itself that emerge from the DASAR bearing calibrations. Assuming a Von Mises probability distribution for the measured bearings, a maximum likelihood estimate for location and its associated covariance matrix can be derived (Lenth 1981). To address the problems caused by any outliers in the measured bearings, a robust Huber estimator is utilized that effectively downweights outliers (Huber 1964; Lenth 1981). Finally, a bivariate normal ellipse is calculated from the covariance matrix to quantify the error in the final location estimate.

RESULTS AND DISCUSSION

After an initial year of partially successful acoustic monitoring operations in 2000, the autumn migration of bowhead whales has been monitored acoustically offshore of Northstar Island since 2001. In the four years 2001–2004, we utilized 10 DASARs forming an offshore array to localize whale calls and to estimate the offshore displacement of the distribution of calling bowheads in response to industrial sound produced by Northstar activities. In 2005–2007, the procedure was changed on the basis of the results obtained during 2001–2004. The modified effort involved a smaller array consisting of DASARs at three or four locations; the main function in those years was to count whale calls for comparison with previous years, but bearings of calls from location EB / C were also determined. In 2008 and 2009, a larger array of DASARs was used again, but with the array configuration extending farther offshore than in 2001–2004. The primary objective in 2008–2009 was again to measure the spatial distribution of calling bowhead whales and to relate variation in that distribution to variation in underwater sounds. The offshore extension of the DASAR array in 2008–2009 relative to 2001–2004 was intended to provide data across a larger fraction of the width of the bowhead migration corridor. Both configurations are shown in Figure 4.2.

Whale Call Detections

Number of Calls Detected Each Year

The number of bowhead whale calls detected on the DASAR arrays varied significantly from year to year. This is due to a number of factors such as the number and location of DASARs deployed, their deployment duration, the masking effects of ambient noise, and natural variability in whale calling behavior. Table 5.1A provides an overview of call detection statistics for all the DASARs deployed in the offshore array in terms of (1) the number of DASAR locations, (2) number of operating days, (3) the total number of calls detected, (4) the average number of calls per day, (5) the maximum number of calls per hour, and (6) the date this peak occurred. A call that is detected at several DASARs is counted as a single call.

TABLE 5.1. Numbers of bowhead whale calls detected during the study's nine years ***(A)*** on the entire offshore DASAR array and ***(B)*** on DASAR EB / C. A call that is detected at more than one DASAR is counted as a single call. See Tables 4.1 and 4.2 for details on dates of operation[a,b] and DASARs deployed, and Figure 4.2 for a map of DASAR locations. Note that fewer DASARs were operated in 2005–2007 than in other years. Also shown for each year is the number of operating days (which depends on the deployment period and functionality of the DASAR) and the mean number of calls detected per day. When dividing the total number of calls by the season length, discrepancies in the listed mean number of calls per day may arise from rounding error.

	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
A. All DASARs									
No. of DASAR sites	10	10	10	10	3	3	4	10	10
Data collection begins	~29 Aug	30–31Aug	29 Aug	30 Aug	4 Sept[b]	7 Sept[b]	28 Aug	27 Aug	26 Aug
Data collection ends	1–3 Oct	23 Sept[a]	28 Sept	26 Sept	3 Oct	25 Sept	3 Oct	25 Sept	28 Sept
No. of operating days	33	23[a]	30	27	29[b]	18[b]	36	30	33
Total calls detected	10,738	10,576	45,622	66,232	1566	1484	12,754	85,669	19,772
Mean calls detected/d	330	464	1501	2490	56	84	353	2914	592
Max. calls detected/hr	262	185	567	623	112	67	229	627	466
Date with max. calls/hr	13 Sept	21 Sept	19 Sept	21 Sept	13 Sept	11 Sept	7 Sept	20 Sept	13 Sept
B. DASAR EB / C									
No. of operating days	25	24	30	27	29	18	36	30	33
Total calls detected	1624	4317	21,726	26,546	951	331	9076	39,550	6859
Mean calls detected/d	65	180	724	989	33	18	250	1337	205

[a] Season ended unusually early (23 Sept.) in 2002 due to storm action.

[b] Season started unusually late (4 Sept. and 7 Sept., respectively) in 2005 and 2006.

The late summer/autumn seasons of ***2003***, ***2004*** and ***2008*** were the ones when the highest numbers of bowhead calls were detected (Table 5.1A). The 2008 season was notable for having the highest number of call detections in the history of the study with 85,669 calls detected, resulting in an average of 2914 calls/day, and a peak hourly call detection rate of 627 calls on 20 Sept. of that year. The 2004 and 2003 seasons were also years when impressively high numbers of whale calls were detected. For 2004, the total number of calls detected (66,232) was about 77.3% of that in 2008, but the daily call detection rate was 85.4% of that in 2008 given the shorter deployment period in 2004 compared to 2008. The 2003 season had fewer detected calls, both over the season and per day, compared with 2008 and 2004, but even so we detected 45,622 calls and 1501 calls per day on average. Peak call detection rate for any single hour was slightly lower in 2003 and 2004 than in 2008: 567, 623, and 627 calls/hour, respectively. These three seasons when high numbers of calls were detected were all years with 10-DASAR arrays.

During other years with 10-DASAR arrays (***2001***, ***2002***, and ***2009***), the DASARs detected fewer calls (10,000–20,000 calls), fewer average calls per day, and a lower maximum number of calls per hour (Table 5.1A). Call detection statistics were comparable and array configuration was the same for 2001 and 2002. However, the 2002 season was the shortest in duration of the years with 10-DASAR arrays due to a storm that prematurely ended data collection period. Thus, total calls detected and perhaps daily average and peak call detection rates might have been higher were its operating duration longer. The 2009 season had the same array configuration as 2008, i.e., covered a greater spatial extent than during previous years with 10-DASAR arrays (2001–2004). During 2009, there was a reasonably high peak call detection rate (466 calls/hour). However, despite the longer deployment duration than in 2008, during 2009 the DASARs detected significantly fewer calls over the season, further confirming 2008 as a year with unusually high numbers of detectable bowhead calls.

The high call detection rate in 2008 was no doubt partly related to the larger north–south extent of the DASAR array in 2008 than in previous years. However, the same extended array was used in 2009, and the call detection rate in 2009 was lower than in some earlier years (2003, 2004). Likewise, the call detection rate at DASAR EB / C was lower in 2009 than in 2003 and 2004 as well as 2008 (Table 5.1B). Thus, the high call detection rate in 2008 represented a real phenomenon.

As expected, during the years with the fewest (three) DASAR locations, ***2005*** and ***2006***, the DASAR array detected the lowest total numbers of calls, and the daily and peak hourly detection rates were the lowest measured (Table 5.1A). • In 2005, the locations of the three DASARs (WB, CC, and EB—see Fig. 4.2) were limited by ice and were along an east–west line near the 20-m isobath. However, even comparing call statistics at the same DASAR locations shared with previous years, the number of call detections was low in 2005 (Blackwell et al. 2006). Low call counts in 2005 were hypothesized to be a result of the bowhead migration corridor occurring farther offshore combined with higher mean wind speeds than in previous years of the study (see Fig. 4.8 *in* Chapter 4). High wind speeds would result in higher average background noise levels and lower average call detection ranges than in previous years. • In 2006, three DASARs (CC, EB, and CA) were configured as a triangle, with one of the DASARs (CA) being farther offshore than the previous year. Despite lower mean wind speed (Fig. 4.8), similarly low call counts in 2006 were hypothesized to be related to the presence of heavy nearshore ice during the 2006 season. That ice may have deflected the southern part of the migration pathway farther offshore than in years with open water (i.e., 2001–2004; Blackwell et al. 2007a).

The low call counts in 2005 and 2006 are only partially explained by the smaller array configuration in those years compared to years with DASARs at 10 locations. The mean number of calls detected per day at EB / C, a location where a DASAR has been deployed every year of the study, were 33 and 18 calls/day for 2005 and 2006, respectively (see Table 5.1B). These were the lowest of the study's nine years, which suggests that the call detection rate was lower in 2005 and 2006 not simply due to fewer DASARs but perhaps due to natural annual variability in calling rates as well as location of the migration corridor relative to the DASAR array.

During the **2007** season, despite having DASARs at only four locations, the DASAR array detected 12,754 calls. In addition to the three DASAR locations of the previous year (CC, EB, and CA), a fourth DASAR (NE) was deployed further offshore in roughly 25-m deep water. The notably higher call counts in 2007 compared to the two previous years were hypothesized to be related to the absence of nearshore pack ice during the 2007 season, i.e., whales were likely swimming closer to shore due to the absence of ice near shore (Blackwell et al. 2008a).

Variation in Call Detection Rate

The peak hourly call detection rate during the three years with the highest numbers of whale call detections (2003, 2004, and 2008), based on all DASARs, occurred during the 19–21 Sept. period (Table 5.1A). The peak daily call detection rates at EB / C during those three years occurred on a similar range of dates, 20–22 Sept. (Fig. 5.4). One other year, 2002, experienced its peaks in hourly and daily call detections during the 21–22 Sept. period, but with significantly lower call detection rates. In all remaining years (2001, 2005–2007, 2009), the maximum hourly call detection rate for the DASAR array as a whole occurred one to two weeks earlier (Table 5.1A), as did the maximum daily rate at EB / C (Fig. 5.4). During at least some years, calling bowhead whales were already present in the general Northstar area by the last week of August. In addition, due to retrieval of the DASARs in late September or early October, the latter portion of the migration season is not reflected in the aforementioned peak detection statistics.

The aforementioned whale call detection results for 2001–2009 are displayed in more detail in Figure 5.5, which shows the hourly call detection rate as a function of time (black histogram). In addition, the hourly wind speed, measured at the Northstar weather station through 2006 and at the Prudhoe Bay weather station thereafter, is shown (gray line). The number of calls detected per hour varied widely, fluctuating from 0 to over 600 calls per hour. This variation can be attributed to several factors including varying measurement methods in different years (see above), varying wind speeds (and

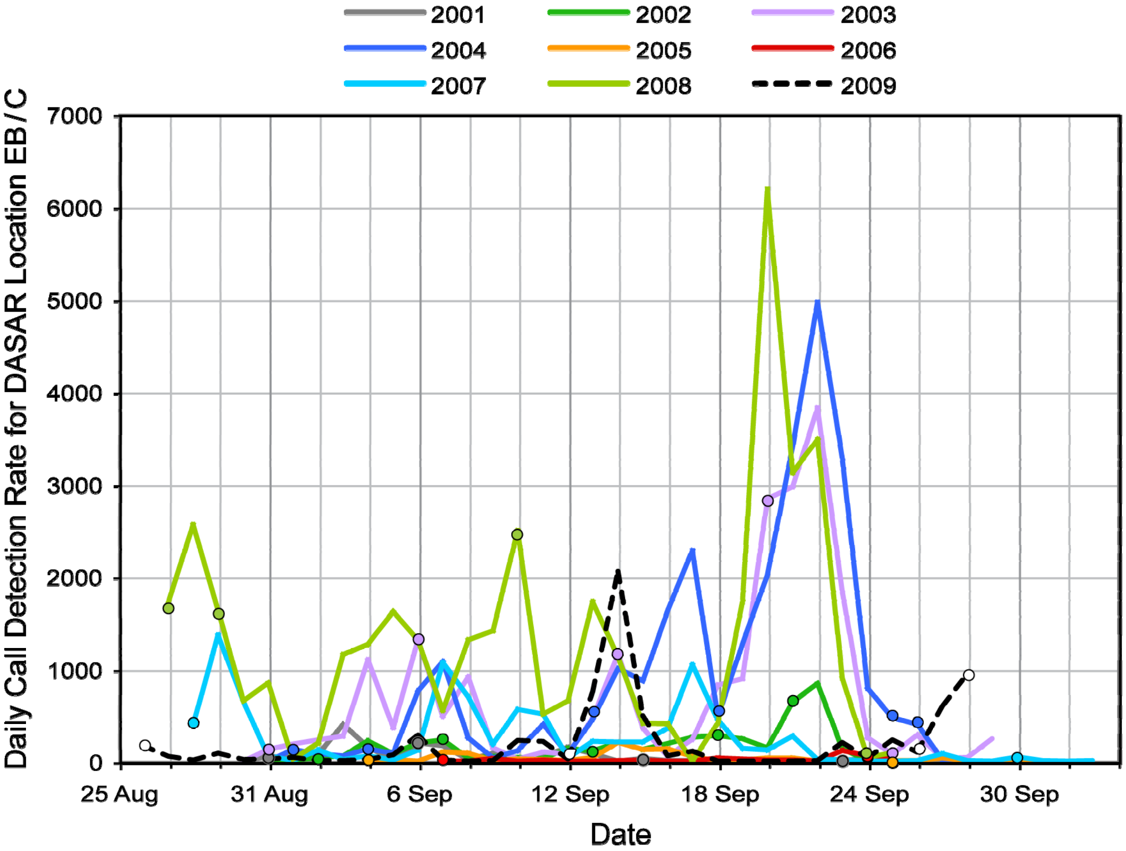


FIGURE 5.4. Daily detection rate of bowhead whale calls vs. date in late August to early October in 2001–2009 considering data from a DASAR at location EB / C. Note that, in 2001, 2002, 2005, and 2006, total number of calls detected at location EB / C never exceeded 1000 calls/day. Daily counts marked with a dot indicate days when the acoustic research vessel operated near the DASAR array.

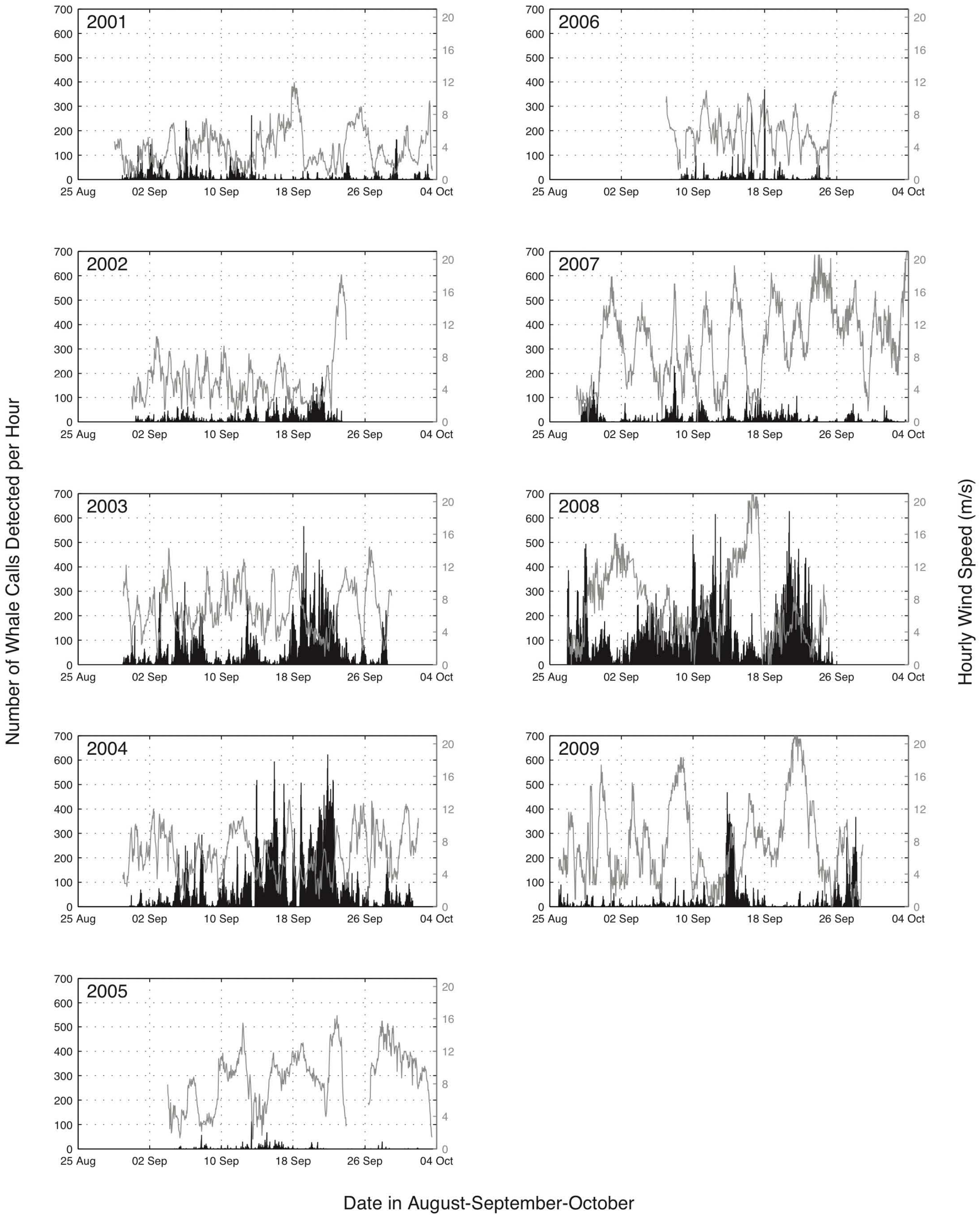


FIGURE 5.5. Hourly detection rate of bowhead whale calls as a function of date in late August to early October in 2001–2009 considering all offshore DASARs. Tick marks on X-axis represent midnight (local daylight time). Tick marks on the left Y-axis represent the hourly call detection rate (black line), while those on the right Y-axis represent the mean hourly wind speed (gray line). In 2005–2007, 3- and 4-DASAR arrays were deployed while all other years involved 10-DASAR arrays (see Table 5.1).

thus ambient noise), the seasonal progression of bowhead migration, year-to-year differences in the location of the bowhead migration corridor relative to the DASAR array, and day/night effects:

1. Year-to-year variations in measurement methods included differences in the number and spatial extent of DASARs, and differences in their deployment and retrieval dates (Table 5.1A). Counting each call only once regardless of the number of DASARs that detected it reduces, but does not eliminate, the effect of number of operating DASARs on the results. Extension of the DASAR array into deeper waters in some years (especially 2008–2009) had the potential to detect more calls.
2. Underwater ambient noise levels are highly dependent upon the wind speed (e.g., Chapter 4), and this affects the ability to detect calls. In general, windy days resulted in high background noise levels and reduced call detection rates, whereas periods of lower background noise levels during calm days included times with both high and low calling rates (Fig. 5.5). Typically, the highest numbers of calls were detected during low-wind days.
3. Westward migration of bowhead whales past the Prudhoe Bay/Northstar area is generally understood to begin in earnest during late August/early September, peak in mid-late September, and gradually diminish through much of October (Moore and Reeves 1993). The acoustic results from 2001–2009 are generally consistent with this concept. However, because the DASARs were retrieved in late September or early October each year to minimize problems and risk associated with ice and deteriorating weather, we have no specific data on the latter portion of the migration season in October.
4. The offshore distance of the bowhead migration corridor is known to vary from day to day within a migration season. Also, the average location is farther offshore in some years than others. These day-to-day and year-to-year differences are evident from aerial surveys (e.g., Treacy et al. 2006) and whaler observations (e.g., Chapter 7), and are also evident in the acoustic monitoring results (Blackwell et al. 2007b; see also Fig. 5.9–5.12 and 5.14, below).
5. Interactions between the offshore distances of the DASARs in any one year relative to the location of the main migration corridor in that year are likely to have an important influence on number of calls detected. For example, 2001 was a year when the southern edge of the migration corridor was relatively far from shore (Treacy 2002; Blackwell et al. 2007b), and the number of calls detected that year was relatively low as compared to numbers in other years with 10-DASAR arrays.
6. The call detection rates were found to be significantly higher at night than during the day during all four years (2001–2004) of autumn bowhead data analyzed by Blackwell et al. (2007b). As discussed in that paper, a higher call detection rate at night has also been noted in some earlier studies of bowheads, and in studies of calling by a few other species of baleen whales.

Whale Call Classification

Figure 5.6 shows a percentage breakdown of all bowhead whale calls detected by DASARs at location EB / C by call type for 2001–2009. Calls are broken down into two main categories: simple calls and complex calls. Simple calls are further broken down into four sub-categories: upsweeps, downsweeps, constant frequency calls, and undulated calls. Until 2007, undulated calls were split into ∪-shaped and ∩-shaped undulated calls, but some undulated calls fit neither of these categories. Consequently, a third category of "other" undulated calls was created. To facilitate comparison among years, undulated calls are treated here as one category. As shown in Figure 5.6, the percentage use of these five different call types—upsweep, downsweep, constant, undulations, and complex—varied from year to year with no discernible pattern.

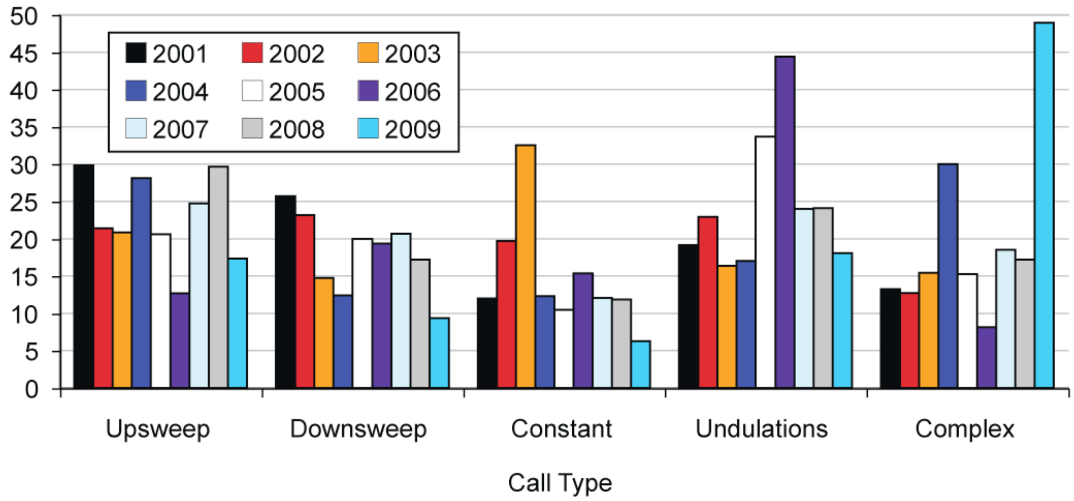


FIGURE 5.6. Percentage breakdown by call type in 2001–2009 for calls detected by DASARs at location EB / C. Simple calls include upsweeps, downsweeps, constant calls, and undulations.

For all years of the study combined, the most common type of simple call was the upsweep, comprising 26% of all calls detected over the nine years. The remaining simple call types (downsweep, constant, and undulations) occurred in roughly equal proportions: 16%, 16%, and 19%, respectively. Complex calls comprised 22% of all call types in 2001–2009. For the most common call, the upsweep, its average percentage use was 23% (mean of 22.8%, median of 21.4%) with a standard deviation of ±6%. This ±6% variability in upsweeps from year to year was slightly greater than that for downsweeps (±5%) but less than the variability observed for all other call types, which ranged from ±8% to ±12%.

Figure 5.7 shows the percentage of simple versus complex calls in 2001–2009. For the first eight of the study's nine years, simple calls comprised the vast majority, roughly 80%, of call types detected. In 2009, complex calls assumed an uncharacteristically larger proportion of calls than in previous years, accounting for approximately half, 49%, of all calls. Likewise, the remaining 51% of the calls that were "simple" comprised a smaller percentage of total calls compared with 70% to 92% "simple" in 2001–2008.

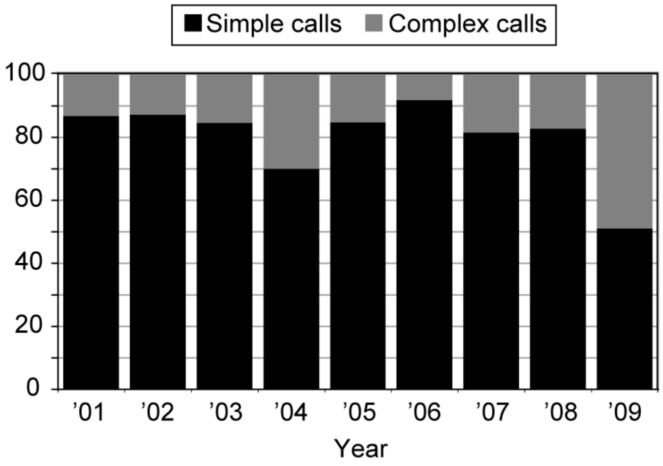


FIGURE 5.7. Percentage of simple versus complex calls in 2001–2009 for calls detected by DASARs at location EB / C. Simple calls include upsweeps, downsweeps, constant calls, and undulations. Simple and complex calls occurred in equal proportion in 2009, the only season when this occurred at Northstar.

Inferring broad conclusions on bowhead calling behavior from results at a single location (EB / C) or a single year is not recommended. Call type percentages are not uniform across DASARs in the array, either in space or time (unpubl. data). In addition, changes in the percentage use of different call types from year to year (Fig. 5.6, 5.7) clearly occurred, but are difficult to interpret because little is known about the behavioral significance of specific types of bowhead calls. Of the calls detected at EB / C in 2001–2008, the percentage that were simple averaged 84%. This is consistent with previous findings in which 86% of bowhead calls recorded in the fall of 1979 were simple (Ljungblad et al. 1982), and 86% of calls recorded during the spring migration off Point Barrow in 1984 were classified as simple (Clark et al. 1986). In contrast, we found that only 51% of the calls detected in 2009 at EB / C were simple, whereas 49% were complex. A few other studies have found a relatively high percentage of complex calls and a correspondingly low percentage of simple calls, similar to the 2009 Northstar results. High proportions of complex calls were detected near socially active groups of bowheads in Baffin Bay (Richardson et al. 1995) and on days of peak calling rates off Barter Island and Barrow (Ljungblad et al. l988). The 2001–2004 Northstar data, on further study, show a positive correlation between number of calls detected per day and percentage use of complex calls (Blackwell et al. 2007b). These studies suggest that complex calls may be related, at least in part, to social behavior (Würsig and Clark 1993; Richardson et al. 1995).

Bearings of Bowhead Calls

Table 5.2 summarizes the main results of the bearing analyses. Location EB / C is the one DASAR location for which nine consecutive years of bearing data exist. Considering all nine seasons (2001–2009), vector mean bearings to the whale calls detected by the DASAR at location EB / C were most often (in 8 of 9 years) within the northeastern quadrant, i.e., between 0º and 90º true. Indeed, in 7 of 9 seasons, the vector mean bearing was within a smaller sector to the northeast or east-northeast (44º to 78º; Table 5.2; see also Fig. 5.8). In the other two years, the vector mean was approximately north or north-northeast of EB / C (348º in 2005 and 33º in 2006). The least variable bearings (longest mean vector length, L) were in 2002 when the vector mean was to the ENE (64º). In 2009, the mean vector length, 0.70, rivaled that of 2002, and the vector mean was also to the ENE (65º) and very similar to that in 2002. Also, 2002 was the year with the highest O/I ratio (see Fig. 5.5), i.e., the year with the highest number of offshore calls in relation to the number of inshore calls. Conversely, 2005 had the most variable bearings (shortest mean vector length) and the lowest O/I ratio (Table 5.2).

TABLE 5.2. Bearings of bowhead calls from location EB / C. See Figure 4.2 (in Chapter 4) for a map of DASAR locations. α is the vector mean bearing in degrees with respect to true north, and L is the length of the mean vector (see Fig. 5.2). O/I is the ratio of the numbers of offshore versus inshore calls (see Fig. 5.3). *n* is the number of calls.

Year	α (°)	**L**	**O/I**	***n***
2001	44	0.65	5.7	1624
2002	64	0.74	13.6	4317
2003	78	0.55	2.5	21,726
2004	69	0.42	2.4	26,546
2005	348	0.14	1.3	951
2006	33	0.46	4.0	331
2007	75	0.45	2.9	9076
2008	59	0.53	5.1	39,550
2009	65	0.70	5.6	6859

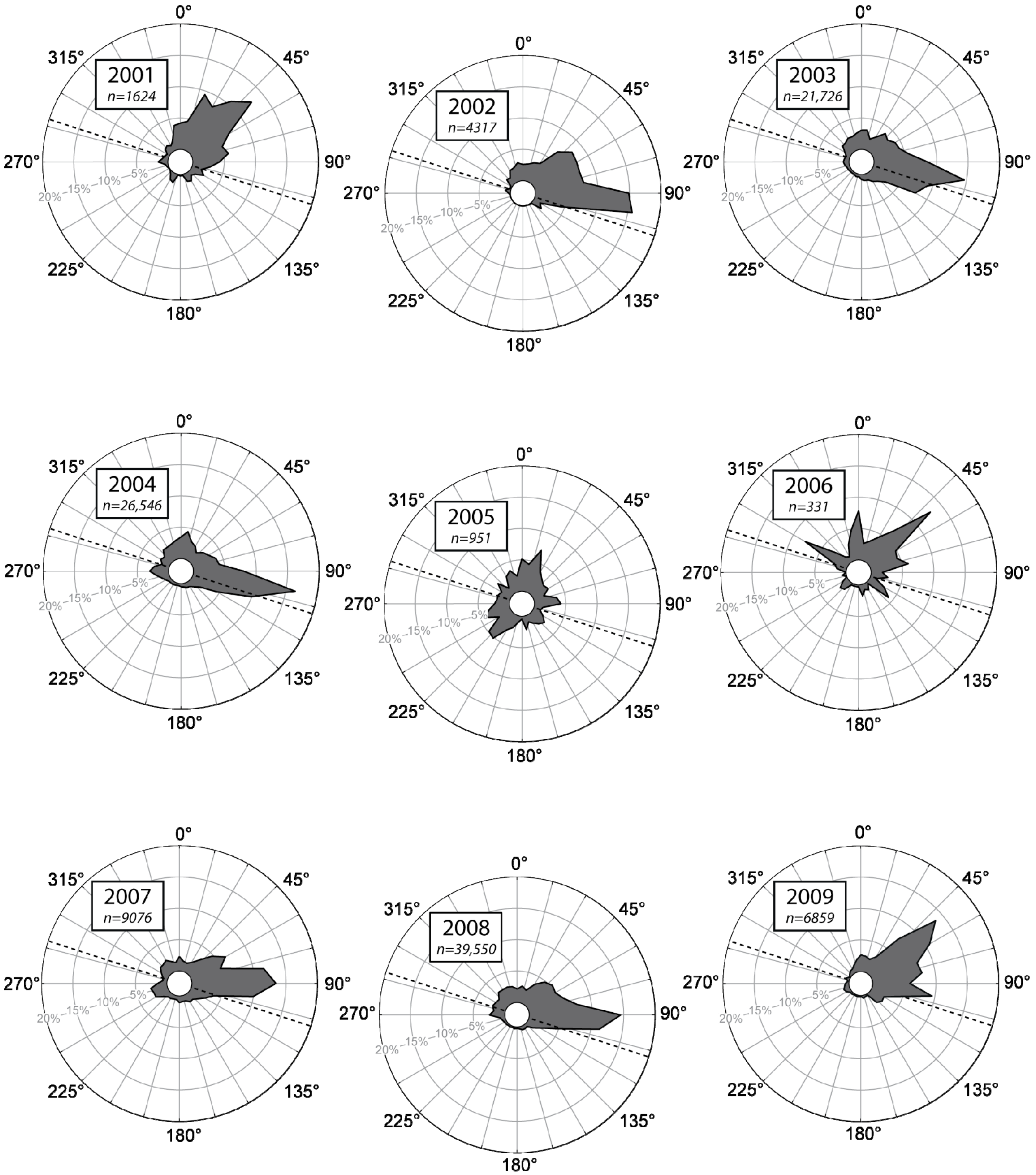


FIGURE 5.8. Directional distribution of bearings to bowhead whale calls detected via DASAR EB / C in 2001–2009. Results for each 10° sector are expressed as a percentage of all bearings obtained via the DASAR at location EB / C that year. The approximate orientation of the coast (see text) is shown as a dashed line. Sample sizes vary widely, from 331 in 2006 to 39,550 in 2008.

Figure 5.8 shows the percentage distribution of all bearings to bowhead whale calls as obtained by the DASAR at location EB / C in each year from 2001 to 2009. The bearings for each year were grouped into thirty-six 10° bins centered on multiples of 10° (i.e., 355°–4.99°, 5°–14.99°, etc.). The number of bearings in each bin is expressed as a percentage of the total number of call bearings determined via DASAR EB / C for that season. These plots emphasize the preponderance or relative rarity of bearings in certain directional sectors. For example, the 2009 plot shows that bearings in the range 135°–325° were relatively uncommon that season, whereas bearings in the range 45°–55° were most common. The distribution of bearings in 2009, predominantly to the northeast, was very similar to the distribution in 2001, which was a year when the southern edge of the whale migration corridor was relatively far offshore (Treacy 2002; *cf.* Monnett and Treacy 2005; see also Blackwell et al. 2007b). In contrast, the distribution of bearings in 2008, with easterly bearings being most common, was very similar to the distributions of bearings in 2002–2004 and 2007.

Call Directionality

Bearing data shown in Table 5.2 and Figure 5.8 show that, in most years, more calls are detected to the east than to the west of EB / C. Likewise, for most years, plots of the estimated locations of the bowhead calls around the DASAR array show more calls to the east than to the west (Fig. 5.9 through 5.12, below). In fact, for all years of the study in which call locations were analyzed (2001–2004 and 2006–2009), more calls were detected east of the DASAR array than west of it (details in Annex 5.2 at the end of this chapter). Similarly, based on a more elaborate analysis of bowhead calls localized near Northstar in 2001–2004, Blackwell et al. (2008b) showed that call detection rates remained significantly higher to the east of Northstar than to the west after allowance for physical and environmental covariates.

One possible explanation could be that the predominantly westward-oriented whales produce calls that are stronger ahead (west) than behind (east) of the animals. However, there are other possible explanations. The predominance of easterly bearings could also occur if bowheads call more often, or with higher source levels, when in waters east than west of Northstar, or if they tend to linger in areas to the east vs. travel more quickly through areas to the west.

Because this effect might indicate some influence of the Northstar Development on the whales, it was of interest to determine whether the preponderance of easterly bearings could be explained by an alternative hypothesis — call directionality. Prior work seeking evidence of directionality in calls of bowhead and other mysticete (baleen) whales calls has been largely inconclusive (Clark et al. 1986; Au et al. 2006). However, based on data from the Northstar study's 2008 season, statistical tests comparing received levels of bowhead calls at DASARs to the east and west of calling whales found that calls are indeed directional, i.e., higher (on average) to the west than at a comparable distance to the east of the whales (see Annex 5.2). Our analysis assumed that the majority of the whales were oriented approximately westward or northwestward when they called. Because not all bowheads in the Northstar area are actively migrating or oriented to the west (Miller et al. 1996), the assumption was only partially correct, and the actual degree of directionality in bowhead calls was probably greater than that estimated in Annex 5.1. Thus, the lower number of calls detected west of the array than east of the array during this study can be explained, at least in part, by this call directionality.

Locations of Bowhead Calls

Figures 5.9 through 5.12 show the estimated locations of the calls detected by the offshore DASAR array during the 2001–2004 and 2006–2009 late summer/early autumn period. The 2005 localization estimates are not depicted because the bearing estimates produced by two of the three DASAR positions that

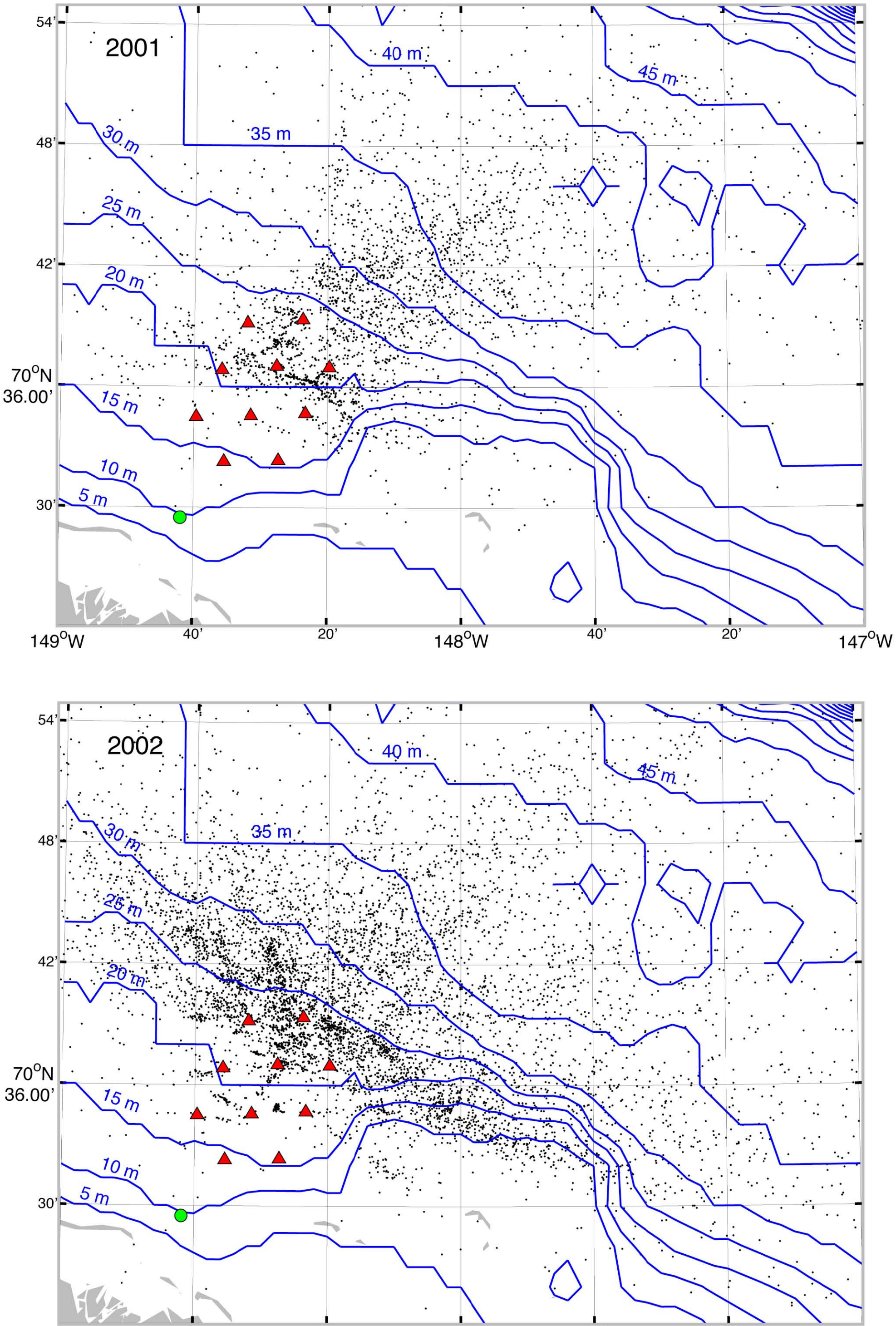
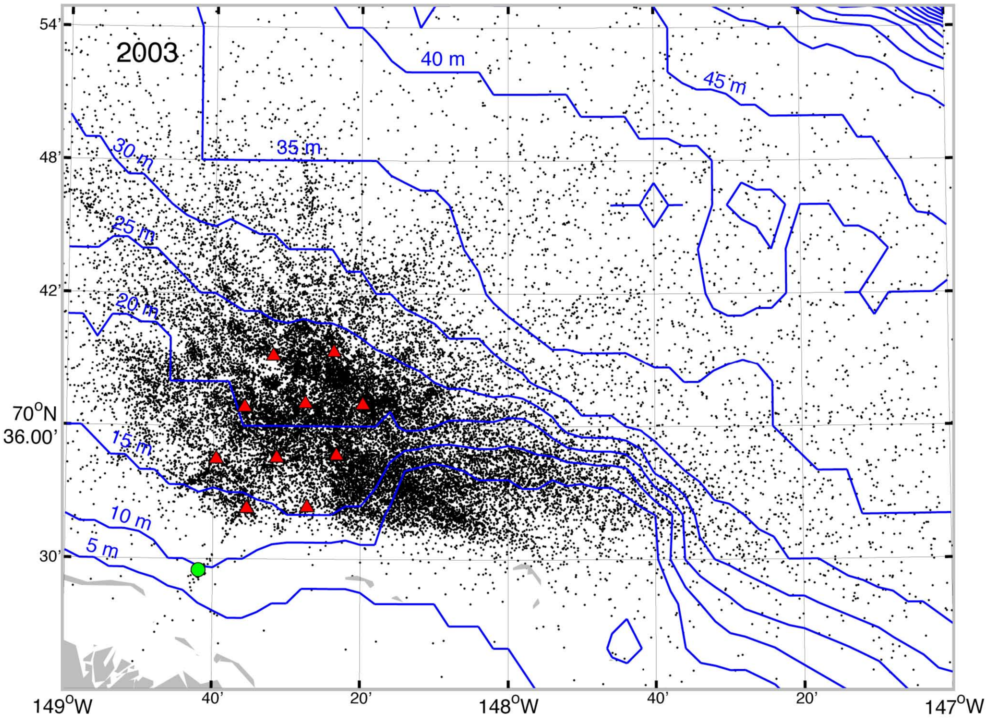


FIGURE 5.9. Estimated locations of whale calls that were detected by two or more offshore DASARs in 2001–2002. Northstar is shown as a green circle and the DASAR locations as red triangles. Calls recorded by the near-island DASARs were not used in the location estimations. Location accuracy decreases with distance from the array. For calls far outside the periphery of the DASAR array, bearing from the array is estimated quite accurately, but distance from the array is quite uncertain.



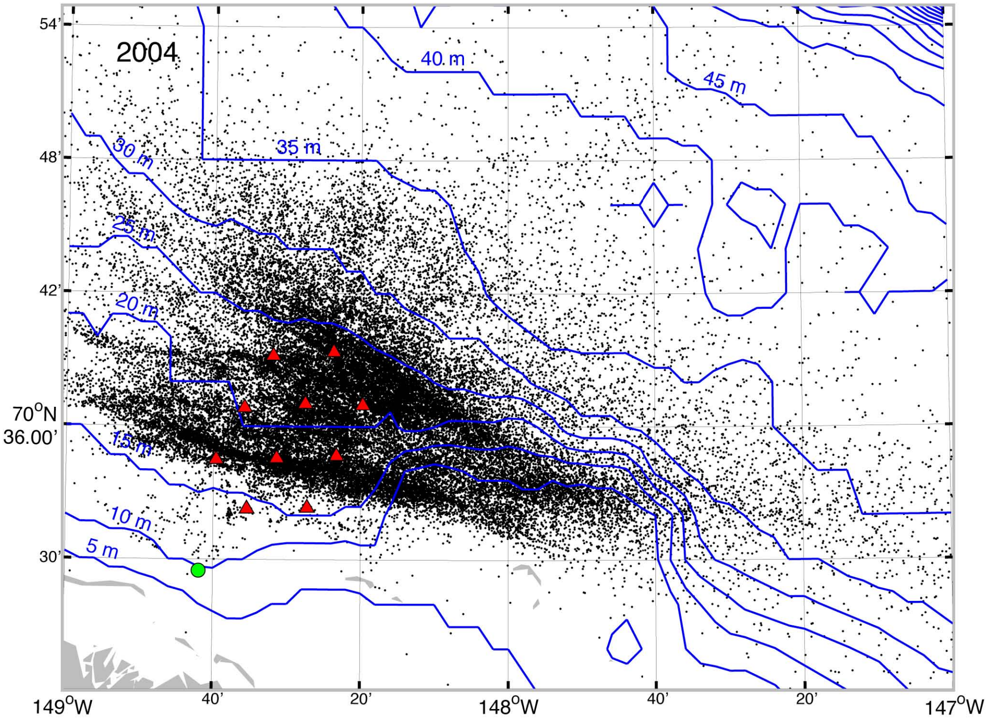


FIGURE 5.10. Estimated locations of whale calls that were detected by two or more offshore DASARs in 2003–2004. Plotted as in Figure 5.9.

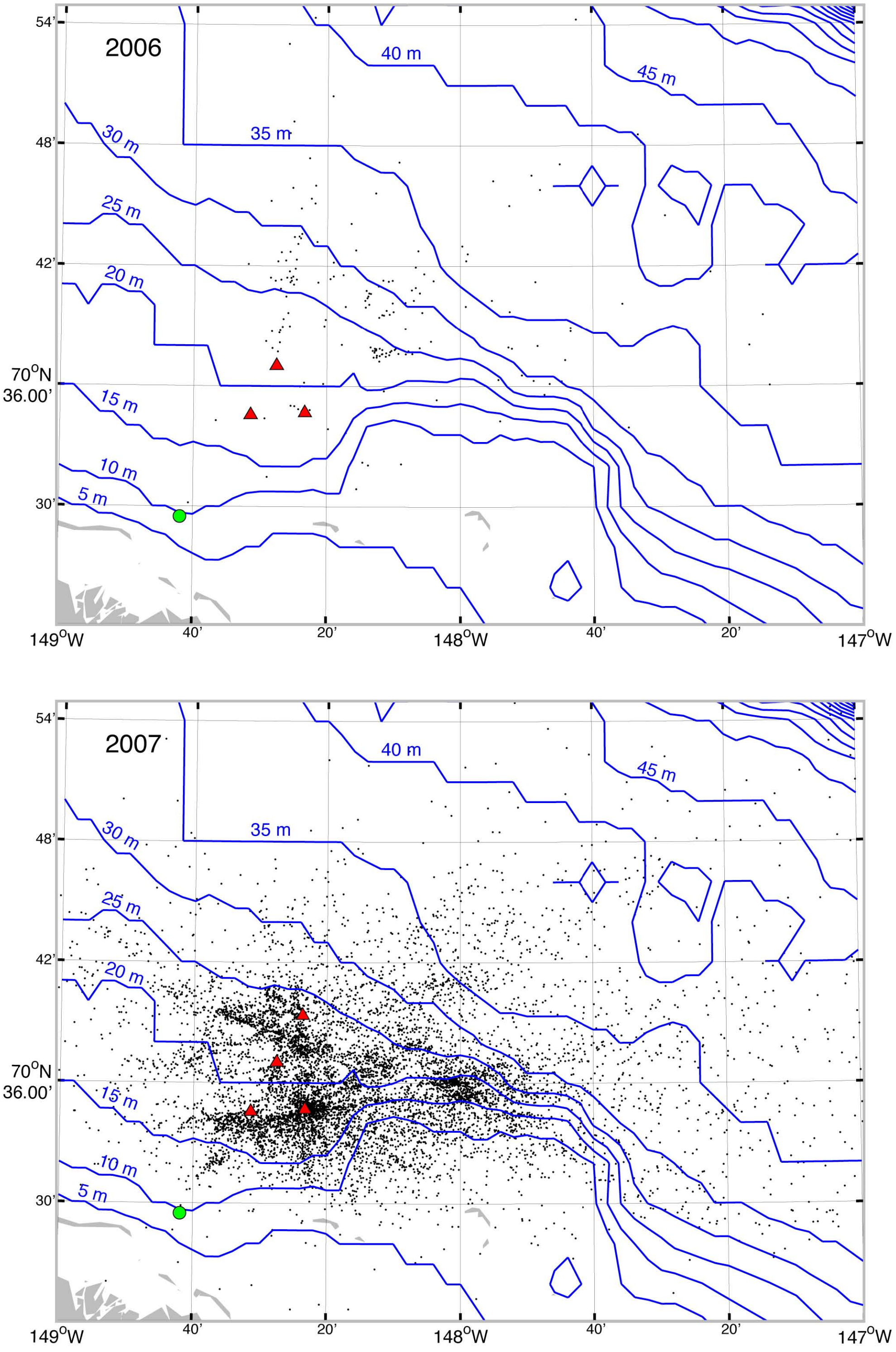


FIGURE 5.11. Estimated locations of whale calls that were detected by two or more offshore DASARs in 2006–2007. Call detection probabilities and location accuracies were reduced relative to 2001–2004 and 2008–2009 because of the lower number of DASARs operated in 2006–2007. Plotted as in Figure 5.9.

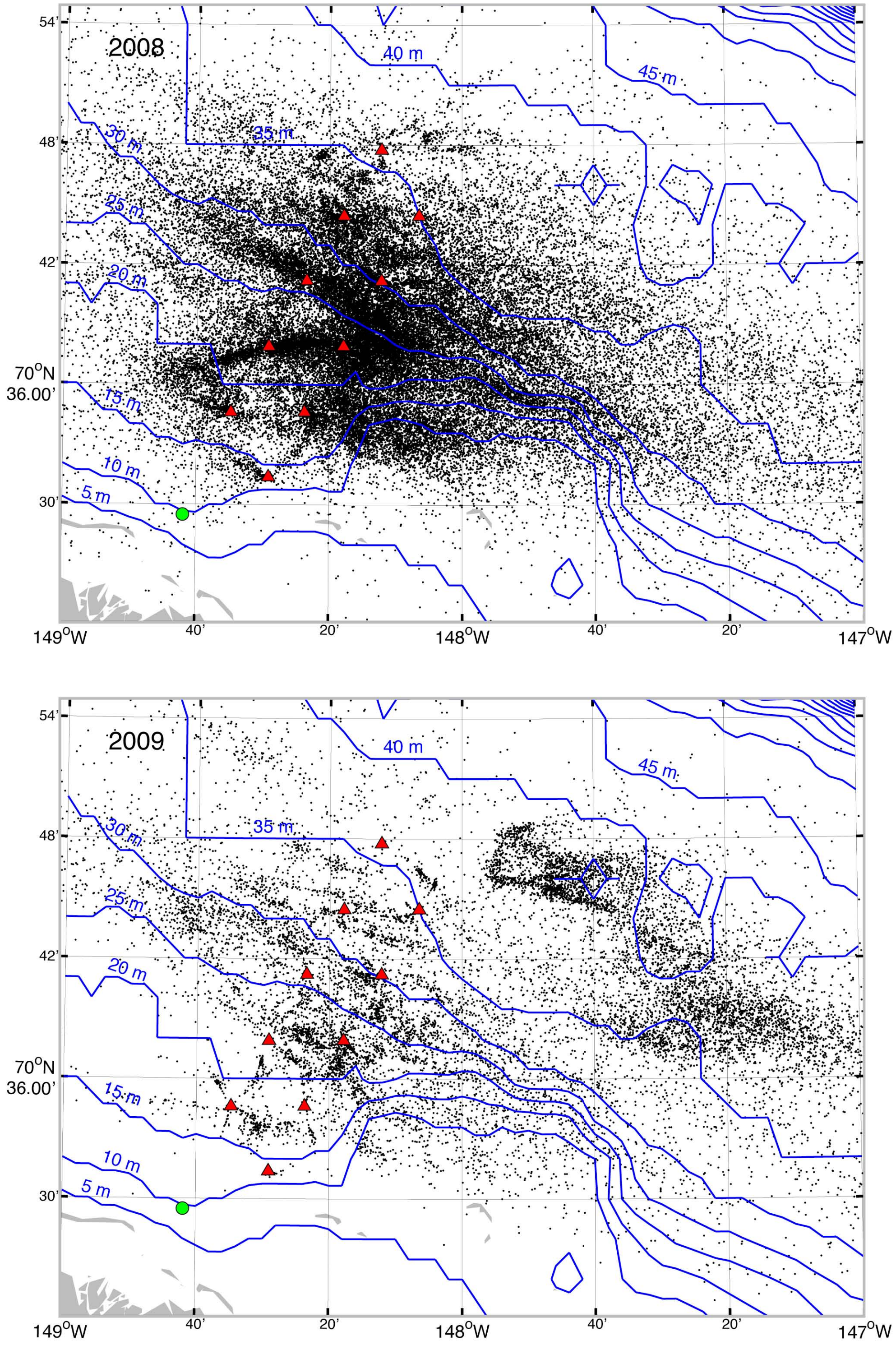


FIGURE 5.12. Estimated locations of whale calls that were detected by two or more offshore DASARs in 2008–2009. Plotted as in Figure 5.9.

year (WB and CC) were unreliable due to repeated storm-related DASAR movement that prohibited accurate bearing calibration.

Uncertainty in Estimated Locations

For all years except 2001, 2005 and 2006, the vast majority, greater than 72%, of recorded whale calls were detected by two or more DASARs and most of these were localizable by triangulation. In 2001, many of the detected calls were far to the northeast of the DASAR array, and distant calls are less likely to be detected by multiple DASARs; 68% of the calls detected in 2001 were single-DASAR detections (Greene et al. 2002). In 2005 and 2006, the small array configuration led to similarly high percentage of calls detected by only a single DASAR (65% and 86%, respectively, in those years). When a call is detected by two or more DASARs, its location can usually be estimated by means described in the ***Methods*** section of this chapter.

In Figures 5.9 through 5.12, most but not all of the localized calls are displayed. There are several reasons for exclusion of certain calls:

1. Calls greater than 10 km (6 mi) from the periphery of the array are at highly uncertain locations (Greene et al. 2004; Blackwell et al. 2007b). Our plots extend much farther than 10 km outside the array, so include many calls at quite uncertain locations. However, we do limit the mapped area somewhat, thus excluding some calculated (but extremely imprecise) call locations beyond the mapped area.
2. The imprecisely located calls whose estimated locations lay beyond the map boundaries were close enough to the array to be detected, which means that many of their actual locations probably were within the map boundaries shown.
3. The original objective of the study was to acoustically monitor the southern portion of the whale migration corridor. The original array of DASARs, as deployed up to 2004, was positioned on the inner continental shelf within the southern part of the migration corridor, with the most offshore DASAR being 21.5 km (13 mi) from Northstar (Fig. 4.2, Table. 4.2). The array was not designed or intended to monitor bowhead migration over the outer shelf or beyond. In 2008–09, DASAR coverage was extended farther offshore, with the most offshore DASAR being 38.4 km (24 mi) from Northstar, but even then, coverage did not extend to the north side of the migration corridor. The bowheads' preferred water depth during migration is 20–50 m (66–164 ft). The water depth at the most offshore DASARs was 24 m (79 ft) in 2001–2004 and 38 m (125 ft) in 2008–2009.

Accuracy of the position estimates generally increases as a call is heard by more DASARs. In addition, confidence in the position estimates decreases with increasing distance from the DASARs; this decrease is quite steep beyond a distance of 6–10 km (4–6 mi) from the periphery of the DASAR array. In general, bearings to distant calls well outside the DASAR array are known quite accurately, but their estimated distances are known only imprecisely. Furthermore, the degree to which bearings are in line with the long axis of the array can affect localization accuracy since the greater the effective array aperture, the greater the localization accuracy. Localization accuracy and factors affecting it were investtigated during the early years of this study and are addressed in Greene et al. (2004) and in Chapters 7–9 of Richardson (ed., 2008).

Localization accuracy is quantified by means of confidence ellipses calculated for each position estimate. The sizes of these confidence ellipses are considered in subsequent statistical analyses regarding the spatial distribution of the whale calls (described in Chapter 6). Due to the weighting used in those analyses, bowhead whale calls with uncertain localizations contribute little to the analysis. Nevertheless, we investigated some indubitably erroneous whale call locations that the standard localization procedures estimated to be on land generally south of Northstar. In 2008, 0.75% of the localized whale calls were estimated to be on land. Of the calls estimated to be on land, 86% had 90% confidence ellipses extending into the ocean. In other words, the analysis indicates that, for most calls with estimated locations on land, there was a >10% statistical probability that the call was actually in the sea. A random sample of 2158 location estimates from the 2008 data (4% of the total calls localized in 2008) is depicted in Figure 5.13. The sample locations are shown in blue, and 90% confidence ellipses for a subset of southernmost locations are shown in red. DASAR locations are shown in green. In this random sampling, 0.65% of calls were estimated to be on land. Whale call locations on land were a result of either imprecision or bias in the location estimate, and most locations on land that were examined had error ellipses that extended into the ocean. This evaluation of calls with estimated locations well outside the DASAR array and to the south provides further corroboration of earlier evidence that estimated locations of calls far outside the DASAR array can be very imprecise in terms of distance from the array, although quite precise in terms of bearing from the array.

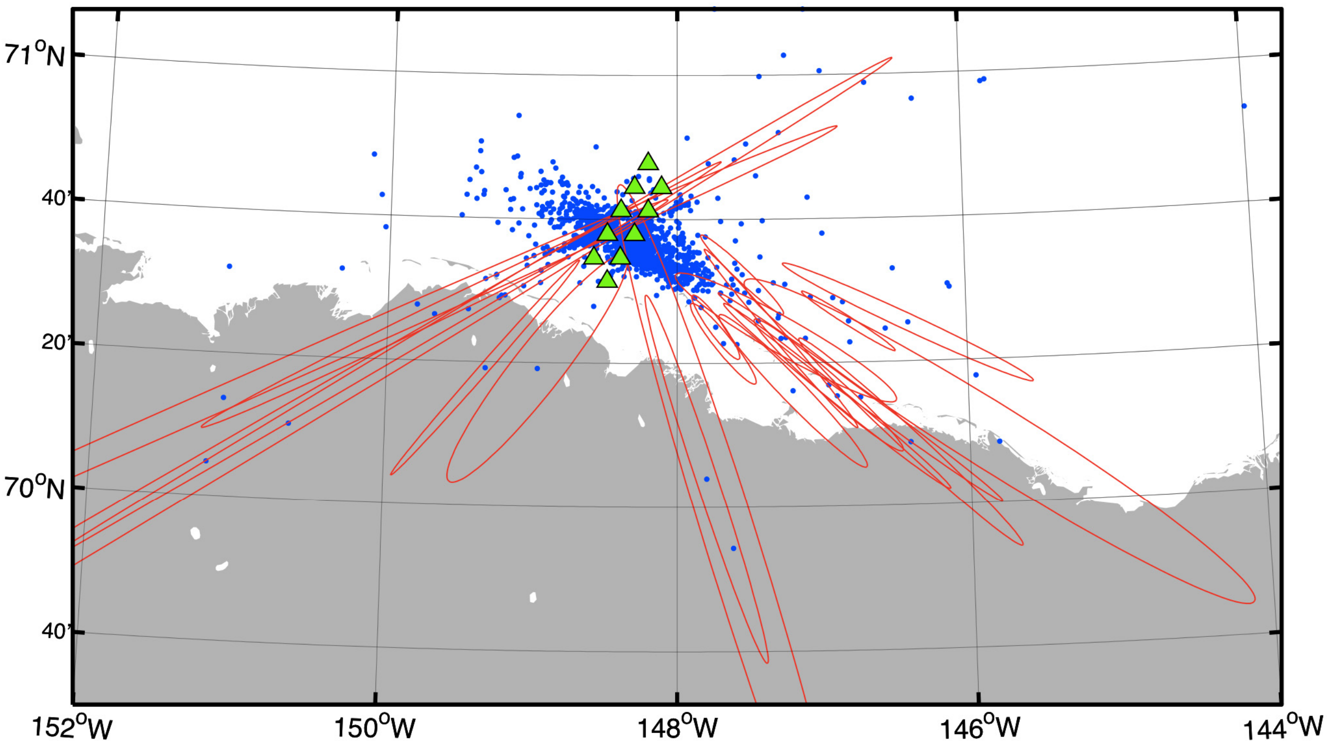


FIGURE 5.13. Localization accuracy for a random sample of whale calls detected in 2008 whose estimated positions were on land. See text for more information.

Distribution of Calling Bowhead Whales

The maps of localized whale calls for 2001–2004 and for 2008–2009 (Fig. 5.9, 5.10, 5.12) provide much information about the distributions of calling bowhead whales over the inner and middle parts of the continental shelf offshore of Northstar during those late summer/early autumn seasons. The 2005–2007 localization data are not considered here because the objectives of the acoustic monitoring in those years did not include detailed localization; DASARs were not deployed over a wide area in those years. Also, in 2005 there were additional ice- and storm-related limitations as previously mentioned.

Comparison of the aforementioned maps shows that the distribution of calling whales was relatively far offshore in 2001, slightly closer to shore in 2002, and notably closer to shore in 2003 and 2004. Those results, and their relationship to BWASP aerial survey results from the same seasons, were discussed by Blackwell et al. (2007b). The acoustic and aerial survey data were generally consistent, but the aerial survey data did not show the 2003 migration corridor to be unusually close to shore. However, these comparisons of acoustic and aerial data cannot be taken too far. The number of aerial survey sightings within the Northstar area each season was orders of magnitude smaller than the number of acoustic localizations. The low number of sightings achievable by aerial surveys was one of the main reasons why BP chose to use an acoustic method rather than aerial surveys for the Northstar monitoring study.

In 2008, the distribution of calling whales was again relatively close to shore, with a large number of whale calls being detected (Table 5.1). A large proportion of the calls originated either within the periphery of the DASAR array or from locations to the east of the array (Fig. 5.12, top). Most of the whales at the latter (easterly) locations would be expected to pass through the array as they subsequently travelled to the west or west-northwest, parallel to the coast.

In 2009, numerous whale calls were received from those same locations either within or east of the DASAR array, but the number of calls from those areas was much lower than in 2008. Also, in 2009, a concentration of bowhead calls was detected east and northeast of the northeastern portion of the array (Fig. 5.12, bottom). That was an unusual pattern, not seen during any other year of the study. Overall, the 2009 call distribution suggests that the migration corridor tended to be somewhat farther offshore than in 2008. As noted earlier, the bearings from DASAR EB/C to calls detected by that DASAR also suggest that the migration corridor was farther offshore in 2009 (Fig. 5.8).

In most years of the study, the distribution of detectable calls appeared to become broader (in the onshore–offshore dimension) in the area west of the DASAR array than it was east of the array. This was most conspicuous in 2004 (Fig. 5.10, bottom), but was also evident in 2003 and 2008 (the other two high-call-count years) and to a lesser degree in some other years. In at least these years, it appears that the migration corridor may have tended to "spread out" as the whales progressed westward through the area. It may be relevant that the depth contours also become farther apart west of Northstar. This tendency to "spread out" to the west might also be, at least in part, a response to Northstar or other industrial operations in the Prudhoe Bay area. On the other hand, aerial survey data collected up to 1999 suggest that, even before the existence of Northstar, the migration corridor tended to spread out west of the future Northstar location (see Fig. 10 in Blackwell et al. 2007b). That would tend to suggest that the "spreading out" phenomenon is not primarily, if at all, related to the Northstar Development.

In at least some of the years, including recent years (2008, 2009, and possibly 2007), the distribution of the detected bowhead calls within and near the DASAR array was "irregular". There were apparent concentrations of calls oriented roughly parallel to the coast in some years, e.g., 2004 (Fig. 5.10, bottom) and 2008 (Fig. 5.12, top). These concentrations might reasonably represent real concentrations of whales moving west (predominantly) parallel to shore. However, some other concentrations of calls were oriented in different directions, e.g., in 2008, toward the southwest in the area southwest of the center of the array. In 2009 there was an irregularly-shaped concentration of call locations to the east and northeast of the offshore end of the array. We do not know whether these call concentrations that were not aligned roughly parallel to shore were actual concentrations of calling whales at these locations, or whether they were artifacts of some unknown geographic or geometric (relative to the DASAR array) variation in call detectability.

Offshore Distances

In addition to plotting two-dimensional (latitude and longitude) location estimates, we examined offshore distances to whale call locations as a function of time. A "baseline" was defined that ran through Northstar Island and was approximately parallel to the Beaufort Sea coast (orientation 108°–288° True). Blackwell et al. (2007b) provide additional details. Offshore distances of whale calls were calculated perpendicular to the baseline and are shown in Figure 5.14 for the six monitoring seasons when we utilized a 10-DASAR array (2001–2004, 2008, and 2009).

Year-to-year variation in the location of the migration corridor relative to shore is apparent from the offshore distance plots (Fig. 5.16), generally consistent with earlier discussion based on the maps of whale call locations. On average, offshore distances tended to be large in 2001 and to some degree also in 2002 and 2009, and smaller in 2003, 2004 and 2008. Prior studies have shown that bowheads tended to inhabit shallow inner-shelf waters close to shore during years with light and moderate ice coverage and deeper waters farther from shore in heavy ice conditions (Moore 2000; Treacy 2002; Treacy et al. 2006). However, comparison of 2001–2004 versus 2008–2009 distances is complicated by the seaward extension of the array in the last two years. That extension presumably increased the numbers of calls detected relatively far offshore as compared with the numbers that would have been detected there had the 2001–2004 array design been used.

Calls tended to occur in "pulses" not only in time (see Fig. 5.6) but also in space (Fig. 5.16). In all years, the predominant offshore distances varied from day to day. For example, in 2004, most calls that were detected on 17 Sept. were 15 km or more or seaward of the baseline through Northstar, but several days later, beginning around 21 Sept., numerous calls were detected closer to shore, with some very close to the baseline through Northstar. Likewise, in 2003 and 2008, notable within-season variation in offshore distances is readily apparent. The clustering of calls in time and space is consistent with observations by researchers and native whalers (Braham et al. 1979; Würsig and Clark 1993; Chapter 7 of this report).

Analysis of the 2001–2004 call localization data indicated that within-season variation in offshore distances during those years was partly correlated with natural environmental factors such as date in the season, whether it was day or night, and the east–west position of the whales (McDonald et al. 2008; Richardson et al. 2008). However, those analyses also showed an apparent small effect of fluctuating Northstar sound levels on the offshore distances. The southern edge of the distribution of calls, as quantified by the 5th percentile of offshore distance, tended to be slightly farther offshore when Northstar sounds were stronger, and slightly closer to shore when they were weaker. Chapter 6 of this report examines whether similar effects were evident in 2009.

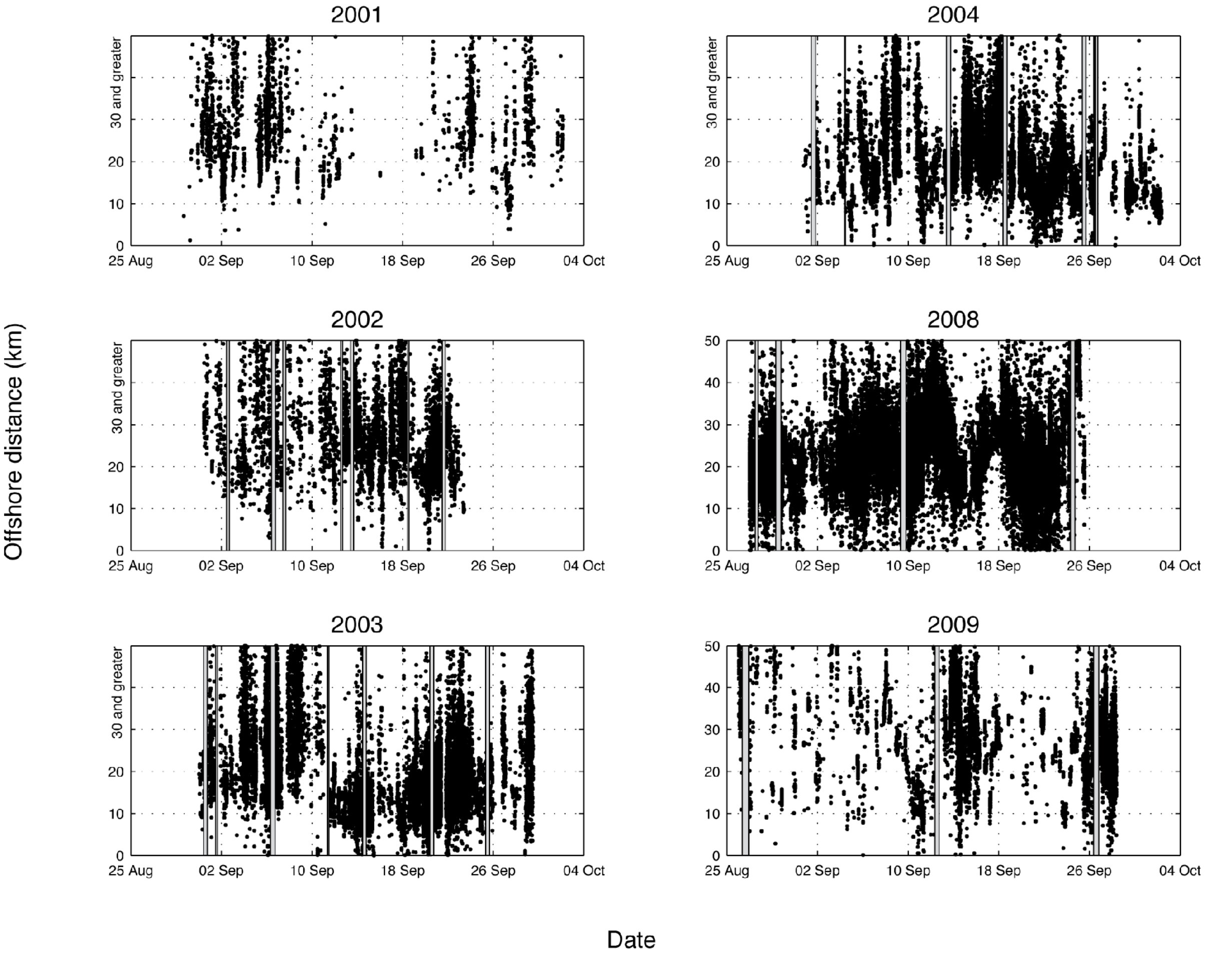


FIGURE 5.14. Offshore distance for each whale call with a location estimate, as a function of date, for the six monitoring seasons with a 10-DASAR array. Gray areas in the 2002–2009 plots delimit times excluded from the analysis because the service vessel was in the DASAR array. Date labels appear at the start of each day (00:00 AKDT). Call locations greater than ~10 km from the periphery of the array are imprecise. In 2001–2004, the array extended 21.5 km offshore and, in 2008–2009, the array extended 38.4 km offshore.

SUMMARY BULLETS

- The number of bowhead whale calls detected via the DASAR arrays varied substantially from year to year. The highest numbers of bowhead calls detected during the late summer/early autumn seasons were detected in 2003, 2004 and 2008, which were years with 10-DASAR arrays. The 2008 season was notable for having the highest number of call detections during the study, with 85,669 calls detected, an average of 2914 calls/day, and a peak hourly call detection rate of 627 calls on 20 Sept. of that year. For 2004, the total number of calls detected (66,232) was about 77.3% of that in 2008, but the daily call detection rate was 85.4% of that in 2008 given the shorter deployment period in 2004 compared to 2008. The 2003 season had fewer detected calls, both over the season and per day, compared with 2008 and 2004, but even so we detected 45,622 calls and 1501 calls per day on average.

- During other years with 10-DASAR arrays (2001, 2002, and 2009), the DASARs detected fewer calls, fewer average calls per day, and a lower maximum number of calls per hour. These lower call detection statistics most likely result from differences in (a) the arrays' spatial extent in 2001–2004 vs. 2008–2009, (b) operating durations, and (c) location of the whale migration corridor relative to the DASAR array configurations.
- In years with the fewest (three) DASAR locations, 2005 and 2006, the DASAR array detected the lowest total numbers of calls as well as the lowest daily and peak hourly numbers. The mean numbers of calls detected per day at location EB / C were also the lowest of the study's nine years. That suggests that the low call statistics in 2005 and 2006 were not simply due to fewer DASARs but also attributable to the location of the migration corridor relative to the DASAR array, high mean wind speeds (and thus high ambient noise), and possibly seasonal variability in calling rates.
- During the 2007 season, despite having DASARs at only four locations, the DASAR array detected 12,754 calls. The notably higher call counts in 2007 compared to 2005 and 2006 (with DASARs at 3 sites) may have been related to the absence of nearshore pack ice during the 2007 season, i.e., whales were likely swimming closer to shore due to the absence of ice near shore.
- For the three years (2003, 2004, and 2008) with the highest numbers of whale call detections, and also for 2002, the peak hourly and daily call detection rates, based on both all DASARs and EB / C alone, occurred during the 19–22 Sept. period. In all remaining years (2001, 2005–2007, and 2009), the maximum hourly call detection rate for the DASAR array as a whole and the maximum daily rate at EB / C occurred one to two weeks earlier.
- Call detection rate varied widely from year to year and from day to day within each season, fluctuating from 0 to over 600 calls per hour. This variation can be attributed to several factors including varying DASAR configurations and operating periods in different years, varying wind speeds (and thus ambient noise), and year-to-year differences in the timing and spatial extent of the bowhead migration relative to the DASAR array.
- Five bowhead call types were classified into two broad categories: complex calls and simple calls, with the latter category including upsweeps, downsweeps, constant calls, and undulations. The percentage use of call types varied from year to year, but the most common type of simple call was the upsweep, comprising 26% of all calls detected over the study's nine years. In 2001–2008, the four types of simple calls comprised, on average, 84% of call types detected. In 2009, complex calls accounted for a larger proportion of calls than in previous years (49%). Changes in the percentage use of different call types are difficult to interpret because little is known about the behavioral significance of specific types of bowhead calls.
- Bearings from location EB / C to bowhead calls detected by the DASAR at that site were estimated for all nine seasons (2001–2009). In 8 out of the 9 seasons, the average bearing to whale calls was northeast or east-northeast. In the remaining year (2005), the bearings were highly variable. The distribution of bearings in 2009, predominantly to the northeast, was very similar to the distribution in 2001, which was a year when the southern edge of the whale migration corridor was relatively far offshore. In contrast, the distribution of bearings in 2002–2004, 2007, and 2008 was mainly to the east of location EB / C.
- For the eight years of the study in which call locations were analyzed, more calls were detected east of the DASAR array than west of it. The preponderance of easterly bearings might indicate some influence of the Northstar Development on the whales, but directionality in the calls of the

predominantly westward-oriented bowheads apparently accounts for at least some of the effect. Based on data from 2008, bowhead calls were found to have higher received levels (on average) to the west than at a similar distance to the east of the whales. The lower number of calls detected to the west can be explained, at least in part, by call directionality.

- Localized whale calls provided considerable information about the distribution of calling bowhead whales over the continental shelf offshore of Northstar during late summer/early autumn. The distribution of calling whales was relatively far offshore in 2001, slightly closer to shore in 2002 and 2009, and notably closer to shore in 2003, 2004, and 2008. In addition, calls tended to occur in "pulses" in time and space. In all years, the predominant offshore distances varied from day to day. The clustering of calls in time and space is consistent with observations of "pulses" of whales by researchers and native whalers.
- In most years of the study, the distribution of detectable calls appeared to be broader (in the onshore–offshore dimension) west than east of the DASAR array. Aerial survey data suggest that, even before the existence of Northstar, the migration corridor tended to spread out west of the future Northstar location, suggesting that the "spreading out" phenomenon is not primarily, if at all, related to the Northstar Development. It may be relevant that the depth contours also become farther apart west of Northstar.
- In some of the years, including recent years (2008, 2009, and possibly 2007), the distribution of the detected bowhead calls within and near the DASAR array was "irregular", i.e., concentrations of bowhead calls were not all aligned roughly parallel to shore. In 2009, an unusual concentration of calls, not evident during any other year of the study, was detected east and northeast of the array. The origin and significance of these call concentrations are unknown.

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ANNEX 5.1: BEARING CALIBRATION ANALYSES

The acoustic data from a DASAR consist of three channels whose respective time series are combined to determine the direction of an incoming signal. When calibration signals are identified in the acoustic records (manually by an analyst for the 2001–2007 seasons and, since 2008, automatically using the matched filter method described in the previous chapter), the relative bearing of the DASAR to the known position of the calibration vessel can be obtained. This is accomplished for all six calibration stations around each DASAR, and the resulting reference bearing is then used to compute the actual bearing to a whale call, relative to true north. The procedure used for bearing calibration analyses is detailed below.

The acoustic data from a DASAR consist of three channels (omnidirectional, cosine directional, and sine directional):

$$I_{NS}(n) = cosch(n) \cdot omni(n) \qquad \text{Eq. (1)}$$

$$I_{EW}(n) = sinch(n) \cdot omni(n) \qquad \text{Eq. (2)}$$

Here, *cosch(n)* is the cosine directional channel time series, *sinch(n)* is the sine directional channel time series, and *omni(n)* is the omnidirectional channel time series. The two directional channels are oriented relative to the DASAR's orientation on the bottom. The *cosch(n)* and *sinch(n)* time series are proportional to particle velocity, and the *omni(n)* time series is proportional to acoustic pressure, so their products are proportional to acoustic intensity, *I(n),* a vector quantity with magnitude and direction. The direction, or bearing, is the measure of interest for calibration signals and other sound sources, for example, a whale call.

Figure 5.15 presents an example of a scatterplot in which the values of I_{NS} and I_{EW} for a specific sample define the location of a dot. The signed amplitude of $I_{NS}(n)$ is the y-coordinate and the signed amplitude of $I_{EW}(n)$ is the x-coordinate. The effect is to show a scattering of sample values that, collectively, show the direction from which the sound is arriving with respect to the reference axis direction of the DASAR on the ocean bottom. Were there no noise (no sound coming from anywhere other than the direction to the calibration sound transmitter), all the points would lie on a line indicating the direction to the source. The presence of background noise along with the calibration signal results in the variation in bearings.

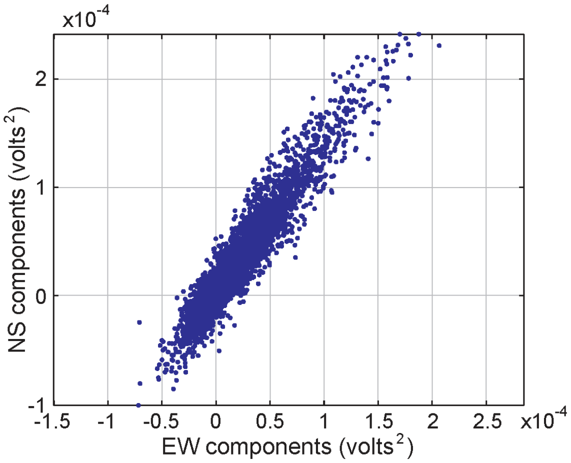

FIGURE 5.15. Example of a scatterplot illustrating the estimated bearing, B_{rel}, to a calibration signal relative to the DASAR's cosine axis. NS = north–south, and EW = east–west.

The bearing of a sound relative to the DASAR orientation is estimated by averaging the $I_{NS}(n)$ and the $I_{EW}(n)$ values determined for all the samples in the received calibration sound and taking the arctangent of their ratio

$$B_{rel} = \arctan\,[\mathrm{avg}\{I_{EW}(n)\}\ /\ \mathrm{avg}\{I_{NS}(n)\}] \qquad \text{Eq. (3)}$$

where avg denotes the average or mean intensity, arctan is the inverse tangent operation yielding results in the range of 0° to 360°, and B_{rel} is the estimated bearing of the sound source relative to the DASAR's cosine axis. In Figure 5.15, the measured B_{rel} is 33.2°.

The true bearing from the DASAR to the calibration source, Bgrd, is calculated directly from the known deployment locations of the DASARs and the known GPS positions of the calibration vessel. Examples of true bearings (B_{grd}) for a grid coordinate system, for 63 groups of calibration signals detected by one of the offshore DASARs, are depicted in Figure 5.16A. Figure 5.16B shows the same groups of calibration signals and their measured bearings, B_{rel}, relative to the DASAR's cosine axis, obtained from the scatterplots and methodology described in the previous paragraph. Note that the true bearings to the

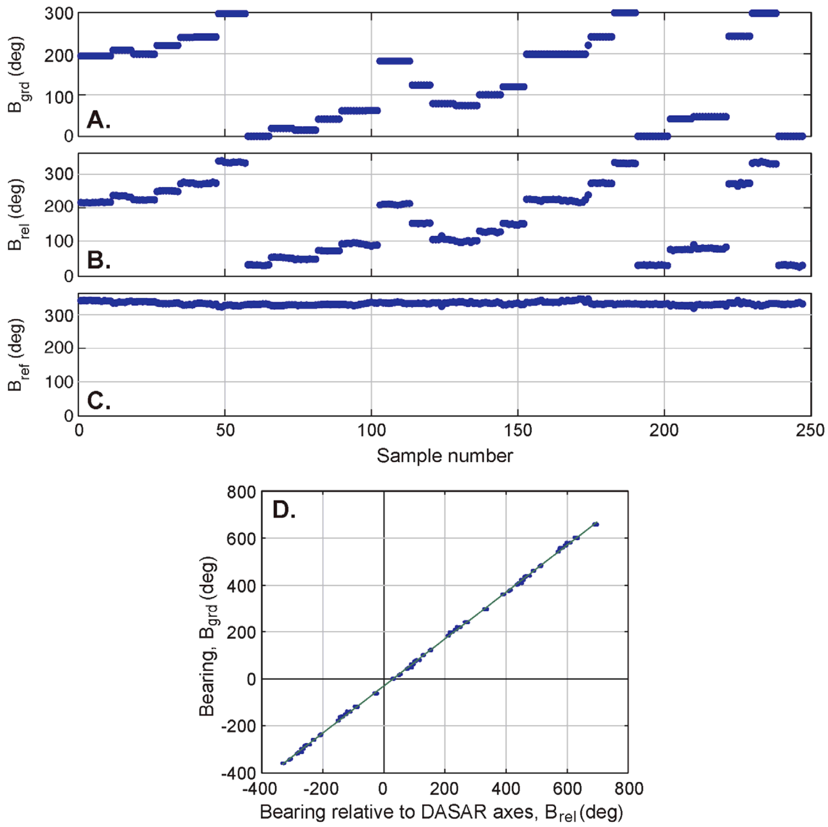

FIGURE 5.16. DASAR bearing calibration. ***(A)*** True bearings (or grid bearings), B_{grd}, from array DASAR D to the calibration source for 27 groups of calibration transmissions. ***(B)*** Measured relative bearings, B_{rel}, from the DASAR to the same calibration transmissions. ***(C)*** Resultant reference bearing, B_{ref}, used to translate estimated bearings received on and relative to the DASAR to bearings relative to true north (μ=329.9°, S.D.=4.5°, n=247). ***(D)*** A secondary method of estimating the reference bearing, B_{ref}, using a straight-line fit between B_{grd} and B_{ref}. Note that the slope of the line is unity, indicating directionally-unbiased sensors, and the y-intercept of the line yields an estimate of B_{ref} (-30.3° or, equivalently, 329.7°).

calibration source and their measured bearings relative to the DASAR share the same pattern and are simply offset by a constant bearing, an indication that there was no direction-dependent bias in the DASAR's bearing measurements, as expected for directional sensors with matched sensitivities (Greene et al. 2004). By subtracting B_{rel} from B_{grd}, one obtains B_{ref}, the reference bearing subsequently used to translate a measured bearing of a sound relative to the DASAR to a bearing relative to true north (Fig. 5.16C). For this example DASAR, B_{ref} is estimated to have a mean value of 329.9° with a standard deviation of 4.45°.

The fact that B_{ref} is a constant, with the same value regardless of the source's bearing, is also verified by the fact that a straight line with slope 1 fits a plot of B_{grd} vs. B_{ref}. A close fit and slope of 1.0 are indicative of directionally-unbiased sensors. The line's y-intercept yields the estimate of B_{ref}. An example of this for one DASAR is shown in Figure 5.16D. Using this alternative approach, B_{ref} was estimated to be 329.7°. In practice, the former method was used to estimate B_{ref} since it provides additional quantitative statistics describing the quality of the estimate, such as its variability (standard deviation) and the number of samples used in the estimate.

ANNEX 5.2: DIRECTIONALITY IN THE CALLS OF BOWHEAD WHALES *

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When an animal vocalization shows directionality, or directivity, it radiates more strongly in some directions than others. Directionality in acoustic signals has been shown across many taxa, from insects to higher vertebrates (e.g., Miller 2002) including humans (Dunn and Farnsworth 1939). Some species possess calls with differing levels of directionality, and use them in context-dependent fashion (e.g., Larsen and Dabelsteen 1990, Patricelli et al. 2007, Bernal et al. 2009, Yorzinski and Patricelli 2010). It makes evolutionary sense, for example, that alarm calls would lack directionality if a calling bird does not wish to reveal its location to a predator (Yorzinski and Patricelli 2010). Directionality in acoustic signals is particularly well-suited for echolocating animals, as it increases the signal-to-noise ratio of returning echoes, and therefore increases the efficiency and accuracy of the system (Au 1993). Strong directionality of echolocation signals has indeed been shown in bats (*e.g.*, Simmons 1969, Surlykke *et al.* 2009) and odontocetes (Møhl *et al.* 2000; Au *et al.* 1987, 1995; Au 1993). Among mysticetes, Clark *et al.* (1986) investigated the directionality of two types of calls (upcalls and downcalls) from bowhead whales (*Balaena mysticetus*) during the spring migration off Barrow, Alaska. They found that calls were slightly stronger ahead of the animals. Au *et al.* (2006) used a vertical array to describe the acoustic properties of singing humpback whales (*Megaptera novaeangliae*) in Hawaii, and reported directivity in certain types of song units, but the trend was not quantified.

Since 2000, we have investigated the effects of sounds emanating from oil production operations on an artificial island (Northstar) offshore of Prudhoe Bay, Alaska, on bowhead whale migration and calling behavior (Blackwell *et al.* 2007, McDonald *et al.* in review). Each year, from late August to late September, an array of Directional Autonomous Seafloor Acoustic Recorders (DASARs, see Greene *et al.* 2004) was placed on the seafloor offshore of Northstar. The methodology and basic results for 2001–2004 are presented in Blackwell *et al.* (2007). Thousands or tens of thousands of bowhead calls were recorded yearly, and the locations of the calling animals were estimated by triangulation for 72–86% of the calls each year. Because the estimated locations of bowhead calls were the primary data during the study of Northstar effects, understanding the nature of the calls is important in interpreting results. For example, for all years of the study in which call locations were computed (2001–2004 and 2006–2009), more calls were detected east of the array than west of it, as shown in Figure 1 for 2008. This could be due to several reasons, including geographic differences in calling behavior and location-specific propagation effects. It could also be due to directionality in the whales' calls.

Mysticetes do not have vocal cords in their respiratory system, so the anatomical site of sound production has been unknown (Haldiman and Tarpley 1993). However, a vocal fold homolog that could serve as a low frequency sound source was recently discovered in six species of mysticetes (Reidenberg and Laitman 2007, 2010). During autumn migration, bowhead whales tend to travel west-northwestward, parallel to the north shore of Alaska (Moore and Reeves 1993; Figure 1). If we hypothesize, for the sake of this investigation, that whatever the sound source in the body, sound production is directional and stronger ahead of the whales, then calls would tend to be weaker behind the migrating whales. Since weaker calls have a lower probability of detection by the recorders, the call distribution would show a skew such as the one shown in Figure 1, with more calls detected to the east of the array of recorders, upon the migrating whales' approach.

The main objective of this paper is to determine whether bowhead whale calls are directional, at least in the roughly two-dimensional (horizontal) space that our array of seafloor recorders enables us to investigate. We compared the received levels (RLs) of calls at DASARs located WNW vs. ESE of calling whales, *i.e.*, "ahead" vs. "behind", assuming most whales were oriented approximately WNW during their migration. To allow for the possibility that an omnidirectional call might appear directional because of differences in westward vs. eastward acoustic propagation effects, we also measured and

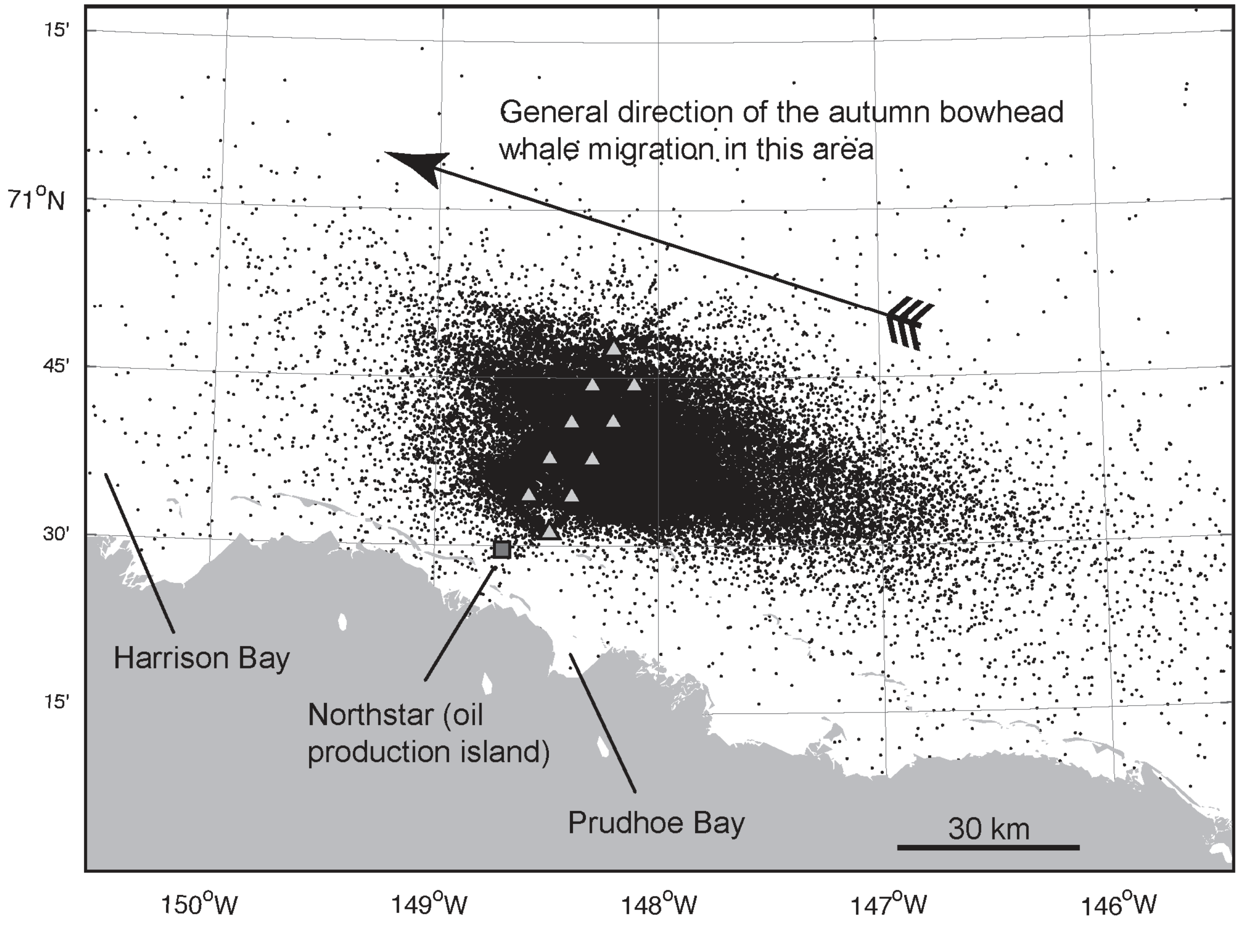

FIGURE 1: Estimated locations of 58,243 whale calls detected in 2008, in relation to the DASAR array (10 light gray triangles) and Northstar (gray square). Estimated distances of calls from the DASAR array become increasingly uncertain as distance from array increases beyond *ca.* 5–7 km from the periphery of the array, but bearings from array remain reliable (Greene *et al.* 2004).

analyzed the levels of omnidirectional sound transmissions at the same DASARs. Specifically, we determined whether whale calls showed a greater tendency than omnidirectional sounds to be received at higher level WNW vs. ESE of the source locations.

DASARs were deployed on the seafloor from 27 August to 25 September 2008, in the configuration shown in Figures 1 and 2. Water depth at DASAR locations was 15–38 m. The sensitivity of the omnidirectional hydrophone in each DASAR was measured prior to deployment. Omnidirectional sound projections were used to calibrate the recorders' clocks and reference bearings (Greene *et al.* 2004, Blackwell *et al.* 2007). These calibration transmissions, projected from a J9 transducer at locations surrounding each DASAR, were a combination of tones and sweeps with frequencies in the range 200–400 Hz (source level = 150 dB re 1 μPa·m). The frequency range of these transmissions was within that of bowhead whale calls (Ljungblad *et al.* 1982, Clark and Johnson 1984, Würsig and Clark 1993), and the source level was toward the low end of the range of typical source levels for bowhead calls (Cummings and Holliday 1987). At each calibration station (Figure 2), an average of 10 calibration transmissions (each 8 s long) were projected over a period of ~2 min. The GPS position was recorded automatically for each transmission. Calibrations were performed on three days: after DASAR deployment, in mid-season, and before DASAR retrieval.

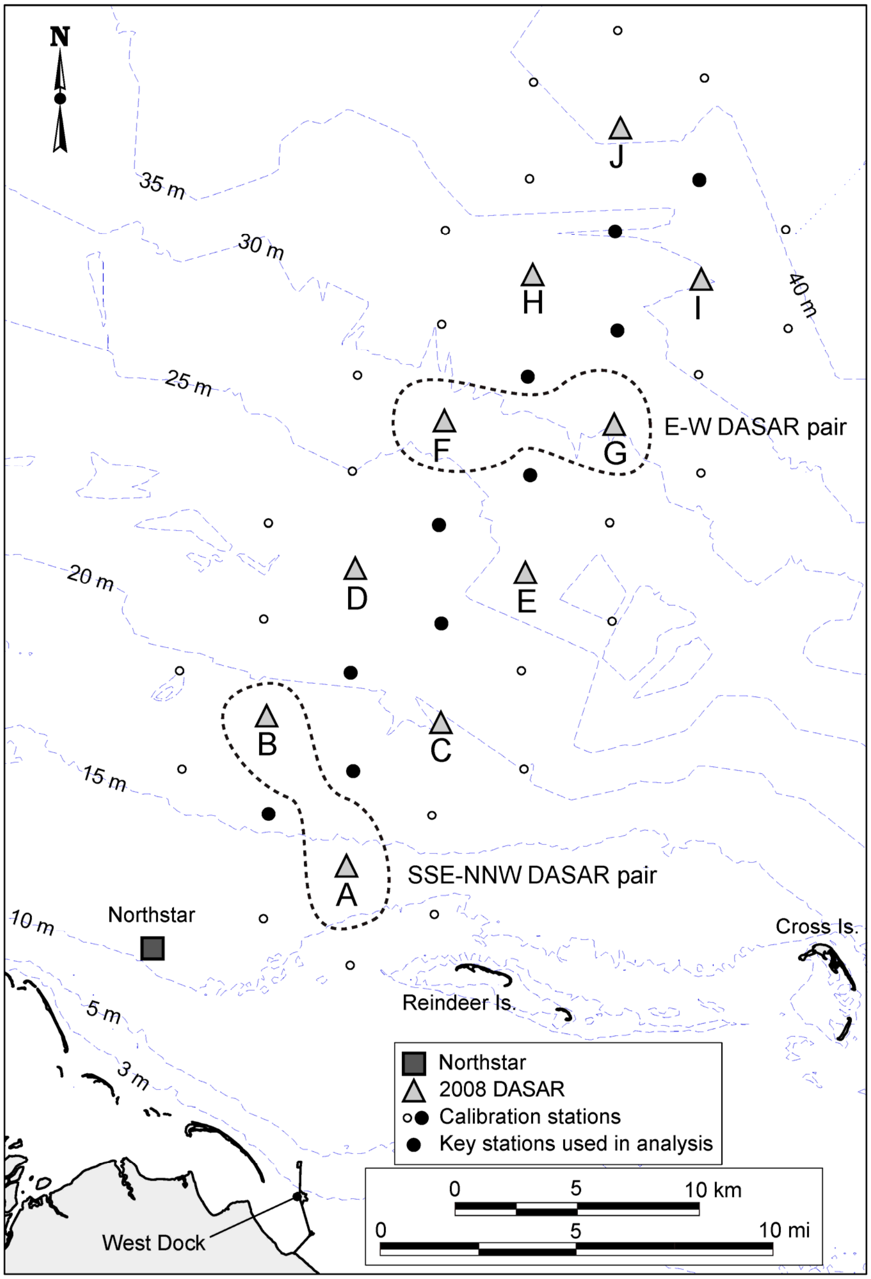

FIGURE 2: Northstar array of DASARs (triangles) as deployed in 2008, plus locations of calibration stations (dots) including "key" calibration stations (black dots) for the present analysis. DASARs (labeled A–J) were deployed at the vertices of equilateral triangles with 7 km sides. Whale calls were matched to calibration transmissions projected from key stations located midway between pairs of DASARs placed E–W of each other (*e.g.*, F and G) or SSE–NNW of each other (*e.g.*, A and B).

Calibration transmissions used in testing for call directionality were a subset of all calibration transmissions, and involved those projected from 10 "key" stations evenly spaced between DASARs. These key stations, shown in Figure 2, were equidistant between pairs of DASARs placed E–W of each other (*i.e.*, DASARs C–B, E–D, G–F, and I–H) or SSE–NNW of each other (*i.e.*, DASARs A–B, C–D, E–F, G–H, and I–J). Distance from each calibration station to the two nearest recorders was *ca.* 4 km, and calibration sounds were received on both members of the E–W and SSE–NNW DASAR pairs. There were ~300 calibration transmissions from the key stations used to test directionality (10 stations × 10 transmissions/station × 3 calibration dates).

The 2008 call data set included 58,243 localized bowhead calls. Calls near key calibration stations were likely to be received on both members of the adjacent E–W or SSE–NNW DASAR pair. We aimed to compare the difference in RLs of whale calls at the westward and eastward DASARs ("ahead" versus "behind" typical migrating whales) relative to the corresponding differences for calibration sounds known to be omnidirectional. Therefore, we sought whale calls and calibration transmissions near one another in order to apply a matched-pair paradigm to control for possible differences in propagation that might be caused by unknown waveguide environmental characteristics. To do this, we matched each of the 300 relevant calibration transmissions to the geographically closest whale call detected and localized over the entire 2008 field season, provided the two were less than 200 m from each other. Each whale call was matched to only one transmission, and vice versa. This resulted in 43 paired whale calls and calibration transmissions between adjacent E–W DASARs, and 40 pairs between adjacent SSE–NNW DASARs. The whale call–calibration transmission pairs were located midway between the DASAR pairs: the mean distance between DASAR and calibration transmission was 4054 m, whereas that between DASAR and whale call was 4051 m ($n = 129 = (2\times43) + (2\times40) - 37$, where 37 is the number of pairs that were used in both an E–W and SSE–NNW comparison).

RLs of each selected whale call and paired calibration transmission were determined from the sound records of both members of the relevant DASAR pair. Calibration transmissions were analyzed over their entire duration and frequency range (*i.e.*, 8 s and 200–400 Hz). Whale calls varied in duration and frequency range, so for a given call, the RLs at all DASARs that detected a particular call were determined over the same duration and frequency range.

To test for directionality of the whale calls, we computed

$$\Delta RL = (RL_{Wwc} - RL_{Ewc}) - (RL_{Wct} - RL_{Ect}) \tag{1}$$

for each matched whale call / calibration transmission pair, where RL is the received level of the whale call ($_{wc}$) and calibration transmission ($_{ct}$), respectively, at either the westernmost DASAR ($_{W}$) or easternmost DASAR ($_{E}$) of a pair. For example, RL_{Wwc} is the received level of a whale call at the westernmost DASAR. In the absence of any directionality we would expect the quantities in the two sets of parentheses of equation (1) to be equal and, thus, $\Delta RL = 0$. In the presence of directionality resulting from a physical phenomenon affecting propagation (*e.g.*, seafloor composition), such a propagation effect would act equally on both calibration transmissions and whale calls, in which case we would expect the two parenthetical values to be similar and, again, $\Delta RL = 0$. Similarly, differences in the source levels of calibration transmissions and whale calls are eliminated by the differencing in both sets of parentheses, again yielding $\Delta RL = 0$. If whale calls are forward–directional, RLs should be higher at the DASAR "ahead" of the whale than at the DASAR "behind" the whale. Assuming that a considerable majority of whales detected during the study period were oriented approximately westward on migration (see below), we would expect that, on average, ΔRL would be positive.

There is evidence, based on aerial surveys, that during the month of September the majority of bowhead whales off northern Alaska are heading roughly westward during their migration. Miller *et al.* (1996) compiled the headings of 72 groups of swimming (=traveling) and 38 groups of "non-swimming" bowheads, sighted during aerial surveys by the U.S. Minerals Management Service and LGL Ltd. in 1979–1994 and covering the longitude range 147°–150° W (Northstar is at longitude 148.7° W). They

TABLE 1: Results from one-sample *t*-tests comparing the differences in levels of received whale calls and calibration transmissions at pairs of DASARs located either E–W or SSE–NNW of each other. See text for more details.

DASAR pairs:	E–W	SSE–NNW
t-statistic	3.6404	3.7889
df	42	39
p-value	0.0003701	0.0002559
95% lower limit for ΔRL	2.120647	1.818667
Mean of ΔRL (dB)	3.942	3.275
Mean of whale call differences (dB)	4.79	4.19
Mean of calibration transmission differences (dB)	0.85	0.92

report that 60% of swimming whales were heading to the W or NW. The vector mean heading for all groups of swimming whales was 276°T (true) and the angular deviation was 44° (Batschelet 1981). Headings of non-swimming whales were also westerly on average (vector mean heading 283°T), with somewhat more variability (angular deviation 52°).

We tested the null hypothesis that the true average ΔRL was less than or equal to 0 using two one-sided, one-sample Student's t-tests. The first test utilized RLs on DASARs positioned E–W relative to one another. The second test utilized RLs on DASARs positioned SSE–NNW of one another. The alternative hypothesis for both of these tests was that ΔRL exceeded 0, which (if correct) would imply directionality of the whale calls.

This analysis showed that on average, bowhead whale calls are directional. RLs of whale calls were, on average, 4.8 dB and 4.2 dB higher W and NNW of the whale call location, respectively, than they were a corresponding distance E or SSE of it (Table 1, Figures 3A and 4A). In contrast, the distribution of ΔRL values for the calibration transmissions was narrower, symmetric, and centered near 0 (Table 1; Figures 3B and 4B), as expected for omnidirectional signals. Bowhead whale calls were significantly stronger at the western member of E–W DASAR pairs, and at the NNW member of SSW–NNW DASAR pairs, than expected based on the RLs of omnidirectional calibration transmissions (p=0.0004 for E–W pairs; p=0.0003 for SSW–NNW pairs). On average, whale calls were 3.9 dB (95% lower limit=2.1 dB) and 3.3 dB (95% lower limit=1.8 dB) stronger to the W and NNW, respectively, than expected based on an omnidirectional source (Figures 3C and 4C). It is unlikely that all whales were oriented to the WNW, so the actual average directionality was probably greater than calculated here.

Notwithstanding any selective pressures for the evolution of directionality in calls (as for example in songbirds with high predation pressures, *e.g.*, Witkin 1977, Klump and Shalter 1984, Dantzker *et al.* 1999, Yorzinski and Patricelli 2010), directionality in acoustic signals could be the result of the whale's lungs causing a shadowing effect (Schnitzler and Grinnell 1977). In a bowhead whale, the long axis of each lung is largely horizontal, but the diaphragm slopes upward from front to back. In other words, the lungs are thicker at the front and taper to be thinner and more dorsal at the back[2]. If the location of sound production in mysticetes is the vocal fold homolog described by Reidenberg and Laitman (2007), then the lungs would be at least in part behind this structure.

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[2] Pers. comm., J. S. Reidenberg, Center for Anatomy and Functional Morphology, Mount Sinai School of Medicine, New York, NY, March 2010.

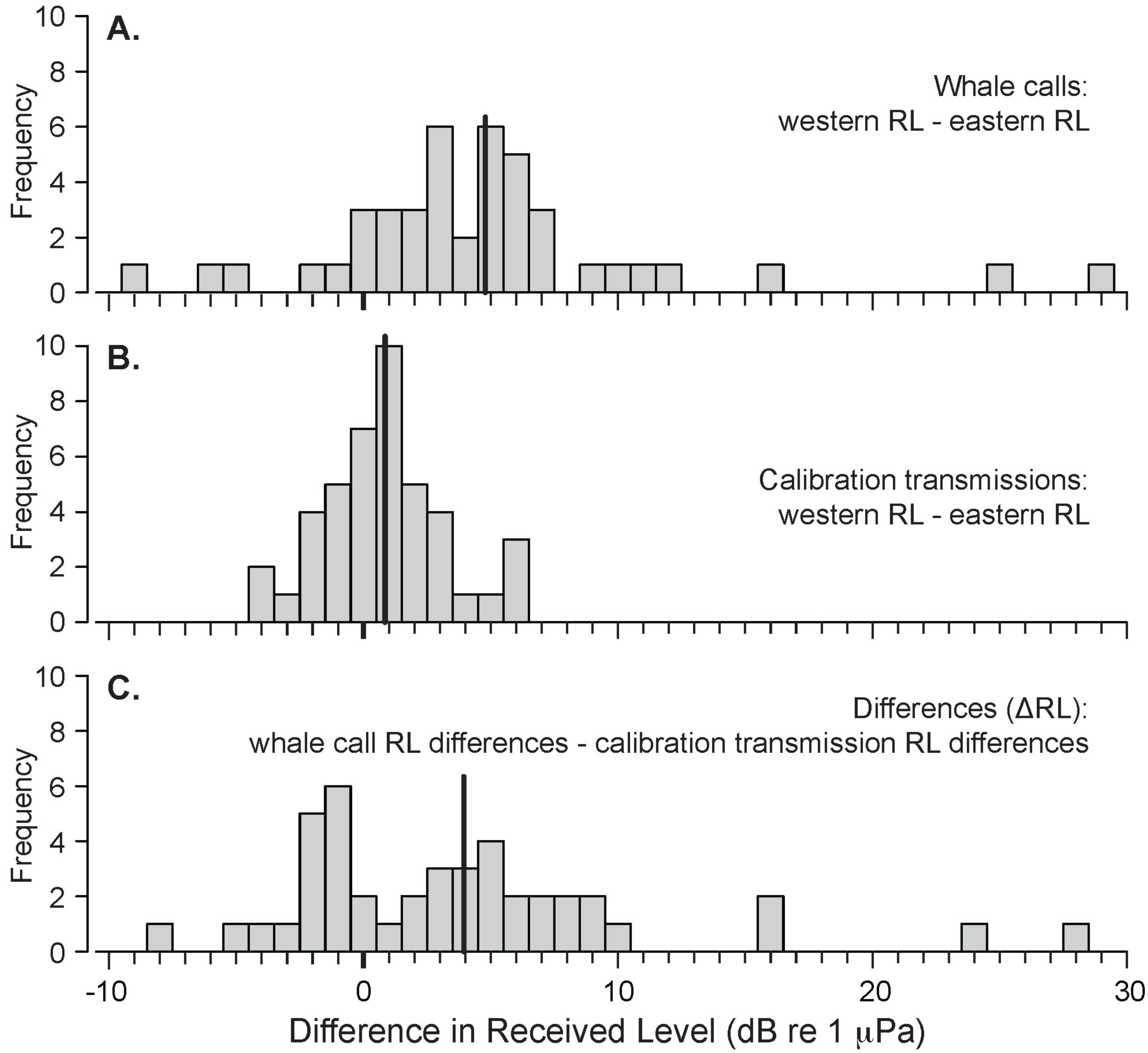

FIGURE 3: Differences in received levels at pairs of DASARs located E–W of each other (*n*=43), for ***(A)*** bowhead calls and ***(B)*** calibration signals. ***(C)*** Differences of differences, *i.e.*, the values of ΔRL, see text for details. Means are shown with thick black lines (see Table 1 for numerical data).

The effects of air bubbles on propagation of sound through water have been studied extensively (Kinsler *et al.* 1982, Urick 1983, Clay and Medwin 1977). When air bubbles have a resonant frequency matching the frequency of a sound signal, the bubble is a strong scatterer and absorber of acoustic energy. A bubble's resonant frequency is a function of the size of the bubble and its depth below the surface (Urick 1983). For example, at a depth of 18 m the resonant frequencies for bubbles with diameters 1 m and 0.1 m are 5.4 Hz and 54 Hz, respectively. These frequencies are at the lower end of the frequency range for bowhead vocalizations (25–3500 Hz, Richardson *et al.* 1995). At the resonant frequency, maximum transfer of sound energy from the water to the bubble occurs, and consequently transmission loss in the propagation direction of the sound (from the source) will be maximized. Modeling this transmission loss would be complex, as bowhead lungs are far from spherical, they change shape through time and space as the animal changes depth in the water column, and bowheads vocalize at a range of frequencies. Nevertheless, the fact

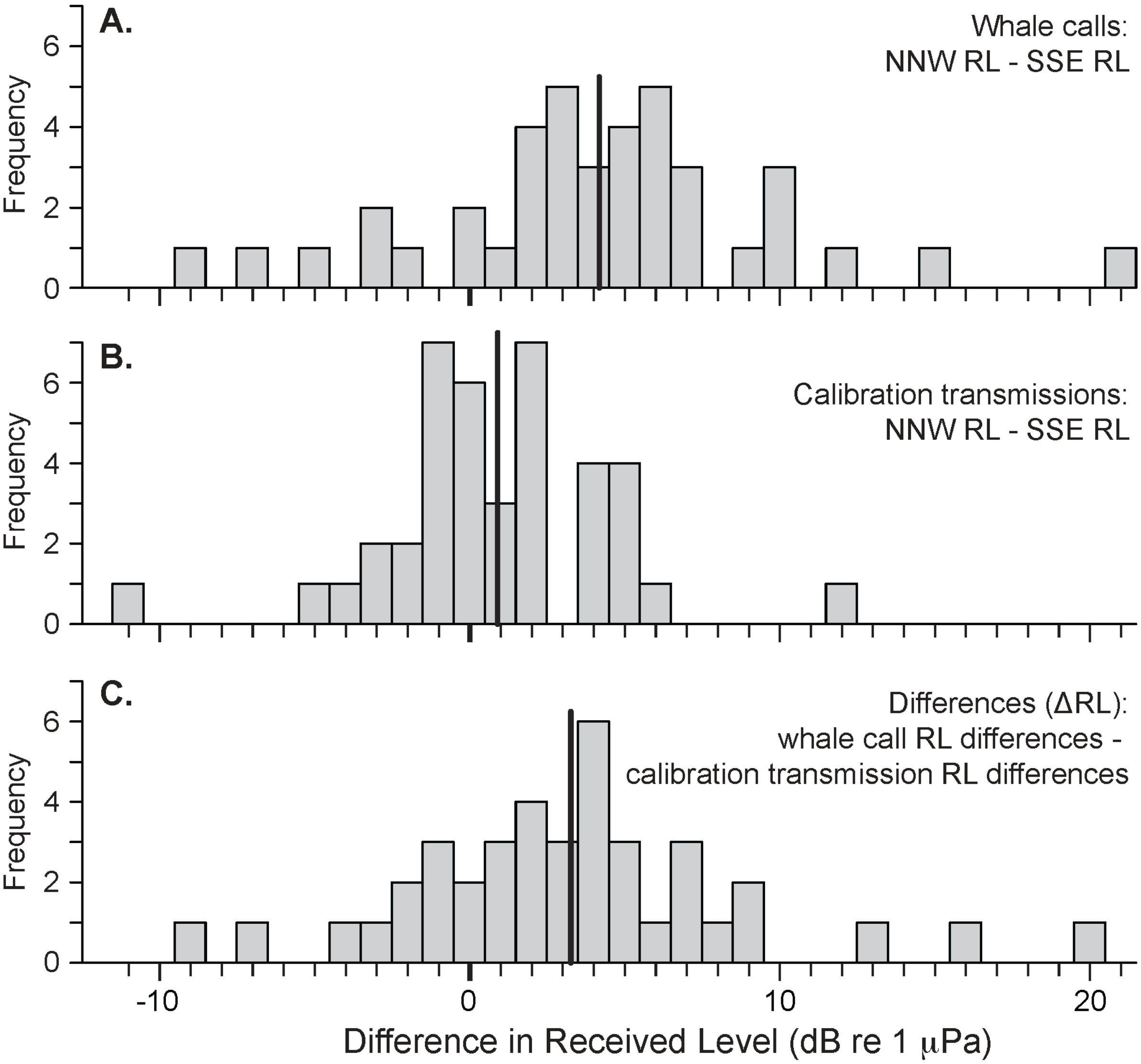

FIGURE 4: Differences in received levels at pairs of DASARs located SSE–NNW of each other (*n*=40), for ***(A)*** bowhead calls and ***(B)*** calibration signals. ***(C)*** Differences of differences, *i.e.*, the values of ΔRL, see text for details. Means are shown with thick black lines (see Table 1 for numerical data).

that sound exciting an air bubble loses energy suggests that the RL of sounds that encounter the air cavities of a whale will be lower than the RL of those sounds that do not. In addition, acoustic impedance differences introduced by an air cavity in the propagation path can result in energy loss. Therefore, the effect of the whale's air cavities on transmission of sound likely accounts for much of the 3.5–4 dB difference between average RLs of bowhead calls in the forward and backward directions.

The above results have implications for studies that rely on vocalizations to study the movements or behavior of whales. Directionality of calls affects the detectability of calls by seafloor recorders, based on whether the recorder is in front of or behind the whale. Unequal detectability in different directions, in turn, will influence the apparent geographic distribution of calls and should therefore be taken into account. Consider the following example: assume a westward-facing bowhead whale calls with a source level of 160 dB re 1 μPa·m (Cummings and Holliday 1987), and propagation loss north of Northstar at relevant frequencies is ~15 dB / tenfold change in distance (Blackwell and Greene 2006). Under these assumptions and using the observed average difference in RL for E–W DASARs (3.9 dB), the distance to a particular RL (and thus, a particular signal-to-noise ratio) will be about 1.8 times greater in front of the whale than behind. In other words, a call that is detectable 18 km in front of the whale will only be detectable (on average) to 10 km behind the whale. Given the aforementioned expectation that average directionality was underestimated because of variability in whale headings, the actual average difference in fore vs. aft detection ranges would probably exceed 1.8 ×. The ratio of the number of calls detected east versus west of the array (E/W ratio) in Figure 1 is 2.1. Ratios for data collected in 2001, 2002, 2003, and 2004 and shown in Blackwell *et al.* (2007) are 3.2, 1.5, 1.7, and 1.8, respectively. For 2009 (data not shown), the ratio was highest at 3.3.

The variability in these E/W ratios across years could be due to several factors that are worth mentioning. First, the directionality of a signal may vary across frequencies. In other words, some parts of a call could be more directional than others, whereas in this study we looked at the directionality of calls as a whole. Second, there is well-known differential propagation of frequencies as a function of water depth. These two factors combined could lead to different E/W ratios for arrays located in different water depths. Third, aerial surveys have shown that during the fall migration across the Alaskan Beaufort Sea, steady westward travel can alternate with periods of feeding, sometimes in localized feeding areas (Ljungblad *et al.,* 1986, Landino *et al.,* 1994). During these times the whales would be oriented more or less randomly and calls recorded at a nearby array would not be expected to show any directionality.

In conclusion, this study showed a directionality in bowhead calls as received on an array of DASARs. This directionality was assessed in one dimension (forward vs. behind), *i.e.,* no attempt was made to investigate more complex directionality patterns occurring to the sides of the animals or below / above a calling whale. The directionality of calls should be accounted for in studies that rely on data from bowhead vocalizations. As calls from other mysticete species may be directional as well, this factor should also be considered during acoustic monitoring of those species. For certain cases, such as animals moving in random directions, directionality may not play a critical role as it may average out. In other cases, the directionality of calls can be an important factor, for example, if the study requires determining a probability of detection. We recommend limiting the study area in such cases to relatively small areas with a high probability of detection despite call directionality effects. A detailed study of the probability of detection (*e.g.*, using regression models) that directly accounts for directionality and other factors is a reasonable path in these cases.

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CHAPTER 6:

DISTRIBUTION OF CALLING BOWHEAD WHALES EXPOSED TO UNDERWATER SOUNDS FROM NORTHSTAR AND DISTANT SEISMIC SURVEYS, 2009 [1]

by

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ABSTRACT

This chapter describes an analysis designed to detect effects of underwater sound produced by Northstar Island and its support vessels on the distribution of calling bowhead whales (*Balaena mysticetus*) during their westward autumn migration in 2009. This analysis builds on past analyses of similar 2001–2004 data. Underwater sound levels were measured both near the source and offshore near the southern edge of the migration corridor. Locations of calling whales were determined by a seafloor array of directional acoustic recorders. Weighted quantile regression (QR) was used to relate the 5th quantile of offshore distance (a measure of the southern edge of the call distribution) to varying levels of industrial sounds near and offshore of Northstar, and to measures of airgun pulses from distant seismic exploration. Weights in the primary QR were inversely proportional to estimated location uncertainty and probability of including a call in our data set. To overcome lack of independence among calls, block permutation of uncorrelated call clusters was used to assign significance levels to coefficients in the QR model. Normal within-season variation in the migration corridor's apparent southern edge was accommodated by considering day–night changes, distance of the call east or west of Northstar, and date as covariates. Occurrence and received levels of weak airgun pulses from seismic surveys occurring intermittently >200 km (>320 mi) to the east and north were also considered as covariates. Data were collected from 26 August to 28 September 2009, during which time there were 11,263 usable calls.

Based on the primary analysis, the apparent southern edge of the distribution of calling whales was significantly ($P = 0.011$) closer to shore when underwater sound measured near the southern edge of the overall 2009 call distribution included transients in the 10–450 Hz band during the 75 minute period just prior to the call. The southern edge of the distribution of calling whales was an estimated 1.82 km or 1.13 mi (95% confidence interval 0.72 to 2.77 km) closer to shore when transients were detected offshore than without. That measure of industry sound was a better predictor of the southern edge of the call distribution than was any measure of sound near Northstar itself, and the analysis was structured to allow only one such variable to enter the model. In addition, when received levels of airgun pulses from seismic exploration far to the east of Northstar were above background, the apparent southern edge of the call distribution was another 0.68 km or 0.42 mi (95% CI 0.37 to 0.93 km; $P < 0.001$) closer to shore for every 1 dB increase in received airgun pulse level.

Sensitivity analyses revealed that the measure of Northstar sound most closely associated with the southern edge of call distribution, and possibly even the direction of the apparent effect, depended on analysis decisions and assumptions, including the order in which variables were considered and decisions about case weighting. With one exception, alternative methods of model selection and weighting (like the primary analysis) estimated the southern edge of the call distribution to be *closer* to shore when sound variables associated with Northstar were elevated. However, the specific measure of industrial sound most closely related to call distribution varied among analyses.

Although not specifically designed to characterize effects of airgun pulses on bowhead whale behavior, the primary analysis and all but one sensitivity analysis suggested that the calls nearest to shore tended to be *closer* to shore with increasing received levels of airgun sound arriving from the east. This trend is especially noteworthy as the seismic operation to the east was in Canadian waters, hundreds of kilometers away.

The results for 2009 differ from those obtained during 2001–2004, when the southern edge of the call distribution tended to be farther offshore when anthropogenic sounds, as measured near Northstar, were elevated. Also, sensitivity analyses showed that 2001–2004 results were largely insensitive to weighting and other analysis decisions, although fewer covariates were considered and the order of model selection was not tested in 2001–2004 studies. Reasons for the differences between 2009 and 2001–2004 (and among alternative 2009 analyses) are speculative. In any case, for 2009, we could not conclusively identify one specific relationship between offshore distances of bowhead whale calls and industrial sound.

INTRODUCTION

In early 2000, a man-made oil production island named Northstar Island was constructed in 12 m of water *ca.* 10 km offshore and 20 km west of Prudhoe Bay, Alaska, in the Beaufort Sea (Fig. 6.1). In late summer and autumn each year, bowhead whales migrate west-northwest past the island on their way to over-wintering habitat in the Bering Sea (Moore and Reeves 1993; Treacy et al. 2006). During active migration, bowheads travel roughly parallel to shore at highly variable offshore distances (Fig. 6.1; Moore 2000; Treacy et al. 2006). The whales closest to shore pass within several kilometers of the island during at least some years (Moore and Reeves 1993; Chapter 5 of this report). When whales are within several kilometers of Northstar Island, they could be exposed to underwater industrial sounds, especially during periods of high sound production at the island or of low ambient noise (Chapter 4; also Blackwell and Greene 2006). Underwater noise from certain oil-industry activities is known to deflect some migrating whales (Richardson et al. 1995b). Because of this, and the bowhead's protected status and importance to subsistence hunters, the migration corridor has been monitored annually since Northstar construction began in 2000. Specifically, monitoring was designed to detect any Northstar-related change in the distribution of bowhead whale calls, and if present, quantify it insofar as possible. This monitoring, in part, addressed concerns of subsistence whale hunters based at Cross Island (27 km east of Northstar; Fig. 6.1) that their hunt for bowheads would be impaired and more risky if there is offshore displacement of the whales migrating closest to shore.

Previous studies of whale deflection at other locations have focused on detecting deflection of individuals (e.g., Malme and Miles 1985; Richardson et al. 1985, 1995b, 1999; Croll et al. 2001). Some of these studies tracked individual whales, usually by visual means, as they passed the sound source, or as the sound source passed the whales. By comparing tracks with and without the sound emanating from the source, these studies sought to assess deflection. However, sample sizes were usually low due to the difficulties in following individual whales, inability to observe visually at night, weather limitations, etc.

Bowhead whales call frequently during both spring and autumn migration (Clark et al. 1986; Moore et al. 1989). An approach utilizing continuous acoustic monitoring methods was tested in 2000 and became operational in 2001 near Northstar Island; this, in conjunction with a new application of quantile regression analysis (Koenker 2005), provided a method to assess whether and to what degree changes in the call distribution were related to fluctuations in underwater sounds associated with Northstar activities. These studies were repeated annually from 2001 through 2004 (McDonald et al. 2008, in review; Richardson et al. 2008). In each year, various indices of anthropogenic sound measured near the island were associated with an offshore shift in the distribution of calls. In 2001, the strongest anthropogenic predictor of offshore distance was a measure of sound level in the 28–90 Hz range. In 2002, the strongest anthropogenic sound predictor was the presence of transients (often associated with boats) near the island. In both 2003 and 2004, the strongest anthropogenic sound predictor was the presence of tones near the island. Analytical methods developed during processing of the 2001–2004 call data provide ways of addressing the lack of independence among calls and the effects of naturally varying cofactors (McDonald et al. 2008, in review).

Our objective in this chapter is to re-apply the previous analysis approach, as closely as possible, to new data collected during autumn 2009. As in the past, the main objective of this analysis is to detect and quantify changes in the distribution of calls northeast of Northstar during the autumn migration season, after allowing for natural factors. Offshore distances to call locations were, as for 2001–2004, computed using data from 10 Directional Autonomous Seafloor Acoustic Recorders (DASARs), but the arrangement of DASARs extended farther offshore than in the past. Greene et al. (2004) described the methods used to detect and locate bowhead whale calls, and to estimate the accuracy of those call positions. Blackwell et al. (2007) described the characteristics of the calls, and of the 2001–2004 autumn

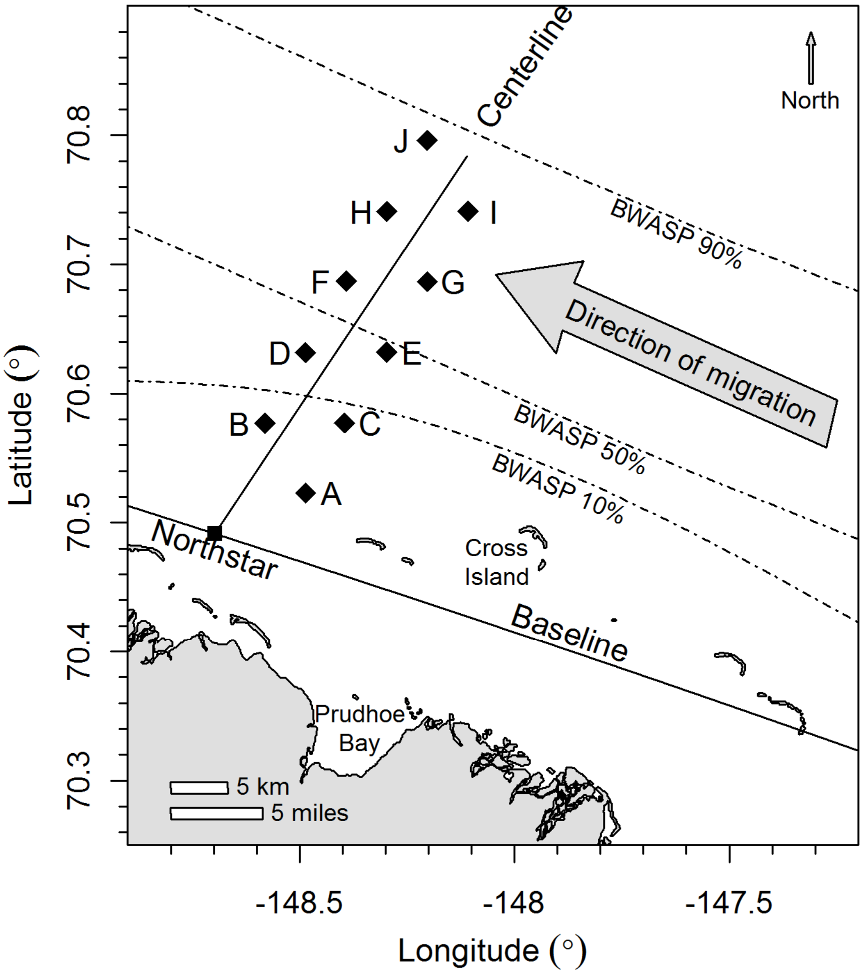

FIGURE 6.1. Study area location in northern Alaska near Prudhoe Bay and Cross Island, showing the main autumn migration direction of bowhead whales. DASAR locations A through J (diamonds) were located northeast of the Northstar Island oil development (square). The WNW–ESE line through Northstar ("Baseline") is the line from which perpendicular "offshore distances" were measured. The NE–SW line through the array shows the "centerline" for the study, which was established in 2001. The centerline runs from Northstar through the position of the center of the DASAR array as deployed in 2001 (location "CBa"). The "centerline" was used to calculate several study covariates. Dotted and dashed lines show historical position of the bowhead migration corridor as estimated by the 10th, 50th, and 90th percentiles of offshore distances of bowhead whale observations during the Bowhead Whale Aerial Survey Program (BWASP, e.g., Monnett and Treacy 2005). Ten percent, 50% and 90% of all BWASP bowhead observations during the low-ice years of 1998–2004, 2007, and 2008 were shoreward of the designated BWASP curves.

migrations as evident from calls. The bowhead migration in 2009 (and in 2001–2008) was described in Chapter 5 of this report, and Chapter 7 provides additional information about those migrations from the perspective of the subsistence whalers based at Cross Island, 27 km (17 mi) east of Northstar.

During late summer/early autumn 2008, a dataset similar to that for 2009 was acquired. The 2008 data have not been analyzed in the manner described here. During the study period in 2008, there were several seismic survey programs operating in various directions from Northstar (Chapter 4). As seismic surveys are known to influence the distribution and probably the calling behavior of migrating bowheads (e.g., Greene et al. 1999a,b; Miller et al. 1999; Blackwell et al. 2009), and Northstar effects in previous years were relatively subtle (Richardson et al. 2008), we expected that Northstar effects might be difficult to discern in 2008. Consequently, BP, NMFS and stakeholders agreed to collect a similar dataset in 2009 (when less seismic survey activity was expected), and to examine the 2009 data in detail looking for Northstar effects.

Prior to 2000, there was evidence that industrial sounds do not propagate efficiently through gravel islands into the shallow waters of the Beaufort Sea (Richardson et al. 1995b, p. 127–130). As a result, underwater industrial sounds offshore of Northstar were not expected to be especially strong. However, vessels supporting Northstar were expected to introduce sound into the sea. Low-frequency underwater sounds from both the island and support vessels were expected to attenuate rapidly with increasing distance because of the shallow water. Subsequent empirical studies of Northstar sounds have confirmed that Northstar Island sounds as measured underwater are generally not very strong, and that vessels supporting Northstar produce stronger underwater sound than does machinery on the island (Blackwell and Greene 2006). As such, anthropogenic sounds are unlikely to be heard by, or to act equally upon, all members of the migrating population, and deflection was expected to be maximal in animals at the proximal (southern) edge of the migration corridor. Our analyses of both the 2001–2004 and the recent 2009 data focused on detecting changes near the southern edge of the migration corridor, rather than on detecting a change in the corridor's central tendency. The southern edge of the migration corridor was quantified, for both 2001–2004 and 2009, by the 5th quantile of the distribution of offshore distances to calls, although other similar quantiles could have been used. Offshore distances were measured perpendicular to the baseline shown in Figure 6.1

As in past analyses, we estimated a quantile regression relationship (Koenker and Basset 1978; Koenker and Machado 1999; Koenker and Xiao 2002; Koenker 2004, 2005) between offshore distances and anthropogenic sound after adjusting for other covariates. A block permutation method similar in functionality to block bootstrapping (Fitzenberger 1997; Lahiri 2003) was again used to establish statistical significance levels and confidence limits for coefficients in the quantile regression model due to potential lack of independence of calls close in time and space.

Along with the acoustic measures considered in the 2001–2004 studies, the current study utilized additional anthropogenic sound variables measured in a different location offshore of Northstar and near the average position of the southern edge of the migration corridor. In 2009, our standard set of "Industrial sound indices" (ISIs) that characterize low-frequency industrial sounds was measured at the location of DASAR C (14.9 km northeast of Northstar in 23 m water depth) as well as at the previously-used location ~450 m northeast of Northstar in 13 m water depth. We considered both sets of ISIs as potential covariates in the quantile regression. The ISIs measured at the two locations characterized the sound level in the 28–90 Hz band (where Northstar sound is relatively strong), the presence of tones within the 10–450 Hz band, and the presence of transients within the latter band (often indicative of vessels).

In addition, in 2009 we had available a method to automatically detect the presence of airgun pulses in the recordings from offshore DASARs (see Annex 4.1 *to* Chapter 4). We used this method to detect pulses received at DASAR C and quantify them such that measures of airgun sounds could also be considered for inclusion as a covariate in the quantile regressions. Despite these additions to the list of variables considered as potential covariates, model fitting was conducted in essentially the same manner as done for 2001–2004. Thus, direct comparisons between the 2001–2004 studies and this study are possible.

METHODS

Details on field methods, data collection, and data analysis through the call localization stage were provided in Chapters 4 and 5 of this report, in the "annual summary report" for 2009 (Aerts and Richardson [eds.] 2010), and in the final report and publications concerning the 2001–2004 study (Greene et al. 2004; Blackwell and Greene 2006; Blackwell et al. 2007; Richardson [ed.] 2008). These details include DASAR design, construction, deployment, field calibration and retrieval; analysis of near-island sound recordings; call extraction and localization; and general characterization of the bowhead calls and migration corridor. The next two subsections summarize the previously-described methods pertaining to (1) whale call localization and offshore distances of calls, and (2) the measurements of underwater sound near the island and in the southern part of the whale migration corridor. The third subsection describes the statistical analysis methods used to relate offshore distances of whale calls to measures of anthropogenic sounds and covariates. The methods used to acquire and analyze 2009 data were similar to those used to analyze 2001–2004 data; consequently, the next two subsections are similar to corresponding subsections in earlier reports.

Whale Call Localization and Offshore Distances

In 2009, whale calls were recorded continuously from 00:06 local time on 26 Aug. to 09:59 on 28 Sept. using two lines of 5 DASARs that, taken together, formed an elongated grid with DASARs at 10 locations 8.5–38.5 km offshore of Northstar Island (Fig. 6.1). This configuration of DASARs was the same as that used in 2008, but differed from the configuration used in 2001–2004 (which did not extend as far offshore). The area where DASARS were deployed in 2009 extended from south of the historical migration corridor to the approximate northern edge of the main corridor during low-ice years (Fig. 6.1), although historically there has been substantial annual variation in the corridor (Moore 2000; Treacy et al. 2006; Blackwell et al. 2007; see also Chapter 5). The main bowhead migration season has typically been assumed to occur from 1 Sept. into mid-Oct. (Moore and Reeves 1993), but some bowheads pass Northstar earlier (Chapter 5) and later in the season. During the 2000–2009 phases of this study, we have retrieved the DASARs in late September or early October. Experience has shown that deteriorating weather conditions and incursion or formation of ice are likely to make it impossible to retrieve the acoustic gear much later in the autumn. In 2009, the DASARs were retrieved on 28 Sept.

We determined DASAR orientations on the bottom by projecting calibration sounds from known (via GPS) locations around each DASAR. Calibration sounds were played at precisely known times on three dates (26 Aug., 12 Sept., 26 Sept.) during the 2009 field season. This allowed us not only to calibrate DASAR orientation but also to correct for slight drift in each DASAR's internal clock. After correcting for clock drift, times of calls were determined to an accuracy of 1 or 2 s, which was adequate to assess whether a call received at several DASARs represented a single call or multiple calls.

When a call occurred, each DASAR receiving the call provided a directional bearing, with some uncertainty, to the call (Greene et al. 2004). Each channel in the DASARs was sampled at 1 ms intervals and provided reliable acoustic data up to 450 Hz, which was adequate for most bowhead whale calls (Clark and Johnson 1984). We used the Huber robust triangulation location estimator (Lenth 1981; Greene et al. 2004) to compute call locations based on the intersection(s) of bearings from multiple DASARs. The Huber estimator downweighted the occasional outlying bearing and yielded a location solution more often than alternative techniques. Calls received by a single DASAR could not be localized. Calls could have been detected by only 1 DASAR, or missed completely, if the call was weak, occurred far from the DASAR array, or occurred during times when background levels of underwater sound (mainly due to wind and wave action) were high. Even when calls were received by ≥2 DASARs they occasionally did not produce a location estimate because estimated bearings either did not cross or were too disparate to allow the Huber estimator to converge.

For each call location, a 90% confidence ellipse was calculated using methods in Lenth (1981). These methods were based on the number of DASARs that received the call, configuration (geometry) of all pair-wise bearing intersections, disparity of intersections, and inherent variation estimated from calibration data for each DASAR (Greene et al. 2004).

Offshore distances were computed as perpendicular distances from the best estimate of each call's location to a "baseline" oriented 108° to 288° True (WNW–ESE line in Fig. 6.1), parallel to the general trend of the coast, and through Northstar Island. Orientation of the chosen baseline was the same in 2009 as in 2001–2004. During those prior years, minor changes in baseline orientation of ±5° or ±10° did not influence final results (see Annex 10.3 *in* Richardson et al. 2008). Based on this finding, a single baseline orientation was used in 2009.

Near-Island and Offshore Sound Measurements

Underwater sounds associated with activities on the island and island vessel traffic were measured 450 m seaward (north) of the northern edge of the island by an additional DASAR (see Chapter 4 of this report). This nearshore DASAR ("NS_c") operated from 12:05 on 25 Aug 2010 until 09:48 on 25 Sept. 2010 and provided acoustic data for sounds with frequency up to ~450 Hz. The sensor head of the DASAR was positioned *ca.* 31 cm above the sea floor in water 12–13 m deep. From the near-island recordings, sound spectral densities were determined for 1-min periods every 4.37 min, or ~330 times per 24-h day. These spectral densities were used to determine broadband (10–450 Hz) and one-third octave band levels for each 1-min sampling period. A total of 10,986 1-min samples were obtained from the near-island DASAR during the 2009 study period. Various acoustic measures derived from these near-island data were considered as potential predictors of the offshore distances to whale calls. These near-island acoustic measures (ISIs) were computed the same way in 2009 as in previous analyses of the 2001–2004 whale call data.

In addition to sounds recorded near the island, underwater sounds were also recorded at all of the offshore DASARs (Fig. 6.1). Acoustic measures derived from a single offshore DASAR near the average southern edge of the migration corridor were also considered as potential predictors of offshore distances to whale calls. (This had not been done in the earlier analyses of 2001–2004 data.) The average southern edge of the migration corridor during 2009 was estimated by fitting an intercept-only weighted quantile regression (see Analysis Methods below) to the offshore distances of all calls localized in 2009. This quantile regression estimated a line parallel to the baseline (Fig. 6.1) that crossed the centerline farther offshore than DASAR B but closer to shore than DASAR C. Sounds recorded on DASAR C were chosen for analysis, rather than those on DASAR B; DASAR C was farther east and closer to the theoretical location where a westbound "5th quantile" migrating bowhead would first detect industrial sounds and presumably either react or not react to the sounds.

It was known that, at the location of DASAR C, the strength of received industrial sounds emanating from Northstar would be low, and sometimes below ambient levels, due to propagation loss (Chapter 4). Nonetheless, during times of low ambient sound, industrial sounds from Northstar could propagate to DASAR C. As was done for the near-island DASAR, sound spectral densities were determined from data recorded by DASAR C for 1-min periods every 4.37 min. These spectral densities were used to determine broadband (10–450 Hz) and one-third octave band levels for each 1-min sampling period. A total of 10,986 1-min samples were obtained from DASAR C.

Near-island and offshore sounds were partly from industrial activities on the island, partly from vessels (in most cases supporting the island), and partly from wind and wave action (Blackwell and Greene 2006; also Chapter 4 of this report). The wind-and-wave contribution was proportionally greater at the offshore location. Sound recordings were quantified via five "Industrial Sound Indices" (ISIs) that were described in Chapter 4 and are summarized below. These ISI variables were defined in the same way as in our earlier analyses of 2001–2004 data, although in the earlier analyses we considered only ISI values near Northstar, not those at DASAR C. Besides describing the derivation and construction of the ISIs, Chapter 4 provides historical perspective on the magnitude of these sounds in 2009. For the exact formulation of the ISI measures used in the statistical analysis, see below and Table 6.1:

(1) 5 band ISI: Sounds in the 28–90 Hz range, which represented the five contiguous one-third octave frequency bands centered at 31.5, 40, 50, 63, and 80 Hz, were predominantly of industrial origin (Blackwell and Greene 2006). Total sound pressure in these five ⅓-octave bands, expressed in dB re 1 μPa, was the first ISI, labeled ***isi5***. During previous years, this five band ISI (28–90 Hz) as measured *ca.* 460 m from Northstar, was (on average) 3.4–11.0 dB less than the broadband (10–450 Hz) sound pressure level at the same location (Table 4.4 *in* Chapter 4). In 2009, the differences between the 5-band and broadband levels averaged 8.9 dB near Northstar and 19.2 dB at DASAR C (Chapter 4).

(2) Tones: The near-island and to a lesser degree the offshore recordings included prominent and recurrent tonal sounds in the 10–450 Hz range at specific frequencies associated with industry activities (Chapter 4; Blackwell and Greene 2006). Two measures of industrial sounds based on these tones were computed. The first of these variables, ***isi.tone.pres***(ent), was a true/false variable that was true if, during a 1-min sample, sound spectral density at one or more frequencies was ≥5 dB above average spectral density at the 4 adjacent frequencies. The second variable, ***isi.tone***, measured the total strength of tones at frequencies that contained tones, as indicated by *isi.tone.pres*. Total strength of tones was the total sound pressure averaged over a 1-min sample in all tone frequencies recognized via the ≥5dB criterion of the first variable, expressed in dB.

(3) Transients: Vessels routinely visited the island throughout the season, producing both tonal and non-tonal underwater sound that was recorded by the near-island DASAR, and to a lesser extent by the offshore DASAR. Vessel sounds tended to occur as relatively brief transients lasting minutes to tens of minutes (Chapter 4; see also Blackwell and Greene 2006). Similar to the treatment of tones, two measures of industrial sounds based on transients were computed. The first variable, ***isi.trans.pres***(ent), was true if, for a 1-min sample, sound pressure level in the 28–90 Hz range (i.e., the 5 band ISI) was ≥5 dB above a moving average sound pressure level in the 28–90 Hz range. The moving average was computed by averaging over the previous and subsequent 2 hr (i.e., a 4-hr moving average). The second transient variable, ***isi.trans,*** measured strength of the transients. This variable was 0 if no transients were present in a 1-min sample (based on the ≥5 dB definition used by *isi.trans.pres*), and was the difference in sound levels between the five band transient and the 4-hr moving average when a transient was present.

In addition to the above ISI measures, ***air gun pulses*** were detected on recordings from DASAR C (see Chapter 4) and were analyzed for level (strength) and arrival direction (bearing). Bearings to detected airgun pulses were then plotted and this information was used to assist in identification of distinct seismic operations, of which two were recognized (Fig. 6.2). When airgun pulses from either of these operations were identified, RMS (root-mean-square) levels of individual airgun pulses received from a given operation were computed. Later, RMS levels of individual pulses were averaged over a specific period of time prior to a call and used as another covariate(s) in the quantile regressions.

In 2009, the majority of airgun pulses received on DASAR C originated to the east whereas another group of pulses originated from the north (Fig. 6.2). Subsequent investigation revealed that one seismic

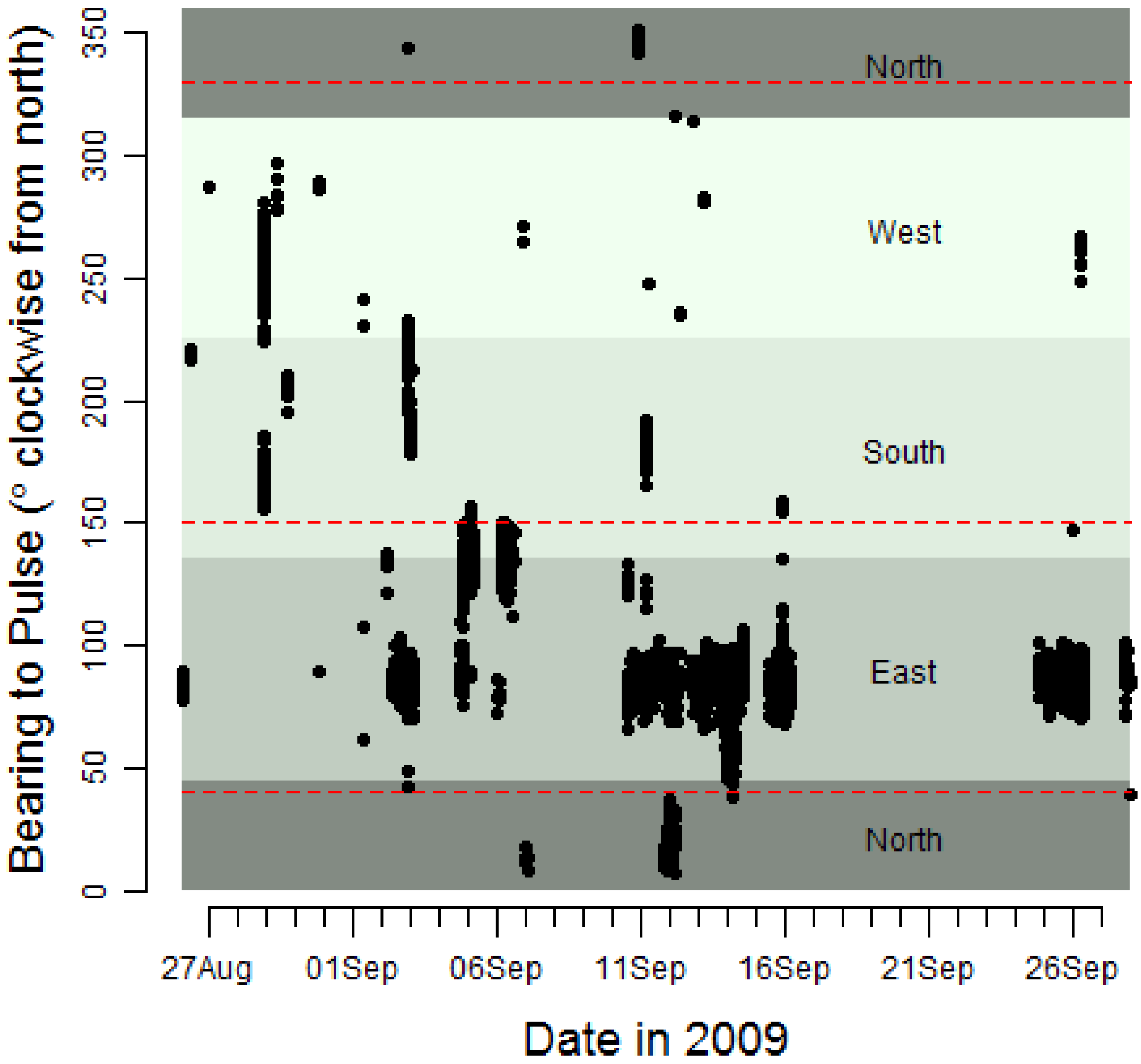

FIGURE 6.2. Bearings to airgun pulses detected at DASAR C throughout the 2009 field season. All airgun pulses with bearings between 40° and 150° (dashed lines) were ascribed to the eastern seismic operation (BP). All pulses with bearings >330° or <40° (dashed lines) were ascribed to the northern seismic operation (USGS). See text regarding apparent pulses from other directions.

operation was underway in each of those general directions during the study period. Pulses arriving from the east presumably originated from the BP-sponsored seismic program operating in the Canadian Beaufort Sea far to the east of the DASAR array during the time period in question (B. Streever, BPXA, pers. comm.). Pulses arriving from the north presumably originated from joint USGS/USCG/GSC[2] seismic mapping operations that occurred in deep water of the Canada Basin far to the north of the DASAR array during that period (Mosher et al. 2009). To compute separate measures of the received levels from each of these operations, all airgun pulses with bearings between 40° and 150°True were ascribed to the east-

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[2] U.S. Geological Survey (USGS), U.S. Coast Guard (USCG), and Geological Survey of Canada (GSC) involving the icebreakers USCG *Healy* and the CCGS (Canadian Coast Guard Ship) *Louis S. St.-Laurent.*

ern seismic operation (BP), while all pulses with bearings ≥330° or <40° were ascribed to the northern ("USGS") seismic operation (Fig. 6.2).

Purported seismic pulses with bearings between 150° and 330° (Fig. 6.2) originated to the south and west of DASAR C. These sounds were pulses at regular intervals, but were unlikely to be airgun pulses because they occurred over a short period of time, arrived across a wide range of bearings, and could not be associated with any known seismic operation. Such pulses may have been acoustic signals generated by boats that were not distinguished from airgun pulses by the automated airgun detection procedure. This includes the boat we used to service the DASAR array on some dates, e.g., 26 Sept. However, we cannot be sure of that explanation for some of the apparent pulses to the south and west. In any case, they were not considered when constructing measures of airgun sound.

Analysis Methods

This section addresses four major and several minor topics related to the analysis of offshore distances of bowhead whale calls. Major topics were as follows: ***(1)*** The exclusion of certain calls from the analysis, specifically calls when the vessel used to support the DASAR operations was offshore of Northstar, and calls detected and localized in situations where probability of detection and localization was low. ***(2)*** Quantile regression analysis, including model building procedures, selection of ISI averaging time, and the block permutation method. ***(3)*** Methods for estimating the size of the anthropogenic sound effect, i.e., its effect on the southernmost offshore distances under various anthropogenic sound scenarios. ***(4)*** Methods for assessing the robustness of the analysis results, i.e., whether similar analysis results were obtained when plausible alternative assumptions and analysis decisions were made. To assess robustness, we repeated the analysis several times making specific changes in assumptions and procedures, and we compared the results with those from the "primary" analysis.

All estimation and significance testing was performed using the R programming language (http://www.r-project.org) augmented with packages *quantreg* (http://cran.r-project.org/src/contrib/Descriptions/quantreg.html) and *splines* (in base R). *Quantreg* (version 4.44) performs quantile regression using a linear programming approach (Koenker and d'Orey 1987). The *splines* package was used to compute B-spline orthogonal base transformations of certain variables.

Call Exclusion

Calls were excluded from the analysis in two situations: When the vessel used to support the DASAR operations was offshore of Northstar, and (in the primary analysis) when calls were detected and localized despite being in situations where probability of detection and localization was low.

Vessel Offshore. — Calibration sounds projected near the DASAR array, along with boat noise from the associated vessel, may have temporarily affected whale positions or calling behavior. Primary interest was in the effects of Northstar itself.[3] Consequently, periods when our boat was >2 km north of Northstar Island, and periods within 2 h after the boat returned to waters <2 km north of Northstar, were excluded from analysis. This procedure had also been applied in the 2002–2004 analyses. Two hours was chosen based on typical durations of avoidance reactions to boats (usually ½–1 h, Richardson et al. 1985; Richardson and Malme 1993), plus a 1–1½ h allowance for displacement and behavioral effects to subside. In 2009, the calibration cruises plus their 2 hr buffers resulted in excluding 11.50 hr of data and

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[3] It could also be of interest to assess the combined effect of routine Northstar operations and vessel-based monitoring of the whale migration. However, the primary project objective, developed in consultation with regulatory, peer, and stakeholder groups, was to characterize effects of activities at and near Northstar Island on bowheads, not to address combined effects of Northstar and intermittent monitoring activities elsewhere.

76 calls on 26 Aug., 7.05 hr and 4 calls on 12 Sept., and 9.28 hr and 114 calls on 26 Sept. These 194 excluded calls represented 1.1% of the 16,825 calls localized in 2009.

***Low Probability of Detection and Localization*.** — Calls are more difficult to detect during times of high ambient (background) noise, e.g., during times of high wind and wave action, and this could have introduced bias. Specifically, some calls far from the DASARs that would have been detectable at times of low noise would be undetected during times with high background noise. Thus, large distances from shore would be underrepresented in the data during times of high background noise. This bias in sampling, if not addressed, could have caused us to erroneously conclude that calling bowhead whales were farther offshore during times of low ambient noise, and conversely could have hidden a change in the distribution of calling whales during high ambient noise times.

To eliminate this bias, we used an approach analogous to that in distance sampling. Calls were excluded if the joint probability of detecting and localizing a call in those circumstances was estimated to be <10%. McDonald et al. (2008 and in review) applied logistic regression to data from calibration cruises conducted during 2004 to estimate (1) the probability of a DASAR detecting a sound occurring in a given location relative to the DASARs and with a given background noise level, and (2) the probability that the sound would be localized (which required detection by two or more DASARs). The two resulting equations included distance of the sound source from every DASAR, ambient sound levels at the time of the call, whether the sound source was "upstream" or "downstream" of the array (relative to the predominant westward movement of the bowhead whales), and the number of bearings that crossed. The equations of McDonald et al. (2008) modeled detection at different DASARs as independent and therefore did not include the specific arrangement of DASARs nor size of the overall array. We used these same equations based on 2004 data to estimate the probability that a call occurring at a given location and with a given ambient noise level would be detected and thus included in the data set during 2009.

The background sound level used in both regressions was measured at the DASAR farthest from Northstar (J; Fig. 6.1). Northstar sounds were less likely to propagate to that location than to other closer DASARs, and would be weaker at DASAR J than closer to Northstar on occasions when they were received at J. In determining background levels, airgun pulses received at DASAR J were included (Chapter 4). Intermittent and generally weak pulses from distant airguns do not contribute strongly to average received noise level. Even so, the average received levels probably slightly overstated background levels during intervals between airgun pulses. Thus, estimated probabilities of detection for whale calls may have been somewhat underestimated at times with distant airgun sounds.

Based on the two logistic regressions, calls were excluded from the primary analysis if the estimated probability of detecting and localizing a call in the circumstances was below an arbitrary cutpoint, which we set at <10%. We set the cutpoint at 10% for three reasons. First, a 10% cutpoint retained the majority of the detected calls (*ca.* 68%), although this was a lower percentage than in 2001–2004 (*ca.* 90% each year). Second, we reasoned that most bias in our sample was represented by calls with small (<10%) probability of detection and localization because, for every such call detected, we in theory missed >10 similar calls. Third, during line transect studies that exclude distant sightings for similar reasons, a common criterion for exclusion is probability of detection less than 10% to 15% (Buckland et al. 1993). Almost all calls excluded because their probability of inclusion was <10% were well outside the perimeter of the DASAR array at locations where localization precision was low (Fig. 6.3). Conversely, calls with probability of detection and localization greater than 10% were both inside and outside the perimeter of the DASAR array (Fig. 6.4, later). Together, these statements imply that the probability of our array detecting and localizing nearby calls was generally high, especially within or near the array's perimeter, and that most excluded calls were at logical and explainable locations and times.

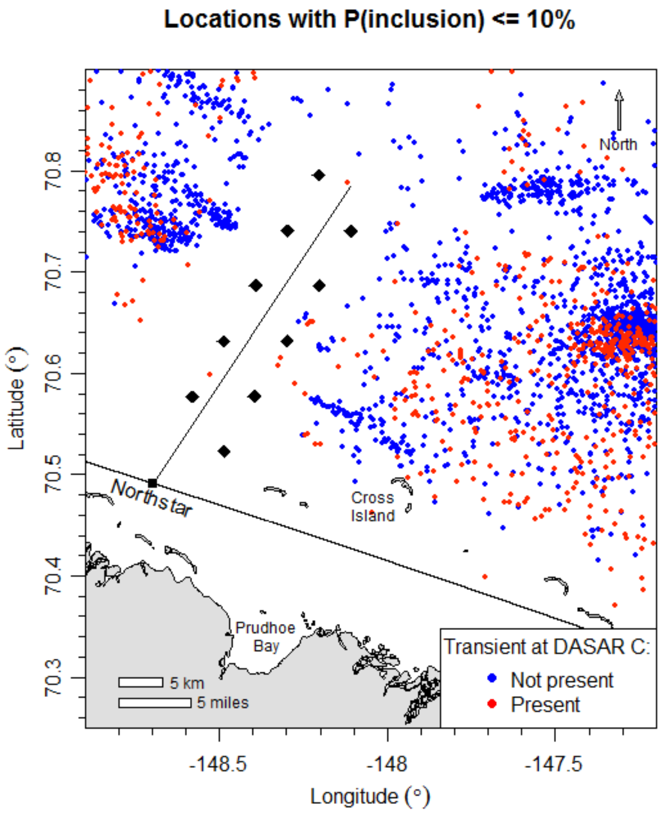

FIGURE 6.3: Locations of calls excluded because estimated probability of inclusion (=probability of detection and localization) for a call in that situation was <10%. Call locations are color coded based on presence or absence of transient sounds at DASAR C within 75 min preceding the call (i.e., *os.isi.trans.pres.75* = 1 vs. 0).

During analysis of 2001 through 2004 data, it was found that exclusion of these mostly distant calls had little effect on the final conclusions (McDonald et al. 2008 and in review). The sensitivity of the 2009 analysis to exclusion of calls with low probability of inclusion was also tested (see "*Robustness of Results*", below). For this test, the "probability of inclusion ≥10%" requirement was dropped, and the analysis was re-run on all calls. In addition, the analysis weights designed to compensate for varying inclusion probabilities (see below) were excluded during this test.

Quantile Regression Analysis

Conceptually, the quantile regression estimated a semi-linear model with functional form

$$Q_5(y\mid x) = \beta_0 + f(non\text{–}industry\ \ variables) + g(industry\ variable) + h(airgun\ variable)$$

where $Q_5(y|x)$ was the predicted 5th quantile of offshore distance given the values of all explanatory variables. The *f(non-industry variables)* portion was a smooth function of naturally occurring environmental variables that could be expected to influence offshore distance, and *g(industry variable)* was a linear function of one measure of anthropogenic sound level. The procedure used was very similar to that applied to the 2001–2004 data by McDonald et al. (2008 and in review) and by Richardson et al. (2008). The main difference is that additional measures of anthropogenic sound levels were considered for inclusion. Additional measures of anthropogenic sounds were • the ISI measures computed at a location near the typical 5th-quantile distance offshore, and • average RMS level of airgun pulses received at that location.

Selecting a reasonable set of variables to include in the best fitting quantile regression model was done in three stages. First, a reasonable model for *f(non-industry variables)* containing natural variables was determined. This "background" model explained as much natural variation in offshore distance as possible, given the available predictor variables. Second (in the primary analysis), a variety of potential covariates representing postulated models for *g(industry variables)* were considered for addition (one at a time) to the background model and the additional predictive strength of each nearshore and offshore industrial sound variable was assessed. The one industrial sound covariate with the highest incremental predictive ability was added to the model. Third, measures of airgun pulse strength at the time were added to *g(industry variables)* to assess whether any nearshore or offshore industrial effects in the model changed when airgun pulse levels were taken into account. In the primary analysis, model selection was performed in the three stages outlined above in order to compare results to those obtained in 2001–2004. In 2001–2004, offshore measures of ISI and airgun variables were not present, and model selection stopped after stage 2.

In the remainder of this section, the weighting of calls based on location uncertainty and probability of inclusion is described. Following that, the variables included in the three stages of the model-selection process are described, including the new measures of industrial and airgun sound near the typical 5th-quantile distance. Methods necessary to estimate individual models, select the best fitting model, and compute associated significance levels are then described; those methods are essentially unchanged from the earlier analyses of 2001–2004 data. Finally, methods for estimating effect size are described; again, these are essentially unchanged.

Weighting by Localization Uncertainty.—Because uncertainty in offshore distance measurements differed by several orders of magnitude among calls, a weighting factor derived from the size of the 90% confidence ellipse for the call location was used in the primary (and most other) quantile regressions. Calls with highly precise estimates of offshore distance (generally those close to one or more DASARs) were up-weighted, while calls with low-precision estimates of offshore distance (generally those far from the array) were down-weighted. Localization uncertainty weights were computed in the same way as during previous analyses of 2001–2004 data (McDonald et al. 2008 and in review).

Weights based on localization uncertainty involved a number of analytical assumptions and decisions. Chief among these assumptions was that error ellipses were estimated appropriately (e.g., they are actually ellipses) and that the proper weighting function was proportional to the inverse of error ellipse width measured perpendicular to the baseline. To investigate whether our conclusions were sensitive to the inclusion of localization weights, we ran a separate quantile regression analysis excluding these weights (see "*Robustness of Results*", below).

Weighting by Detection and Localization Probability.—Even after excluding calls with low (<10%) detection and localization probability, we expected that the ability of the DASAR array to record a call and to estimate its location would be correlated with distance, background sound level, and possibly other factors. Therefore, the quantile regression analysis included a second weighting factor that was inversely proportional to probability of detection and localization. Calls detected in situations with low probability of detection and localization (generally those far from the array or at times with high background noise) were up-weighted while calls with large probabilities were downweighted. These weights were the estimated Horvitz-Thompson (HT) inflation factors (Horvitz and Thompson 1952; Särndal et al. 1992, p. 43; Buckland et al. 2004, p. 9). In general, these HT weights were negatively correlated with the localization weights, but in 2009, localization weights decreased faster than HT weights with increasing distance from the array. Consequently, localization weights generally dominated the HT weights.

This HT weighting factor depends on the "detection and localization probabilities" (probabilities of inclusion), which were computed for 2009 from equations derived based on 2004 data (when the DASAR array configuration was different). Those probabilities depend on the background noise values measured at DASAR J, which were at times were somewhat affected by airgun sounds (see above). To investigate whether the HT weights affected results, we conducted a sensitivity analysis that excluded those weights from some quantile regression runs (see "*Robustness of Results*", below).

Non-Industry Variables.—During stage 1 of model selection, linear combinations of the non-industry variables were fitted and potentially included in *f(non-industry variables)*. The non-industry variables considered for inclusion were measures of date within the migration season, day/night, and east-west location relative to the "centerline" (Table 6.1).

TABLE 6.1. Natural, or non-sound, variables considered for inclusion in the *f(non-industry variables)* portion of the quantile regression models.

Variable	Degrees of Freedom	Description
sunlight	1	Day/night indicator: *Sunlight* = 1 if sun was above the horizon; *sunlight* = 0 if sun was below the horizon. Local sunrise and sunset times for Prudhoe Bay, AK, obtained from www.sunrisesunset.com.
upstream	1	East/west indicator: *Upstream* = 1 if location was east of the "centerline" shown in Fig. 6.1. Placement of the centerline was determined in 2001 as a line extending from Northstar through the position of DASAR CA in 2001 (see Fig. 4.2 *in* Chapter 4). *Upstream* = 0 if location was west of the centerline.
uprange.smu	5	B-spline smooth function of east–west distance along baseline, in meters. Computed as the distance from a call location to the centerline parallel to the baseline. Call locations east and west of Northstar were coded as positive and negative values, respectively. B-splines allowed us to fit piecewise cubic polynomials between 5 "anchors" (or "knots", 3 equally spaced internal, 2 at extremes). Number of "anchors" was chosen by inspecting smooths with 2, 3, 4, …, 9 knots and selecting the best-fitting one visually. Orthogonal B-spline expansions were computed by function bs() in R contributed package *splines.*
dayofyear.smu	3	B-spline smooth function of day of the year. Day of the year was coded as a continuous measure (fractional days) with 31 Aug 2009 00:00 as the origin. This meant that 1 Sept. 00:00 = 1.0, 1 Sept. 12:00 = 1.5, 2 Sept. 18:00 = 2.75, etc. B-splines allowed us to fit piecewise cubic polynomials between 3 "anchors" (or "knots", 1 at median, 2 at extremes). See *uprange.smu* concerning how number of "anchors" was chosen, and how orthogonal B-spline expansions were computed.

Among these variables, day of the year (1 = 1 Sept., 2 = 2 Sept., etc.) and uprange distance (east–west distance of call along axis parallel to baseline) were fitted as 3 and 5 degree of freedom smoothing splines, respectively. This allowed estimation of non-linear and high order polynomial relationships between these variables and the 5th quantile of offshore distance. To fit the polynomial relationships, day of the year and uprange distance were expanded into orthogonal bases (variables) using cubic B-splines (i.e., variables *dayofyear.smu* and *uprange.smu* in Table 6.1) and either 3 or 5 coefficients were estimated if either day of the year or uprange distance was included in the model. To establish the degree of smoothing (i.e., 3 vs. 5 coefficients), we included splines with 1 to 9 degrees of freedom in a preliminary form of the quantile regression and chose the one with the best visual fit. These preliminary quantile regressions had no other terms in them. The degrees of freedom (df) in each set of smoothing splines was not critical to overall conclusions because these variables were in the non-industrial part of the model and because other df near the chosen ones estimated very similar trends. If we had included too many date or uprange-distance terms, it is theoretically possible that the model would "over-fit" the data and estimate trends through time or along the baseline that were not actually there. However, the number of calls in our analysis is large enough to reasonably assume that polynomials of degree 3 and 5 can be estimated. Nonetheless, we use caution when attempting to interpret trends through time or along the baseline. Primarily, we treat these effects as "nuisance" effects to be taken into account before we estimate anthropogenic effects. The best combination of natural predictors to include in *f(non-industry variables)* was determined using backward stepwise elimination, as described under "*Model Fitting and Significance Levels*", below.

Industry Variables (Excluding Airguns).—In the primary analysis, stage 2 of model estimation started with the best fitting *f(non-industry variables)* model from stage 1, and successively evaluated 70 postulated models each of which contained one anthropogenic sound variable, i.e., one ISI (Table 6.2A). Seventy models arose by combining

- 7 forms of the industrial sound indices (ISIs) measured near the island with 8 possible averaging times (56 models; averaging times = 15, 30, 45, 60, 75, 90, 105, and 120 min preceding the call in question), plus
- 2 forms of the industrial sound indices measured offshore near the 5th quantile distance with 2 possible averaging times (14 models; averaging times = 15 and 75 min).

Seven of the eight averaging times for ISI were considered during the 2001–2004 phase of the project (McDonald et al. 2008 and submitted). The eighth averaging time (105 min) was added to fill a gap between 90 and 120 min. We implemented these averaging times because we expected that any response by bowhead whales to Northstar sound would be a function of sound summarized over a period much longer than the 4.37-min interval between our successive 1-min sound measurements. Typical swimming speed for a bowhead during autumn migration is 4–5 km/h (Koski et al. 2002), so whales would take a few hours to travel through the area where our DASAR array could reliably detect and locate their calls. ISI variables averaged over different time periods were not considered in the same model due to high correlation amongst them.

The resulting 70 models were ranked based on amount of variation explained. The amount of residual variation explained was measured by the drop-in-dispersion *F* statistic (Cade and Richards 2006; McDonald et al. 2008 and in review). The model explaining the highest proportion of residual variation was selected as the best fitting model for stage 2. Akaike's Information Criterion (AIC) (Burnham and Anderson 2002) was not used to rank competing models because AIC depends on the maximized value of a statistical likelihood, and quantile regression does not utilize a statistical likelihood. The significance of terms in the best stage 2 industrial model was determined by the same block permutation method used to determine significance during previous analyses of 2001–2004 data (McDonald et al. 2008 and in review). If the anthropogenic effect in the top ("best") stage 2 model was not significant at $\alpha = 0.05$, the anthropogenic effect was dropped and the best fitting model from stage 2 would be identical to the best fitting model from stage 1 (non-industry variables only).

The resulting 70 models were ranked based on amount of variation explained. The amount of residual variation explained was measured by the drop-in-dispersion *F* statistic (Cade and Richards 2006; McDonald et al. 2008 and in review). The model explaining the highest proportion of residual variation was selected as the best fitting model for stage 2. Akaike's Information Criterion (AIC) (Burnham and Anderson 2002) was not used to rank competing models because AIC depends on the maximized value of a statistical likelihood, and quantile regression does not utilize a statistical likelihood. The significance of

TABLE 6.2. Industrial sound and airgun sound variables considered for inclusion in the quantile regression of offshore distances during stages 2 and 3 of model selection. ***(A)*** During stage 2 of the primary analysis, 70 models representing nearshore and offshore anthropogenic sound effects were considered, each containing one measure of industrial sound either near Northstar or at DASAR C: 7 measures of near-island sounds × 8 averaging times (XX = 15, 30, 45, 60, 75, 90, 105, and 120 min), plus 7 measures of offshore sounds × 2 sound averaging times (YY = 15 and 75 min). ***(B)*** During stage 3, 8 models reflecting offshore airgun effects were considered: 2 measures of airgun sounds × 2 airgun operations (east and north) × 2 airgun sound averaging times (YY = 15 and 75 min).

Variable	Description
A. Industry Variables near Northstar or Offshore at DASAR C	
ns.isi5.XX *os.isi5.YY*	Variable *ns.isi5.XX* = sound level (in dB re 1 μPa) measured at near-island DASAR within the five 1/3rd octaves spanning 28–90 Hz, averaged over XX min immediately prior to the call. Variable *os.isi5.YY* was the same measure computed from records collected by a DASAR close to the 5th quantile distance. Models containing these variables fit a linear relationship between *ns.isi5.XX* or *os.isi5.YY* and the 5th quantile of offshore distance.
ns.isi.tone.pres.XX *os.isi.tone.pres.YY*	Variable *ns.isi.tone.pres.XX* = 1 when at least one tone (≥5 dB above levels at neighboring frequencies) was present at 10–450 Hz in the near-island sound record during XX min immediately prior to the call. *ns.isi.tone.pres.XX* = 0 when no tone was present at any sampling times in the XX min period. Variable *os.isi.tone.pres.YY* was the same measure computed from records collected by a DASAR close to the 5th quantile distance. Models containing these variables estimated the average amount by which the 5th quantile of offshore call distance increased or decreased when industrial tones were present prior to the call.
ns.isi.trans.pres.XX *os.isi.trans.pres.YY*	Variable *ns.isi.trans.pres.XX* = 1 when at least one transient was present in the 28–90 Hz near-island sound record during XX min immediately prior to the call. *Isi.trans.pres.XX* = 0 when no transient was present. Variable *os.isi.trans.pres.YY* was the same measure computed from records collected by a DASAR close to the 5th quantile distance. Models containing these variables estimated the average amount by which the 5th quantile of offshore call distance increased or decreased when transient sounds of an industrial nature were present prior to the call.
ns.isi.tone.pres.XX + *ns.isi.tone.XX* *os.isi.tone.pres.YY* + *os.isi.tone.YY*	Variable *ns.isi.tone.XX* = dB in tones, when present, averaged over XX min immediately prior to the call. *ns.isi.tone.XX* = 0 when no tones were present during XX min prior to a call. Variable *os.isi.tone.YY* was the same measure computed from records collected by a DASAR close to the 5th quantile distance. Models containing these variables fitted no relationship between strength of tones and offshore call distance when no tones were present, and a linear relationship when tones were present.
*ns.isi.trans.pres.*XX + *ns.isi.trans.XX* *os.isi.trans.pres.*YY + *os.isi.trans.YY*	Variable *ns.isi.trans.XX* = sum over previous XX min of dB in transients minus dB of background levels, when dB in 28–90 Hz band was >5 dB above its 4 h moving average. *Ns.isi.trans.XX* = 0 when no transients were present during XX min prior to a call. Variable *os.isi.trans.YY* was the same measure computed from records collected by a DASAR close to the 5th quantile distance. Models containing these variables fitted no relationship between strength of transients when no transients were present, and a linear relationship when transients were present.
ns.isi.tone.pres.XX + *ns.isi.tone.pres.XX* * *uprange.smu* *os.isi.tone.pres.YY* + *os.isi.tone.pres.YY* * *uprange.smu*	Models containing these variable combinations fit separate smooth curves between uprange distance and the 5th quantile distance when tones were and were not present in the previous XX or YY min. *These models allowed the estimated 5th quantile line drawn on a map of the area to be a polynomial having one shape when sound of this type was not present and another shape when sound of this type was present.*

continued….

TABLE 6.2. Concluded.

Variable	Description
ns.isi.trans.pres.XX + *ns.isi.trans.pres.XX* * *uprange.smu* *os.isi.trans.pres.YY* + *os.isi.trans.pres.YY* * *uprange.smu*	Models containing these variable combinations fit separate smooth curves relating uprange distance and 5th quantile distance when transients were and were not present in the previous XX or YY min. *(See explanatory note in italics above.)*
B. Airgun Variables Offshore at DASAR C	
airgun.east.pres.YY *airgun.north.pres.YY*	Presence of airgun pulses from either the eastern (BP) or northern (USGS) seismic operations on records from offshore DASAR C within YY min prior to a call. Both variables were 0 when no airgun pulses were detected from the respective direction during the YY min prior to a call. Both variables were 1 when one or more airgun pulses were detected during the YY min period prior to a call.
airgun.east.pres.YY + *airgun.east.rms.YY* *airgun.north.pres.YY* + *airgun.north.rms.YY*	Presence of airgun pulses from the eastern (BP) or northern (USGS) seismic operations on records from DASAR C within YY min prior to a call, and average RMS level (dB re 1 μPa) of all pulses arriving from the respective direction within YY min prior to the call (*airgun.east.rms.YY,* and *airgun.north.rms.YY*). Together, these variables estimated no effect of pulse RMS levels when airgun pulses were not detected. When airgun pulses were detected, these variables estimated a linear relationship between the 5^{th} quantile of offshore distance and average pulse RMS levels.

terms in the best stage 2 industrial model was determined by the same block permutation method used to determine significance during previous analyses of 2001–2004 data (McDonald et al. 2008 and in review). If the anthropogenic effect in the top ("best") stage 2 model was not significant at $\alpha = 0.05$, the anthropogenic effect was dropped and the best fitting model from stage 2 would be identical to the best fitting model from stage 1 (non-industry variables only).

Airgun Variables.—In the primary analysis, stage 3 of model estimation started with the best fitting model from stage 2 and added terms to the *h(airgun variable)* portion of the model. Stage 3 successively evaluated 8 models that included background effects (*f(non-industry variables)*), industry sound effects (if significant at stage 2) (*g(industry variable)*), and some form of airgun sound effect (Table 6.2B). The 8 models fitted during stage 3 were ranked according to the proportion of residual variation explained, again measured by drop-in-dispersion *F* statistic. The top ranked model became the final reported model for the 5^{th} quantile of offshore distance. The significance of terms in the model was determined by the same block permutation method used to determine significance during previous analyses of 2001–2004 data (McDonald et al. 2008 and in review).

It can be argued that the possible effects of airgun sound on the offshore distances should be considered and (if significant) taken into account before considering whether offshore distances to bowhead whale calls are influenced by Northstar. Our primary analysis considered Northstar-related variables at stage 2 and airguns at stage 3. However, as part of the sensitivity analysis, we also ran quantile regression analyses considering *h(airgun variable)* before *g(industry variable)* (see "*Robustness of Results*", below).

Model Fitting and Significance Levels.—The best combination of predictors to include in *f(non-industry variables)* was determined using backward stepwise elimination and relied on computed significance levels, with alpha-to-enter and alpha-to-exit = 0.2. Procedures were the same as in our previous analyses of 2001–2004 data. Briefly, significance levels were computed using the drop in dispersion test of Cade and Richards (2006), with one amendment: we utilized block permutation (Lahiri 2003) to account for possible space and time correlations in offshore distances, rather than the regular bootstrapping of Cade and Richards (2006) who assumed independent responses. Our blocks were constructed to be uncorrelated clusters of calls, where clusters were determined by the hierarchical clustering procedure implemented during 2001–2004 (McDonald et al. 2008, Annex 9.2). The clustering procedure grouped calls together that were close in space and time until the centroid locations and average arrival times of calls within each group were uncorrelated, as measured by Mantel's test. These groups (or clusters) contained calls that were potentially correlated with other calls in the same group, but that were as a whole uncorrelated with calls in other groups. Further details of the block permutation test, the drop-in-dispersion F test, estimation of effect sizes, and construction of 95% confidence intervals can be found in McDonald et al. (2008 and in review).

Size of Sound Effects

To estimate the magnitude of industrial sound effects in the best fitting model, we estimated change in the 5th quantile of offshore distance as a function of change in anthropogenic sound level. If decibel-based measures such as *ns.isi5.XX* or *os.isi.tone.XX* (Table 6.2) were significant in the best-fitting model, we estimated average displacement as the difference between the predicted 5th quantile offshore distances during periods when sound levels were apparently below background levels vs. at their 95th percentile value. Background levels were measured at the farthest-offshore DASAR (J). If presence-absence variables such as *ns.isi.tone.-pres.XX* or *os.isi.trans.pres.XX* were significant in the best model, we estimated the 5th quantile's locations when the sound was characterized as present and as not present. As for coefficients, confidence intervals (95% CI) on displacement were computed using Hall's percentile method (McDonald et al. 2008).

Robustness

Many decisions were made in the process of constructing the primary analysis described above. Among all these methodological decisions, the most important are those that have the highest likelihood of changing results if the decision had been different. In this study, such decisions include the following three: (1) the decision to exclude certain calls, (2) the decision to include the two weighting factors during quantile regression estimation, and (3) the decision to conduct model selection the way we did. Ideally, results would not depend upon these and other analysis decisions. In previous related analyses of 2001–2004 Northstar data, this was the case. In McDonald et al. (2008), we verified that results for 2001–2004 were essentially insensitive to various key decisions by reversing the decision, re-running the analysis, and finding that the results were essentially unchanged. For 2009, we applied the same approach to test the sensitivity of results to key analysis decisions.

Weighting Factors and P(inclusion) <10%.—A key component of the primary analysis is estimation and inclusion of two weighting factors; one for probability of inclusion and one for location error. These weights were included because, during peer review of early analyses of 2001–2004 data, reviewers requested that we extend the study area to include calls detected farther from the DASAR array then in use. In general, distant calls (as compared with those within or near the DASAR array) have lower probability of inclusion and higher location uncertainty. We developed the weighting factors to allow us to minimize biases that might otherwise occur when we included the more distant calls (McDonald et al. 2008 and in review). For 2009, we studied the effects of including these weighting factors in two ways.

First, we restricted attention to calls estimated to be close enough to the DASAR array for weighting factors to be non-essential, and re-ran the analysis without either of the weighting factors. Calls included in this analysis were restricted to those within a "silo"-shaped study area around the DASAR array, with all parts of the "silo" being within 8 km of the centerline shown in Figure 6.1. All calls, regardless of their estimated probability of detection and localization, were included in the analysis if they occurred within the silo. (However, calls occurring during times our boat was in or near the DASAR array were excluded, as in the primary analysis.) The size and configuration of the silo-shaped area were chosen based on early analyses of 2002 data indicating that all calls localized inside such an area had high probability of inclusion. The "silo" shaped study area was a rectangle topped by a semi-circle. The rectangle extended from the baseline to the end of the centerline shown in Figure 6.1, and extended 8 km WNW and ESE of the centerline. The semi-circle was centered on the end of the centerline and had a radius of 8 km (see Fig. 6.7, later).

Second, we studied the effect of retaining the weighting factor for localization uncertainty but excluding probability of inclusion information. If we could not reliably compute probabilities of inclusion, we should not use them either to exclude locations based on the <10% probability of inclusion criterion or to calculate the second weighting factor in the quantile regressions, the inverse of probability of inclusion. There was concern that (for 2009) the probability of inclusion estimates might be biased by the effects of airgun sound on estimated background noise levels. Also, there was evidence from 2001–2004 that probability of inclusion weights were unimportant after localization-accuracy weights were included (McDonald et al. 2008 and in review). For this examination of sensitivity, we included all localized calls in the analysis except for those during times when "our" boat was offshore within or near the DASAR array, and we re-ran the quantile regression analysis using only the case weight that represented location uncertainty.

***Order of Variable Selection*.—** Changes in model selection procedures can have dramatic effects on final models. As stated earlier, for comparison to the 2001–2004 results, we chose to perform the primary model selection in the following three ordered stages: (1) consider natural variables first, then (2) consider industrial variables associated with Northstar, and finally (3) consider received levels of airgun sound. It is, however, arguable that received levels of airgun sound should be considered nuisance variables when estimating industrial effects associated with Northstar. If so, airgun sound levels should be considered for inclusion in the quantile regression models prior to consideration of industrial sound variables associated with Northstar. We examined the effects of this change in sequence by reversing the order of the last two stages of model selection and re-running the quantile regression analysis, i.e., model selection was conducted in the sequence (1), (3), (2). In addition, because changes in model selection could potentially interact with inclusion of the weighting factors mentioned above, we performed this re-analyses twice. One of the "airguns before Northstar" runs was otherwise similar to the primary analysis scheme, i.e., drop calls in situations with estimated probability of inclusion <10% and include both weights. The other run excluded estimated probability of inclusion information, i.e., include all calls and include only the weighting factor representing location error.

RESULTS

Bowhead Whale Calls in 2009

A total of 19,772 calls were received by the DASAR array during the 33.5-day recording period, of which 2234 were received by only 1 DASAR, and 713 others could not be localized because the bearings involved were too disparate, leaving 16,825 localized calls. Of these localized calls, 219 were excluded because they were localized during times when our boat was servicing the array, 5314 were excluded because estimated probability of detection in the prevailing circumstances was <10%, and 29 had non-positive definite variance-covariance matrices (and thus no estimate of error). This left 11,263 locations in the primary quantile regression analysis.

Figure 6.4 shows estimated locations of most localized whale calls, excluding calls with probability of detection and localization <10% and some calls estimated (very imprecisely) to be outside the mapped area. In Figure 6.4, each call is color-coded according to *os.isi.trans.pres.75*, which represents the presence or absence of transient sound at DASAR C over the 75 min preceding the call — specifically transient sound characteristic of vessels (Table 6.2A). There was no immediately discernible difference in the distributions or offshore distances of calls with vs. without transient sounds present offshore in the 75 min preceding the calls (Fig. 6.4).

Calls were detected in "pulses", both in time and in space, during each year of this study (Chapter 5; see also Blackwell et al. 2007). This is evident in plots of offshore distance to whale call locations, measured perpendicular to the "baseline", as a function of date (Fig. 6.5). For example, the majority of calls detected on 13 Sept. 2009 were 30 km to 40 km offshore, whereas 2 to 3 days earlier most calls were

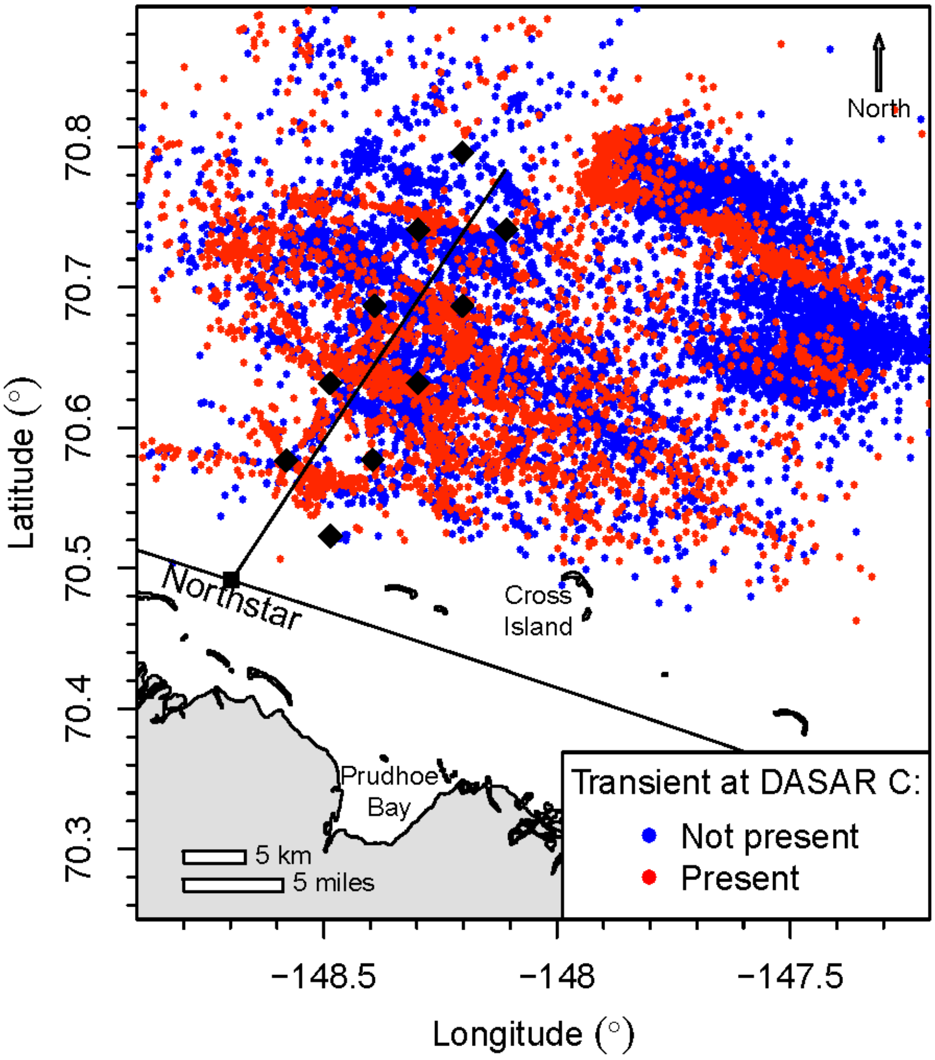

FIGURE 6.4. Map of estimated whale-call locations in 2009, excluding calls in situations where probability of detection and localization was <10% (*cf.* Fig. 6.3). Whale calls are color-coded based on presence or absence of transients at offshore DASAR C in the 75-min period preceding the call (*os.isi.trans.pres.75*). Estimated distances of calls from the DASAR array become quite imprecise more than ~10 km outside the periphery of the array, but bearings from the array remain quite accurate regardless of estimated distance.

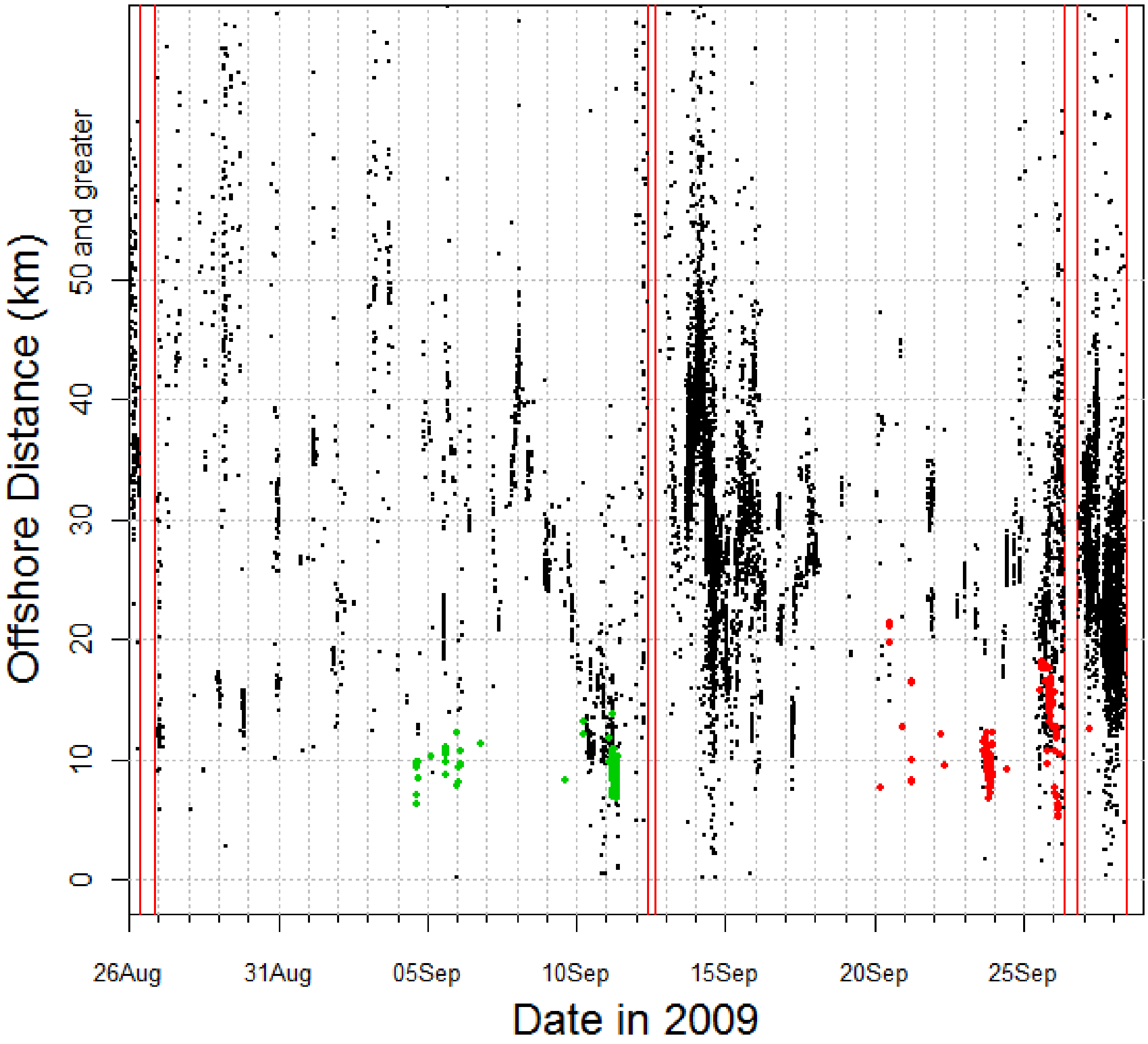

FIGURE 6.5. Offshore distance for every detected whale call estimated to be within 70 km of shore as a function of date during the 2009 study period. All localized calls are included, regardless of probability of inclusion. Distances >50 km offshore have large uncertainties and should only be used as an index of the frequency of whale calls far from Northstar. Paired vertical lines delimit times when our vessel was in the DASAR array; whale calls during those periods were not analyzed and were excluded from the graph. Date labels appear at the start of each day (00:00 AkDT). Green and red dots indicate the offshore distances of 2 large clusters of whale calls that may include 2, 3 or 4 distinct groups of whales. These call locations were near the overall 5th quantile of offshore distance, and occurred when *os.isi.trans.pres.75* equaled 1 (transient present). These calls had high influence on the final result (see DISCUSSION).

10 km to 15 km offshore. Clustering of calls in time and space is consistent with numerous visual observations of "pulses" of bowhead whales as reported by both Inupiat whalers and researchers (see Blackwell et al. 2007, p. 260, 264, for review; see also Chapter 7). For purposes of statistical analysis, cluster analysis grouped the 11,263 calls into 72 clusters that could be treated as independent.

More calls were detected to the east than to the west of the DASAR array in 2009 (Fig. 6.4). This phenomenon was also found in 2001–2004. It may be a result, at least in part, of the slight directionality of bowhead calls documented in Chapter 5's Annex 5.2.

Stage 1, 2 and 3 Models for 5th Quantile Offshore Distance

In this section, we present the results from the primary analysis. That analysis • excluded calls in situations with estimated probability of detection and localization <10% and calls when our boat was in or near the DASAR array, • included all other calls, • used both types of weighting factors, and • considered first non-anthropogenic variables, then ISI (industrial sound) variables, and finally airgun variables.

Non-Industrial Effects

In stage 1 of the primary analysis, considering non-anthropogenic variables only, the best-fitting quantile regression model at the end of backward elimination contained *upstream* ($\beta = -730$ meters, 95% CI = (–1697, 427), $P = 0.070$), and *uprange.smu* ($P = 0.003$) (see Table 6.1 for definitions). None of the coefficients in this model changed much when anthropogenic sound variables were added, but *upstream* became non-significant (see "*Best Predictors of 5th Quantile Offshore Distance*", below). For consistency and brevity, we focus on models from stages 2 and 3, and do not report the 5 coefficients for *uprange.smu* in the stage 1 (natural factors) model. The seasonal variable *dayofyear.smu* was eliminated during backward selection and therefore was not included in the top model at the end of stage 1. This means that there was not enough progressive variation in the 5th quantile over the season to warrant inclusion of the *dayofyear.smu* term. We note that relatively few calls were detected from 26 Aug. to 12 Sept. or 18 Sept. to 24 Sept. (Fig. 6.5). These periods represented a substantial part of the season and reduced our ability to detect seasonal fluctuations in the southern edge of the call distribution. (Analyses for 2001–2004 showed that offshore distance was significantly related to date in those migration seasons — Richardson et al. [2008].)

Apparent Industrial Sound (ISI) Effects

The top 10 quantile regressions at the end of stage 2 of model selection, considering both industrial (ISI) and natural (non-industrial) variables but not airguns, are summarized in Table 6.3. Among these models, the one containing presence of transients in the offshore acoustic record within 75 min preceding the call (*os.isi.trans.pres.*75) was the strongest predictor of 5th quantile distance. Terms and coefficients in this model appear in Table 6.4. When transients were present offshore, the top model from stage 2 estimated the 5th quantile offshore distance to be 2.7 km (95% CI = 1.5 to 3.6 km) <u>closer to shore</u> than during times without transients (after allowance for the natural factors *upstream* and *uprange.dist.smu*). Of the top 10 models, the "best" two incorporated measures of transients in offshore waters, and the other eight incorporated measures of industrial sound near the island (Table 6.3). However, each nearshore ISI variable (and other combinations of offshore ISI variables aside from *os.isi.trans.pres.75*) had a drop in dispersion statistic less than half that of the top model (Table 6.3). Thus, *os.isi.trans.pres.75* explained substantially more variation than did other ISI variables measured offshore or nearshore.

For the top 10 stage 2 models, the ISI coefficients in all but two models were negative, further indicating that in 2009 the 5th quantile distance apparently tended to be closer to shore when the 5-band or transient ISI variables were larger. The two variables with positive coefficients were those associated with the strength of offshore transients and nearshore tones (Table 6.3). The second-ranked model included strength of offshore transients (*os.isi.trans.75*) and its coefficient indicated that the 5th quantile distance was 0.51 km <u>farther offshore</u> for every 1 dB increase in strength of the transient. In the one model within the top 10 that incorporated a measure of the presence and strength of tones (*ns.isi.tone.pres.15*), the sign of the relationship was also positive: the 5th quantile distance tended to be farther offshore when tones were present near Northstar in the 15 min preceding the calls. The fact that 2 of the 10 top models had sound variables with positive signs indicates a need for caution in interpretation (see also "*Robustness of Results*", below).

TABLE 6.3. Apparent industrial effects in the top ten 5th quantile regression models estimated during stage 2 of model selection incorporating natural and ISI variables (primary analysis). Models were ranked by proportion of variation explained (i.e., %Δ F_{effect} = 100(max(F_{effect}) – F_{effect})/max(F_{effect}). *df* = number of coefficients estimated for the effect. *Coefficient* is the estimated coefficient of the industrial effect (in meters). Stage 2 models also included the natural variables (*upstream, uprange.dist.smu*) from the final stage 1 model. Airgun variables were not included at this stage.

Model Stage	Industrial Effect	*df*	Drop in dispersion statistic: F_{effect}	% ΔF_{effect}	Coefficient (m)
Stage 2	os.isi.trans.pres.75	1	233.44	0%	-2706.63
	os.isi.trans.pres.75 + os.isi.trans.75	2	117.72	50%	51.32*
	ns.isi5.45	1	99.44	57%	-100.96
	ns.isi5.75	1	90.95	61%	-100.04
	ns.isi5.60	1	90.00	61%	-101.80
	ns.isi.tone.pres.15	1	88.95	62%	2572.53
	ns.isi5.30	1	88.50	62%	-92.84
	ns.isi5.90	1	88.04	62%	-100.70
	ns.isi.trans.pres.120	1	84.07	64%	-1444.43
	ns.isi.trans.pres.105	1	84.01	64%	-1507.64

* Coefficient of the slope term. Slope term is the 2nd term listed under *Industrial Effect.*

TABLE 6.4. Coefficients and 95% confidence intervals for apparent effects in the best fitting stage 2 quantile regression model for data collected in 2009 (primary analysis). This quantile regression related the 5th quantile of offshore distance to natural and industrial (ISI) sound variables; airgun variables were not included at this stage. Units of coefficients are meters.

Term Type	Term	2009		
		Coefficient	Low 95%	Upper 95%
Background	*(Intercept)*	22026.98	22026.98	22026.98
	upstream	-520.17	-1847.48	579.93
	uprange.dist.smu.1	8296.21	-10094.93	18214.69
	uprange.dist.smu.2	-16976.78	-28677.08	-11617.64
	uprange.dist.smu.3	-872.06	-16290.66	8034.54
	uprange.dist.smu.4	-946.17	-15052.09	9533.35
	uprange.dist.smu.5	-7159.61	-27312.06	14392.58
Industrial	*os.isi.trans.pres.75*	-2706.63	-3633.95	-1484.95

Apparent Airgun Sound Effects

In stage 3 of the primary analysis, we considered eight models that each incorporated one measure of airgun sound as received offshore at DASAR C, along with the natural and ISI variables included in the final stage 2 model (Table 6.5). The model representing the presence and level of airgun sound received from the east in the 75 min preceding detection of the call accounted for most variability in the offshore distances of the calls. The negative coefficient in Table 6.5 indicates that the 5th quantile distance tended to be closer to shore as airgun sound levels from the east increased. The models incorporating the other seven measures of airgun sound had drop in dispersion statistics less than half, and in most cases much less than half, that of the top model (Table 6.5). The four measures of airgun sound from the seismic operation far to the east all were better predictors of 5th quantile distance than were any of the four measures of airgun sound from the seismic operation far to the north, but the top-ranked measure of airgun sound was a much better predictor of offshore distance than any other.

TABLE 6.5. Apparent airgun effects in all eight models estimated during in stage 3 of model selection incorporating natural, ISI and airgun variables (primary analysis). Models were ranked by proportion of variation explained (i.e., %Δ F_{effect} = 100(max(F_{effect}) – F_{effect})/max(F_{effect}). *df* = number of coefficients estimated for the effect. *Coefficient* is the estimated coefficient of the industrial effect (in meters). Stage 3 models also included the natural variables (*upstream, uprange.dist.smu*) and the "best" ISI variable (*os.isi.trans.pres.75*) from the final model from stages 1 and 2.

Model Stage	Industrial Effect	*df*	Drop in dispersion statistic: F_{effect}	% ΔF_{effect}	Coefficient (m)
Stage 3	airgun.east.pulse.pres.75+airgun.east.rms.75	2	398.83	0%	-684.73*
	airgun.east.pulse.pres.15+airgun.east.rms.15	2	181.06	55%	-746.56*
	airgun.east.pulse.pres.75	1	106.36	73%	2140.05
	airgun.east.pulse.pres.15	1	88.84	78%	2120.10
	airgun.north.pulse.pres.75+airgun.north.rms.75	2	74.79	81%	-1327.03*
	airgun.north.pulse.pres.15+airgun.north.rms.15	2	17.64	96%	-599.68*
	airgun.north.pulse.pres.15	1	5.65	99%	6890.13
	airgun.north.pulse.pres.75	1	na**	na**	na**

* Coefficient of the slope term. Slope term is the 2nd term listed under *Industrial Effect.*

** Model did not converge.

Best Predictors of 5th Quantile Offshore Distance

The top model at the end of stage 3 of model selection was adopted as "best" among all models fitted by the primary analysis. It included the natural variables *upstream* and *uprange.smu,* the industrial-sound (ISI) variable *os.isi.trans.pres.75*, and the airgun sound variables *airgun.east.pulse.pres.75* and *airgun.east.rms.75* (Table 6.6). Each of these apparent effects is described in turn below.

The effects quantified by *uprange.smu* were significant ($P \leq 0.004$) in the best fitting model. The *upstream* variable was marginally significant in the final model at the end of stage 1, and became insignificant once other terms were added to comprise the final model (*upstream* $P = 0.530$). According to our model fitting protocol established *a priori,* the *upstream* variable was retained in the final model despite its insignificance. In general, the southern edge of the distribution of bowhead calls, as estimated

TABLE 6.6. Coefficients and 95% confidence intervals for apparent effects in the best fitting stage 3 quantile regression model for offshore distance data collected in 2009, *case weights included* (primary analysis). The quantile regression related the 5th quantile of offshore distance to natural (background) variables and measures of industrial sound (ISI) and airgun sound. Units of coefficients are meters.

Term Type		2009			
	Term	Coefficient	Low 95%	Upper 95%	*P*-value
Background	*(Intercept)*	22190.41	22190.41	22190.41	n/a
	Upstream	-585.25	-1811.48	548.43	0.53
	uprange.dist.smu.1	7581.70	-7248.89	17302.03	0.004
	uprange.dist.smu.2	-18032.36	-26072.39	-13011.67	
	uprange.dist.smu.3	-2281.67	-14944.83	5570.22	
	uprange.dist.smu.4	-6575.59	-18761.07	3335.33	
	uprange.dist.smu.5	-11958.26	-29926.46	5372.63	
Industrial	*os.isi.trans.pres.75*	-1819.93	-2768.08	-719.21	0.011
Airgun	*airgun.east.pulse.pres.75*	61251.91	33518.38	81923.42	0.001
	airgun.east.rms.75	-684.73	-928.04	-370.03	0.001

by *uprange.smu*, was substantially closer to shore near the study's centerline than farther east or west (Fig. 6.6). This made the estimated 5th quantiles appear to bend shoreward near Northstar Island.

In the best-fitting stage 3 model, as in the final model at the end of stage 2 before airguns were considered, the presence of transients near the general offshore position of the 5th quantile during the 75 min period prior to a call (i.e., *os.isi.trans.pres.75*) was statistically significant at $P = 0.011$, with a negative coefficient. The magnitude of the negative coefficient for *os.isi.trans.pres.75* indicated that the 5th quantile of offshore distance tended to be 1.82 km (95% CI = 0.72 to 2.77 km) closer to shore when transients were present during the 75 min immediately preceding a call (Table 6.6; red vs. blue curves in Fig. 6.5). In contrast, a small but statistically significant *positive* effect was found in the autumns of 2001, 2002, 2003, and 2004 at times in those seasons when levels of underwater sound near Northstar were elevated (Richardson et al. 2008). Although the presence of transients offshore was not a specific variable considered in past analyses for 2001–2004, the presence of Northstar-related transients and tones in the nearshore recordings was considered in those past analyses. Comparing coefficients of these nearshore variables in the 2009 vs. 2001–2004 analyses, it is clear that the coefficients for the 5-band and transient variables in the current best-fitting model are of opposite sign to those in 2001–2004. The coefficients for presence and magnitude of nearshore tones had the same sign in current and past work, although variables based on tones were not strong predictors in 2009. For discussion later, we note the presence of a large number of tightly grouped calls between DASARs A and B when *os.isi.trans.pres.75* = 1 (red dots on red line in left panel of Fig. 6.6). Although these calls could potentially exert high leverage on the regression model, the model remained essentially unchanged if these points were removed and the model was recomputed (see DISCUSSION).

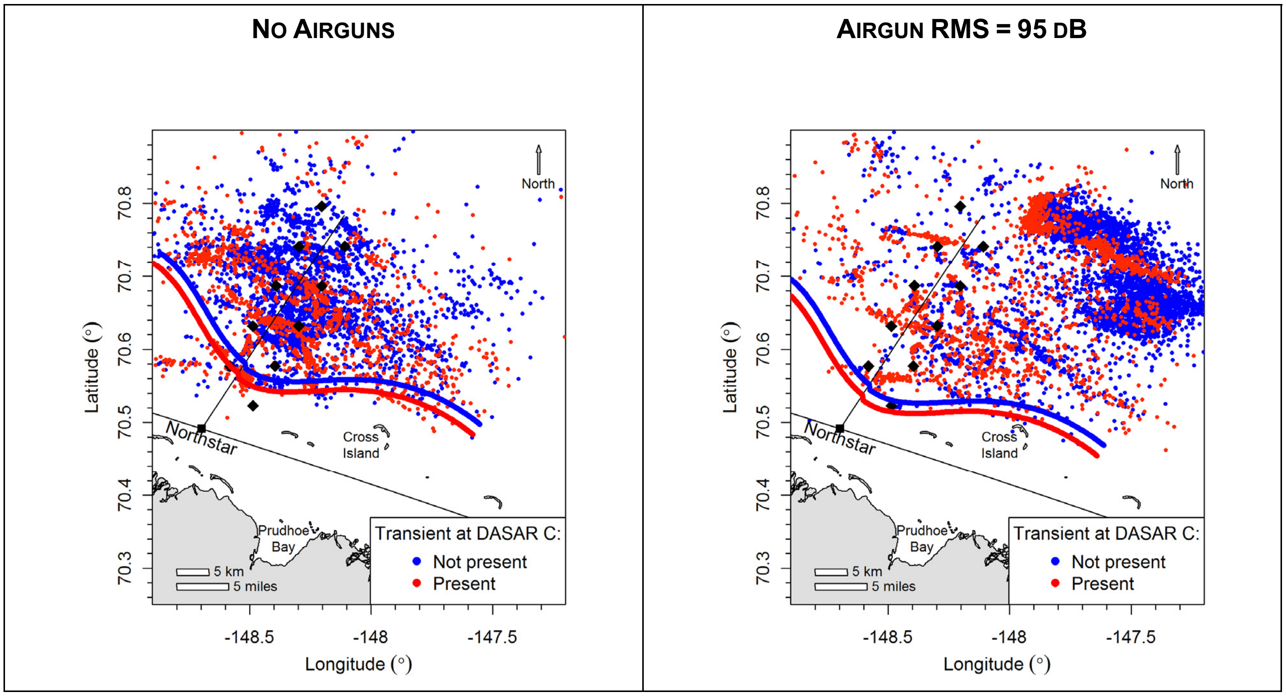

FIGURE 6.6. Relationship of the 5th quantile of offshore distance to presence of transient sounds and airgun sounds as received and measured at DASAR C in 2009 , based on the best-fitting model from the primary analysis. Curves show estimated 5th quantile of offshore distance to whale calls when transient sounds were (*os.isi.trans.pres.75* = 1) and were not (*os.isi.trans.pres.75* = 0) present at DASAR C during the 75 min immediately preceding a call. Left panel indicates position of 5th quantile when no airgun pulses were present at DASAR C. Right panel indicates position of 5th quantile when received RMS levels of airgun pulses from the eastern (BP Canada) seismic operation reached 95 dB re 1 μPa. In both cases, change in 5th quantile distance = –1.82 km (95% CI = –2.77 to –0.72 km) when industrial transients were present at DASAR C.

Inclusion of the airgun variable combination *airgun.east.pulse.pres.75* + *airgun.east.rms.75* substantially improved the fit of the final model. The levels of airgun pulses received at DASAR C from the seismic operation far to the east in the Canadian Beaufort Sea were generally low (see Fig. 4.28C *in* Chapter 4); the received pulse levels were usually not much above ambient sound levels (generally 70 to 90 dB re 1 μPa). However, the coefficient for *airgun.east.rms.75* indicated that, on average, the 5th quantile of offshore distance was 0.68 km (95% CI = 0.37 to 0.93 km) closer to shore for every 1 dB increase in received airgun pulse level above ~90 dB re 1 μPa (compare left and right panels of Fig. 6.6). Due to the positive airgun intercept term (*airgun.east.pulse.pres.75*), the predicted 5th quantile offshore distance did not become closer to shore than average until received airgun pulses exceeded ~90 dB re 1 μPa.

Robustness of Results

The re-analyses designed to assess sensitivity of the primary results to changes in key analysis assumptions and decisions are summarized in Table 6.7. In this section, we describe each of the sensitivity analyses. In each case, we excluded periods of time (and all calls detected) when our boat was in or near the DASAR array servicing the DASARs. Line (A) of Table 6.7 summarizes the primary model for 2009, as previously described.

TABLE 6.7: Results of the sensitivity analyses designed to assess effects of changes in key analysis assumptions and decisions. The primary analysis is reported in detail in earlier sections, Tables and Figures. The sensitivity analyses (lines B–E in this Table) are described in this "Robustness" section. *P(inclusion)* is the estimated probability of detecting and localizing a call via the DASARs given the time and place of the call. Industrial and airgun variables are explained in Tables 6.1 and 6.2. Calls occurring at times when our research vessel was in or near the DASAR array were excluded from all analyses summarized here.

		Call locations included				Results	
Line ↓	Analysis Description	P(inclusion) <10%?	Outside 8k silo?	Case Weights Used	Order* of Model Selection	Industrial Variable Included (sign of coefficient)	Airgun Variable Included (sign of coefficient)
A	Primary	No	yes	P(inclusion) & Loc'n uncert.	(1)(2)(3)	*os.isi.trans.pres.75* (-)	*airgun.east.pres.75* + *airgun.east.rms.75* (-)
B	Silo	Yes	no	[no weights]	(1)(2)(3)	*os.isi.trans.pres.75* (-)	(non-significant)
C	Loc'n uncert. weights only	Yes	yes	Loc'n uncert. only	(1)(2)(3)	*ns.isi.tone.pres.120* (+)	*airgun.east.pres.75* + *airgun.east.rms.75* (-)
D	Revised model selection	No	yes	P(inclusion) & Loc'n uncert.	(1)(3)(2)	*ns.isi.trans.pres.120* (-)	*airgun.east.pres.75* + *airgun.east.rms.75* (-)
E	Rev. model selection; Loc'n uncert. weights only	Yes	yes	Loc'n uncert. only	(1)(3)(2)	*ns.isi5.45* (-)	*airgun.east.pres.75* + *airgun.east.rms.75* (-)

* (1) = natural environmental variables; (2) = near shore and offshore industrial sound (non-airgun) variables; (3) airgun variables.

Line (B) of Table 6.7 shows the model results when a specific and relatively confined study area was defined (the "silo"), allowing case weights to be excluded. During the entire 2009 study period, a total of 4199 calls were localized inside the "silo". Cluster analysis of these 4199 calls yielded 65 clusters for use in the block permutation method. The quantile regression analysis was re-run considering all calls (and only the calls) within the silo, no case weights, and the same model selection sequence as in the primary analysis, i.e., stages (1)(2)(3). With this approach, no natural variables entered *f(non-industry variables),* presumably due to the restricted extent of the silo study area and/or the lower sample size (reduced statistical power). However, the same industrial sound variable that entered the primary model (i.e., *os.isi.trans.pres.75*) also entered the silo model (see lines A and B of Table 6.7). The size and direction (negative) of the coefficient for this *os.isi.trans.pres.75* effect were approximately the same in the main and silo analyses. The coefficient in the main analysis was –1.82 km (95% CI = –2.77 to –0.72 km) and the corresponding coefficient in silo analysis was –3.48 km (95% CI = –8.70 to –0.40 km). No significant airgun effect was found in this analysis, contrary to the otherwise consistent airgun effect found in the primary analysis and all other sensitivity analyses (Table 6.7). A map of the calls within the silo, also showing the industrial sound effect estimated by this model, appears as Figure 6.7.

Line (C) of Table 6.7 summarizes a model run differing from the primary analysis in that probability of inclusion weights and the "P(inclusion) ≥ 10%" requirement were both dropped. The location-uncertainty weights were retained, and the model selection sequence was the same as for the primary analysis, i.e., stages (1)(2)(3). The natural variables that entered *f(non-industry variables)* were *uprange.-smu* and *dayofyear.smu.* The top model at the end of stage (3) contained the nearshore industrial sound variable *ns.isi.tone.pres.120* (coefficient = 9.9 km, 95% CI = 8.8 km to 11.3 km). Note that the sound variable had a positive coefficient, contrary to the negative coefficients found by the primary analysis

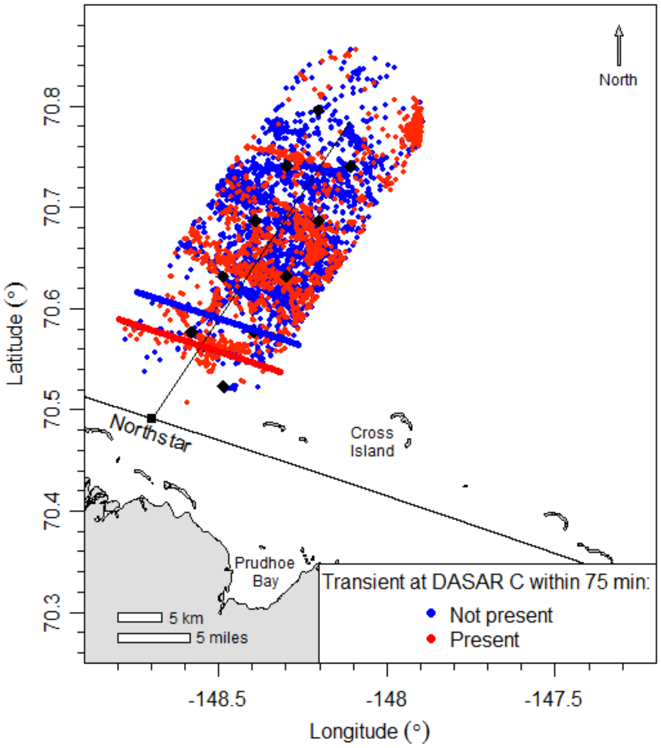

FIGURE 6.7. Call locations included in the "silo" sensitivity analysis to assess effects of excluding case weights and the "estimated probability of inclusion ≥10%" requirement for 2009. The fixed-boundary study area ("silo") extends 8 km on either side of the centerline, and from Northstar (baseline) to 8 km beyond the northern end of the centerline. Calls with estimated locations inside the silo were included whether or not the estimated probability of detection and localization was ≥10%, and no case weights were used. Calls that occurred during times when our boat was in or near the array were excluded. Red and blue lines across the "silo" show the estimated 5th quantile of offshore distance when transient sounds were (*os.isi.trans.-pres.75* = 1) and were not (*os.isi.trans.pres.75* = 0) present, respectively, at DASAR C during the 75 min immediately preceding a call. Other sensitivity analyses consider the calls mapped in Figure 6.4, and those results are summarized in Table 6.7

and all other sensitivity analyses for 2009 (Table 6.7), but consistent with findings in 2001–2004. Airgun variables *airgun.east.pulse.pres.75* + *airgun.east.rms.75* were significant, with coefficients = 37.8 km and –0.46 km respectively. As in the primary analysis, the 5th quantile of offshore distance to calls tended to be closer to shore when airgun sound was arriving from the east.

Line (D) of Table 6.7 summarizes a model run in which the model selection sequence was revised to include airgun variables before other industrial sound variables; both case weights were included, as in the primary analysis. In this case, the top model at the final stage contained the nearshore industrial sound variable *ns.isi.trans.pres.120* (coefficient = –2.6 km, 95% CI = –3.8 km to –1.6 km). The negative sign again indicates that the 5th quantile of offshore distances tended to be closer to shore as this industrial sound index increased, as found in most (but not all) analyses for 2009. However, the specific sound measure in the best-fitting model was from the nearshore rather than offshore measurement location. Airgun variables *airgun.east-.pulse.pres.75* + *airgun.east.rms.75* were significant, with coefficients = 70.7 km and –0.80 km respectively; again, the calls tended to be closer to shore when airgun sound arrived from the east.

Line (E) shows that, when probability of inclusion weights were excluded under the revised model selection scheme (airgun sound before other industrial sound), the top model at the end of the final stage contained the nearshore industrial sound variable *ns.isi5.45,* again with a negative coefficient (coefficient = –0.39 km, 95% CI = –0.48 km to –0.32 km). Airgun variables *airgun.east.pulse.pres.75* + *airgun.east.rms.75* were again included, with coefficients 39.8 km and –0.49 km respectively. As for all previous models except the fixed-study-area (silo) model, the southernmost calls tended to be significantly closer to shore when airgun sound arrived from the east during the preceding 75 min.

Overall, results of the sensitivity analyses are not fully consistent with the primary analysis. That is to say, some important details of the results reported here depend upon assumptions and decisions taken in constructing the analysis. In particular, analysis decisions affected the apparent relationship between (a) the 5th quantile of offshore distances of calls and (b) industrial sounds measured underwater near or offshore of Northstar. Analysis decisions affected not only the specific measure of industrial sound that was most related to offshore distance, but also affected the sign of the relationship identified by the analysis. This means that, for the late summer/early autumn period of 2009, ***the overall analysis was not conclusive in characterizing a specific relationship between the offshore distances of bowhead whale calls and industrial sound***.

There are, however, two general observations that can be made based on the primary analysis and subsequent sensitivity analyses:

- First, all except one analysis (the exception being (C) in Table 6.7) indicated that the 5th percentile of the distribution of whale calls tended to be *closer* to shore when the measure of industrial sound included in the "top model" increased. This pattern, aside from analysis (C), is contrary to that expected and contrary to that found during 2001–2004. In those earlier years, increases in industrial sound (as measured near Northstar) were associated with a tendency for increased offshore distances to the 5th percentile of the call distribution (see DISCUSSION for possible reasons).
- Second, all analyses except (B) indicated that the lower tail of the distribution of calls was *closer* to shore with increasing received levels of airgun pulses arriving from the east. Analysis (B) did not include any significant airgun variables in the final model, perhaps because of the limited spatial study area used here and the limited sample size relative to other analyses (reduced statistical power). It is noteworthy that received levels of airgun pulses entered all other models as a significant predictor of offshore distances to calls, given that the seismic operation to the east was in Canadian waters, hundreds of kilometers away.

DISCUSSION

This study in large part repeated previous studies conducted during 2001–2004. The one major difference in data collection methods between this study and prior studies was the extended array of DASARs used in 2009 relative to 2001–2004, now spanning a larger fraction of the autumn migration corridor. Analysis differences between 2001–2004 and 2009 included • consideration of additional ISI variables measured at an offshore position near the average position of the 5th quantile of offshore distances, and • consideration of variables characterizing exposure to sound pulses from distant airguns. Otherwise, the data collection and analysis methods used in the "primary" analysis of 2009 data (see "Results") were identical to those used in the most recent analyses of 2001–2004 data (McDonald et al. 2008 and in review; Richardson et al. 2008).

Three general features of the study warrant mention before discussion of the specific analysis results. First, this study was based on remote detection of bowhead whale calls, with no visual observation component. The acoustical monitoring approach was chosen before the start of the study in 2000 given the inability of any alternative approach (especially aerial surveys) to provide a sample size sufficient to detect and characterize the then-anticipated small effects on whale distribution. However, the acoustical approach can only detect a whale if it calls. In this study, if whales were present but silent, then their presence was unknown. More importantly, if the rate of calling or source level of the whale calls was affected by exposure to anthropogenic sound, then sound exposure could cause a change in the distribution of the detected calls even if there were no change in whale distribution. Acoustic effects on calling behavior are known to occur in some other cetacean species and are suspected to occur in bowhead whales (Blackwell et al. 2008). Therefore, the present analyses, and those based on the 2001–2004 data, concern factors affecting the distribution of bowhead whale calls. Bowhead distribution *per se,* which we did not measure, may or may not have the same relationships to sound exposure. When we identify a tendency for whale calls to be closer to or farther from shore when anthropogenic sound is higher, that suggests an effect of the sound on some aspect of bowhead behavior, either distribution or calling behavior. However, from the acoustic localization data alone, we cannot say whether the effect is on distribution or calling behavior, or both. This topic was discussed in more detail in our earlier reports on the 2001–2004 study (e.g., Richardson et al. 2008).

A second general feature of the study, and of any other study based on statistical analysis of data from an uncontrolled field study, is that one is ultimately identifying and describing patterns of correlation, which may or may not be indicative of causal relationships. This well-known generalization is true no matter how large the sample size and how elaborate the analysis. However, careful analysis can improve the ability to identify real relationships in the data, and that is an underlying reason for the exhaustive approach that has been taken in analyzing both the 2001–2004 data and these 2009 data.

Third, due to the inherent complexity and variability of cetacean behavior, and the small scale of the "Northstar effect" on call distribution relative to natural variability, different results might be found in another year or area. That was one of the reasons for conducting this study in 2009 despite the extensive related work already done in 2001–2004 (Richardson [ed.] 2008). Furthermore, given the complexity of the analyses, there can be differences of opinion about the most appropriate way to conduct the analysis, and analysis decisions may at times lead to different analysis results. That was the reason for conducting sensitivity analyses, both in this study and in the 2001–2004 work, to check on the robustness of the results relative to decisions about the analysis approach.

Analysis Approach

It was our intention to replicate the 2001–2004 work as closely as possible in order to verify results or gain additional insights into changes in behavior of bowheads. We adhered to that strategy in conducting and reporting our "primary analysis" despite the fact that certain aspects of the analysis approach were not optimal for 2009 data. In particular, inclusion of airgun pulse levels in background sound measurements may have biased the computed "inclusion probability" weights, which were designed to represent the probability of detecting and localizing calls in the circumstances of each detected call. If there were a large bias in these estimated inclusion probabilities, that could have affected the outcome of the analysis in unpredictable ways. That may be one reason why the 2009 results (as compared to 2001–2004 results) were more sensitive to some of the key analysis decisions, e.g., whether to use case weights based on inclusion probabilities (see Table 6.7, line C vs. A).

The role of case weights based on inclusion probabilities and/or localization accuracies deserves reconsideration before any future analyses of this type are done. Early analyses of the 2001–2004 data utilized a clearly defined ("bounded") study area analogous to the silo shown in Figure 6.7, though the study area in 2001–2004 did not extend as far offshore. When the analysis considers only those calls within a few kilometers of the closest DASAR, most calls included in the analysis are in situations where detection probability is high. In that situation, use of inclusion probability as a case weighting factor is logically unnecessary, and if it is used, the analysis should be less strongly affected by those weights. Case weights based on inclusion probability, and associated estimation issues, became important when (in 2005) a scientific review panel recommended re-analysis of the 2001–2004 data to include calls at locations far from the DASAR array (NSB SAC 2005). To include distant calls, it was necessary to consider distance-dependent variation in inclusion probabilities because calls far from the array are not observed at the same rate as calls near the array. As it turned out, inclusion probabilities were correlated with localization accuracy, as both depend on distance from the DASARs. In many cases, it may be sufficient to consider only one of these weights as a case weighting variable—see McDonald et al. (2008 and in review). Also, the expanded DASAR array used in 2009 (and 2008) extends across most of the width of the bowhead autumn migration corridor during light-ice years (Fig. 6.1). With this extended DASAR array, there may be less need to include distant calls in the analysis, particularly when (as is true here) the primary objective is to assess anthropogenic effects on the southern part of the migration corridor. If the calls included in the analysis are limited to a fixed area such as that shown in Figure 6.7, it might still be desirable to consider at least one of the intercorrelated case weights, but the dependence of results on case weights should logically be reduced.

In our "primary analysis", we first considered the effects of natural variables such as uprange-downrange distance, day/night and date (stage 1), and then considered measures of industrial (Northstar and similar) sound in the water (stage 2). That sequence was also used during analysis of 2001–2004 data. Only then did we consider airgun sound (stage 3). Stage (3) did not occur during analysis of 2001–2004 data because airgun sound was not one of the covariates considered for those years.[5] As noted in the "*Robustness of Results*" section earlier, assuming that Northstar effects are of primary interest in this study, it would perhaps be more logical to allow for airgun effects before attempting to detect and characterize effects of Northstar and Northstar-like sounds. That alternative approach was applied in two of the model runs done during the sensitivity analysis (see Table 6.7, lines D and E). As shown there and in the associated *Robustness* text, the analysis results depended to at least a limited degree on the order in which airgun vs. industrial sound variables were considered. This is shown in Table 6.7 by a comparison of line D vs. A, and of line E vs. C.

Airgun Sound Effect

The "primary analysis" (with unbounded study area and case weights) found a statistically significant tendency for the 5th quantile of the offshore distances to whale calls to be closer to shore in the presence of airgun sound arriving from far to the east. The same statistically-significant effect was found in all but one of the re-analyses done as part of the sensitivity analysis (Table 6.7). The one exception was the "bounded study area" (silo) analysis that considered a smaller study area and lower sample size. Overall, the tendency for the southern edge of the call distribution to be closer to shore when airgun sounds were arriving from the east seemed largely consistent and robust.

Effects of airgun operations on bowhead call distributions are not of primary interest in this study. Rather, airgun sound was considered as a covariate in order to account for a potentially confounding

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[5] Seismic surveys did not occur in the Alaskan Beaufort Sea during the 2001–2004 autumn migration seasons of bowhead whales. There were seismic surveys in the Canadian Beaufort Sea during some of those years (2001–2002; Miller et al. 2005). However, before the present analysis of 2009 data was done, it was not suspected that seismic surveys in the Canadian Beaufort would be relevant to bowheads in the Northstar area.

influence on call distribution before or while characterizing Northstar effects on call distribution. Nonetheless, this apparent effect of distant airguns is of interest with regard to airgun effects on bowhead whales and cetaceans in general. The one seismic operation underway to the east during the study period was a BP project in the Canadian Beaufort Sea a few hundred kilometers east of Northstar (B. Streever, BPXA, pers. comm.). The median received levels of the airgun pulses in waters near the southern edge of the migration corridor (e.g., at DASAR "C") were quite low, and levels farther offshore (e.g., near DASAR "J") were not much higher (see Fig. 4.28C *in* Chapter 4).

It should be noted that the evidence presented here that distribution of bowhead calls was related to presence and received levels of sounds from distant airguns does not necessarily mean that airgun sounds affected the distribution of bowheads. First, the observed effect on call distribution was found in a single situation in a single year via a complex analysis. Although sensitivity analyses showed that the trend was largely consistent regardless of the specific details of the analysis, it would be desirable to confirm the effect in another year or situation, or by some alternative study procedure, before concluding that such a distant seismic survey can affect the distribution of bowhead calls. Second, if the effect was real and repeatable, it might have been an airgun effect on whale distribution, but it might also have been an effect on calling rate rather than on whale distribution or movement. Either way, it would represent an effect (admittedly subtle and detectable only by detailed statistical analysis) of distant airguns on some aspect of bowhead behavior.

As an example of a possible mechanism by which the apparent effect might arise, consider what might happen if occurrence or an increasing received level of airgun sound tends to suppress bowhead calling rate. Shallow water tends to attenuate in-water propagation of airgun sound, especially the predominating low-frequency components. Therefore, sound levels from a seismic operation far to the east would be expected to be higher in deeper waters far offshore of Northstar than in shallow waters closer to Northstar. Received levels of airgun sound at DASAR J in water depth 38 m did tend to be higher than those at DASAR C in 23 m (Fig. 4B vs. 4C). If higher levels of airgun sound tend to suppress bowhead calling rate, that could in theory account for a tendency for the 5th quantile of the call distribution to be closer to shore with airgun pulses from the east, whether or not airgun sounds affected actual whale distribution.

We are not aware of any previous study that has found statistically significant evidence of an apparent airgun effect on behavior of bowheads or other cetaceans at such a long distance. However, Bowles et al. (1994) did find hints of airgun sound effects on sperm whale (*Physeter macrocephalus*) calling behavior at similarly long distances. Previous studies in the Alaskan Beaufort Sea have shown that the number of bowhead calls tends to be reduced in the presence of airgun sounds from closer seismic operations (e.g., Greene et al. 1999a,b; Blackwell et al. 2009), and some migrating bowheads are known to avoid waters within 20–30 km of an operating seismic vessel (Miller et al. 1999; Richardson et al. 1999). However, in those cases, received levels of airgun pulses were higher than in the waters off Northstar in 2009.

Northstar and Vessel Effects

The past analyses of 2001–2004 Northstar data detected, for each of the four autumn seasons, a small but statistically significant *offshore* shift in the distribution of whale calls when indices of anthropogenic sound (as measured ~450 m from Northstar) were elevated. In 2009, similar methods found evidence of a small but statistically significant *onshore* shift in the distribution of whale calls when anthropogenic transient sounds (typical of a vessel passage) were found in offshore recordings. That onshore shift was unexpected, given the contrasting 2001–2004 results and the general expectation that bowhead whales would show stronger avoidance of a source of industrial sound when source and received sound level increased (Richardson and Malme 1993). Nonetheless, the onshore shift when industrial sound transients were detected offshore was evident both before and after we considered the significant effect of airgun sound received from the east. Roughly the same onshore shift was evident when the analysis was repeated with a fixed study area and no case weights (see lines B vs. A *in* Table 6.7).

However, when the analysis was repeated with other adjustments of the analysis procedure, the apparent relationship between offshore distances and industrial sound changed. Two additional analyses (lines D and E *in* Table 6.7) found evidence of an *onshore* shift in calls when industrial sound levels were elevated, in some respects consistent with that found in lines A and B. However, another analysis (line C) found evidence of an *offshore* shift with elevated industrial sound. Also, all three of these alternative analyses found that an industrial sound index measured near Northstar was the best predictor of a sound-related shift in call distribution, whereas the first two analyses (lines A and B *in* Table 6.7) suggested that an industrial sound index measured offshore (near the 5th quantile distance) was a better predictor of that distance.

There are several possible explanations for these seemingly contradictory analysis outcomes. • First, the differential effects found in the 2001–2004 studies (offshore shift) and the current study (onshore shift according to most analyses) could be genuine. The opposite directions of effect might be due to changes in whale behavior between years (attraction to certain weak industrial sounds?), or some interaction with the presence of airgun sound in 2009. • Second, the predominantly opposite effect (onshore shift) found during the current study might be an artifact of the generally low number of whale calls and especially the low number of distinct call clusters detected during 2009. • Third, the opposite effects might be attributable to some problem, or at least a change, in the way the main analysis was performed for 2001–2004 vs. 2009. For example, consideration of offshore sound measures in 2009 but not in 2001–2004 might have had some unexpected consequences.

We do not have a conclusive answer as to why some seemingly-significant results are in opposite directions, but we note the following potentially relevant considerations:

- The 2001–2004 results were internally consistent in that the same analysis procedure was applied each year, and a small but statistically significant sound-related northward shift in the 5th quantile of offshore distances was found in each of those years. It seems unlikely that one would, as a result of random sampling effects, find spurious evidence of a northward shift 4 years in a row if it were not real.
- The temporal pattern of calls observed in 2009 was quite different than in 2001–2004. In 2009, the vast majority of calls occurred during two relatively short intervals, 13–15 Sept. and 27–28 Sept. (Fig. 6.5). This highly pulsed pattern of calls could have made the 2009 analysis more sensitive to the locations of a few whale groups. In Figure 6.5, we highlighted the presence of what appeared to be 2, 3 or perhaps 4 whale groups at locations between DASARs A and B; these groups, near the typical 5th quantile distance, might have had a high influence on results. Further investigation showed, however, that these few cases did not have undue influence on results because, when they were removed and the quantile regression model was re-run, the coefficient of *os.isi.tran.pres.75* changed only slightly (from –1.82 km to –2.63 km), as did the coefficient of *airgun.east.rms.75* (from –0.68 km/dB to –0.53 km/dB). If the highly pulsed and spatially aggregated pattern of calls caused the contrary results in 2009, that effect was subtle and probably was not a result of the presence of large groups of calls near the typical 5th quantile distance.

- Given the scrutiny and review that previous reports and analyses have received, it seems unlikely that there is a flaw in the main analysis approach large enough to cause spurious or opposite results. We are therefore left to conclude that the predominant evidence for an *onshore* shift with elevated industrial sound in 2009 (as indicated by 4 of 5 models summarized in Table 6.7) most likely results from some change in the character of the sounds measured, a change in whale behavior between years, or some interaction with the presence of airgun sound in 2009.

One potentially important consideration is the fact that the 2009 analysis considered industrial sound indices (ISIs) measured offshore, near the typical 5th quantile distance, as well as ISIs measured near Northstar, whereas the 2001–2004 analyses considered only the near-Northstar ISIs. The near-Northstar ISIs undoubtedly better represent fluctuations in sound emanating from Northstar, as they are less affected by other sound sources (natural and anthropogenic) than are the offshore ISIs. Conversely, the offshore ISIs are a better representation of the sounds received by whales near the 5th quantile distance. The latter sounds include some components from Northstar (see Chapter 4), but also include major components of natural background sound, "non-Northstar" vessel sound, and probably also sounds from other human activities not related to Northstar. Thus, the offshore ISIs are not predominantly indices of Northstar sound, but rather are indices of the composite sound in offshore waters, including occasional contributions from Northstar but mainly representing other sound sources. If the offshore ISIs are not (for the most part) measures of Northstar sound, one would not necessarily expect to find a positive relationship between the offshore distances of whale calls (or whales) and the offshore ISIs.

Hence, in any future related analyses, we consider it important to again assess the relationship between call locations and ISIs measured close to the source of interest (here Northstar), along with any further analyses of call locations relative to ISIs measured closer to the whales and farther from the industrial source of interest. Notwithstanding that whales no doubt react to sounds they receive rather than to sounds being emitted from some distant source, whale response to an industrial sound source may be better correlated with its emitted industrial sound than with a measure of the composite sound received by the whale, much of which may be non-industrial.

Notwithstanding the above considerations, and the fact that one analysis approach showed an apparent offshore shift in call distribution with increased ISI near Northstar (line C *in* Table 6.7), two other analysis approaches showed an apparent onshore shift with increased ISI *near Northstar*. The latter result might occur if bowheads are curious about relatively low-level sound from Northstar, and if they tend to be attracted to that sound. Some other cetacean species are attracted to other anthropogenic sounds that they apparently do not perceive as threatening, e.g., minke whales *Balaenoptera acutorostrata* and Dall's porpoises *Phocoenoides dalli* attracted to some types of boat noise (reviewed in Richardson et al. 1995b).

One could speculate further about these variable and sometimes difficult-to-understand results. In the end, however, we cannot draw a concrete conclusion about Northstar effects in 2009 as evident from the statistical analyses, given their inconsistencies. One conclusion that can be drawn comes from simple inspection of Figure 6.4: Any onshore or offshore shift in bowhead call distribution that did occur when industrial transients were evident offshore must have been quite small and minor or very transient in nature. There were no major visually-obvious differences in call distribution, and there was no dramatic cessation of calling, when industry-related transient sounds were present vs. absent in the water near the southern edge of the bowhead migration corridor at DASAR C.

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CHAPTER 7:

THE 2005–2009 SUBSISTENCE WHALING SEASONS AT CROSS ISLAND, WITH REFERENCE TO PREVIOUS SEASONS[1]

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ABSTRACT

The North Slope Borough's Science Advisory Committee (NSB SAC) recommended in 2005 that local and traditional knowledge of Nuiqsut whalers be incorporated into reports concerning BP's Northstar marine mammal and acoustic monitoring program. This chapter does so in large part by summarizing data acquired during the Minerals Management Service (MMS) project "Annual assessment of subsistence bowhead whaling near Cross Island" (2001–present). Those data were supplemented by interviews with the whalers in 2005–2009 focusing on specific aspects of the 2001–2009 whaling seasons relevant to BP's Northstar monitoring program. The interviews concentrated on whalers' encounters or concerns with non-whaling vessels, and the whalers' observations of the general offshore distribution of bowhead whales, whale feeding behavior (if any), and "skittish" behavior. The emphasis in this chapter is on the period 2005–2009, with prior years being discussed only where especially pertinent.

Historically, Cross Island was used periodically as a base for subsistence whaling during the first half of the 20th century (prehistoric use is not well documented). After a hiatus in mid-century, whaling in the general area resumed in 1973 when Nuiqsut was resettled, and a bowhead whale was taken that year near the Canning River. For several years after 1973, relatively few crews from Nuiqsut whaled, and they had infrequent success. Subsequently Cross Island came to be used increasingly as a base, and both the number of crews and hunting success increased, especially in the 1990s. However, in certain years, there were difficulties that the whalers attributed variously to weather, ice conditions, or interference by marine seismic surveys and offshore exploratory drilling operations. At times, whales were perceived as having been deflected offshore by industrial activities east of Cross Island, or to be "spooky" and difficult to approach. Stakeholder discussions of these issues resulted in 1986 in the "Oil/Whaler Agreement" to mitigate and minimize such effects. This mechanism continued (after a lapse of several years with no offshore oil and gas exploration in the Alaskan Beaufort Sea) under the label "Conflict Avoidance Agreement" (CAA). The CAAs, combined with BP Standard Operating Procedures and agency stipulations, have been largely successful in preventing or mitigating Northstar effects on Cross Island whaling.

The variability among the 2001–2009 whaling seasons that was documented by the MMS project was primarily due to differences in ice and wind conditions, differences in the distribution (distance from Cross Island) and apparent local abundance of whales, and variable behavior ("normal" or "skittish") of whales. Year-to-year differences in effort expended by whalers ("boat hours") were fairly well quantified. However, the relationships between variable whaling effort and variability in ice and wind conditions, whale distribution, or whale behavior were not as clear-cut. The ice conditions that occurred during the nine seasons sometimes prevented access to whales altogether but otherwise seemed to have no net effect. Adverse weather conditions hinder whaling, but the shortest seasons were those that were measurably the worst in terms of weather. Perhaps the least ambiguous factor associated with the effort expended per landed whale was the distance of whales from Cross Island, i.e., the distance from Cross Island where whalers found whales. The two were directly related: the greater the distance, the greater the effort. That result is hardly surprising.

Of the anthropogenic activities considered in this chapter, vessel traffic probably had the greatest direct or perceived adverse effects on Cross Island subsistence whaling during 2001–2009, even though precise effects would be difficult to demonstrate in a rigorous way. Vessel effects were almost totally related to non-oil-industry commercial vessel traffic that operates outside the provisions of the CAA. The CAA has effectively managed most industry-whaler potential conflicts, at least in the area of industry-whaler vessel interaction. The problematic vessel interactions, most prominently those of 2005, were all with non-oil-industry vessels not subject to the CAA.

7.1 INTRODUCTION

Each year, subsistence hunters from Nuiqsut have a two- to four-week window of opportunity to harvest bowhead whales during their autumn migration. In late August or early September, Nuiqsut whalers travel to Cross Island (about 118 km or 73 miles ENE of Nuiqsut, 27 km or 17 miles east of Northstar Island) in order to hunt bowhead whales. In recent years, a quota of four whales has been allotted to the Nuiqsut hunters. Cross Island is also relatively close to the Prudhoe Bay area and its associated industrial activities. There is considerable concern among the Nuiqsut hunters about the potential for vessel and aircraft traffic, and other industrial activities, to interfere with the hunt.

The North Slope Borough's Science Advisory Committee (SAC) reviewed the results of BP's Northstar marine mammal and acoustic monitoring program during early 2005. One of their recommendations was to use Traditional Knowledge (TK) in future monitoring. Specifically, the SAC recommended that the observations of subsistence whale hunters at Cross Island should be integrated into the Northstar monitoring study. The SAC noted that "Such observations might include general offshore distribution of whales, feeding behavior, "skittish" behavior, number of vessels and reaction to them. We recommend that TK observations be summarized in a section of the Northstar annual report." Since 2005, this information has been included in each of BP's annual and comprehensive reports on Northstar monitoring (Galginaitis 2006b, 2007, 2008a,b, 2009a, 2010a). Those reports are included on the CD-ROM of Appendices to the present report.

Since 2001, the Minerals Management Service has sponsored a detailed study of the whaling activities at Cross Island (Galginaitis and Funk 2004a,b,c, 2005; Galginaitis 2006a, 2008c,d,e, 2009b,c, 2010b). It was apparent that the ongoing MMS study provided a good starting point for the compilation of the types of traditional knowledge that the NSB's SAC had recommended be incorporated into BP's Northstar monitoring program. Consequently, BP agreed to augment the ongoing MMS-supported program during 2005 in order to compile the specific types of information mentioned by the SAC, and has continued to do so through the present.

This chapter describes information provided by the Nuiqsut subsistence whalers, based on their experiences and observations, on selected aspects of the 2005–2009 (and to a limited degree earlier) whaling seasons. Emphasis is given to cases when human activities or natural phenomena were perceived as interfering with whaling at Cross Island. Thus, the chapter primarily describes and discusses the general offshore distribution of bowhead whales as observed by the whalers, any observations of feeding behavior of whales, observed "skittish" behavior of whales, the number of vessels (aside from whaling vessels) encountered at sea, and observed whale reactions to non-whaling vessels. To provide broader context, this chapter also includes some more general material. The chapter begins with a discussion of the methods used for gathering the information upon which this chapter is based. That section is followed by a brief and very general description of the equipment and methods used for fall subsistence whaling. The subsequent two sections summarize historic whaling in the Cross Island area and general information from years prior to 2001 on the issues of primary concern in this chapter. The following longer section, comprising the majority of the chapter, addresses the 2001–2009 whaling seasons.

Information from the annual and more comprehensive studies cited above is, for the most part, not reproduced in this chapter, but is incorporated by reference where appropriate. This is, in part, a result of the decision to focus the present Comprehensive Report on 2005–2009. However, for some topics ('skittish" whale behavior, or offshore distribution of bowhead whales), it is useful to discuss 2001–2004 information in more detail. Details from years prior to 2001 are included only when especially pertinent.

7.2 METHODS

The BP-funded portion of the Cross Island research supplemented the main effort that was funded by MMS. Each year since 2005, BP has supported a few days of effort in Nuiqsut, some additional analysis, and reportage—all focused on Northstar. Thus, much of the information that informs this chapter derives from the MMS-sponsored Cross Island research, using the methodological framework of that project. This methodology is described in all the reports to MMS that are cited above, and is only briefly summarized in this chapter.

The objective of the MMS Cross Island project is to describe Cross Island whaling using measures that document year-to-year variability in whaling; when sufficient time series data are available, those data will allow tests of hypotheses on the causes of this variability. Concern about potential effects of oil and gas development on whaling is the prime motivation for the MMS project, but it is recognized that other factors can strongly affect Cross Island whaling and thus need to be considered as well. These other factors include weather and ice conditions, equipment problems, whalers' decisions, and human activities not associated with the oil-and-gas industry. During the MMS-sponsored study, information is collected on level of hunting effort, including how many boats go out each day, crew size, how much time is spent on the water, lengths of trips in miles, and furthest point away from Cross Island during each trip. Information is also collected on the abundance and distribution of whales encountered by the whalers, including the number and location of whales observed and/or struck by the whalers, whale behavior, and conditions or events that affect whale behavior and/or subsistence whaling.

Information on the level of hunting effort was collected through the systematic observations of a researcher (the same one each year since 2001) stationed on Cross Island for most of each whaling season. This information was supplemented by conversations with all of the boat crews after most hunting trips, and at other more irregular times. Further information on hunting effort, and on the abundance and distribution of whales, was obtained by issuing Garmin handheld GPS (Global Positioning System) units to all boat crews. The whalers were given instructions on how to record the GPS coordinates (track) for each boat trip, and how to mark waypoints of significance, including whale sightings and strikes, sightings of vessels other than whaling vessels, and other pertinent observations. This information was then mapped, and is the basis for the Figures included in this report. It should be noted that whaling crews mark relatively few points when on the water, and the points they do mark represent their boat's position at the time a whale or group of whales was seen. These whales may be quite close to the recorded coordinate or may be miles away (depending on the conditions of the day and sighting distance).

This GPS information was supplemented by subsequent conversations with each boat crew while reviewing the mapped GPS information on a laptop computer with the crew. When reviewing tracks after their return, crew members would often identify locations where they saw whales, and these points were added to the GPS information. Some of these points were boat positions, and some were estimated positions of whales (and thus not on a boat track). Other points were reference coordinates and may represent past whale sightings, so they also may not be on boat tracks. The researcher did not accompany the whalers in their boats while they were hunting, since it is not permissible for any non-Native to participate actively in hunting marine mammals.

The original work for 2001–2004 was done on behalf of MMS with no particular emphasis (or lack of emphasis) on BP-related concerns. In mid-2005, the objectives were expanded (in response to the NSB SAC's recommendation) to include topics of particular concern to BP. Supplemental systematic interviews that focussed on those topics have been conducted in Nuiqsut annually since 2005, following each whaling season. These interviews have been primarily with whaling captains or senior crew members about overall characteristics of each whaling season, whaler encounters with non-whaling vessels while scouting for bowheads, and observations of unusual whale behavior. The interviews have been guided by an informal protocol developed to document this information within the context of the scouting/whaling activities of which it was a part. Thus there were no "sampling" issues *per se*; information was collected concerning all crews. However, in 2009 one captain (with one boat) declined to participate actively in the research. His rationale was that his information was adequately represented by the other boats, since they all had GPS units and talked with the researcher, and he was never very far from another boat. This refusal did result in the loss of some detail from the 2009 season, but does not appear to have affected the description and analysis of the overall characteristics of the 2009 Cross Island subsistence whaling season (Galginaitis 2010b).

7.3 SUBSISTENCE WHALING EQUIPMENT, METHODS, AND CONSTRAINTS

A basic understanding as to how subsistence whaling is conducted by Nuiqsut whalers is important in interpreting how those activities might be affected by industry activities. The following is intended to provide only enough detail to ensure that the following material is understandable. For a broader review, see Stoker and Krupnik (1993), Rexford (1997), or the reports to MMS cited above.

The community of Nuiqsut is located about 26 km (16 miles) inland ("as the crow flies") on the Colville River. Nuiqsut crews harvest whales only in the late summer and fall (collectively referred to as the fall hunt), at a location about 117 km (73 miles) "straight line" or 148 to 171 km (92 to 109 miles) by boat from Nuiqsut, on Cross Island. Cross Island is located about 16.1 km (10 miles) north of BP's Endicott Development along the coast, 24 km (15 miles) NW of West Dock, and 27 km (17 miles) east of Northstar (see Fig. 1.1 in Chapter 1). Since 2001, there have been from 3 to 6 captains from Nuiqsut actively whaling from Cross Island. Some captains use more than one whaling boat. The total number of whaling boats at Cross Island each season has varied from 7 to 12 since 2001. Nuiqsut whaling boats are generally 5 to 7 m (18 to 24 ft) long, with aluminum or fiberglass hulls, and single outboard motors of 80 to 250 horsepower. The management plan of the Alaska Eskimo Whaling Commission (AEWC) specifies the equipment to be used for the whale hunt, and the general manner in which the hunt is to be conducted (AEWC 1995).

Nuiqsut whalers generally go scouting for whales on any day when the weather is suitable for finding and striking whales, unless a whale was taken the prior day, in which case butchering usually has priority. Whalers invariably use the term "scouting" rather than "hunting". Good whaling weather is determined mainly by wind speed and sea conditions. Whalers prefer days with no wind, but winds up to 5 mph, or even 10 mph, are acceptable. Sea conditions generally correspond with wind speed. Scouting can occur even with higher winds, depending on the circumstances. Ice cover generally moderates the effect of wind by dampening wave height. Boats typically scout for whales with a complement of 3 or 4 people, although some boat crews are as small as two and as big as eight. Although solitary boats do take whales on occasion, it is not encouraged and Nuiqsut boats almost always scout for whales with at least one other boat, in case of mechanical break downs or other emergencies. Whaling crews with 2 or 3 boats are willing to whale on their own, but it is commonly agreed that 5 to 7 boats is a preferable number to have available for whaling on a given day. More boats would be useful, and the availability of fewer boats decreases the efficiency, safety, and overall chance for a successful hunt.

Once Nuiqsut whalers spot a whale and determine that it is a proper whale to take (generally 25 to 35 feet long, and not a mother with calf), they will approach it at high speed so that it dives. The noise from their motors alerts the whale to the presence of the whalers, but because of the extent of open water and the use of motorized vessels during the Cross Island hunt, it is generally impossible for Nuiqsut whalers to approach whales stealthily. After the whale dives, the whalers estimate where it will reappear (usually in 5 to 10 minutes, but sometimes longer) from the clues they observe where the whale dived. Once in the area where the whale is expected to resurface, they wait and search at low speed until the whale surfaces and is spotted. They will then approach it so that it dives again, and so on. The objective is to tire the whale so that it must stay on the surface for longer periods of time, until one of the boats can finally get close enough to the whale while it is on the surface to strike it.

The whale is killed by the delivery of whale "bombs", which are in essence very large explosive projectiles with timed fuses (generally 4 to 8 seconds) so that they explode inside the whale. Inupiat whalers adopted this technology from the commercial Yankee whalers who operated in northern Alaska in the latter half of the 19th century and early in the 20th century.

During fall whaling, the first bomb is delivered via a darting gun, which at the same time deploys a harpoon with an attached float. Current AEWC bylaws require that the first strike on a whale in the fall must be made with a darting gun. The harpoon and darting gun are both attached to a long wooden handle. This is thrown from the boat at the whale, usually at a distance of no greater than 10 or 15 feet, and ideally closer. Once the whale is struck, the harpoon separates from the handle. A trigger rod fires the darting gun which shoots the bomb into the whale. An internal hammer ignites the bomb's fuse once it hits and penetrates the whale's skin and the bomb explodes 4 to 8 s later (depending on how long a fuse was used). The darting gun remains on the handle and thus floats in the water until it can be recovered. It must be dried and cleaned before being used again. In extreme cases this can be done on the water, but is usually done on shore. Thus, most darting guns are effectively one-shot weapons. Each whaling boat has at least one darting gun, and sometimes two, on board.

The second weapon used to deliver whale bombs is the shoulder gun — a very heavy, short barrel, smooth bore, seven gauge firearm used to shoot the same sort of bomb as is used in the darting gun, only with fins to help stabilize its flight in the air. In the fall, the shoulder gun can only be used after a float has been attached to a whale, and is generally used only after one or more darting guns have delivered bombs. A good proportion, but not a majority, of whales are killed by the first bomb. When multiple bombs are required, the shoulder gun is useful because it can be used to fire several bombs, as long as the barrel is cleaned after each shot.

The darting gun is always thrown from the right side of the boat, since it is attached to a line and the float, and this line is always rigged on the right side of the boat. If the darting gun were thrown to the left of the boat, the float line would then stream across the boat at high speed, endangering the crew and the structural integrity of the boat. Thus the whale is almost always approached on the whale's left side, since the boat normally "catches up" to the whale from behind it to achieve a striking position.

Once the whale is dead, all available boats are normally expected to assist in towing it back to Cross Island to be butchered (a small whale may not require all boats, or it may be desirable to try to land a second whale). The whale is hauled up on the beach at Cross Island with the assistance of a loader and/or a cable and diesel-powered winch. The loader and winch are part of the logistical support provided by industry as part of the Oil/Whaler Agreement (Conflict Avoidance Agreement, CAA). This equipment is comparable to that used by other fall whaling communities. All cutting is done with an assortment of knives with long handles. The initial butchering and division into crew shares is done on Cross Island, but further division among crew members is done after the crew and whale products are in Nuiqsut at the end of the whaling season.

7.4 HISTORIC WHALING IN THE CROSS ISLAND AREA

Prehistoric use of Cross Island has not been well documented or investigated archaeologically, but documentation for more recent use is quite extensive. Families who lived on and used Cross Island seasonally during the first half of the 20th century included the Woods, Pausanna, Saavgaq, Ulaaq, Ahsoak, Ahgook, Ikpikuk, Ahvakana, Akpik, Sovalik, Kaigelak, Tigulak, Ahsogeak, Ahkivgak, Ekolook, and Ekowana families (Smith 1980). Among the most important in terms of whaling was a man named Taaqpak, who used Cross Island (among other sites) as a whaling base from the early 20th century through the late 1940s. Documentation for his whaling harvests is incomplete, but includes accounts of whales taken near Cross Island in 1922, 1927, 1928, and 1938. Taaqpak also had a reindeer herd in the area and many of the men on his whaling crew worked for him, and some of those with reindeer herds to the east of him also whaled with him. Many of today's active whalers learned from those who had been members of Taaqpak's crews. Taaqpak himself maintained that Inupiat had hunted whales near Cross Island for centuries (Carnahan 1979:21-31). Thus whaling near Cross Island has a strong cultural foundation.

It is not altogether clear why whaling was suspended in this area during the middle part of the 20th century. It is probable that the decline of the reindeer industry (and earlier, trapping) prompted most of the people who had been in the mid-Beaufort (including the Colville River region) area to relocate to Barrow or Kaktovik. Certainly, this made the area effectively more distant for the purposes of whaling, given the local technology of the time, since there were not even semi-permanent residents in the immediate area. Schools and wage labor jobs attracted people off the land and into central communities. At any rate, the last documented whale taken in the mid-Beaufort area before the resettlement of Nuiqsut was in 1940 by Taaqpak (NSB 1987).

In 1973, the same year that Nuiqsut was resettled, the Mayor (who was also the village corporation President at that time, and had been instrumental in the resettlement effort) decided to take a boat and a crew out to sea in order to look the area over. He took his whaling equipment with him. After staying out for six weeks and running out of almost all supplies, this crew came upon a whale feeding inshore of the barrier islands near the Canning River (western Camden Bay). They killed this whale and towed it west until it became dark, and ended up near Flaxman Island. Because it had grounded in the shallow water, they had to butcher the whale there, in the water, starting the next morning. As the meat was spoiling and they had only one boat, they butchered for muktuk only, and cut most of the fat off that. It took them two days to return to Nuiqsut with a boat load, after which they returned to Flaxman Island accompanied by two other boats which helped transport the rest of the muktuk to Nuiqsut.

The Nuiqsut whaling captain in command of the crew that took the 1973 whale was proud of the accomplishment. He and many others believed that it was his success with this whale that established Nuiqsut as a whaling village, an identity that is now pervasive and fundamentally important for Nuiqsut. This captain continued to go out whaling, with only his single crew, from 1973 to 1979 or 1980. Prior to 1982, most Nuiqsut residents who wanted to whale went spring whaling in one of the other coastal villages, some as captains of their own crews and others as crew members for non-Nuiqsut captains. Nonetheless, from 1973 to 1982, crews whaled in autumn from various locations, including Pingok Island, Narwhal Island, and Cross Island. The next whale taken by Nuiqsut hunters was landed in 1982 by the same captain who took the 1973 whale, and almost as far to the east of Cross Island. It was towed to and butchered at Narwhal Island. All subsequent whales landed by Nuiqsut whalers have been butchered at Cross Island.

Cross Island is a low sandy barrier island with an artificial higher area built from gravel. This higher area was constructed for past oil and gas exploratory drilling. Cross Island is about 3 miles (5 km) long and 150 yards (137 m) wide, and is constantly changing due to erosion and re-deposition. Especially in the 1970s and early 1980s, logistical support for whaling on Cross Island was very difficult. Whalers had to haul or find their own gasoline and water, and hunted and fished to provide most or all of their food. There was limited shelter for those who were whaling.

With the advent of the Oil-Whalers Agreement (OWA) in 1986 between the oil industry and fall whalers (represented by the AEWC), logistical considerations have become somewhat easier for the whalers in terms of time and effort, but more expensive in terms of direct costs to both the whalers and industry. The oil and gas industry has provided logistical support of various sorts to Nuiqsut whalers, under the renamed Conflict Avoidance Agreement or CAA (also referred to as a Plan of Cooperation in some documents). Under the CAA, a Communication Center is established at Deadhorse (Prudhoe Bay) during the autumn whaling season to facilitate communication and conflict resolution between the whalers and industry operators who are parties to the CAA. The CAA is understood by the whalers to be a mitigation measure required by NOAA (National Oceanic & Atmospheric Administration) to counter the potential disruption of subsistence whaling by exploration, development, and/or production activities. In actuality, there is provision, under 50 CFR section (§) 216.104, for industry activities to proceed in the absence of a CAA/Plan of Cooperation if industry has made a good-faith effort to negotiate a CAA (and failed), and if NOAA and industry have agreed on an alternative set of mitigation measures in place of a CAA.

The level of mitigation or required support defined under previous CAAs has been authorized by NOAA as not affecting the nature of the subsistence hunt, although it may contribute to its continued success (which is the nature of mitigation). In total, such support has been on a par with the logistical support generally available in the other fall whaling communities through community infrastructure such as the electrical grid, a public water system, the availability of NSB and village corporation heavy equipment, and so on. The CAA process has generally succeeded in minimizing potential conflicts between industry and whaling activities at least since the inception of Northstar. Specific examples from 2006 and 2008 are discussed in §7.6.1, below.

A summary of whale harvests by Nuiqsut crews is presented in Table 7.1. Nuiqsut whalers attribute at least part of their relative lack of success in the 1970s and 1980s to interference from oil and gas exploration, as well as poor weather and ice conditions in some years, and a difficult logistical situation. These factors were also perceived by the whalers as important in the three years with the greatest incidence of "struck and lost" whales (1989–1991 or 1992). Once Cross Island was established as a logistical center for Nuiqsut whaling, and Nuiqsut whalers gained experience there, harvest success became much more regular. Additional factors in this increased success may be more moderate ice conditions since 1992 (although this may be counterbalanced by more problems with high winds when ice cover is lacking), and the gradual increase in the number of bowheads in the Bering–Chukchi–Beaufort population (George et al. 2004). By the 1990s, the number of crews had also increased to as many as 11 during a given season (mostly with single boats). The present level of effort appears to be about the same (11 or 12 boats), with fewer captains but more boats per crew.

7.5 WHALING SEASONS PRIOR TO 2001

The ANIMIDA and cANIMIDA programs sponsored by MMS ("Arctic Nearshore Impact Monitoring in the Development Area" and "Continuation of ANIMIDA") have collected specific information on Cross Island whaling since 2001, but some limited generalizations for seasons prior to 2001 are also

TABLE 7.1. Recent harvest of bowhead whales near Cross Island.

Year	Bowhead Whales			Notes Based on Whalers' Accounts
	Quota	Landed	Struck & Lost	
1973	NA	1	0	
1982	1	1	0	
1986	2	1	0	Hammerhead prospect drilling (also 1985); Corona drilling
1987	2	1	0	
1989	2	2	2	Oil industry vessel disturbance noted
1990	3	0	1	Oil industry disturbance; also rough seas
1991	3	1	2	Poor weather, bad ice conditions, industry effects (Galahad)
1992	3	2	1	Kuvlum prospect drilling
1993	3	3	0	Very favorable conditions; Kuvlum prospect drilling
1995	4	4	0	
1996	4	2	0	
1997	4	3	1	
1998	4	4	1	
1999	4	3	0	
2000	4	4	0	Very favorable conditions
2001	4	3	0	Some floating ice, whales relatively distant and skittish
2002	4	4	1	Less ice than 2001, whales closer than in 2001
2003	4	4	0	Little or no ice, poor weather, whales close to Cross Island
2004	4	3	0	Little or no ice, poor weather, whales close to Cross Island
2005	4	1	0	Severe local ice, very poor weather, vessel traffic interference
2006	4	4	0	Ice restrictions first half of season
2007	4	3	1	No ice, poor weather, rough sea conditions, whales close to CI
2008	4	4	0	No ice, rough seas, whales close to Cross Island
2009	4	2	1	No ice, difficult sighting conditions, whales relatively distant

Notes: Years of no harvest and no "struck and lost" are not listed. This does ***not*** imply that there was no whaling effort those years. "Quota" was not applicable in 1973.

Sources: Compiled from AEWC records, personal communications from Nuiqsut whalers, and MSG's field notes from the 2001–2009 whaling seasons.

available. This information is discussed briefly in this section, concentrating on a few key areas: natural and uncontrollable conditions (weather and ice), ongoing industry activities, and whale behavior ("skittishness" as well as abundance and distribution). Subsequent sections provide related information from the 2001–2009 whaling seasons (and especially 2005–2009).

7.5.1 Natural Conditions

One of the reasons whalers give for the eventual choice of Cross Island as the base from which Nuiqsut whalers would hunt bowheads is that this area tends to have more open water than the area to its west. Pingok Island, farther to the west and closer to Nuiqsut (see Fig. 7.1, later), was tried as a logistical base in the early 1980s, and was stated to be a good whaling station except for two factors: (1) Ice cover was commonly dense, and (2) Beaching whales on Pingok Island for butchering would have been difficult to impossible due to high banks and shallow water. No whales were ever landed on Pingok Island by Nuiqsut whalers. As Nuiqsut whalers tried areas farther to the east of Pingok Island, they found more open water. By the mid-1980s, Nuiqsut whalers also report that the initial development of Seal Island as a site for offshore oil exploration, had changed whale behavior and diverted the bowhead migration route farther from Pingok Island. (Seal Island was an artificial gravel island between Pingok and Cross Islands; BP's Northstar Development was subsequently (2000) built on the eroded remnants of Seal Isl.) Nuiqsut whalers also tried Narwhal Island as a logistical base, but settled on Cross Island because Narwhal Island provides less protection during poor weather and is subject to greater erosion.

Information on natural conditions judged to have affected whaling in years prior to 2001 is relatively sparse, and is summarized in Table 7.1 above. Heavy ice cover was characterized as more the norm than the exception for the 1980s — sometimes preventing access to the whale migration altogether, and at other times taking the form of heavy floating broken pack ice. Poor weather (high winds, rough seas) was a factor in 1990 and 1991, and ice was an additional factor in 1991. It will be possible to compile and compare weather information for the Cross Island area eventually, but this task has not yet been attempted as part of this effort.

7.5.2 Whale Distribution and Abundance

Information on the distribution and relative abundance of bowhead whales near Cross Island in autumn migration seasons prior to 2001 is contained within the MMS BWASP (Bowhead Whale Aerial Survey Project) dataset (e.g., Treacy 2002a), but has not been compiled for this MMS project. However, the BWASP surveyors avoid the Cross island area during the subsistence whaling season. Thus, direct observational information for the period of greatest whaling effort concerns sightings of animals and their distances from shore in areas not immediately around Cross Island, and perhaps relative abundance from year-to-year. Direct observational data from the Nuiqsut whalers are not easily elicited retrospectively, especially for specific years, and little effort was allocated to this topic for this project.

7.5.3 Whale Feeding

Nuiqsut whalers indicate that migrating whales feed in the Cross Island area, but few specific observations can be cited by time and date, especially prior to 2001. Whalers report that, in 1997, they landed a whale near the present location of Northstar Island in an area where they saw many feeding whales. This retrospective observation was tied to the landing of a whale, a particularly salient event for Nuiqsut whalers. Other feeding observations do not have such a salient time referent, but contribute to the whalers' perception of the Cross Island area as important for feeding bowheads. Stomach contents of a few of the bowheads landed at Cross Island prior to 2001 were examined; 4 of 5 showed evidence of feeding on a wide variety of invertebrates (Lowry et al. 2004). It is likely that the Cross Island area is a feeding area in at least in some years, and that would be one reason why the area has been a consistently productive one for fall subsistence whaling.

7.5.4 Whale Behavior and "Spookiness"

Even when industry activities are not perceived to have deflected bowhead whales farther away from Cross Island, whalers report that the noise from such activities makes whales behave in a more "spooky" manner. This means that the whales are more difficult to approach and react to approaching whalers in less predictable ways (Napageak 1996; Lampe 2001). An undisturbed whale is normally expected to surface every 20 minutes at locations that are about ¼ mile (0.4 km) apart, as reported by a

Nuiqsut whaler for the spring migration, but applied by him to the fall Nuiqsut hunt. He said that disturbed or "spooked" whales travel much faster. He also said that they may surface to breathe at shorter intervals, followed by longer dives that may take them much farther than normal before the next surfacing. This makes them almost impossible to follow, let alone approach close enough to strike with a darting gun. However, little extended discussion or description of this behavior exists in Native testimony or the literature, especially for years prior to 2001. More specific information is available for more recent years (see § 7.6.1, 7.6.5).

7.5.5 Industry and Other Anthropogenic Activities

MMS contracted for the compilation of a Human Activities Database for the Alaskan Beaufort Sea for 1979–1999, and a summary of the results is available (Wainwright 2002). That report provides some systematic information on industry activities that were undertaken in the area up to 1999. However, the database itself, which contains more specific information, contains data that are proprietary to industry and MMS cannot release them or allow open access to them.

Inupiat perceptions of the effects of such activities in years prior to 2001 are well documented in public testimony, but are often relatively general or broad in scope (especially for earlier lease sales — for example BLM 1979). These perceptions, in relation to Cross Island whaling, are discussed below. Several of the cases of industry effects reported by Nuiqsut whalers were attributed to offshore drillsites.

Several whaling seasons are characterized by Nuiqsut whalers as having been affected by industry activities. During 1985, 1986, 1991, 1992, and 1993, whaling near Cross Island was considered to have been affected by the open water drilling of exploratory wells to the east of Cross Island. The most commonly cited effect was that whales were farther from Cross Island than would normally be expected, and this was attributed to deflection of bowheads in response to noise from the drilling (Ahkiviana 2001; Nukapigak 2001). Similar arguments were not made by the whalers for open-water drilling operations to the west of Cross Island or inside the barrier islands (1982, 1985, and 1986). Northstar is in this category of industrial sites to the west of Cross Island that have not been reported by whalers to cause deflection of whales away from Nuiqsut whalers (although by choice they avoid whaling near Northstar). Seismic operations, on the other hand, were commonly cited by whalers as affecting whaling, and may be the source of industry disturbance noted for 1989 and 1990 (Ahtuangaruak 2001). (In 2005, and perhaps other years, whalers reported that commercial boats interfered with the hunt, as discussed in § 7.6.1, 7.6.5, and 7.6.6.)

For many (if not all) years mentioned above as being years with industry effects, bowhead whales were reported to be migrating farther from Cross Island than "normal". For 1991, Nuiqsut whalers report that the loss of one of the "struck and lost" whales (Table 7.1) was directly related to the noise from exploratory drilling (Ahkiviana 2001). The whale was killed about 48 km (30 miles) from Cross Island. The weather and seas worsened during the tow to such an extent that the line had to be cut for the safety of the whalers. The distance of this whale from Cross Island (and the lack of whales closer to Cross Island) were blamed on deflection due to noise from the Galahad drillsite, located north of Camden Bay. Hammerhead, Corona, and Kuvlum, other offshore drillsites active in that same general area in the 1980s or early 1990s, are commonly cited by Nuiqsut whalers as examples of industry activities that have adversely affected whaling activities (Oyaguk 1986; Tukle 1986; Long 1996; Napageak 1996).

7.6 WHALING SEASONS OF 2001–2009

More specific information about whaling near Cross Island, and interactions between whaling and industry activities, is available for 2001–2009 as a result of the specific MMS- and (since 2005) BP-sponsored study of these matters. The GPS tracks collected for the MMS Cross Island project (2001–2009) are displayed in Figure 7.1, color-coded by year. Selected summary descriptive measures of the whaling activities for each year, some derived from the GPS tracks, are displayed in Table 7.2. A more complete table appears in Galginaitis (2010b). As discussed above, this information has been supplemented since 2005 with additional work for BP. This section will first characterize each whaling season in the period 2001–2009, and then will discuss those seasons in terms of three groups of related years. Finally, the 2001–2009 results are considered in relation to natural conditions, whale distribution and abundance, whale feeding observations, whale behavior and "spookiness", and industrial and other anthropogenic activities.

7.6.1 Whaling Activities and the Categorization of Years

There are obvious similarities and differences among the nine whaling seasons, but classifying them into mutually exclusive categories is difficult, due to the interactions of numerous independent (or partially independent) factors. Choices made by the Nuiqsut whalers are influenced by the following considerations concerning scheduling and their own consumptive needs and preferences:

- They cannot start whaling until the "fall" migration reaches Cross Island, and the weather is cool enough so that the butchered whale does not spoil. This is no earlier than late August and more typically the first week of September.
- Although the migration usually continues into October and ice is not usually problematic into early October, experienced whalers indicate that after 20 September or so, weather conditions at Cross Island are unpredictable and tend to be difficult for whaling.
- Most whalers prefer to take smaller (25–35 ft) rather than larger (45+ ft) whales, and these tend to predominate in the early part of the migration, with larger (and more mature) animals late in the migration (Koski and Miller 2009).
- The annual quota for Nuiqsut is four strikes, which is sufficient to provide enough muktuk and meat for Nuiqsut residents and sharing obligations, even if all four animals landed are "small" (25–30 ft). If only three animals are landed, these needs can be met as long as the combined lengths of the whales total about 100 ft or more. Landing fewer than three whales usually means that people "run out of muktuk too soon" and cannot share as much as usual with friends and relatives outside of Nuiqsut. This places some pressure on the whalers at Cross Island to land at least three whales.

These considerations combine to define a window of opportunity for Cross Island whaling approximating the first week of September through 20 Sept. or so — a period of duration three weeks or thereabouts. Of the nine documented hunting seasons, four exceeded 21 days in length. Two of the "long" seasons (2004 and 2005) were cases where one crew went to Cross Island much earlier than all other crews, as an experiment to see if whales were available in late August. They were not, and in subsequent years no crew has gone to Cross Island before the first week in September. The other two "long" seasons were 2001 and 2002. In 2001, weather delayed the departure from Cross Island for several days and extended the season past 21 days. In 2002, one crew went to Cross Island on 30 Aug., but was not joined by the second crew until 1 Sept., and the third crew on 5 Sept. All crews left Cross Island by 21 Sept. For all years except 2001, the "average" crew spent 21 or fewer days on Cross Island. Again, this was due to staying into late September and then being "stuck" on the island waiting for weather and sea conditions good enough for small-boat travel to Nuiqsut. Thus, shorter seasons (less than

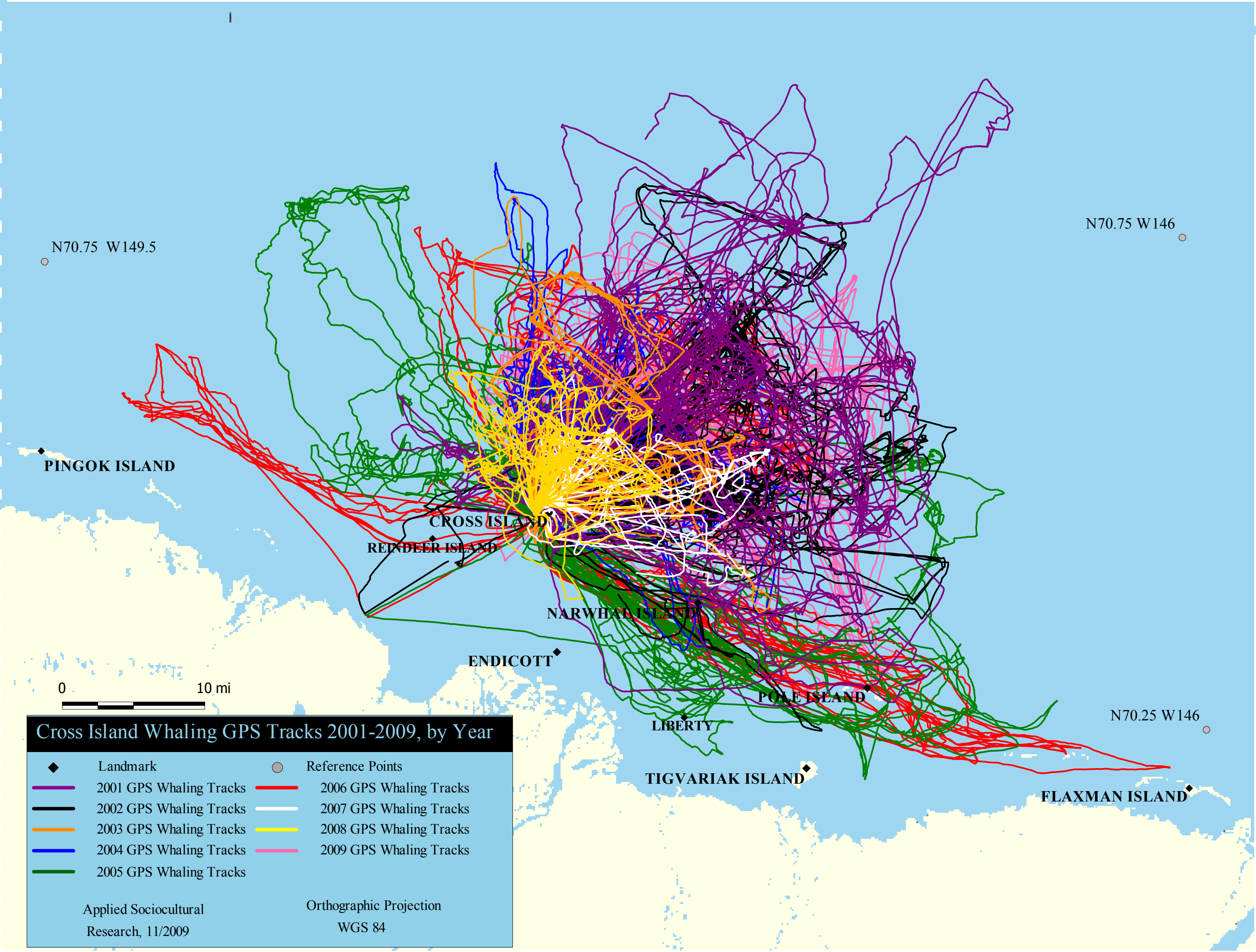

FIGURE 7.1. Cross Island GPS whaling tracks in 2001–2009, color-coded by year.

TABLE 7.2. Selected Measures of Cross Island Whaling, 2001–2009

Metric		**Cross Island Subsistence Whaling Season**								
		Prior Seasons for MMS Study				**Primary Focus of Comprehensive Report**				
Measure	Type	**2001**	**2002**	**2003**[9]	**2004**[9]	**2005**[9]	**2006**	**2007**	**2008**[10]	**2009**[2]
Whales Landed/Whales Struck and Lost	count	3/0	4/1	4/0	3/0	1/0	4/0	3/1	4/0	2/1
Length of Season[1]	Count	24	23	19	30	27	21	13	14 (7)	20
Weather Days	Count	8-9	4	8	10	11-15	4	3	6 (0)	5 (6)
"Length of Season" – "Weather Days"[11]	Count	15 (16)	19	11	20	12 (16)	17	10	8	14 (15)
Average Length of Season/Crew	Average	22.5	19.34	13.25	19.25	21	21	10.4	7.3	19.2
# days scouting[3]	Count	12	15	7	12	9	10	5	5 (5)	12 (10)
# days whales seen[4]	Count	9	9	7	6	7	8	4	5	10 (10)
Length of trip (miles)	Average	84.0	64.3	37.2	45.3	60.7	60.8	30.1	32.1	61.6
Furthest point from Cross Island (miles)	Average	23.6	19.5	11.6	12.1	19.1	22.2	10.4	8.3	15.8
Strike distance from Cross Island (miles)[5]	Average	19.5	13.4	9.3	9.7	25.9	17.0	12	6.5	13.8
# boat trips (possible # of GPS tracks)[5]	Count	59	67	42	46	48	53	22	33 (31)	113
Duration of trip (hours:minutes)	Average	9:43	7:58	4:31	6:51	7:07	8:13	5:39	5:03	6:43
Total Seasonal Boat Effort (Boat-Hours)[8]	Sum	572.9	533.6	162.9	301.2	341.3	427.1	124.3	158.0	751.7
Boat Hours/Strike	Average	191.0	106.7	40.7	100.4	341.3	106.8	31.1	39.5	250.6

Season Categories: **GREEN**="Successful and Low Effort" **YELLOW**="Successful and Intermediate Effort" PINK="Mixed Success and High Effort"

[1] Number of days with at least one crew on Cross Island — includes day of arrival at and departure from Cross Island

[2] Figures in parentheses ( ) are values excluding marginal scouting days

[3] Number of days when at least one boat went out scouting for whales

[4] Number of days when at least one crew saw whales while scouting from a boat. Blows seen from Cross Island on non-scouting days are not included

[5] Includes "struck and lost" whales in 2002, 2007, and 2009

[7] Due north is 0 (and 360) degrees, due east is 90 degrees; includes struck and lost as well as landed strikes

[8] Yearly total equals aggregate sum of duration of all whaling trips by all boats (or # of boat trips multiplied by average duration of trip). Includes estimates for missing information

[9] One crew went to Cross Island well before other crews, so total season measures may be somewhat misleading. See 2003, 2004, and 2005 Annual Reports.

[10] Figures in parentheses ( ) are values for the 7 days when more than 1 crew was on Cross Island

21 days) should represent relatively good whaling conditions. Longer seasons (21 days or more) should represent relatively poor whaling conditions or unusual circumstances. "Shorter seasons" would be expected to share more characteristics than "longer seasons" since the conditions that result in a "shorter season" are much more restricted than are those for "longer seasons". That is, it only takes an extreme value of one variable to result in a "longer season" whereas most variables must fall into relatively standard ranges to result in a "shorter season". It is not intuitively obvious which variables are more important than others, or the relative weights of the variables. This will be discussed briefly below.

Before addressing the issue of the similarities and differences among the Cross Island subsistence whaling seasons of 2001 through 2009, they will be briefly characterized in terms of the following categories: strikes expended, natural conditions (weather and ice), whale distribution and abundance as observed by Nuiqsut whalers, observed whale feeding in the Cross Island area, observations on whale behavior and "spookiness", and observed effects of industrial and other anthropogenic activities. Since this Comprehensive Report focuses on 2005–2009, each of those seasons is summarized separately, while the 2001–2004 seasons are treated more generally. Figure 7.1 displays the GPS tracks collected for all years, color-coded by year for easy inter-annual comparisons. Figure 7.2 compares the tracks for the 2001–2004 period vs. 2005–2009. Table 7.2 displays values for selected measures of whaling activity, as discussed below, with color-coding to distinguish three groups of years. See Galginaitis (2010b) for a more complete Table. The tracks for those three groups of years are distinguished by color-coding in Figure 7.3. Additional details concerning Cross Island whaling during each of these years can be found in the relevant annual reports to MMS and (from 2005 onward) BP as listed under "Galginaitis" in the "Literature Cited" section.

Year-by-Year Summary

***2001–2004*.—**All four of these seasons can be termed "successful" in the sense that the whalers were satisfied that they had adequately provided for the village. Four whales were landed in each of 2002 and 2003, and the landing of the fourth whale effectively defined the end of the season. Only three whales were landed in each of 2001 and 2004, and these seasons were declared over once the whalers concluded the future weather was unlikely to be favorable for whaling. There was significant floating ice in 2001, but not so much the other three years. Whales observed by the hunters were distant from Cross Island in 2001 (32.2 to 40.2 km or 20–25 miles), somewhat closer to Cross Island in 2002 (24.1 to 32.2 km or 15–20 miles), and at "normal" distances from Cross Island in 2003 and 2004 (16.1 to 24.1 km or 10–15 miles). Whales were judged to be quite spooky and few in numbers in 2001, less spooky and somewhat more numerous in 2002 (but still erratic in behavior), and not very spooky and more numerous in 2003 and 2004. Weather was good for the first half of September in 2001 and 2002, but then was quite poor. In 2003 and 2004, weather was poor throughout both seasons. Whale feeding was observed only in 2004, when a whale with its mouth open was seen feeding on the surface. No specific effects of industrial or other anthropogenic activities on subsistence whaling were noted in 2001–2004; whalers may have observed other vessels, but did not remark on them. Effort expended "on the water" per strike used was lowest in 2003 (41 boat hours), higher in 2004 and 2002 (100 and 107 boat hours, respectively), and highest in 2001 (191 boat hours).

***2005*.—**Only one whale was landed during a 27-day season. Weather and sea state prevented whaling on 11 to 15 days (weather conditions were so poor that some crews went scouting on some quite marginal days). The 2005 season was one of very poor weather, very bad ice conditions (for whalers), and a general inability to travel beyond the barrier islands (to the "normal" migration corridor of the whales) except on one day. There were three extended periods with high wind speeds, and few periods

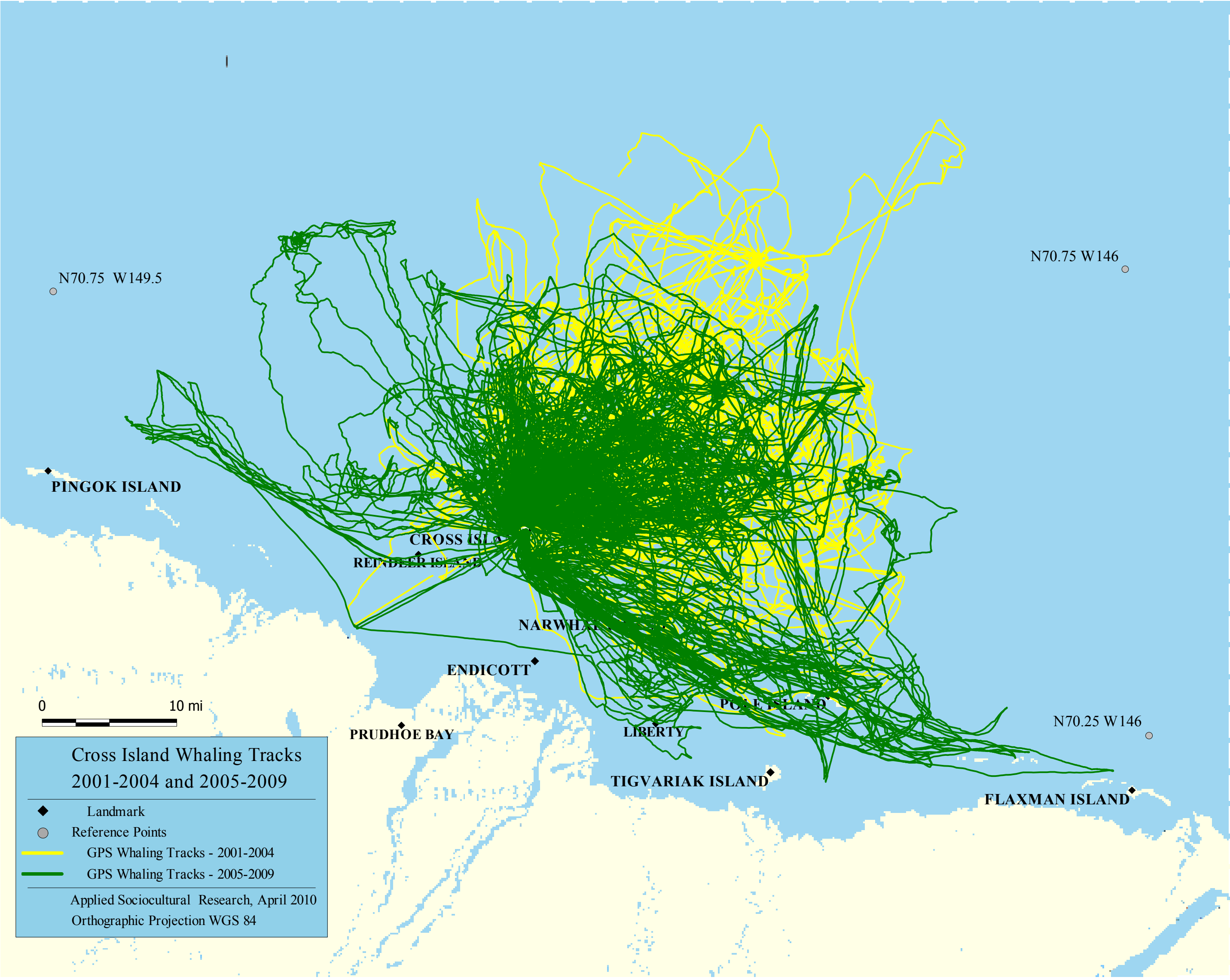

FIGURE 7.2. Cross Island GPS whaling tracks, 2001–2004 compared with 2005–2009.

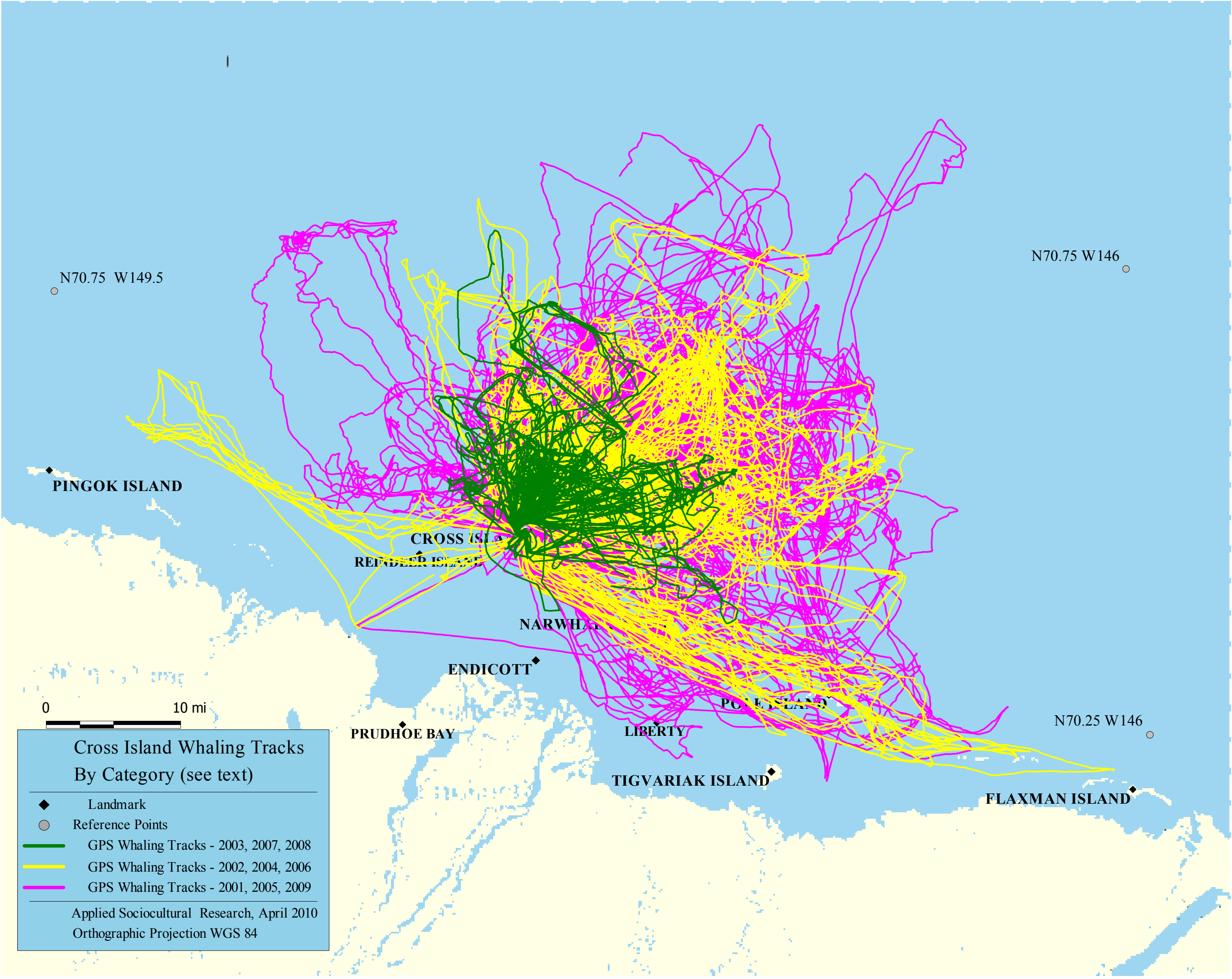

FIGURE 7.3. Cross Island GPS whaling tracks, 2001–2009 categorized into three groups with similar characteristics (see text).

with wind speeds less than 10 or even 15 mph. The poor weather of 2005 differed from that of previous years of bad weather in that, during 2005, there were not even many "half days" of good scouting weather. The one whale landed was struck during a rare period when wind speed was almost 0 mph. The whalers encountered severe local packed floating ice and for the most part scouted only within the barrier islands. On the one day whalers when could reach open water beyond the barrier islands, they found whales about 40.2–48.3 km (25–30 miles) east of Cross Island and, later in the day, much closer northwest of Cross Island. The whalers saw few whales except on the one day of scouting north of the barrier islands, when they saw quite a few. No whale feeding was reported. The whalers also encountered commercial barge vessels on three different days, including the day when they landed a whale, and they reported that their whaling activities were adversely affected by vessels on at least two of these days. An estimated 341 "boat hours" of "on the water" effort was expended for each strike used (reduced to about 324 "boat hours" if the early crew effort is excluded). This was the highest "effort per strike" of any year in the 2001–2009 period (Table 7.2)

2006.—Four whales were landed during a 21-day season. Weather and sea state prevented whaling on 4 days. In contrast to preceding seasons, wind speeds were usually less than 20 mph and never over 30 mph, although there were still periods of time when weather and sea state prevented scouting for whales. There were three extended and several shorter periods with high wind speeds, and few periods with wind speeds less than 5 mph for any length of time. All whales were struck when wind speed was 5 to 10 mph, with 3 struck and landed on 3 successive days when wind speeds were generally 5 to 15 mph. During the first half of the season, whalers experienced ice conditions similar to those for the 2005 season and were restricted to the area inshore of the barrier islands. Once this ice pack moved north, whales were found somewhat distant from Cross Island. On some days few whales were seen, and on others more, but not in large groups. No whale feeding was reported. During the first half of the season, four encounters with commercial vessels were reported inshore of the barrier islands. None of these encounters was reported to have interfered with whaling activities. No additional vessel encounters were reported during the second half of the season (outside of the barrier islands). An estimated 107 "boat hours" of "on the water" effort was expended for each strike used (reduced to about 56 "boat hours" if the effort before ice conditions moderated is excluded).

2007.—Three whales were landed, and one struck and lost, during a 13-day season. Weather and sea state prevented whaling on 3 days in what the whalers termed a "poor weather" season with rough seas. There were three extended periods with high wind speeds, and very few periods with wind speeds less than 5 or even 10 mph. All whales were struck when wind speed was between 2 and 17 mph — with 2 taken on the last day of scouting, when conditions were the better than on any earlier day of the whaling season. The whalers encountered little or no ice (one reason for the high sea states encountered), but found whales closer to Cross Island than in most previous years, although not in large numbers. Whalers reported that sighting conditions were generally difficult, however, due to the rough seas, and it was in localized areas of calmer water where the strikes took place. No whale feeding was reported. No special reports of industrial or other anthropogenic activities affecting subsistence whaling were noted, although Nuiqsut whalers were quite concerned about the possibility of exploratory drilling in Camden Bay (which did not in fact occur). An estimated 31 "boat hours" of "on the water" effort was expended for each strike used, the lowest of any year from 2001 to 2009 (Table 7.2)

2008.—Four whales were landed during a 14-day season, but one crew went to Cross Island a week sooner than other crews, so for most crews the season was in effect 7 days in duration. Weather and sea state prevented whaling on 6 days of the 14-day season, but 0 days of the 7-day season. Ostensibly, weather and sea states were similar to those of the 2007 season, but winds speeds when only one crew was on the island were generally 15 to 35 mph, while for the second half of the season wind speeds were generally 5 to 15 mph. The whalers encountered little or no ice (one reason for the high sea states), and found whales closer to Cross Island than in previous years, although not in large numbers. Whalers reported that sighting conditions were generally difficult, as in 2007, due to the rough seas and standing swells. They thought that there were substantial numbers of whales in the area and that the whales were not "skittish", but that whale sightings were infrequent due to the difficult sighting conditions. No whale feeding was reported. No special reports of effects of industrial or other anthropogenic activities on subsistence whaling were noted. The Deadhorse Communication Center log recorded two cases of successful coordination between planned oil and gas support vessel activities and subsistence whaling activities. An estimated 40 "boat hours" of "on the water" effort was expended for each strike used.

2009.—Two whales were landed, and one struck and lost, during a 20-day season. Weather and sea state prevented whaling on 5 or 6 days in what the whalers termed another "poor weather" season with rough seas. There were three extended and two shorter periods with high wind speeds, but also periods with wind speeds less than 10 mph. Two whales were struck when wind speeds were 2 or 3 mph. The other whale was struck either just before or just after wind speed increased to about 15 mph. The whalers encountered little or no ice (one reason for the high sea states encountered), and also had great difficulty spotting whales. They thought this reflected the relatively low number of whales present in the area and their greater distance from Cross Island than in 2008. Whalers reported that sighting conditions were generally difficult, due to the rough seas, and that most whales seemed to be "skittish" in their behavior. No consensus on the cause(s) for this skittish behavior was expressed. At least one bowhead was observed to be feeding on the surface with its mouth open. Most whalers compared the 2009 season to 2002, in terms of whale distribution, abundance, and behavior, although whaling success was greater in 2002 than in 2009, and no whale feeding was reported in 2002. Four encounters with commercial vessels (two on one day) were reported, with at least two raising concerns of potentially "spooking" whales. The one such incident involving a vessel engaged in oil support activities took place northwest of Cross Island and involved only one whaling boat looking for whales. All other whaling boats were actively chasing whales northeast of Cross Island at the time. This incident, for which an official incident report was filed, is discussed in more detail in § 7.6.6, below. An estimated 251 "boat hours" of "on the water" effort was expended for each strike used.

Categorization of Years

Before discussing categorizations based on various similarities and differences among years, it should be noted that there are clear similarities and, more significantly, differences between the whaling track distributions for 2001–2004 and those in the current 2005–2009 reporting period (Fig. 7.2). The primary similarity is in the area where they overlap — the entire quadrant northeast of Cross Island and the northeast half of the quadrant southeast of Cross Island. This is an empirical definition of the area where Nuiqsut whalers have looked for whales in the recent past. Most whales have in fact been struck in the quadrant northeast of Cross Island. Crews frequently travel southeast toward Narwhal Island, as in the past some crews used Narwhal Island as a logistical base, and still like to scout that area. Differences between the two periods are that, for 2001–2004, whalers confined their efforts to this "overlap" area but extended their trips to the northeast. For 2005–2009 much of the whalers' effort was northwest and southeast of these areas, and not as far northeast into the northeast quadrant. This is most directly related to the distribution and abundance of whales in 2001 and 2002 (far from Cross Island and relatively few sightings) and the relatively good boating conditions. This contrasted with severe restrictions on access to whales northeast of Cross Island in 2005 and 2006 and swells in most years 2005–2009 that made it difficult to travel as far from Cross Island as in 2001 and 2002 (and to see whales in general). In a more simplified generalization that lumps many interacting factors together, 2001–2004 were generally “good” years for Cross Island whaling, whereas 2005–2009 (and especially 2005 and 2009) were more challenging. However as the following discussion will show, variable whale distribution, local whale abundance, and boating and sighting conditions interact to affect success in any one season.

Figure 7.3, showing the whaling tracks during three categories of years, accompanies the following discussion. The clearest category is that for which Nuiqsut whalers complete their quota of 4 strikes and do so with a relatively low level of effort — low values of both “on the water” effort (31 to 41 “boat hours”/”strike used”) and “length of season” minus “weather days” (8 to 11 days). The three seasons in this category — 2003, 2007, and 2008 — were all “poor weather” seasons with rough seas and difficult conditions for sighting whales. However, whales were found near Cross Island and in good numbers, and the whalers filled their quota for all three years. The weather conditions in these seasons may have discouraged whalers from traveling any farther than they had to in order to find whales, but were adequate for them to find the whales available and close to Cross Island.

The next “logical” category of seasons with similar “effort measures” — 2002, 2004, and 2006 — have “boat hours/strike used” values of 100 to 107 hr/strike and “length of season minus weather days” values of 17 to 20 days. For two of these years the whalers filled their quota, and for the third they landed three whales averaging 34 feet long. Otherwise these years had a variety of offsetting characteristics. In 2002, there was little ice but the whales sighted by whalers were skittish, few in numbers, and relatively distant from Cross Island. Weather and sea states were not limiting. In 2004, whales were closer to Cross Island (comparable to 2003 and perhaps 2007) but weather and sea state conditions were more limiting and whales were sighted in relatively low numbers. In 2006, weather and sea state were not limiting, but ice conditions restricted whaling activity for the first half of the season and whales were relatively distant from Cross Island. One crew also went to Cross Island significantly before the other crews.

The remaining three seasons — 2001, 2005, and 2009 — do not fit into either of the first two categories. They have relatively high “boat hours/strike used” values (191 to 341 hr/strike) and “length of season minus weather days” values of 15 or 16 days. In 2001 and 2009 the whalers used three strikes each season, but they used only one strike in 2005. In 2001, whales were quite distant from Cross Island, skittish, and infrequently sighted. Weather and sea state were somewhat limiting during the season, and worsening conditions determined the end of the season. In 2005, ice and sea state restricted the whalers to areas inshore of the barrier islands on all but one day, when they landed the only whale harvested that season. Whales may or may not have been close to Cross Island, but the one that was struck was not. The whalers also encountered a commercial vessel while chasing a whale prior to finding and landing the one that they took. Worsening weather determined the end of the season. In 2009, whales were relatively distant from Cross island, weather and sea state were limiting, whales were skittish, and seemed to be relatively few in numbers in waters searched by the whalers. Worsening weather determined the end of the season.

The factors that appear to be most significant for whaling success seem to be the presence of a large number of whales close to Cross Island. “Good” weather is not as necessary in such a case, but whalers require at least some “windows” or “breaks” in the weather when wind speeds are below 15 mph (and preferably lower) and when sea states allow whales to be spotted and followed reliably. That was the situation in 2003, 2007, and 2008, plus 2004 with somewhat more effort than the other three seasons. “Skittish” whale behavior lowers the whalers’ success, or at least increases effort required for harvest, but it is not totally clear what behaviors this label describes and how the term is assigned by whalers to the whales they observe. When whales are relatively distant from Cross Island and/or few in numbers within the area where the hunters scout, good weather and passable ice conditions are necessary for Cross Island whaling success (2001, 2002, 2006). When whales are distant and access to them is restricted due to weather and/or ice, Cross Island whaling is less successful (2005 and 2009 to some extent).

7.6.2 Natural Conditions

Natural conditions have been described at some length above, and that material will not be repeated here, other than for summary points. The main factors of concern are wind speed, sea state related to wind speed and standing swells, and ice cover. Wind speed and sea state were limiting factors at some point during all the seasons under discussion, but were more significant for some than for others. The further whales were from Cross Island, and the fewer whales there were within scouting range of Cross Island, the more significant wind speed and sea state appeared to be. Deteriorating weather conditions were the primary cause for ending the 2005 season (one landed whale) and 2009 season (two landed whales). For seasons when only three whales were landed and one strike remained (2001 and 2004), deteriorating weather played at least some role in the decision to end the season. Ice was especially significant in 2005 and 2006, when localized ice conditions near Cross Island restricted Nuiqsut whalers to waters inshore of the barrier islands for essentially all but one day of the 2005 season, and for the first half of the 2006 season. In 2005 these ice conditions also restricted commercial barge traffic to the same area as the whalers (see section 7.6.6 below). In 2001, floating ice some distance from Cross Island may have been one factor explaining why the whales were so distant from Cross Island. Whalers state that whales prefer to stay near the ice edge, or floating ice. 2005 and 2006 were the only other years with significant amounts of ice, and when the whalers were able to travel beyond that ice they did find whales.

Ice cover can also serve to moderate the effects of wind on sea state, but this was a potential benefit only in 2001, when there was a significant amount of floating ice. In 2005 and in 2006, the whales that were seen (and struck and landed) were in essentially open water, beyond the floating ice.

7.6.3 Whale Distribution and Abundance

Nuiqsut whalers can only judge the distribution and abundance of whales near Cross Island, since that is where they look for whales and make their observations. For some years, these observations are quite limited, either because weather and/or ice prevent hunters from going out to whale, or because conditions are so favorable that they only need three or four days of whaling to fill their quota. They have chosen Cross Island as a logistical base because it is well sited for hunters who want to intercept the bowhead migration in the fall. Although whalers are loathe to generalize about the “normal” behavior of whales, if pressed they tend to settle on the whale migration (or at least a significant part of it) usually being within 16.1 km (10 miles) of Cross Island, and often considerably closer. Whalers say that whales are most often found in “currents”, but it is not always clear to a non-whaler what is meant by “current”. Sometimes it appears to refer to a flow of water, sometimes to a constant water depth, and sometimes both. Nuiqsut whalers frequently refer to the “30 meter” or “3 mile” current occurring about 2.5 to 5.6 km (1.6 to 3.5 miles) from Cross island, the “5 mile current” occurring about 8.9 to 10.5 km or 5.5 to 6.5 miles from the island, the “60 meter” current (16.1 to 19.3 km or 10 to 12 miles from the island), and the “20 mile” current. The locations of these currents are said to change from year-to-year, and are at best approximate. Nuiqsut whalers, when scouting, often look to find one of these currents and then follow it, and state that they usually can find whales in the “30 meter” and “60 meter” current. When they have to go beyond the “60 meter” current, the whales are considered to be relatively far from Cross Island.

This general conceptual framework is consistent with how Nuiqsut whalers characterized each of the seasons in terms of whale distributions. They were able to find whales at a "normal" distance from Cross Island in 2002 and 2003; a closer distance in 2007 and 2008; somewhat greater distances in 2002, 2006 (once ice conditions moderated), and 2009; and at greater distances in 2001. [Aerial surveys and acoustic monitoring also found that bowheads tended to be relatively far offshore in 2001 (Treacy 2002b; Blackwell et al. 2007; see also Chapter 5).] These observations were also affected by the relative abundance of whales, which the whalers could only judge from the numbers they were seeing, as well as the whales' behavior. Based on these observations, they concluded that whales were abundant and behaving "normally" (or at least did not report much "skittish" behavior) in 2003, 2004, 2006, 2007, and 2008. They thought that whales were few in numbers within their scouting area in 2001 and 2009, and relatively infrequent in 2002, and many were acting as if they were "skittish" in those years (§ 7.6.1, and more specifically § 7.6.5). These descriptions of whale distribution agree for the most part with the information available from the whale call localizations from the Northstar DASAR monitoring array (see Chapter 5 and Blackwell et al. 2007). Although acoustic localizations far from the DASARs are at very imprecise positions, the acoustic data provide good information on the general distribution of calling whales in a season. More importantly, only those whales that are vocalizing within detection range of the DASARs (and not the entire population of migrating whales) are recorded and localized by the DASAR array. Nonetheless, the offshore distances of the whale call localizations, and the relative numbers of calls detected from year-to-year, tend to agree with the whalers' estimates of whale distribution and abundance during their whaling seasons.

The above summary did not mention 2005 because there was only one day when the whalers were able to reach open water (and the whale migration corridor) beyond the nearshore band of ice, and thus they had little information with which to assess whale distribution and numbers. Ice was also a factor in 2001, but not in the same way. In general, Nuiqsut whalers report that significant ice cover allows whales to "hide" and thus makes them more difficult to spot. Significant ice cover also allows whales, once they are spotted, to escape more easily. Ice makes it more difficult to follow whales, since whales can dive under ice whereas boats must travel around it. Thick ice cover, such as that encountered near Cross Island in 2005, may also direct most of the migration farther north into more open water, while at the same time effectively preventing Nuiqsut whalers from reaching or accessing those areas. When Nuiqsut whalers were able to reach the more open water to the north of the ice pack in 2005 and 2006, they did find whales and were able to follow and chase them. Nuiqsut whalers believe that the migration of whales in 2005 was similar to that of previous years, but that ice and weather conditions prevented the whalers from reaching and seeing most of the whales. The whalers also believe that many of the whales that they did see in 2005, at least in the area SE and E of Cross Island, were affected by non-whaling vessel activity in the area, and that this had a detrimental effect on the success of their subsistence whaling (see section 7.6.6).

One co-captain constructed a local model to indicate how the 2001–2009 observations were consistent with his lifetime of experience of the migration path of the bowhead whale near Cross Island, and how the migration route varies depending on conditions. At least in the past, the edge of the pack ice was "normally" not too distant from shore, and migrating bowhead whales followed this ice edge. When there was considerable coverage by floating ice floes, bowheads would migrate close to the floes (as in 2001). When there is little or no ice, the whales were said to use the barrier islands as navigation aids and are thus closer to shore than in most years with ice. This is one reason, the co-captain surmised, that the area between Narwhal and Cross Islands, and to the north of Narwhal Island (and the quadrant NE of Cross Island in general), has been so consistently productive for the Cross Island whalers. He also indicated that Nuiqsut whalers encounter whales moving in all directions, and not just west or northwest. He suggested that whales going north could be simply moving offshore, while those going east (or other directions) could be feeding (see section 7.6.4). He also indicated that sometimes whales migrate inshore of the barrier islands.

7.6.4 Whale Feeding

As discussed in all previous reports, whalers do not often observe whale feeding in the Cross Island area. During the nine years of the MMS study, observations of whale feeding were reported in only two seasons — one in 2004 and one (or two) in 2009. Both were spectacular displays of a whale feeding on the surface with its mouth open. Whalers universally said this was an unusual thing to observe, but indicated that they thought whales commonly fed in the Cross Island area. They observe that in some years whales stay in the Cross Island area longer than in other years, but believe that most feeding takes place underwater where they cannot see it.

The first whale taken by a Nuiqsut crew, in 1973, was feeding in shallow water and disturbing the bottom. Nuiqsut whalers did not scout such shallow waters during the 2001–2009 study years. Whalers do indicate that they have seen evidence in past years of whale feeding, but for most of these cases the dates of observation are uncertain. This does not make the observations any less certain for the whalers. One feeding sighting that is tied to the salient event of landing a whale occurred in 1997, near the present location of Northstar Island. The whalers saw many whales feeding in the area (estimates range from the tens to the hundreds, depending on the source) and they indicate that they had seen whales feeding there before — but not since the construction of Northstar Island (see section 7.6.6)

Nuiqsut whalers tend not to speculate on what an animal ***may*** be doing — if they are unsure, they usually will not say anything. If other obvious feeding behavior had been observed during 2001–2009, it probably would have been reported. Nuiqsut whalers do believe that whales feed near Cross Island, especially when whales appear to be staying in the area rather than swimming directly through it. When whaling, however, they are often not in a position to make such observations due to less than ideal weather and sea conditions, or the need to concentrate on the immediate tasks of whaling, or because the approach of the whalers' powerboats may disturb the feeding behavior before they are close enough to see it. Whalers do look for "whale food" in the water, report at least some of these observations, and carefully search those areas for whales. They are also very attentive to "whalebirds" (phalaropes) that tend to congregate on the same sort of food patches that whales do. Most often, whale food patches and whalebirds do not lead to whales, or at least that seems to have been the case in 2001–2009.

This does not necessarily indicate that Nuiqsut whalers observed no whale feeding behavior on other occasions in 2001–2009 when they were out scouting. However, it probably means that such observations were not common. In a few cases, whalers stated that the whales they had seen may have been feeding, but were not specific as to location or behavior. Possible explanations for this lack of reports, not mutually exclusive, are as follows:

- Most feeding by bowhead whales is below the surface and difficult to recognize via surface observations.
- Few whales were observed by whalers during some (probably most) whaling seasons;
- On some days when scouting was possible, ice conditions made it difficult to observe whales for more than the shortest periods of time;

- On some days when scouting was possible, swells and waves (due to wind) still made spotting and observing whales difficult;
- Barge and other vessel activity may have "spooked" whales in general (whether seen or not), or the whalers' vessels may have disturbed specific bowheads before the whalers were close enough to them to observe possible feeding behavior;
- Food may be more abundant in the Cross Island area in some years than in others;
- A major part of the migration may have bypassed the area accessible to the whalers, or occurred later in the season, after scouting ended.

7.6.5 Whale Behavior and "Spookiness"

In 2001, 2005, and 2009 (and in 2002 to a lesser extent) whalers reported that whales seemed to be more skittish than normal. Conditions, and potential explanations of skittish behavior, were different for each of these years, except that skittish behavior in 2002 was considered to be a more "moderate" form of that in 2001. For other years, whalers may have reported cases of a few skittish whales, but not a general pattern of whales acting skittish.

2001–2004 Period

In ***2001***, there was almost no ice near Cross Island and the whales found by whalers were quite distant from Cross Island in the proximity of floating ice floes. Whalers went far to the northeast and north of Cross Island when scouting for whales in 2001. Whalers saw few whales, and all of the whales that they saw were difficult to approach. At least three components were mentioned as being part of this pattern of behavior. • First, whales were observed to be staying around ice floes rather than spending more time in open water. That is, whales were described as "playing hide-and-seek" amidst the floating ice, even though there was a significant amount of open water. • Second, as compared to previous (non-study) years, whales seemed to be spending more time on the surface, and swimming more while on the surface. The normal pattern from previous years was described as one where a whale would surface briefly, with a noticeable "blow", dive and swim for perhaps 20 minutes or so, surface briefly again, dive, and so on. • Third, the underwater paths of whales in 2001 were more unpredictable than in previous years. In past years, whales tended to swim in straight paths when they dived, and thus surfaced in predictable places. In 2001, they tended to turn when underwater and thus surfaced in unpredictable locations. Perhaps related to this, whales were more difficult to spot in 2001 than in previous years. "Blows" were not as observable, even in flat or calm waters, as in past years; and at times whalers could hear the "blows" from whales but still could not see them. Whalers reported that the only time in 2001 when they observed "blows" was when the whalers themselves "spooked" whales out of the ice. Whalers prefer not to hunt in this way, but found that this was the only way to spot and follow whales in 2001. Some whalers also reported that the whales they saw in 2001 appeared to be skinnier (not as round) as had been the ones seen in previous years.

In ***2002***, there were some observations of skittish or "spooky" whales. These behaviors were not explicitly compared to those observed in 2001, however. It was noted that some whales stayed around ice floes, as they had in 2001, but that there was less ice in 2002. Somewhat more whales were seen in 2002 than in 2001, and the whales were found closer to Cross Island than in 2001. No observations of surface versus subsurface swimming were noted. Several crews were able to follow individual whales for several dives before either losing the whale or being able to strike it; it seemed that crews were better able to track whales in 2002 than in 2001. It may be that the greater degree of success in 2002 compared to

2001, with "on water" effort per strike being little more than half as much in 2002 as in 2001 (Table 7.2), also contributed to fewer references to "skittish" whale behavior in 2002.

There were few or no references to skittish whale behavior during the ***2003*** and ***2004*** Cross Island subsistence whaling seasons.

2005–2009 Period

In ***2005***, whalers attributed the skittish behavior to vessel traffic, whereas they did not propose a specific explanation in 2001. In 2005, they observed tugs with barges several times while they were scouting for whales, and once when they actually in pursuit of a whale. In 2001, they had not reported such encounters, and suggested several possible alternatives (other than possible unobserved industrial or vessel activity) for the skittish behavior of whales. These alternatives were primarily natural causes of various sorts: ice to the east, the possible presence of killer whales or other predators, or natural variability. None of these alternatives was suggested as an alternative explanation in 2005, when whalers were only able to scout for whales effectively on one day, and encountered a commercial barge while chasing a whale (see section 7.6.6).

2001 and 2005 were very different in terms of environmental conditions. In 2001, there was almost no ice near Cross Island and the whales found by whalers were quite distant from Cross Island in the proximity of floating ice floes. Whalers went far to the northeast and north of Cross Island when scouting for whales in 2001. In 2005, ice and weather effectively confined whalers to waters inshore of the barrier islands, to the southeast and northwest of Cross Island, for all but one day. On that one day they did manage to travel through the ice to the east and the northwest of Cross Island. Ice and weather are not considered to be factors that would make whales behave in a more "skittish" manner. However, especially to the SE of Cross Island inside the ice pack, Nuiqsut whalers reported that — once whales were found — they were often difficult to follow and chase because of "skittish" or "spooky" behavior induced, they thought, by other (non-whaling, non-Northstar) vessel activity in the area.

In 2005, whalers described whales as skittish when they were traveling fast, not staying on the surface very long, and changing direction in unpredictable ways when first sighted. In other cases they indicated that a whale that had been traveling at normal migration or traveling speed suddenly began to take evasive action — more than would be expected simply from the approach of the whalers' boats — and the whalers then sighted and/or heard a commercial vessel nearby. Whalers interpreted such "spooked" behavior by whales as reactions to encounters with barges and other vessels in the area. This interpretation was based on the whalers' previous encounters with similar bowhead behavior in the presence of vessels. The whalers noted that the one day and area where they found a large number of whales behaving in a normal ("unspooked") way during the 2005 season was northwest of Cross Island in an area with no other vessel traffic (at least none that they knew of).

During the ***2006*** season, Nuiqsut whalers reported that when they found and could reach the whales, it was usually possible to follow them. "Spooked" whales were not a major concern. However, a few whales were described as appearing to be "spooked" from the time the whalers first saw them. On the first five scouting days, relatively few whale observations were reported and some of those were described as "spooked". On the last five scouting days, when the most whales were seen, there were also some reports of "spooky" behavior. Whether there was a difference in the frequency of "spooked" whales between the first and second parts of the season would be difficult to assess, since so few whales were seen in the first part of the season. Overall, the whalers did not elaborate on possible explanations for the "spooked" behavior and did not make a distinction between the first and second parts of the season in this regard. However, some possible general explanations for "spooky" behavior suggested at various times by whalers would predict more "spooky" behavior early in the season:

- ice cover persisted throughout the season, but was much more extensive early in the season and confined the whalers, other vessel traffic, and perhaps whales within a relatively confined area;
- non-whaling vessel traffic was much more evident to the whalers in the early part of the season; and
- a higher proportion of the whales seen in the first part of the season were solitary whales — solitary whales may exhibit more "spooky" behavior than do bowheads in groups.

In ***2007,*** "skittish" whale behavior was even less of a concern for the whalers than in 2006. For the most part, Nuiqsut whalers reported that when they found whales in 2007, they were able to follow them. Only a few whales were described as appearing to be "spooked" from the time the whalers first saw them.

Similarly, in ***2008,*** "skittish" whale behavior was not a whaler concern. Nuiqsut whalers reported that whales were difficult to see and follow in 2008, but this was attributed to waves and swells and not because the whales were skittish. The whalers thought that there were plenty of whales near Cross Island, and one captain even stated that "One thing you can say this year [2008] is that the whales are NOT spooky" [his emphasis] (Galginaitis 2009a,c). No other whaling captains were this emphatic, but in discussions with each of them during the 2008 whaling season, whales were seldom described as acting in a "spooky" manner.

In ***2009***, Nuiqsut whalers reported that the "skittish" behavior of the whales contributed greatly (along with the relative lack of whales and the large waves and swells) to the difficulty in spotting and following whales throughout the season. Whalers identified several components to the constellation of behaviors that were indicative of "spooked" behavior:

- Swimming at a fast speed rather than staying in the area;
- Surfacing only one time between dives, and not exhibiting a visible "blow" when surfacing;
- Not showing flukes when diving, but simply sinking down under the water;
- Being difficult to spot upon the next surfacing after a dive.

Note that this is only a general description of most whales seen in 2009, and does not necessarily contradict the reports of one (or two) feeding whales and several that were sleeping or resting when they were first seen. A similar suite of behavioral changes has often been reported by biologists who have observed bowheads and some other baleen whale species exposed to vessels, seismic surveys, and some other sources of potential anthropogenic disturbance (Chapter 9 *in* Richardson et al. 1995).

In the context of skittish behavior, one captain remarked that as of that date in 2009 (2 Sept.), all the whales seen up to that point had behaved similarly to the only whale landed in 2005. He described this as a whale that appeared to be coming from the Camden Bay area and exhibiting spooked behavior (fast speed, single surfacings). The whalers had also encountered a barge in the area where they chased and landed this whale in 2005. During the 2009 season the whalers experienced several vessel encounters while scouting (see section below) and so were quite sensitive to the possibility that whales were spooked by vessel traffic.

Other whalers compared the 2009 season to 2002 and 2001, in terms of skittish (and more general) whale behavior. All three were seasons that whalers characterized as years when they saw few whales, with whales farther from Cross Island than "normal", and with whales exhibiting skittish behavior. For

2001, they suggested several possible explanations for the skittish behavior (as above). For 2009, the whalers directly observed more barges and other vessels in their immediate whaling area than in 2001 or 2002, and some whalers believed that the vessel activity was likely a cause of skittish whale behavior in 2009. Other whalers were not convinced that this vessel activity was the most important factor, although it certainly was considered a possible contributing factor, and one that they wanted eliminated. They cited the lack of ice, difficult sighting conditions, and apparent overall low number of whales in the area as other possible factors.

Although few overall generalizations can be stated concerning “skittish” whale behavior, it appears that in 2001–2009, seasons when bowheads were considered abundant near Cross Island were seasons when the whales generally did not display behaviors classified as “skittish”. In contrast, seasons when whales were less abundant (fewer animals seen) and found mostly at longer distances from Cross Island were seasons when “skittish” behavior was noted more frequently. Ice conditions may also be a factor, in several ways. Too much or too little ice may affect whale behavior in ways important to subsistence whale hunters (i.e., affecting distance of the migration corridor from Cross Island, or whale surfacing patterns), which could contribute to the perception of “skittish” behavior. Too much or too little ice clearly affects the success and efficiency of fall subsistence whaling. A moderately high percentage cover by floating ice, especially, may be fine for bowhead whales but can present a severe handicap to subsistence whalers, who could then describe the behavior of the whales in eluding the whalers in the ice as “skittish” behavior. Too much ice may also, as in 2005 and the first half of 2006, concentrate subsistence whalers, commercial vessel traffic, and the only whales potentially available to the subsistence whalers in the same area(s), greatly increasing the chances that these whales will be “spooked and skittish” as a result of commercial vessel activity. This would decrease the chances of subsistence whalers even spotting the whales or, if whales were spotted, of following them and successfully landing them.

7.6.6 Industry and Other Anthropogenic Activities

Nuiqsut whalers have some generalized perceptions about how industrial activities affect their hunt, based on their collective experiences with such activities. The proximity of onshore development facilitates the logistical support of Cross Island whaling, and Nuiqsut whalers make frequent supply runs (weather permitting) between Cross Island and West Dock. Logistical support and emergency assistance (barge, helicopter) from industry are at times requested by the whalers. However, whalers perceive offshore exploration, development, production, and support activities as fundamentally adverse to whaling, primarily because of noise and/or potential spills and accidents. Mitigation of these potential but (in their minds) inevitable effects of offshore oil and gas activities is thus always incomplete and a work in progress.

Concrete, physical, examples are often used to summarize these perceptions and attitudes, and whalers often avoid approaching industry sites. Some examples particular to Cross Island and often mentioned by the whalers are as follows:

- In 2002, the McCovey exploration drilling site was a little over 8 km (5 miles) WNW of Cross Island. Although the SSDC drilling caisson was onsite and visible from Cross Island during the 2002 whaling season, there was no apparent activity at McCovey during that period. The rig had been towed into place prior to the start of the whaling season, and drilling did not commence until later. The whalers perceived McCovey to have little effect on the actual conduct or success of the 2002 hunt, but whalers avoided approaching it when out scouting (or towing), to the extent possible.

- Regarding Northstar, whalers have not reported direct effects on their hunt from Northstar development and production activities, although noise and potential oil spills are still of concern because of the potential for disruptive effects. BP has made efforts to decrease the risk of spills and to reduce the effects of vessel and air traffic to Northstar. Northstar is to the west of Cross Island and "downstream" relative to the bowheads' autumn migration direction and the area where the Nuiqsut hunters normally scout for whales. Thus, they do not expect Northstar to be as problematic, in terms of direct effects on whaling, as would development to the north and east of Cross Island (Ahmaogak 2002: 5, 14). This view is not inconsistent with the demonstration of a statistically significant, but relatively small, effect on the distribution of bowhead calls in the southern part of the bowhead migration route near Northstar when noise from Northstar was at its highest levels (Richardson [ed.] 2008). Nuiqsut whalers, however, prefer not to whale near industry facilities, if they can avoid doing so. In 2005, whalers explicitly indicated that they turned away from Northstar rather than approach it too closely (the closest approach was 4 km or 2.5 miles), and in general whaling boats maintained a distance of at least 6.4–8 km (4–5 miles). More indirectly, Nuiqsut whalers relate that in 1997 they landed a whale near the present location of Northstar Island, and observed many whales feeding in that area and near Reindeer Island. Since the construction of the Northstar facilities, they have not observed whale feeding in that area (although, as stated above, they now seldom choose to look for whales there).
- Oil and gas infrastructure is visible on any clear day or night from Cross Island. The gas flares at Endicott, near the coast south of Cross Island, are quite audible at times and whalers remark on them frequently. Air traffic (not all associated with oil and gas activities) is not uncommon in the area, along with other unidentified noises, and these are common whaler concerns.
- Nuiqsut whalers have observed whales to react to and avoid industry (and other) vessels. The most well known historical cases were in relation to seismic and exploratory drilling activities in Camden Bay in the 1980s and early 1990s. The most salient case during the years of concern for this report occurred in 2005 on 14 Sept. (discussed below).

Conflict Avoidance Agreements (CAAs) between the whalers and industry have been negotiated as far back as 25 years ago (Oil/Whalers Working Group 1986), in part in response to such incidents, in an attempt to minimize and mitigate such effects.

The MMS- and more recently BP-sponsored effort to document whaler activities and perceptions at Cross Island has provided more specific information about interactions between the Nuiqsut whalers and human activities on the water near Northstar since 2001. Details concerning each year and incident have been reported in previous annual and summary reports by the present author, as listed in the Literature Cited section. The annual reports prepared for BP concerning the 2005–2009 seasons are included in Appendices A–F (respectively) on the CD-ROM that is part of the present report. The following summarizes the specific interactions with industry and other human activities near Northstar during the years 2001–2009. Emphasis is given to the 2005–2009 period, which is of specific concern in the present report.

2001–2004 Period

Although Nuiqsut whalers reported some observations of industry activity during the 2001–2004 whaling seasons, no such activities were documented in any detail for the MMS-funded projects, primarily because the whalers did not make large issues of them. This may have been due to the relatively open water conditions during those years, and the fact that Nuiqsut whalers were able to find and harvest whales. The CAA process also seemed to work well to minimize friction during these events. For example, there were four documented whaler-commercial vessel interactions in 2002 (Galginaitis 2008b; Deadhorse Communications Center log 2002). One involved an unidentified barge east of Cross Island, about which the whalers expressed potential concerns. However, they did not indicate that whaling had been affected. The three other cases concerned requests by Alaska Clean Seas (ACS) vessels for permission to perform actions in certain areas. In two cases, ACS delayed these activities at the request of the whalers, who planned to scout for whales in those areas. In one case, permission was granted because the whalers were butchering and not scouting. Thus, in these cases the system worked to avoid potential industry-whaler conflicts.

2005–2009 Period

In ***2005***, due to the ice conditions and poor weather that restricted both whaling and commercial vessel movements, whalers concluded that they were adversely affected by commercial vessel traffic that they encountered in the limited area of open water available to them. Although these vessels were not supporting oil and gas activities, and thus not parties to the CAA in effect for 2005, their effects are anthropogenic in nature and, rightly or wrongly, are perceived by whalers as those that could be expected of any commercial vessel activity taking place in those areas.

Whalers reported seeing vessel activity on six separate days during the 2005 whaling season, five of which were days when the whalers were actively scouting for whales (see Galginaitis 2008b,d,e for details). None of the vessels encountered were engaged in support activities for Northstar. Whalers' accounts of these encounters became more detailed later in the season, perhaps because the whalers became increasingly sensitive as the season progressed to the potential disruptive effects such vessel encounters could have on their whaling activities. Whalers also had few good opportunities to approach or strike whales early in the season, as conditions for finding whales were not very good. Few whales were seen prior to 14 Sept., and those whales that were seen were seen for relatively brief periods. How much of this can be attributed to vessel activity in the area as opposed to the unequivocally adverse environmental conditions (see § 7.5.1) is difficult to assess, and Nuiqsut whalers did not express explicit statements in this regard. Given the conditions, they perceived that vessel traffic may have been a factor on days prior to 14 Sept., but the scarcity and brevity of whale sightings could not be attributed definitely to that vessel traffic.

However, whalers reported that vessel activity directly affected the conduct of their hunt on 14 and 21 Sept. (the last two scouting days of the 2005 season). It is not possible to demonstrate that, in the absence of vessel activity, the Nuiqsut whalers would have landed a whale sooner on 14 Sept., or landed more than one, and they did not make that assertion. However, within the cultural constraints of not taking the harvest of any animal for granted, it was fairly clear that the whalers thought that their chances for taking more than one animal on 14 Sept. would have been substantially increased without the interference posed by the vessel traffic. Similarly, chances for a strike on 21 Sept. were apparently quite promising prior to the appearance of a barge, after which the whale was "spooked" and never seen again.

In ***2006***, concerns were heightened by the memory of the events in 2005, particularly because ice conditions during the first half of the season replicated those of 2005 (although weather was somewhat better in 2006). Whalers reported seeing activity by commercial vessels on four separate days during the 2006 whaling season, all of which were days when the whalers were actively scouting for whales. On a fifth day, two private sailboats overnighted at Cross Island, having come from the east. They traveled west the next day. All five of these days were early in the 2006 whaling season, when ice conditions still confined the whalers inshore of the barrier islands and few whales were being seen. The supposition was that whales were staying in the open water beyond the ice, out of the reach of the whalers. Because of their experience in 2005, when they were able to reach the whales in the open water during only one day and part of another, and when whaling was disrupted by commercial vessels, Nuiqsut whalers were very sensitive to the issue of such commercial traffic in 2006.

Although the whalers did not report this vessel activity in 2006 as disruptive to their activities, they were concerned with the possibility that the few whales potentially accessible inshore of the ice would be harder or impossible to spot and approach because of those vessels. These potential concerns fostered long conversations with the Deadhorse Communication Center about the provisions of the CAA, as well as two lengthy phone conversations between a representative of the Nuiqsut Whaling Captains Association (NWCA) and the AEWC. Once the whalers were able to reach the open water and the whales (mid-Sept.), these concerns were no longer so much in evidence. This may have been a result of the physical separation of the whalers and any commercial vessel traffic, the practical fact that whalers could then concentrate on hunting whales rather than the lack of accessible whales, the absence of commercial vessel traffic after mid-Sept., and/or some other factors.

The whalers seemed, in fact, to be relatively satisfied with the implementation of the CAA as it applied to vessels operating on behalf of the oil industry. The logistical support of the Cross Island operation (generator, lights, fuel, and so on), provided by industry under the CAA provisions, also received high marks. Industry-related vessel activity was, for the most part, identified for the whalers in advance via the Com Center. Whalers exhibited no desire to prevent vessel activity in general — only those activities that could interfere with whaling. For example, when BP's acoustical crew planned to pass near Cross Island on 5 Sept. 2006, while attempting to move around the ice in order to reach the deployment location for their seafloor acoustic recorders, they contacted the Cross Island whalers and were granted permission. The hunters considered that this was not a potential disruption to whaling, as the whalers were scouting SE of Cross Island. Ice conditions prevented the deployment, however. The following day, permission for similar activity (but not BP-related) was requested. The whalers determined that it could potentially interfere with whaling activity, requested that it be deferred, and it was. Once the Nuiqsut whalers filled their quota by landing their 4th whale (18 Sept.), they called a cease fire and issued permission for industry activities to proceed with no objections from Nuiqsut whalers. This action was consistent with both the letter and the spirit of the CAA.

However, when the whalers encountered a loud commercial (but non-industry) barge on 9 Sept. 2006 engaged in other activities (they thought hauling gravel), the whalers were very concerned that those activities were not subject to the CAA. They contacted the NSB to request that the gravel hauling operation be suspended until after the whaling season.

In ***2007*** and ***2008***, there were no specific occasions during the Cross Island whaling seasons when Nuiqsut whalers complained about the effects of vessel traffic on their subsistence activities. Although a great deal of vessel activity was taking place, most of it was of a regular or scheduled nature in support of operations to the west of Cross Island. As has been stated in the past and is repeated in the Deadhorse Communication Center Call Log for 2007, Nuiqsut whalers do not want vessel activity to the east of Cross Island during the subsistence whaling season, but are much more tolerant of such activities to the west of Cross Island. In the one case where there was some question as to whether vessel traffic could proceed or not, the conflict avoidance process worked well and prevented any potential effects on whaling activities. Both 2007 and 2008 were seasons when Nuiqsut whalers filled their quota and found whales close to Cross Island.

In ***2009***, in strong contrast to 2007 and 2008, there were two instances early in the whaling season when the whalers filed Vessel Conflict Incident reports about non-industry vessels that they encountered while out scouting for whales (Galginaitis 2010a,b). Whalers also reported two other instances when they observed vessels later in the season while they were out whaling, but in those cases did not file Vessel Conflict Incident reports through the Deadhorse Com Center. It is not clear why reports were not filed in the latter cases, or if such reports were filed directly with AEWC. It may be that the whalers were frustrated by the process of logging complaints to no apparent purpose, since the complaints did not seem to affect the non-whaling vessel traffic. One of these later encounters involved the ACS vessel *Mikkelsen Bay* when it was servicing BP's DASAR array north of Northstar. Advance notification of that trip had been sent by the vessel operators to the Deadhorse Com Center via FAX (although it does not appear in the Communications Center log) and no objection was received. However, when a single whaling boat encountered the *Mikkelsen Bay* at sea northwest of Cross Island, the whalers contacted the Com Center, which in turn contacted the *Mikkelsen Bay,* which then aborted its activities and returned to West Dock, with a short stop at Northstar to retrieve an acoustic recorder. The *Mikkelsen Bay'*s activities were confined to the area from West Dock to Northstar and then northeast to the DASAR array area, i.e., to waters well to the west or northwest of Cross Island (see Fig. 4.2 *in* Chapter 4). The other incidents in 2009 all involved vessels whose owners and operators were not parties to the CAA, and those vessels were actually traversing the area (most or all from east to west) at various distances from Cross Island.

None of these incidents in 2009 affected the immediate pursuit of whales, but more generally had the potential to disturb whales and elicit skittish behavior, making it more difficult to see and approach the whales. It is impossible to determine whether the difficulty that Cross Island whalers had in spotting and following whales during 2009 was at least partially due to the effects of vessel traffic. The whalers were far from unanimous on this topic, as general conditions for sighting whales were quite difficult for most of the 2009 season, and whales were seen on some days even when other vessels had been seen. However, The AEWC and the Nuiqsut whalers have long been aware that vessels operated by entities that are not parties to the CAA may have adverse effects on whaling activities, and are especially sensitive about this issue. Until a mechanism is developed to include such vessels in at least the reporting and communication requirements coordinated through the Deadhorse Com Center, this will continue to be a point of contention.

7.7 SUMMARY AND CONCLUSIONS

The main motivation for the MMS project (2001–2009), which served as the foundation for this assessment, was the question whether Cross Island subsistence whaling had been, or was likely to be, affected by oil and gas activities. The principal objective of this report is much more narrowly constrained, to address whaler perceptions concerning the effects of Northstar on Cross Island subsistence whaling. However, the MMS project since 2001 and the BP-sponsored extension of that work since 2005 have also provided much new information on the nature of whaling activities at Cross Island, variation in those activities from year to year, and whaler perceptions concerning various questions about bowhead whale activities near Cross Island and Northstar during the whaling season in late summer and early autumn.

Information available prior to 2001 was not adequate to examine in detail the key question about industry influences on the hunt. However, narratives from whalers described how seismic and drilling activities in the mid-1980s through 1990 had reportedly diverted the whale migration away from Cross Island, increased the distance whalers had to travel to find and strike whales, and so decreased their success in landing whales. Although this project was designed to collect quantitative measures of Cross Island whaling from 2001 to date, and so to be capable of evaluating differences from one season to another, it was not designed to collect specific information about oil and gas activities. Furthermore, the very activities to which whalers objected in the mid-1980s through 1990 were specifically prohibited during the whaling seasons documented for this project (2001–2009).

Northstar was in production mode during most of the study period (i.e., in 2002–2009), and whalers noted few if any direct effects of Northstar on their whaling activities — other than that the whalers themselves avoided scouting for whales near Northstar. Whalers did note that, since the construction of Northstar Island in 2000, they no longer observe whales feeding near Northstar or Reindeer Islands. However, the avoidance of that area by the whalers may have contributed to that lack of sightings. The lack of direct effects of Northstar on whaling was attributed primarily to Northstar being west of Cross Island. The whales come from the east and so did not encounter any potential disturbance from Northstar until they had passed Cross Island and the Nuiqsut whalers. The whalers did not consider their own avoidance of the Northstar area as being much of an effect in "normal" years, since their primary (preferred) search area for whales is to the northeast of Cross Island. However, in years with more restrictive ice conditions (for example, 2005 and 2006), the Northstar area northwest of Cross Island was formerly an area where Nuiqsut whalers could sometimes find both open water and whales. This may no longer be the case, but the magnitude of this possible effect on whaling in years when ice constrains whaler movements is difficult to evaluate.

The year-to-year and within-season variability in whaling activities that the MMS project documented was primarily due to differences in ice and wind conditions, and in the distribution of whales (distance from Cross Island), their apparent abundance (how many whales the whalers could find), and their behavior ("normal" or "skittish"). Further, differences among the seasons in effort expended (e.g., "boat hours" and "boat hours per strike") could be fairly well quantified. However, the relationship between variability in whaling effort vs. variability in ice and wind conditions, or whale distribution, or whale behavior, were not as clearly evident. The ice conditions present during the nine seasons either prevented access to whales altogether, or seemed to have little or no net effect. The absence of ice, in combination with high winds and/or large swells, contributed to difficult whaling conditions in some seasons. Adverse weather conditions hinder whaling, but the shortest seasons were those that were measurably the worst in terms of weather. Perhaps the least ambiguous factor associated with the effort expended per landed whale was the distance of whales from Cross Island, i.e., the distance from Cross Island at which the whalers found bowhead whales. The two were directly related — the greater the distance, the greater the effort. That result is hardly surprising.

Of anthropogenic activities considered in this chapter, vessel traffic probably had the greatest perceived adverse effects on Cross Island subsistence whaling during 2001–2009, even though precise effects would be difficult to demonstrate in a rigorous way. These effects can be assigned almost totally to commercial vessel traffic not associated with BP's Northstar development or other oil and gas operations, and operating outside the provisions of the Conflict Avoidance Agreement. The CAA has effectively managed most industry-whaler potential conflicts (at least in the area of industry-whaler vessel interaction). The problematic vessel interactions, most prominently those of 2005, were with non-oil-industry vessels not subject to the CAA. On the infrequent occasions when vessels involved in Northstar or other oil industry activities were of concern to the whalers, real-time communications via the Communication Center at Deadhorse and subsequent actions by the oil-industry vessels prevented any significant effects upon whaling activities.

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CHAPTER 8:

POTENTIAL EFFECTS OF NORTHSTAR ACTIVITIES ON MARINE MAMMALS AND ON THEIR AVAILABILITY FOR SUBSISTENCE [1]

by

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[3] This chapter is an update of the corresponding Chapter 14 in the final Comprehensive Report on monitoring during the 1999–2004 period (Richardson [ed.] 2008).

ABSTRACT

Letters of Authorization (LoA) issued by NMFS to BP annually in 2000–05 and in 2006–09 authorized the "taking" of small numbers of seals and whales incidental to Northstar activities. For 2000–04, estimates of numbers of seals potentially affected were made annually, with the most recent estimates being for Nov. 2003–Oct. 2004. In that period, an estimated 61 ringed seals, 1 bearded seal, and probably no spotted seals were close enough to Northstar activities for there to be a possibility of disturbance. Those estimates took account of monitoring results showing no more than highly localized effects on seals. The overwintering seals that were potentially affected probably were limited to those excluded from physically-disturbed areas, including the artificial island and ice road plus a 100 m (328 ft) buffer zone. Estimated numbers of seals potentially affected were less than the numbers of "takes" authorized by the LoAs issued by NMFS to BP. Furthermore, most seals counted as "potentially affected" probably did not incur biologically significant effects. In the present 2005–2009 reporting period, no intensive monitoring was required or done, but ongoing counts of seals visible from Northstar show that ringed seals continue to occupy the area within *ca.* 1 km (0.6 mi) in variable numbers. The overall results suggest that any effects of Northstar production activeities on seals are minor, short-term, and localized, with no consequences for the seal populations. The Northstar location is not an area where seal hunting was common before Northstar was built. Insofar as we know, there has been no subsistence hunting of seals there since Northstar was constructed, and availability of seals for subsistence harvest probably was not affected.

Acoustic localization data indicated that, during late summer and early autumn of 2001–2004, some bowhead whales in the southern part of the migration corridor (closest to Northstar) were affected by vessel or Northstar operations. The southern edge of the distribution of calling whales tended to be slightly but (statistically) significantly farther offshore, by an estimated 0.76–2.35 km (0.47–1.5 mi) in the various years, at times with higher levels of underwater sound from Northstar. At these times, most "Northstar sound" was from vessels supporting Northstar, not the island itself. Results from 2009 are equivocal as to how the southern edge of the distribution of calling whales was related to measures of Northstar sound; there were some indications in 2009 that (with elevated underwater noise levels) the closest calls tended to be slightly *closer to*, not farther from, Northstar. In all years, the small shift in the southern edge of the distribution of calling whales was probably partly attributable to a noise-related change in calling behavior rather than actual deflection. Based on guidance in recent reviews as to what effects are biologically significant, migrating bowheads whose paths are deflected offshore (or inshore) by no more than a few kilometers, or whose calling behavior is altered temporarily, would not be expected to incur biologically significant effects. Thus, numbers of bowheads (if any) that were truly "harassed" by Northstar would be, at most, low and presumably well within provisions of the Northstar regulations and associated LoAs. Those authorized up to 765 harassment "takes" annually (or 1533 in 2 years or 3585 in 5 years) during the most recent years when a specific number of "takes" was authorized.

The bowhead monitoring results do not explicitly show how far east the slight "deflection effect" extended, and in particular, whether it extended east into waters where Nuiqsut whalers commonly hunt bowheads. However, during 2005–2009, the Nuiqsut whalers struck 3 or 4 bowheads (of their annual quota of 4) during each autumn except 2005, and the whalers did not attribute their problems in 2005 to Northstar.

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 Northstar drilling, production or ancillary operations in 2005–09. Gray whale sightings have been infrequent this far to the east, and it is likely that no gray whales were affected by Northstar activities. For belugas, estimated numbers that might approach within an assumed 1–2 km (0.6–1.2 mi) disturbance radius are 10–20 in an average year.

INTRODUCTION

BP Exploration (Alaska) Inc. (BP) began constructing oil-production facilities for the Northstar Development during the winter of 1999–2000, began drilling in late 2000, and began producing crude oil from the Northstar Unit on 31 October 2001. Oil production, gas injection, and periodic drilling have continued since then. Chapter 2 describes BP's Northstar activities during the current reporting period from 2005 to date.

Regulations concerning incidental "taking" of seals and whales via BP's Northstar project were promulgated by the National Marine Fisheries Service during May 2000, effective for five years (NMFS 2000a). Those regulations were renewed in 2006 for the period April 2006 to April 2011 (NMFS 2006). The annual Letter of Authorization (LoA) issued by NMFS under provisions of those regulations required monitoring of industrial sounds and marine mammals to estimate the nature, amount, and geographic extent of any effects on marine mammals and on their availability for subsistence hunting. Some of the primary purposes of monitoring were to assess the nature of any effects of BP's Northstar activities on seals and whales, to assess the numbers of seals and whales potentially affected by Northstar activities, and to compare those estimated numbers with numbers estimated in the LoA request and/or authorized in the annual LoA. There was also a requirement to assess any apparent Northstar effects on availability of marine mammals to subsistence hunters.

The monitoring work planned and conducted by BP in 2005–2009, and to some extent in years before 2005, has been described earlier in this report, with details for some studies being provided in the Appendices. A previous Comprehensive Report (Richardson [ed.] 2008) provided details on monitoring work up to 2004. In this report, Chapter 3 summarizes counts of ringed seals near Northstar, primarily during the late spring and early summer periods, in 2005–09. Chapters 4 and 5 describe physical acoustics and bowhead whale monitoring studies conducted during the open-water seasons of 2005–2009, with frequent references to previous data from 2001–04. Chapter 6 examines the extent to which the distribution of bowhead whales offshore of Northstar during later summer/early autumn in 2009 was related to fluctuations in Northstar sounds and other natural and anthropogenic variables. Chapter 7 summarizes whaler perceptions of Northstar effects on bowhead migration with emphasis on 2005–2009 but with considerable information from years back to 2001.

Estimates of the number of seals and whales that might be affected by Northstar production and maintenance activities were discussed by NMFS (2000a) in the preamble to the regulations issued in May 2000, and again in a general way by NMFS (2006) in comments on the renewed regulations. BP's petitions for the initial and renewed regulations (BPXA 1999, 2004) estimated the numbers of marine mammals that might be affected based on the evidence available at that time. The monitoring programs were implemented to improve understanding of the nature of the effects and the numbers of mammals potentially affected. It should be noted that most seals and most or all whales occurring in areas "potentially affected" by Northstar probably did not incur long-term consequences for their well-being or reproductive productivity. Thus, most individual seals and whales that were "potentially affected" probably were not "harassed" in any meaningful sense.

The regulations and LoAs issued by NMFS set limits on the types and levels of "taking" that were authorized. Different levels of "taking" were authorized in different years. For the latter stages of the first 5-year regulations (which were effective in 2000–2005),

(i) during the ice-covered and ice-breakup periods, up to 139 ringed seals and 5 bearded seals may be incidentally harassed annually during production operations;

(ii) during the ice-covered period, up to 5 ringed seals may be incidentally killed annually;

(iii) during the open-water period, up to 52 ringed seals, 5 spotted seals, 5 bearded seals, 5 gray whales, and 91 beluga whales may be incidentally harassed annually;

(iv) during the open-water period, 765 bowhead whales (maximum of 1533 bowheads in 2 out of 5 seasons, or 3585 in 5 years) may be incidentally harassed annually.

The regulations and LoAs issued for the second 5-year period (2006–2011) again authorize Level A harassment or mortality of up to five ringed seals per year, and authorize Level B "takes" of ringed, bearded and spotted seals plus bowhead, gray, and beluga whales. However, the recent LoAs do not specify particular limits on the number of Level B (disturbance) "takes" of any of these species.

The immediately following sections of this chapter summarize numbers of ringed seals that were estimated to have been potentially affected by activities associated with BP's Northstar development in 2003–04, as authorized in the LoA then in effect. Our estimates of maximum numbers that might actually have been affected take account of evidence accumulated from studies, monitoring, and observations of seals in 1997–2004 and (in a more general way) 2005–2009. We compare those estimates with earlier predictions. Specific monitoring and research on ringed seals near Northstar over the 1997–2002 period showed that effects were very limited (Richardson [ed.] 2008), and only a limited level of monitoring has been required in the present reporting period. Therefore, the best available information on current Northstar effects on seals comes from years previous to 2005 when detailed studies were done.

A subsequent section discusses the nature and extent of the potential Northstar effects on bowhead whales based on monitoring results described in Chapters 5 and 6, in the previous Comprehensive Report for years previous to 2005, and in associated refereed publications and manuscripts.

Bearded and spotted seals and gray and beluga whales, which were unlikely to interact significantly with activities at Northstar, are also addressed briefly. Numbers and densities of bearded and spotted seals near Northstar are low, and gray and beluga whales are infrequent near Northstar. [Most belugas of the Beaufort Sea population migrate east and west much farther offshore, at and beyond the shelf-break (Braham et al. 1984; Miller et al. 1999; Moore et al. 2000; Richard et al. 2001).]

To date, the MMPA and its implementing regulations have not had a clear operational definition of "take by harassment". As a result, there has been much debate concerning how substantial and prolonged a change in behavior must be before it constitutes a "take by harassment". There is general recognition that minor and brief changes in behavior generally do not have biologically significant consequences for marine mammals and do not "rise to the level of taking" (NMFS 2000b, p. 60409; NRC 2005). Criteria and procedures for estimating numbers of marine mammals present and potentially affected are still being developed and improved (NMFS 2005; Southall et al. 2007), and a variety of plausible estimates can be presented depending on assumptions.

The final section of this chapter discusses potential impacts of Northstar activities on subsistence hunting for seals and whales near the development area.

ICE-COVERED AND BREAK-UP PERIODS

During the ice-covered and break-up periods, 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 through offshore areas north of the landfast ice, which excludes whales from areas close to Northstar. Detailed monitoring of ringed seals near Northstar was done during spring and (in some years) winter of 1997 to 2002, including three years of Northstar construction and initial oil production (2000–2002). During the subsequent winter/spring seasons of 2003–04 through 2009–2010, no intensive ringed seal monitoring was required, although frequent counts of seals visible near Northstar in late spring and early summer have been obtained since 2005 (Chapter 3). Therefore, our estimates of the number of seals potentially affected during years since oil production began are based primarily on data collected before 2005. Based on six consecutive seasons (1997–2002) of detailed studies and monitoring of ringed seals, we did not detect statistically significant displacement or exclusion of ringed seals from areas near the island, ice roads, or physically-disturbed ice (see Chapter 3 plus Appendices K–M of this report, and Chapter 3 plus Appendices K–O *in* Richardson [ed.] 2008).

Possible Displacement, Ice-Covered Period

It was not expected that there would be any seal deaths or injuries as a result of the activities at and near Northstar on the sea ice. Although little specific investigation to document seal mortality or injuries was conducted at Northstar, the studies that were done provided no evidence of (and no reason to expect) any seal mortality or injuries attributable to Northstar construction or operation. Early studies (e.g., Frost et al. 1988; Kelly et al. 1988) near other industry sites off northern Alaska suggested that activities on the sea ice near the present Northstar location might have displaced some seals, or caused some seals to cease using one or more breathing holes or lairs. Most Northstar monitoring studies directed toward seals were designed to detect the occurrence and geographic scale of displacement. Monitoring work consisted primarily of intensive aerial and ice-based studies concentrated close to Northstar so as to be able to detect small-scale effects. The aerial surveys also extended farther from Northstar for comparative purposes. One study of seal use of holes and lairs was done during Northstar construction (Williams et al. 2006).

For purposes of estimating the numbers of seals potentially affected by Northstar activities, we defined two zones of progressively increasing size around Northstar:

(1) The “***Northstar development zone***”, in any particular year, was defined as the sea ice that was artificially thickened, cleared of snow, or used to deposit snow and ice and then subsequently used as a road or work area. In addition to the disturbed sea ice, Northstar Island was also included in the development zone. In 2003–04, for example, this narrow strip totaled ~0.93 km^2 (see linear area shaded dark gray in Fig. 8.1). We did not include, as part of the “development zone”, small areas near Northstar where emergency equipment was occasionally tested, or the strip along the pipeline route where monitoring for oil spills was conducted intermittently.[4] These “excluded” activities were limited in scope, geographic extent, and frequency, i.e., five or fewer operations during the 8-month ice-covered period. In addition, we also did not

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[4] See Rodrigues and Williams (2006) for a detailed description of these activities during the years up to 2002 when intensive seal monitoring was done, and Chapter 2 of the present report for a description of the same activities as implemented in more recent years.

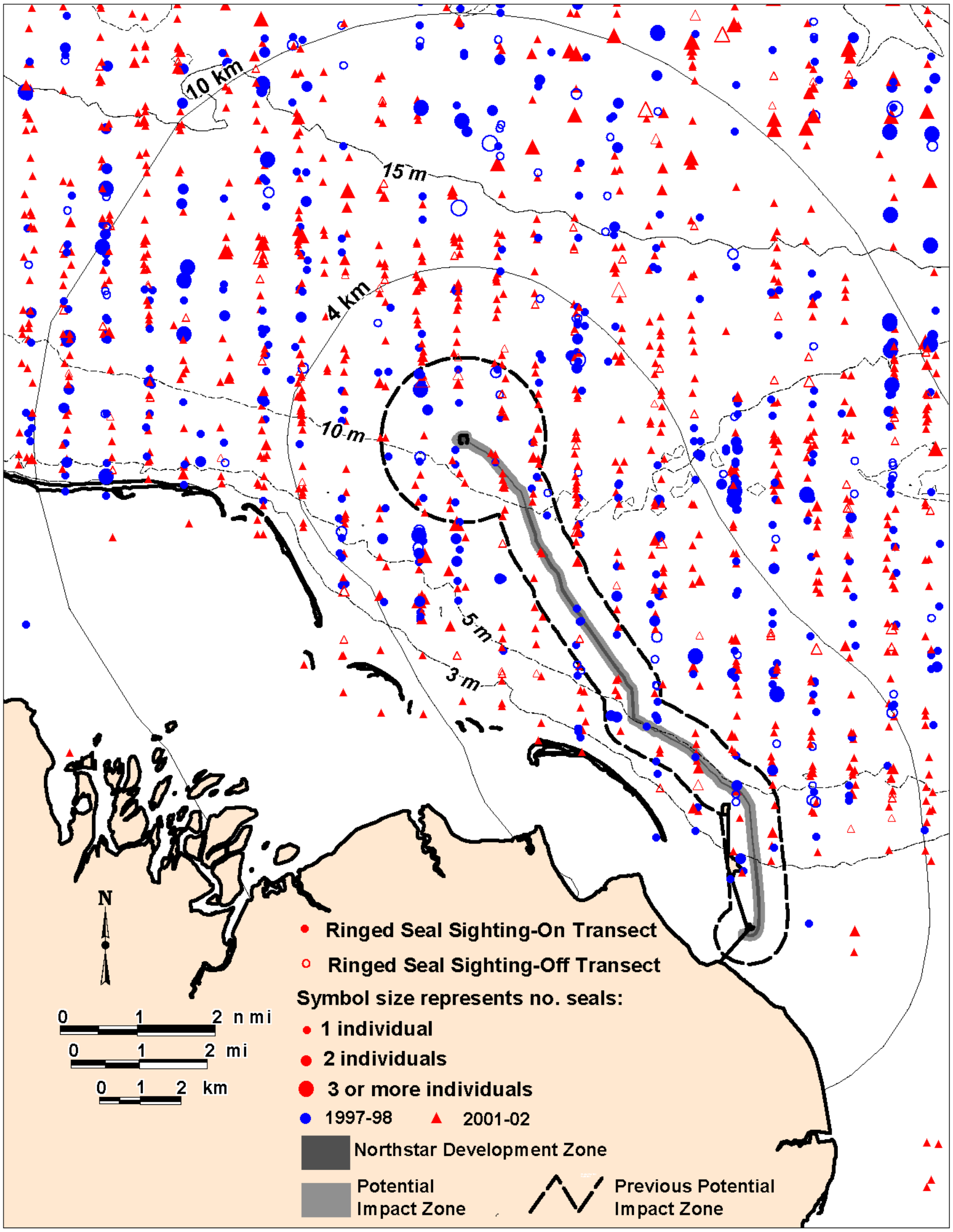

FIGURE 8.1. Distribution of ringed seal sightings near Northstar during spring aerial surveys in 1997–98 (pre-industry, blue circles), and in 2001–02 (red triangles; limited construction and drilling in 2001; oil production in 2002). In 2004, the “Northstar development zone” consisted of the ice road and artificial island (dark gray linear area). The “potential impact zone” (see text) is indicated with medium gray shading. The “previous potential impact zone” as defined for 2001–2002 is shown for comparison (dashed line). The 4 and 10-km bins are measured from the edge of the 2004 “potential impact zone”. The 4-10 km “reference” zone (stratified by water depth) was used to calculate expected number of seals within the potential impact zone in the absence of industrial activity at Northstar. 1 km = 0.62 mile = 0.54 n.mi.

include the hovercraft trail, after the hovercraft began operating in 2003, as the sea ice was not manipulated along the route. It was considered unlikely that emergency equipment procedures and hovercraft activities would have any biologically important effects on seals. This conclusion was based on the very limited evidence of such effects even after the much more intensive industrial activities on the sea ice during the construction phase (Moulton et al. 2003a, 2005; Williams et al. 2006a).

(2) The "***potential impact zone***" included the "Northstar development zone" plus an additional area of ~3.07 km^2 (corresponding to a 100 m buffer around the development zone) resulting in a total area of ~3.99 km^2 for the impact zone. NMFS (2001, p. 65930) states that "NMFS does not consider an animal to be 'taken' if it simply hears a noise, but does not make a biologically significant response to avoid that noise." Given the lack of evidence for reduced seal density or reduced utilization of subnivean structures near Northstar (Moulton et al. 2005; Williams et al. 2006a), we treat the Northstar development zone plus a 100 m buffer around that zone as the "potential impact zone". Seals near the island might be affected during helicopter landings and takeoffs at the island. However, the low-altitude portion of the helicopter route was small and the area potentially affected in a significant way by helicopter traffic was assumed not to extend beyond the aforementioned 100 m buffer. Helicopter altitude was normally ~460 m (1500 ft) while en route.

The "potential impact zone" for 2004, as defined above, is shaded medium-gray in Figure 8.1. Based on the limited information available prior to this study, the "potential impact zone' for seals after construction ended was assumed to extend out to 1.85 km from the island and 0.64 km from the ice road (Moulton et al. 2003b). Results from aerial monitoring in 2000–02, along with the on-ice studies in 2000–01, indicate that the distance categories applied in defining the previous "potential impact zone" were overestimates of actual impact distances. The currently-defined "potential impact zone" is much smaller than assumed earlier, and the numbers of seals significantly affected by Northstar are lower than reported in our early reports (e.g., Moulton et al. 2003b). *Our current estimates better reflect the number of seals likely affected by an offshore oil and gas facility such as Northstar.*

In order to evaluate how seals may have been affected by industrial activities during the ice-covered season of 2004 (representative of the period of production operations), we estimate the number of seals that might have occurred within the potential impact zone if the Northstar Development had not been constructed. These estimates are based on aerial survey data collected in 1997–2002, as no aerial surveys were required or conducted thereafter. Industrial activities at Northstar in 2004 (production) were more similar to those in 2002 than to those in other (earlier) years with aerial surveys and the Northstar Development Zone in 2002 was very similar to the Development Zone in 2004. Hence, we primarily use the number of seals expected to have been present in 2002 if there had been no industrial activities in that year as a basis for estimating the number of seals that may have been affected by Northstar activities in 2004. The expected number in the absence of industrial activities was based on surveys of otherwise-similar non-industrial areas, or surveys of the Northstar area in 1997–1999 prior to island construction. In these comparisons, we used average densities from BP/LGL aerial surveys in various zones in 1997–2002 (Miller et al. 1998; Link et al. 1999; Moulton et al. 2000, 2001, 2002, 2003c).

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. Although the BP/LGL aerial surveys extended farther from Northstar, we limited the reference area to these nearby locations in case there were undocumented characteristics (independent of industry) of the Northstar area that made it either more or less "favorable" to ringed seals. We also controlled for water depth, because ringed seal density in our overall study area depends on water depth, and is highest in waters 5–20 m deep (Moulton et al. 2005). We would expect higher densities in some areas 4–10 km from Northstar than within the potential impact zone even in the absence of Northstar activity; the 4–10 km zone includes some areas deeper than any areas in the potential impact zone (Fig. 14.1). That potential bias was addressed by stratifying the 4–10 km "reference" zone and the potential impact zone by water depth.

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 3.99 km^2) to give the expected numbers of ringed seals within that zone, i.e., within 100 m of the ice road to the island and/or within 100 m of the artificial island. This was done separately based on 1997, 1998, 1999, 2000, 2001, 2002, and average 1997–2002 data from the BP/LGL aerial surveys. Based on the 1997–2002 surveys of the 4–10 km "reference" zone, the expected "uncorrected" numbers of seals in the 2004 potential impact zone, if there were no avoidance, ranged from 1 to 3, depending on the year. The estimate based on 2002 survey data was 3 seals (Table 8.1).

The estimates quoted above are the estimates prior to correction 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 numbers 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 8.1. Numbers of ringed seals expected to occur in spring 1997–2002 within the "Potential Impact Zone" (as defined for 2004) in the absence of any Northstar impact, based on observed seal densities in a reference area 4–10 km away from Northstar in 1997–2002. The potential impact zone included areas within 100 m of the ice road and Northstar Island. All values differ from those previously reported for 1997–2002 (e.g., Moulton et al. 2003b) because the "Potential Impact Zone" as now recognized is limited to smaller distances from Northstar facilities.

		Expected Number of Seals Within Potential Impact Zone	
BP/LGL Survey	Expected Density[a] (seals/km^2)	Uncorrected	Corrected Total[b]
1997	0.54	2	6
1998	0.36	1	4
1999	0.29	1	3
2000	0.59	2	7
2001	0.56	2	6
2002	0.67	3	8
Average 1997-2002	0.50	2	6

[a] These average uncorrected densities are based on data from the zone 4-10 km away from the 2004 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).

We adjusted the above estimates to allow for seals hauled out but not sighted by observers (detection bias; ×1.22, based on Frost et al. 1988) and for the proportion of ringed seals not hauled out during the survey coverage (availability bias; ×2.33, based on Kelly and Quakenbush 1990). These adjustments 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 8.1). For example, based on the 2002 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 3 seals to a corrected estimate of 8 seals.

The adjustments for "availability" bias used above and in our previous related reports are based on a study of five ringed seals whose haul-out behavior was monitored until 4 June during two springs (1982 and 1983) near Reindeer Island, within our study area (Kelly and Quakenbush 1990). More recently, Kelly et al. (2002), in a preliminary report, estimated daily availability correction factors ranging from 1.63 to >11 in 1999 and 2000. Those authors continued their study in 2001 and 2002. We have not used correction factors from Kelly et al. (2005) given that the researchers have not recommended them for use (see "Recommendations—Survey Protocols" in Kelly et al. 2005). Kelly et al. (2005) note that the sample size in their study may not adequately "capture the variation in behavior between individual animals, and that increasing that sample size would be desirable". Many factors confound the use of correction factors based on a small number of tagged seals in a limited area (Frost et al. 2002); perhaps most noteworthy is the large variability in individual seal basking behavior between and within years. Depending on the actual correction factor applicable to the surveys conducted in a given year, the total number of seals in the area could be over- or underestimated when the generic ×2.33 factor of Kelly and Quakenbush (1990) is used. However, the relative densities and numbers at different distances from Northstar in a given year should be unaffected.

It is noteworthy that, in the spring of 2004, personnel at Northstar frequently sighted ringed seals hauled out on the ice near Northstar (Chapter 3). Although the distances to individual sightings were not specifically estimated, most of these sightings were made from vehicles on the sea ice. Distances to sightings were generally characterized by personnel as being 0–200 yd (0–182 m) from Northstar Island (and West Dock).

Similarly, the frequent counts of seals within *ca* 1 km (0.6 mi) of Northstar during the late spring of 2005 through 2009 confirm that seals continue to occur (in varying numbers) on fast ice near Northstar during the latter part of the ice-covered season (Chapter 3 of this report).

Based upon aerial survey data from 2002, if there was some displacement of ringed seals away from Northstar in the ice-covered season of 2004, we would have expected fewer seals within the potential impact zone during 2002 than in the pre-construction years, 1997, 1998, and 1999. That was not observed, although inter-year comparisons should be treated cautiously given the possibility of year-to-year differences in sightability of seals during aerial surveys. Also, there was no evidence of reduced densities or lair use near Northstar in 2000, a winter of intensive construction activity, or in 2001 (Moulton et al. 2003a,c, 2005; Williams et al. 2001, 2006a). The presence of numerous seals near the Northstar facilities during late spring of 2000, 2001 and 2002 indicates that any displacement effect was localized and, if it occurred at all, involved only a small fraction of the seals that would otherwise have been present.

Complications and limitations exist in our analyses, but overall it seems clear that distribution and activities of overwintering ringed seals were largely unaffected by Northstar beyond *ca.* 100 m outside the areas where the ice was physically altered. • We are uncertain whether the 2002 aerial survey data are a good approximation of the ringed seal densities in 2004 or subsequent years. However, in the absence of aerial survey data for 2004 and beyond, data from 2002 seem most suitable for estimating ringed seal densities near Northstar in 2004 given the similarities in type and level of industrial activity in 2002 and 2004. • We also do not know whether the individual seals seen near Northstar during aerial surveys in late May and early June 2002 (and other years) had been resident at the same locations during the winter/early spring period. Results from monitoring of seal structures periodically throughout the winter and spring of 2000–2001 showed that seals in the Northstar area are quite mobile (Williams et al. 2002, 2006a), and they are likely to be especially mobile during spring at the onset of breakup. However, the on-ice dog-assisted studies provided no indication of greater turnover close to Northstar activities than farther away. • Using aerial survey data from the basking period in spring is a standard method for assessing possible effects of human activities over the preceding winter, but that method by itself does not assess whether turnover of seals during winter differed among locations. However, the on-ice studies complemented the aerial surveys and showed that turnover was no higher close to Northstar than farther away. • The monitoring work focused on the distance to which Northstar might have affected seal densities and numbers, and did not examine the reproductive success or detailed behavior of over-wintering seals within or beyond that distance in detail. However, data from the seal structure study in 2000 and 2001 (Williams et al. 2006a) provided no indication of increased abandonment or other unusual utilization of seal structures close to Northstar.

Estimated Numbers of Seals Present, Break-up Period

Potential sources of disturbance to marine mammals from the Northstar project during the break-up period once oil production began at Northstar consisted primarily of helicopter plus (limited) vessel traffic, plus the ongoing production and drilling operations on the island (see Chapter 2). Helicopter flights to and from Northstar were especially frequent during break-up and freeze-up. A hovercraft was used to transport personnel and freight to Northstar beginning in June 2003 (Chapter 2; Blackwell and Greene 2005, included as Appendix H).

The available evidence indicates that no more than a few seals near Northstar were affected by Northstar activities during winter or spring, and there is no reason to believe that effects were greater during the subsequent break-up period. If any seals were affected during break-up in some subtle way, it is probable that some 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. Even so, our estimates of numbers of seals present and potentially affected during break-up assume complete weekly turnover.

BP's initial 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. The expected average density of seals hauled out on the landfast ice depended on the specific area considered and the year of aerial surveys considered, but was 0.67 seals/km^2 (uncorrected) within the 2004 "Potential Impact Zone" based upon 2002 aerial survey data from the zone 4–10 km away from the 2004 development zone (Table 8.1). 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 1.90 seals/km^2. Thus, an estimated 6 seals would be present within 1 km of the island (1.90 seals/km^2 × 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).

Impact of Northstar Activities during Ice-Covered and Break-up Periods

The number of ringed seals potentially affected by Northstar activities during the ***ice-covered period*** was considerably lower than had been assumed before Northstar was built:

- BPXA (1999) estimated that after production began, on average, 77 ringed seals might be expected to occur within the potential impact zone around Northstar during the ice-covered season. An upper limit of 105 seals was predicted during production.
- BP's request for an LoA for the initial period of production (BPXA 2001) revised the latter figures to 53 and 139, respectively. In the 2004 "production LoA", NMFS authorized the "taking by harassment" of a maximum of 139 ringed seals during the ice-covered and break-up seasons combined.
- The production LoA also states that "During the ice-covered period, up to 5 ringed seals may be incidentally killed annually".
- It was expected that one to five bearded seals might also occur within 2–4 km of the Northstar facilities during any one winter/spring season. The 2004 "production" LoA authorized the incidental harassment of up to 5 bearded seals during the ice-covered and break-up periods.

These estimates were based upon an assumed potential impact zone considerably larger than the area now considered to be realistic, as discussed earlier.

There was no evidence, and no reason to suspect, that any seals were killed or seriously injured by Northstar-related activities during the ice-covered period (or at any other time) during the 5 years covered by the initial Northstar regulations or during the current reporting period from 2005 to date. The one activity that might have produced underwater sounds strong enough to cause auditory damage was impact pile driving, but acoustic and seal monitoring during pile driving (Blackwell et al. 2004) showed that no seals were exposed to received levels approaching or exceeding 190 dB re 1 μPa, the "do-not-exceed" criterion specified by NMFS (2000a, 2001). Oil spills would be a concern with regard to the potential for injuries or deaths. There were occasional small oil spills onto the sea ice or island during the period covered by the first and second sets of 5-year regulations, but these were cleaned up upon discovery (see Rodrigues and Williams [2006] and Chapter 2 of the present report) and there was negligible risk to marine mammals. No spills reached water.

Based on observed ringed seal densities in a reference area 4–10 km from the 2004 Northstar development zone (corrected for observer and availability bias), *the highest estimate of the number of seals potentially affected by Northstar during the 2004 ice-covered season is 8*. However, of this estimated 8 seals, it is likely that most tolerated the proximity of Northstar and remained in the potential impact zone. The estimated number of seals potentially affected by Northstar in 2004 was considerably less than the early estimates of the maximum number that might be present near Northstar and potentially affected (139—see BPXA 2001). That was the number of ringed seals authorized by NMFS to be "taken" during the ice-covered period. The difference between the initially-predicted numbers and the much lower estimates of the actual number for 2004 was mainly a result of the smaller "potential impact zone" now recognized.

Very few bearded seals occur during the ice-covered period within 10 km of Northstar (see Moulton et al. 2001, 2002, 2003c). Most bearded seals leave the Beaufort Sea in fall, and those that remain are believed to occur mainly in the moving pack ice farther offshore than Northstar. There is no indication that any bearded seals were affected by Northstar activities during the ice-covered seasons.

Overall, during the ***break-up period*** of 2004 (as an example year), on the order of **36** ringed seals might have been present within 1 km of Northstar Island at some time. This total assumes complete turnover of the seals each week for 6 weeks. *The actual number of different individuals present would probably be lower, and there is no indication that these seals were deleteriously affected.*

The LoA issued by NMFS for 2004 indicated that incidental harassment was authorized for 139 ringed seals during the break-up and ice-covered period. The actual estimates derived above for 2004 are 36 ringed seals present during break-up and 8 during the ice-covered period. The total estimate for ringed seals during the break-up plus ice-covered periods (44) was less than the authorized total (139). Also, there is no reason to believe that most of the 44 seals estimated to be present were in fact affected by the presence of Northstar.

OPEN-WATER SEASON

Potential sources of disturbance to marine mammals from the Northstar project during the open-water seasons consisted primarily of vessel and helicopter traffic, plus construction activities on the island in the early years and ongoing production and (sometimes) drilling operations on the island in later years (see Rodrigues and Williams [2006] and Chapter 2 of this report). Helicopter flights to and from Northstar were less frequent during the open-water period than at some other times of the year. Vessel traffic included crew vessel operations between West Dock and Northstar up to 2003, and tug and barge operations during July to early October. A hovercraft was used to transport personnel and freight to Northstar beginning in June 2003 and continuing through the 2009 open-water season (Chapters 2). The regular use of the hovercraft since 2003 has resulted in much-reduced crew-vessel traffic as compared to previous summers (Chapter 2). After the arrival of the hovercraft, there was no longer a dedicated crew-transfer vessel. After construction ended, vessel traffic near Northstar was responsible for most of the peaks in underwater sound associated with Northstar, whereas ongoing production and drilling operations produced relatively steady sound at lower levels (Blackwell and Greene 2006, *in* Appendix I). The hovercraft produced relatively little underwater sound (Blackwell and Greene 2005, *in* Appendix H). The characteristics of underwater sound near and offshore of Northstar during the open-water season in 2001–2009 are documented in Chapter 4.

Estimated Number of Seals Present, Open-water Period

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; Harris et al. 1997, 1998; Lawson and Moulton 1999; Moulton and Lawson 2000, 2001); 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. Passing boats and helicopters might cause startle reactions and other short-term effects. However, NMFS has indicated that short-term behavioral effects having no negative consequences for biologically important activities are not relevant in estimating the number of ringed seals potentially affected (NMFS 2000b, p. 60409).

Based on the above assumptions, an estimated **18** seals might be present and potentially affected, i.e., 3.11 $\text{km}^2 \times 0.38$ $\text{seals/km}^2 \times 15$ 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. These estimates are subject to wide uncertainty (in either direction) given the uncertainties in each of the three assumptions listed above.

There is no specific evidence that any of the seals occurring near Northstar during the open-water seasons were disturbed or otherwise affected by BP's activities, but the possibility of such effects was not specifically studied. However, ringed seal sightings have been reported by Northstar personnel during the open-water period (Williams et al. 2006b). Following NMFS (2000b, 2001), we assume that simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a biologically significant manner, do not constitute harassment or "taking". The LoA issued by NMFS for 2004 (as a representative year) indicated that incidental harassment was authorized for 52 ringed seals, 5 bearded and 5 spotted seals during the open-water period; the estimated 18 seals present and potentially affected by Northstar activities is less than the authorized total.

Estimated Effects on Whales

Bowhead Whales

Acoustic monitoring of the bowhead whale migration past Northstar in 2005–2009 was described in Chapters 5 and 6 of this report, and in BP's annual summary reports for 2005–2009 (included on CD-ROM as Appendices B–F). Acoustic monitoring in 2001–2004 was described in Chapters 7–12 of the previous Comprehensive Report (Richardson [ed.] 2008), and in published papers and manuscripts (Greene et al. 2004; Blackwell et al. 2007; McDonald et al. in review). The monitoring was designed to determine (with the limitations discussed in Chapters 5 and 6 and earlier reports) whether the southern edge of the distribution of calling bowhead whales tended to be farther offshore with increased levels of underwater sounds from Northstar construction and operational activities. 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 a Northstar effect. The initial monitoring objectives did not call for estimating the numbers of bowhead whales that were affected based on the acoustic localization data. This was added as an objective in an updated monitoring plan (LGL and Greeneridge 2000) prepared subsequent to issuance of the initial 5-yr regulations, but proved to be impractical based on acoustical data alone (see McDonald and Richardson 2008).

2001–2004 Results.—The acoustic monitoring results from 2001–2004, on visual inspection, showed that the distribution of bowhead calls near Northstar was not greatly different at times with higher than with lower levels of Northstar-related sound (McDonald et al. 2008 and in review; Richardson et al. 2008). However, detailed statistical analysis provided evidence ($P < 0.01$ each year) that fluctuating sounds from Northstar and its supporting vessels did have effects on that distribution during all four autumn migration seasons for which detailed data were acquired (McDonald et al. 2008 and in review; Richardson et al. 2008). Acoustic monitoring occurred during the early–mid portion of each of those migration seasons. In *2001*, the southern edge of the distribution of bowhead calls was an estimated 1.53 km (0.95 mi) farther offshore when sound at industrial frequencies (28–90 Hz), as measured 440 m from Northstar and averaged over 45 min preceding the call, increased from 94.3 to 103.7 dB re 1 μPa. In

2002, the apparent southern edge of the call distribution was an estimated 2.35 km (1.5 mi) farther offshore during times when transient sounds associated with boat traffic were present during the preceding 2 hr. In *2003* and *2004*, the apparent southern edge was estimated to be farther offshore when tones were recorded in the 10–450 Hz band just prior to the call. In 2003, the apparent offshore shift in call distribution was by an estimated 0.76 km (0.47 mi) when tones were present within the preceding 15 min. In 2004, the apparent shift was 2.24 km (1.39 mi) when tones were present within the preceding 2 hr.

Thus, in 2001–2004, there was an apparent offshore displacement of the southern edge of the distribution of bowhead calls when underwater sound levels from Northstar and associated vessels were above average. It is uncertain whether the apparent displacement was attributable to actual displacement of whales, or whether it was at least partly caused by noise-induced changes in bowhead calling patterns. The analyses described by Blackwell et al. (2008) indicated that various measures of bowhead calling behavior were significantly correlated (in a statistical sense) either with levels of underwater sound being emitted by Northstar activities or with whale location relative to Northstar. It is not certain how many of these correlations represent direct Northstar effects on calling behavior. However, the results of Blackwell et al. (2008) are consistent with the possibility that the apparent Northstar effect on bowheads in the southern part of their migration corridor may have been at least partly attributable to effects on calling behavior.

Much effort was given to the problem of estimating the numbers of bowhead whales passing Northstar in 2001–2004 that were displaced offshore by various distances, e.g., by ≥0.5, 1, 2, 3 and 5 km (≥0.3, 0.6, 1.2, 1.9 and 3.1 mi), based on the acoustic localizations of calling whales. From the outset, this process has been treated with caution because of the possibility that effects of Northstar sound on distances offshore might be confounded by effects on bowhead calling behavior. Given the finding that some aspects of calling behavior were correlated with levels of underwater sound being emitted by Northstar and its associated vessels (Blackwell et al. 2008), along with other complications (McDonald and Richardson 2008), we are not satisfied that reliable or defensible estimates of numbers affected by Northstar sound can be derived from acoustic localization data alone. Three external reviewers who read a detailed description of the most recent methods and results agreed. Therefore, we did not present such estimates in the final Comprehensive Report for work up to 2004, and do not do so here.

2005–2009 Results. — Results from acoustical monitoring of the 2005–2009 autumn migrations of bowhead whales past Northstar were described in Chapter 5. In consultation with NMFS and stakeholders, the 2005–2007 effort was reduced relative to previous years. Data from those years were mainly in the form of call counts at one standard monitoring station (DASAR EB / C), along with bearings to calls from that site.

In 2008 and 2009, a larger monitoring effort resumed, with DASARs at 10 offshore locations (as in 2001–2004), although all but one of the specific locations differed and the monitoring effort extended farther offshore. For ***2008***, no attempt was made to determine whether call locations were related to fluctuating Northstar sounds, as the situation was confounded by marine seismic surveys in various directions from Northstar. In any case, the average call detection rates overall and at EB / C were higher in 2008 than in any other year (2001–2009), and the distribution of calls was relatively close to shore as compared with other years (see Fig. 5.12 *in* Chapter 5).

In ***2009***, there were no marine seismic surveys near Northstar, although weak underwater sounds from very distant seismic surveys did reach the Northstar area. On visual inspection, it did not appear that the southern part of the call distribution differed much with lower vs. higher levels of industrial sound

(Fig. 6.4 *in* Chapter 6). A statistical analysis similar to that applied in 2001–2004 has been done with the 2009 data, including additional covariates to represent the fluctuating received levels of airgun sound and the levels of industry-related sounds offshore (as well as near Northstar). Results are shown in Chapter 6. Analyses of the relationship between offshore distances to calls and the level of Northstar-related sound gave different outcomes depending on how the analysis was done. Results from most analysis options indicated that the southern part of the distribution of calling whales during periods with elevated industrial noise levels tended to be somewhat *closer to* Northstar — contrary to expectation and contrary to results from 2001–2004 (Chapter 6). In any case, any onshore or offshore shift in bowhead call distribution that occurred in 2009 when industrial sound transients were evident offshore must have been quite small and minor or brief, given the similar distributions of calls with lower vs. higher levels of industrial sound (Fig. 6.4).

Significance of Effect.— There is no established criterion for determining how large a displacement or change in calling behavior would need to occur before a bowhead whale should be considered “taken by harassment”. NMFS has concluded that minor and brief changes in behavior generally do not “rise to the level of taking” (NMFS 2000b, p. 60409). It seems improbable that the apparent Northstar-related displacements or changes in calling behavior evident in the southern part of the migration corridor at the higher-noise times during 2001–2004 or possibly 2009 would have negative consequences for the individual whales involved, let alone their population. There is considerable natural variation in the distances of bowheads from shore both within and between years (Treacy 2002a,b; Treacy et al. 2006). The displacement would need to be by many kilometers before the whales could be said to be following a migration route outside the normal range of routes. Offshore (or onshore) displacement of the migration route of a given whale by 2 or 3 km, or even 5 km, is well within the natural range of variability, and is unlikely to have negative consequences for an individual migrating whale.

An exception could occur if the whales were displaced from a localized area of particular significance to bowheads. Bowhead whales do feed to some degree in the area east of Northstar, as evident from food items in stomachs of some whales harvested at Cross Island (Lowry et al. 2004) and from infrequent whaler reports of feeding (Chapter 7). However, bowheads did not show any special tendency to congregate or feed near Northstar prior to the construction of Northstar Island in 2000 (e.g., Miller et al. 1996; Treacy 2002b).

For the bowhead whales in the southern part of the migration corridor that exhibited a slight “apparent offshore displacement” in 2001–2004, it is not known how long the effect (whether actual offshore displacement or altered calling behavior) persisted. It was not within the agreed scope of this study to address how far east or west of Northstar any effect extends. Even if this effect were prolonged, it is unlikely that a slight offshore displacement or a change in calling behavior among whales traveling through largely open water would result in long-term negative effects on biologically important activities of those individuals. Potential implications for subsistence hunting are addressed below.

In discussing how to identify effects on marine mammals that would and would not be biologically significant, NRC (2005, p. 82) suggested that, for migrating animals, biologically significant effects might be possible if either the path length or the duration of migration were increased into the upper quartile of the normal time or distance of migration. NRC (2005) further noted that, if the effect of the activity extends for only a small duration or along only a small part of the migration path, such data alone might be sufficient to determine that the effect is not biologically significant. Apparent displacements of the scale evident at Northstar (at most a few kilometers) would increase the duration or distance of migration by only a very small percentage. Also, NRC (2005) notes that fully one-fourth of the population have migration durations or distances in the upper quartile normally, so the suggested criterion is likely to be a conservative (i.e., precautionary) one. Similarly, Southall et al. (2007) emphasize the need to distinguish minor short-term changes in behavior with no lasting biological consequences from biologically significant effects on critical life functions such as growth, survival, and reproduction. Southall et al. (p. 448) concluded that "a reaction lasting less than 24 h and not recurring on subsequent days is not regarded as particularly severe unless it could directly affect survival or reproduction".

Based on these considerations, *it is doubtful that the apparent Northstar effects found in this study during 2001–04 would have had biologically significant consequences for any individual bowheads or for the population*. The same was probably true in 2008 and 2009, based on the acoustic monitoring results from the large array of DASARs deployed in those years. The 2008 data have not been analyzed in detail given the potentially confounding influence of nearby seismic surveys in 2008, but the southern part of the migration corridor was relatively close to shore and to Northstar in 2008 (Chapter 5). In 2009, the migration corridor tended to be somewhat farther offshore, but not much different with lower vs. higher levels of Northstar-related noise.

Although there was no indication of biologically significant effects of Northstar sound on bowhead whales themselves, there is also concern that displacement of bowheads would reduce their accessibility to subsistence hunters. That is a separate issue and is discussed in a later section of this chapter.

Gray Whales

The initial Northstar regulations and annual LoAs indicated (e.g., NMFS 2000a, 2002) that no more than five gray whales could be incidentally harassed by Northstar production activities in any one open-water season. There are no quantitative data on numbers of gray whales (if any) that were present near Northstar in the 2000–04 or 2005–2009 open-water seasons. 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, 2002a,b; Monnett and Treacy 2005; Ireland et al. 2009). Gray whales do not call very often when on their summer feeding grounds, and the infrequent calls are not very strong (M. Dahlheim and S. Moore, NMFS, pers. comm.), so acoustical monitoring is unlikely to be effective in detecting them in summer. In any event, no gray whale calls were recognized in the data from the acoustic monitoring system near Northstar during the autumns of 2000–07. However, some probable gray whale calls were noted in 2008 and 2009 (Blackwell et al. 2009, p. 2-20; Blackwell et al. 2010, p. 2-20).

If a few gray whales did occur in the Prudhoe Bay area in 2000–04 or 2005–09, it is unlikely that they were affected significantly by Northstar sounds. Gray whales typically do not show avoidance of sources of continuous industrial sound unless the received broadband level exceeds *ca.* 120 dB re 1 µPa (Malme et al. 1984, 1988; Richardson et al. 1995). The broadband received level *ca.* 450 m seaward from Northstar rarely exceeded 135 dB in 2001–02 and rarely exceeded 125 dB subsequently (see Fig. 4.6 *in* Chapter 4). Allowing for propagation loss of about 15 log R (Blackwell and Greene 2006), broadband levels rarely exceeded 120 dB re 1 µPa beyond 4 km from Northstar in 2001–02 and beyond 1 km from Northstar in 2003–04. Levels 14.8 km (9.2 mi) offshore were considerably lower than that (Fig. 4.9 *in* Chapter 4). It is possible that one or more gray whales might have been disturbed briefly during close approach by a vessel, but no such occurrences were documented. It is very unlikely that more than 5 gray whales were disturbed by Northstar activities in any year, and it is most likely that no gray whales were affected in any biologically significant way by activities at Northstar.

Beluga Whales

There are no specific data on the numbers of beluga whales (if any) disturbed or otherwise affected by Northstar construction or production activities in 2000–04 or 2005–09. During aerial surveys of the central Alaskan Beaufort Sea, the great majority of beluga sightings have been far offshore, near or beyond the shelf-break (Miller et al. 1996; Moore et al. 2000; S. Treacy, MMS, pers. comm.). Satellite-linked telemetry also shows that most belugas follow offshore migration routes across the Alaskan Beaufort Sea during late summer and autumn (Richard et al. 2001). Specific monitoring of the beluga migration was not identified as a requirement, given the predominantly offshore nature of the beluga migration. The DASARs were not designed to monitor the beluga migration; the DASARs did not record sounds with frequencies above ~500 Hz, and beluga calls are mostly at frequencies higher than that.

Moulton et al. (2003b), 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 of the Beaufort Sea population that migrates through the surveyed area is not specifically known but is low and 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 in the Beaufort Sea is not well defined (Richardson et al. 1995), but 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 size of the Beaufort Sea population of beluga whales during the period of applicability of the initial Northstar regulations was estimated as ~**39,258** animals (Angliss and Lodge 2002). That estimate is still used, although it is recognized to be negatively biased (Allen and Angliss 2010).
- Satellite-tagging data show that some members of the Chukchi Sea stock of belugas could also occur in the Beaufort Sea generally near Northstar during late summer and autumn (Suydam et al. 2001, 2003). However, they (like the Beaufort belugas) tend to remain at or beyond the shelf break when in the Alaskan Beaufort Sea during that season. That, combined with the small size of the Chukchi stock, means that consideration of Chukchi belugas would not appreciably change the estimated numbers of belugas that might occur near Northstar.

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. If the disturbance effects extended to a radius of 2 km, then the estimated number of belugas potentially involved during a typical year would be ~20. If the actual population size exceeds 39,258, as is likely (Allen and Angliss 2010), these estimates of 10–20 belugas could be somewhat underestimated. The initial Northstar regulations noted that as many as 45 belugas might be harassed per year (NMFS 2000a), and LoAs issued to BP authorized harassment of up to 91 belugas per year. If some belugas did exhibit behavioral reactions to Northstar, it is unlikely that any of these incurred biologically significant effects in the sense of NRC (2005) or Southall et al. (2007).

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 (T. Napageak [now deceased] 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. Few seals have been harvested from Cross Island during September; however, the primary activity at this time is bowhead whaling and seals are typically incidental harvests (Galginaitis and Funk 2004; M. Galginaitis, 2006, pers. comm.). Pingok Island, the closest edge of the main hunting area, is ~27 km (17 mi) west of Northstar.

Disturbance from production activities at Northstar during the winters of 2003–04 and previous years did not displace seals near Northstar (let alone those ≥27 km to the west) to the extent that their availability to hunters from Nuiqsut would be reduced. However, some concern has been expressed that seals near Northstar may be avoided by hunters given the perception that these seals would be at greater risk of exposure to contaminants, including oil from Northstar. We cannot say that there are no effects on subsistence *per se*, only that seals were not displaced to the extent that their availability for harvest would be a concern. No seal hunters were observed near the Northstar development during our intermittent monitoring work in that area. In winter and spring, a small number of ringed seals may have been displaced from the immediate location of the development area. If this occurred, the effect was sufficiently limited and localized as to be undetectable by aerial surveys (Moulton et al. 2005) and undetectable in the data on abandonment of structures used by ringed seals (Williams et al. 2006a). Given the results of ringed seal studies and recent sightings, any net displacement of ringed seals that might have occurred during the ice-covered period was small and would not have affected their availability to subsistence hunters at that time of year.

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 (17.5 mi) east of Northstar. Most bowheads that are taken by Nuiqsut hunters are struck east or north of Cross Island (Long 1996; Chapter 7). In recent years, Nuiqsut hunters have had a quota of four whales. The number of whales landed ranged from two to four per year during 1995 to 2009, with the exception of 2005 when only one bowhead was landed (Chapter 7).

Five bowhead hunting seasons occurred at Cross Island during the period of applicability of the initial Northstar regulations, with construction and subsequently oil production occurring at Northstar during those years. Galginaitis (2008 and Chapter 7) provides detailed information on these whaling seasons at Cross Island: • In ***2000***, four bowheads were landed, 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. 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—in the opposite direction to Northstar (see Chapter 7). • In ***2002***, four bowheads were landed; they were struck on 5, 12, 13 and 15 Sept. The 2nd and 4th of these whales initially sank, and were not landed until 7 and 2 days after they were struck, respectively (Galginaitis and Funk 2004). The hunters did not make any specific comments about possible Northstar effects on the 2002 hunt during interactions with the sociocultural researcher who documented that hunt (M. Galginaitis, pers. comm., May 2003). • In ***2003***, four bowheads were landed, on 1, 5, 5 and 6 Sept. (*Arctic Sounder,* 11 Sept. 2004; J.C. George, NSB, pers. comm.). Thus, the 2003 hunt was also completed successfully at an early date. • In ***2004***, three bowheads were landed, on 5, 6 and 14 Sept.; whales were not found as close to Cross Island or seen as easily as in 2003. Weather was relatively poor, and hunting extended over a longer period. The required level of effort was higher than in 2003. Industry activity was not reported as being an interfering factor during 2004 (M. Galginaitis, *in* Chapter 7).

Five additional bowhead hunting seasons have occurred during the specific reporting period addressed in this report, with details given by M. Galginaitis *in* Chapter 7. • In ***2005***, only 1 bowhead was landed at Cross Island over a lengthy (27-day) whaling season, and "boat hours on the water per strike" was the highest of any year in the 2001–2009 period (see Table 7.2 *in* Chapter 7). The limited success in 2005 was ascribed by the whalers to ice and weather problems, and possibly to tug and barge traffic not related to Northstar — see Chapter 7. • In ***2006***, four bowheads were landed in a 21-day season, with a moderate amount of effort per landed whale. Weather and ice caused some difficulties, although less than in 2005. • In ***2007***, four bowheads were struck and three landed in a short (13-day) season with relatively little effort per landed whale. Weather conditions were considered somewhat difficult, but whales were found close to Cross Island. • In ***2008,*** four bowheads were struck and landed in a short season (only 7 days for most crews) with relatively little effort per landed whale. Sighting conditions were considered difficult because of prevailing rough seas, but whales were found close to Cross Island. There was some concern about potential interference by vessel traffic, but not associated with Northstar. • In ***2009***, three bowheads were struck and two landed in a relatively long (20-day) season, with a relatively high number of boat hours per strike (Chapter 7). The difficulties in 2009 were ascribed by the whalers to another "poor weather" season with rough seas, a relatively low number of whales sighted near Cross Island, indications of "skittish" behavior by the whales, and presence of potentially interfering vessel traffic in the area on some days. On one occasion a whaling vessel operating well to the northwest of Cross Island encountered the boat servicing the BP DASAR array; the BP vessel broke off its activity and returned to shore (Chapter 7).

Over all years from 2001 to 2009, the whalers considered that vessel traffic sometimes was a source of actual or potential interference with the hunt, but this vessel traffic was (with the one exception noted above) not related to Northstar. The whalers have indicated that the Conflict Avoidance Agreement (CAA) between the oil industry (including BP) and the Alaska Eskimo Whaling Commission generally works well to avoid interference issues between oil-industry activities and whaling. The perceived interference problems are usually with vessels not operating under the provisions of the CAA (Chapter 7).

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 east of Northstar. In 2001–2004, the acoustic localization data revealed a “Northstar effect” on the distribution of whale calls during times when Northstar sounds were strongest. This effect seemed largely attributable to sounds from maneuvering vessels rather than Northstar island itself (Richardson et al. 2008). It is unclear how much of this effect was attributable to actual displacement, and how much was attributable to Northstar effects on bowhead calling behavior. The maximum distance east of Northstar to which the “Northstar effect” extended has not been determined, but the statistical analysis gave most weighting to areas and calls closer to Northstar. The results from the 2009 acoustical monitoring study are difficult to interpret and possibly complicated by distant seismic surveys (see Chapter 6), but visual inspection of the mapped data showed no major difference in distribution of calls in relation to levels of sound of the type produced by Northstar.

The acoustic monitoring study was designed to assess the distribution of whale calls near Northstar, and by implication the distribution of bowhead whales in that area. It was not designed to study other aspects of bowhead behavior (e.g., “skittishness”) as a function of distance from Northstar, or to assess how far east or west of Northstar the apparent displacement effect extended. Nonetheless, it did not appear that the effects at higher-noise times extended far enough east to reduce the number of calling bowhead whales near Cross Island. The distribution of bowhead calls in the southeastern part of the monitored area was not much different at times with higher vs. lower sounds from Northstar (see Fig. 6.3 and 6.5 *in* Chapter 6; also McDonald et al. 2008, Fig. 9.3; Richardson et al. 2008, Fig. 10.3–10.5). Furthermore, most whaling effort is east or north of Cross Island (distant from Northstar) with only a small minority being to the northwest (Chapter 7). As discussed in that chapter, the Nuiqsut whalers did not attribute problems in their bowhead hunts during recent years to Northstar operations.

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