MONITORING OF INDUSTRIAL SOUNDS, SEALS, AND BOWHEAD WHALES NEAR BP'S NORTHSTAR OIL DEVELOPMENT, ALASKAN BEAUFORT SEA, 2008: ANNUAL SUMMARY REPORT

by

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Greeneridge Sciences Inc. & Applied Sociocultural Research

for

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*Cover Photographs***:** Northstar Island (photo by Megan Blees) and Deployment of DASAR model A and C (photo by Lisanne Aerts).

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CHAPTER 1:

INTRODUCTION, DESCRIPTION OF BP'S ACTIVITIES, AND RECORD OF SEAL SIGHTINGS, 2008[1]

by

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INTRODUCTION

BP Exploration (Alaska) Inc. began constructing offshore oil-production facilities in the Prudhoe Bay area, Alaskan Beaufort Sea, during early 2000, and began producing crude oil from Northstar Island during late 2001. Northstar is the first offshore oil production island in the Beaufort Sea. 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 power generation and field injection. 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 (now used infrequently) and facilities for waste grind and injection and for oil production and gas injection. The production facilities include gas turbine engines to operate power generators and gas compressors. Northstar Island is approximately 9.5 km (6 mi) offshore from Point Storkersen, northwest of the Prudhoe Bay industrial complex, and 5 km (3 mi) seaward of the closest barrier island. Northstar is 87 km (54 mi) northeast of Nuiqsut, the closest Native Alaskan (Inupiat) community, and approximately 27 km (16.5 mi) west of Cross Island where Nuiqsut residents hunt for bowhead whales during autumn (Fig. 1.1). Northstar Island is, to date, the only offshore oil production facility in the Beaufort Sea north of the barrier islands.

Since August 1998 BP has submitted various requests to the National Marine Fisheries Service (NMFS) to authorize incidental "taking" of small numbers of marine mammals that may result from BP's activities at Northstar. An overview of these requests is provided in Table 1.1. The current Northstar LoA is valid from 7 Jul 2008 through 6 Jul 2009. The LoAs issued under the previous and current

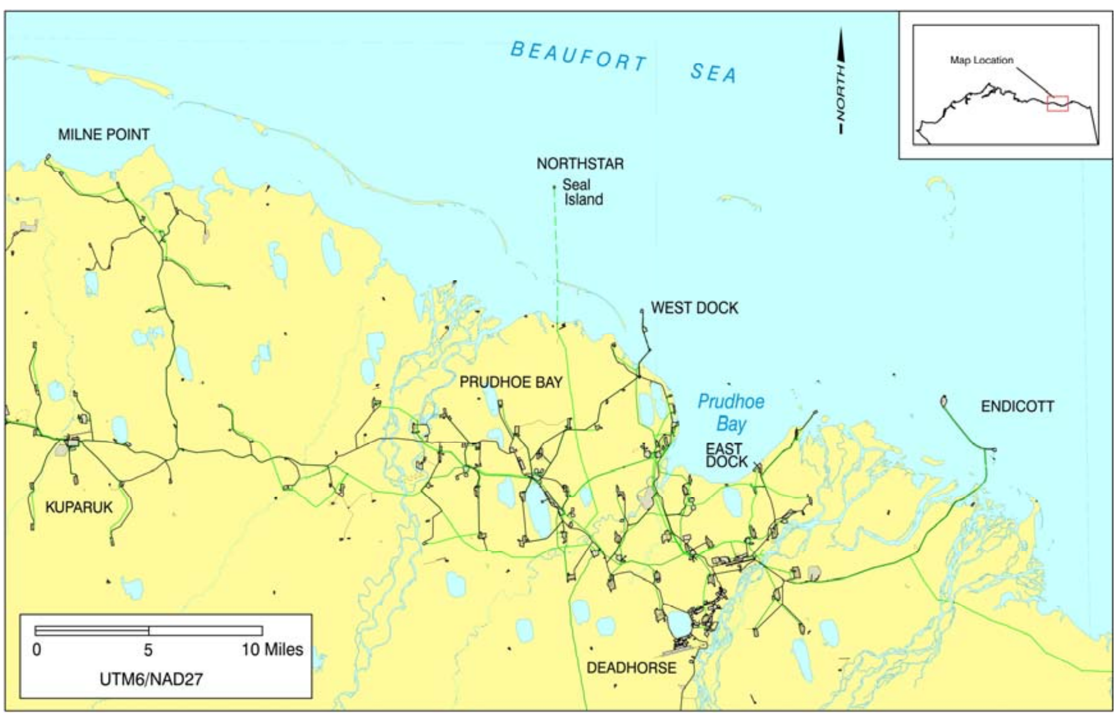

FIGURE 1.1. Location of the Northstar Development at Seal Island in the central Alaskan Beaufort Sea. Seal Island was an artificial gravel island constructed for exploration drilling in the 1980s. Northstar facilities were built on the eroded remnants of Seal Island in 2000.

TABLE 1.1. Overview of BP requests to NMFS and issuance of IHAs, Regulations and LoAs allowing "taking" of small numbers of marine mammals that may result from BP's activities at Northstar.

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 Mar 1999	NMFS issued interim IHA for construction phase
25 May 2000	NMFS issued Regulations, effective from 25 May 2000 to 2005
18 Sep 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 Mar 2006	NMFS renewed the Regulations, effective from 6 Apr 2006 to 2011
7 Jul 2006	NMFS issued initial LoA under the new Regulations, effective until 6 Jul 2007
7 Jul 2007	Second LoA issued to BP, effective until 6 Jul 2008
1 Jul 2008	Third LoA issued to BP, effective from 7 Jul 2008 until 6 Jul 2009

Northstar regulations have required marine mammal and acoustic monitoring studies. These studies started in 1997 and are ongoing (Richardson and Williams [eds.] 2005; Richardson [ed.] 2006b, 2007, 2008; Aerts and Richardson [eds.] 2008).

The marine mammal and acoustic monitoring results from 1999 to 2004 were reviewed by the Science Advisory Committee (SAC) of the North Slope Borough, which met in Anchorage on 7 Mar 2005. These monitoring results were also reviewed during the annual open-water meetings convened by NMFS to review all existing and planned monitoring studies in the Beaufort Sea. The reviews concluded that the bowhead whale monitoring program could be modified starting in 2005, with the possibility of conducting additional whale monitoring during future years. This additional monitoring effort was conducted in 2008. Consistent with the recommendations of the SAC and the open-water meeting participants, during 2008

- personnel at Northstar counted seals near the island in a standardized way,
- underwater sounds near Northstar were monitored during the September whale migration season, and
- calling bowhead whales were monitored offshore of Northstar, based on an array of 10 bottom-mounted recorders designed to detect and localize calling bowhead whales offshore of Northstar.

The acoustic and bowhead call data for 2008 were collected and, where possible, analyzed in ways consistent with prior years to allow comparison of the 2008 results with those from 2001 to 2007.

This report describes BP's activities during the period 1 Nov 2007 through 31 Oct 2008, and it describes the results of the marine mammal and acoustic monitoring studies conducted during 2008. The structure of the current report slightly differs from preceding annual reports for 2005, 2006 and 2007 (Richardson [ed.] 2006b, 2007, Aerts and Richardson 2008), consistent with the expanded effort in 2008. Descriptions of BP's activities and the seal counts are included in this chapter. Chapter 2 provides information on the methodology for the acoustic measurements and localization of bowhead whale calls. Chapter 3 summarizes the results from measurements of the underwater sounds from Northstar and other industrial activities, and Chapter 4 describes the results from the localization of bowhead whale calls.

Since 2005, observations by subsistence whale hunters at Cross Island have been integrated into the Northstar monitoring study, following a recommendation from the NSB's SAC. They noted that 'Such observations might include general offshore distribution of whales, feeding behavior, "skittish" behavior, number of vessels and reaction to them'. Chapter 5 of this report summarizes the results of the 2008 whaling season at Cross Island, consistent with the descriptions provided in the annual reports of 2005, 2006 and 2007 (Galginaitis 2006, 2007, 2008).

This report satisfies annual reporting provisions of the current Letter of Authorization issued by the NMFS for incidental "taking" of whales and seals by Northstar activities. This report also addresses BP's company goal of implementing studies intended to understand and minimize the environmental effects of BP operations. BP and its contractors plan to conduct additional analyses with the 2008 results to address objectives 3-5 as listed in Chapter 2 later in 2009, following discussions during the 2009 open-water peer review meeting. When those additional analyses are completed, it is anticipated that the results will be incorporated in the 2010 comprehensive report.

A comprehensive report was developed based on the monitoring results from 1999 to 2004; it contained a combined presentation of the monitoring results up to 2004, along with analyses of the combined data. Various drafts of the comprehensive report were circulated in December 2004, April 2006, and April 2007. The latest revision, dated February 2008 (Richardson [ed.] 2008), was circulated in March 2008. This latest revision will be re-issued as a final report and distributed prior to the open water meeting in April 2009. In addition to the annual reports issued since 2006, the current Federal rules and regulations at 50 CFR § 216.206 require BP to develop a similar comprehensive report on the monitoring results from 2006 to mid-2010, to be submitted no later than September 2010.

Based on the Northstar monitoring studies conducted to date, a total of 13 peer-reviewed papers have been published in scientific journals since 2001. Of these, one was published in 2007 and two appeared in early 2008 (Table 1.2).

TABLE 1.2. Authors and titles of publications and manuscripts resulting from the Northstar marine mammal and acoustic studies program, 1999–2008.

Authors	Title	Status
Harris, R.E., G.W. Miller and W.J. Richardson. 2001.	Seal responses to airgun sounds during summer seismic surveys in the Alaskan Beaufort Sea.	***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.
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, plus sound files. Available at http://scitation.aip.org/arlo/
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.
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.

TABLE 1.2. Continued.

Authors	Title	Status
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.
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.
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.
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.
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.	***Aquatic Mamm.*** 32(3):311-324.
Blackwell, S.B., W.J. Richardson, C.R. Greene Jr. and B.J. Streever. 2007	Bowhead whale (*Balaena mysticetus*) migration and calling behaviour in the Alaskan Beaufort Sea, autumn 2001-2004: an acoustic localization study.	***Arctic*** 60(3): 255-270.
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.
Streever, B., R.A. Angliss, R. Suydam and others. 2008.	Progress through collaboration: a case study examining effects of industrial sounds on bowhead whales.	***Bioacoustics*** 17 (1-3): 345-347.
	In Preparation (titles and author lists are tentative)	
Moulton, V.D., M.T. Williams, S.B. Blackwell, W.J. Richardson, R.E. Elliott and B. Streever. In prep.	Zone of displacement for ringed seals (*Pusa hispida*) wintering around offshore oil-industry operations in the Alaskan Beaufort Sea.	***In prep.***
McDonald, T.L. and others	Detecting changes in the distribution of calling whales exposed to fluctuating anthropogenic sounds.	***In prep.***
Richardson, W.J. and others.	Distribution of calling bowhead whales near an oil production island at low and higher-noise times.	***In prep.***
Blackwell, S.B. and others	Effects of an oil production island in the Beaufort Sea on calling behaviour of bowhead whales.	***In prep.***

OVERVIEW OF BP ACTIVITIES, NOVEMBER 2007 – OCTOBER 2008

This section discusses BP's activities during the period from 1 Nov 2007 through 31 Oct 2008 as required by the 2008/09 LoA issued by NMFS. The ice-covered season is defined by the period 1 Nov 2007 until 15 Jun 2008, followed by the open-water season from 16 Jun through 31 Oct 2008.

Transportation To and From Northstar Island

Transportation of personnel and equipment to and from Northstar Island during both the ice-covered and the open-water season occurred by Bell 212 helicopters and the Griffon 2000TD hovercraft. In addition to these two forms of transport, transportation during the ice-covered season was provided by Tucker tracked vehicles and by standard vehicles traveling over an ice road between West Dock and Northstar. During the open-water season additional transportation was provided by tugs, barges and ACS (Alaska Clean Seas) Bay-class boats. More details about transportation are provided below.

Bell 212 Helicopters

Bell 212 helicopters are medium-sized helicopters each with two turboshaft engines, a 2-bladed main rotor, and a 2-bladed tail rotor (Fig. 1.2). Helicopters were used to transport crew and materials to and from Northstar during the entire year. As in previous years, they were mainly used during transition periods (freeze-up and break-up), and intermittently at other times when ice and water conditions did not permit use of land-based vehicles or boat traffic. During the present reporting period, a total of ~341 helicopter round trips were made to Northstar. This included ~222 during the 2007/08 ice-covered season, of which the majority occurred in November and December 2007. During the 2008 open-water season helicopters made ~119 round trips to Northstar, most frequently in September and October (Table 1.3). During the ice-covered season, helicopter traffic to and from Northstar was more frequent during the early production period (2002/03) than in later years. This difference was not apparent for the open-water season. In general, the number of helicopter round trips in 2008 was within the range of the numbers recorded in previous production years (Table 1.4).

The helicopter routes were negotiated among the U.S. Fish and Wildlife Service (USFWS), NMFS, and BP, at an early stage in the planning of the Northstar operations, to minimize impacts to waterfowl and marine mammals. During regular helicopter operations in 2008, recommended flight corridors and altitude restrictions were maintained, as in previous seasons. For visual flight rule (VFR) conditions, standard flight altitude was 460 m (1500 ft), weather permitting. One-way flight time to Northstar was ~15 min from West Dock Base of Operations (WDBO) and 30 min from the Deadhorse airport.

FIGURE 1.2. Bell 212 helicopter used for transportation to and from Northstar.

TABLE 1.3. Number of helicopter and hovercraft round trips to Northstar Island for each month during the ice-covered and open-water season of 2007/08. A ½ round trip occurs when the hovercraft leaves shore prior to midnight, and returns from the island after midnight or, occasionally, if the hovercraft leaves the shore but doesn't complete the trip due to weather or other reasons.

Month	Helicopter	Hovercraft	Month	Helicopter	Hovercraft
	Ice-covered season			*Open-water season*	
November 2007	131	23	June 16-30, 2008	7	64
December 2007	81	101.5	July 2008	11	122.5
January 2008	8	149.5	August 2008	13	135
February 2008	0	37	September 2008	28	84
March 2008	0	0	October 2008	60	40
April 2008	0	0			
May 2008	0	47.5			
June 1-15, 2008	2	67.5			

TABLE 1.4. Total number of helicopter and hovercraft round trips to Northstar Island for each year since 2003 during the ice-covered and open-water seasons. A ½ round trip occurs when the hovercraft leaves shore prior to midnight, and returns from the island after midnight or, occasionally, if the hovercraft leaves the shore but doesn't complete the trip due to weather or other reasons. The hovercraft was first tested and used in spring 2003. na = not applicable.

Year	Helicopter	Hovercraft	Helicopter	Hovercraft
	Ice-covered season		*Open-water season*	
2002/03	1122	na	277	202
2003/04	253	141	189	302
2004/05	118	180	103	188
2005/06	465	249	271	560
2006/07	335	574	190	347
2007/08	222	426	119	445.5

Griffon 2000 TD Hovercraft

A hovercraft was also used to transport personnel during both the ice-covered and the open-water period (Fig. 1.3). The hovercraft was powered by a 355 hp air-cooled Deutz diesel engine and was 11.9 m (39 ft) in length (Blackwell 2004; Blackwell and Greene 2005). The hovercraft was capable of carrying a payload of 2268 kg (5000 lbs). During the ice-covered season, most hovercraft activity occurred in December 2007 and January 2008. No hovercraft activity occurred in March and April 2008, when mainly pick-ups, SUVs, and buses were used to transport personnel. During the 2007/08 ice-covered season, the hovercraft made ~426 round trips to Northstar (Table 1.3). Hovercraft use continued into the subsequent open-water season, during which ~445.5 round trips occurred from West Dock to Northstar (Table 1.3). Hovercraft activity peaked during July and August.

FIGURE 1.3. Hovercraft (Griffon 2000 TD) transporting personnel during the break-up period.

The hovercraft made its first test trips in spring 2003, and has been used for transport of personnel and supplies since then. Hovercraft traffic during the ice-covered season has increased since 2004. During the open-water season, hovercraft use has been more variable over the years, varying from 188 to 560 round trips per year (Table 1.4).

Ice Road Transportation

As during previous years, an offshore ice road was built during the 2007/08 ice-covered season to transport personnel, equipment, materials, and supplies between the Prudhoe Bay facilities and Northstar Island. The ~12 km (~7.4 mi) offshore ice road was built between West Dock and Northstar. Ice-road construction started on 11 Dec 2007 and was completed on 4 Mar 2008. The ice road was open to light duty traffic on 2 Feb and was officially closed on 23 May 2008.

Tucker tracked vehicles (model 1600 Tucker-Terra; Fig. 1.4) were mainly used in 2008 to transport personnel and materials between West Dock and Northstar Island during periods when the ice road did not permit standard vehicle and van traffic. These situations occurred mainly in the months just prior to completion of the ice road and during break-up when meltwater accumulating on the ice road prevented standard vehicles from safely transiting to and from the island. Passenger capacity is between 2 and 15 persons. Tucker tracked vehicles made a total of 111.5 round trips between West Dock and Northstar Island during the 2007/08 ice-covered season, of which 3.5 occurred in December 2007, 92.5 in January 2008 and the remaining 15.5 from February to May 2008. In previous years, Hägglund tracked vehicles were the main form of personnel and material transport to and from the island. During the current reporting period Hägglund and Mattrak vehicles made only occasional round trips to Northstar Island. The use of tracked vehicles in 2007/08 was much higher than in 2006/07 (37 round trips), 2005/06 (70 round trips) and 2004/05 (25 round trips). No detailed records of round trips are available for the construction and early production years (2001-2003), other than that Hägglunds were used on average 14 times a day, mainly prior to the completion of the ice-road.

FIGURE 1.4. Tucker tracked vehicle. Power is from a Cummins 6-Qsb 173hp diesel engine; weight of the Tucker ranges between ~4536 and 7257 kg (10,000 – 16,000 lbs).

Standard vehicles, including vans, pick-up trucks, and buses, were the main method of transportation for Northstar personnel from 2 Feb to 23 May 2008. A total of 3780.5 round trips were made in this period.

Tugs and Barges

During the 2008 open-water season, tug and barge activity from and to West Dock to supply Northstar occurred from July to October. The barges used to transport fuel and cargo to the Island are typically ~46-61 m (160-200 ft) in length and the tugs ~20 m (65 ft). Large vessel spikes from tugs maneuvering at Northstar could be detected to a distance of at least 21.5 km and possibly farther (see Chapter 3). A total of ~45 tug and barge trips were made to Northstar during this period. Most barge activity occurred in August (Table 1.5A). The total number of barge trips in 2008 was very similar to the number in 2007, lower than in 2003 and 2006, and higher than in 2004 and 2005 (Table 1.5B).

ACS Boats

Alaska Clean Seas (ACS) Bay-class boats (Fig. 1.5) were used to transport personnel to and from Northstar when weather conditions prevented the use of the hovercraft. These boats are ~13 m (~42 ft) in length and normally used as oil spill response vessels. A total of ~55 round trips to and from Northstar were recorded during the 2008 open-water season, with the lowest number of trips during August (Table 1.5A). There were 6 additional trips by Bay-class boats in association with acoustic monitoring of the bowhead whale migration (see “Sound Measurements and Acoustic Monitoring”, below).

Records of crew boat trips for 2003 include only the round trips of the dedicated crew boat that was used in 2002 and earlier years; those records do not include possible additional trips by ACS boats. After the hovercraft became available in spring 2003, the dedicated crew boat was no longer used, and the trip records for 2004 to 2008 include therefore only the ACS boats. In 2004 and 2005 no round trip records were obtained for July and most of August; the numbers mentioned in Table 1.5B cover a ~32-day period from late August to early October. The number of round trips in 2008 is lower than in 2007 and 2006 (Table 1.5B).

TABLE 1.5. Number of round trips to Northstar Island by tugs and barges and by ACS boats during the 2008 open-water season ***(A)*** for each month and ***(B)*** for each year since 2003. The open-water season includes the break-up period. In 2003, a dedicated crew boat was used in stead of an ACS boat, until the hovercraft became available. The trip records of the ACS vessels in 2004 and 2005 cover only a ~32-day period from late Aug to early Oct.

(A)

Month	**Tugs/Barges**	***ACS* boats**
	Open-water season	
June 16-30, 2008	0	0
July 2008	5	15
August 2008	26	8
September 2008	12	16
October 2008	2	16

(B)

Year	**Tugs/Barges**	***ACS* boats**
	Open-water season	
2003	82	392*
2004	24	22
2005	21	14
2006	64	106
2007	40	137
2008	45	55

* Records from a dedicated crew boat.

FIGURE 1.5. ACS Bay-class boat "*Harrison Bay*".

Activities At and Near Northstar Island

Production Facilities

Oil production at Northstar began on 31 Oct 2001 and has occurred almost continuously from that date through the present reporting period. Power generation and compressor equipment on the island was unchanged from previous reporting periods. Three Solar® gas turbine generators provided the main power to the island. Emergency diesel generators were also used intermittently during the reporting period, as back-up to the gas-turbine generators. Two gas-turbine high-pressure compressors (model GE LM-2500) and one electric-powered compressor were also on the island. These three compressors were in use for gas injection into the formations.

Drilling and Pile-Driving

Drilling activities were conducted over two wells on Northstar Island from 18 Jan to 12 May 2008. Drilling of well NS-16A started on 18 Jan and continued until 25 Mar. Well NS-34A was drilled from 26 Mar until 12 May. Vibratory pile driving, using an APE 200 vibratory pile driver, occurred from 15 to 19 Feb and from 24 Jul to 10 Aug 2008 to place thermosiphons as part of the thaw protections system. No impact pile driving was used during the present reporting period.

Training Activities

A total of three articulated ARKTOS evacuation craft are available as the island emergency escape vehicles, which is two more than in previous years (Fig. 1.6). The two extra ARKTOS vehicles were added in October 2007 to increase emergency escape capacity and therefore allow for additional personnel to be present on the island. These vehicles can operate both on ice and in water. Testing and training activities with the ARKTOS evacuation craft were conducted on 1 Jul 2008.

No oil spill exercises were conducted on floating ice during the 2007/08 ice-covered season. During the open-water season, offshore oil spill response training activities occurred on 8 days from 21 Jul to 8 Sept 2008. Spill response vessels with lengths of 6.7 to 12.8 m (22 to 42 ft), containment booms and 2” and 3” trash pumps were used for these exercises.

Training sessions for the Spill Response Team were given every Monday evening. The Fire Brigade underwent weekly training on Saturday evenings. This training included classroom instruction and field activities. The field activities involved simulation of a fire scenario by activation of fire fighting equipment including deployment and charging of hoses.

FIGURE 1.6. Articulated ARKTOS evacuation craft used as island emergency escape vehicles.

Oil Spill Inspections

Aerial overflights were conducted weekly with a twin-engine fixed-wing aircraft (Twin Otter DHC-6) to inspect the pipeline for leaks or spills. Forward-looking infrared (FLIR) devices are used on an as needed basis. LEOS technology (Leck Erkennung und Ortangs System, also known as Leak and Location System) and Ed Farmer Mass-Pack leak detection system are used continuously to detect oil spills. No reportable conditions were recorded during those surveys.

Reportable Spills

Two of the nine reportable Northstar-related spills during the ice-covered and open-water seasons reached Beaufort Sea water or ice (Table 1.6). The contaminated material was recovered completely. The first spill consisted of 3 gallons of power steering fluid spilled on the Northstar ice-road. The spilled material stayed on the ice surface, which made recovery easy. All contaminated material was scraped up and collected in oily waste bags. The second spill consisted of 0.25 gallons of hydraulic fluid released from a backhoe that was performing dredging operations in front of Northstar Dock on a barge. About 0.03 gallon sprayed into the water. Sorbent materials were used to clean affected areas of backhoe and barge surfaces. The sheen in the water was recovered using a sorbent boom sweeping back and forth inside the containment boom. Material from the remaining seven spills did not reach the Beaufort Sea or sea ice. Contaminated snow, ice and gravel were removed with various types of equipment and sorbents. Material spilled included corrosion inhibitor, sewage, triethylene glycol and hydraulic fluid (Table 1.6). No clean-up activity was necessary after Northstar flare events during the reporting period.

TABLE 1.6. Record of material spilled at Northstar Island during the ice-covered season (1 Nov 2007 – 15 Jun 2008) and the open-water season (16 Jun – 31 Oct 2008).

Date	Location	Material Released	Volume Released (Gallons)	Did Release reach Beaufort Sea or Sea Ice	Clean Up Action
15 Nov	Process Module	Corrosion Inhibitor	0.05	No	Spilled material was collected with sorbents
31 Dec	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	NS-20 Well Cellar	Corrosion Inhibitor	0.035	No	Sorbent was used to collect material (100% spilled to lined well cellar).
9 Jan	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	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	Process Module	Corrosion Inhibitor	4	No	100% of the material spilled to containment - easily collected for disposal

TABLE 1.6. Continued.

Date	Location	Material Released	Volume Released (Gallons)	Did Release reach Beaufort Sea or Sea Ice	Clean Up Action
24 Jun	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	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	North Process Module	Corrosion Inhibitor	0.004	No	Fluids collected (100% spilled to containment) using sorbent materials.

Construction and Maintenance Activities

As in previous years, maintenance activities to repair the block system and fabric barrier around Northstar Island were necessary. The 2008 repair activities consisted of placement of boulders along the northeast corner of the island during the ice-covered season from 7 Mar to 24 Apr 2008 and some minor repair activities during the open-water season in August 2008. These activities are described in more detail below.

Most of the damage to the slope armor protection around Northstar Island is the consequence of combined wave and ice interactions, e.g., through local pressure of large blocks of ice rubble moving at high speed onto the slope of the island. During a heavy storm in October 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 rocks at this location.

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 Island. A total of 812 round trips were made during March–April, using the ice road for transport from West Dock to the island. Boulder placement was conducted with a CAT 966 loader, a CAT 345B excavator, and a JD 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).

Following inspection of the slope protection, minor below-water repairs were conducted during August 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 August (excluding weather downtime). In addition, two swales (one on the north side and one on the southeast corner of the Island) were identified for repair. Each repair section would benefit from below-water repair; however, it was determined that attempting below-water repairs in late August was imprudent given the active storm potential. In the case of the southeast corner, the proximity of the rock berm precluded access to the below-water slope in this area. 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. 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. The repair on the north side extended to wading depth, while the southeast corner repair was entirely above 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, with less than one shift of weather downtime. Figure 1.7 shows before and after photos of the repair areas on the north side and southeast corner.

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 deployed at three locations ~1 mile offshore from Northstar Island (70^{o}29.973 N 148^{o}44.960 W; 70^{o}29.993 N 148^{o}41.981 W; 70^{o}29.986 N 148^{o}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. 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 these frequencies, 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).

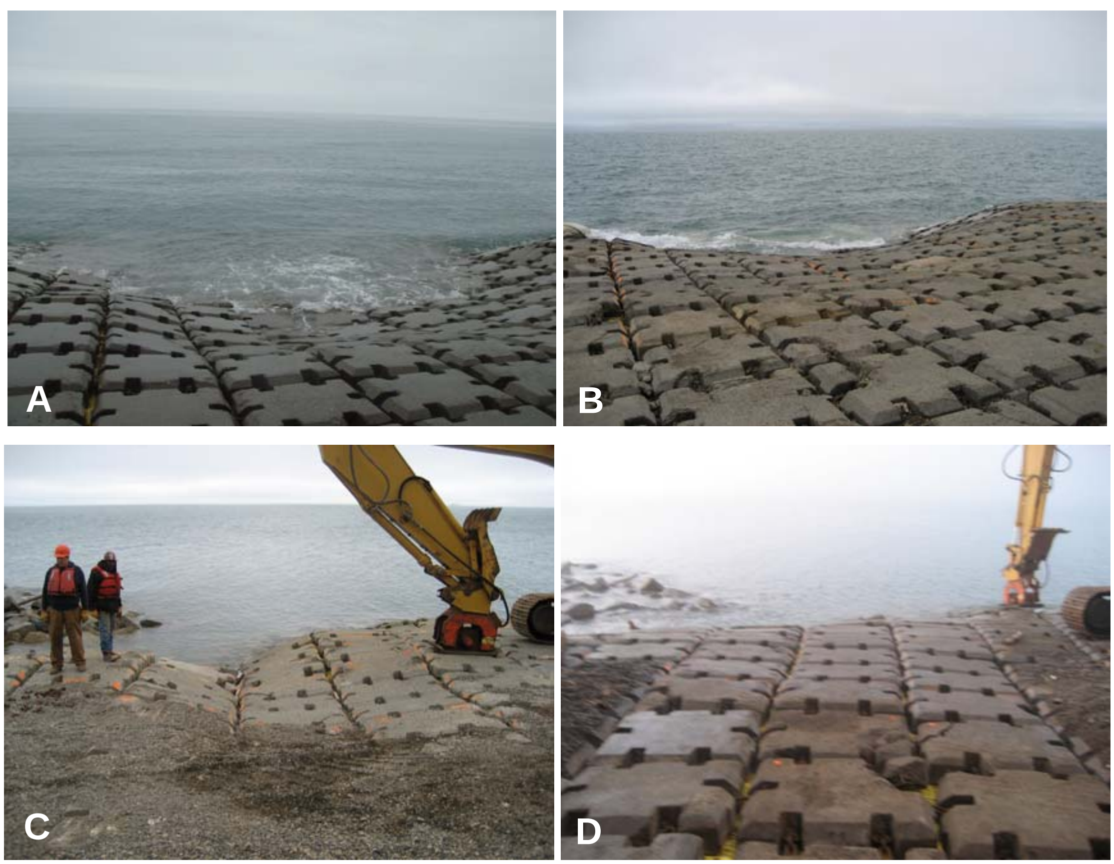

FIGURE 1.7. Before and after repair conditions at the north side swale area (A: before and B: after) and the southeast side swale area (C: before and D: after).

Acoustic and Bowhead Whale Migration Monitoring

Boat-based work in support of monitoring of Northstar sounds and of bowhead whale calls during fall migration was conducted by Greeneridge Sciences, with field assistance by LGL, on six days from late August to late September 2008. On 26 Aug the ACS boat *Mikkelsen Bay* was used to deploy a total of fourteen Directional Autonomous Seafloor Acoustic Recorders (DASARs) offshore of Northstar. Three recorders, two new DASAR-C and one "old" DASAR-A, were deployed ~450 m (~1476 ft) north of Northstar's northern shore. The remaining eleven DASARs were deployed farther offshore, ~8 to 38 km (~4.3 to 23.5 mi) north-northeast of Northstar. On 25 Sep all DASARs were retrieved. Time and orientations of the DASARs were calibrated on 29 Aug, 10 Sep, and again and on 24 Sep. Health checks were performed one day after the deployment on 27 Aug and during mid-season on 10 Sep. Overall, these operations required use of an ACS "Bay"-class boat in waters offshore of Northstar on six dates during late August and September. Chapters 2 to 4 describe in detail the methods and results of the acoustic monitoring of Northstar sounds and bowhead whale calls.

Non-Northstar Related Activities

The MMS and its precursor the Bureau of Land Management have funded and/or conducted aerial surveys of the fall migration of bowhead whales through the western Beaufort Sea each year since 1979. Starting in 2007, the Bowhead Whale Aerial Survey Program (BWASP) was coordinated through NMML, and in 2008 these surveys were extended across the northeast Chukchi Sea to document marine mammal distribution during the open-water (ice-free) months. The surveys in the Chukchi Sea are referred to as COMIDA (Chukchi Offshore Monitoring In Development Area).

Seismic surveys were conducted in the Beaufort Sea between 31 Aug and 10 Oct on or near lease holdings in Harrison Bay and Camden Bay. In the same areas, but prior to the start of the seismic surveys, shallow hazards and site clearance surveys were conducted. These surveys were completed on 24 Aug (Ireland et al. 2009), 2 days before the deployment date of the Northstar DASARs. Aerial surveys in support of these activities were flown from 6 Jul to 11 Oct and covered the bowhead whale migration area north of Northstar Island during the fall (Ireland et al. 2009). In the nearshore waters off Oliktok Point, seismic survey activities took place from 2 Aug to 28 Sep. Associated aerial surveys were flown from 25 Aug to 27 Sep (Hauser et al. 2008).

OBSERVED SEALS

This section summarizes Northstar seal sightings during the last part of the ice-covered season and the start of the open-water season for 2005 through 2008. These observations were conducted from the 33 m (109 ft) high process module by Northstar Environmental Specialists on behalf of BP. The protocol of the systematic seal count that has been used since 2005 includes the following:

- Count the number of basking seals from 15 May to 15 Jul on a near-daily basis. Counts are done once each day between 11:00 and 19:00 local time for at least five days per week, when practicable. No counts are made if the cloud ceiling is less than 91 m (300 ft).
- Make seal counts from the roof of the Northstar process module along a strip of width ~950 m (3116 ft) around the entire perimeter of the island. Scan a 360° field of view, thus covering an area of ~281 ha (695 acres).
- Scan with the naked eye, using binoculars to confirm suspected seal sightings. Use an inclinometer to estimate the distance to the seal. If the inclinometer shows that the line of sight to the seal is 2 degrees or more below the horizon, then keep it in the count. (From the height of the observation platform, a 2º depression angle corresponds to a distance of ~950

m or 3116 ft). If the distance is <2 º with the inclinometer, then the seal is too far away and is not counted.

Seal observations in 2008 were conducted during 54 days from 15 May to 15 Jul. A total of 415 seals were observed (including presumed repeat sightings of the same animal on different days), which is more than in the previous years over the same period. There is no clear trend in seal abundance near Northstar. The daily number of seals sighted shows large within-year variations, as shown by the standard deviation values that provide an indication of the variability of the data (Table 1.7).

Over the 4-year period, most of the seals observed in May and June were basking on the ice. Each year the number of observations increased in June and decreased again toward the end of June. In 2005, the high number in July was the result of an observation of 124 seals on an ice floe on 11 Jul (Fig. 1.8). Reports from Northstar do not provide evidence, or reason to suspect, that any seals were killed or injured by Northstar-related activities.

TABLE 1.7. Summary of seal data collected in the period 15 May to 15 Jul from 2005 to 2008.

Year	Total # of seals	Total obs. days	Mean # seals/day	Max. # observed	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

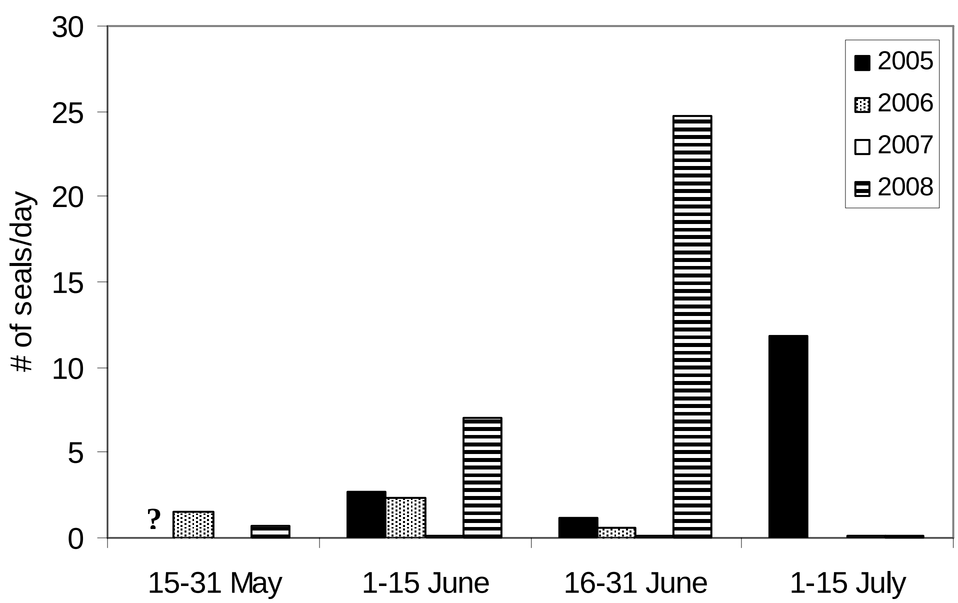

FIGURE 1.8. Average number of ringed seals observed per day from Northstar Island, by half-month, from 15 May to 15 Jul during 2005 through 2008. In 2005 observations started 1 Jun, so the number of seals in the period 15-31 May is unknown. Other bars with no values (15-31 May 2007 and 1-15 July 2006) indicate zero counts.

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CHAPTER 2:

METHODS USED DURING THE ACOUSTIC MONITORING OF BOWHEAD WHALE MIGRATION, AUTUMN 2008[1]

by

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ABSTRACT

During the bowhead whale migration in September 2008, Greeneridge Sciences, on behalf of BP, implemented an acoustic monitoring program north-northeast of BP's Northstar oil development at Northstar Island. The primary objective was to assess the effects of Northstar production activities, especially underwater sounds, on the southern edge of the distribution of calling bowhead whales during their autumn migration. This was to be done by comparing the offshore distances of calling bowheads at times with varying levels of industrial sound. If the closest calling bowhead whales tend to be farther offshore at times when Northstar sounds are stronger than average, this would be an indication that some whales are affected by Northstar activities. The acoustic method cannot distinguish whether this effect is a deflection of the whales, a change in their calling behavior, or a combination of both, but the geographic scale of any such effect would provide evidence of the magnitude of the effect, if it occurs.

In 2008, an array of 10 directional autonomous seafloor acoustic recorders (DASARs) deployed offshore of Northstar for ~29 days (27 Aug–25 Sep) and recording continuously provided bearings to calling whales. When two or more DASARs detected a call, its location was triangulated. Concurrently, sounds produced by Northstar and its attending vessels were recorded continuously by DASARs located ~450 m north of the island over the same period. In 2008, the scope of the study was augmented relative to that in 2005–2007 and was generally similar to that in 2001–2004, although the study design was somewhat modified from that in 2001–2004. The geometry of the DASAR array was changed, and new emphasis was placed on understanding how far Northstar sounds propagate offshore, i.e., what type and quantity of Northstar sounds reach the locations of migrating whales.

The present chapter describes the methods used in the study during the 2008 field season. It describes DASARs, the acoustic recorders that were used to make all the sound measurements. It describes the 2008 field operations, including deployment and retrieval of DASARs, and the health check and calibration procedures. It also describes the analyses performed on the acoustic data collected by the DASARs. These include the computation of broadband, narrowband, and one-third octave band levels on the data collected by DASARs close to Northstar (~450 m away) and farther offshore (8.5–38.5 km or 5.3–24 mi from the island). It also includes the computation of industrial sound indices (ISIs) for a range of DASARs, to allow comparisons between years and between DASARs within 2008. Analyses performed to detect helicopter tones in the sound records are described, as are the methods used to analyze a new "popping" sound found on the near-island recorders and the numerous airgun sounds present on the sound record of all offshore DASARs. Finally, the whale call analysis procedure is described.

Most of the results from these analyses are described in Chapter 3, *Sounds Recorded at Northstar and in the Offshore DASAR Array, Autumn 2008*. All the results from the analyses of whale calls are described in Chapter 4, *Acoustic Localization of Migrating Bowhead Whales near Northstar, Autumn 2008.*

INTRODUCTION

This chapter is one of three chapters (2, 3, and 4) on the acoustic monitoring of bowhead whale migration near the Northstar development during the early autumn of 2008. It includes most of the introductory material, the background to the study, and the objectives, followed by the methods used in the field and during data analyses. Chapter 3 reports on the sounds recorded near Northstar – including vessel sounds and helicopter sounds – and in an offshore array of recorders. It also reports on other industrial sounds, such as airgun pulses from non-BP sources that were detected on the recorders throughout the 2008 field season. Chapter 4 reports on the whale call analyses, i.e., the number of bowhead calls detected, bearings to the calls, call locations, and call types.

In several respects the project parallels the efforts of 2001–2004, with similar objectives and a similar study design (e.g., Greene et al. 2002, 2003), and to a lesser degree it parallels the efforts of 2005–2007 (Blackwell et al. 2006a, 2008). However, there are a number of differences from what was done in both of those periods. Therefore, this chapter is written as a stand-alone document, with little need to find information in the numerous reports that have been produced on the Northstar bowhead study since 2000 (Greene et al. 2002; Greene et al. 2003; Blackwell et al. 2006a, 2006b, 2006c, 2007a, 2008).

BP's business rationale for the overall monitoring project, and for the specific bowhead monitoring task, was driven both by corporate policies and by regulatory requirements. BP corporate policies support studies that objectively assess environmental effects that may result from BP operations. In addition, monitoring the autumn migration of bowhead whales past Northstar was required, during the open-water season of 2008, to satisfy (a) provisions of the North Slope Borough zoning ordinance for Northstar, and (b) the monitoring requirements of a Letter of Authorization issued by NMFS to BP on 1 July 2008, under regulations that are effective from 6 April 2006 through 6 April 2011 (NMFS 2006).

Background

Since development plans for Northstar Island were announced in the late '90s, concern was expressed that the autumn migration corridor of bowhead whales might be deflected offshore in response to underwater sounds from Northstar construction, operations, and associated vessel and aircraft traffic. Whales, including bowhead whales, are known to avoid various industrial activities when the received sounds are sufficiently strong (Richardson et al. 1995). During the planning phase of the acoustic monitoring project, it was assumed that construction (and operational) sounds from Northstar would be detectable underwater for only a relatively short distance, typically on the order of a few kilometers. For that reason, the effort to monitor Northstar effects on the bowhead migration near Northstar concentrated on the southern part of the migration corridor, and was designed to detect small-scale effects.

The main goal of the acoustic monitoring program was to understand the relationship between sounds generated by Northstar activities and the distribution of the southern (proximal) edge of calling bowhead whales during their autumn migration. Every year in 2001–2007, between late August and late September, near-island recorders were deployed ~450 m north of the island to obtain a continuous record of Northstar sounds. In addition, directional autonomous seafloor acoustic recorders (DASARs) were deployed in an array of 10 locations (2001–2004) or four locations (2005–2007) in the southern part of the migration corridor, ~6.5–21.5 km (~4–13.4 mi) northeast of Northstar. The array DASARs were used to record and, where possible, locate bowhead whale calls and obtain information on calling behavior. All acoustic recorders were deployed for ~30 days during autumn when bowhead whales were known to migrate past Northstar, i.e. from late August to late September/early October. (The migration is known to continue later in October, but the recorders were recovered in late September or early October each year before boat-based operations were curtailed by ice formation.)

Analyses of the DASAR sound records showed that vessels were the main contributors to the underwater sound field, as documented in Blackwell and Greene (2006). Vessel activities around Northstar include crew boats (until 2003), tug-and-barge operations, a hovercraft, and other vessel operations (e.g. oil spill response training) in the general area. Although many of these vessel movements were in support of Northstar, others had no direct connection with the island. Vessel traffic associated with Northstar construction and operations rarely extended >1 km (0.6 mi) north of the island, but the sounds produced by these vessels were often detectable as much as ~30 km (19 mi) offshore. Without vessels and with low ambient sound levels (sea state 0.5–1), broadband island sounds reached background values 2–4 km (1.2–2.5 mi) from Northstar. This is consistent with results from other studies in which most underwater sounds propagating from a gravel island like Northstar were found to be quite weak and usually not detectable beyond a few kilometers (Greene 1983; Davis et al. 1985). Statistical analyses of the 2001 to 2004 data, conducted to detect the effect of Northstar sound on migrating bowhead whales, showed that with increased levels of certain types of Northstar sounds, there was an offshore shift in the locations of whale calls (McDonald et al. 2008). This shift could be the result of whales deflecting away from the island, of the nearest whales reducing their calling rates in response to increased sounds, or both.

The monitoring results from 1999–2004 are summarized in the updated comprehensive report (Richardson [ed.] 2008) and in various peer-reviewed publications (see Table 1.2, Chapter 1). These monitoring results were reviewed by the North Slope Borough's Science Advisory Committee (SAC), and at various annual open-water meetings convened by NMFS. The SAC review concluded that the bowhead whale monitoring program could be reduced in 2005–2007, with the possibility of conducting additional whale monitoring in the future. During September of 2005, 2006, and 2007, Northstar sounds were monitored as in previous years. The smaller array that was deployed offshore of Northstar in those years allowed counting of whale calls and characterizing the location of the migration corridor by analyses of the bearings to the calls. The results of the acoustic monitoring in 2005–2007 are presented in the respective annual reports (Blackwell et al. 2006c, 2007a, 2008).

In 2008 the monitoring program was enlarged compared to 2005–2007. The primary objective of the 2008 monitoring program is 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. This primary objective is similar to that in previous years, but specific objectives were developed in 2008 that resulted in a new DASAR array layout: the spacing between DASAR locations was increased from 5 km to 7 km (3.1 to 4.3 mi or 2.7 to 3.8 nmi), the recorders were deployed in a double row instead of two overlapping hexagons, and the most northerly DASAR was now 38.5 km (24 mi) seaward of Northstar (vs. 21.5 km or 13.4 mi in 2001–2004).

Specific Objectives

The 2008 objectives were developed based on results from previous years, discussion with stakeholders, and monitoring requirements outlined in the LOA issued by NMFS on 1 July 2008. The specific objectives for the 2008 bowhead migration study were as follows:

1. Increase the understanding of levels of sound from Northstar as received further offshore by processing the near-island and offshore DASAR sounds and, where possible, relating those levels to reported industrial and vessel activities at and near Northstar;

2. Determine to what extent in-air sounds from Northstar helicopter traffic propagate under-water, using sound recordings of the near-island, and if required, offshore DASARs.
3. Determine whether the lower whale call detection rates west vs. east from Northstar (as documented in previous years) might be, in part, attributable to directionality of whale calls;
4. Identify and characterize any change in bowhead whale call distribution that is related to Northstar sounds, based on both near-island levels and estimated received levels at whale call locations (or as close as possible to these locations);
5. Determine the effect of vessel noise on bowhead calling behavior, assuming that vessel noise is the most relevant type of anthropogenic sound in 2008.

This Chapter and Chapter 3 address Objectives 1 and 2. Compared to previous years, there is an increased focus on understanding to what extent specific Northstar sounds propagate offshore to distances where they could be received by migrating bowhead whales. Chapter 4 summarizes the number of whale calls detected, whale call locations and other call characteristics specific to the 2008 monitoring, and compares those with similar data from previous years. The whale call localization data will be used to address the question whether whale calls are directional as outlined in Objective 3 above. In addition, the whale call data, together with information on Northstar sounds, form the basis for more detailed statistical analyses required to address Objectives 4 and 5.

The presence of airgun pulses[2] on the 2008 sound records complicate the analyses to address Objective 4, if possible at all. Airgun pulses were prominent on the array DASARs, offshore from Northstar where most whales are known to migrate and where most Northstar sounds reach background levels. Elimination of airgun pulses from sound records is not practicable when the seismic surveying is closer than a certain distance, because reverberation from the pulses combined with sounds from vessels associated with these surveys cause a continual increase in sound levels (see Chapter 3). In addition, changes in whale call distribution presumably occur with a certain delay, further complicating the determination of the contribution of Northstar sounds in the presence of other sound sources.

Changes in call behavior are assumed to take place more rapidly than changes in whale call distribution. Also, due to the transient nature and relatively high sound pressure levels of vessel sounds, it may be feasible to isolate those from sounds generated by airgun pulses. Based on this, Objective 5 may be achievable, though it will require substantial more time and effort to analyze appropriately.

Proposed analyses to address Objectives 3, 4 and 5 with the available sound records will be discussed with stakeholders and, where possible, conducted later in 2009. The results will be incorporated in the 2010 comprehensive report, when available.

INSTRUMENTATION: DASARS

In this study, sounds were recorded using **D**irectional **A**utonomous **S**eafloor **A**coustic **R**ecorders (DASARs, see Greene et al. 2004). Each DASAR contains an omnidirectional pressure sensor and a pair of orthogonal directional sensors from which bearings to sounds can be determined. A first generation of DASARs (model A) were built in 2001 and were used in 2001–2007 for monitoring whale calls during the bowhead whale migration. From 2003 onwards, these DASARs were also used to record Northstar sounds

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[2] These airgun sounds are from non-BP sources. The BP Liberty Ocean Bottom Cable (OBC) seismic survey was completed on 25 Aug 2008, two days before the near-island and offshore DASARs were deployed at Northstar.

~450 m from the island. In 2008 a new generation of DASARs were designed and built, the DASAR model C08. This new model differs from the DASAR-A by the following: (1) smaller size, lower profile, and lower weight, making handling easier and improving stability on the seafloor; (2) larger disk space, allowing longer continuous deployments; (3) longer battery life, which also allows for longer deployments; (4) different computer, with corresponding upgrades in performance; (5) decreased sensitivity to overloading, which leads to greater dynamic range in response to high-intensity sounds; (6) an analog anti-alias filter, which has the advantage of being quieter (less self-noise) than the switched-capacitor filter of the DASAR-A; (7) ability to program the instrument from the outside (without opening up the housing), which allows easy reprogramming of the recorders in the field, if necessary; (8) gain matching of the directional sensors, which leads to greater bearing calibration accuracy. In addition, the DASAR-C08's omnidirectional channel was calibrated (see below). Unless specified otherwise, "DASAR" in this report will refer to the new DASAR-C08.

A DASAR-C08 consists of a pressure housing containing the recording electronics and alkaline batteries, plus a sensor suspended elastically about 5 in above the pressure housing. The pressure housing is ~17.8 cm (7 in) high and 32.4 cm (12.75 in) in diameter. The sensor 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 in) sides. A schematic representation of a DASAR is shown in Figure 2.1A. Before deployment, a spandex "sock" is stretched over the tubular "cage" surrounding the pressure housing to protect the sensors from motion in water currents (see Fig. 2.1B). 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 axis perpendicular to the cosine channel. Each directional 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 minutes, and then written to an internal 60 GB hard drive, which takes about 20 s. Allowing for anti-aliasing, the 1 kHz sampling rate allows for 116 days of continuous recording and a data bandwidth of 450 Hz.

DASAR Hydrophone Calibration

The omnidirectional hydrophone in each DASAR was used for sound pressure measurements of the background sounds, whale calls, and other anthropogenic sounds. Each hydrophone was procured with information from the manufacturer permitting its sensitivity to be computed. In addition, two DASARs were taken to the U.S. Navy's sound transducer calibration facility TRANSDEC at San Diego for calibration. The two DASARs calibrated at TRANSDEC were then used as secondary standards for cross-calibration of all remaining DASARs.

For conducting cross-calibration at the Greeneridge facilities, a plywood box sufficiently large for two DASARs was constructed with a loudspeaker at one end. The box served to isolate the subject DASAR hydrophones from the local room noises and to permit accurate positioning of the DASARs within the box. Two calibration methods were used: (1) Measure the response in the box of a DASAR calibrated at TRANSDEC, then substitute an "unknown" DASAR and repeat the measurement, comparing the two results to determine the sensitivity of the "unknown" hydrophone. (2) Put a DASAR calibrated at TRANSDEC in the box next to an "unknown" DASAR, run the calibration transmission, and compare the results of the known-sensitivity and "unknown" DASAR hydrophones to calibrate the "unknown" one.

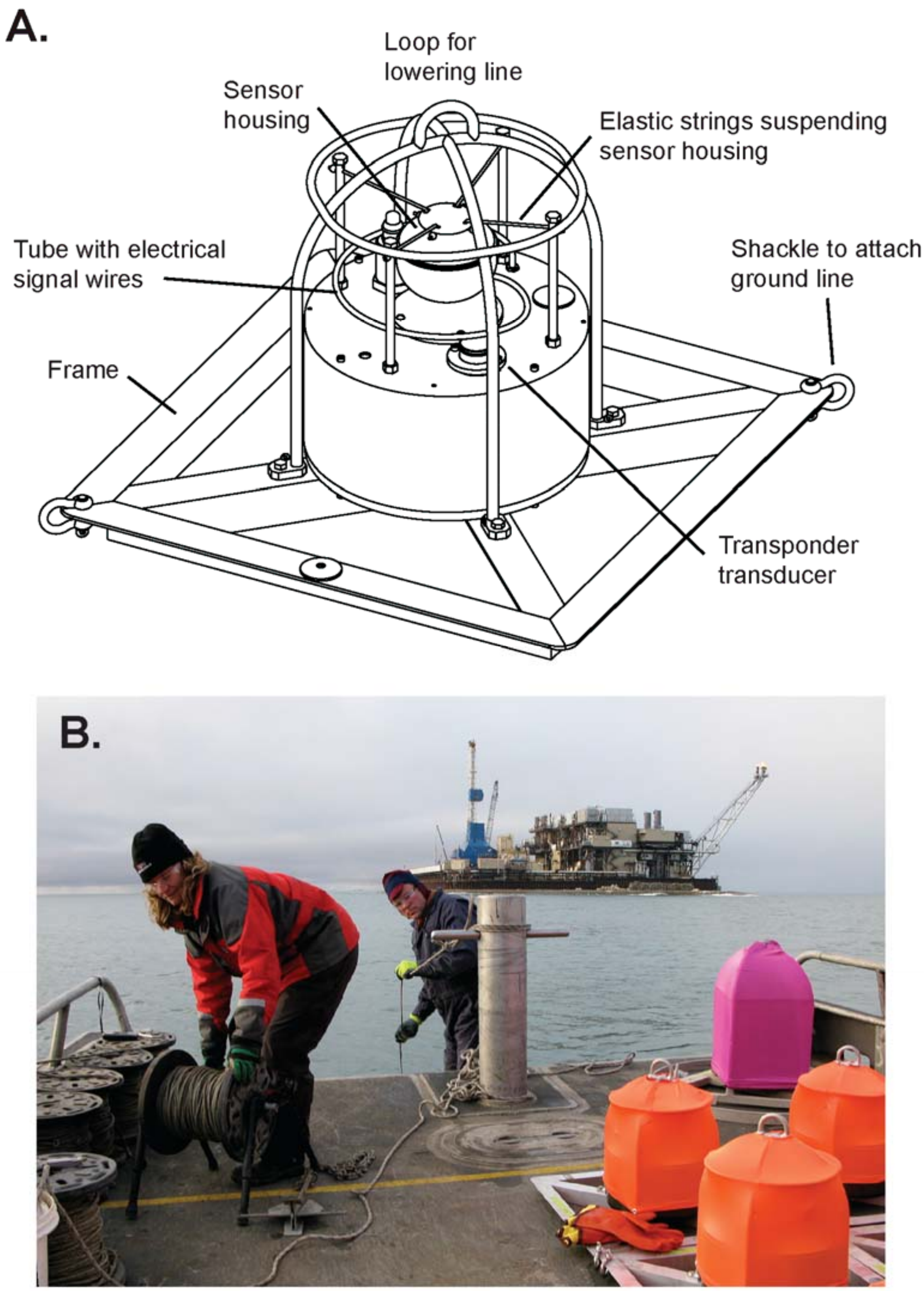

FIGURE 2.1. DASAR recorders. ***(A)*** Schematic diagram of the components of the DASAR-C08 recorder. ***(B)*** DASARs on the back deck of the ACS vessel *Mikkelsen Bay*, with Northstar in the background. The three DASARs that are closest to the photographer are DASAR-C08 recorders, whereas the recorder farthest back on the deck is a DASAR-A. The near-island DASAR NSa is being lowered to the seafloor with the lowering line (tied to the davit) by ACS deck supervisor Mark Stopha. LGL scientist Lisanne Aerts is readying the spool of ground line, which is connected to the DASAR and is to be laid out on the seafloor in the next step of the deployment.

These two methods gave the same results within 0.5 dB, and comparison of the two known-sensitivity DASAR hydrophones, treating one of them as "unknown", yielded similarly close results to those obtained at TRANSDEC. The hydrophone sensitivity varies with frequency. The manufacturer's specifications listed a sensitivity of -149 dB re 1 V/μPa at 100 Hz, which was confirmed during the TRANSDEC calibrations. The hydrophone recorder electronics in the DASAR-Cs overloaded (saturated) when the instantaneous sound pressure exceeded 151 dB re 1 μPa at 100 Hz. The sensitivity increases with frequency at a 6 dB/octave rate until it flattens at about 800 Hz, then decreases rapidly above 2000 Hz. (This is the same frequency response shape specified for the AN/SSQ-53F DIFAR sonobuoy. Fig. 7.6 in Blackwell et al. 2006a shows the frequency response for the AN/SSQ-53D, which is very similar to the 53F.) The DASAR-C08 self-noise at 100 Hz is about 20 dB below the extended Knudsen spectral density for sea state zero (Knudsen et al. 1948), close to the minimum sea noise spectrum presented by Wenz (1962).

2008 Field Operations

DASAR Deployments and Retrievals

DASARs are deployed as follows: the DASAR is connected to a Danforth anchor by a 110 m (360 ft) ground line. When the ACS Bay vessel is at the target DASAR deployment location, the DASAR is lowered to the sea floor off the stern of the vessel, and a GPS waypoint is obtained of the location. The vessel then moves in a straight line until the end of the ground line is reached, at which point the anchor is deployed and a GPS waypoint is obtained (Fig. 2.1B). DASARs are retrieved by dragging a set of weighted grappling hooks on the seafloor, perpendicular to and over the location of the ground line, as defined by the GPS locations of the anchor and DASAR.

DASAR installations took place on 26 Aug 2008 from the ACS vessel Mikkelsen Bay. DASARs were deployed in an array located 8.5–38.5 km (5.3–24 mi or 4.6–20.8 nmi) NNE of Northstar Island (Fig. 2.2). The array was organized as a stack of eight equilateral triangles, tilted to the east by 30° from true north. Adjacent DASARs were spaced 7 km (4.3 mi or 3.8 nmi) apart. The 10 array-DASAR locations were referred to as locations A, B, C, D, E, F, G, H, I, and J, from south to north and west to east (see Fig. 2.2). One DASAR-C08 was deployed at each location. In addition, a DASAR-A (constructed in 2001) was deployed as a backup at location C, which is the one offshore location where a functional DASAR has been deployed every autumn since 2001 (in previous reports, described as location "EB"). Table 2.1 lists the deployment locations and recording start and end times for all DASARs.

On 26 Aug, three DASARs – two model C and one model A – were also deployed ~450 m north of Northstar (Fig. 2.3). The primary function of these DASARs was to provide a continuous acoustic record of sounds produced by Northstar and its attending vessels. The three instruments, referred to as DASARs NSa, NSb, and NSc, were located 430 m, 411 m, and 460 m (1411 ft, 1348 ft, and 1509 ft), respectively, from the center of the north shore of Northstar. NSa and NSb were separated by 160 m (525 ft), and NSb and NSc by 165 m (541 ft). One DASAR-C was deployed as a backup to the other, and the DASAR-A was deployed to ensure that the recordings of the new DASAR-C model were comparable to those of the older model.

All 14 DASARs were successfully retrieved on 25 Sep 2008.

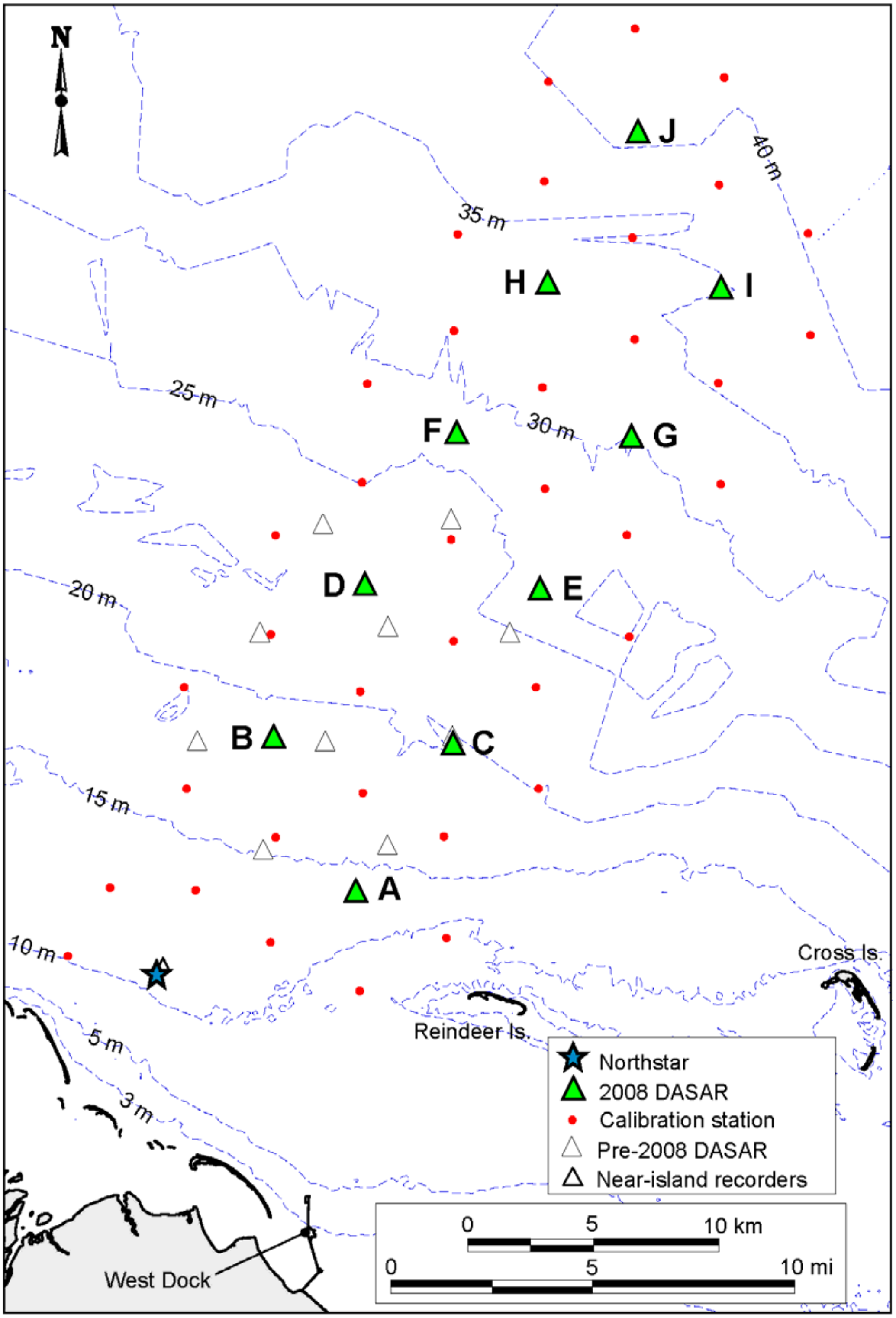

FIGURE 2.2. Locations of 11 array DASARs (2 DASARs were deployed at location C) and 37 calibration stations with respect to Northstar Island, September 2008. The three near-island DASARs are shown just north of Northstar (see Fig. 2.3). For comparison, DASAR locations used in 2001–2004 are also shown (a subset of these locations were used in 2005–2007).

TABLE 2.1. DASAR locations in 2008, with installation date and time, start and end of data collection, position, water depth, and distance from Northstar. All times are local Alaska Daylight Saving times. The "Data End" time is the recovery time. DASAR units A2, 58, and 6 were installed close to Northstar and are redundant of each other. All the other units were deployed in the offshore array. Location C in the array is the same as location EB in 2001–2007. DASARs A1 and 36 were both at the C location.

Location	Unit #	Installed (Date & time)	Data Start	Data End	Latitude (deg N)	Longitude (deg W)	Depth (m)	Distance from Northstar (km)	(mi)
A	45	26 Aug 10:00	27 Aug 00:00	25 Sep 16:12	70.523	148.487	14.9	8.55	5.31
B	51	26 Aug 14:00	27 Aug 00:00	25 Sep 09:40	70.577	148.579	17.7	10.45	6.49
C (=EB)	36	26 Aug 10:36	27 Aug 00:00	25 Sep 15:37	70.576	148.387	22.9	14.87	9.24
C dupl.	A1	26 Aug 10:26	27 Aug 00:00	25 Sep 15:06	70.577	148.391	23.2	14.82	9.21
D	37	26 Aug 13:33	27 Aug 00:00	25 Sep 10:14	70.632	148.486	22.9	17.48	10.86
E	48	26 Aug 11:02	27 Aug 00:00	25 Sep 14:33	70.632	148.297	25.0	21.53	13.38
F	47	26 Aug 13:06	27 Aug 00:00	25 Sep 10:50	70.687	148.391	28.3	24.51	15.23
G	65	26 Aug 11:26	27 Aug 00:00	25 Sep 14:00	70.687	148.202	30.2	28.41	17.65
H	52	26 Aug 12:38	27 Aug 00:00	25 Sep 11:42	70.741	148.296	34.7	31.46	19.55
I	49	26 Aug 11:49	27 Aug 00:00	25 Sep 13:29	70.741	148.108	35.1	35.21	21.88
J	50	26 Aug 12:13	27 Aug 00:00	25 Sep 12:18	70.796	148.202	38.1	38.43	23.88
NSa	A2	26 Aug 09:29	27 Aug 00:00	25 Sep 08:58	70.495	148.694	12.8	0.43	0.27
NSb	58	26 Aug 09:17	27 Aug 00:00	25 Sep 08:43	70.494	148.691	12.8	0.41	0.26
NSc	6	26 Aug 09:07	27 Aug 00:00	25 Sep 08:32	70.494	148.688	12.8	0.46	0.29

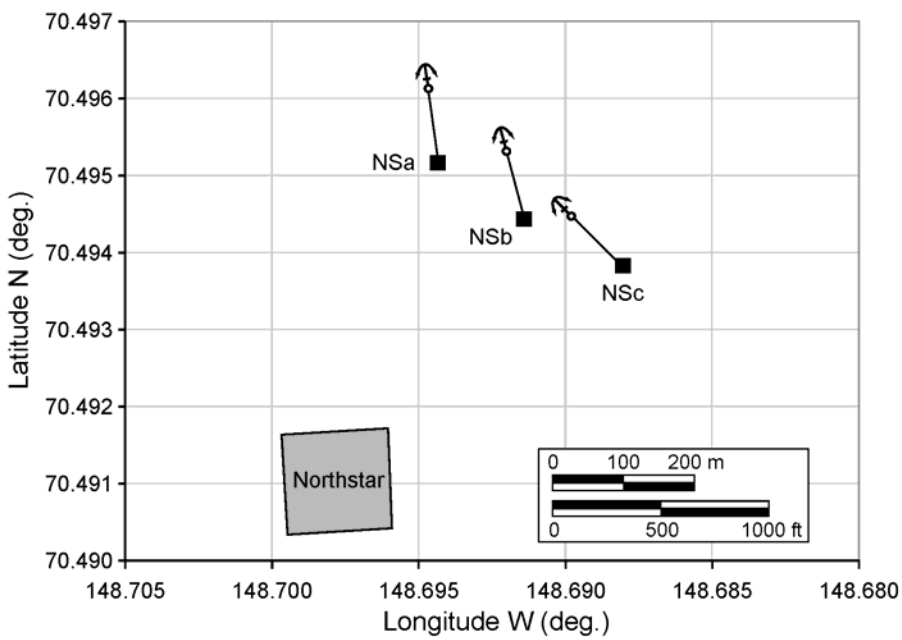

FIGURE 2.3. Locations of the three near-island DASARs (■) and their associated ground lines and anchors in relation to Northstar, September 2008. The primary function of these DASARs was to provide a continuous acoustic record of sounds produced by Northstar and its attending vessels.

Health Checks and Calibrations

Health Checks

On 27 Aug, health checks were performed on all DASARs. Health checks ensure that the recorders and their software are functioning as expected. A surface-deployed transducer (a line- or pole-mounted Benthos DRI-267A Dive Ranger Interrogator) was placed 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. None of the array DASARs reported any health problems. Health checks were repeated in mid-season, on 10 Sep, again with no health problems reported.

Time and Bearing Calibrations

On 29 Aug, soon after the DASARs were deployed, the clock and reference bearing of each DASAR was calibrated. Time and bearing calibrations were also performed in mid-season (10 Sep) and on 24 Sep, before DASAR retrievals. Bearing calibrations are conducted because during initial deployment a DASAR's orientation on the seafloor is random with respect to true north. In addition, during inclement weather DASARs sometimes move on the seafloor. Clock calibrations are conducted because each DASAR's clock has a small but significant drift, which needs to be compensated for over the course of the deployment period (Greene et al. 2004).

Field calibrations consist of projecting test sounds underwater at known times and known locations, and recording these sounds on the DASARs. After processing, the collected data allow us to determine each DASAR's orientation on the seafloor, so the absolute direction of whale calls can be obtained. The calibration transmissions also allow us to synchronize the clocks from various DASARs, so that the bearings from a call heard by more than one DASAR can be combined, allowing an estimate of the caller's position by triangulation. Clock synchronizations are also important in other situations, for example when matching a particular industrial sound on several DASARs.

Calibration transmissions were projected at six locations around each array DASAR and four locations around the near-island DASARs, resulting in a total of 37 calibration locations (Fig. 2.2). In good weather conditions (2–4 knot winds, 2 ft swell) it took about 11 hours to check the health and calibrate all 14 DASARs.

Equipment used for calibrations included a J-9 sound projector, an amplifier, a computer to generate the projected waveform, and a GPS to control the timing of the sound source. The waveform has been the same since 2001, and consists 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, and a 2-s linear sweep from 400 to 200 Hz. A spectrogram of this waveform can be found in Blackwell et al. (2006a, Fig. 7.3). 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). The rationale for the choice of waveform was that the tones provided a well-defined start time, which is used for the DASAR clock calibrations, and the bandwidth of the sweeps provided more accurate bearing measurements than would a tone.

ANALYSIS OF ACOUSTIC DATA FROM DASARS

After retrieval on 25 Sep, the DASARs were opened and dismantled. The sampling program was shut down, and the 60 GB hard drives were removed and hand-carried back to the main Greeneridge office, where they were backed up. Data were transferred to computers running MATLAB and custom analysis software, and were equalized. Equalization is a calibration process that compensates for the fact that the sensitivity curve of a DASAR sensor is not flat across all frequencies (see Blackwell et al. 2006a). Equalization permits computing calibrated sound pressure levels, both on a spectral density basis and in frequency bands (e.g., 10–450 Hz).

Various analyses were performed to address the 2008 study objectives. Certain sound analyses were performed using the same techniques as in 2001–2007, to allow comparisons with previous years. Other analyses required techniques that are new to this study, to deal with unforeseen sounds on the sound records, such as airgun pulses or a new unknown popping sound near Northstar (see Chapter 3). Details on each of these analyses are presented in the following sections:

- Calibration of DASAR time and bearing.
- 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.
- Helicopter sounds.
- New unknown impulsive sound, found principally on records of near-island recorders; seemed to originate at or close to Northstar.
- Sounds from airgun pulses, from non-BP seismic exploration.
- Whale call analyses, including the calculation of vector mean bearing and vector length.

The results from all of these sections are presented in Chapter 3, except for the results of the whale call analyses that are presented in Chapter 4.

Time and Bearing Calibrations

Time Calibration

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 since 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 2.4A shows a spectrogram of a group of nine calibration signals received by an offshore DASAR. In this example, the calibration signals of interest are obscured by airgun pulses and ambient noise, making them difficult to analyze manually, as was done in previous years. To overcome this problem and speed up the analysis, we developed software that utilizes a matched filter to automatically detect the calibration signals received at a given DASAR (matched filtering is a form of correlation processing). Figure 2.4B shows the matched filter output of the data shown in Figure 2.4A. The software 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) was then characterized as a linear function of date, shown in Figure 2.4C, and used to correct the time measured by the DASAR clock to true time. For the DASAR in Figure 2.4C, the estimated initial time offset is 0.6 sec, and the estimated clock drift is -1.8 sec/day.

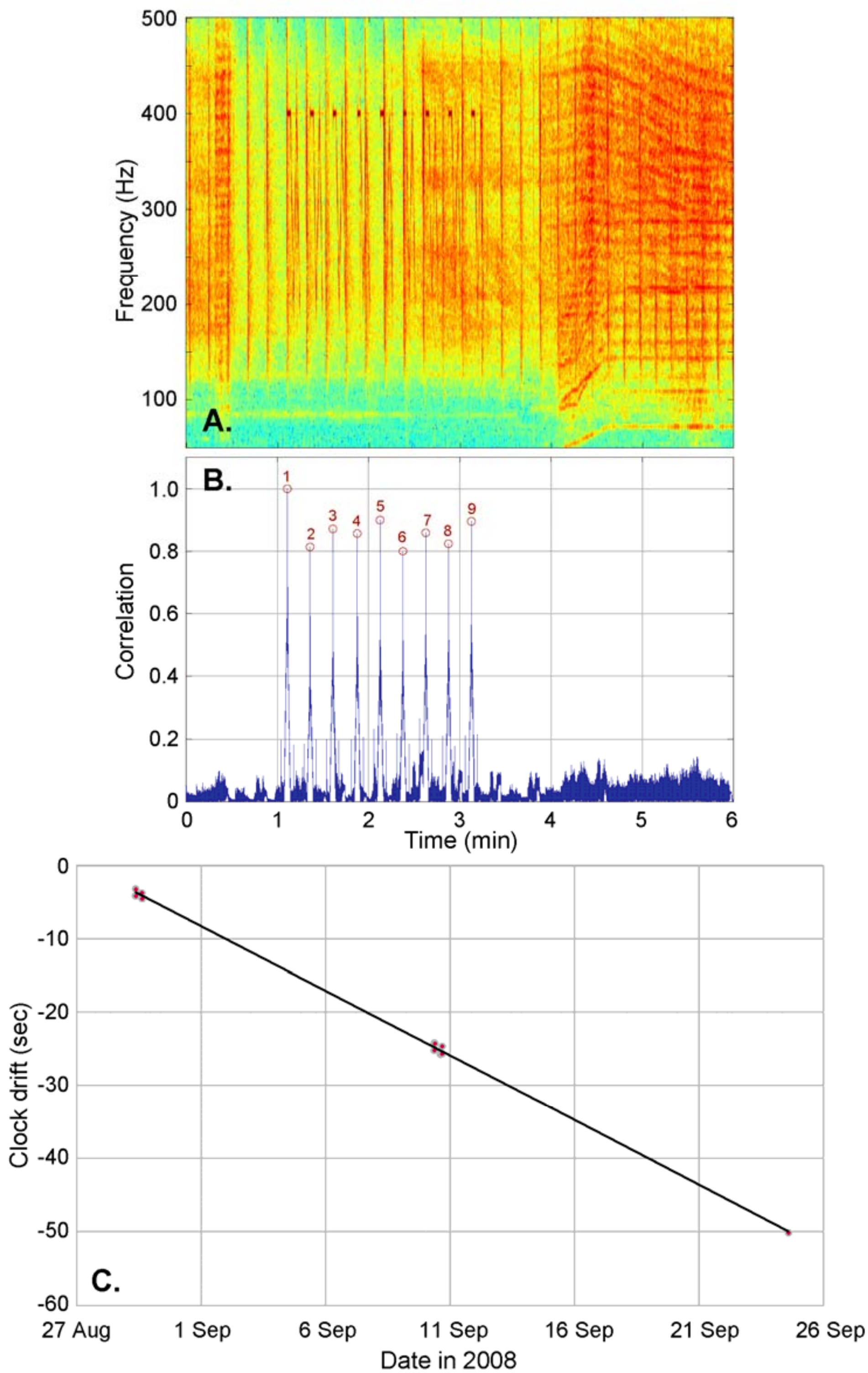

FIGURE 2.4. Calibration of DASAR clocks. ***(A)*** Spectrogram of nine calibration signals contaminated by seismic pulses at 12-s intervals, boat noise before and after the calibration period, and ambient noise throughout. ***(B)*** Matched filter output, coincident with above spectrogram, showing detections of the calibration signals. ***(C)*** Clock drift for array DASAR A determined by plotting time error as a function of date and time. Calibration transmissions were performed on 29 Aug, 10 Sep, and 24 Sep 2008 (red dots).

Bearing Calibration

The acoustic data from a DASAR consist of three channels (omnidirectional, cosine directional, and sine directional) whose respective time series are combined to determine cosine and sine components of the incoming signal:

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

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

where *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 (which is determined via the bearing calibration procedure, described earlier). 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 2.5 presents an example of a scatterplot in which the individual sample values of I_{NS} and I_{EW} are graphed together to create a dot. The signed amplitude of $I_{NS}(n)$ is indicated on the y-axis and the signed amplitude of $I_{EW}(n)$ is indicated on the x-axis. The effect is to show a scattering of sample values favoring 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 bearing relative to the DASAR orientation is estimated by averaging the $I_{NS}(n)$ and the $I_{EW}(n)$ values independently for all the samples in the received calibration sound and taking the arctangent of their ratio:

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

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 2.5, the measured B_{rel} is approximately 143°.

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 13 groups of calibration signals surrounding one of the offshore DASARs are depicted in Figure 2.6A. Figure 2.6B shows the same 13 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 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. 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. 2.6C). For this example DASAR, B_{ref} is estimated to have a mean value of 161.2° with a standard deviation of 3.4°.

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 2.6D. Using this alternative approach, B_{ref} was estimated to be

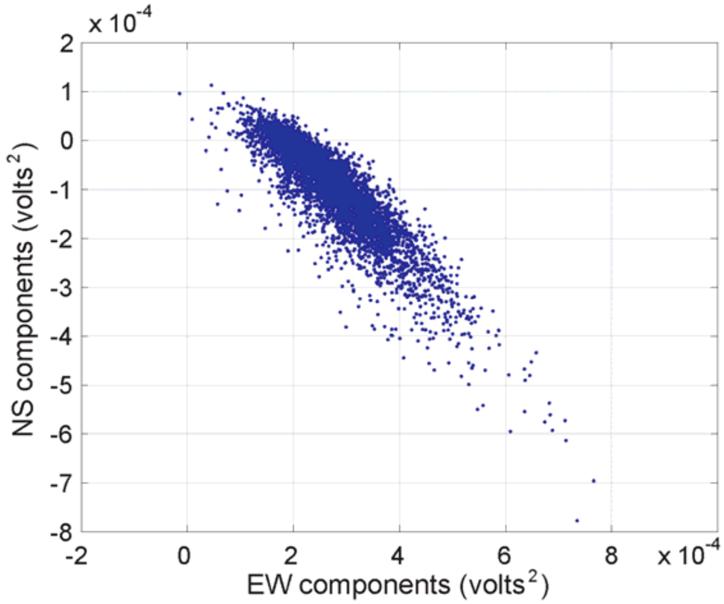

FIGURE 2.5. Example of a scatterplot illustrating the estimated bearing, B_{rel}, to a calibration signal relative to the DASAR's cosine axis. NS = north–south, and EW = east–west.

161.1°. 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.

Broadband, Narrowband, and One-third Octave Band Levels

Broadband, narrowband, and one-third octave band levels of the sounds received by all DASARs were determined using the same method as applied in previous years, to allow between-year comparisons. For each DASAR, narrowband spectral densities (1 Hz intervals, 1.7 Hz bandwidth, 23.5% overlap) 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, 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. 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 bandwidth of the one-third octave band in question. This provided a measurement of the sound level in each bandwidth, 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 provided a continual record of the levels of low-frequency underwater sounds ~450 m from Northstar during the period 27 Aug –25 Sep 2008.

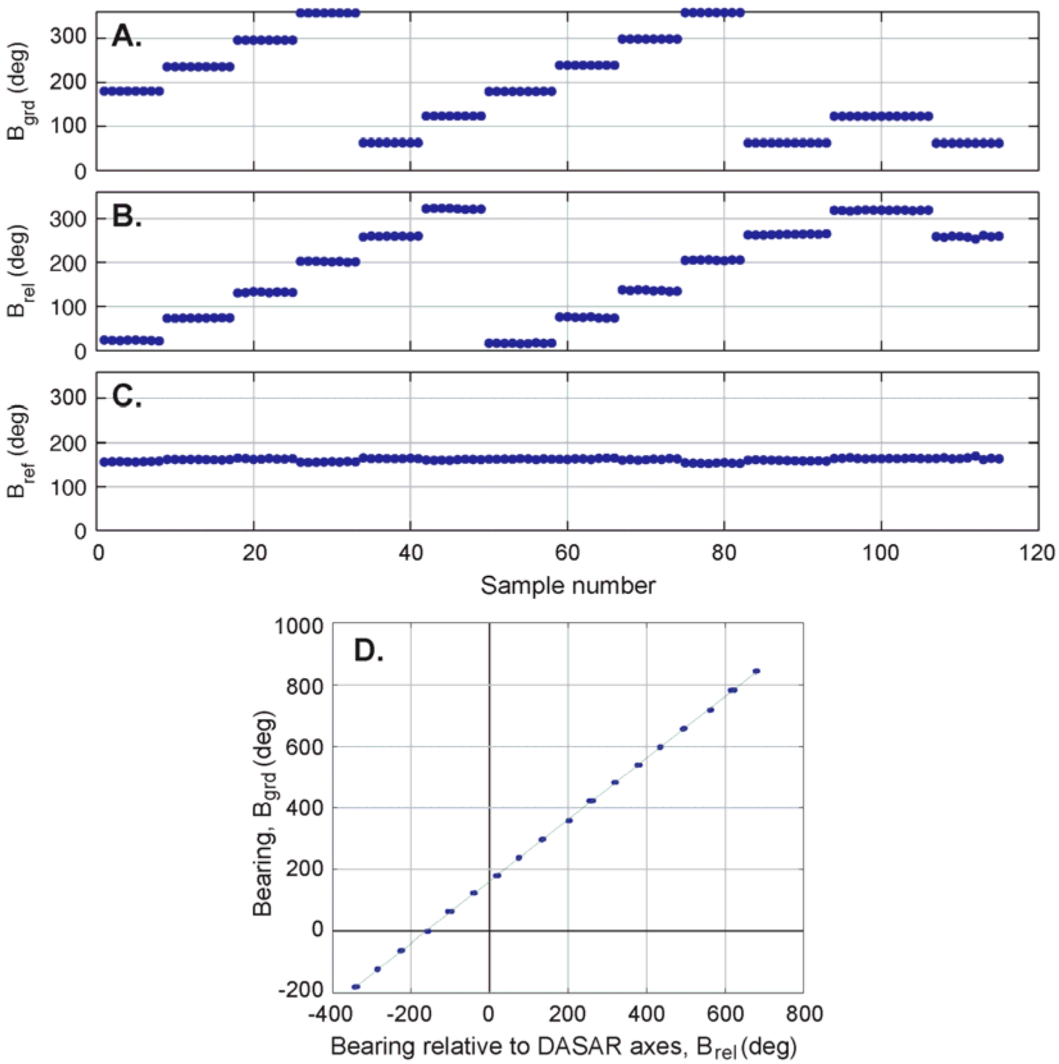

FIGURE 2.6. DASAR bearing calibration. ***(A)*** True bearings (or grid bearings), B_{grd}, from array DASAR B to the calibration source for 13 groups of calibration transmissions. ***(B)*** Measured relative bearings, B_{rel}, from the DASAR to the same calibration transmissions. ***(C)*** Resultant reference bearing, B_{ref}, used to translate estimated bearings received on and relative to the DASAR to bearings relative to True North (μ=161.2°, S.D.=3.4°, n=115). ***(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} (161.1°).

The narrowband and one-third octave data were also summarized over the entire deployment period 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 cells in the spectra, the values were sorted from smallest to largest, and the minimum, 5th-percentile, 50th-percentile, 95th-percentile, and maximum values for that frequency cell 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 the entire season. It therefore allowed general comparisons between years by identifying, for example, prominent tones or the dominant frequency ranges of industrial sounds.

During the 2008 field season there were at least two types of sounds that were fairly prominent on the DASAR records and were therefore expected to influence the results of the sound analyses (see Chapter 3). These two types of sounds were either not known from previous years or not very prominent. One was the presence of "popping sounds", mainly on the records of the near-island DASARs. The other was the presence of airgun pulses on the array DASARs, from non-BP sources. To provide a measure of broadband sound exclusive – as much as possible – of both pops and airgun pulses, we calculated broadband (10–450 Hz) levels over 2-s periods. This was done for every second throughout a DASAR's sound record, so each 2-s period had 50% overlap with the period preceding it. For each 10-min period throughout the DASAR record only the lowest value was stored. This essentially provided a record of minimum broadband levels, by 10-min period, throughout the season for a particular site.

Industrial Sound Indices (ISIs)

For purposes of this study, where the main interest lies in understanding the relationship between sounds generated by Northstar and migrating bowhead whale distribution and behavior, it is important to understand the contribution of industrial components to the overall underwater sound. For that reason, industrial sound indices (ISIs) were developed in earlier years (Blackwell et al. 2006a) 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.pres* and *ISI_tone*; and the ***presence of transient sounds***, such as those produced by passing vessels, as represented by *ISI_trans.pres* and *ISI_transient*.

During the first years of the Northstar study, *ISI_5band* (formerly called simply "*ISI*") was the only index of island sound. In 2005, in response to comments by the SAC, the other indices were developed and used in follow-up analyses of 2001–2004 data (e.g., Blackwell et al. 2006a, 2006b). However, the other indices were not used in 2005–2007. This was one reason why comparison of the 2008 data with those from previous years (2001–2007) was only done for *ISI_5band*. Another reason relates to the changing acoustic conditions near Northstar in 2008 relative to earlier years. The ISIs were originally developed as indices of Northstar sound, to be used in quantifying the Northstar-related sound to which bowhead whales were exposed, and to which they did or did not react when near Northstar. The higher levels of industrial activities in 2008 – including mainly vessel traffic and seismic exploration unconnected to Northstar – have meant that the ISIs in 2008 were more a measure of overall anthropogenic sound rather than specifically Northstar sound. For example, in 2008, *ISI_transient* was severely affected by the presence of nearby seismic exploration unrelated to Northstar, and no longer (as currently defined) provided information useful to evaluate *Northstar transients*. *ISI_transient* is not presented in this version of the report but may be reassessed in the future. *ISI_5band* was also influenced by the increased offshore industrial activities but values from the near-island DASARs in 2008 were still useful for comparisons with previous years. *ISI_tone* seemed the least affected by seismic exploration, probably because airgun pulses have no tonal components. The following subsections describe how *ISI_5band* and *ISI_tone*, two ISI indices that are used in this report, were defined and calculated.

ISI_5band.—This ISI was constructed by summing the mean square sound pressure levels (SPL) in 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 were 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 et al. 2003). Total mean-square sound pressure in the five one-third octave bands considered was computed as

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

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 in the sound spectrum. Tones are produced by machinery and are therefore a 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 when the spectral density value for a set frequency was at least 5 dB above the average level of the two spectral components below and the two spectral components above the component being examined. The average of those 4 "nearby" frequency bins constituted the "background"[3]. 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 (micropascals-squared) of these differences, for all the tones identified by the ≥5 dB criterion, converted back to dB re 1 μPa.

Helicopter Sounds

During the BP Liberty OBC seismic survey in July 2008, sounds from helicopters were detected on the ocean bottom cables. Over deep water away from shore the transmission of sounds from helicopters into the water is generally limited to an area below 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 provide bottom-reflected and bottom-transmitted paths for sound transmission. BP decided to further investigate if and to what extent 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 1). The presence of tones from these helicopters was investigated in the record of near-island DASAR NSc. 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 can also be expected. Patenaude et al. (2002) detected tones up to the 13^{th} harmonic (140 Hz) for the main rotor and up to the 6^{th} harmonic (330 Hz) for the tail rotor.

Records of helicopter landings and takeoffs at Northstar during the period 26 Aug–25 Sep 2008 were used to identify the times on the sound records at which helicopter sounds might be detected. The calibrated but otherwise unprocessed DASAR NSc 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 Sep 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.

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[3] 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.

New Unknown Impulsive Sound

On the three near-island recorders a new sound, not evident in comparable recordings from prior years, was detected. Based on its occurrence primarily on the near-island recordings, and its bearings (predominantly south and southwestward) from those recorders, this sound appeared to originate at or close to Northstar Island. The frequency of occurrence of these sounds was examined over a few hours on each of three days, at the beginning, middle, and end of the field season. The sound was impulsive and was therefore analyzed using routines developed for transient pulses <1 s in duration (Greene 1997; McCauley et al. 1998, 2000; Blackwell et al. 2004a). The following parameters were computed for a total of thirty pulses: (1) *peak pressure*, i.e., the instantaneous maximum of the received sound pressure (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 of the energy in the pulse, defined as the squared instantaneous sound pressure integrated over the pulse duration (dB re 1 $\mu Pa^2 \cdot s$); (5) *background levels*, as recorded immediately preceding the onset of the pulse as defined in (2). Spectrograms and spectral density plots were produced for a subsample of pulses to identify pulse frequency composition.

Airgun Pulses

During the 2008 field season airgun pulses from seismic surveys by companies other than BP were detected on the acoustic record of all array DASARs. Because airgun pulses have energy distributed over our entire analysis band of 10–450 Hz, they were a source of interference in the sound records of the offshore DASARs (see for example Fig. 2.4A). In addition, bowhead whales have been shown to react to sounds from airguns (Richardson et al. 1986, 1999; Ljungblad et al. 1988). We analyzed airgun pulses in the records of all DASARs using software developed by Dr. Aaron Thode (Scripps Institution of Oceanography). 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 (pulse detection and interval estimation) are described in detail in Annex 2.1. Once pulses were identified, the software calculated the following five parameters for each detected pulse: (1) *peak pressure* (in dB re 1 μPa); (2) pulse *duration* (in s); (3) pulse *sound pressure level* (SPL, in dB re 1 μPa); (4) pulse *sound exposure level* (SEL, in dB re 1 $\mu Pa^2 \cdot s$); (5) *background levels*. These parameters were defined and measured in the same manner as described above for the new unknown impulsive sounds. Pulses that overloaded the DASAR sensor (i.e., pulses for which the instantaneous sound pressure exceeded 151 dB re 1 μPa) were not included in the analysis. Data were then summarized as follows: for each 10-min period with detected airgun pulses, the median and maximum values of SPL, instantaneous peak pressure, and SEL were computed.

Whale Call Analyses

Concurrent with the early stages of manual whale call processing in late 2008, BP considered the possibility of using an automated call detection system that has been under development since 2007. However, at the time that a decision had to be made on whether to use a manual or automated approach, it was felt that the automated analysis did not yet yield results that were close enough to the manual approach that has been used since 2000. BP plans to continue to explore the possibility of automated call detection, but for the 2008 data the analysis of all whale calls was done manually by trained staff. Identification 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. 2.7). The sounds recorded during a given 1-min interval by all DASARs comprising one site were analyzed by a single analyst before that analyst moved on to the next 1-min period. Using a computer mouse, analysts delimited each call within a rectangle, thereby "tagging" it in the records. The computer then calculated several parameters such as the bearing to the call, or the duration of the call. The lead analyst performed regular checks for consistency among analysts. Most calls were detected by more than one DASAR, but each call was classified and tallied only once. 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).

Calls were classified into two major categories, simple calls and complex calls, on the basis of call descriptions by Clark and Johnson (1984), Würsig and Clark (1993), and Blackwell et al. (2007b). Simple calls were frequency modulated tonal calls or "moans" in the 50–300 Hz range. We distinguished (1) ascending or "up" calls ("/"), (2) descending or "down" calls ("\"), (3) constant calls ("—"), and (4) u-shaped ("∪") and (5) n-shaped ("∩") inflected calls and (6) variations thereof ("~"). Complex calls were infinitely varied and included pulsed sounds, squeals, growl-type sounds with abundant harmonic content, and combinations of two or more simple and complex segments. Subcategories of complex calls could not be consistently discerned, so all subcategories were pooled. The presence of call sequences (see Blackwell et al. 2007b) was noted by tagging the first call of a sequence, and noting the type of calls and the approximate number of calls in the sequence. In addition to sounds from bowhead whales, acoustic records included sounds produced by bearded seals (*Erignathus barbatus*), Pacific walruses (*Odobenus rosmarus divergens*), and probably gray whales (*Eschrichtius robustus*) and ringed seals (*Phoca hispida*).

Five days of the season (30 Aug, 5 Sep, 12 Sep, 19 Sep, and 24 Sep) were analyzed in great detail: all marine mammal calls were tagged, as well as vessels, airgun sounds, calibration sounds, and other man-made sounds. For all remaining days of the season only bowhead whales, vessels, and airgun pulses were tagged.

During the whale call classification process, the bearing from each DASAR to each detected call was determined automatically, using information from the bearing calibrations (see section Time and Bearing Calibrations above). If a call was detected by at least two DASARs, the bearings to that call were combined to estimate a position by triangulation. After all the calls were processed, two parameters were calculated for DASAR C (called "EB" in 2001–2007) based on the bearings from that DASAR to all whale calls detected by that DASAR: the vector mean bearing and the mean vector length (Batschelet 1981). Figure 2.8 shows how to calculate these two parameters using example bearings to nine different calls. The vector mean bearing indicates the average direction from a given DASAR 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 (say 45°), then the vector mean would be 45° and the mean vector length would be 1. If the bearings were spread evenly in all directions (say 4 bearings at 0°, 90°, 180°, and 270°), then the vector mean 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 C and compared with values from previous years at that location (referred to as location EB in Blackwell et al. 2008). "Offshore" and "inshore" were defined in relation to a ***baseline***, which is a line parallel to the general trend of the shoreline (108° to 288° True). Offshore calls were defined as those whose bearings from a specific DASAR were between 288° and 107.9° True (including 360°/0°, true north), and inshore calls were defined as those with bearings between 108° and 287.9° (including 180°, south; Figure 2.9).

FIGURE 2.7. Eight of the 21 work stations at Greeneridge Sciences where analysts identify and localize whale calls. In the left picture, note 10 spectrograms on the screen of the closest analyst, representing the 10 DASAR locations of the Northstar offshore array.

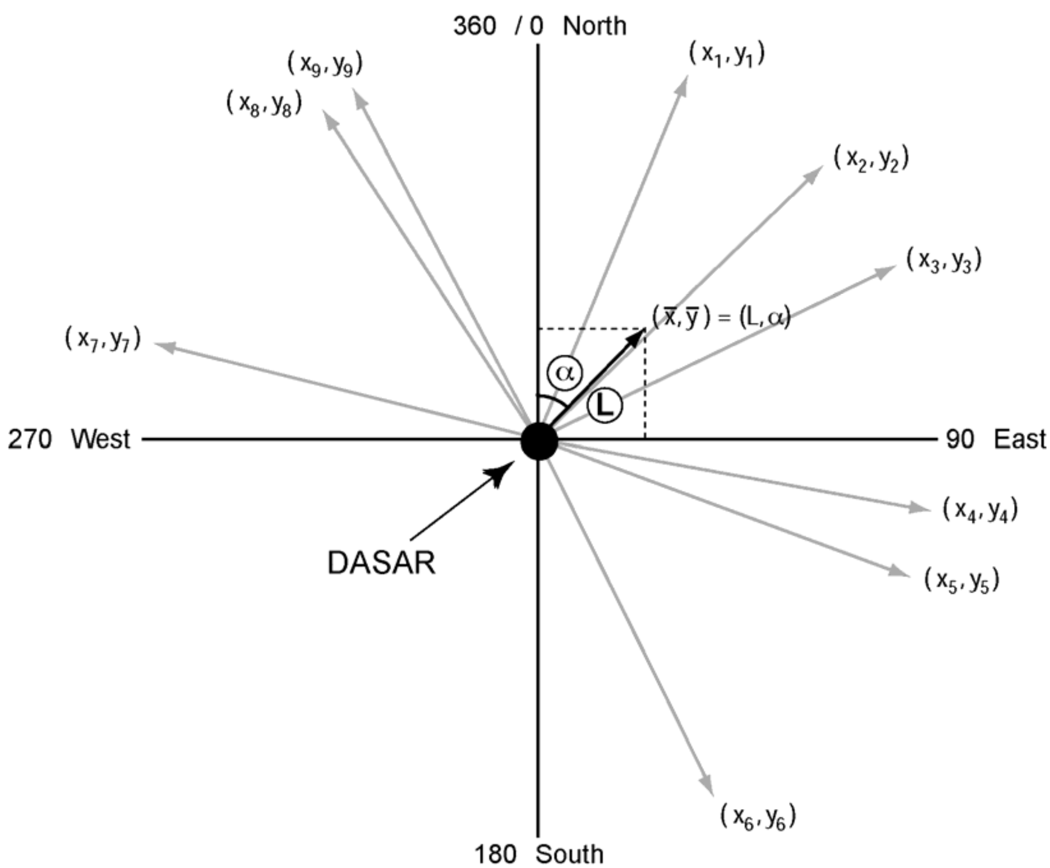

FIGURE 2.8. Average bearing calculation. The gray arrows are example bearings from a DASAR. Mean bearing angle a = $\arctan(\bar{x}, \bar{y})$, where $\bar{x}$ and $\bar{y}$ are the average cos and sin, respectively, of all bearings obtained at one DASAR during a season. Mean vector length L = $\sqrt{\bar{x}^2 + \bar{y}^2}$, is a measure of the variation of individual bearings around the vector mean direction.

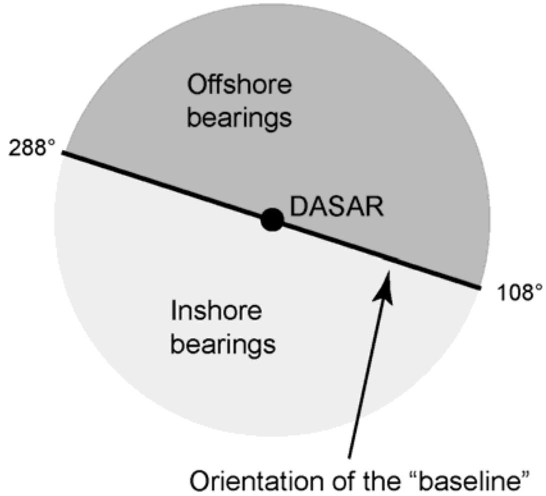

Figure 2.9. Definition of the "offshore" and "inshore" sectors in relation to the orientation of the baseline and DASAR location (filled circle in center). See text for details.

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ANNEX 2.1: 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 creates a running spectrogram of FFT (Fast Fourier Transform) length 256 samples (0.256 s), overlap 62%, and then creates a set of "detection functions" by integrating the FFT output over a set of overlapping 30 Hz frequency bands between 50 and 400 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 one minute. 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. 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 20 ms, the event is logged for further analysis, along with the 30 Hz window that attained the greatest SEL value. If the detection lasts longer than 10 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 0.5 s 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 any given pulse, the program looks 40 s into the future and past for the presence of any other pulses that attained maximum SEL level at a frequency within 50 Hz of the current pulse's peak frequency. These "candidate" detections, if they exist, provide a set of possible intervals to test. Each candidate interval is tested by searching four time intervals into the future, and four time intervals into the past, relative to the current pulse under consideration. If a pulse occurs within 1.5 s of where an interval would be expected, that candidate interval is awarded a "hit". If six out of the eight 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 a high-resolution estimate of the pulse duration is obtained by working directly on the time series. The time series is run through a calibration filter that 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 and SEL of the pulse can be computed. 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 within the duration is saved as the instantaneous peak pressure. If a pulse reaches the maximum permissible value of the A/D converter four times, it is flagged as “clipped”. All “signal” and “noise” metrics are written to a file for further analysis.

CHAPTER 3:

SOUNDS RECORDED AT NORTHSTAR AND IN THE OFFSHORE DASAR ARRAY, AUTUMN 2008[1]

by

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ABSTRACT

During the bowhead whale migration in September 2008, Greeneridge Sciences (on behalf of BP) implemented an acoustic monitoring program north-northeast of BP's Northstar oil development. The overall study objective is similar to previous years, i.e., to assess the effects of Northstar production activities, as manifested in underwater sounds, on the behavior of migrating bowhead whales. Understanding what sounds are produced by Northstar and its attending vessels, and what part of those sounds are received by migrating bowhead whales, is an important component of the study. The current chapter presents results from the analyses of sounds recorded near Northstar and in the offshore DASAR array during the early autumn of 2008.

An array of 10 directional autonomous seafloor acoustic recorders (DASARs) was deployed offshore of Northstar for ~29 days (27 Aug–25 Sep) and recorded sounds continuously at a 1 kHz sampling rate. Concurrently, sounds produced by Northstar and its attending vessels were recorded by DASARs located ~450 m north of the island over the same period. Broadband levels of Northstar sound, as recorded near the island, were generally similar to previous years. The density of vessel spikes was lower in 2008 than in 2007 and 2006, but short-term variability in sound levels was higher than in previous years. This was attributed to the presence of a new type of impulsive sound on the records of the near-island DASARs, referred to as "pops", and whose source is not known. Pops were broadband in nature, of short duration (~0.05 s), and of high enough intensity that they sometimes overloaded the DASAR hydrophone. Received sound pressure levels at the near-island DASAR ranged from 107 to 144 dB re 1 μPa.

One of the specific objectives in 2008 was to better understand which island sounds propagate offshore and the distances at which these sounds can be detected in the offshore array. Large vessel spikes from tugs maneuvering at Northstar could be detected to a distance of at least 21.5 km and possibly farther. The 60 Hz power frequency tone, on the other hand, despite omnipresence at Northstar and being the strongest tone in the island spectrum, could no longer be detected at the southernmost array DASAR (A), even in the quietest condition.

Tones from helicopters were detected in the records of the near-island DASAR, but they were faint and only detected during helicopter departures from Northstar, not during arrivals.

More than 90,500 airgun pulses were detected on the record of DASAR J, the farthest from shore. Airgun pulses were omnipresent during the 2008 deployments, occurring in over 70% of the 10-min periods within the project's field season at the northern end of the DASAR array. These airgun pulses therefore constitute a strong confounding factor in achieving our objective of assessing the effects of Northstar sounds on bowhead whale behavior. Bowhead whales have been shown to react to airgun sounds, by deflecting or by changing their calling behavior, or both. The airgun pulses could be added to the overall analysis as an additional covariate to be taken into account, but it is also possible that their effects on bowhead behavior will overshadow any effects by Northstar. How to deal with this added factor is currently being investigated; results will be presented in the final report.

INTRODUCTION

The overall study objective is to assess the effects of Northstar production activities, as manifested in underwater sounds, on the behavior of migrating 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 to react. The current chapter presents results from the analyses of sounds recorded near Northstar and in the offshore DASAR array during the early autumn of 2008. Underwater sounds generated by Northstar, as recorded by near-island DASARs, were compared with similar data from previous years. In addition, to determine to what extent Northstar sounds propagate offshore, sound records obtained close to the island were compared to those obtained in the DASAR array, 8.5–38.5 km (5.3–23.9 mi) northeast of Northstar. When possible, changes in industrial and vessel activities at and near Northstar were related to observed changes in the sound records. Results from an analysis of airgun sounds from non-BP sources[2] that were prevalent on the sound records of all array DASARs are also presented in this Chapter (airgun sounds were not detected on the near-island records). Although not related to Northstar or other BP activities, airgun pulses were part of the sound field to which migrating whales were exposed in 2008, and as such it is important to understand their relative contribution.

The analysis methods of the sounds described in this chapter are presented in Chapter 2. The results are presented in this chapter in a way that facilitates two types of comparisons that are important for this data set: comparisons of Northstar sounds in 2008 with previous years, and comparisons of Northstar sounds as recorded close to and farther away from the island. Specifically, the results are presented in the following five sections:

1. Broadband sounds near Northstar and offshore;
2. Statistical spectra of near-island and offshore sounds, including percentile one-third octave band and spectral density levels;
3. Industrial sound indices (ISIs) of near-island and offshore sounds, including *ISI_5band* and *ISI_tone*;
4. Sounds from specific island-related sources, including vessels, helicopters, and a new unknown sound source;
5. Airgun pulses, including sound pressure levels and numbers of pulses detected at different DASARs.

BROADBAND SOUNDS NEAR NORTHSTAR AND OFFSHORE

Broadband Sounds Near Northstar

Three DASARs were deployed ~450 m north of Northstar, with two of the instruments considered backups to the third. DASAR NSa was a DASAR-A (see Greene et al. 2004) whereas NSb and NSc were of the newer DASAR-C type (Chapter 2). Data from these three recorders were in close agreement, with differences that were well within the variation one might expect based on reception at slightly different

[2] The BP Liberty ocean bottom cable seismic survey was completed on 25 Aug 2008, two days before the near-island and offshore DASARs were deployed at Northstar.

locations (see Fig. 2.3 in Chapter 2). Mean received levels and variability in received levels (S.D.) decreased from east to west, being highest at DASARs NSc (104.5 ± 8.5 dB re 1 μPa), intermediate at DASAR NSb (103.8 ± 7.9 dB), and lowest at DASAR NSa (102.8 ± 6.9 dB). Of the three near-island recorders, DASAR NSc (southeasternmost) was chosen to be most representative of Northstar sounds because its location was closest to the path taken by barges and other vessels arriving at Northstar, and vessels are one of the most important sources of sound associated with the Northstar operation (Blackwell and Greene 2006).

The signals from DASAR NSc were analyzed to determine the broadband (10–450 Hz) level of underwater sound based on a one-minute sample every 4.37 minutes. This is the same descriptive technique used since 2001 (see Chapter 2). Figure 3.1B shows the 2008 received levels of broadband (10–450 Hz) sound as recorded by DASAR NSc, located 460 m northeast of Northstar (see Chapter 2, Fig. 2.3). The range of broadband levels shown for 2008 is 91–141 dB re 1 μPa. Much of this variation in received levels was dependent on sea state, which is correlated with wind speed. Figure 3.1A shows mean hourly wind speed as recorded by the Prudhoe Bay weather station (70.4° lat N, 148.517° long W, elevation 15 m=50 ft), during the period 27 Aug–25 Sep 2008[3]. The lowest sound levels in the time series (Fig. 3.1B) are indicative of the quietest times in the water near the island, and generally correspond to times with low wind speeds (Fig. 3.1A). Conversely, times of high wind speed (e.g., 2 or 17 Sep) usually correspond to increased broadband levels in the DASAR record. Mean hourly wind speed in 2008 (31 Aug–30 Sep) was 7.2 m/s (16.2 mph), which is almost 28% lower than during the same period in 2007 (10.0 m/s or 22.3 mph), as collected at the same weather station. Figure 3.2 summarizes mean wind speed during September in each year of the Northstar study, as recorded by the Northstar[4] (2001–2006) or Prudhoe Bay (2007–2008) weather stations. The Northstar and Prudhoe Bay weather stations are about 12 km apart (7.6 mi) and therefore not directly comparable, but it is likely that mean wind speeds in September 2008 were more similar to values in 2001–2006 than to 2007, which was an outlier year with higher-than-normal wind speeds. For example, a comparison of mean wind speeds recorded by the Northstar versus Endicott weather stations over six years (2001–2006) showed larger differences between years than between the two stations, which were 36 km (22 mi) apart (Blackwell et al. 2008a).

Figure 3.3 compares broadband levels, as recorded ~450 m northeast of the island, over eight seasons of monitoring (2001–2008). There were fewer "vessel spikes" in 2008 compared to previous years but more short-term variability in received levels. For each year, percentile levels of broadband sound (maximum, 95th, 50th, and 5th percentile, and minimum) were computed over the entire field season and are summarized in Table 3.1. Figure 3.4 illustrates how the percentiles of broadband sound in 2008 compare to previous years (2001–2007). Percentile levels of broadband sound near Northstar in 2008 were well within the range for 2001–2007 except for the 75th percentile, which was 1.5 dB higher than the maximum for previous years (see Fig. 3.4). The maximum levels in Table 3.1 and Figure 3.4 are mainly determined by the presence of vessels. Therefore these maximum values could be underestimated, since a vessel such as a tug traveling or maneuvering close to a near-island DASAR could overload the sensor.

A new popping sound appeared on the near-island DASAR records and was also apparent on array DASAR A during the 2008 field season. These "pops" were most prevalent on the near-island DASARs

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[3] As described in Chapter 2, wave, current, and ice thickness sensors were deployed ~1 mile offshore of Northstar in August 2008. Data from these instruments will be very useful for the sound analyses, but have not yet been retrieved.

[4] The Northstar weather station was dismantled after the 2006 open-water season.

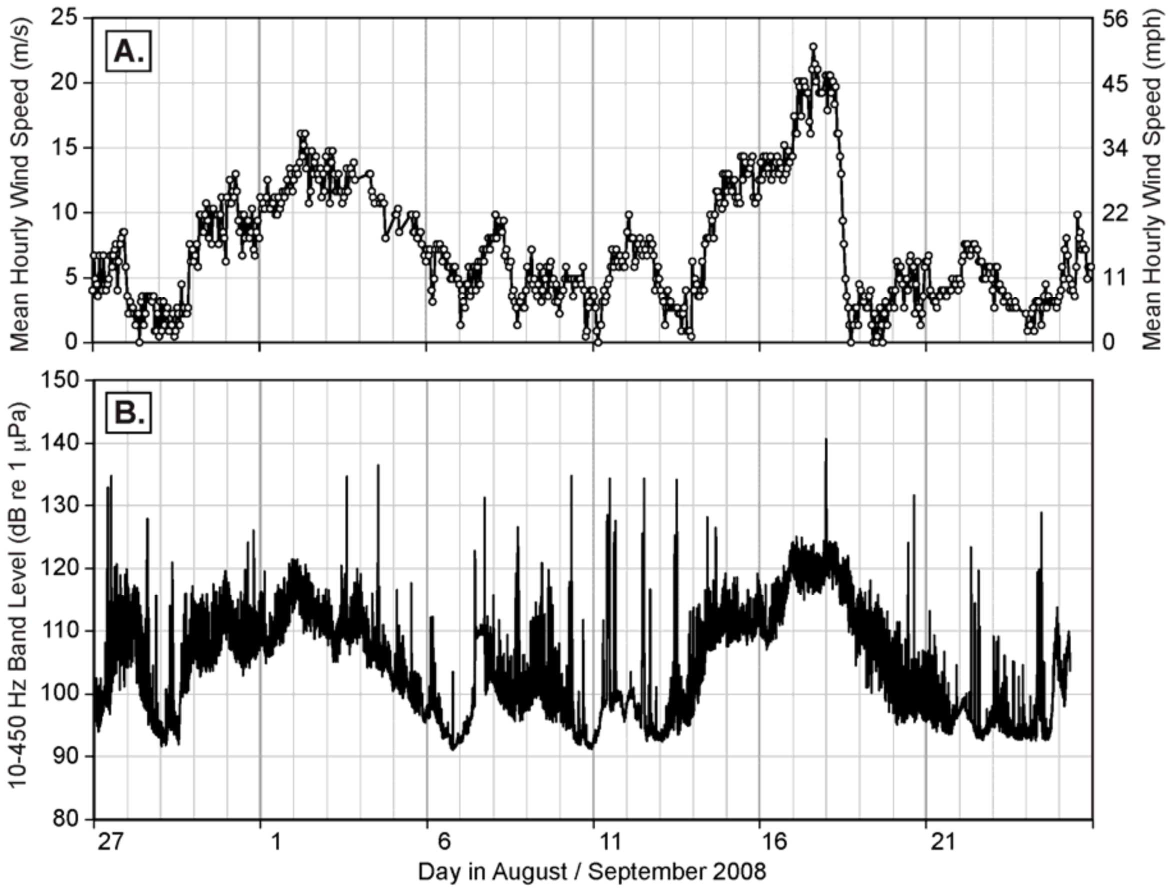

FIGURE 3.1. Variation in levels of underwater sound near Northstar in relation to date and wind speed, 27 Aug–25 Sep 2008. ***(A)*** Mean hourly wind speed as recorded by the Prudhoe Bay weather station[3] (see text for more information). ***(B)*** Broadband (10–450 Hz) levels of underwater sound (1-min averages) near Northstar vs. time, as recorded by DASAR NSc, located 460 m north of the island. Vertical spikes in the sound pressure time series are generally produced by vessel arriving at or departing the island.

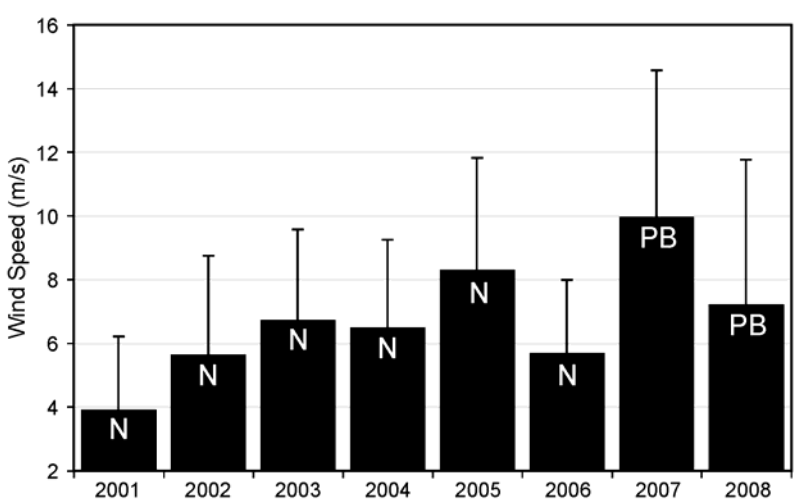

FIGURE 3.2. Mean wind speed for the period 31 Aug–30 Sep for 2001–2008, plus one standard deviation. Data for 2001–2006 were collected by the Northstar (N) weather station, and data for 2007–2008 were collected by the Prudhoe Bay (PB) weather station.

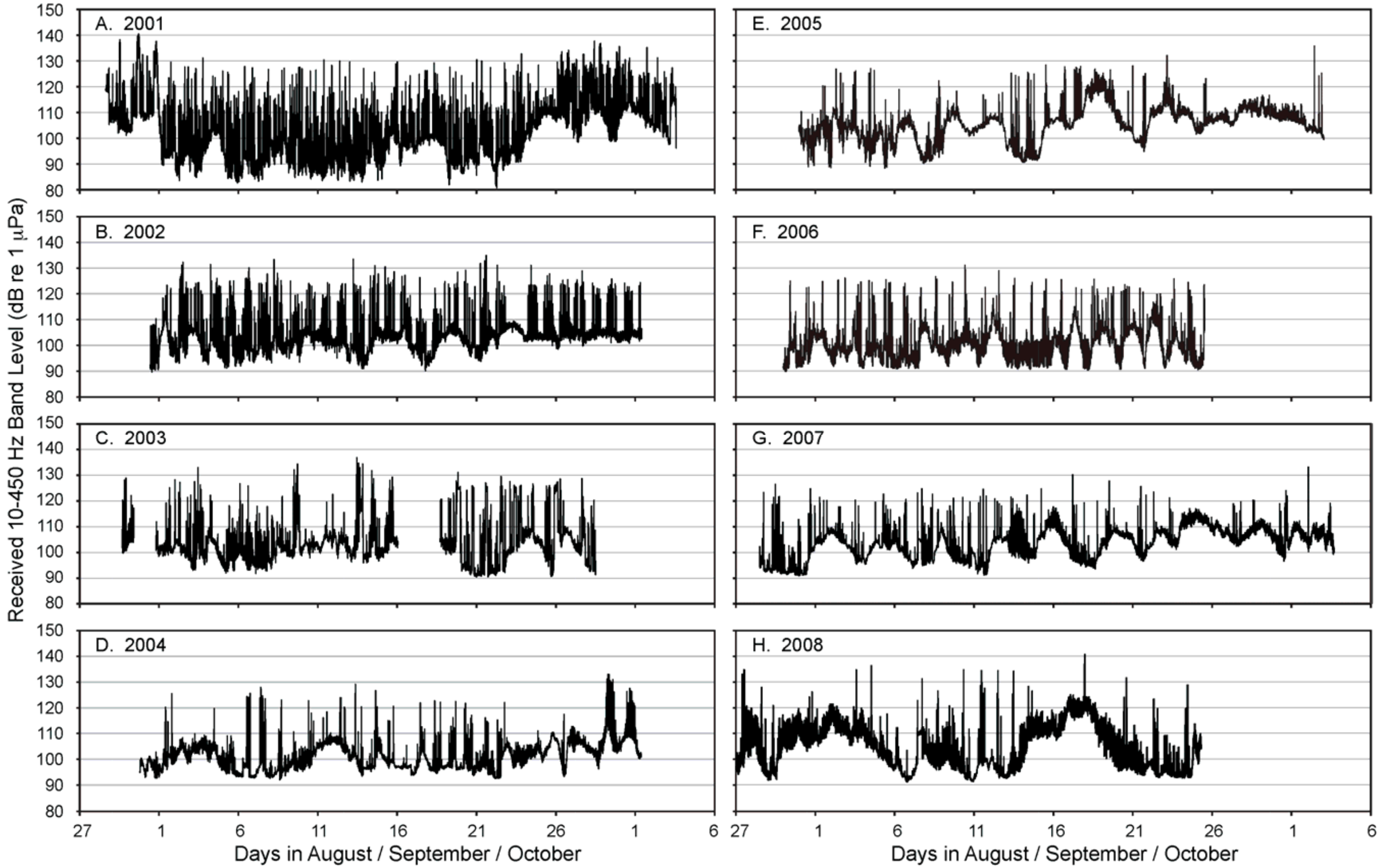

FIGURE 3.3. Sound pressure time series (10–450 Hz band; 1-min averages) for the entire 2001–2008 seasons, as recorded by the near-island recorders – a cabled hydrophone in 2001, 2002, and the first part of 2003, and a DASAR for the second part of 2003 and all of 2004–2008.

TABLE 3.1. Percentile levels, in dB re 1 μPa, of broadband (10–450 Hz; 1-min averages) underwater sound recorded near Northstar Island in 2001–2008. In 2001 (1–21 Sep) and 2002 (31 Aug–23 Sep), data were collected by cabled hydrophone (CH) #2. In 2003, data were recorded both by CH #2 (29 Aug–16 Sep) and DASAR NS (18–28 Sep). In 2004, 2005, 2006, and 2007 data were recorded, respectively, by DASAR NSa (30 Aug–1 Oct), DASAR NSb (1 Sep–2 Oct), DASAR NSc (30 Aug–25 Sep), and DASAR NSb (28 Aug–3 Oct). In 2008, data were recorded by DASAR NSc (27 Aug–25 Sep). "Range" is the difference between maximum and minimum. All hydrophones were at similar distances (410–550 m or 1345–1804 ft) north of Northstar.

	2001	2002	2003		2004	2005	2006	2007	2008
	CH #2	CH #2	CH #2	NS	NSa	NSb	NSc	NSb	NSc
Max	140.5	135.0	136.8	131.1	133.1	135.8	131.4	133.3	141.1
95^{th} %ile	122.7	117.3	116.7	125.1	110.1	118.2	111.4	112.5	119.4
50^{th} %ile	101.8	103.5	101.8	103.4	100.5	105.5	98.7	104.0	103.6
5^{th} %ile	87.3	94.8	95.2	91.7	93.7	92.4	91.7	93.4	93.2
Min	80.8	89.7	91.8	90.4	92.0	88.0	89.8	90.9	91.0
Range	59.7	45.3	45.0	40.7	41.1	47.8	41.6	42.8	50.0

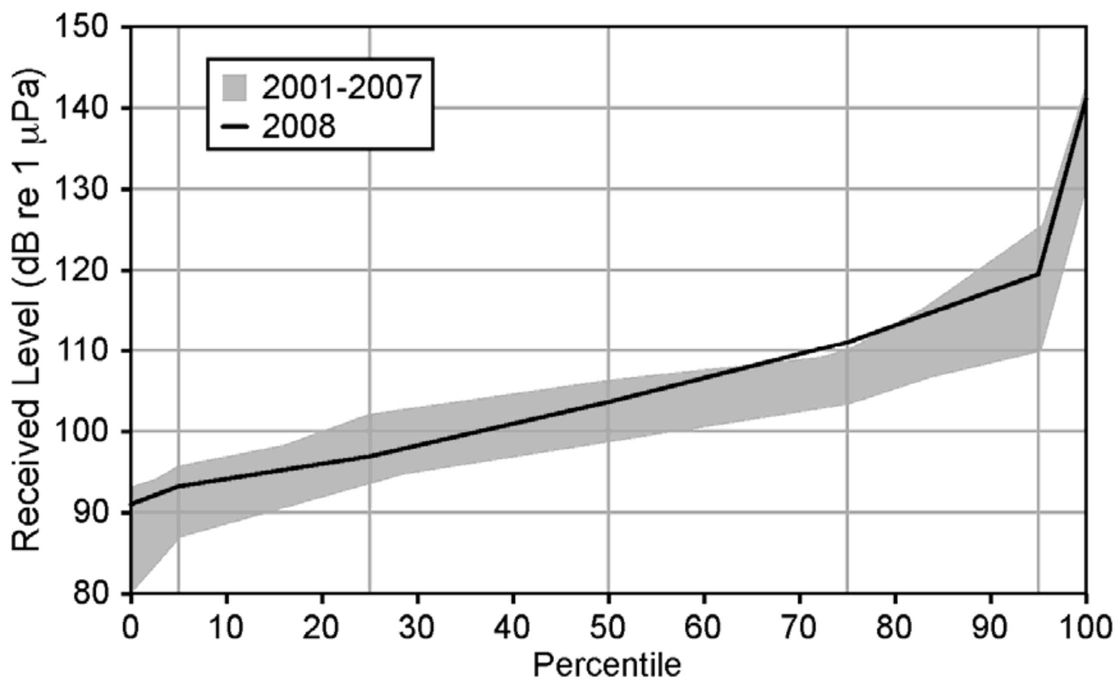

FIGURE 3.4. Percentile levels of broadband (10–450 Hz) sound at DASAR NSc in 2008 (black line) compared to values for the period 2001–2007 (gray shading). For each year these percentiles were calculated using data collected over the entire field season (7551–11,906 sampled minutes per year).

and seemed to originate at or close to the island (see section *Sounds from Specific Island-Related Sources* below). To examine what the levels of sound at Northstar would have been in the absence of pops[5], a "minimum broadband level" was obtained for near-island DASAR NSc by calculating broadband levels (10–450 Hz) every second over a 2-sec interval (i.e. 50% overlap between samples) and keeping the lowest value per 10-min period. The results of this analysis are shown in Figure 3.5, together with the standard analysis of Northstar sounds (1 min average every 4.37 min) that was shown in Figure 3.1. Mean received levels were 5.9 dB lower for the 2-s minimum analysis compared to the standard one (98.6 dB vs. 104.5 dB re 1 μPa, respectively). For comparison, minimum broadband levels were also calculated for DASAR NSb in 2007, a year without pops. Mean received levels were then 3.4 dB lower for the minimum analysis as compared to the standard one (100.0 dB vs. 103.4 dB re 1 μPa, respectively). This supports what can be seen by eye in Figure 3.3, i.e., that short-term variability in sound levels at DASAR NSc – as shown by the width ("thickness") of the sound pressure time series line in Figure 3.3B, plot H – was higher in 2008 than in some previous years.

Broadband Sounds Offshore

Sounds recorded by a selection of offshore DASARs (also referred to as "array DASARs") were analyzed in the same way as the near-island sounds shown in Figures 3.1, 3.3, and 3.5, i.e., average levels over one min every 4.37 min (our "standard" analysis), and the minimum level for each 10-min period, based on two-s averages computed every second (see Chapter 2 for more details). These two types of

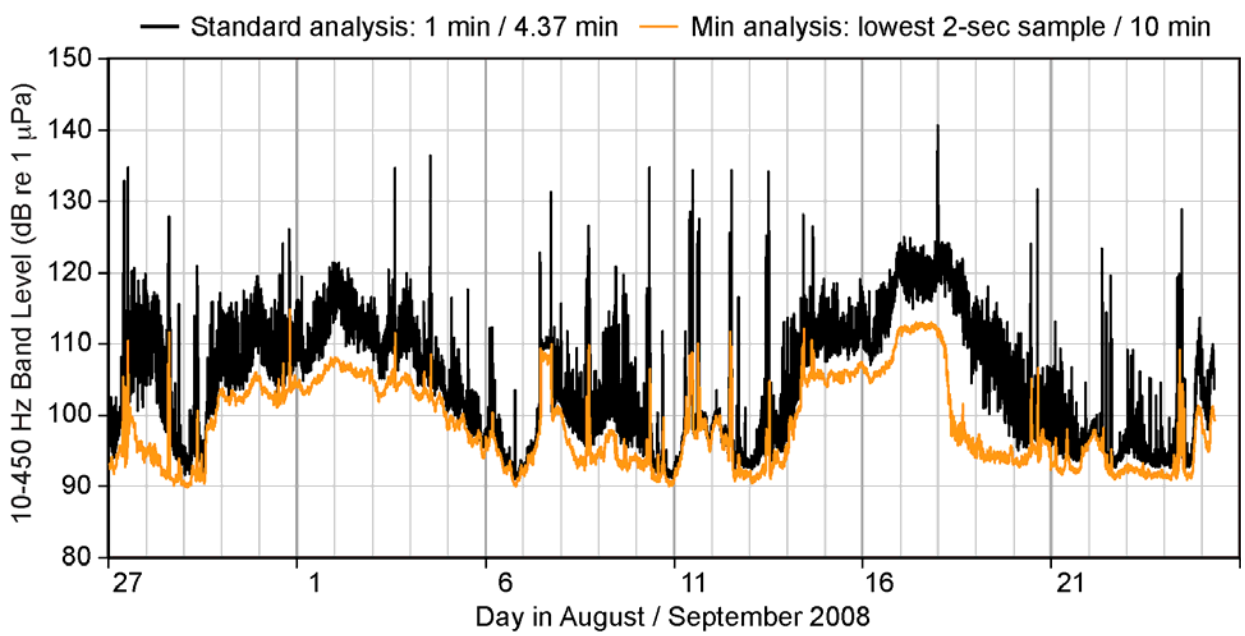

FIGURE 3.5. Broadband (10-450 Hz) levels of sound at DASARs NSc, as calculated two different ways: (1) "Standard method" (black line): average over one min every 4.37 min (see Fig. 3.1); (2) "Minimum method" (orange line): lowest 2-sec sample for every 10 min period. See text for more information.

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[5] If airgun pulses had been detected on the near-island DASARs they would also have been removed by this method.

broadband (10–450 Hz) levels are shown in Figure 3.6 for five DASARs spanning the entire southwest-to-northeast extent of the array: DASARs A, C, E, G, and J (see Fig. 2.2). These five DASARs were 8.6 km, 14.9 km, 21.5 km, 28.4 km, and 38.4 km from Northstar, respectively (or 5.3 mi, 9.2 mi, 13.4 mi, 17.7 mi, and 23.9 mi, respectively). Sea state, and therefore wind speed, determine "baseline" levels of sound. For the standard analysis, baseline refers to the lower edge of the envelope around the plotted SPL (sound pressure level) time series. The minimum level plot also represents a baseline. The five array DASARs shown in Figure 3.6 have similar baseline levels, which parallel seasonal variations in wind speed (Fig. 3.1A), as well as the overall shape of the sound pressure time series near the island (Fig. 3.5). However, there was a tendency for the mean broadband level over the entire season to increase with distance from Northstar. Mean broadband level (27 Aug–25 Sep) for DASARs A, C, E, G, and J was 91.5 dB, 95.3 dB, 97.1 dB, 96.6 dB, and 100.4 dB re 1 μPa, showing a trend opposite of what we would expect if sounds from Northstar were a large contributor to these levels (mean whole-season broadband level at the near-island recorder was 104.5 dB). Instead it is likely that the unusual amount of industrial activities offshore in 2008 (consisting mainly of seismic exploration and associated vessel traffic) contributed to increasing sound levels at the most offshore DASARs.

During health checks the acoustic crew's vessel was stationed above the DASAR, creating sound "spikes" with received level (at the DASAR) in the range 120–135 dB re 1 μPa. These sound spikes are shown with diamond symbols in Figure 3.6. A striking feature of the Figure 3.6 plots, which has not been seen in previous years of this study, is the presence of periods with dense groups of regular increases and decreases in sound levels, for example on 13, 14, and 19–25 Sep. These correspond to periods of non-BP airgun operations in other areas of the Beaufort Sea. Airgun operations took place on most days in September 2008 (see section *Airgun Pulses*, later). However, the seismic operations that are visible in Figure 3.6 as series of parallel vertical lines are likely the ones occurring closest to the DASAR array, where sound from airgun pulses and associated reverberations, and from the seismic vessels themselves, was sufficiently strong to increase the received broadband levels averaged over an entire minute. (Note that, because airgun pulses from a single seismic vessel are of short duration (~1 s) and only occur every 10–20 s, pulses received from a distant seismic operation will not alone cause much of an increase in the average broadband level calculated over a minute even though the peak received levels may be high.)

A comparison of Figures 3.1A and 3.6 shows that regardless of the wind speed, the difference in baseline values between the standard and minimum method is generally small in the offshore DASARs. The largest differences between these two lines occurred during the times when numerous airgun pulses were identified on the DASAR records (i.e., 13, 14, and 19–25 Sep, see section *Airgun Pulses* below) and in the presence of what are presumably vessel spikes.

The layout of the DASAR array in 2008 was different from previous years, with greater spacing between DASARs (7 km vs. 5 km or 4.3 mi vs. 3.1 mi) and a northeasterly double row of recorders instead of the two overlapping hexagons (see Fig. 2.1). However, one geographic location where a functional DASAR was deployed in each previous year since 2001 was maintained in 2008: location EB, which is now designated location C. This gives us the opportunity to compare broadband levels at this location since 2001 (average level over one min every 4.37 min). This comparison is shown in Figure 3.7. Broadband levels of sound at location C / EB were similar in 2008 and previous years, with the exception of the aforementioned sounds from seismic exploration on 13, 14, and 19–25 Sep 2008. Figure 3.8 shows percentile levels of broadband sound at C / EB in 2008 compared to the range of values in previous years. The minimum 1-min broadband value was lowest in 2008, and other percentiles were well within the range of previous years (Fig. 3.8).

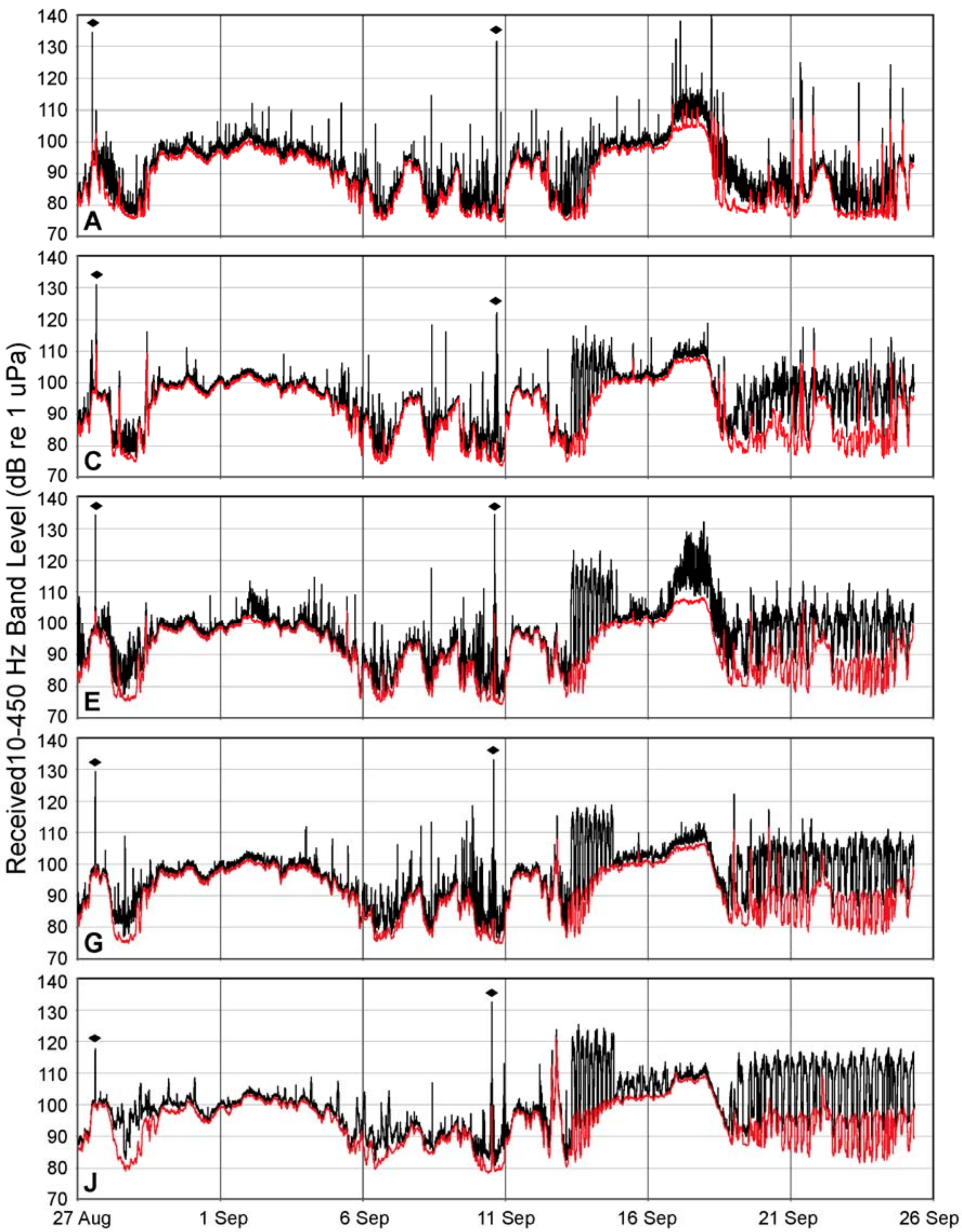

FIGURE 3.6. Broadband (10–450 Hz) levels of sound at five array DASARs (from top to bottom: A, C, E, G, and J), 27 Aug–25 Sep 2008, as calculated two different ways: (1) "Standard method" (black line): average over one min every 4.37 min; (2) "Minimum method" (red line): lowest 2-s sample for every 10-min period. DASAR A is closest to Northstar and DASAR J is farthest offshore (see Fig. 2.2). Diamonds indicate spikes (brief periods of higher-level sound) created by the acoustic crew's vessel during DASAR health checks on 27 Aug and 10 Sep.

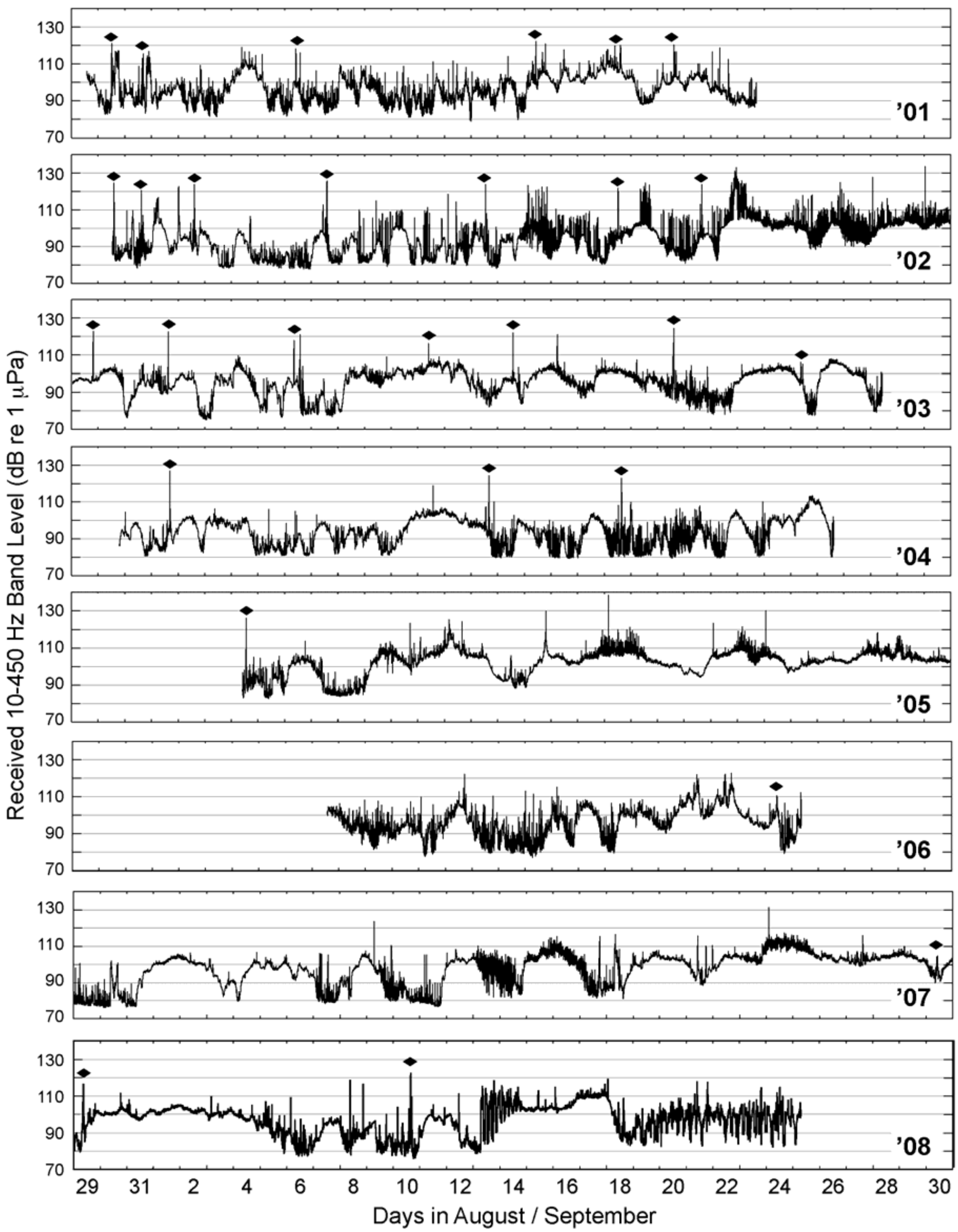

FIGURE 3.7. Broadband (10–450 Hz) sound pressure levels (averaged over 1 min) versus time as recorded at the same array location (called EB in 2001–2007, C in 2008) during eight consecutive years, 2001–2008. Diamonds indicate sound spikes created by the acoustic crew's vessel during servicing of the array of DASARs.

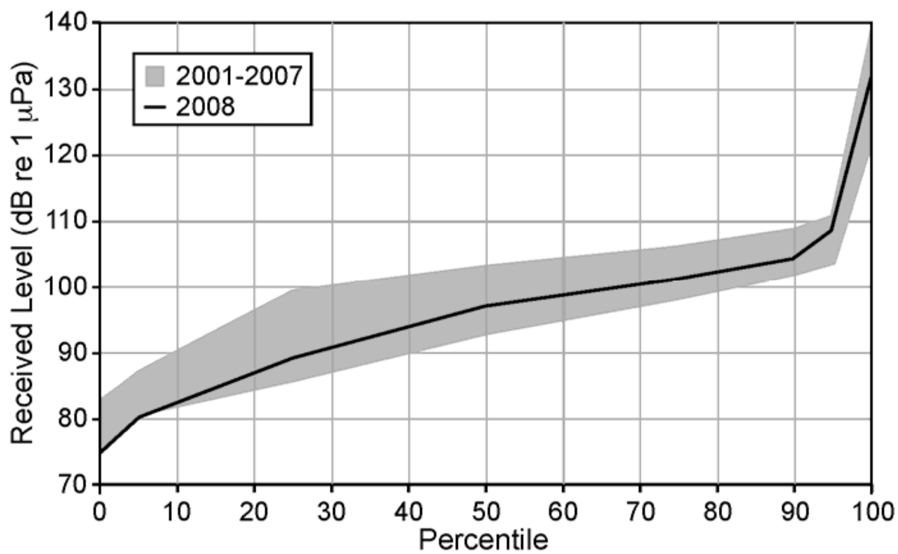

FIGURE 3.8. Percentile levels of broadband (10–450 Hz) sound at DASAR C (=EB in 2001–2007) in 2008 (black line) compared to values for the period 2001–2007 (gray shading). For each year these percentiles were calculated using 1-min average values collected over the entire field season (5862–11,906 sampled minutes per year).

STATISTICAL SPECTRA OF NEAR-ISLAND AND OFFSHORE SOUNDS

To characterize the frequency composition of sounds near Northstar and offshore during the study period in 2008, percentile distributions of one-third octave band levels and spectral density levels were calculated for three DASARs: NSc (near-island), A (offshore, farthest south of array DASARs), and J (offshore, farthest north of array DASARs, see Fig. 2.2). In all cases, the measurements were averages over 1 min. These plots are shown in Figure 3.9 (one-third octave bands) and Figure 3.10 (spectral density levels). Overall, the spectra for Northstar (top plots in both figures) are similar to those from previous years[6]. For example, as in previous years, peaks were present at 30 Hz and 60 Hz – these peaks have been present every year of monitoring and are associated with generation of 60 Hz power. There was also a peak at 87 Hz, which has been present since 2003 and which we attribute to the LP compressor of compressor Module L1 (Spence 2006).

Figure 3.9 shows percentile one-third octave band levels. The main difference between the top plot (near Northstar) and the two bottom plots (in the array) is the presence, in the data collected near Northstar, of one large "hump" at the one-third octave bands centered at 25 Hz, 31.5 Hz, 40 Hz, 50 Hz, and 63 Hz, and visible in the min, 5th, and 50th percentile lines. The sound contained in these frequencies is largely of anthropogenic origin, at least when ambient levels are low. It is this observation that led to the definition of the industrial sound index *ISI_5band* in 2001 (Blackwell 2003).[7] Note however that compared to array DASARs A and J (Fig. 3.9, middle and bottom plots), the minimum, 5th, 50th, and 95th percentile one-third

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[6] 2007: Fig. 2.9 in Blackwell et al. 2008a; 2006: Fig. 2.7 in Blackwell et al. 2007; 2005: Fig. 2.8 in Blackwell et al. 2006c; 2004: Fig. 8.9 in Blackwell et al. 2006b; 2003: Fig. 7.16 in Blackwell et al. 2006a; 2002: Fig. 6.19 in Blackwell 2003; 2001: Fig. 7.19 in Blackwell and Greene 2002.

[7] As defined, *ISI_5band* covers a slightly different range of one-third octave bands, i.e., those centered at 31.5, 40, 50, 63, and 80 Hz.

octave band levels are elevated at Northstar (Fig. 3.9, top) across the entire frequency range. Because the maximum levels can be caused by a single vessel pass, they are not used for comparisons.

The same comparison can be made for the percentile spectral density levels shown in Figure 3.10. If again we ignore the maximum lines, two things distinguish NSc from the array DASARs: (1) The elevated 5th, 50th and 95th percentile values near Northstar across the frequency range 10 Hz to at least 400 Hz, but especially at 25–63 Hz. (2) The presence of tones, which in NSc's case can be identified in the minimum, 5th percentile, and 50th percentile lines.

The percentile spectral density plots (Fig. 3.10) give us the opportunity to examine how far from the island these Northstar signature tones can be detected. Near Northstar, the 60 Hz power frequency tone is present in the underwater sound all the time, unless the island shuts down completely, which did not happen during our study period. The top plot in Figure 3.10 shows that at least half the time (50th percentile) the received level for the 60 Hz tone is above that at other nearby frequencies, i.e., the 60 Hz tone is easily detected. In fact, a peak created by the 60 Hz tone is still visible in the 90th percentile (not shown in Fig. 3.10). In contrast, the percentile spectral density plot for the array DASAR that was closest to Northstar (A, 8.5 km or 5.3 mi from the island), shown in the middle plot in Figure 3.10, shows no sign of a 60 Hz tone even in the minimum line, which represents the time of lowest background sound during the entire recording period. A 1.7 Hz bandwidth was used in the standard spectral-density analyses. The data from array DASAR A were reprocessed with 0.43 Hz and 0.17 Hz bandwidths. By decreasing the bandwidth, the "dilution" (masking) of the tone in background noise is decreased and consequently the suspected tone becomes more likely to stand out, yet in both of these enhanced-analysis cases the 60 Hz tone was not detectable at DASAR A. This means that the strongest power frequency tone at Northstar (60 Hz) was not detectable 8.5 km (5.3 mi) from the island, even at the times of lowest ambient sound levels.

Industrial Sound Indices (ISIs) of Near-island and Offshore Sounds

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 (i.e., the 28 to 90 Hz frequency range). Each measurement was for a 1-min interval. Figure 3.11 shows *ISI_5band* values for DASARs NSc, A, C, E, G, and J. Generally, *ISI_5band* was closely related to the overall 10–450 Hz level (compare Fig. 3.11 with Figs. 3.1B and 3.6), but *ISI_5band* tended to be 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 broadband data.) Direct comparison of the two values showed that, in 2008, the mean 1-min *ISI_5band* value at NSc was 8.7 dB below the mean 10–450 Hz broadband value. This difference was 5.7 dB in 2003, 5.0 dB in 2004, 5.7 dB in 2005, 4.2 dB in 2006, and 6.9 dB in 2007. The somewhat higher value in 2008 could be due to the presence of numerous "pops" on the near-island recorders. The pops were a new sound type, detected for the first time in 2008. These pops were broadband impulsive sounds with most of their energy outside the 28–90 Hz frequency range (see Fig. 3.19, later). To test this hypothesis, a day with many pops (28 Aug, 00:00–12:00 local time) was compared to a day with few pops (13 Sep, 00:00–12:00). The two days had similar wind speeds. Every 4.37 min, the difference between the broadband value and *ISI_5band* value was calculated for a one min sample. The results lend support to the hypothesis: on 28 Aug the mean difference (± one S.D.) was 13.3 ± 2.4 dB, compared to 4.9 ± 2.1 dB on 13 Sep.

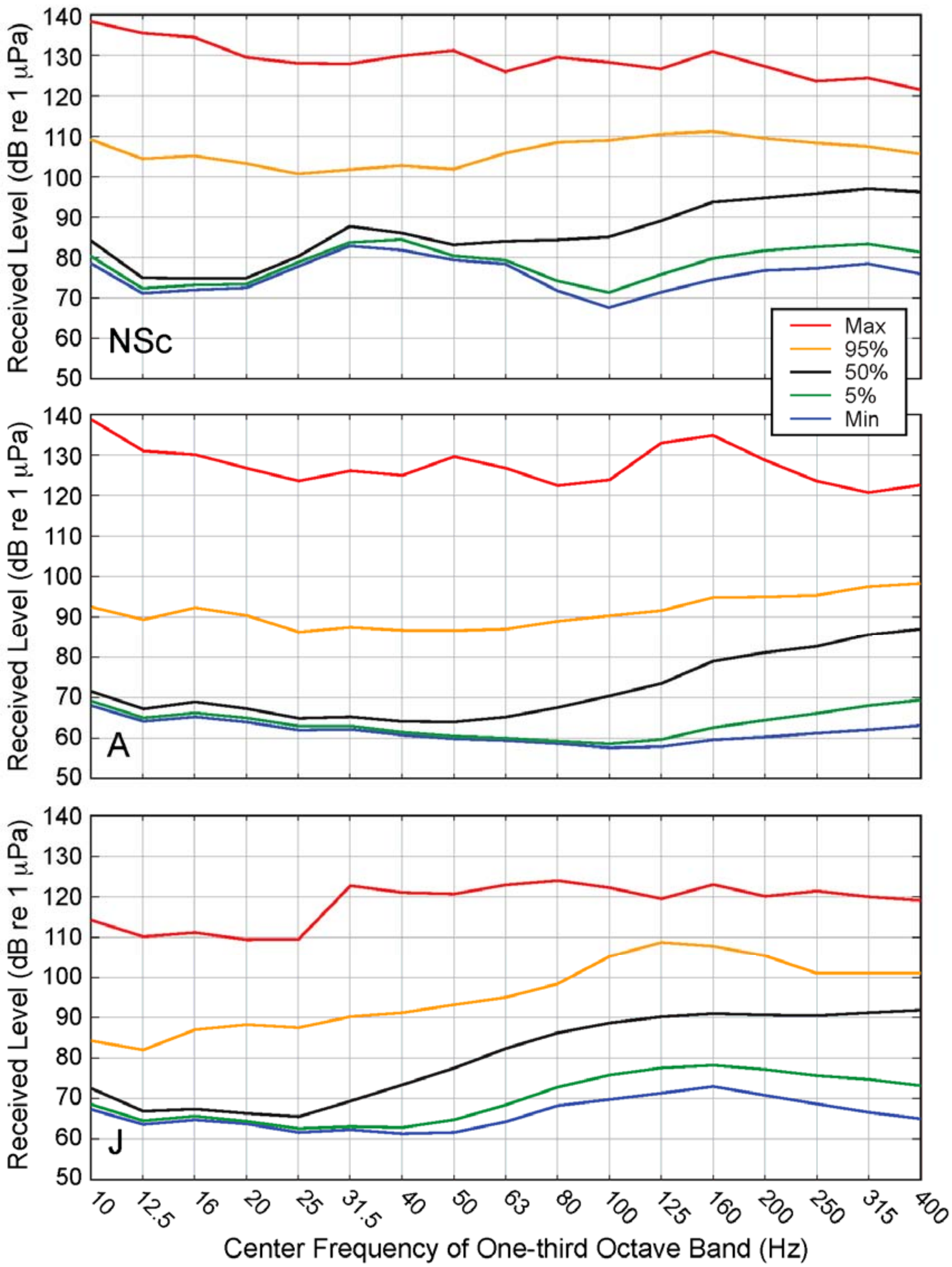

FIGURE 3.9. Percentile one-third octave band levels for sounds recorded by DASARs NSc (near-island, top), A (southernmost DASAR in offshore array, center), and J (northernmost DASAR in offshore array, bottom) during the period 27 Aug–25 Sep 2008. In these plots the five curves show, for each frequency, the minimum, the 5^{th}, 50^{th}, 95^{th} percentiles, and the maximum of the 1-min averages. For all plots the number of 1-min measurements used was 9661.

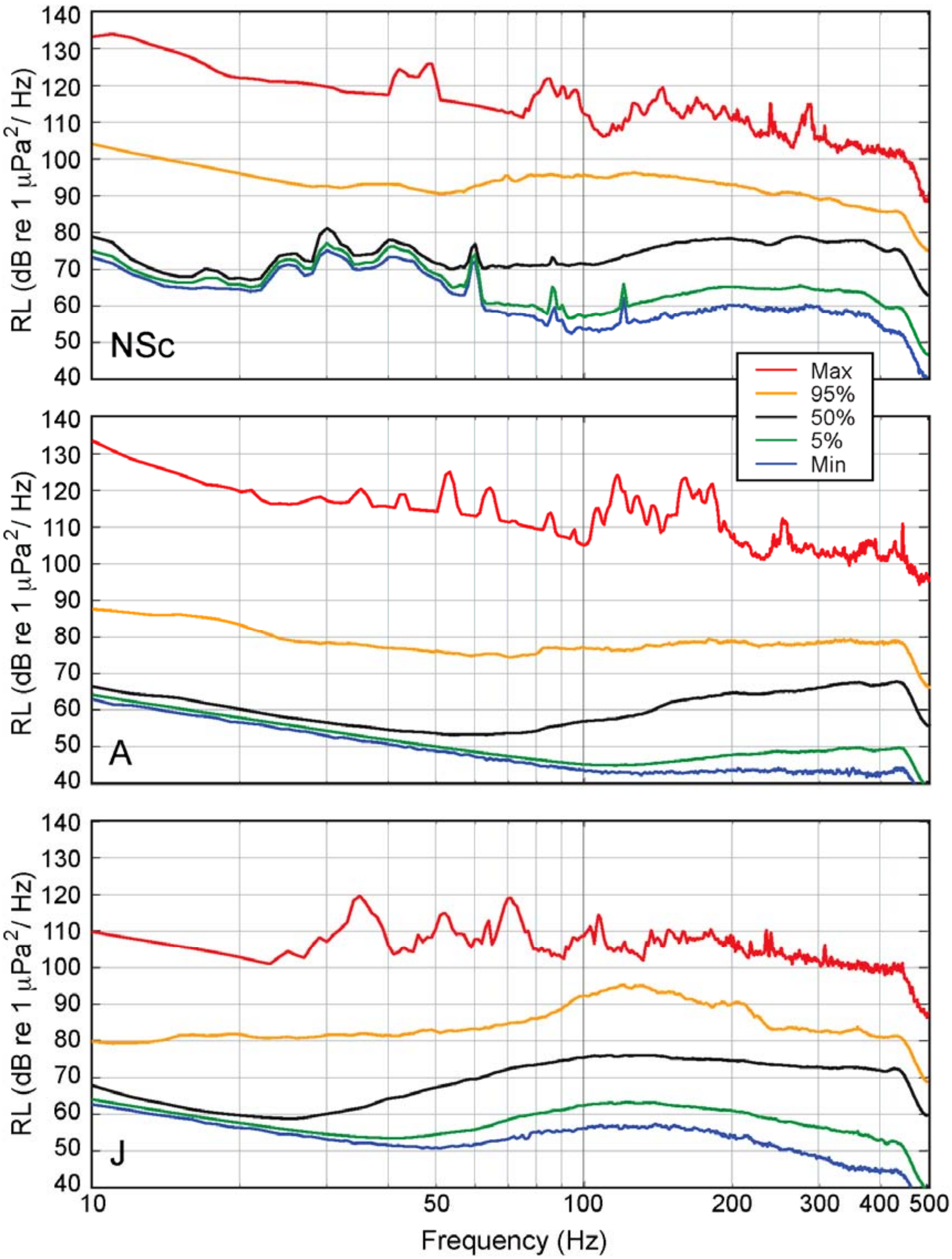

FIGURE 3.10. Percentile spectral density levels for sounds recorded by DASARs NSc (near-island, top), A (southernmost DASAR in offshore array, center), and J (northernmost DASAR in offshore array, bottom) during the period 27 Aug–25 Sep 2008. In these plots the five curves show, for each frequency, the minimum, the 5th, 50th, 95th percentiles, and the maximum of the 1-min averages. For all plots the number of 1-min measurements used was 9661.

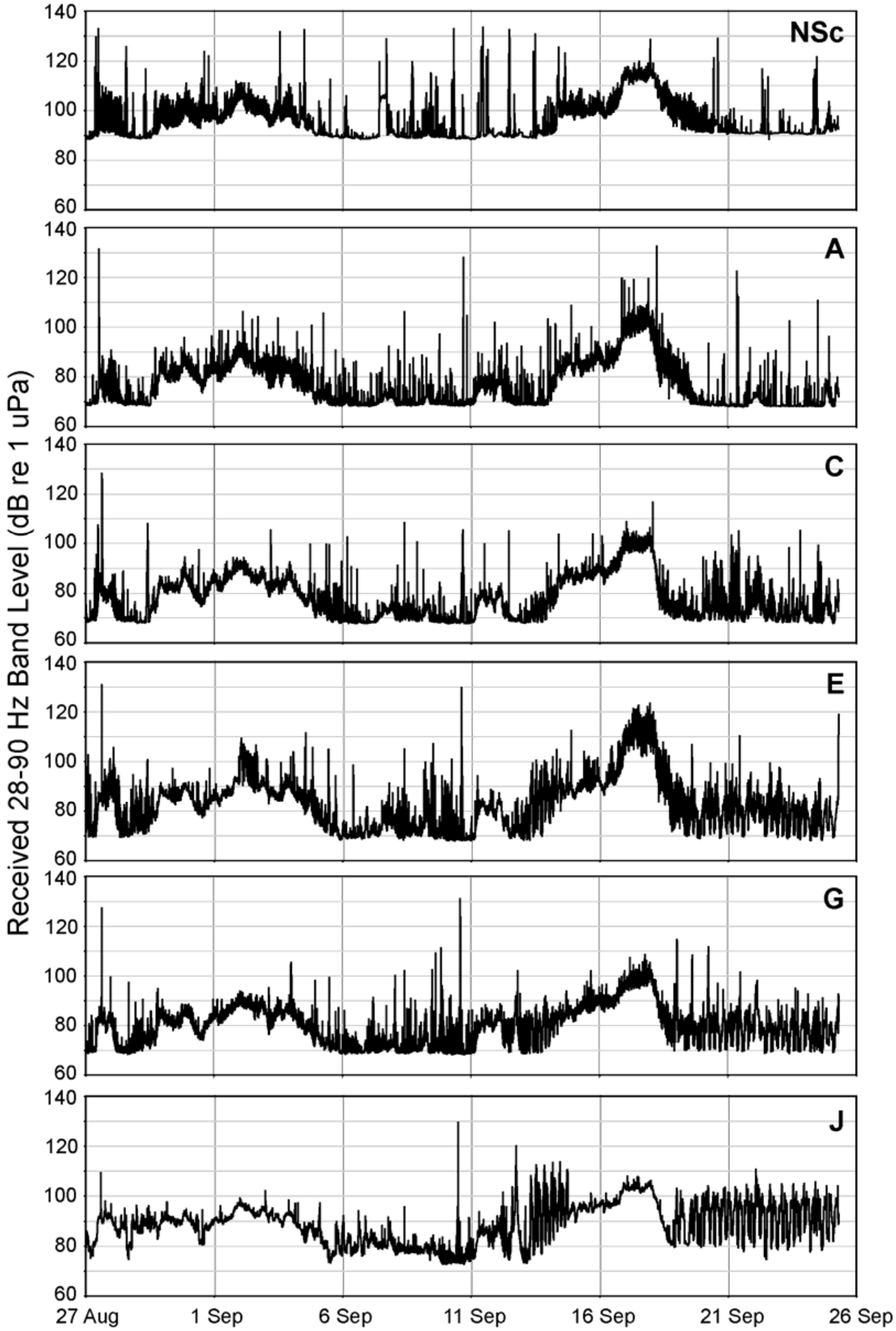

FIGURE 3.11. *ISI_5band* levels (1-min average) as a function of time for near-island DASAR NSc and array DASARs A, C, E, G, and J.

The difference between mean broadband level and mean *ISI_5band* level was greater at the array DASARs than near Northstar: it was 14.9 dB, 17.5 dB, 14.5 dB, 17.0 dB, and 11.6 dB at DASARs A, C, E, G, and J. This is likely due to two factors: (1) the presence of numerous airgun pulses on array DASAR records. Like the pops recorded near Northstar, airgun pulses contain energy outside of the 28–90 Hz frequency range; (2) the fact that near Northstar the 28–90 Hz band level is always somewhat elevated by Northstar itself, thereby reducing the difference between broadband levels and *ISI_5band* levels. *ISI_5band* levels were about the same at all array DASARs, i.e., there was no decrease in *ISI_5band* level with distance from the island. Near Northstar *ISI_5band* levels were higher, exceeding the values in the offshore array by ~20 dB. For broadband levels, values at the island exceeded those in the offshore array by less, 10–15 dB. This supports the fact that *ISI_5band* is a better measure of industrial sounds than broadband levels.

There is a condition in which the ISI does not perform well as a measure of low-frequency industrial sound: stormy weather, when background sound levels at those frequencies are high because of wind and wave action. The period 14–18 Sep had the worst weather during the 2008 field season, with mean hourly wind speeds in the range 10–23 m/s (22–51 mph, see Fig. 3.1). Sound from wave action is broadband in nature and includes *ISI_5band* frequencies. High winds therefore result in both high broadband levels (Fig. 3.6) and high ISI levels (Fig. 3.11). In this case, high ISI levels did not indicate high amounts of industrial sounds.

ISI_tone

ISI_tone evaluates the presence and amplitude of tones, which are typical of 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 3.12 is a graphical representation of the presence of tones near Northstar (DASAR NSc) and in the DASAR array (DASARs A, C, E, G, and J). The entire season's sound record is shown in a spectrogram for each recorder. Black dots denote the times (x-axis) and frequencies (y-axis) at which a tone was detected according to the *ISI_tone* definition (see Chapter 2). Tones are more numerous on NSc's record than on any of the array DASARs. Tones at certain frequencies, like 30 Hz, 60 Hz, and 87 Hz, are present continually for extended periods of time at NSc, creating black horizontal lines on the spectrogram (Fig. 3.12, top left). These tone frequencies can also be seen on the percentile spectral density plot in Figure 3.10. Some tones were only prevalent at the array DASARs, which indicates that these tones are from a non-Northstar source. The most likely candidates are vessels, which are associated with any offshore industrial activities (e.g., seismic exploration, barge traffic).

The presence of tones was examined in one-min long samples every 4.37 min (see Chapter 2). If no tones were found according to the *ISI_tone* criterion, then *ISI_tone* = 0. Figure 3.13A shows the percentage of *ISI_tone* samples with a value of zero, for the same six DASARS as in Figure 3.12. This percentage was about 65% close to Northstar, and in the range 95–96% in the DASAR array. Not surprisingly, this confirms that tones were in general more prevalent close to the island than offshore.

Figure 3.13B shows mean values for *ISI_tone*, when using all of the data points (black circles, left y-axis), or when excluding samples for which *ISI_tone* = 0 (gray squares, right y-axis). Overall mean *ISI_tone* values were much lower for array DASARs (~3 dB re 1 μPa) than for NSc (~28 dB, see Fig. 3.13B, black circles). However, when excluding null samples, *ISI_tone* values were noticeably lower for DASAR A (~71 dB) than for the other array DASARs (~77 dB, see Fig. 3.13B, gray squares). This shows that even though the proportion of samples with tones detected was about the same at all array DASARs (Fig. 3.13A), the mean received level of tones was lower at DASAR A than at the island (NSc) or at the other array DASARs

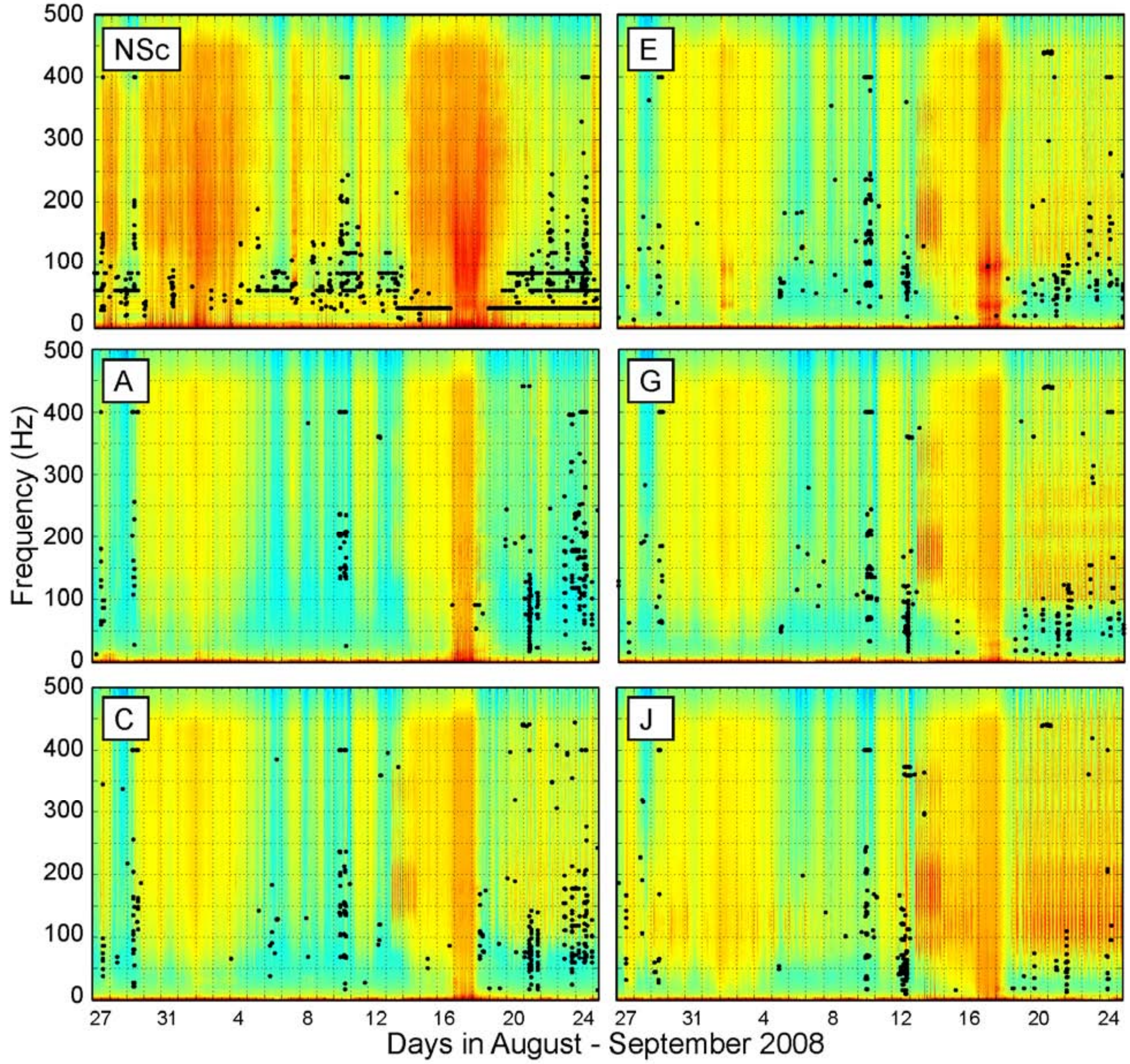

FIGURE 3.12. Spectrograms of the entire 2008 season for DASARs NSc (near-island), A (array DASAR closest to shore), C, E, G, and J (most offshore, see Fig. 2.2). Black dots denote times and frequencies at which tones were identified by the *ISI_tone* algorithm, using a ≥5 dB criterion as described in Chapter 2. Color on the spectrograms varies with received levels of sound, from low (blue) to high (red).

(C, E, G, J). This would indicate that while DASAR A may sometimes have been detecting weak tones from Northstar, the tones occasionally detected by the more offshore DASARs were probably of local (i.e., offshore) origin from non-Northstar sources near those DASARs.

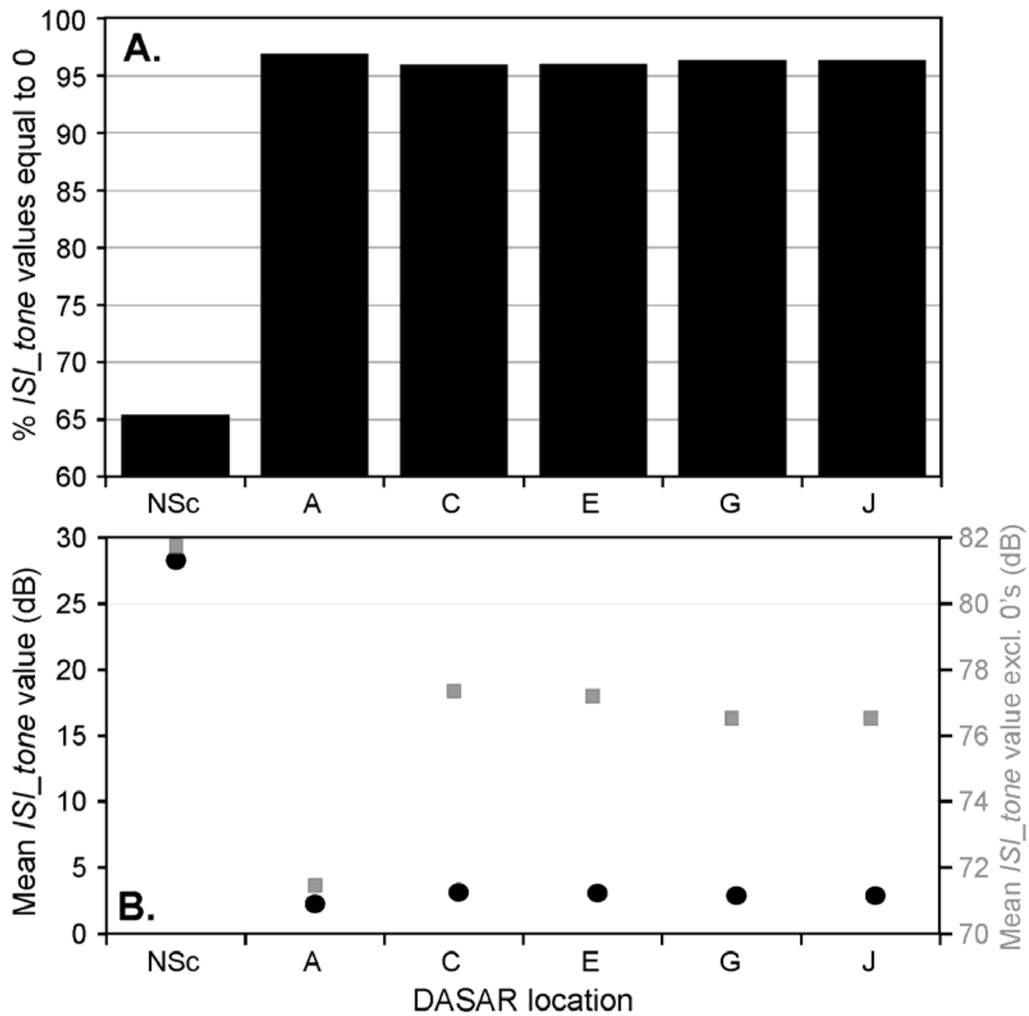

FIGURE 3.13. ***(A)*** Percentage of *ISI_tone* samples with a value of 0 (no above-threshold tones detected) for near-island DASAR NSc and array DASARs A, C, E, G, and J. To be counted as "above threshold", a tone had to have a received level ≥5 dB higher than the level at nearby frequencies (Chapter 2). ***(B)*** Mean *ISI_tone* values for the same six DASARs as shown in *(A)*. Values calculated using all samples are shown with black circles (left y-axis). Values calculated while excluding samples when *ISI_tone* = 0 are shown with gray squares (right y-axis).

SOUNDS FROM SPECIFIC ISLAND-RELATED SOURCES

Vessel Sounds

Vessels transport goods and personnel to Northstar. Most personnel transfer during the open-water season is done with a hovercraft, although occasionally with an ACS "Bay" boat or Bell 212 helicopter when sea state precludes the use of the hovercraft (see Chapter 1). Barges bring goods and equipment to the island. During the period 27 Aug–25 Sep 2008 (30 days) the hovercraft, barges, and ACS vessels made a total of 88, 14, and 11 round trips to Northstar, respectively[8]. These numbers average out to 2.9, 0.5, and 0.4 round trips / day, respectively. The values for ACS vessels do not include the four trips (27 and 29 Aug,

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8 Records obtained from the Northstar Scheduler.

10 and 24 Sep) the acoustics crew made to Northstar and the DASAR array using an ACS "Bay" boat. The number of daily round trips to Northstar by the hovercraft, barges, and ACS vessels are shown in Figure 3.14 for the 2008 field season. The mean daily number of round trips to Northstar for each type of vessel is summarized in Figure 3.15 for the period 2003–2008. For comparison, round trips by the dedicated crew boat are also shown, even though that vessel has not been used since the 2003 season, when the hovercraft became available.

Vessels such as tugs (which accompany barges) and ACS "Bay" boats produce a sound "spike" on the near-island recordings when they are close to or at Northstar (see Fig. 3.1). More than 95% of the arrivals and departures at Northstar by tugs and ACS vessels could be matched to a spike on the sound pressure time series of DASAR NSc. Figure 3.15 shows that the number of round trips by spike-producing vessels was reduced in 2008 compared to 2007 and 2006. Compared to 2007, the number of trips by tugs and barges remained about the same, but use of ACS vessels decreased, with a concomitant increase in the number of hovercraft trips.

We investigated how far vessel spikes created at Northstar were detectable on DASAR sound records offshore. On 11 and 12 September there were three round trips by tugs and barges to Northstar (including some maneuvering at the island itself), which produced some of the largest vessel spikes of the season. Wind speed was about average (see Fig. 3.1A), and airgun sounds from offshore seismic activities were either not present or more distant than most of the time, but started up in the afternoon of 12 Sep (see later section). Figure 3.16 shows the sound pressure time series for 11–12 Sep for DASARs NSc, A, C, E, G, and J. To facilitate comparisons, the plots for the different DASARs have been spread apart on the Figure by increments of 10 dB. The sound record from the near-island recorder NSc is shown in the top plot, and barge arrivals and departures are indicated with stars (the sound sources for the other spikes on these two days are not known). Spikes on the array DASAR records that occurred within a minute of the spikes identified on DASAR NSc are shown with red circles[9]. After subtraction of the contribution of background noise, received levels for these spikes were then plotted as a function of distance from Northstar, and a simple propagation model was fitted to the data by the least squares method; this is shown in Figure 3.17. Spreading loss terms for the six equations were similar, in the range 22–24.8 dB/tenfold change in distance. The peak at DASAR G (11 Sep at 11:13) was omitted in Figure 3.17 because its received level was higher than those at distances closer to Northstar, and could therefore have been caused by another concurrent sound source. Figures 3.16 and 3.17 indicate that, on a day with average levels of background sound, the larger vessel spikes produced at Northstar can be detected at least to DASAR E, 21.5 km (13.4 mi) northeast of Northstar.

The hovercraft was used for transport of goods and personnel to the island whenever possible. As in previous years, the arrival or departure of the hovercraft was not associated with any characteristic and well-defined increases in the 1-min averages calculated every 4.37 min at DASAR NSc, 460 m offshore of Northstar[10].

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[9] This analysis was done using broadband data analyzed over one minute every 4.37 min. A sound produced at Northstar would, if sufficiently strong, reach DASAR A in about 6 sec and DASAR J in about 25 sec.

[10] Examination of the raw sound pressure time series as received at near-island DASAR NSc revealed tones produced by the hovercraft, for periods of 1–2 min during the hovercraft's arrival at or departure from Northstar. However, these tones were very faint, and not strong enough to increase the one-min broadband levels by a noticeable amount.

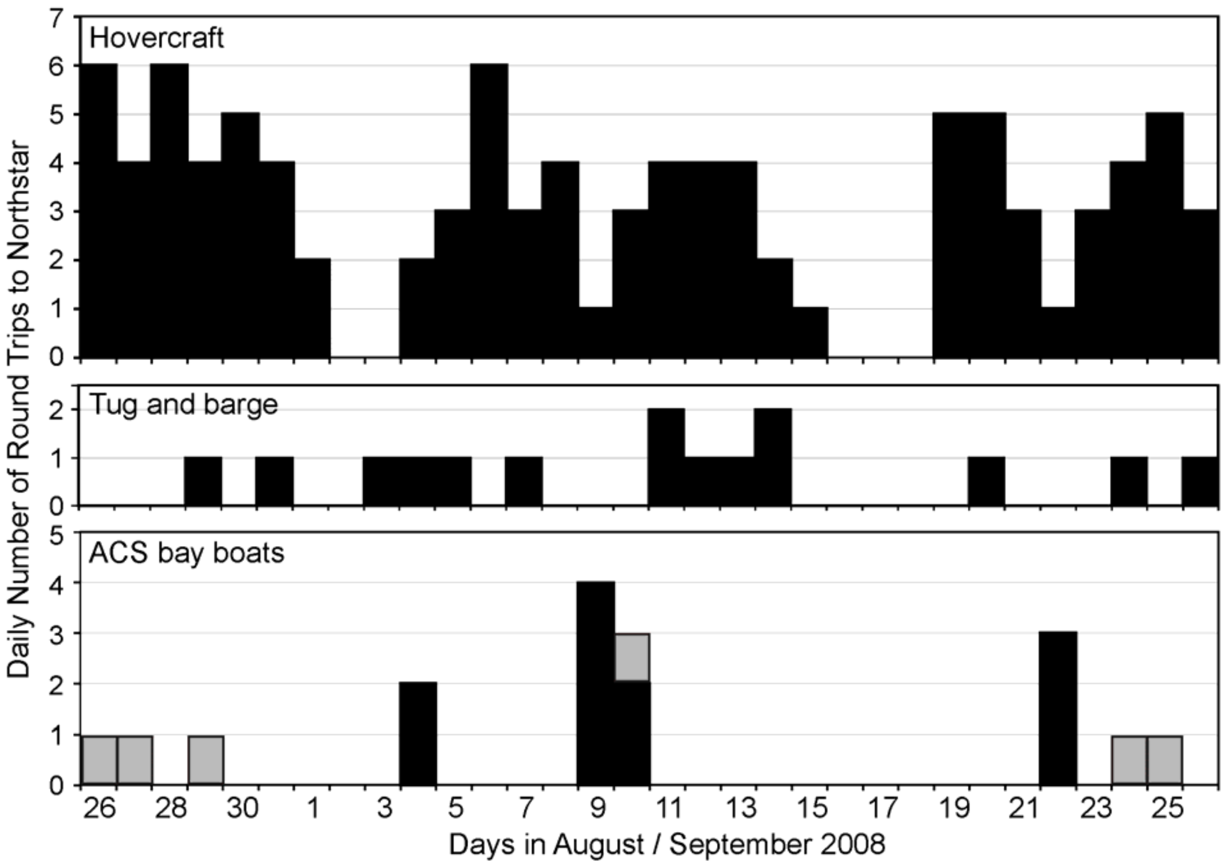

FIGURE 3.14. Daily number of round trips to Northstar by the hovercraft, tugs and barges, and ACS vessels (black shading = Northstar related; gray shading = acoustics crew) during the 2008 field season.

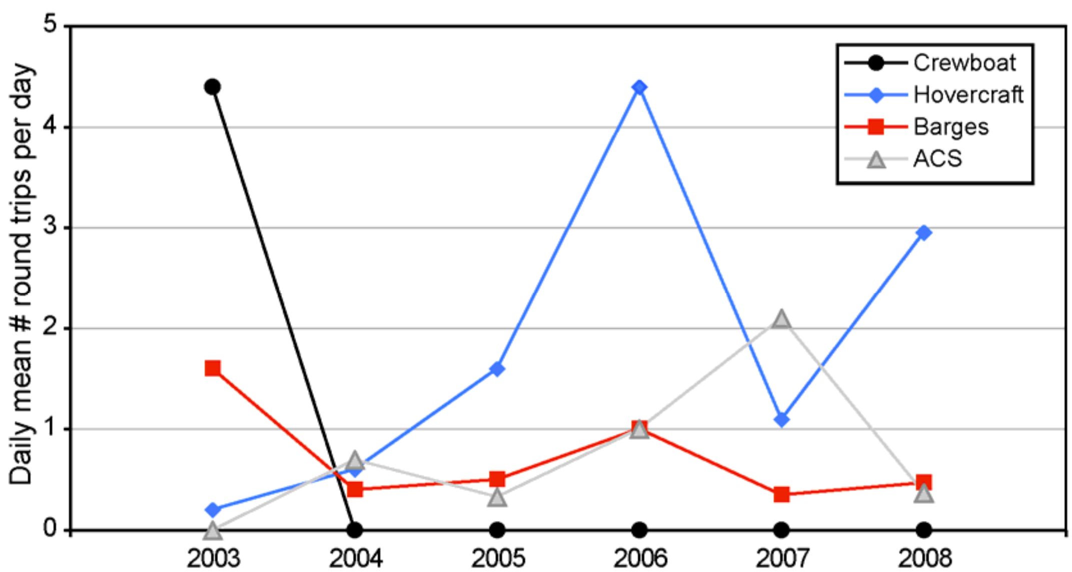

FIGURE 3.15. Daily mean number of round trips to Northstar by the crewboat (not used since 2003), the hovercraft, barges, and ACS vessels, 2003–2008. Each year, these numbers were calculated over the DASAR deployment duration, which varies from year to year, but is generally late Aug to late Sep.

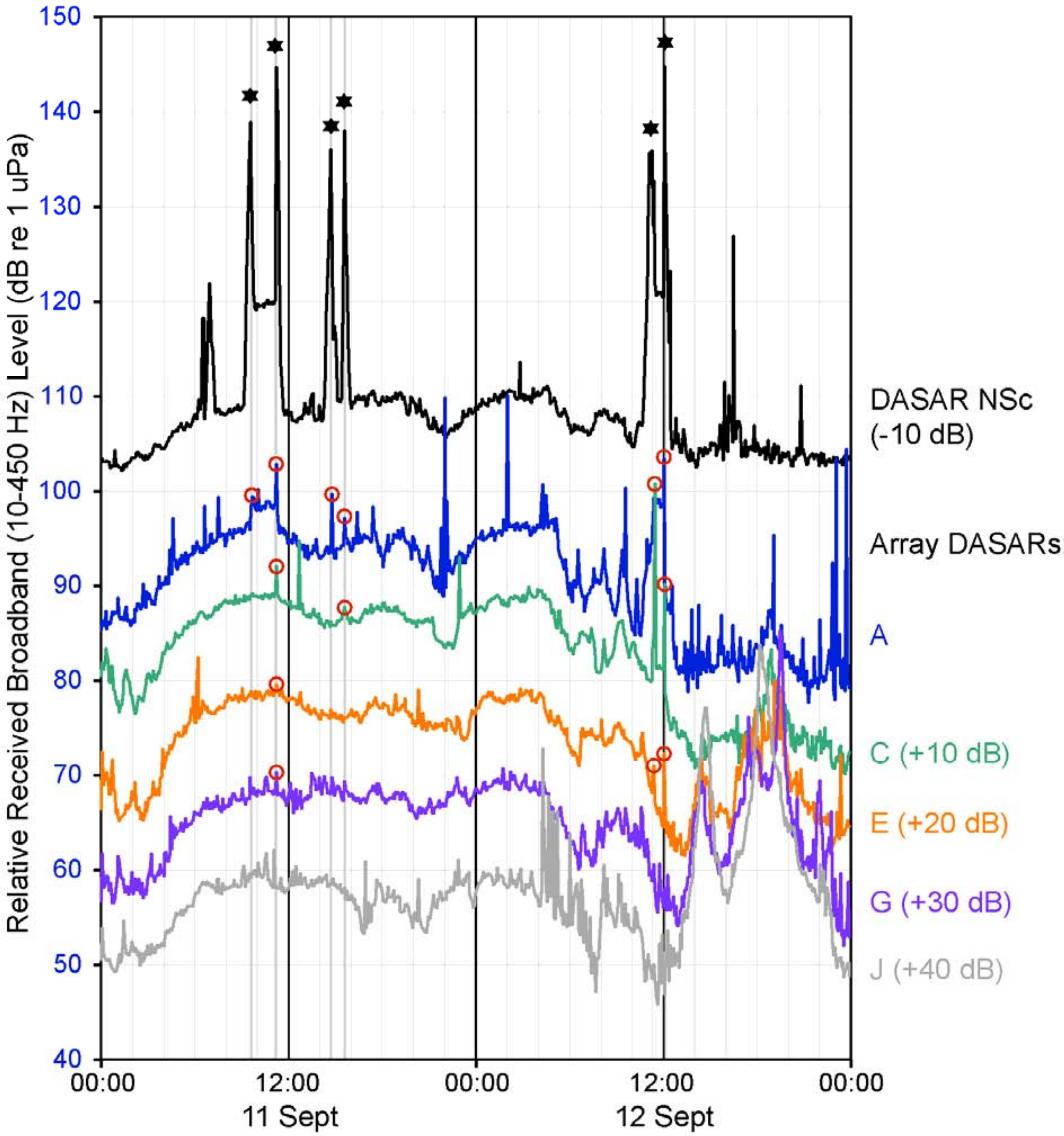

FIGURE 3.16. Broadband (10–450 Hz) sound pressure levels (1-min averages) during 11–12 Sep 2008 at near-island DASAR NSc, as well as array DASARs A, C, E, G, and J. Spikes created by the arrivals and departures of a tug and barge at Northstar are indicated with stars. Plots for different DASARs have been offset by different multiples of 10 dB in reference to the plot for DASAR A. To obtain the actual received broadband levels at any DASAR other than DASAR A, the amounts given in parentheses to the right of the Figure must be added or subtracted to the values read off on the y-axis. For example, to obtain the actual received broadband levels at DASAR NSc, 10 dB must be subtracted from the values read off the y-axis. Red circles indicate peaks at array DASARs that occurred at the same time as those created by the tug and barge at Northstar.

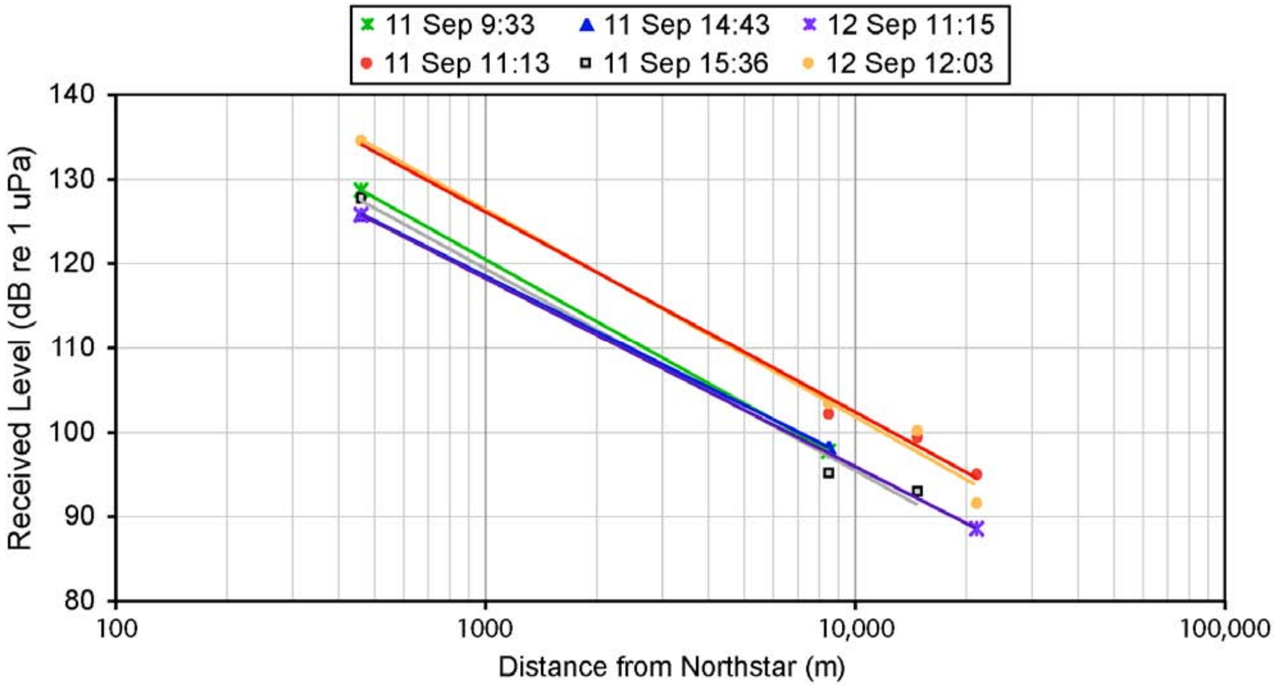

FIGURE 3.17. Broadband (10–450 Hz) received levels of sound (1-min average) from the arrival and departure of tugs at Northstar on 11 and 12 Sep 2008, as recorded at near-island DASAR NSc (460 m from Northstar), and array DASARs A (8.5 km or 5.3 mi away), C (14.9 km or 9.2 mi away), and E (21.5 km or 13.4 mi away). Spreading loss terms for these logarithmic fits varied between 22 dB and 24.8 dB/tenfold change in distance.

New Unknown Sound

A new sound, which will be referred to as "pops", was identified on certain DASAR records in 2008. These sounds were detected by all three near-island DASARs, indicating that they were not artifacts of the new DASAR design; the near-island DASARs included one of the old design and two of the new design. The pops were also identified on DASAR A, the southernmost of the array DASARs. To characterize this new type of sound we examined the first 12 h of three days in the record of DASAR NSc: 28 Aug, 13 Sep, and 23 Sep. These days were spread in time over the field season and had low levels of background sound (mean wind speed generally <4 m/s or 9 mph, see Fig. 3.1).

The frequency of occurrence of pops varied over the course of the season. Figure 3.18A shows 5 min of DASAR NSc's sound record on 28 Aug, during which time ~100 pops occurred. On 13 and 23 Sep the frequency of pops was much lower, in the range of 0–20 per 5 min. For each of the three days we analyzed the properties of 10 pops, for a sample size of 30. Pops were very short in duration, on average 0.05 s ± standard deviation 0.03 s. This can be seen on the single pop shown in Figure 3.18B. Figure 3.19 shows a spectrogram and spectral density plot for 4 pops recorded on 27 August at DASAR NSc. These two plots show that pops had very little energy in the 28–90 Hz range, which defines *ISI_5band*. Rather, most of their energy was in the 150–450 Hz range, with some variation between pops (see Fig. 3.19B). Pops overloaded the DASAR hydrophone when the received instantaneous peak level exceeded 151 dB re 1 μPa (at 100 Hz). Excluding those high-level pops, whose levels could not be measured, received sound pressure levels were on average 130.9 dB ± 8.8 dB re 1 μPa, ranging from 107.3 dB to 143.5 dB re 1 μPa (n = 30).

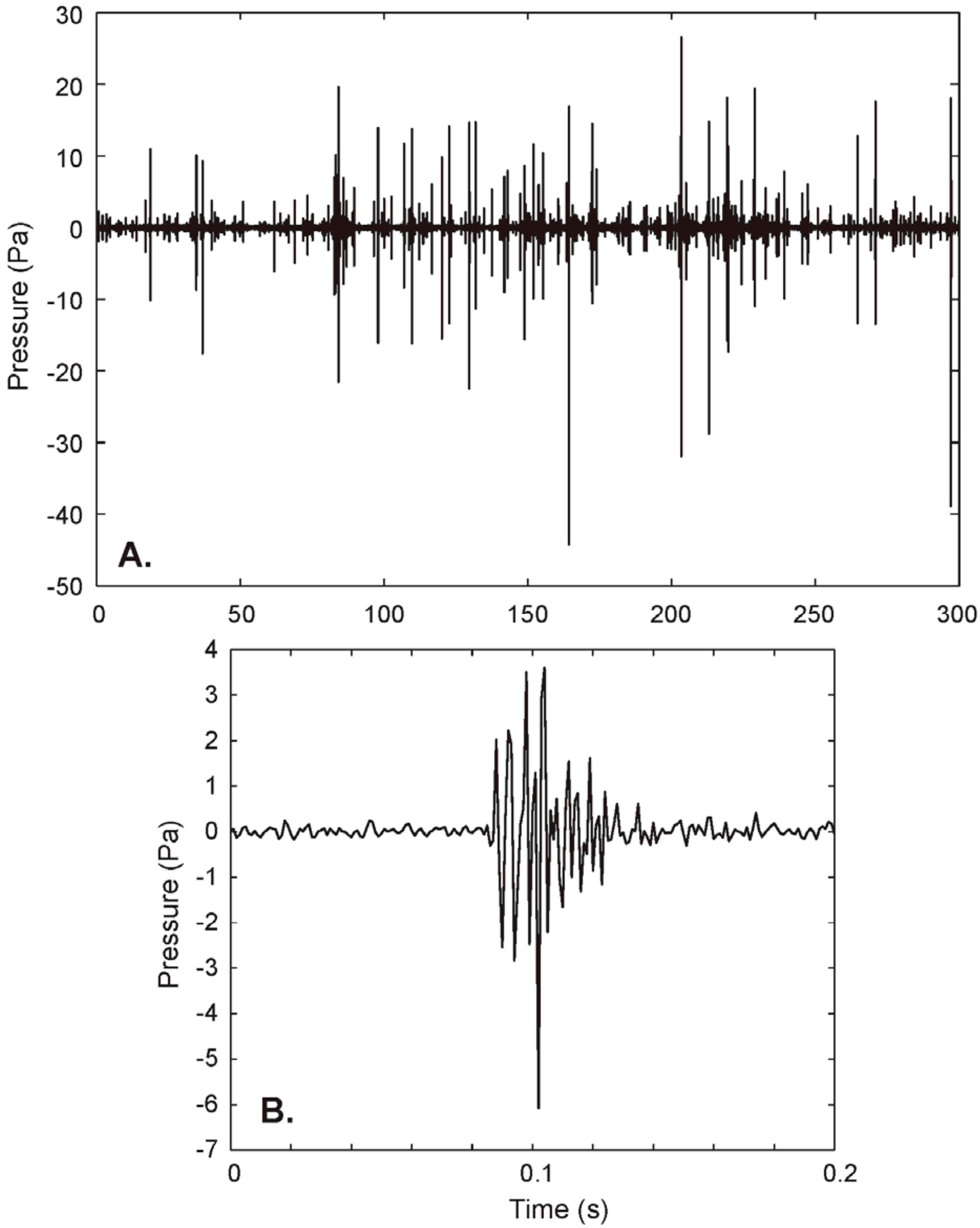

FIGURE 3.18. Sound pressure time series from near-island DASAR NSc showing pops, a new type of sound associated with Northstar (see text for details). ***(A)*** Five minutes of data showing roughly 100 of these pops. ***(B)*** A single pop lasting about 0.045 s.

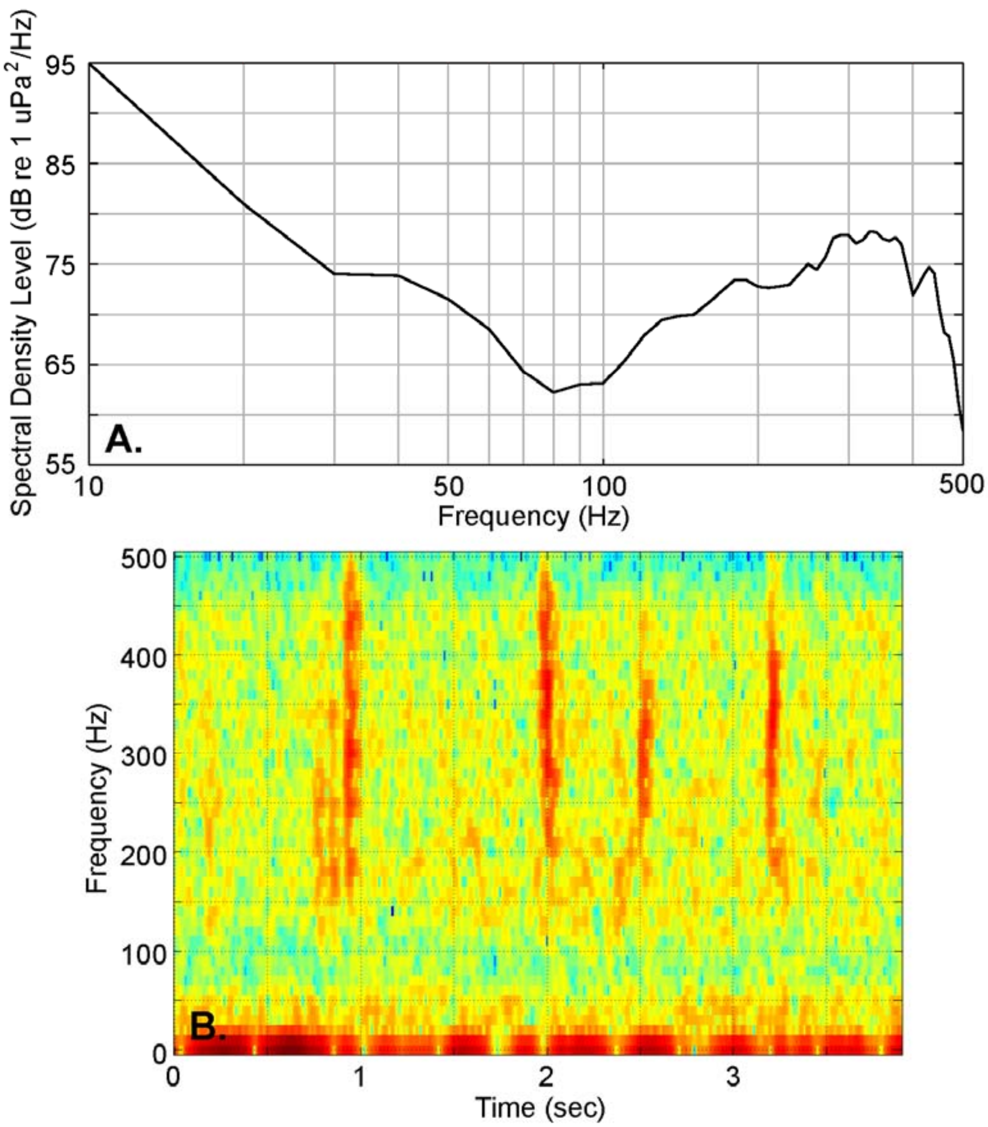

FIGURE 3.19. Frequency composition of four consecutive pops on the record of DASAR NSc, 27 Aug 2008. ***(A)*** Spectral density plot. ***(B)*** Spectrogram. Note that the high levels at frequencies below ~50 Hz are not related to the pops, but constitute background noise.

Received sound exposure levels were on average 117.6 dB ± 8.1 dB re 1 $\mu Pa^2 \cdot s$, ranging from 101.9 dB to 131.1 dB re 1 $\mu Pa^2 \cdot s$ (n = 30).

In order to narrow-down the origin of this sound, bearings were obtained to a dozen pops on the records of the three near-island DASARs (four pops from each DASAR record). Figure 3.20 shows the 16resulting "bearing scatterplots". The average bearings from DASARs NSa, NSb, and NSc to pops were 189°, 199°, and 231°, respectively. This put the sound source on the eastern side of Northstar (see Fig. 2.3 in Chapter 2), so the pops could have originated at Northstar itself or in the water next to the island. The pops also appeared to be synchronous across DASARs, i.e., a particular series of pops at one near-island DASAR could also be found, with some variation, at the other near-island DASARs. Again, this supports an origin that is independent of the instrumentation itself (e.g., self-noise).

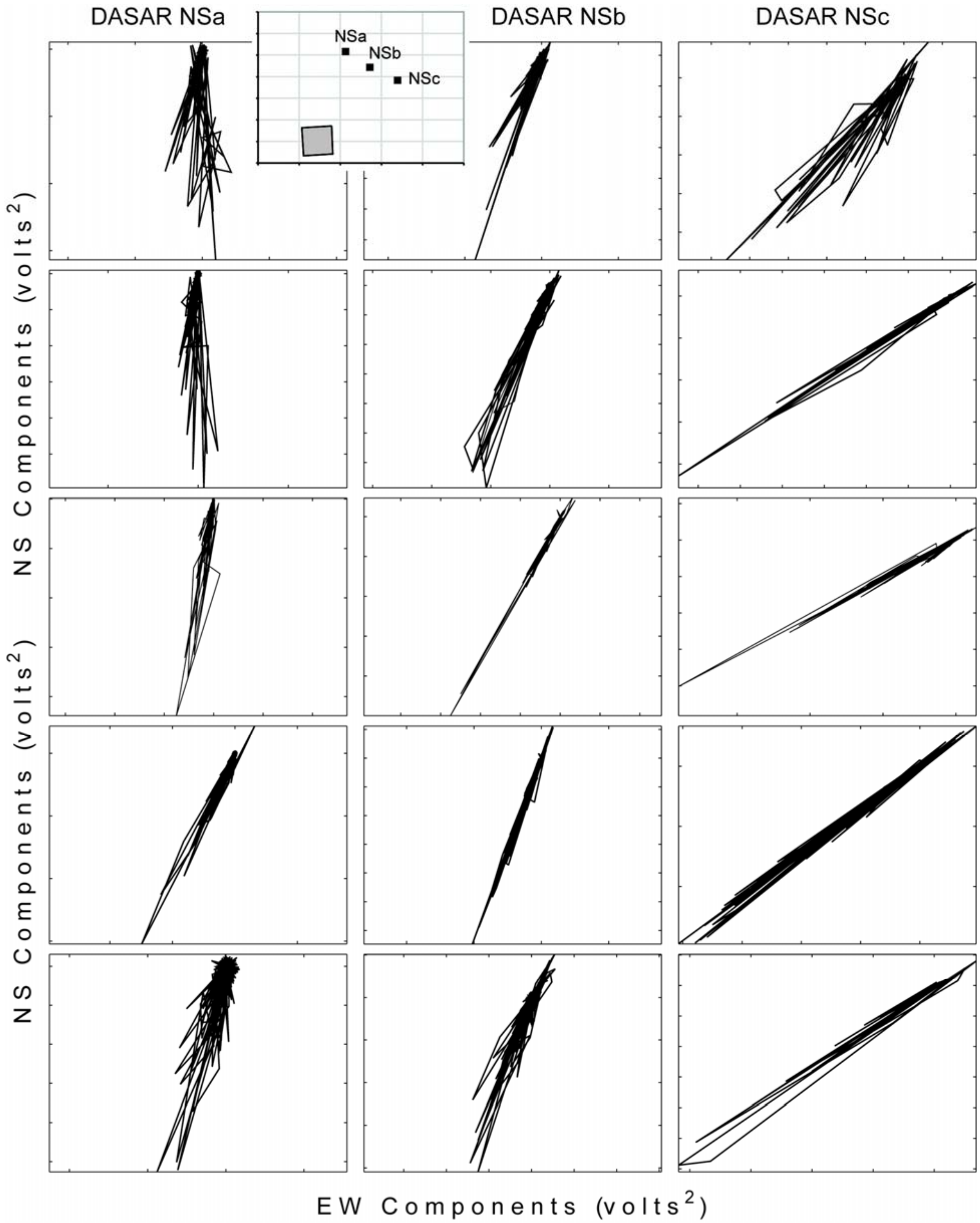

FIGURE 3.20. Scatterplots for 15 bearings to "pop" sounds, from DASARs NSa (left), NSb (center), and NSc (right). For comparison, the insert shows the locations of the three DASARs in relation to Northstar. The three sets of bearings point towards Northstar, specifically the eastern side of Northstar. This type of plot is shown in Figure 2.5 and explained in the accompanying text in Chapter 2.

Helicopter Sounds

Helicopters were recorded as arriving at and departing from Northstar 54 times during the period 26 Aug–25 Sep, and 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 from E to NE, Northstar is generally approached from the SW and take-off occurs to the NE. With DASAR NSc located NE from Northstar, sounds from helicopter departures are more likely to be detected than from arrivals. Figure 3.21A and B show two spectrograms of the type that were used to identify the presence of tones, while Figure 3.21C 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. These tones were weak and could not easily be heard on the near-island acoustic record by listening with headphones. Tones were generally present for 20–50 s with weaker tones sometimes extending for another 10–50 s.

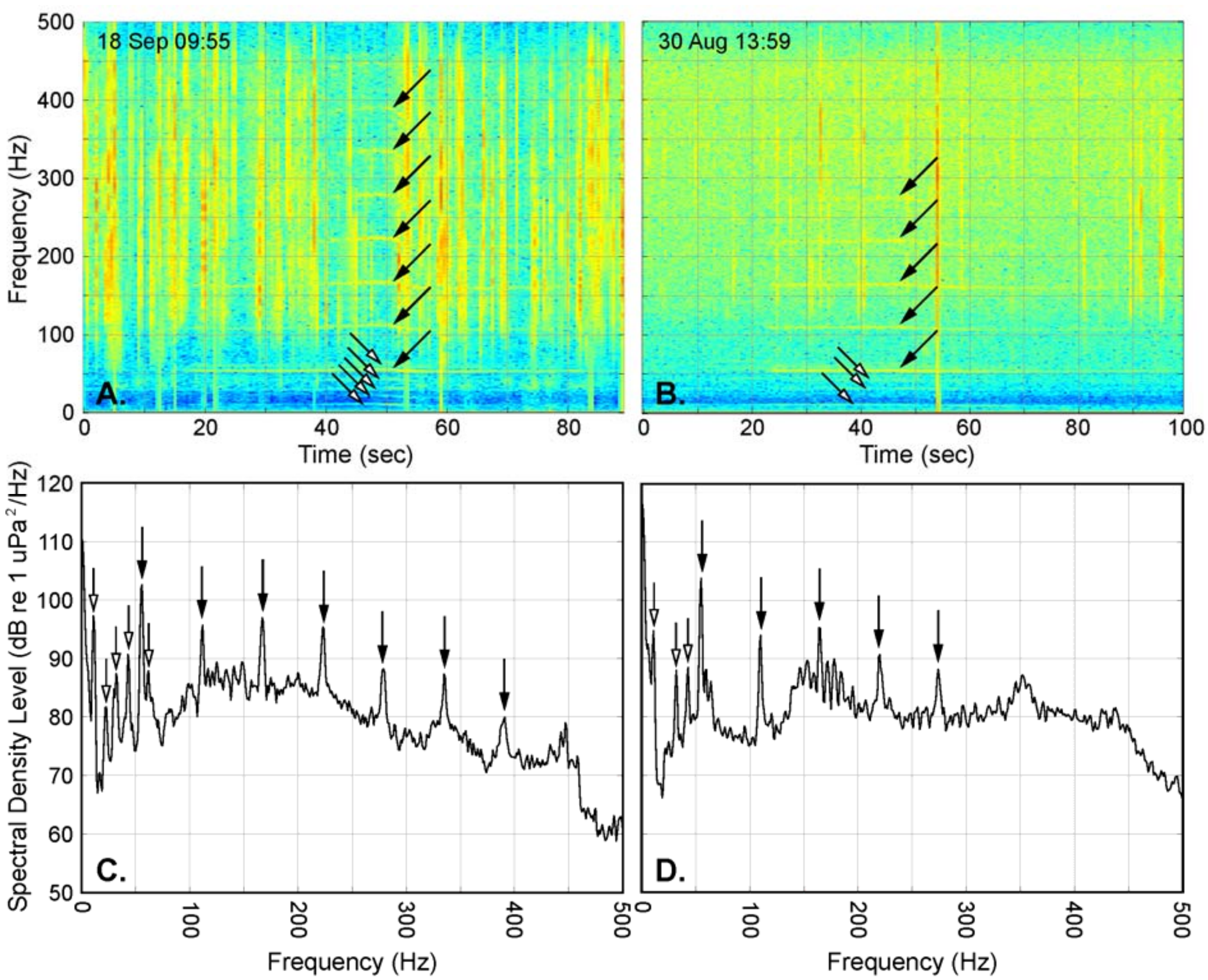

FIGURE 3.21. Spectrograms (A and B) and spectral density plots (C and D) of two helicopter departures from Northstar, on 18 Sep at ~09:55 (A and C) and on 30 Aug at ~13:59 (B and D), as recorded by near-island DASAR NSc. Black arrows point to tail rotor tones, and white arrows point to main rotor tones. Some pops are visible on the spectrograms.

AIRGUN PULSES

During the 2008 field season, sound pulses produced by airguns from non-BP seismic exploration[11] were detected on the acoustic records of all array DASARs, using automated pulse detection software (see Annex 2.1, Chapter 2). This software could not be used on the near-island DASARs because the pops confused the algorithm. Airgun pulses were therefore searched for manually on the record of DASAR NSc for a selected period by examining sound pressure time series for regularly spaced pulses, examining spectrograms, and listening to the recorded sounds with headphones. If airgun pulses were to be present, a day with low wind speed and the highest recorded airgun pulse levels at the offshore DASARs was considered the most appropriate for this manual detection (e.g. 13 Sep, see Fig. 3.22). No airgun pulses were detected, but examination of the near-island DASAR records is continuing. The detection rate was highest at the most offshore DASAR (J), where >90,500 airgun pulses were detected in ~29 days (27 Aug–24 Sep). However, the actual number of airgun pulses received in the DASAR array was likely higher than that. During the automated search for airgun pulses the signal to noise (S/N) ratio in the algorithm was set at a high-enough level that non-airgun sound pulses were excluded[12]. Therefore, weak airgun pulses were also excluded by this analysis. Figure 3.22 shows received levels of airgun pulses at DASARs A, D, F, H, and J, i.e., spanning the north-south extent of the offshore array (see Fig. 2.2). For each 10-min period with detected airgun pulses, Figure 3.22 shows (1) the median received sound pressure level (black dots); (2) the maximum instantaneous peak values (red triangles); and (3) the number of detected airgun pulses included in each analyzed 10-min period (light blue dots). Figure 3.23 shows an enlargement of the data in Figure 3.22 for DASAR J on 21–22 Sep. Table 3.2 summarizes the number of airgun pulses detected at each array DASAR. This number tended to increase with distance from shore. At the northern end of the DASAR array, sounds from airguns were present during at least 70% of the 10-min periods within the project's field season (Table 3.2). Similarly, Figure 3.22 shows that at DASAR J only one day (17 Sep) was devoid of detected airgun pulses, and three days (11 Sep, 16 Sep, and 18 Sep) contained periods of several hours during which no airgun pulses were detected.

Table 3.3 presents summary statistics on detected airgun pulses for each DASAR. Overloaded pulses were not included in this analysis. DASARs A, B, D, and G had no overloaded pulses. DASAR C had 6, E had 20, F had 1, H had 23, I had 468, and J had 24 overloaded pulses. For DASAR I the overloaded pulses represented 0.6% of the total number of pulses detected at that DASAR. For all other DASARs the overloaded pulses represented less than 0.05% of detected airgun pulses at each DASAR.

Except at DASAR A, where values were lower, median SPLs were in the range 103–107 dB re 1 μPa. The highest received SPLs were at DASARs D and G, where they reached 145–146 dB. The values for sound exposure levels were generally slightly smaller than those for SPLs, indicating that the length of detected airgun pulses was generally somewhat under 1 s (note however that SPL and SEL have different units: dB re 1 μPa and dB re 1 $\mu Pa^2 \cdot s$, respectively). The median instantaneous peak values were in the range 115–118 dB re 1 μPa, and again lower at DASAR A, ~107 dB. Maximum instantaneous peak values are not given in Table 3.3 for DASARs at which airgun pulses overloaded.

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[11] The BP Liberty ocean bottom cable seismic survey was completed on 25 Aug 2008, two days before the near-island and offshore DASARs were deployed at Northstar.

[12] The automatic airgun pulse detection software used in this analysis only considers pulses with a signal-to-noise ratio of at least 8 dB, so in reality there would have been more airgun pulses than reported in this section.

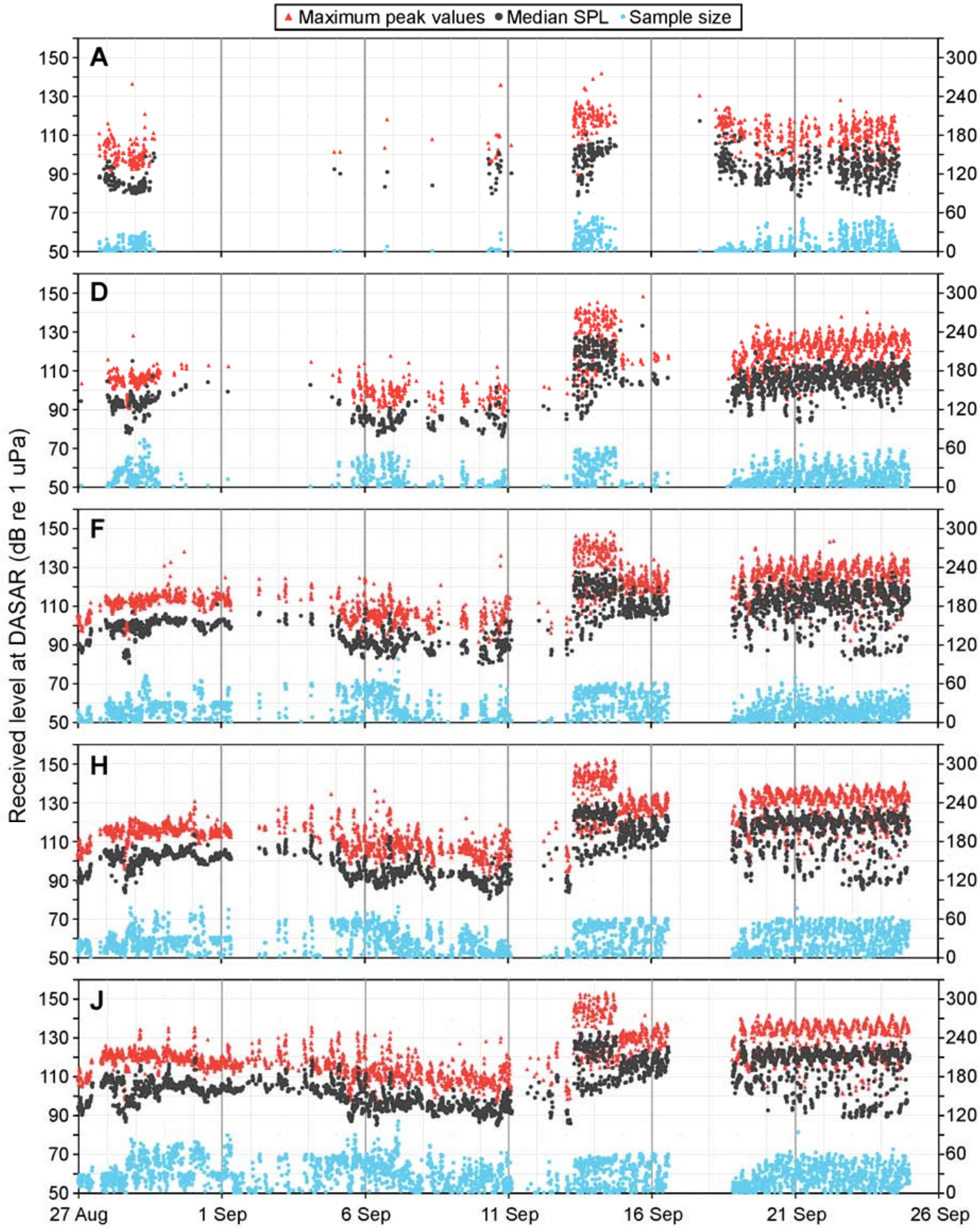

FIGURE 3.22. Levels of sound from airgun pulses, as received at DASARs A (most inshore), D, F, H, and J (most offshore), 27 Aug–24 Sep. Overloaded pulses were not included in the analysis. Data are summarized over 10-min periods. Median received SPLs are shown with black dots, and maximum instantaneous peak pressures are shown as red triangles; values for both of these variables are to be read on the left y-axis. The number of airgun pulses detected per 10-min period is shown with light blue dots; these sample sizes are to be read on the right y-axis.

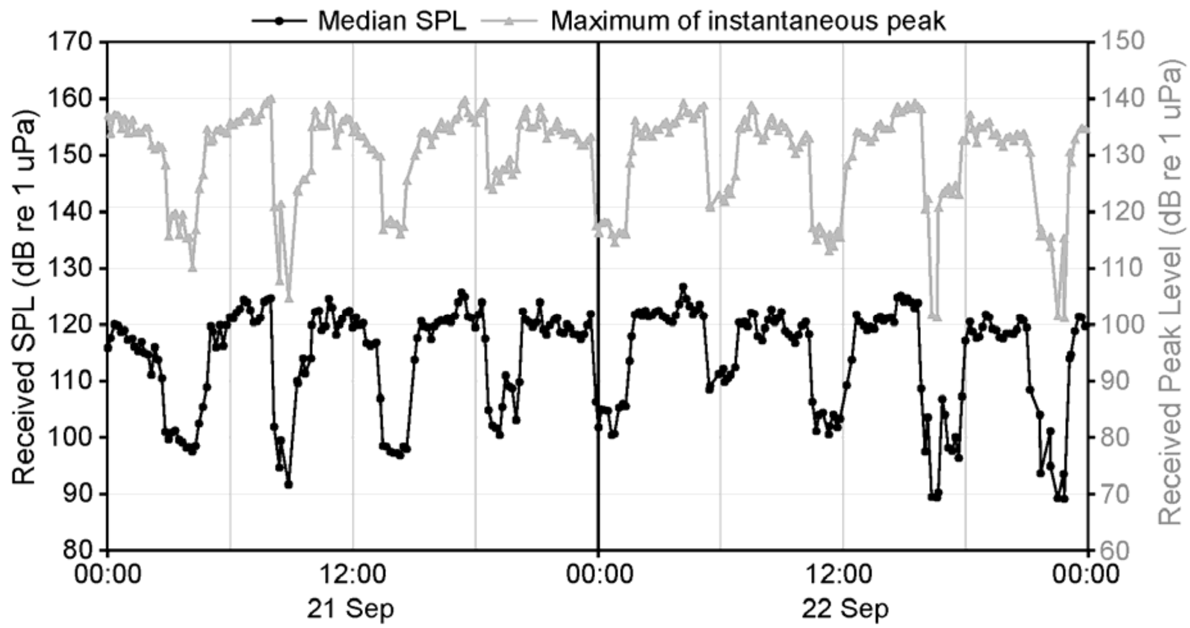

FIGURE 3.23. Median sound pressure levels (left y-axis) and maximum of instantaneous peak levels (right y-axis) as recorded by DASAR J on 21–22 Sep. Data are summarized over 10-min periods, see Fig. 3.22. This figure illustrates the “mowing the lawn” (or “racetrack”) procedure during the acquisition of seismic data. The seismic ship travels in straight lines, alternatively being closer to or farther away from DASAR J, leading to the alternating gradual increases and decreases in received levels. The dips in received levels correspond to the ship turning around, during which time the number of firing airguns is reduced.

TABLE 3.2. Total number of airgun pulses detected[9], number of 10-min periods with at least one airgun pulse detected, average number of airgun pulses per 10-min, and percentage of 10-min intervals – over the entire season – with at least one airgun pulse detected (there were 4176 10-min periods during the 2008 field season). No airgun pulses were detected at near-island DASAR NSc.

DASAR	Airgun pulses detected	10-min periods with airgun pulses	Average # airgun pulses per 10 min	Percentage of 10-min intervals with airgun pulses
A	10,786	723	14.9	17.3 %
B	19,848	1205	16.5	28.9 %
C	28,283	1468	19.3	35.2 %
D	27,965	1465	19.1	35.1 %
E	44,553	1988	22.4	47.6 %
F	53,647	2236	24.0	53.5 %
G	45,518	2120	21.5	50.8 %
H	74,546	2575	28.9	61.7 %
I	75,228	2705	27.8	64.8 %
J	90,582	2938	30.8	70.4 %

Table 3.3. Received levels of sound from airgun pulses at each of the 10 array DASARs over the period 27 Aug–24 Sep. Overloaded pulses were not included in the analysis. The median and maximum values are shown for sound pressure level (SPL), instantaneous peak level, and sound exposure level (SEL). Sample sizes for all DASARs are those shown in Table 3.2. ** indicates that the maximum peak value is not known because some airgun pulses recorded by those DASARs overloaded the hydrophone.

	SPL		SEL		Peak	
DASAR	median	maximum	median	maximum	median	maximum
A	94.0	134.4	90.9	137.9	107.3	141.9
B	104.9	140.0	103.5	132.7	118.0	147.6
C	104.3	143.3	104.5	142.9	117.7	**
D	104.8	145.2	104.6	142.3	118.3	149.1
E	103.2	141.2	101.6	138.3	114.6	**
F	104.0	141.3	102.6	139.1	115.1	148.9
G	103.9	145.7	102.2	150.6	115.6	141.1
H	106.8	135.6	105.6	133.4	118.2	**
I	106.3	136.9	104.9	136.7	117.5	**
J	105.9	137.5	104.9	135.7	117.5	**

Bearings were obtained for 30 airgun pulses during the period 27 Aug–25 Sep. These bearings showed that the pulses detected on the array DASARs originated from several directions depending on the date. In relation to the location of DASAR J (see Fig. 2.2), the following bearings were obtained: late August (28–30): NNE; 6–10 Sep: WNW; 13–25 Sep: E to ESE of the location of DASAR J.

DISCUSSION

Northstar Sounds Recorded Near the Island

Broadband Sound Levels

In all years, broadband levels at the island have been much influenced by wind and thus wave action, but superimposed on this natural variability are the effects of industrial activities. Figure 3.3 and the data presented in Table 3.1 describe how broadband (10–450 Hz) levels of underwater sound, as recorded ~450 m north of Northstar, have changed over eight fall seasons of monitoring. The most striking change among years is the variation in the density of “vessel spikes” in the sound pressure time series. Even though a few of these spikes can be attributed to other activities (i.e., vibratory pile driving), the vast majority of the spikes are caused by vessels going to and from Northstar. From 2001 to 2005 the frequency of occurrence of vessel spikes decreased progressively from year to year. In 2006 it increased, and then decreased again in 2007 and 2008. However, most of these spikes are short in duration, generally in the range 30–45 min, so even though they are prominent visually (as in Fig. 3.3) and are an important component of the soundfield around the island, they count for little when computing mean broadband levels over an entire season. For example, the median level of sound was highest in 2005 (Table 3.1), a year with relatively low spike density and vessel traffic (Fig. 3.15), but one of the windiest years during the period 2001–2008 (Fig. 3.2).

In 2008, broadband sound levels as recorded by the near-island recorder were within the range recorded for 2001–2007 (Fig. 3.4). However, during times without vessel spikes, there was more short-term variability in sound levels near the island (DASAR NSc) than in all previous years except 2001, which was a year with much construction. This could be due to the presence of the new popping sound identified on the near-island records (see below). As in previous years, broadband levels in the offshore array (Fig. 3.6) were lower than at Northstar by ~10–15 dB, but there was a pattern of increasing mean broadband levels with increasing distance from shore. The increased amount of offshore industrial activity in 2008 is the most likely explanation for this observation.

New Unknown Sound

A new impulsive sound – which we refer to as "pops" – was detected on some DASAR records in 2008 (Figs. 3.18, 3.19, and 3.20). It was detectable at array DASAR A located 8.5 km (5.3 mi) northeast of Northstar, but was much more prominent on the near-island recorders NSa, NSb, and NSc. Bearings to individual pops recorded by near-island DASARs pointed to a location on the eastern side of Northstar, possibly in the water next to the island. There is some preliminary evidence that the 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. For the first time in 2008, instrumentation was deployed on the seafloor close to Northstar to measure wave, current and ice conditions. However, these instruments were deployed ~500 m north of the locations of the near-island DASARs, while the popping sounds were determined to originate south or southeast of the DASARs. Another possibility would be that these popping sounds originated from the Northstar dock, but this has not yet been confirmed. Other possible sources are being investigated.

A comparison of time periods with a high and a low rate of occurrence of pops (~100 per 5 min and 0–20 per 5 min, respectively) showed that short-term variability in broadband levels (in the absence of vessels) was higher when more pops were present, ~10–12 dB vs ~2 dB. This anecdotal evidence supports the hypothesis that the presence of pops contributed to the greater short-term variability in broadband levels in 2008 compared to other years.

To determine the contribution of pops to overall sound levels as recorded at the near-island DASARs, broadband sound levels were calculated in two different ways: the "standard way" (mean over 1 min every 4.37 min and thus including pops) and the "minimum way" (lowest 2-s average over 10 min and thus excluding pops, see Figs. 3.5 and 3.6). As expected, levels for the minimum analysis were lower than those for the standard analysis, but of note is the fact that the difference between the two was 5.9 dB in 2008 versus 3.4 dB in 2007, a year without the presence of pops. Again this supports the hypothesis that pops contributed to increasing mean broadband levels near the island.

Helicopter Sounds

Tones from helicopter traffic were detected on the record of DASAR NSc, but only during departures from Northstar. The tones were weak (strongest tones at 82–106 dB re 1 μPa) and sometimes barely detectable – the examples shown in Figure 3.21 were the most obvious. The short periods of time during which these tones were present in the spectrograms – generally 20–50 s – is a result of the complex process of air-to-water transmission in shallow water where reflected sound paths exist. There is little penetration of sound pressure from air to water unless the helicopter is nearly overhead. Therefore, the lack of tones during arrivals at the island is due to the fact that, during prevailing E to NE winds, Northstar was approached from the SW and not close to the near-island DASARs. Finally, low frequencies such as the fundamental frequency from the main rotor (10.9 Hz) cannot propagate well in the shallow water around Northstar. The tail rotor blade rate (55 Hz) and its harmonics would propagate well. Helicopter sound can be highly directional and tail rotor sounds tend to radiate more to the rear of the aircraft (Patenaude et al. 2002). On the spectrograms (Fig. 3.21A and B) the tones at 55 Hz and harmonics are the ones that are visible for the longest duration, presumably as the helicopter flies towards the mainland with its tail turned towards the island. Nevertheless, the lack of tones in 65% of the investigated helicopter arrivals and departures at Northstar supports the importance of the aircraft's path in determining whether or not helicopter tones will be detectable underwater. The likelihood of these tones being detectable at array DASAR A is extremely small. BP hopes to look more closely at in-water helicopter sounds in 2009.

Northstar Sounds Recorded Offshore

One of the specific objectives in 2008 was to “increase the understanding of received levels of sound from Northstar farther offshore”. This was done by comparing various sounds recorded at the near-island DASAR with the same sounds recorded by the array DASARs at different distances offshore. Three types of sounds were of particular interest and are discussed below: (1) *ISI_5band* (28–90 Hz), (2) Vessel sounds, and (3) Tones produced by Northstar machinery.

ISI_5band

The *ISI_5band* measure was developed to characterize the sound components most closely related to industrial activities. The bandwidth of *ISI_5band* (28–90 Hz) includes island operational sounds (generators, compressors and the like) as well as the sounds from vessels. It also inevitably includes sounds from wind and waves, but sounds at all frequencies are influenced by wind and waves. The salient observation about *ISI_5band* values at the near-island DASAR in 2008 is that they differed from the broadband background sound in the 10–450 Hz range by a greater amount than in previous years. This is attributable to the presence in 2008 of the pop sounds, which contained most of their energy outside the 28–90 Hz band (see Fig. 3.19) and therefore contributed to broadband levels but not (or little) to *ISI_5band* levels. Although these popping sounds are from an unconfirmed source, they are likely to be island-related and therefore are a component of the industrial sound that was not well represented by *ISI_5band*. *ISI_5band* levels in the offshore array were ~20 dB lower than near Northstar and they differed from the corresponding broadband levels by large amounts, up to 17.5 dB. This is a result of the presence of airgun sounds which, just like pops near the island, include energy outside the 28–90 Hz range. Therefore, in 2008 *ISI_5band* did not perform as an index of industrial sound as well as it has in the past, because both types of industrial sounds that were new for 2008 – pops and airgun pulses – did not get included in the index.

Vessel Sounds

Vessel spikes are a prominent feature in the sound pressure time series. Spikes from tugs (Figs. 3.16 and 3.17) were at least some of the time detectable in the sound pressure time series offshore as far as DASAR E, 21.5 km (13.4 mi) from Northstar, and possibly farther. The presence of sounds from other sources made it unclear whether the tug sounds were ever detectable beyond DASAR E. This makes sense if one calculates the distance at which tug sounds at Northstar will drop below background levels, using data collected by the DASARs. Whole-season median broadband levels at DASAR C, 14.9 km (9.3 mi) from Northstar, were in the range 93–103 dB re 1 μPa in 2001–2008 (Fig. 3.8). The regressions in Figure 3.17 show that the strongest vessel sounds (top lines in Fig. 3.17) would reach 93–103 dB and therefore begin to be masked by background sounds 9.4–24.6 km (5.8–15.3 mi) from Northstar, 50% of the time (because we are using the 50^{th} percentile, or median, of whole-season broadband levels). Similarly, Blackwell and Greene (2006) showed that in low to moderate ambient sound conditions vessels were often detectable 30 km from Northstar.

Island Tones

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) that propagate into the water. In addition, tones are produced by vessels. Most of these tones are of low frequencies, in the 28–90 Hz band (Fig. 3.12). Specific tones at frequencies such as 30 Hz, 60 Hz, and 87 Hz, were present continually over extended periods. The 60 Hz tone that emanates from Northstar is at levels much lower than the spikes produced by a barge (~80–90 dB versus ~130–135 dB re 1 μPa as measured ~460 m away). In addition, it consists of a single frequency, whereas the barge spike is a broadband level containing many frequencies. The 60 Hz power frequency tone was no longer detectable at the nearest offshore DASAR (A, 8.5 km or 5.3 mi from Northstar), even when the analysis bandwidth was reduced to 0.17 Hz. This confirms previous findings that sounds from the island itself do not propagate beyond a few km, whereas vessels can be detected at least to 21.5 km (13.4 mi) and possibly farther (Blackwell and Greene 2006). The *ISI_tone* measure also provided information on the presence of tones offshore of the island. The near-island DASAR NSc had the highest proportion of *ISI_tone* values>0 and the highest mean *ISI_tone* value over the season (Fig. 3.13). If the presence of tones is a measure of industrial activity, then one would expect decreasing numbers of tones with increasing distance from Northstar. However, in 2008 array DASAR A, the closest array unit to Northstar, had the smallest mean *ISI_tone* value of all DASARs (Fig. 3.13B). Airgun pulses do not contain tones so are not expected to contribute to the *ISI_tone* measure. In contrast, vessels are tone producers and are likely responsible for most of the tones detected in the array, either through normal passing vessel traffic (which may take place north of the location of DASAR A) or through the vessels that are part of the seismic operation.

Non-Northstar Sounds: Airgun Pulses

Over 90,500 airgun pulses were received on array DASAR J, the farthest from Northstar, while none were detected on the record of the near-island DASAR located ~450 m north of Northstar. Received levels of airgun sound were noticeably lower on array DASAR A, possibly because of the shallow water (<15 m) or by some shielding effect by the barrier islands (Reindeer and Cross Islands). Median (50th percentile) received sound pressure levels (SPLs) from airgun pulses were 94 dB at array DASAR A and in the range 103–107 dB re 1 μPa at DASARs B through J. Maximum SPLs were 134 dB versus 136–146 dB re 1 μPa, respectively, and median peak levels reached 107 dB at DASAR A and 118 dB re 1 μPa in the offshore array[13]. Airgun pulses were detected on all but one day (17 Sep) during the DASARs' deployment season (27 Aug–25 Sep).

The most likely explanation for the fact that airgun pulses were not detected on the sound record of the near-island DASAR NSc is the shallow water depth near the island. Most of the energy in airgun pulses is at low frequencies, which do not propagate well in shallow water. The highest SPLs recorded by the outer array DASARs were on 13 Sep. On that day, median levels of airgun sounds only decreased by a few dB between DASAR J and southwestward to DASARs H, F, and D (see Fig. 3.20). However, between DASARs D and A there was a much greater drop in median received levels, on the order of 10–15 dB. This drop was likely due to the decreasing water depth. By the time these airgun sounds reached the near-island DASARs (depth 12 m), median levels could have been on the order of ~90 dB. This would make them difficult to detect, considering that whole-season minimum and median levels of sound on the near-island DASAR NSc were 91.0 dB and 103.6 dB, respectively (Table 3.1). On other days received levels of airgun sounds were lower and background sound levels were higher (13 Sep was a low-wind speed day, see Fig. 3.1), making it more difficult to detect airgun sounds at Northstar.

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[13] Note however that these analyses did not include overloaded pulses, which were present at five of the ten offshore DASARs. Actual received levels of sound (SPL, SEL, instantaneous peak) are therefore higher at some DASARs than reported here.

To evaluate the contribution of airgun pulses to overall sound levels, broadband levels were calculated in two different ways for 5 of the 10 array DASARs: the “standard way” (mean over 1 min every 4.37 min and thus including airgun pulses) and the “minimum way” (lowest 2-s average over 10 min and thus excluding airgun pulses, see Figs. 3.5 and 3.6). In the offshore array (Fig. 3.6) the minimum line hugs the bottom of the standard line most of the time. The exceptions are during the occurrence of vessel spikes and during seismic exploration. During “nearby” seismic exploration, for example on 13–14 Sep and 19–24 Sep, minimum levels no longer represent background levels as they vary synchronously with levels obtained in the standard analysis. This shows that even though airgun pulses are short in duration and occur infrequently (generally 3–6 per min), eliminating them from the sound record is not possible when the seismic survey is closer than a certain distance. Reverberation from the pulses combined with the sounds of the vessels that are part of the seismic operation will cause a continuous increase in sound levels.

These airgun pulses therefore constitute a strong confounding factor in achieving our objective of assessing the effects of Northstar sounds on bowhead whale behavior. Bowhead whales have been shown to react to airgun sounds, by deflecting or by changing their calling behavior (Richardson et al. 1986, 1999; Ljungblad et al. 1988; Blackwell et al. 2008b), or both. The airgun pulses could be added to the overall analysis as an additional covariate to be taken into account, but it is also possible that their effects on bowhead behavior will overshadow any effects by Northstar. How to deal with this added factor is currently being investigated; results will be presented in a future report.

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CHAPTER 4:

ACOUSTIC LOCALIZATION OF MIGRATING BOWHEAD WHALES NEAR NORTHSTAR, AUTUMN 2008[1]

by

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ABSTRACT

Calls from migrating bowhead whales near Northstar were recorded and localized using an array of 10 directional autonomous seafloor acoustic recorders (DASARs) offshore of Northstar for ~30 days (27 Aug–25 Sep). The primary objective of the study was to assess the effects of Northstar production activities, especially underwater sounds, on the southern edge of the distribution of calling bowhead whales during their autumn migration. In this chapter we report on the number of whale calls detected, bearings to calls and the estimated location of calls, and the call types used. Prior to processing the acoustic data from the 2008 field season, plans called for application of analyses comparable to those used on data from 2001–2004, which was in a sense a dose-response approach that assumed the industry sound impacts were associated almost exclusively with Northstar operations. Because of the preponderance of airgun[2] sounds on the DASAR acoustic records during the 2008 field season, this analytical approach could not be responsibly applied. An alternative analytical approach is currently being investigated and may be presented in a future report.

A total of 85,669 bowhead whale calls were detected on the records of the 10 array DASARs combined, from a total of 350,597 call detections. The highest number of calls was detected by DASAR E, close to the center of the array. About 86% of calls were detected by two or more DASARs, and over 2% were detected by all 10 DASARs concurrently. The highest call detection rate was 612 calls per hour and occurred on 20 Sep. In addition to this peak in call detection rate, there were others in late Aug and mid-Sep. DASARs have been deployed at location C (2008) / EB (2001–2007) every year of the study. Therefore, data collected at that location serve to make comparisons across years. Call detection rates at DASAR C in 2008 were the highest to date with on average 1337 calls/day. Mean bearings to calls from DASAR C were on average at 59° and similar to bearings at that location in 2002, 2003, 2004, and 2007, which were all low-ice years like 2008. Call type percentages recorded at DASAR C in 2008 were within the range of previous years. In short, the number of calls detected was the highest since monitoring began in 2001, and both call distribution and call types were similar to those seen in some previous years.

INTRODUCTION

The overall aim of this study is to assess the effects of Northstar production activities, as manifested in underwater sounds, on the behavior of migrating bowhead whales. An acoustical approach was used to locate calling bowhead whales near Northstar, and a dose-response analysis was used to determine whether the distribution of calling whales was related to 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 shift in the locations of whale calls at the southern edge of the whale migration corridor (McDonald et al. 2008). This shift could be the result of whales deflecting away from the island, of the whales changing their calling rates in response to increased sounds, or both. Because estimated locations of calling bowhead whales constitute the primary data on whale distribution, understanding the nature of whale calls is important in interpreting the results. Prior to processing the acoustic data from the 2008 field season, plans called for application of analyses comparable to those used on data from 2001–2004, which was in a sense a dose-response approach that assumed the industry sound impacts were associated almost exclusively with Northstar operations. Because of the preponderance of airgun[2] sounds on the DASAR acoustic records during 2008 field season, this analytical approach could not be responsibly applied. An alternative analytical approach is currently being investigated and may be presented in a

[2] Airgun sounds were from non-BP sources. The BP ocean bottom cable seismic survey in the Liberty prospect was completed 25 Aug 2008, two days before the near-island and offshore DASARs were deployed at Northstar.

future report. The current chapter presents the results from analyses of whale calls recorded in the offshore DASAR array during the early autumn of 2008, and compares these results with those from previous years. It provides information on annual variation in the number of calls detected, their distribution, their bearings and the use of various call types.

The results of the Northstar whale call analyses as described in more detail in Chapter 2 are presented in the following three sections: (1) Number of whale calls detected; (2) Bearing analysis and whale call locations; and (3) Call types.

NUMBER OF WHALE CALLS DETECTED

A total of 85,669 bowhead whale calls were detected on the records of the 10 array DASARs (A though J) combined during the 27 Aug–25 Sep period in 2008, from a total of 350,597 call detections. A call that is detected at several DASARs is counted as a single call. During the whale call analysis process in February 2009 an error during transfer of raw data resulted in a one and a half hour offset in the time on DASAR J. This problem affected a total of about 60 hours of analyzed data on that DASAR (spread over seven different days). These time blocks are currently being reanalyzed and the corrected data will be presented in the next version of this report. As a consequence, the total number of calls detected at all DASARs will likely show a small increase. The contribution of the corrected DASAR J data to the totals is not expected to change the currently presented results in a meaningful way, because nearly 70% of the total number of calls was detected by three or more DASARs (see below).

Hourly call detection rates for all offshore DASARs over the entire deployment period are shown in Figure 4.1. The highest call detection rate was 612 calls/hour on 20 Sep at 17:00. This is similar to 2003 and 2004, years that were also characterized by large numbers of whale calls detected on 10-DASAR arrays. In those years the highest call detection rates were 567 calls/hour on 19 Sep 2003 and 623 calls/hour on 21 Sep 2004. Therefore, in all three years (2003, 2004, 2008) the highest call detection rate occurred at about the same time, close to 20 September. In 2008 there were two other noteworthy peaks in call detection rates, both with more than 450 calls/hour: one in late August (28–29) and the other in mid-September (10–12). Visual observations were conducted during 21–23 Sep (which coincides with a peak in call detection) from the roof of the Northstar process module. The purpose was to test the feasibility of collecting visual data of bowhead whales that would allow a meaningful comparison with acoustically detected whales. No bowhead whales were observed (see Annex 4.1 for more information).

In 2008 there were a total of 350,597 separate call detections at the ten offshore DASARs. Figure 4.2 shows that call detections were not spread evenly among the 10 offshore DASARs but rather showed a bell-shaped distribution when plotted at increasing distances from shore (i.e. from south to north and west to east). The highest call detection rates were at DASAR E, close to the center of the offshore array. The mean number of detections per call was 4.1 over the entire field season, meaning that on average ~four DASARs detected each call. Figure 4.3 shows the distribution of calls heard by different numbers of DASARs, ranging from 1 (call detection with no localization) to 10, i.e., call detected by all DASARs in the array. Nearly 1,900 individual calls were detected by all DASARs concurrently. Since the offshore array is 32 km (19.9 mi) in its greatest dimension (DASAR A to DASAR J), those calls would have been audible over at least 16 km (9.9 mi). In 2008 14.3% of calls were detected by only one DASAR. This percentage is lower than in other years when data from ten-DASAR arrays were analyzed: corresponding values in 2002, 2003, and 2004, were 19%, 19%, and 22% (Greene et al. 2003; Blackwell et al. 2006a, 2006b).

Every year since 2001 there has been a functional DASAR at location C, also called EB in 2001–2007 and hereafter referred to as location C/EB. Using call data from this location allows us to compare call counts over eight years. This comparison is shown in Table 4.1, and includes the mean number of calls per day, since the length of the DASAR deployment season is different each year. In years when duplicate DASARs were deployed we have only included counts from one of the DASARs. When expressed as a number of calls per day the 2008 number (1337 calls/day) is the highest since the beginning of the study, exceeding even the previous record of 989 calls/day in 2004 (Table 4.1).

Figure 4.4 compares daily numbers of calls detected by DASARs at location C/EB in 2008 and in previous years. The pattern at location C in 2008 was similar to the pattern seen in all DASARs combined (see Fig. 4.1), i.e., the highest peak was on 20 Sep and there were two secondary peaks, one in late August and another in the first part of September. This pattern was also seen in 2002, 2003 and 2004.

A comparison of the number of calls detected in 2008 with previous years supports the general conclusion that 2008 was a year with high whale call counts. The different array configuration in 2008 compared to previous years makes a direct comparison difficult, but call count statistics at DASAR location C/EB confirm this trend.

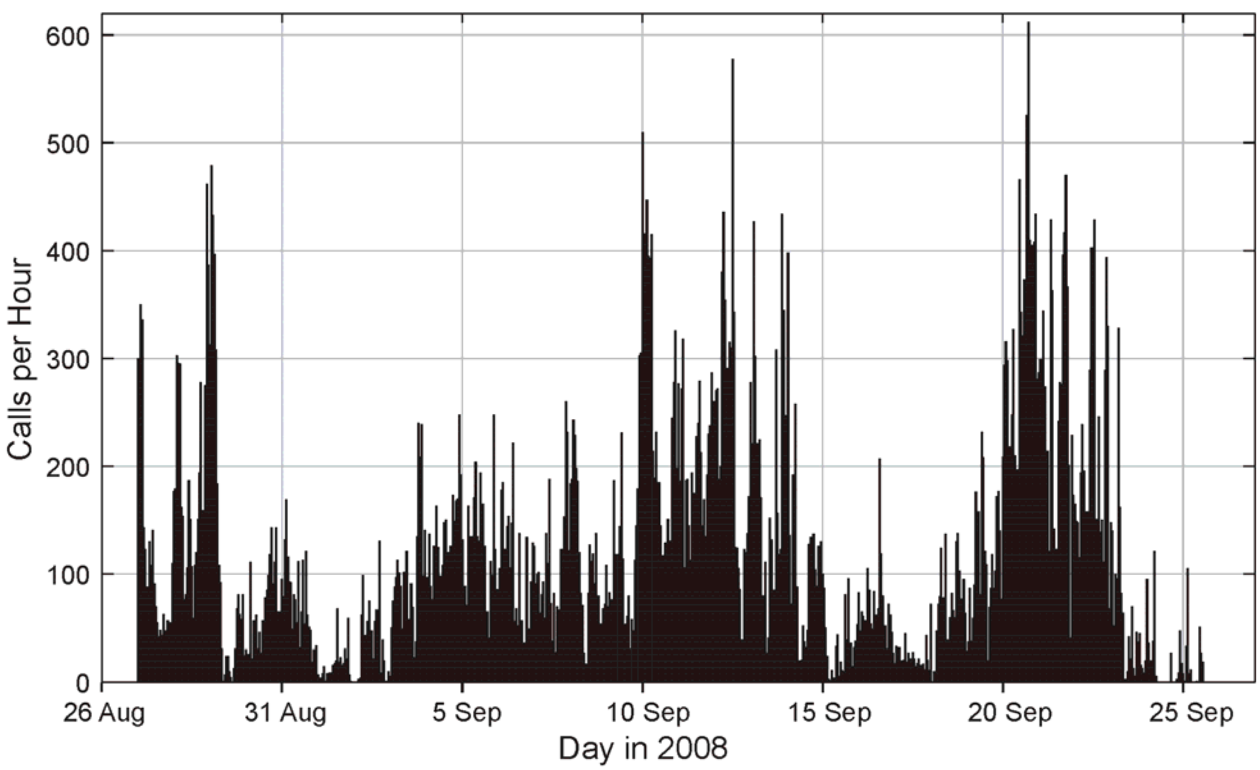

FIGURE 4.1. Hourly detection rate of whale calls as a function of time in late Aug to late Sep 2008. Total number of calls considered in this diagram was 85,669. Tick-marks on X-axis represent midnight. The highest call detection rate was 612 calls/hour on 20 Sep between 17:00 and 18:00.

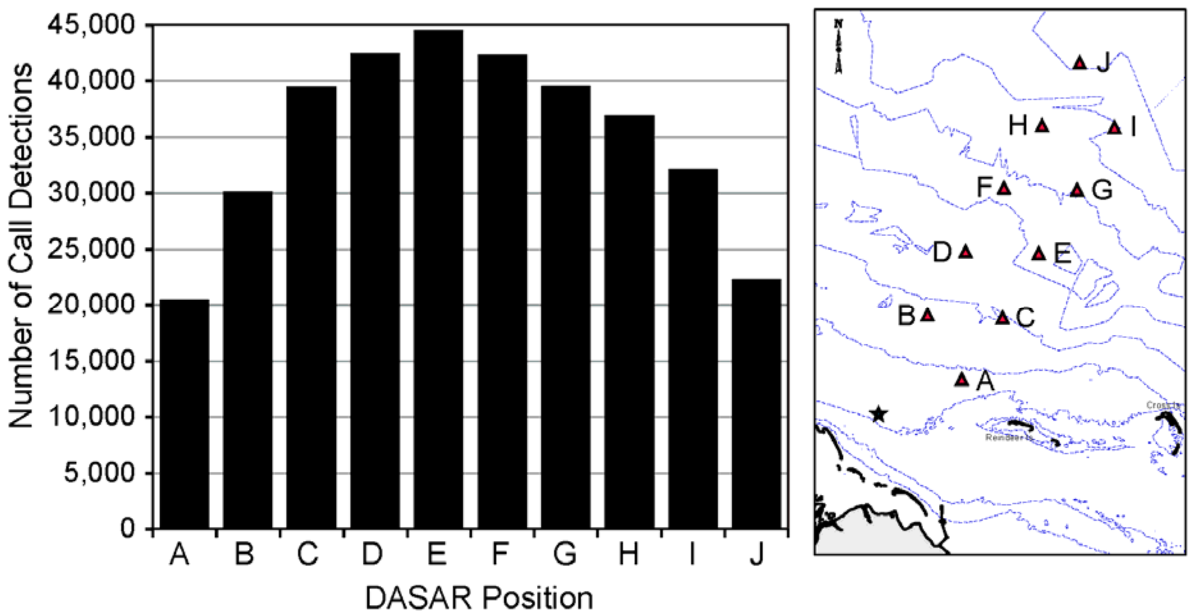

FIGURE 4.2. The histogram shows the number of call detections per DASAR location, for offshore DASARs. DASAR A is southernmost, DASAR J is northernmost, and DASARs are listed (from left to right) in the order of increasing distance from shore. The map shows Northstar (star) and the 10-DASAR array.

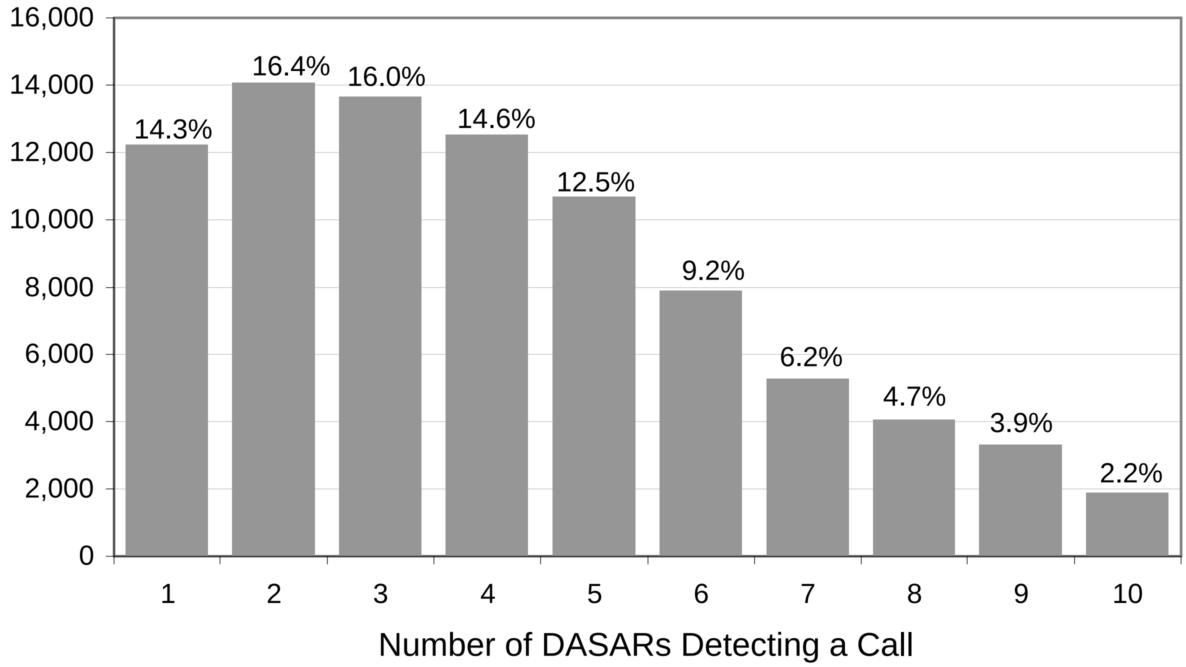

FIGURE 4.3. Number of calls detected by 1–10 DASARs in the offshore array, 27 Aug–25 Sep 2008. Corresponding percentages are shown above the bars.

TABLE 4.1. Comparison of bowhead whale call counts at DASAR location C (2008) and EB (2001–2007). Also shown for each year is the length of the recording season (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 with the listed mean number of calls per day may arise from rounding error.

Year	Total calls detected at C/EB	Length of DASAR recording season (days)	Mean # calls per day
2001 (EB)	1624	25	65
2002 (EB)	4317	24	180
2003 (EB)	21,726	30	724
2004 (EB)	26,546	27	989
2005 (EB)	951	29	33
2006 (EBa)	331	18	18
2007 (EBa)	9076	36	250
2008 (C)	39,550	30	1337

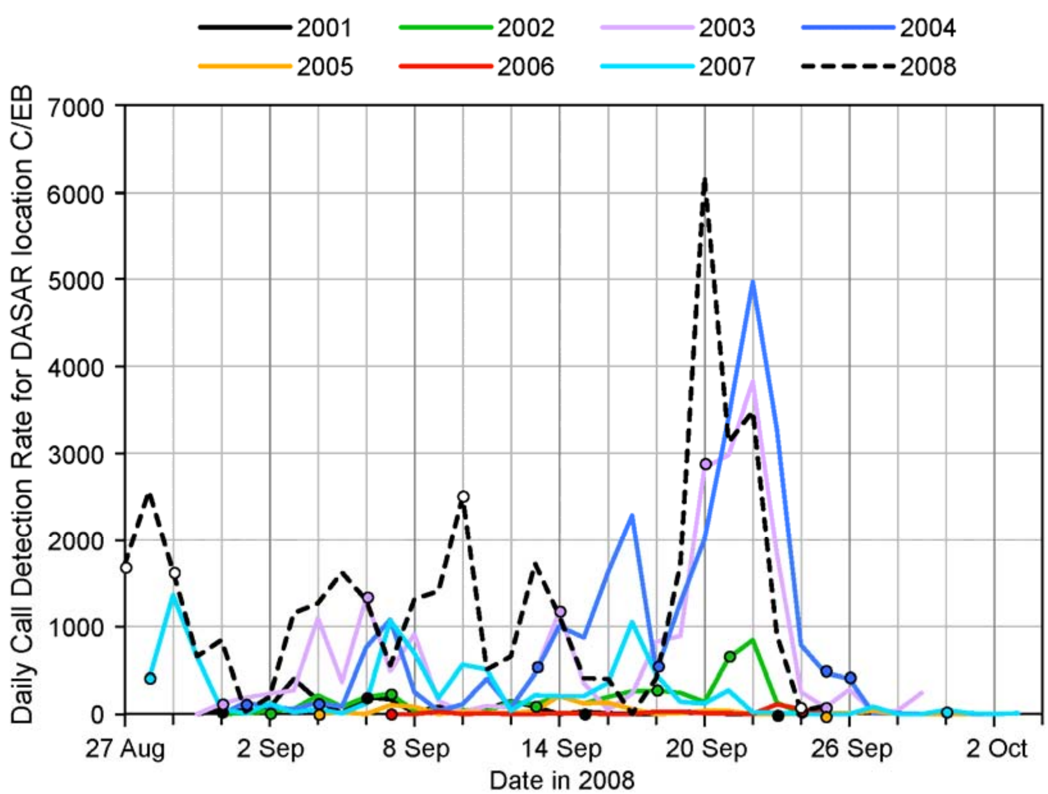

FIGURE 4.4. Daily number of bowhead calls detected by DASAR location C and EB for the entire 2001–2008 seasons. Note that in 2001, 2002, 2005, and 2006 the total number of calls at location EB never exceeded 1000 calls/day. Daily counts marked with a dot indicate days when the acoustic vessel went into the area of the DASAR array to service the DASARs. In 2002–2007 the calls detected at those times are not included and those days are therefore "incomplete". In 2001 and 2008 all calls were counted, regardless of the presence or absence of the acoustic vessel.

BEARING ANALYSES AND WHALE CALL LOCATIONS

In 2008, nearly 86% of the 85,669 whale calls were recorded by two or more DASARs. Figure 4.5 shows the estimated locations of these calls in relation to Northstar and the ten-DASAR array. 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 from the DASARs.

Table 4.2 summarizes the main results of the bearing analyses. Location C (2008)/EB (2001–2007) is the only DASAR location for which eight consecutive years of bearing data exist. Considering all eight seasons (2001–2008), vector mean bearings to the whale calls detected at location C/EB were most often (in 7 of 8 cases) in the northeastern quadrant (specifically in the range 33°–78°), i.e., the offshore range. The longest mean vector length (L), i.e., the strongest tendency for calls to be toward the NE–ENE direction, was in 2002. Predictably, 2002 was also the year with the highest O/I ratios, i.e., the highest number of offshore calls in relation to the number of inshore calls. The vector length value for 2008, 0.53, was well within the range for previous years, and similar to the value obtained in 2003. Out of eight years, the O/I ratio in 2008 was the third highest, with ~5× more calls offshore than inshore (Table 4.2).

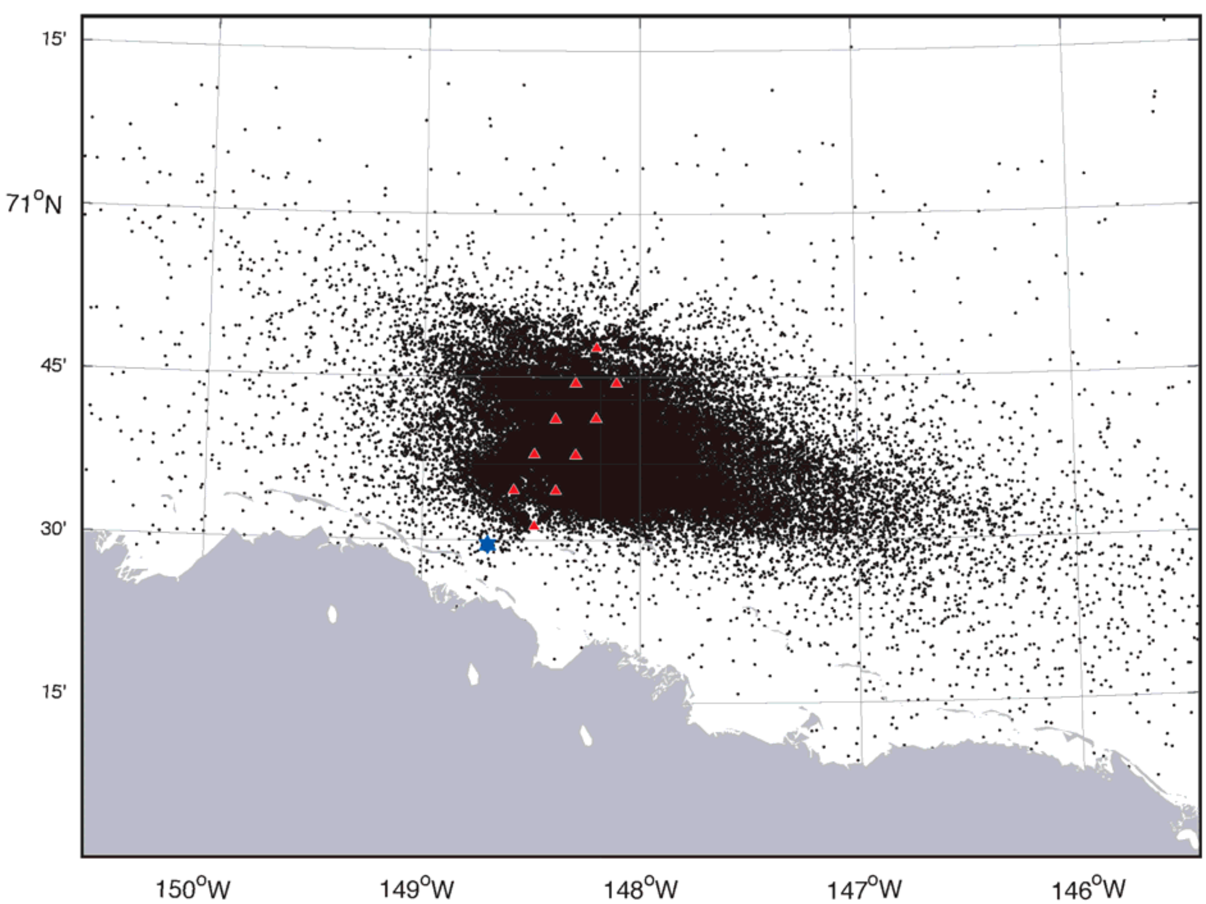

FIGURE 4.5. Estimated locations of all whale calls that were detected by two or more offshore DASARs in 2008. Northstar is shown as a blue star and the DASAR locations as red triangles. Calls recorded by the near-island DASARs were not used in the location estimations. Location accuracy increases with the number of DASARs used for each position calculation and decreases with distance from the array.

TABLE 4.2. Results of the bearing analyses for location C (2008)/EB (2001–2007). α is the vector mean bearing in degrees True, and L is the length of the mean vector (see Fig. 2.8). O/I is the ratio of number of offshore versus inshore calls. See Chapter 2 *Methods* and Figure 2.9 for more information on O/I ratios, and Figure 4.2 for a map of DASAR locations.

Year	α (°)	L	O/I
2001	44	0.65	5.7
2002	64	0.74	13.6
2003	78	0.55	2.5
2004	69	0.42	2.4
2005	348	0.14	1.3
2006	33	0.46	4.0
2007	75	0.45	2.9
2008	59	0.53	5.1

Figure 4.6 shows the percentage distribution of all bearings obtained by the DASAR at location C/EB in each year from 2001 to 2008. 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 C/EB for that season. These plots emphasize the preponderance or rarity of bearings in certain directional sectors. For example, the 2008 plot shows that bearings in the range 135°–270° were very rare that season, whereas bearings in the range 85°–105° were most common. The distribution of bearings in 2008 is very similar to those in 2002–2004 and 2007.

Data shown in Figure 4.6 lend support to the hypothesis that bowhead whale calls are directional, with higher received levels in front of the animal compared to behind it. There is some equally indirect evidence of call directionality for bowheads migrating in spring (Clark et al. 1986). Another hypothesis is that these patterns are explained by differences in whale calling behavior. Based on an analysis of bowhead calls in 2001–2004, Blackwell et al. (2008) showed that call detection rates were significantly higher to the east of Northstar than to the west, after allowance for physical and environmental covariates. It is unlikely that the DASARs would have a bias towards picking up signals from the east if the calls are equally strong "ahead of" and "behind" the predominantly westbound whales. Nevertheless, in 2008 data were collected to address this issue of directionality in calls. These data are currently being analyzed and will be presented in a future report.

CALL TYPES

Figure 4.7 shows a percentage breakdown of all bowhead whale calls detected by DASARs at location C/EB by call type for 2001–2008. Calls are broken down into two main categories: simple calls and complex calls. Simple calls are further broken down into four sub-categories: upsweep, downsweep, constant call, and undulated calls. Until 2007 undulated calls were split into ∪-shaped and ∩-shaped undulated calls, but some undulated calls fit neither of these categories. A third category of "other" undulated calls was therefore created. For the sake of comparison between years undulated calls are hereafter treated as one category. Figure 4.8A shows that the call breakdown at DASAR C in 2008 was similar to the overall call breakdown at all 2008 DASARs. Figure 4.8B shows the percentage of simple versus complex calls in 2001–2008. Simple calls varied in the range 69 to 87% in 2001–2007, compared to 83% in 2008.

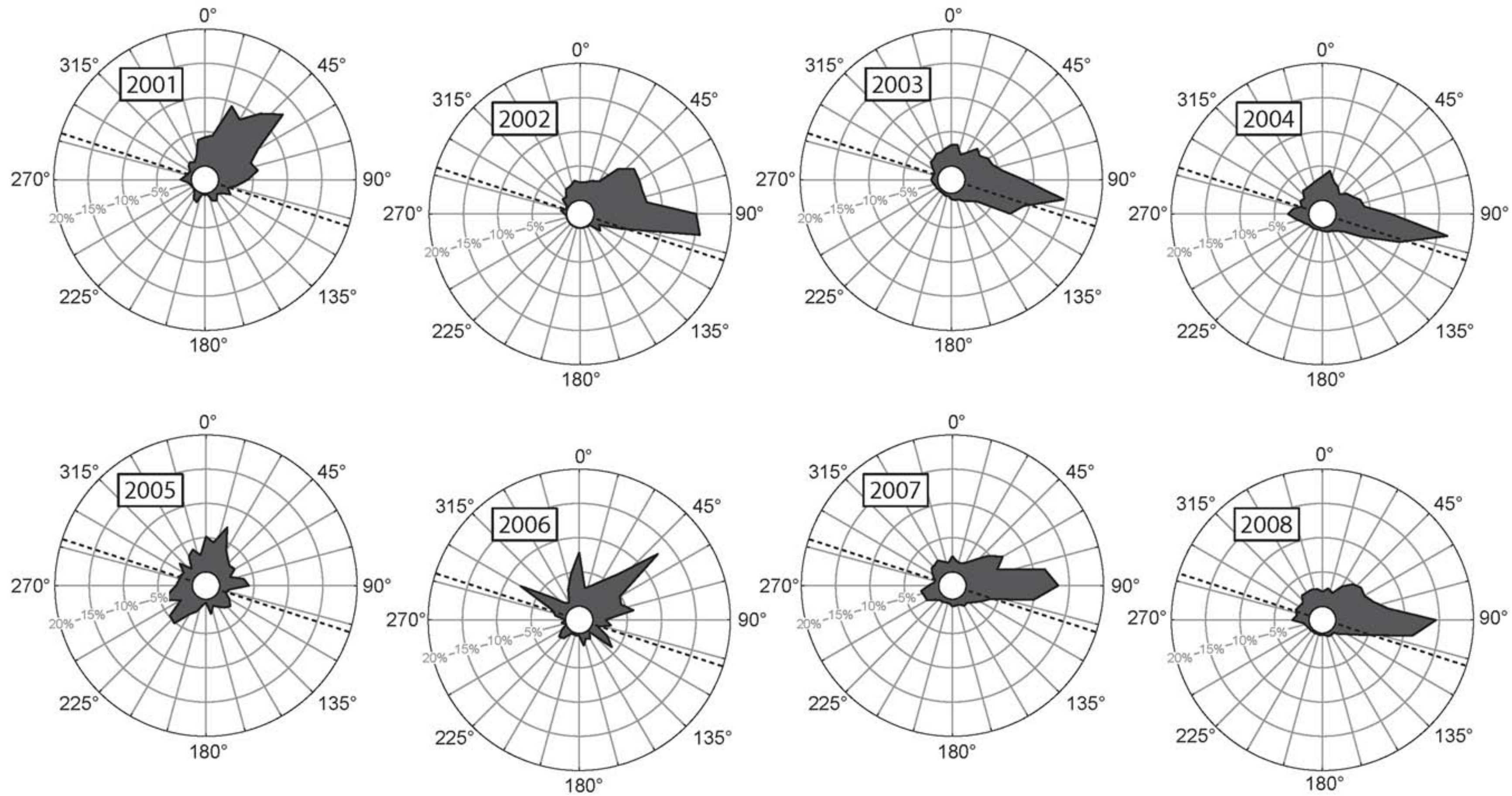

FIGURE 4.6. Directional distribution of bearings to bowhead whale calls detected via DASAR C/EB in 2001–2008. Results for each 10° sector are expressed as a percentage of all bearings obtained via the DASAR at location C/EB that year. The orientation of the baseline (see text) is shown as a dashed line through each DASAR. Sample sizes vary widely, from 332 in 2006 to 39,550 in 2008.

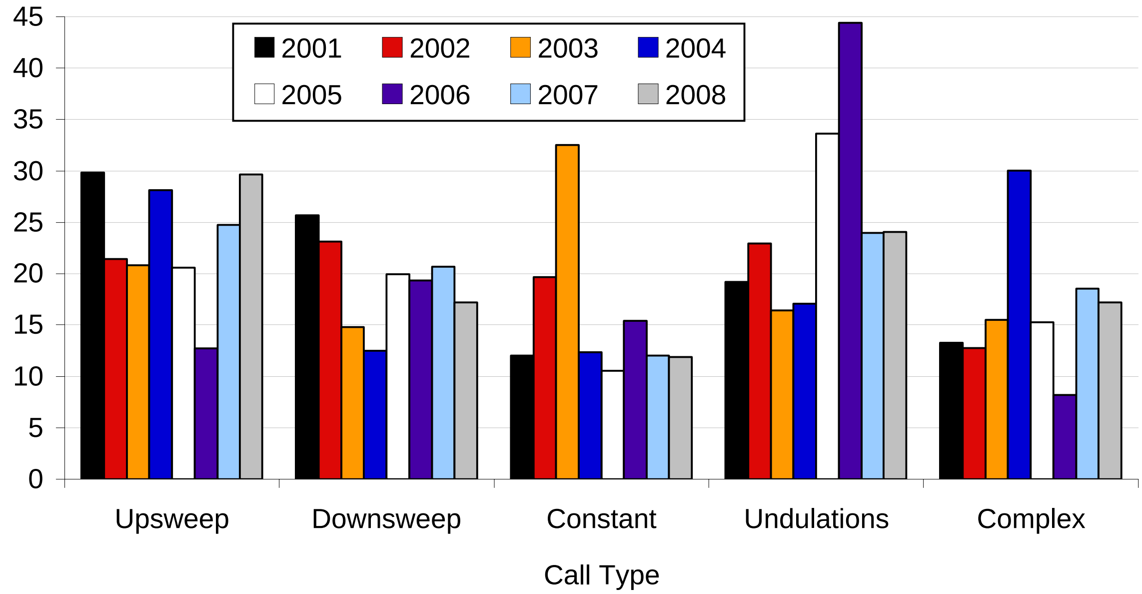

FIGURE 4.7. Percentage breakdown by call type in 2001–2008 for calls detected by DASARs at location C/EB. Simple calls include upsweeps, downsweeps, constant calls, and undulations.

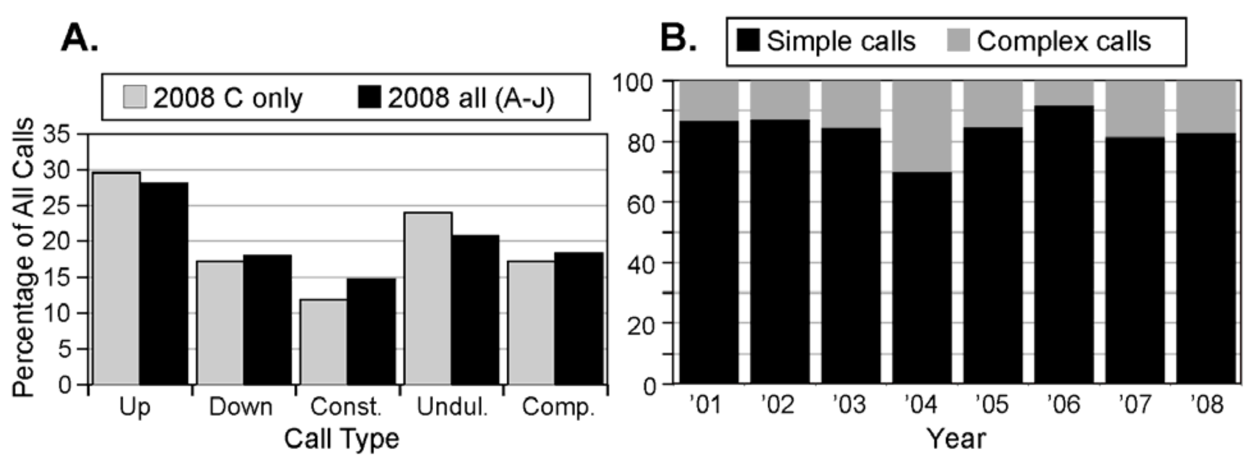

FIGURE 4.8. Comparisons of percentage breakdowns by call type. ***(A)*** Call types detected in 2008 by DASAR C (gray bars) versus all array DASARs (black bars). Simple calls include upsweeps, downsweeps, constant calls, and undulations. ***(B)*** Percentage of simple (black bars) vs. complex (gray bars) calls in 2001–2008.

DISCUSSION

The fall migration of bowhead whales has been monitored acoustically offshore of Northstar Island since 2001. In the first four years (2001–2004) the procedure was roughly the same. In 2005–2007 it was changed on the basis of the results obtained during 2001–2004. The 2008 season was similar to 2001–2004 with regard to the number of DASARs, but the configuration of the array was different, with DASARs farther offshore than in 2001–2004 (both configurations are shown in Fig. 2.2, Chapter 2). The summer of 2008 was considered a low ice year in the Alaskan Beaufort, with open water along the entire

Alaskan Beaufort Sea coastline. Several studies (Moore 2000; Treacy et al. 2006) have shown a relationship between ice coverage and bowhead whales' traveling distance from shore during the migration, with whales traveling farther from shore in heavy ice years. Based on this, and on the call data collected at DASAR site C/EB (Table 4.1), the increase in the number of bowhead whale calls recorded in 2008 and 2007, compared to the heavy ice years 2005 and 2006, was expected. Every year since 1979, systematic aerial surveys of bowhead whale fall migration have been funded and/or conducted by the Minerals Management Service (MMS) and its precursor the Bureau of Land Management off the north coast of Alaska. Their data serve as a confirmation, on a much larger scale, of the relative numbers of whale calls detected on the DASAR array from one year to the next. For example, until 2008, the year with the peak number of calls detected in the DASAR array was 2004. During the aerial surveys by MMS in 2004, sightings of bowhead whales were on average closer to shore than in previous years (1982–2001; Monnett and Treacy 2005). Preliminary data for aerial surveys during the 2008 season are available, but have not yet been examined. The high number of whale calls detected by the DASARs in 2008 is confirmed by the observation of the Nuiqsut whalers that whales were closer to shore during the 2008 fall hunt compared to previous years (see Chapter 5).

The distribution of call locations in 2008, shown in Figure 4.5, bears similarities to the distributions seen in 2003 and 2004, with an overall large number of calls and a high density of calls within the bounds of the complete DASAR array (as deployed in each respective year, see Fig. 2.2). As seen in 2003 and 2004, there were more calls detected to the east of the center of the array than to the west (see Fig. 4.5). The distribution of calls detected by different DASARs, shown in Figure 4.2, seems to indicate that in 2008 the central portion of the migration corridor passed through the center of the offshore DASAR array (close to DASAR E). The bowhead migration corridor is known to extend much farther north, but most whales travel 20–60 km from shore (Treacy 2002; Monnett and Treacy 2005; Treacy et al. 2006). DASAR E was located about 36 km from shore, i.e., almost at the center of that preferred range.

The distribution of bearings to whale calls from DASAR C in 2008, as shown in Table 4.2 and in Figure 4.6, was similar to those in 2002–2004 and 2007, four other years when the migration path offshore of Prudhoe Bay was unimpeded by ice. In these years the majority of bearings were in the 75°–105° range, i.e., roughly from the east. In contrast, in a heavy ice year like 2005, bearings were spread out in various directions, as shown by the small value of the mean vector length (L = 0.14 in 2005, Table 4.2). It is possible that in ice-free years the whales' migration path is more steadily directed westward, leading to the patterns seen in 2002–2004, 2007 and 2008.

The call type analysis (Figs. 4.7 and 4.8) showed that the use of different call types in 2008 was within the range of previous years. Changes in the percentage use of different call types from one year to the next are difficult to interpret, because little is known about the behavioral significance of bowhead call types. Call type percentages are not uniform across DASARs in the array, neither in space nor time, which seems to indicate that external stimuli affect the choice of call type by a migrating whale. Recent exploratory analyses of correlations between sounds from Northstar and bowhead whale calls recorded in 2001–2004 have indicated an increase in the use of constant-frequency calls from east to west as a function of the levels of tones recorded by near-island recorders (Blackwell et al. 2008). In addition, relative use of complex calls increased from east to west, irrespective of sound levels as recorded by the near-island recorder.

This preliminary analysis of the whale call data collected in September 2008 has shown that the bowhead migration corridor was relatively close to shore, resulting in the highest number of call detections to date (over the period 2001–2008). The new array design extends farther offshore, so higher numbers of call detections would be expected from that change alone. However, call detections at location C/EB, for which call detection records exist since 2001, confirmed that 2008 was a record year in terms of whale call detections. There were several similarities between 2008 and other low-ice years, such as 2003, 2004, and 2007: (a) a high overall call detection rate; (b) many call locations within the DASAR array, as opposed to offshore as in 2001, 2002, and to some extent 2006; (c) a similar spread of bearings at DASAR location C/EB, with most calls coming from the 75°–105° range; (d) call locations spread both east and west of the DASAR array (as opposed to 2001 or 2006 when very few calls were detected west of the array); (e) the timing of the peak call detection rate, which occurred close to 20 Sep in 2008, 2003, and 2004. The objective of this study is to assess the effects of Northstar sounds on bowhead whale behavior. In 2008 many airgun pulses were detected on the records of DASARs in the offshore array (see Chapter 3). These airgun pulses constitute a substantial confounding factor that will need to be taken into account in the analyses. How to do this is currently being investigated; results will be presented in a future report.

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Since 2000, and again in 2008, Alaska Clean Seas' captains and crews on the Bay-class boats made the ocean work near Northstar and offshore in the DASAR array safe and successful: we thank Tom Flynn, Lewis Hiatt, Allan Lindstrom, Brian Miller, Mark Stopha, and Brian Wamack. ACS supervisors and coordinators Jim Nevels, Royce O'Brien, Tom Flynn, and Gary Seims made the scheduling and personnel assignments work. Guy Wade (LGL) helped with DASAR deployments and retrievals. From Greeneridge Sciences, Dave Christian tested and prepared the DASARs for the field season, and Bill McLennan and Bob Norman helped with the data analysis. We also wish to thank the Greater Prudhoe Bay Environmental Advisors Bryan Collver and Bill Dawley, and the Environmental Studies Project Coordinator Tatyana Venegas, who provided helpful logistical connections for the Prudhoe Bay fieldwork. We thank Ted Elliott of LGL who produced Figure 2.2. Dr. Bill Streever of BP Alaska supported the project in many ways. He and Drs W.J. Richardson of LGL and Trent McDonald of WEST provided valuable review comments at various stages. Numerous participants in the peer/stakeholder group convened by NMFS provided guidance and support. We thank them all.

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ANNEX 4.1: VISUAL OBSERVATIONS OF MIGRATING BOWHEAD WHALES FROM THE NORTHSTAR PROCESS MODULE

Visual observations were conducted from 21 to 23 Sep 2008 by a marine mammal observer from the process module at Northstar Island, which is the highest point on the island that can be safely reached by a person (Fig. 1; height is ~33 m or 109 ft). The purpose was to test the feasibility of collecting visual data of bowhead whales that would allow a meaningful comparison with acoustically detected bowhead whales. Although there is annual variation in migration patterns, the end of September was chosen because in most years a peak in call detection occurred during this period and this was again the case in 2008 (see Fig. 4.4).

The marine mammal observer scanned an area of ~180^{o} north of the module with the naked eye, using a reticle binocular (Fujinon 7x50) or Zeiss binocular (20x60) with stabilizer and built-in reticles to confirm sightings and estimate the distance.

Observations were made during a total of 22.1 daylight hours. During this period no bowhead whales (or other cetacean species) were sighted. There were 11 sightings of ringed seals at distances of ~50–1,500 m and 3 bearded seal sightings at ~75 m (these sightings included repeat sightings of possibly the same animal). Visibility conditions ranged from 0.2 km to more than 10 km, with visibilities of 1 km or less occurring 30% (= 6.6 hrs) of the observation time (Fig. 2). The cut-off distance at which whales could be reliably detected was estimated at 5 km (a detectability curve could not be calculated due to the lack of sightings).

Results from the call analyses revealed that ~10 bowhead calls were detected and localized within 5 km of Northstar during the hours of observation (Fig. 3). This includes all calls, which means that some (or all) calls within this 5 km circle can have a large localization error.

Based on the number of detected calls close to Northstar compared to those further out in the array and the lack of any bowhead sightings, visual observations from the Northstar module do not seem to be very useful.

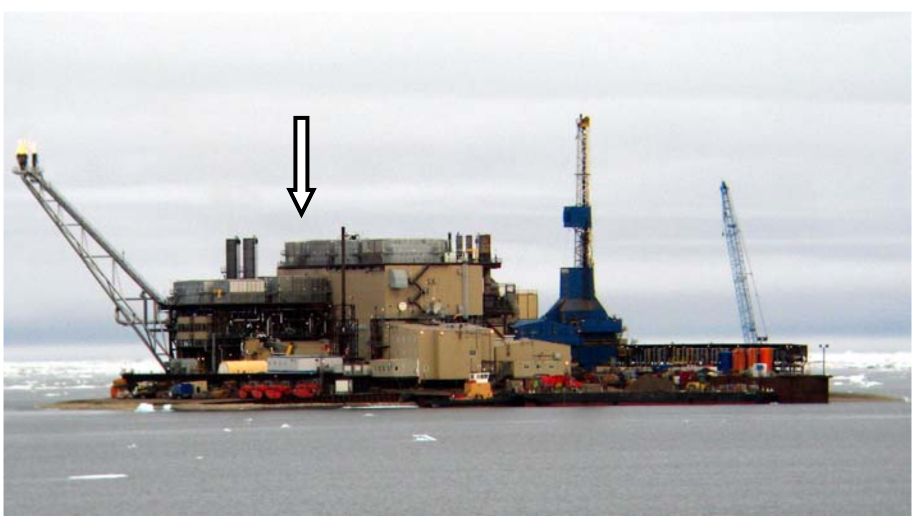

FIGURE 1. Northstar Island (31 Aug. 2006). The MMO observation station on the process module is indicted with an arrow.

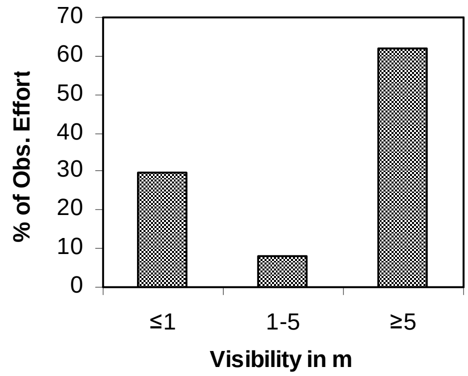

FIGURE 2. Visibility conditions (in percentage) encountered during the 22.1 hours of observations.

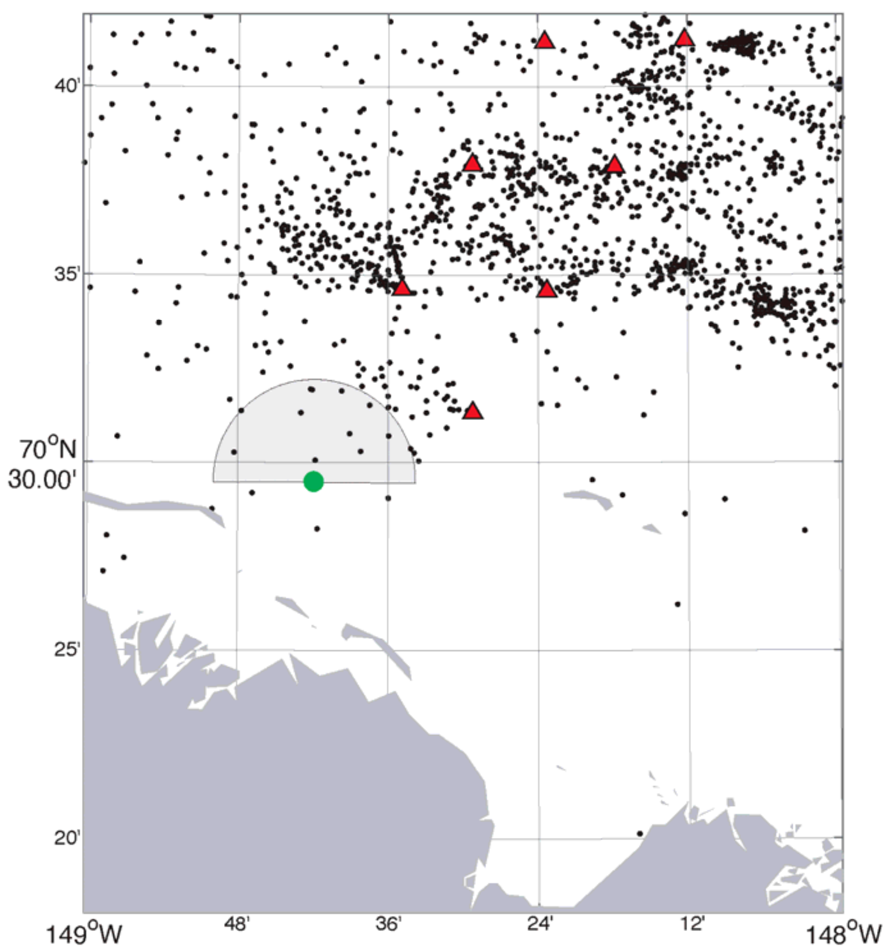

FIGURE 3. Whale calls detected by the array DASARs during the hours of visual observations from the Northstar process module on 21–23 Sep 2008. All calls are plotted, including those with large localization errors. The half circle represents the estimated area in which the observer could reliably detect bowhead whales (depending on visibility conditions).

CHAPTER 5:

SUMMARY OF THE 2008 SUBSISTENCE WHALING SEASON, AT CROSS ISLAND[1,2]

by

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[2] All conclusions and opinions expressed in this report are those of the author and do not necessarily represent those of either BP or the Nuiqsut whalers.

ABSTRACT

The North Slope Borough's Science Advisory Committee has recommended 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 2008 phase of the Minerals Management Service project "Annual assessment of subsistence bowhead whaling near Cross Island". Data analysis and additional interviews with the whalers focusing on specific aspects of the 2008 season relevant to BP's Northstar monitoring program supplemented those data. The interviews concentrated on whalers' encounters or concerns with non-whaling vessels in 2008, the whalers' observations of the general offshore distribution of whales, whale feeding behavior (if any), and "skittish" behavior.

In 2008, a total of six crews whaled from Cross Island. The first whaling crew went to Cross Island on 29 Aug, the second whaling crew on 4 Sep, the third and fourth crews on 5 Sep, and the last two crews on 6 Sep. Wind and sea state conditions prevented any whaling activity until 4 Sep, and the two boats that scouted on that day soon returned to the island as conditions were very rough. Although conditions were still somewhat marginal and highly variable, scouting for whales took place on the following five days (5 through 9 Sep) and single whales were landed on each day except 7 Sep. Whales were seen on each of these five days, but fewer on 6 through 8 Sep than on 5 Sep. Whalers reported most whale sightings on 9 Sep, when wind speeds were low and whales seemed to be closer to Cross Island. On all days when boats went out scouting sea states were quite variable from one area to another, due to swells that ranged from 0.6 to 2 m (2 to 7 ft), making whales difficult to see in general. Despite the overall marginal weather and sea conditions, whales were observed on five of the six days when the whaling crews actively scouted. Because scouting activities were aborted after 48 min on 4 Sep, it can be argued that this day should not count as a scouting day. The Nuiqsut whalers used their full quota of four strikes in a period of five days, and an overall season length of fourteen days. The season consisted of two travel days, one butchering day, five (more likely six) weather days, and six (more likely five) scouting days. Since the four landed whales totaled 38.5 m (126 ft) in length, the captains felt no need to request a fifth strike and announced the end of the Nuiqsut whaling season 9 Sep. All whales were struck at an average distance of 10.5 km (6.5 mi) from Cross Island and were butchered quickly. Most crews were ready to leave Cross Island the day after the fourth whale was struck. All but the crew that struck the fourth and last whale left Cross island on 10 Sep. This last crew left Cross Island the next day, on 11 Sep.

In summary, the 2008 Cross Island hunt was quite successful, and the full quota of whales was landed. Weather and sea conditions prevented any scouting activity on five days, and effectively prevented it on a sixth day, although two boats did "try" to scout on 4 Sep. Two days were used only for travel to and from Cross island, and one day was used for butchering and packing. There were five consecutive days with reasonably favorable scouting conditions, although conditions were still variable and sometimes quite marginal. It was on those five days that Nuiqsut whalers used their four strikes and landed four whales. The proximity of whales to Cross Island in 2008 enabled the whalers to use their full quota on the days when scouting conditions were acceptable. The absence of ice increased the adverse effect of wind, and even on relatively calm days large swells made scouting somewhat difficult. As in previous years, the whalers had a season-long concern with non-whaling vessel traffic, but did not report any specific conflicts. Few, if any, whales were reported to be "spooky" and one captain even stated that "One thing you can say this year [2008] is that the whales are NOT spooky [his emphasis] (Galginaitis 2008 field notes). No whale feeding behavior was reported.

INTRODUCTION

During the autumn migration period of bowhead whales, subsistence hunters from Nuiqsut travel to Cross Island, 28 km (17.5 mi) east of Northstar, in order to hunt bowhead whales. In recent years, a quota of four whales has been allotted to the Nuiqsut hunters. Cross Island is 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 2001, the Minerals Management Service has sponsored a detailed study of the whaling activities at Cross Island (Galginaitis and Funk 2004, 2005; Galginaitis 2006a, 2006b, 2007a, 2009a, 2009b). Each year since 2001, Galginaitis has spent much or all of the autumn whaling season at Cross Island with the Nuiqsut whalers, documenting their activities and interpretations of events. As part of this work, GPS (Global Positioning System) dataloggers have been placed on whaling vessels to document the tracks of the whalers as they scout for whales. Systematic observations and interviews with the whalers supplement the GPS data. The whalers have been very cooperative in supporting this work, and in providing detailed information.

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 has augmented the ongoing MMS-supported program during 2005-08, to compile the specific types of information mentioned by the SAC (Galginaitis 2006c, 2007b, 2008, this report).

This chapter of BP's 2008 Annual Summary Report describes information provided by the Nuiqsut subsistence whalers on selected aspects of the 2008 whaling season. This included the general offshore distribution of whales in 2008, 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 those vessels. To provide broader context, this chapter begins with a discussion of the methods used for gathering the information in this chapter, a very general description of the equipment and methods used for fall subsistence whaling, and a brief summary of the 2008 subsistence whaling season at Cross Island. That introductory summary mentions some factors that may limit the conclusions that can be drawn, e.g., lack or scarcity of observations, indeterminate causes, or possible multiple cause-effect linkages. This chapter deals almost entirely with the 2008 season, which sets definite limits on the conclusions that can be drawn. Some comparative information from previous years is mentioned briefly. More details for prior years can be found in earlier reports prepared for MMS (Galginaitis and Funk 2004, 2005; Galginaitis 2006a, 2006b, 2007a, 2009a, 2009b).

METHODS

The objective of the MMS Cross Island project is to describe Cross Island whaling using measures that document year-to-year variability in whaling and, when sufficient time series data are available, 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 non-industrial human activities. During the MMS-sponsored project, 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, including the number and location of whales observed and/or struck by the whalers.

Information on the level of hunting effort was collected by systematic observations by the author of this chapter (MSG), who was on Cross Island for most of the whaling season in each of 2001–2008. This information was supplemented by conversations with all of the boat crews. Further information on the hunting effort, and on the abundance and distribution of whales, was obtained by issuing Garmin handheld GPS (Global Positioning System) units to all boats operating from Cross Island. The whalers were given instructions on how to record the GPS coordinates (track) of the boat's 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 forms 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 the boat's positions at times a whale or group of whales was seen, or some other significant event took place. Whales sighted may be quite close or miles away, depending on the conditions during that day.

The information collected with the GPS units was supplemented by subsequent conversations with the whalers in English and reviews of the mapped GPS information with each boat crew. During this review of boat tracks shortly after the whalers returned from their trips crew members would often remember and identify locations where they saw whales, and these points were added to the recorded GPS information. Some of these points were boat positions, and some were estimated positions of whales (and thus not located on a boat track). Other points were reference coordinates and may represent past whale sightings, so they also may not be located on boat tracks. MSG 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.

Supplemental systematic interviews that focused on those topics of particular concern to BP were conducted both on Cross Island and in Nuiqsut after the whaling season. These interviews were primarily with whaling captains or senior crew members who had encountered non-whaling vessels while scouting for bowheads or who had other significant information to share. These interviews were guided by an informal protocol developed to record such information within the context of the documentation of that day's scouting/whaling activities. Thus there were no "sampling" issues per se—information was collected from all crews for all whaling trips, and especially for those encountering other vessels or who had other significant information they were willing to share. A more detailed description of the methodology can be found in Galginaitis and Funk (2004, 2005) and Galginaitis (2006a, 2006b, 2007a, 2009a).

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 information in this section is intended to provide only enough detail to provide an adequate context for the results of this report. For a broader review, see Stoker and Krupnik (1993), Rexford (1997), Brewster (2004), or the first two chapters of Wohlforth (2004).

The community of Nuiqsut is located about 25.7 km (16 mi) inland ("as the crow flies") on the Colville River. Nuiqsut crews harvest whales only in the fall. Their whaling location is Cross Island, about 117 "direct" km (73 mi) or 148 to 175 "water" km (92 to 109 mi) from Nuiqsut. Cross Island is located about 16.1 km (10 mi) north of Endicott, 24.1 km (15 mi) NW of West Dock, and 27.4 km (17 mi) east of Northstar. There are currently seven active whaling crews in Nuiqsut. Six of these whaled in 2008. There are also some additional identified crews that have not whaled since at least 2000. Whether a crew goes out during any specific season depends upon the captain's personal and economic circumstances. Some crews use more than one whaling boat. Whaling boats are generally 5.5 to 7.3 m (18 to 24 ft) long, with aluminum or fiberglass hulls, and single outboard motors of 70 to 250 horsepower. The bylaws of the Alaska Eskimo Whaling Commission (AEWC) specify the equipment (weapons, harpoon, float) to be used for the whale hunt, and the general manner in which it is to be conducted. Figures 5.1 and 5.2 provide images of the equipment used for Cross Island whaling in 2008 – darting gun, float, shoulder gun, and the boats used by five of the six crews (Ahkiviana boats not pictured).

Nuiqsut whalers will 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. However, this pattern may be changing. In 2006, Nuiqsut crews landed single whales on three successive days, apparently because the whales were relatively small and the whalers wanted to take advantage of a period of good weather for scouting (Galginaitis 2007a, 2007b). In 2007, they purposely landed two whales on one day in order to complete their quota and close their season due to the uncertainty of future conditions for whaling (Galginaitis 2008, 2009a). In 2008, Nuiqsut whalers landed four whales in the space of five days, again because they wanted to take advantage of relatively good weather conditions after a period of unfavorable weather and before conditions deteriorated again (Galginaitis 2009b). Whalers invariably use the term "scouting" rather than "hunting" to describe looking for whales to strike. Good whaling weather is determined more by wind speed and sea conditions than anything else. Whalers prefer days with no wind, but winds up to 8 to 16 km/h (5-10 mph), or even higher, can be acceptable. Sea conditions generally correspond with wind speed, but scouting can occur even with higher winds, depending on the circumstances. Ice cover, especially when the ice edge is not too far from shore but also to some extent floating ice floes, generally moderates the effect of wind by dampening wave height. During the period of the MMS research (2001 to present) the ice edge has always been quite distant from shore, and significant ice floes have been mostly absent. There were some large ice floes present in 2001, fewer in 2002, and almost none of significance since then. In 2005 and 2006, localized consolidated pack ice along the north shore of Cross Island limited the area where Nuiqsut whalers could hunt for whales.

Boats typically scout for whales with a complement of three or four people, although since 2001 boat crews ranged in size from two to seven, and during the 2008 season it ranged from two to five persons. Although solitary boats do take whales on occasion (for example the first two strikes by Nuiqsut whalers in 2007 were conducted by boats scouting alone), it is not encouraged. Nuiqsut boats almost always scout for whales with at least one other boat, in case of mechanical break down or other emergencies. Whaling crews with two or three boats are willing to whale without the support of other crews, and this is one reason for a single crew to use more than one whaling boat. It is still commonly agreed that five to seven boats is a preferable number to have available for scouting whales on a given day, and in 2008 the average number of boats that went out scouting was 5.4. The availability of fewer boats decreases the efficiency, safety, and overall chance for success of the hunt.

Once Nuiqsut whalers spot a whale and determine that it is a proper whale to take (generally 7.6 to 10.7 m [25 to 35 ft] long, and not a mother with a calf), they will approach it at high speed so that it dives. They will then estimate where it will reappear (usually in 5 to 10 min, but sometimes longer) and once they reach that area will wait and search at low speed until the whale surfaces and is spotted. They will then repeat the process. 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 get close enough to strike the whale on its left side with the darting gun. The whale is killed by the delivery of whale "bombs", which are in essence very large bullets with timed fuses (generally 4 to 8 s) that explode inside the whale. Inupiat whalers adopted this technology from the commercial Yankee whalers. The whale bombs are delivered to the whale via two methods: a darting gun attached to a harpoon, or a shoulder gun.

During fall whaling, the first bomb is delivered via a darting gun, which at the same time deploys a harpoon with an attached float. 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 3 or 4.6 m (10 or 15 ft), and ideally closer. Once the whale is struck, the harpoon separates from the handle. A trigger rod fires the darting gun and 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, and sometimes two, darting guns on board. The second weapon used to deliver whale bombs is the shoulder gun—a very heavy, short barreled, high caliber "rifle" used to shoot the same sort of black-powder bomb as is used in the darting gun, only with fletches or 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 with a darting gun. The first bomb kills some whales. However, when multiple bombs are required, the shoulder gun is useful because it can be used to fire more than one shot.

Until recently, all Nuiqsut whalers used the "traditional" black powder bombs – technology adopted from the commercial Yankee whalers. All captains, or a trusted member of a captain's crew, loaded and assembled these bombs each year, often only after reaching Cross Island, due to the hazards involved. As discussed above, the darting gun and shoulder gun black powder projectiles are essentially the same. The more recently developed "super bomb" can only be used on a darting gun, with a specially modified barrel. It is manufactured in Norway, uses penthrite instead of black powder, and is designed to kill whales faster than a black powder bomb. It is a product of the interest in developing more efficient weapons for subsistence whaling, but development has been somewhat delayed due to the relatively small demand and its somewhat complicated operation compared to the black powder bomb (Øen 1995; Sadler and Grønvik 2003; AEWC 2006).

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 usually approached and struck on the whale's left side, since the boat normally "catches up" to the whale from behind it in order to achieve a striking position. Nuiqsut whalers report that whales are sometimes approached and struck from the front, but that this is unusual and has not occurred at Cross Island during the course of the MMS project (2001-present).

Once the whale is dead, all available boats assist in towing it back to Cross Island to be butchered. It is hauled up on the beach with mechanical assistance. All cutting is done with an assortment of knifes 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.

The harvest of bowhead whales by crews from Nuiqsut is displayed in Table 5.1. Because Nuiqsut was resettled in 1973, years before 1973 are not included in this table.

FIGURE 5.1. Left to right, top to bottom – NOAA archive photo, cleaning shoulder gun, wrapping rope on float (to attach to darting gun), unloaded new whale bombs (quarter for scale), some fragments of exploded bombs recovered from whales

FIGURE 5.2. Clockwise from the top left – Boat with darting gun, bucket for float rope, crew of three (float in back of boat – photo from 2004), Napageak boat, Taalak boats, Oyagak boats, Nukapigak boats, Ipalook boats.

TABLE 5.1. Recent harvest of Bowhead Whales Near Cross Island.

Year	Whales			Notes
	Quota	Landed	Struck & Lost	
1973	NA	1	0	
1982	1	1	0	
1986	2	1	0	
1987	2	1	0	
1989	3	2	2	Oil industry vessel disturbance noted by whalers
1990	3	0	1	Oil industry disturbance noted, also rough seas
1991	3	1	2	Poor weather, adverse ice conditions
1992	3	2	1	
1993	3	3	0	Very favorable whaling conditions
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 whaling conditions
2001	4	3	0	Whalers report whales tended to be "skittish"
2002	4	4	1	
2003	4	4	0	Poor weather
2004	4	3	0	Poor weather
2005	4	1	0	Very poor weather, adverse ice conditions, disruption
2006	4	4	0	Adverse ice conditions first half of season
2007	4	3	1	Overall poor weather, little ice, whales close
2008	4	4	0	No ice, generally poor weather and rough/variable sea conditions, whales close to Cross Island

Notes: Years of no harvest and no "struck and lost" are not listed. This does not imply that no whaling effort was made in those years. "Quota" was not applicable prior to 1978. It is not clear from the records (or informants) when the quota for Nuiqsut increased to 2 whales and then to 3 whales (1983-1991 documentation is not definitive. Values provided for these years are best guesses based on inconsistent information).

Sources: Compiled from AEWC records, personal communications with Nuiqsut whalers, and field notes from the 2001–2008 whaling seasons.

THE 2008 WHALING SEASON

This section contains a general overview of the 2008 Cross Island whaling season. Annex 5.1 provides more detail on a day-by-day basis for both whaling activity and other vessel traffic noted in the Cross Island area.

Six crews whaled from Cross Island in 2008. One of these was a newly formed crew with a captain who had whaled for many years as the co-captain of an existing crew. One crew whaled with one boat, three whaled with two boats, and one whaled with three boats. The sixth crew went to Cross Island with one whaling boat and one "support" boat, but was joined late in the season by a second whaling boat that scouted only one day. This was the only crew in 2008 that used a boat for logistic support. As in previous years, the start of the Cross Island whaling season depended primarily on weather conditions, reports of whale sightings near Cross Island, and the readiness of the whaling boats. The whalers landed their full quota of four whales, as summarized in Table 5.2.

TABLE 5.2. Summary Characteristics[1] of Whales Struck Near Cross Island, 2008

Date	Time Struck	Length	Sex	Whale ID	Miles from Cross Island	Bearing from Cross Island	Notes
09/05/08	17:30	32'5"	F	08N1	5.2	315˚	Ipalook
09/06/08	15:58	29'5"	F	08N2	6.8	341˚	Napageak
09/08/08	09:47	29'0"	F	08N3	6.1	12˚	Oyagak
09/09/08	12:29	35'3"	F	08N4	7.8	72˚	Nukapigak

[1]All characteristics are from direct observations or GPS records made on the day of the activity, other than the Whale ID number. Whale ID numbers are assigned by the North Slope Borough Department of Wildlife Management (NSB DW). Times are approximate and are derived from the recorded GPS tracks and/or radio logs, combined with whalers' accounts, as are the distances from Cross Island.

The first crew left for Cross Island on 29 Aug in order to repair their cabin (a polar bear had damaged it since the end of the 2007 season) and to scout for "early" whales before the other crews arrived on Cross Island. Once on Cross Island, this crew was shorebound due to bad weather for five days. On the sixth day, 4 Sep, weather conditions allowed them to "try" to scout but the two boats stayed out only about 48 minutes and probably did not go beyond the Cross Island "lagoon" (no GPS tracks are available for these two boat trips as no GPS units were used). Weather conditions had improved enough later that day that two crews left Nuiqsut for Cross Island. These crews were able to travel since they had "big boats" that, more importantly, had "deep V" hulls that allowed them to handle rough seas and swells better than the boats of the other three crews that remained in Nuiqsut. One of these two crews made it to Cross Island while the other lost its steering near West Dock and stayed overnight at West Dock to wait for parts. The next day (5 Sep) the two crews already on Cross Island went scouting and landed a whale. The crew that had stayed overnight at West Dock/Prudhoe continued on to Cross Island after they repaired their boat and arrived in time to help with the end of the tow. A fourth crew left Nuiqsut and arrived on Cross Island after the tow was over, but before butchering had begun. The next day (6 Sep) the crew that had landed the whale stayed onshore to butcher their whale. The other three crews on Cross Island went out scouting and landed a second whale. The last two crews left Nuiqsut and arrived on Cross Island about two hours after the tow of the second whale. Butchering of the second whale had started but was not too far along while preliminary butchering of the first whale was completed.

On 7 Sep weather conditions were somewhat marginal and only three crews went out scouting, with four boats (one "two-boat" crew left one boat on shore due to the marginal sea conditions). They saw whales but were unable to approach close enough to strike. The other three crews stayed in to butcher. The boat of the crew that had landed the whale the previous day was disabled, effectively ending this crew's whaling season (except for butchering). The next day (8 Sep) all four crews that had not yet landed a whale went out scouting with seven boats (including one boat that scouted only on this one day), and landed a whale. A second whaling boat arrived to assist one of the "one-boat" crews (the one that also had a support boat), but only after the third whale had arrived at Cross island and butchering had started. Butchering of the first two whales was essentially complete. The following day (9 Sep) all three crews that had not yet landed a whale went out scouting with seven boats (including two boats that scouted only on this one day) and landed the fourth and final whale. Preliminary butchering of this whale was completed the morning of 10 Sep, allowing for the distribution of crew shares so that all crews except the one that had landed this last whale were able to pack and leave for Nuiqsut later that day. They desired to leave because boating conditions were good – perhaps the best of the season. According to weather predictions, the conditions were not expected to change very much, but the whalers never assume that good conditions will continue and if the season is over will leave Cross Island as soon as they can. The last crew decided to wait until 11 Sep to leave the island, as they had to process and pack the *uota* or "community share" of the whale they had landed as well as their crew shares of this and the previous whale, and did not want to travel during the night. By the morning of 11 Sep the weather had deteriorated and seas were rough, but the trip to Nuiqsut was relatively uneventful.

Data from the project's weather station at Cross Island provided information on the weather conditions from when it was set up at 00:30 on 6 Sep through 07:56 on 11 Sep. During this period, crews went out scouting for whales on four days, 6 Sep through 9 Sep (and earlier on 4 Sep and 5 Sep). Wind speeds recorded at Cross Island corresponded well with those recorded at Prudhoe Bay for this period (see Figs. 5.3 and 5.4A). Although the magnitudes may have varied slightly at the two locations, the overall patterns were the same. It is clear that whales were struck when winds were relatively low (0.3 to 1.6 m/s, 1.1 to 5.8 km/h or 0.7 to 3.6 mph; Fig. 5.3). Low wind speeds typically correspond with lower sound levels at Northstar (see Fig. 5.4 and more detailed information on propagation of Northstar sounds in Chapter 3).

At least one crew was on Cross Island from 29 Aug through 11 Sep. Whaler reports indicate that conditions on 29 Aug were suitable for travel, but probably not scouting. Conditions on 30 Aug through 3 Sep were not suitable for travel nor scouting – winds were too high and sea states too rough. Conditions on 4 Sep allowed for travel by boats with deep "V" hulls, but not for other vessels and not for scouting (although one crew and two boats tried). Conditions from 5 through 9 Sep allowed for scouting, although there are no weather station readings for 5 Sep. During the period when the weather station operated, the highest wind speed (a constant of 24.1 km/h [15 mph]) was recorded on 11 Sep, when the last crew left Cross Island for Nuiqsut. High wind speeds of 8 to 24.1 km/h (5 to 15 mph) were also recorded on 7 Sep, the only day when boats went out scouting but did not strike a whale. For all other days wind speeds were 16 km/h (10 mph) or less, with 8 to 16 km/h (5 to 10 mph) on 6 Sep, 0 to 12.9 km/h (0 to 8 mph) on 8 Sep, 0 to 11.3 km/h (0 to 7 mph) on 9 Sep, and 0 to 16 km/h (0-10 mph) on 10 Sep. The barometric pressure peaked on 6 Sep at 30.2 and declined steadily to 29.5 on 11 Sep. Wind direction was quite variable, and was NE to E on 6 Sep, NNE on 7 Sep, E shifting to N and then W on 8 Sep, W shifting to N and then E on 9 Sep, NE to SE on 10 Sep, and W on 11 Sep. The whaling seasons for the five crews ranged in length from 5 to 14 days, counting travel days. The seasons for the individual crews were 5, 5, 6, 7, 7, and 14 days. Weather and sea conditions during the 2008 season were similar to those for 2007, but each season is unique. Ice cover was mostly absent, which exacerbated the effects of the wind that was always a factor and the swells that persisted throughout the season (independent of the windspeed at any given time) until 10 Sep. These factors combined to make scouting for whales difficult. Whales were difficult to see, follow, and approach (on some days more than others – most difficult on 7 Sep, easiest on 9 Sep). However, whales were migrating relatively close to Cross Island so the whalers were able to find and strike whales when conditions were acceptable for scouting. The combination of the proximity of whales to Cross Island, a few days with acceptable scouting conditions, and the whalers' willingness to land four whales within as short a period of time as conditions allowed resulted in a relatively short overall whaling season of 14 days. The "average" crew was only on Cross Island for 7.3 days in 2008. In comparison, there was a 13-day season (10.4 days for the "average" crew) in 2007 (Galginaitis 2009a), a 21-day season (21 days for the "average" crew) in 2006 (Galginaitis 2007a) and a 27-day season (21 days for the "average" crew) in 2005 (Galginaitis 2006b). For 2001-2007, the average length for the overall whaling season was 22.4 days, while the length of season for the "average" crew in this period was 16.4 days (Galginaitis 2009b). Thus the 2008 season vies with the 2007 season to be the shortest whaling season documented for the period 2001-2008.

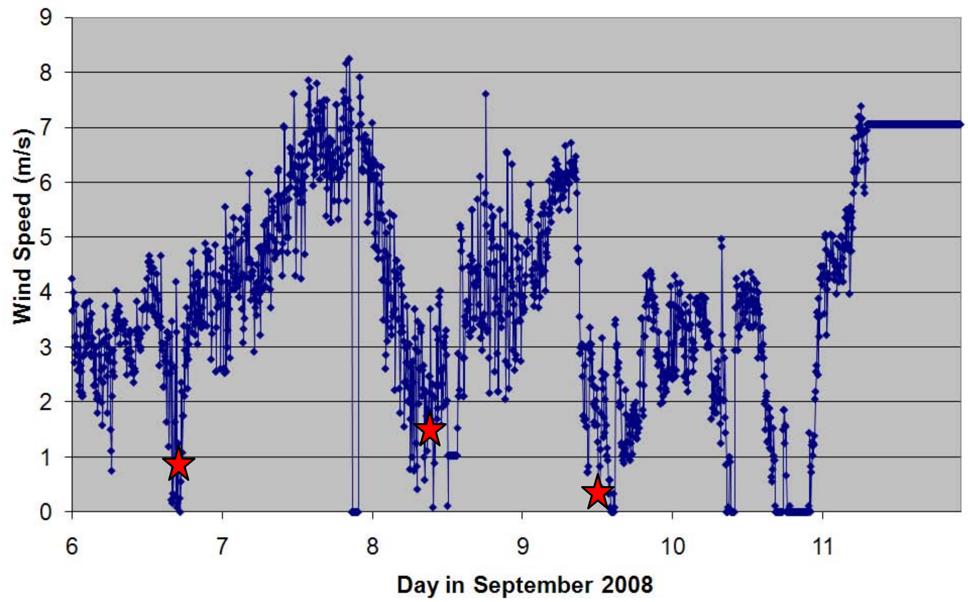

FIGURE 5.3. Wind Speed (in m/s) at Cross Island, 6 Sep – 11 Sep 2008, with date and approximate time of day of whale strikes (red stars). Wind Speed was recorded every five minutes. Source: Galginaitis2009b.

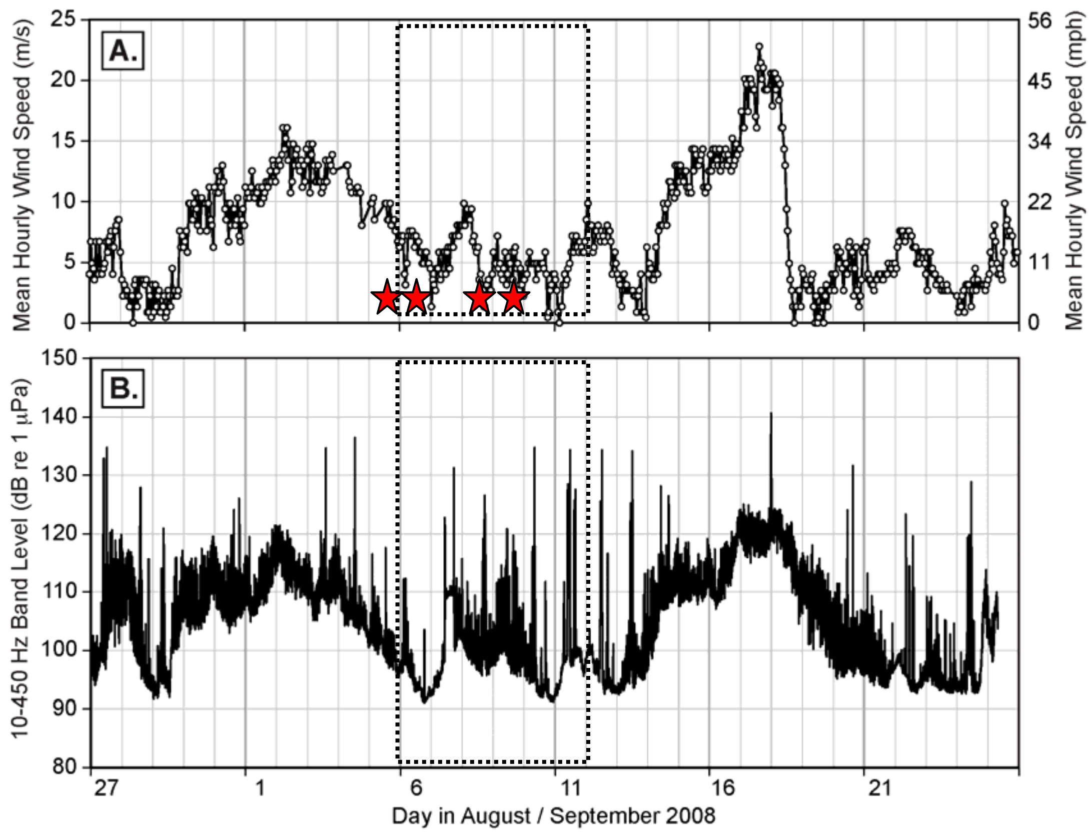

FIGURE 5.4. Variation in levels of underwater sound near Northstar in relation to date and wind speed, 27Aug–25 Sep 2008. ***(A)*** Mean hourly wind speed as recorded by the Prudhoe Bay weather station. ***(B)*** Broadband (10–450 Hz) levels of underwater sound as recorded ~460 m north of Northstar. Vertical spikes in the sound pressure time series are generally produced by vessel arriving at or departing the island. Red stars indicate the days that whales were taken. Dashed squares represent the period in which wind data were available from Cross Island.

The researcher MSG was not on Cross Island for the entire 2008 whaling season, but was able to collect GPS tracks and whaler accounts for all scouting days, except 4 Sep. On that day boats tried to go scouting but aborted the attempt due to high sea states. GPS tracks were collected from most, but not all, boats that went out scouting on all other days. Not counting 4 Sep, there were 27 "boat days" with 33 different scouting trips (since four boats each made two different trips on a single day). For these 33 tracks, 32 are represented by GPS information (97 percent). If 4 Sep is included, there are 29 boat days, 35 different scouting trips, and still only 32 represented by GPS information (91 percent). On 4 Sep, two boats tried to go out scouting, but aborted the effort and returned to Cross Island after only 48 minutes. They did not get far from Cross Island and never turned on their GPS units. The only other GPS track not collected was on 5 Sep, before MSG arrived on Cross Island. The GPS unit used by the boat, a personal and not a project-supplied unit, had the tracking option toggled "off". This was corrected once it was discovered, and will remain a potential problem in the future. To the extent possible, all GPS units are checked before whalers go out on their first scouting trip. The number of boats scouting on any given day ranged from four to seven (and two on 4 Sep). Crews reported spotting whales on all days when at least one boat went out scouting except for 4 Sep, when conditions were so rough that the scouting effort was aborted. The greatest number of whales was seen on 9 Sep, at least three to ten times the number seen on any other single day. Whalers reported seeing "schools of whales all over" and seeing "nothing but whales, of all sizes". When pressed for a numerical estimate, one captain suggested 50, but this is at best a rough guess. On days when so many whales are seen the whalers do not count them and the total number of sightings is at best relative to that seen on other days. It appears that 9 Sep 2008 was one of the two or three days during the term of the project (2001-2008) when the whalers saw the greatest number of whales (along with 14 Sep 2005 and 7 Sep 2007). For other days in 2008 more whales were seen on 5 Sep (12 to 15 whales) than on 6 through 8 Sep (6 to 10 whales each day, although whales were hardest to see on 7 Sep). This is a similar pattern to 2007, where the season had relatively few days when boats went out scouting, and by far the most whales were seen on the last day when boats went out scouting and the last whale of the season was landed.

Figure 5.5 shows all documented GPS tracks for all Cross Island boats for all days in 2008, color-coded by day, along with locations of strikes and other whale sightings. This Figure clearly indicates that whalers stayed closer to Cross Island than in previous years of the MMS project. Whalers again focused primarily on the quadrant northeast of Cross Island, although two whales were struck slightly NW of Cross Island in 2008. Figure 5.6, comparing all GPS tracks for all boats for each season from 2001 to 2008 clearly shows that in 2008 Nuiqsut whalers did not go as far from Cross Island to land their whales as they had in other recent years, although the 2007 season tracks are similar. The combination of overall variable (windy) weather, constant swells, and the presence of whales close to Cross Island likely explains this pattern.

OBSERVED WHALE FEEDING BEHAVIOR IN 2008

There were no reports of whale feeding behavior during the 2008 Cross Island whaling season. This does not necessarily mean that feeding did not occur; however, it is an indicator that whale feeding activity was not very obvious in 2008. Stomach contents were examined from three of the four whales, and all contained a relatively thin reddish liquid with some solids suspended in it. Samples were taken and sent to Barrow, but may have been delayed enough in delivery not to have been usable. Possible explanations for the lack of observed whale feeding behavior, not mutually exclusive, are as follows:

- whale feeding is not commonly observed (or at least not reported) by Nuiqsut whalers near Cross Island (only one incident during the previous seven years);

- most feeding by bowhead whales is known to occur below the surface (e.g., Würsig et al. 1989) where it would be invisible to people in small boats;
- on some days when scouting was possible, swell and waves (due to wind) made spotting and observing whales difficult;
- on days when a relatively large number of whales were observed, most were seen only at a relatively large distance (as blows);
- barge and other vessel activity may have "spooked" whales (although Nuiqsut whalers did not report any specific cases where non-whaling vessels may have influenced whales or whaling activity); and
- a major part of the migration may have bypassed the area accessible to the whalers, as they stayed relatively close to Cross Island (compared to the other years of the study).

For the seven years of the study previous to 2008, only one observation of whale feeding was reported and recorded. This was a spectacular sighting of a whale feeding on the surface with its mouth open, about 12.6 km (7.8 mi) from Cross Island, bearing 34° True. The captain, a very experienced whaler, remarked that this was the first time he had seen this. This does not necessarily indicate that Nuiqsut whalers observed no whale feeding behavior on other occasions in 2001–2008 when scouting for whales. It probably means that such observations were not common or that it is not easy to determine if whales are feeding. Nuiqsut whalers tend not to speculate on what an animal ***may*** be doing – if they are unsure they will usually not say anything. If other obvious feeding behavior had been observed during 2001–2008, 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.

Most feeding by bowhead whales is below the surface and difficult to recognize via surface observations. There have been some previous observations of bowheads feeding actively at the surface in the Canadian and Alaskan Beaufort Sea, with mouths open (Würsig et al. 1985, 1989; Richardson and Thomson [eds.] 2002). The first whale taken by a Nuiqsut crew, in 1973, was reported to have been feeding on the bottom near Flaxman Island. Some other whales landed at Cross Island have been found to have recently-consumed food in their stomachs (Lowry and Sheffield 2002; Lowry et al. 2004). One of the whales taken in 2006 was also reported to have had mud on its jaw, and one of the two stomachs that were examined was quite full (Galginaitis 2007a).

"Skittish" Whale Behavior During 2008

For the most part, Nuiqsut whalers reported that whales were difficult to see and follow in 2008, but because of 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 2008 field notes). A "skittish" or "spooked" whale might be traveling faster, spending more time on the surface, and/or exhibiting a more erratic course than most migrating whales. Such a whale may also stay nearer the ice edge or floating ice (if there is any) than most migrating whales. Thus, spooked or skittish whales are more difficult to follow than other whales. Nuiqsut whalers are also wary of approaching and striking such whales, even if they can follow and catch up with them, since they are less predictable than other whales. In discussions with the whalers during the 2008 whaling season, whales were seldom described as acting in a "spooky" manner.

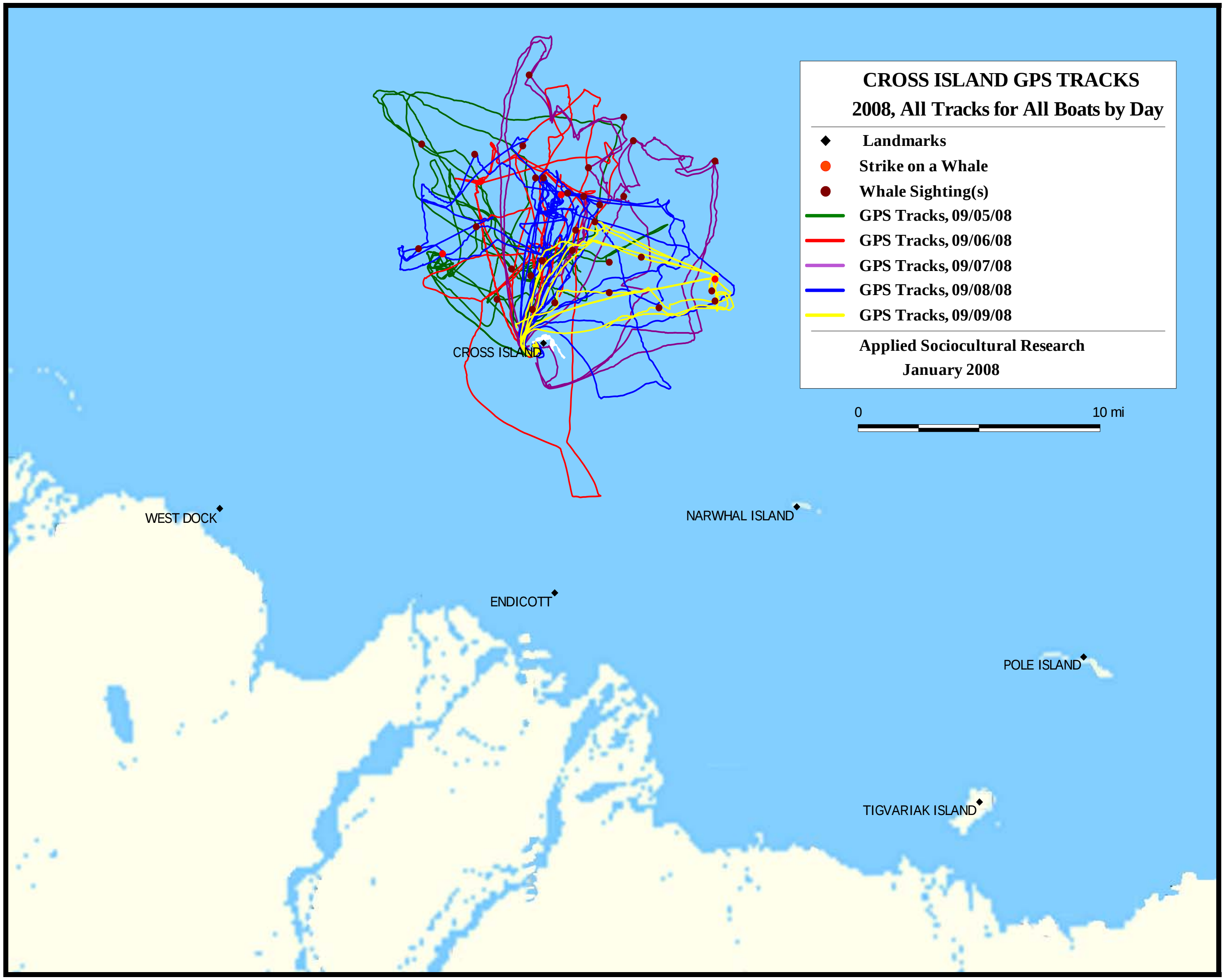

FIGURE 5.5. Cross Island GPS whaling tracks, 2008 season, all tracks color-coded by day.

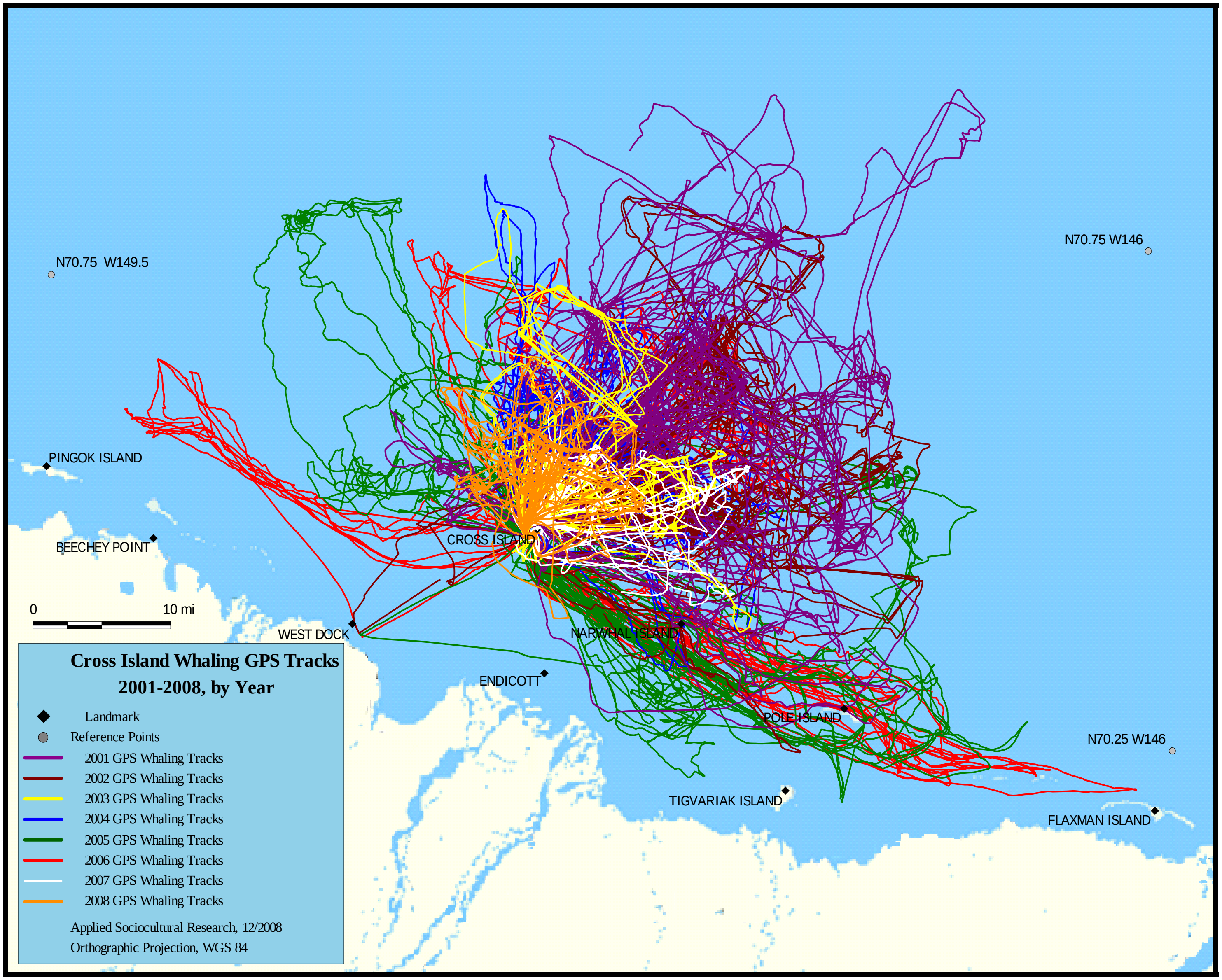

FIGURE 5.6. Cross Island GPS whaling tracks by year, 2001–2008.

In 2001, a season when whalers reported that whales seemed to be much more skittish than normal, they suggested several possible explanations (Galginaitis 2006c). Although Nuiqsut whalers cited industry activities as one possible explanation or factor for this pattern, they said that other explanations were also possible. These other factors were ice conditions to the east of Cross Island, possible presence of natural predators such as killer whales, barge traffic related to the Kaktovik water and sewer project, or other air or vessel traffic to the east of Cross Island. Note that two of these, while not related to oil industry activities, are related to other human economic activities.

GENERAL OFFSHORE DISTRIBUTION OF WHALES, 2008

Although whaling success was good for both 2006 and 2007, there were still relatively few days on which whalers were able to scout in open water and find a good number of whales (5 of 10 scouting days in 2006, 3 of 5 scouting days in 2007). This was quite different in 2008, when whalers saw a good number of whales on all days that they went out scouting (discounting the short trips on 4 Sep, when no whales were seen, but on a day that whalers admitted they went out not because conditions were good for scouting but because they were tired of waiting on shore), and attributed any difficulties to seeing and/or following whales to conditions (high waves and swells) rather than the absence of whales or the skittish behavior of whales. Whales were found relatively far from Cross Island in 2006, mainly because of ice conditions in the view of the whalers (Galginaitis 2007a,b). The whalers were unable to look for whales closer to Cross Island in any event because of the ice. In 2007, the whalers found whales relatively close to Cross Island and as such had no need to travel further offshore. There was little or no ice cover to contend with in 2007. Wind and sea conditions in 2007 would likely have made scouting for whales farther away from Cross Island more difficult and dangerous. The whalers could not determine, and would not hazard an opinion, as to the overall distribution of whales in 2007. They knew that the ones they were seeing were close to Cross Island, but did not know if they represented the bulk of the migration or not.

Similar conditions for whaling from Cross Island existed in 2008 as in 2007. Whales were found close to Cross Island, and there was little or no ice with which to contend. Whalers indicated explicitly that sea conditions were rougher farther from Cross Island. Depending on the daily weather conditions, at about ~8 to 12.9 km (5 to 8 mi) offshore from Cross Island they could no longer spot whales due to the waves and swells. They knew that whales were out that far, since some of the whales they followed in 2008 swam out beyond this distance and vanished, as far as the whalers could tell.

One co-captain indicated that these observations were consistent with the whalers' knowledge of the migration path of the bowhead whale, and how it varies depending on conditions. At least in the past, the edge of the pack ice is "normally" not too distant from shore, and migrating bowhead whales follow this ice edge. If there is considerable floating ice floe coverage, bowheads will migrate close to the floes. When there is little or no ice, the whalers believe that the whales use the barrier islands as navigation aids and are thus closer to shore than in most years with ice. This co-captain also noted the tendency of the coast and the barrier islands to the east of Cross Island to guide such a migration from the SE towards the NW and indicated that is one reason he thought that the area between Narwhal and Cross Islands, and to the north of Narwhal Island (and the quadrant NE of Cross Island in general), was so consistently productive for the Cross Island whalers. He also indicated that Nuiqsut whalers encounter whales moving in all directions, and not just east or northeast. He figured whales going north could be simply moving offshore, while those going east (or other directions) could be feeding. He also indicated that sometimes whales did migrate inside of the barrier islands, and that there was a channel or path between Cross Island and Narwhal Island that was important in this regard.

NUIQSUT WHALERS' REPORTS OF VESSEL ACTIVITIES, 2008

Annex 5.1, at the end of this chapter, summarizes the specific observations of non-whaling vessel activities made by Nuiqsut whalers during the 2008 Cross Island whaling season. It also includes observations on whaling activities. All references to "vessels" in this section refer to vessels other than whaling vessels. The researcher MSG, who was staying with the whalers on Cross Island, recorded this information, and also checked it with the Deadhorse Communication Center Call Log. Summaries are included only for those days on which vessel activity was reported, or for days on which whale scouting activity occurred. Based on the daily information in Annex 5.1, the following summary has been compiled, attempting to draw some generalizations about the effect of vessel traffic and industrial activities on the 2008 Cross Island subsistence whaling season.

Perhaps the most obvious aspect of the daily accounts is the absence of any specific cases in 2008 where Nuiqsut whalers complained about the effects of vessel traffic on their subsistence whaling activities. While 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 (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 west of Cross Island. In past seasons, where there was some question as to whether vessel traffic could proceed or not, the conflict avoidance process worked well and prevented any potential or perceived effects on whaling activities Galginaitis (2008, 2009a). It should also be noted that the 2008 Deadhorse communication Center Call Log continued the trend of the 2007 log of documenting vessel traffic from a wider geographical area and of a more diverse variety than had been the case for earlier seasons. This is another indication that the conflict avoidance agreement procedures are becoming more familiar to all the parties involved and may be working better to avoid potential conflicts.

Nuiqsut whalers have some generalized perceptions as to how industrial activities affect their hunt, based on their experiences of 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 from industry are at times requested by the whalers. However, whalers perceive offshore oil and gas activities as potentially adverse to whaling, primarily because of noise and/or potential spills and accidents.

However, insofar as Northstar in particular is concerned, whalers have not reported effects on their hunt from its development and production activities, although oil spills and noise are still of concern for the potential disruptive effects they could have. BP has made efforts to decrease the risk of spills and to reduce the effects of vessel and air traffic to Northstar as much as practicable. Northstar is to the west of Cross Island and "downstream", in terms of the westward bowhead migration, from the areas where Nuiqsut whalers normally scout for whales. Thus, the hunters do not expect Northstar to be as problematic, in terms of direct effects on whaling, as development to the north and east of Cross Island would be (Ahmaogak 2002: 5, 14). Nuiqsut whalers prefer, however, not to whale near industry facilities, if they can avoid doing so.

ACKNOWLEDGEMENTS

Numerous people contributed greatly to whatever merit exists in this chapter. The Minerals Management Service, Alaska OCS Region, again provided funding for the basic 2008 research. BP provided supplemental funding for additional data collection, interviewing, and analysis. The industrial consortium that operated the Whaler Communication Center in Deadhorse supplied logistical assistance in transporting project equipment and supplies to Cross Island, and allowed me to examine and compile information from the 2008 Deadhorse Communication Center Call Log. The cooperation and participation of the Nuiqsut whalers were indispensable for the success of this project, and I cannot thank them enough. Not only did they collectively provide all the raw data reported in this chapter, but specific crews have also served as my hosts on Cross Island for eight seasons—the Ahkiviana crew in 2002 and 2005–2007; the Napageak crew in 2004; the Oyagak crew in 2003; and the Kittick crew in 2001. The Nukapigak, Aqarguin, Ipalook, and Taalak crews have also been very helpful, both on Cross Island and in Nuiqsut. The AEWC and its staff have also been consistent supporters of the project. There are far too many individuals who have helped me in the last eight years to name individually, but I must single out three members of the Nuiqsut Whaling Captains Association who have strongly supported this research and who first invited me to go out to Cross Island—the late Thomas Napageak Sr., Archie Ahkiviana, and Billy Oyagak. Any errors or misinterpretations are of course solely my responsibility and not the responsibility of those from Nuiqsut, and the North Slope generally, who have contributed so much of their time and knowledge in trying to educate me. Also, I thank Drs. Bill Streever of BP and Lisanne Aerts of LGL Alaska for suggestions concerning the draft, and Dr. W.R. Richardson for his inestimable help (editorial and otherwise) since the 2005 season.

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ANNEX 5.1: DAILY CROSS ISLAND BOAT AND VESSEL ACCOUNTS, 2008

08/29/08

Nukapigak (NUK) crew traveled from Nuiqsut to Cross Island with three boats (NUK1, NUK2, NUK3).

08/31/08

Mobilization of Cross Island infrastructure completed (may have begun 08/30).

09/04/08

Ipalook (IP) crew traveled from Nuiqsut to Cross Island with two boats (IP1, IP2). Napageak (NAP) crew also left Nuiqsut for Cross Island, but their steering broke down near West Dock and they stayed at West Dock overnight to wait for parts and repair their steering.

Two boats went out scouting (NUK2 and NUK3) but it was clear that conditions were marginal and that expectations were not high. Neither boat turned on their GPS (when checked on 09/06, the units had tracks for the trip to Cross Island from Nuiqsut and tracks for 09/05, but none for 09/04). The boats only stayed out 48 minutes, and reported to the Communications Center that conditions were too rough to go out. For comparison purpose with other years it may be advisable not to consider the trips on 09/04 as "scouting" trips. If they are counted as scouting trips, there were two boat-days and two possible GPS tracks (with none collected).

09/05/08

The NAP crew left West Dock and arrived at Cross Island in time to assist with the tow of the first whale landed for the season. The Ahkiviana (UA) crew left Nuiqsut for Cross Island and arrived late at night.

Five boats made some whaling effort during the day (IP1, IP2, NAP, NUK1, NUK3), with one boat (NUK3) making two separate trips. This resulted in five boat-days and six possible GPS tracks (with five collected). The Ipalook crew struck and landed a whale.

The NUK1 and NUK3 boats were out the earliest, at 08:44 and 08:41 respectively. NUK1 reported whales soon after going out and close to Cross Island (nuk1_090508a and nuk1_090508b, 3.2 to 4.3 km (2 to 2.7 mi) from Cross Island), but that because of sea conditions they could not see where the whales went. They thought there may have been as many as 5 whales in this area. They could not follow or chase them effectively, since it was too rough. They then headed more eastwards and towards Narwhal Island, but the swells increased and sea conditions worsened, so they turned back and went more NW of Cross Island. IP1 left Cross island to scout for whales at 10:02, heading north at a moderate speed, but then speeding up and bearing NW to join the NUK boats after NUK3 reported a whale about 14.8 km (9.25 mi) NW of Cross Island (nuk3_090508a). IP1 reached the general vicinity of the NUK boats at about 10:40 and all 3 boats cruise the area at slower speed in search of whales, but have little success after the first sighting. They decided that conditions to the NW were marginal due to the sea state and IP1 headed E while NUK1 and NUK3 headed back SE (again in the general direction of Narwhal Island, and towards where they had seen whales earlier in the day). IP2 left Cross Island to go scouting for whales at 10:59, and IP1 reported its position at the time (IP1_090508a) – about 17.7 km (11 mi) NNW of Cross

Island and heading E. IP2 clearly misunderstood the position and, although there is no GPS track for IP2, seems to have headed out NE of Cross Island. At about 11:59, when IP1 and IP2 were still not in sight of each other, they called each other and gave their approximate positions (IP1_090508b and ip2_090508a) and they may have finally met at about 12:33, at or near the most northeastern point of the IP1 GPS track, 15 km (9.3 mi) NNE of Cross Island. NUK1 reported spotting a whale at 12:52 about 5.3 km (3.3 mi) North of Cross Island (nuk1_090508c). IP1 (and presumably IP2) proceeded at high speed to the area of the NUK boats. This was the first whale seen by the IP boats this day, and may have been the same or a different one than the NUK1 sighting (approximate location ip1_090508c). The IP boats and NUK boats stayed in this area to search for a while (from 12:53 to 01:31) but still had little luck following whales. About 13:40, NUK3 headed back to Cross Island while NUK1 and IP1 and IP2 continued scouting for whales. These boats seem to have spread apart from each other after this to search a wider area, with NUK1 heading S and the NW while the IP boats went E. The IP boats seem to have seen whales at about 14:03 about 7.1 km (4.4 mi) from Cross Island, but soon lost them (ip1_090508d). NUK1 must have seen a whale about 14:43 (nuk1_090508d), as they went to high speed and IP1 (and IP2) also made a 180˚ turn and started towards NUK1 at high speed. Once the boats were together they stayed together and headed NW, before encountering heavier sea conditions again and turning back S at about 15:43. NUK1 and the IP boats continued S and SE at scouting speed (3-4 mph) until IP2 spotted a whale (ip2_090508b – located on IP1 track since IP2 did not produce a track). This is the whale they chased (2 or 3 in the area) and that IP2 struck (ip2_090508d,e,f – had an earlier chance at a whale but missed at IP2_090508c). After the whale was dead (ip2_090508g), NAP and NUK3 came out to help with the tow (IP1_090508g), although only NUK3 tied into the tow. NAP accompanied the tow for a while, to make sure all was well and that they were not needed, and then went out for some “exploratory scouting” as they “just wanted to see a whale” (having arrived at Cross Island just that day). They reported seeing two whales 4 km (2.5 mi) NNW of Cross Island (nap_090508a) and another whale 2.4 km (1.5 mi) from Cross Island (nap_090508b).

IP1 and IP2 said they saw 4 whales total during their trip, all while they were together. NUK crew said they saw 6 to 8 whales during their trips. One captain volunteered that the whales were quite close to Cross Island, seemed to be staying in the area, and were not traveling or transiting the area so much. All captains seemed to agree that the conditions were too rough to scout in some areas due to swells, and acceptable (but not optimal) in others (where swells were smaller). On later days, captains would generalize and say that conditions were rougher the further they went from Cross Island, so that it was more difficult to see whales the further you went from Cross Island.

The Ipalook whale was a female, 9.8 m (32.4ft) length, taken 8.4 km (5.2 mi) from Cross Island, bearing 315˚. Crew used two bombs.

09/06/08

The Oyagak (BO) and Taalak (TL) crews traveled from Nuiqsut to Cross Island. Each used two boats (BO1, BO2, TL1, TL2). The NAP crew traveled from West Dock to Cross Island.

Four boats, from four crews, went out whaling (NAP, NUK1, NUK3, UA1). Only two were really scouting for whales, with the other two going out to help with the tow once the whale was struck and killed by the Napageak (NAP) crew. This has been counted as four boat trips and four possible GPS tracks.

The NAP boat left first at 10:00 with 3 on board and NUK1 left soon after at 10:02 with 5 on board. They stayed in fairly close proximity to each other, but far enough apart to search as wide an area as possible. They went pretty much north to a point about 16.6 km (10.3 mi) from Cross Island, at about

11:41. They saw a "monster whale" and were going to it, thinking that it may be the only whale they would see, since conditions were quite choppy. Both then proceeded SW and at speed, after seeing a blow. NUK1 reported seeing a whale SW of them at 11:54 and 12.6 km (7.8 mi) from Cross Island (nuk1_090608a). Both boats chased this whale until about 13:32, when they apparently lost it (nuk1_090608b, nuk1_090608c). NUK1 went S, while NAP went WNW. At 13:48 NAP turned back E (no reason elicited) towards where they had chased a whale earlier. NAP went through this area and at 14:32 reported a whale (nap_090608a) about 7.2 km (4.5 mi) N of Cross Island (actually about 6.4 km (4.0 mi) NNE of Cross Island [CI] – NAP was 6.4 km (4.0 mi) from CI when the call to the Com Center started, but was at high speed and 7.2 km (4.5 mi) from CI by the time they told the Com Center where they were). NUK1 immediately turned and proceeded at high speed to join up with the NAP boat (at 15:07 or 15:08, about 10 km (6.2 mi) NNE of CI) and indicated they thought this was actually 3 whales together. NAP had apparently lost track of the whale, but NUK1 saw a whale shortly after they were in the area (nuk1_090608d, 15:06 or so) and at 15:28 NAP confirmed that were two whales swimming together (nap_090608b). Both boats were chasing the two whales to the NW. NUK1 reported striking a whale at 15:35 (NUK1_090608e), with coordinates of N70 36.382 W148 03.174 at 12.1 km (7.5 mi) from CI (actually measured as 13 km [8.1 mi]). This was later determined to be a miss, as the float came off (never really was on) and the bomb did not explode, and no evidence was found of a strike. Both boats follow the whale south, and NAP identified a point where they saw the two whales, still together, again (nap_090608c). NAP caught up to the one their right (in position where they could strike it) and struck it (NAP_090608d is the estimated strike location). NUK1 was about 122 m (400 ft) to the east at this point. The whale may have sunk for a short while, as both boats circled at different distances, but then converged on the location of the dead whale (NAP_090608e). NAP described it as the whale simply turning over and being dead. Once it was determined that the whale was dead, NUK1 asked NAP where the second whale had gone, and followed it west. NUK1 could not find any sign of it after 1.6 km (1 mi), and decided to return and help NAP tow the whale. NAP reported landing the whale at 16:09, 11.3 km (7.0 mi) from Cross Island at coordinate N70 35.038 W148 04.389. NAP reported towing at 16:44 at N70 34.858 W148 04.761 (NAP_090608g), but it is likely the tow started about 16:42 at nap_090608f.

NUK3 had left with 2 on board to assist with the tow, but looked to the NNE of Cross Island rather than NNW, and so did not reach NAP and NUK1 until 16:38, after the whale was dead but before the start of the tow. NAP, NUK1, and NUK3 towed the whale back to Cross Island, arriving about 18:21. UA1 left Cross Island with 5 on board to help with the tow about 16:55 and reached the tow about 17:15, but the tow was going well (7 to 8 mph) and only about 8.9 km (5.5 mi) from Cross Island. Rather than slowing down so UA1 could tie-in to the tow, UA1 accompanied them for a short while, briefly looked for other whales, and then returned to Cross Island to help haul up the whale and start butchering.

More whales were seen on 9/05 than on 9/06. The NUK crew estimated they saw 3 or 4 whales on 9/06 compared to 6 to 8 on 9/05

The Napageak whale was a female, 9 m (29.4 ft), taken 6.8 mi from Cross Island, bearing 341˚. 1 or 2 bombs were used.

09/07/08

Four boats total out scouting (BO1, TL1, TL2, UA1). Thus there were four boat-days and four possible GPS tracks (with four collected). No whales were struck.

UA1 was the first boat out with 5 at 07:22. They went out south of Cross Island and then to the NE between Bartlett and Cross Islands. About 8.5 km (5.3 mi) NE of Cross Island they turned off the motor and drifted from about 08:29 to 10:01, for a distance of 1.9 km (1.2) mi (ua1_090708a, ua1_090708b).

They hoped that this would let them see or hear whales better, but it did not. TL1 left Cross Island at 09:46 with 5 boats, TL2 with 3, and BO1 left Cross Island at 09:56 with 4 boats. BO1 headed NNW to join UA1 while TL1 and TL1 headed more northerly and ended up almost due north of Cross Island. UA1 and BO1 were together (at least fairly close to each other) from a little before 11:00 and saw a probable whale at ua1_090708c (perhaps why they drew close to each other). They saw two whales at ua1_090708d, a large one that UA1 says they almost had a chance at and a medium-size one. This was the farthest north these two boats went, as they then turned east, apparently following these (or other) whales. They saw two more whales at bo1_090708a, the most NE point these two boats reached. They could not follow or see these whales for very long and decided to head back to Cross Island slowly, at about 13:07. The Taalak crew boats (TL1 and TL2) headed NNNW, to the west of UA1 and BO1 and saw whales at tl1_090708a and tl1_090708b and tl2_090708a and tl2_090708b. These may not all have been different whales, but as whales were difficult to follow (or even to see on this day), they were not sure. It was a minimum of two different whales. Once they lost track of the whale seen at tl2_090708b they headed west (as the chop was increasing), and then more NW and N as they saw another whale at tl2_090708c. They followed this whale a bit north, but lost track of it and encountered more chop, and decided to head back to Cross Island about 13:20. Although all boats returned to Cross Island at scouting speed (about 8 km/hr or 5 mph), no whale sightings were reported on the way back. UA1 and BO1 did come back by way of the "southern" approach (the way UA1 had gone out) and reported seeing a large polar bear on the SE part of Cross Island.

09/08/08

UA2 traveled from Barrow to Cross Island. During the season it was sometimes referred to as "BO3". However, when this boat went out scouting it was understood to be part of the UA crew. Note that it was a "last minute" addition to the whaling effort, and prior to its arrival on Cross Island the "UA3" boat had been referred to as "UA2" (but it was only used for logistic support, and did not go out scouting).

Seven boats in total went out scouting (BO1, BO2, NUK1, NUK3, TL1, TL2, UA1). Three of these boats made two trips each (TL1, TL2, UA1). Thus there were a total of seven boat-days and ten possible GPS tracks (with ten collected). The Oyagak crew struck and landed a whale.

All seven boats left Cross Island to go scouting between 08:00 and 08:30 (NUK3, UA1, NUK1, BO1, TL2, TL1, BO2). BO1, BO2, TL1, and TL2 all went NNE or N and in the same general area. BO1 headed NNE from Cross Island and then W to where whales had been spotted. BO2 left Cross Island after BO1, and essentially followed the same track. BO2 struck and landed a whale and both BO1 and BO2 participated in the tow and then stayed on the island to start butchering. TL1and TL1 scouted together, and left Cross Island heading N, saw whales, and participated in the chase of the whale that was landed. NUK1 and NUK3 headed ENE and UA1 headed E. The boats that headed NNE soon saw whales (09:37 or so) and the other boats came to join them to the N of Cross Island. The NUK boats had headed ENE about 9 km (5.6 mi), then N about 6.4 km (4 mi), until about 09:37, when they speed up and headed west towards the boats chasing whales. UA1 had headed E from CI about 13.7 km (8.5 mi), but turned NW towards the other boats about 09:37. UA1 was at increased speed, and then went to top speed about 09:49 until they reached the area of the landed whale, and helped in the tow, along with BO1, BO2, TL1, and TL2. After the whale was landed NUK1 and NUK3 stayed out scouting and made a loop of about 11.7 km (7.3 mi) to the west of where the whale was landed. After returning to this area, NUK1 headed SSE towards Narwhal Island, but at about 17:28 headed west and then back to Cross Island. NUK3 essentially accompanied NUK1, but returned to Cross Island after the scouting loop to the west of the area of the landed whale, rather than heading towards Narwhal Island. Thus neither NUK1 nor NUK3 participated in the tow. After the whale was towed to Cross Island, UA1 made a second, short, scouting trip to the NNE and N of Cross Island. TL1 and TL2 also helped tow, and in the afternoon each made a second scouting trip back to the area where they had seen whales in the morning and the Oyagak crew had landed a whale.

There were evidently quite a few whales seen on 09/08, at least in the area about 9.7 km (6 mi) N of Cross Island, just an hour after the boats went out scouting. TL1 spotted a whale 10.4 km (6.5 mi) NNE of CI at 09:37 (tl1_090808a) while BO1 spotted a different whale 9.7 km (6.0 mi) NE of CI at 09:36 or so (bo1_090808a). BO2 saw several whales near them at 09:45 about 9.8 km (6.1 mi) NNE of CI (bo2_090808a). TL1 saw two small whale about 09:43 or so (tl1_090808b). BO2 struck a whale at 09:47 (BO1_090808c) and the kill was announced officially at 10:25 (bo1_090808e, BO1_090808f). The NUK boats continued to scout while the Oyagak whale was being towed to Cross Island and saw two blows 6.1 mi NW of Cross Island about 11:42 (nuk1_090808a) and another whale about 12.6 km (7.8 mi) NNW of Cross Island about 12:43 (nuk3_090808a). After the whale was towed to Cross Island three other boats joined NUK1 and NUK3 in scouting in the afternoon, but no other whales were seen. Conditions had become somewhat more difficult, and all boats except for NUK1 returned to Cross Island by 16:30 to help butcher. NUK1 returned to Cross Island about 21:30.

Oyagak whale was a female, 8.8 m (29 ft) length, taken 9.8 km (6.1 mi) from Cross Island, bearing 12˚. Crew reported that six bombs were used, although only three were found in the whale.

09/09/08

Seven boats went out scouting (NUK1, NUK2, NUK3, TL1, TL2, UA1, UA2). Thus there were a total of seven boat days and seven possible GPS tracks (with seven collected). The Nukapigak crew struck and landed a whale.

Conditions did not look good in the morning and all crews worked on butchering or other tasks on the island. However, the wind died down and three crews (those that had not yet taken a whale) sent out seven boats (three NUK boats, two each for TL and UA), leaving Cross Island between 11:25 and 12:07 (NUK1-3, UA1, TL1-2, UA2). NUK3 struck the whale about 22 min after the last boat left Cross Island to go out scouting. All boats reported seeing a lot of whales, not all of which were necessarily marked or noted. All boats saw whales soon after leaving Cross Island, at 8 or 8.9 km (5 or 5.5 mi) from Cross Island. The NUK boats headed more ENE while the UA and TL boats headed more NNE. Whale locations were noted at nuk1_090908a, nuk2_090908a, nuk3_090908a, nuk3_090908b, tl1_090908a, and ua1_090908a. Some of these points indicate more than one whale at a given location. NUK3 struck a whale at nuk3_090908c. UA1 indicated that they were also just about in position to strike a whale when NUK3 struck. Once NUK3 struck a whale all boats went to assist, and all boats participated in the tow.

UA crew noted that they had chased 2 whales, and had seen “plenty” of others – but that most of these had been blows farther out (to the north). They also say that the whales are not at all “spooky” this year – until the whalers start chasing them. The TL crew saw 3 other whales – one (tl1_090908a) near the one that UA was chasing (ua1_090908a) and 2 others (tl2_090908a) on the way over to assist the NUK boats. As on previous days, sea conditions were variable, with swells of .6 to .9 m (2 to 3 ft) minimum, increasing to 1.2 to 1.5 m (4 to 5 ft) in many places, and 1.8 to 2.1 m (6 to 7 ft) in a number of places (prompting changes of direction). Whales were difficult to see in general, but there were a great number of whales evident nonetheless – mainly when the swells were .6 to 1.2 m (2 to 4 ft). Crews indicated that about 7.2 to 9.7 km (4.5 to 6 mi) north of Cross Island sea states became too extreme to spot (let alone follow) whales. The swells also made the tow somewhat difficult, due to the boats moving so much relative to each other while being attached to the tow rope.

Nukapigak whale was a female, 10.7 m (35.3 ft) in length, taken 12.6 km (7.8 mi) from Cross Island, bearing 72˚. Crew reports three bombs used.

09/10/08

This was demobilization day, and four crews (BO, IP, NAP, UA) with seven boats (IP1, IP2, UA1, UA2, UA3, BO1, BO2) left for Nuiqsut. The NAP boat was disabled and had been towed to West Dock (and then to Oliktok Point) on 09/09. The NAP crew used one of the IP boats (probably IP2) to return to Nuiqsut. Note that the "UA2" boat was sometimes referred to as "BO3" during the season, but the one time it went out scouting (09/09) it was as part of the UA crew effort. This boat did not arrive on Cross Island until 09/08.

09/11/08

The last crew left with three boats (NUK1, NUK2, NUK3).

APPENDIX A:

IN-AIR SOUND MEASUREMENTS OF BOULDER PLACEMENT ACTIVITIES AT NORTHSTAR ISLAND

INTRODUCTION

Most damage to the armor protection around Northstar Island is the consequence of combined wave and ice interactions, e.g. through local pressure of large blocks of ice rubble moving at high speeds onto the slope of the island. During a heavy storm in October 2006, the lower blocks along the northeast corner of the island were removed from the protection barrier through ice impacts. Rather than replacing these lower concrete blocks, BP planned to install large boulders at this location. These boulders were transported with four side-dump trucks (C-500 trucks with 50ft flatbed trailer – Fig. A1) from a quarry in the Brooks Range to Northstar Island. The first trucks arrived at Northstar Island on 7 March 2008, where boulder placement activities continued until ~24 April 2008. During this period 812 round trips were made. Northstar boulder placement activities were conducted with a CAT 966 loader, a CAT 345B excavator (Fig. A2) and a JD 850 dozer.

This brief note reports the results of airborne sound measurements of the boulder placement activities carried out at 18 March 2008. These in-air sound measurements were conducted to meet the requirement of BPXA's Northstar LoA, issued in July 2007, which states that BPXA "*…… will conduct acoustic measurements to document sound levels, characteristics, and transmissions of airborne sounds for sources on Northstar Island with expected received levels at the water's edge that exceed 90 dBA that have not been measured in previous years. These data will be collected in order to assist in the development of future monitoring and mitigation measures*".

FIGURE A1. Side-dump trucks used to transport boulders.

FIGURE A2. A CAT 345B excavator placing boulders at the northeast corner of the Island.

METHODOLOGY

The Northstar boulder placement activities that were of interest for the in-air sound measurements consisted of the following:

- Offloading of boulders from the side-dump truck with an excavator at a temporary storage site at the northwest corner of the Island;
- Loading of boulders from this temporary storage site on a front-end loader for transportation to the northeast corner of the Island;
- Placing of boulders into the moat with an excavator.

Figure A3 shows the offloading and boulder placement locations during the in-air measurements, as well as the entire area where boulder placement was planned. Trucks associated with normal operational activities at Northstar where also present and contributed to the acoustic footprint (see Fig. A3).

The equipment used to measure the airborne sounds of the boulder placement activities on Northstar Island is listed below. A Tucker 1600 Terra track vehicle was available for transportation of the field crew over the ice at distances of >0.5 mile (>0.8 km) from the source.

- QUEST 2700 Impulse and Integrating Sound Level Meter (Quest 2700 SLM). This sound level meter was calibrated;
- BUSHNELL Yardage Pro™ 800 Range finder to measure the distances to the source;
- Kestrel 1000 Anometer for wind speed measurements.

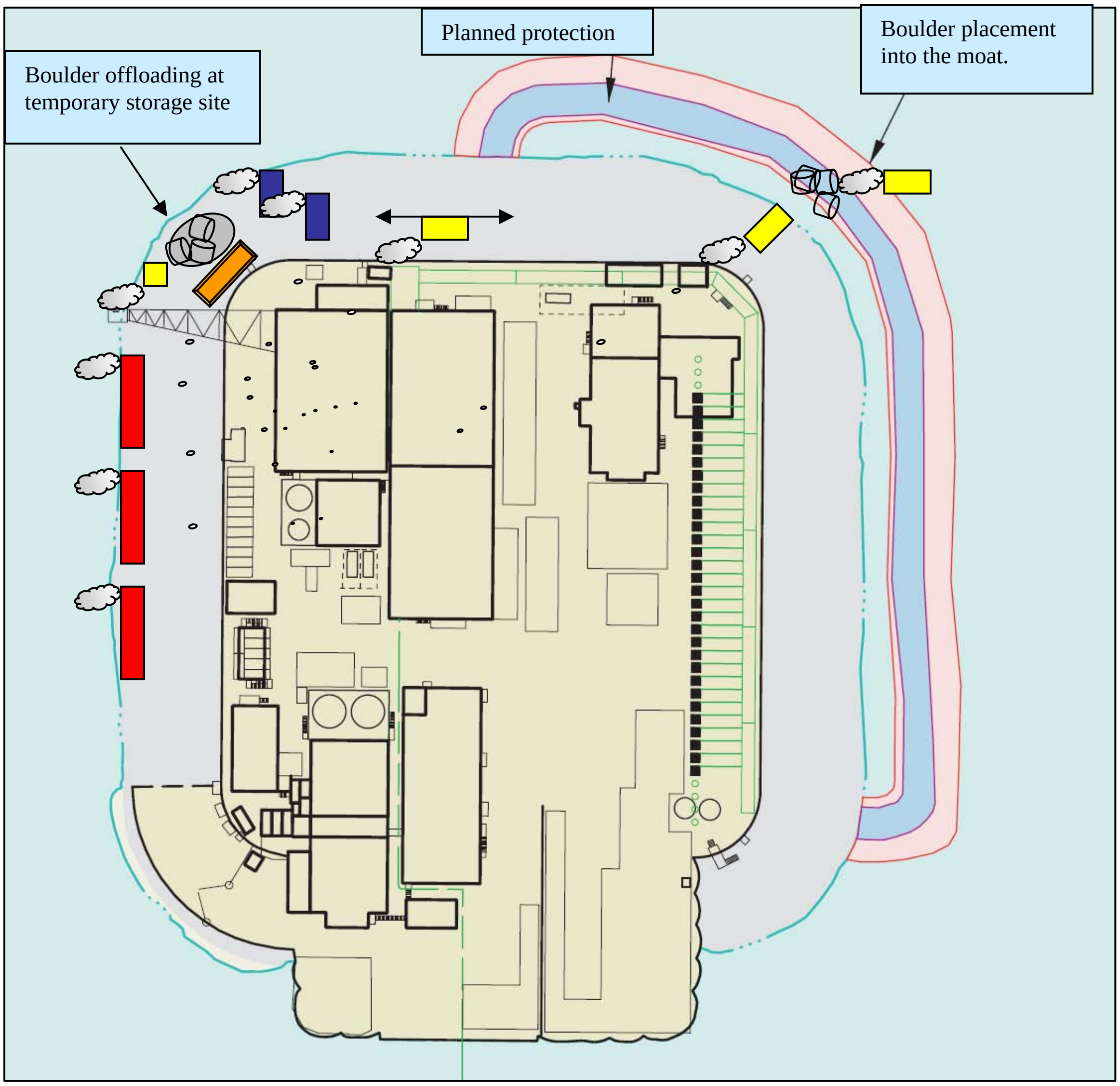

FIGURE A3. Northstar Island and approximate locations of sound sources present during in-air sound level measurements. The dark blue and red squares represent trucks that are associated with regular Northstar activities. The orange square represents the side dump truck and the yellow squares backhoes and front-end loaders associated with the boulder placement activities.

In-air sound level measurements were conducted using the A-weighting setting on the Quest 2700 SLM, as is common practice for measuring environmental and industrial airborne sounds. This weighting factor is also used when assessing potential hearing damage in humans. Sounds were measured with a setting that averages sounds over a 0.125 second period. This was considered appropriate in order to capture non-continuous sounds occurring during the boulder offloading and placement activities, e.g. handling of big rocks. The maximum sound level in dBA re 20µPa (averaged over 0.125 seconds) during a one-minute recording period of a certain activity was noted as the in-air sound level for that activity. A total of three measurements were conducted, resulting in three in-air sound levels at a certain distance from the activity of interest. It is important to note that it was difficult to obtain in-air measurements for specific activities in isolation because other regular production related activities always occurred in conjunction with the activity of interest (see Fig. A3). For this reason attempts were made to measure Northstar background noise levels without boulder placement activities and background levels without or with limited Northstar sounds.

One of the most important natural factor influencing in-air sound measurements is wind speed. Measurements were avoided at wind speeds greater than 16 km/h (10 mph), and would be halted at wind speeds above 24 km/h (15 mph). If possible measurements were taken downwind of the activity of interest, which is especially important for wind speeds in the 16-24 km/h (10-15 mph) range. The reason for a downwind position is that sounds will attenuate more rapidly with increasing distance upwind.

To obtain information on the transmission loss of the in-air sounds, measurements were taken at various positions from the source (Fig. A4). Ideally, measurements started as close as possible to the source (taking into account safety requirements) and doubled in distance until the sound levels were relatively stable, i.e. didn't change with increasing distance. Because of high pressure ridges close to the island the Tucker could not be used for transportation to the measurement locations, so measurements were collected by walking onto the sea-ice (Fig. A5).

FIGURE A4. In-Air measurements were taken at various distances from the boulder placement activities.

FIGURE A5. High ice pressure ridges prevented the use of the Tucker tracked vehicle north of the island.

RESULTS

In-air sound measurements of the boulder offloading and placement activities were conducted on 18 March 2008. During this day boulder placement activities occurred at the northeast corner of the Island (Fig. A3). The side-dump trucks carrying the boulders were arriving at irregular times at the northwest side of Northstar Island.

The wind direction was predominantly NE/ENE, with a variable wind speed reaching maximum levels of 9 km/h (5.6 mph). A temporary increase in wind speed to a maximum of 9 km/h (5.6 mph) started somewhere around noon and decreased again at 1430 hours. The temperature varied from -32 C (-25 F) in the morning to -27 C (-17 F) in the afternoon, with wind chill temperatures reaching -41 C (-42 F) at times with increased wind speeds (Table 1).

Measurements of the boulder placement were recorded between 09:15 and 10:42, at distances of 26 to 300 m (82 to 984 ft) north from the northeast corner of the Island where boulder placement was taking place. A distance of ~300 m (~984 ft) from the island without vehicle support was considered to be the safety limit. Two CAT trucks were present, one picking up and placing boulders and the other idling at ~25 m (82 ft) to the northeast. Both remained at a stable position, i.e. they were not moving. The sound level recorded at 26 m distance (50.3 dB re 20µPa) was clearly higher than the sound levels recorded at 150 and 300m (39.2 and 38.3 dB re 20µPa respectively), but were not distinguishable from background sound levels (Table 1, Fig. A6).

Measurements of boulder offloading at the northwest corner of the island were conducted between 13:25 and 15:47, north from the temporary storage site. Offloading of boulders from the side-dump trucks lasted about 10 minutes. While waiting for the next side-dump truck to arrive, measurements of Northstar background sound levels were alternated with those including boulder offloading activities. About 10 min after the boulders were offloaded from the first side-dump truck, boulder placement activities resumed at the NE side of the Island (at 13:58) and continued during the remaining measurement period. The in-air sound levels of boulder offloading, including Northstar background sounds, didn't show a clear decrease with increasing distance from the activity (Table 1, Fig. A6). The main reason for this is the non-continuous nature of sounds generated by specific boulder offloading and placement activities.

Measurements of background sounds were conducted using the Tucker track vehicle between 16:00 and 16:55, towards the west of Northstar (Fig. A7). The intention was to measure in-air sound levels at larger distances from Northstar to capture background sounds that would not include sounds generated by the Island. The west side of the Island was chosen because: (1) it was downwind of the Island and as far away as possible from onshore facilities (e.g. STP), and (2) there were no large pressure ridges that would prevent the Tucker from traveling over the ice. In-air sound levels were recorded at 0.8, 2.2 and 4 km (0.5, 1.4 and 2.5 mi). During these measurements the engine of the Tucker vehicle was turned off and without support from an extra vehicle it was decided not to go beyond 4 km (2.5 mi). Northstar sounds were still audible at 4 km away. The sound level at this distance (38.0 dB re 20µPa) was similar to the boulder placement measurement at 300 m north of the Island.

TABLE 1. Results of in-air sound measurements of boulder placement activity, boulder offloading and Northstar background sound levels at various distances from the source. Northstar background levels include the trucks as depicted in Figure A3 and in some instances also boulder placement or offloading activities.

Activity	**Distance from source (m)**	**Wind speed (km/h)**	**Wind direc-tion**	**Temp (oC)**	**dB re 20µPa**	**Remarks**
Boulder placement	26	4.5	NE	-32	50.3	2 CAT trucks: one picking up boulders, other stand-by idling at ~25 m to the NE. Both trucks at stable position.
	150	4.5	NE	-32	39.2	
	300	4.3	NE	-32	38.3	
Boulder offloading	83	3.4	ENE	-27	60.9	Idling side dump truck, excavator offloading rocks on island (NW corner). Distance measured to excavator.
	164	3.4	ENE	-27	47.1	
	281	8.0	NE	-27/-41	44.1	
	281	3.4	ENE	-27	52.3	Includes whistling sounds from truck transporting boulders from NW to NE corner.
	367	3.4	ENE	-17	47.0	
	367	3.4	ENE	-17	51.5	
	367	3.4	ENE	-17	54.5	
Nstar background	17	8.0	NE	-27/-41	53.4	Background sounds are from module, drill rigg, trucks on island idling or driving.
	83	7.0	NE	-27/-41	50.4	
	125	9.0	NE	-27/-41	46.3	
	164	8.0	NE	-27/-41	45.9	
	281	9.0	NE	-27/-41	44.1	
	805	1.1	var	-17	41.3	Measurements at distances of >300 m were conducted with the Tucker (at 0.5, 1.4 and 2.5 mile from Nstar)
	2253	1.1	var	-17	46.6	
	4023	1.1	var	-17	38.0	

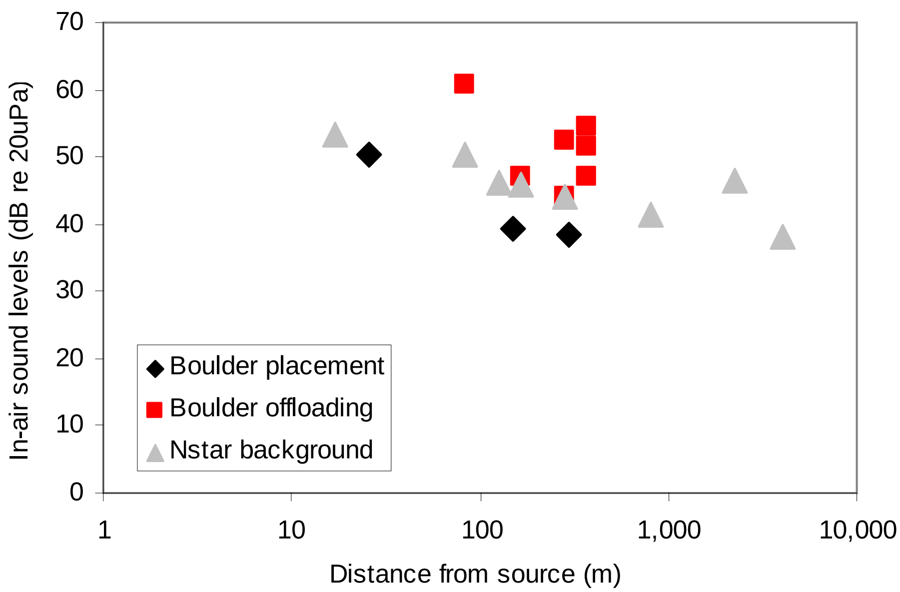

FIGURE A6. In-air sound levels (in dB re 20µPa) of boulder placement and offloading activities, as well as Northstar background sound levels measured at various distances from shore.

FIGURE A7. Tucker SnoCat 1600 Terra at ~1.5 mile (~2.2 km) distance from Nstar Island.

CONCLUSION

The various and variable background sound sources present at Northstar Island made it difficult to determine in-air sound levels specific to the boulder offloading and placement activities. In general, the sound levels associated with boulder placement and offloading were more or less integrated with background sound levels, i.e. sounds from other trucks present at Northstar Island and from the processing module. Only in cases where an exceptional large boulder was handled or when boulders were dumped on the front-end loader or on other boulders, the sounds were distinguishable from their background. These sounds, however, were too short-lived and infrequent to increase the overall background sound levels. Results from the in-air sound measurements suggest that most, if not all, in-air sounds generated by boulder placement activities were below 90 dB re 20 µPa.

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