MONITORING OF INDUSTRIAL SOUNDS, SEALS, AND BOWHEAD WHALES NEAR HILCORP’S NORTHSTAR OIL DEVELOPMENT, ALASKAN BEAUFORT SEA, 2015: SUMMARY REPORT

Edited by

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Cover Photograph: DASARs awaiting deployment (foreground) near Northstar (background) on 19 Aug. 2015, on the deck of the M/V Leeway (photo by Alex Conrad).

Suggested format for citations:
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CHAPTER 1:
INTRODUCTION, DESCRIPTION OF HILCROP’S ACTIVITIES, AND RECORD OF SEAL SIGHTINGS, 2015

by

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INTRODUCTION

BP Exploration (Alaska) Inc. began constructing the Northstar offshore oil production facility in the Prudhoe Bay area, Alaskan Beaufort Sea, during early 2000, and began producing crude oil from Northstar Island during late 2001. Since then, oil has been produced almost continuously. On 22 April 2014, BP announced that it had agreed to sell interests in four BP-operated oilfields on the North Slope of Alaska to Hilcorp Alaska LLC (Hilcorp). On 18 Nov. 2014, Hilcorp assumed 100% ownership and accepted duties and responsibilities of Operatorship of Northstar.

Northstar is the first (and currently only) offshore oil production facility north of the barrier islands 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. Facilities for waste grind and injection and for oil production and gas injection are also on the island. A drilling rig that had been on the island since 2000 was demobilized and removed from Northstar during the 2010 open-water season. The production facilities include gas turbine engines to operate power generators and gas compressors. Northstar Island is 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 27 km (16.5 mi) west of the hunting camp on Cross Island (Fig. 1.1).

Commencing in August 1998, BP submitted various requests to the National Marine Fisheries Service (NMFS) to authorize potential incidental “taking” of small numbers of marine mammals that

![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.](image-url)
might have resulted from BP’s activities at Northstar. Letters of Authorization (LoAs) issued under the initial and subsequent Northstar regulations (NMFS 2000, 2006) required marine mammal and acoustic monitoring studies. The U.S. Army Corps of Engineers (USACE) and the North Slope Borough (NSB) Planning Department adopted these monitoring requirements into, respectively, the USACE Permit (N-950372, special conditions 12 and 13) and the NSB ordinances for Northstar Construction and Operations (NSBMC §1970050(B)(I) and NSBCMP 243(b)).

The monitoring studies actually started in 1997, prior to any construction or formal monitoring requirement, and continued through 2014. In October 2009, BP submitted a request to renew the regulations upon their expiry in April 2011, but that renewal did not occur until December 2013 (NMFS 2013). In the interim, Northstar operations and monitoring continued in a manner consistent with requirements of the USACE permit and NSB ordinances. In March 2011, NMFS convened a peer review of plans for future Northstar monitoring, and a report on that review was released in August 2011. Those recommendations influenced monitoring in 2012–2014.

After Hilcorp took ownership of Northstar, and upon consultation with Alaska NMFS representatives, Hilcorp elected not to request NMFS authorizations for potential takes but continued the Northstar monitoring program in 2015 in a manner consistent with the previous 2014 season. Hence, this is the first report on Hilcorp activities and seal sightings in 2015, but it is a continuation of monitoring and reporting that began before the start of Northstar construction.

Monitoring results up to 2004 were described in a final comprehensive report (Richardson, ed., 2008). Monitoring results for 2005 to 2010 were described in annual summary reports and in a second comprehensive report (Richardson, ed., 2011). Results for 2011, 2012, 2013, and 2014 were described in annual summary reports for those years (Richardson and Kim, eds., 2012–2015). This document is a summary report describing the 2015 monitoring program. The present chapter on Hilcorp’s activities and seal sightings in 2015 is an adaptation of the corresponding chapters in the 2012, 2013 and 2014 BP annual reports (Rodrigues 2013; Patterson and Rodrigues 2014; Patterson 2015), with new or updated information for 2015.

The marine mammal and acoustic monitoring results from 1999 to 2004 were reviewed in March 2005 by the Science Advisory Committee (SAC) of the North Slope Borough, various peer reviewers acting on behalf of journals, and various stakeholders during the (almost) annual open-water meetings convened by NMFS. The reviewers made many suggestions, most of which were later incorporated into data collection, analyses, and interpretation. The most intensive monitoring of bowhead whales occurred in late summer and early autumn of 2000–2004 and 2008–2009 when up to 11 stations were monitored acoustically. In 2001–2004, the southern edge of the distribution of calling bowhead whales tended to be slightly but significantly farther offshore at times when anthropogenic sound levels near Northstar were elevated (Richardson, ed., 2008; McDonald et al. 2012; Richardson et al. 2012). In 2008, acoustic data records were dominated by the presence of airgun pulses from nearby and distant seismic surveys, confounding assessment of Northstar effects on bowhead whales. In 2009, seismic survey activity was reduced and much more distant relative to 2008. Even so, sounds from distant seismic surveys were often detected in the migration corridor offshore of Northstar during September 2009. For 2009, we could not conclusively identify a specific relationship between offshore distance of bowhead whale calls and Northstar sound (McDonald et al. 2011). In 2005–2007 and in 2010–2014, with the concurrence of NMFS, peer reviewers and stakeholders, the bowhead monitoring effort included fewer recording stations than in 2000–2004 or 2008–2009 (Richardson, ed., 2011; Richardson and Kim, eds., 2012–2015).

During the 2015 open-water season, acoustic monitoring of bowhead whale calls continued at the same reduced level as 2014, consistent with the earlier recommendations of the SAC and recommendations from participants in the 2010–2013 open-water meetings. (There were no open-water meetings in
2014 or 2015.) Other aspects of the 2015 monitoring work, i.e., counts of seals near Northstar and documentation of the subsistence whale hunt at Cross Island, were continued by or for Hilcorp generally as done in other recent years by or for BP. During 2015,

- personnel at Northstar counted seals near the island in a standardized way during spring and early summer;
- underwater sounds near Northstar were monitored from 19 Aug. to 22 Sept. during the autumn whale migration season with a bottom-mounted recorder at a standard location near the island;
- calling bowhead whales in the southern portion of their migration corridor were monitored over that same period using a bottom-mounted Directional Autonomous Seafloor Acoustic Recorder (DASAR) at a standard location offshore of Northstar;
- the 2015 subsistence whaling at Cross Island and the opinions of those subsistence whalers about the 2015 whale migration and whaling season were documented by a sociocultural researcher who spent the 2015 whaling season on Cross Isl., provided GPS data loggers to the whalers, and interviewed them after the hunt. Results on subsistence whaling in 2015 are given in a separate report (Galginaitis 2016).

Counts of seals were made by Northstar personnel from mid-May through mid-July as in previous years. Results of seal counts in 2015 were compared with counts from 2005 through 2014. The results of seal counts, along with a description of Hilcorp’s 2015 activities, appear later in this chapter.

The near-island and offshore acoustic recorders were deployed in 2015 at locations where similar recorders had been deployed during all autumn migration seasons since 2001. Types of acoustic data acquired at both sites were generally consistent with those obtained from those two sites in prior years, to allow comparison of the 2015 results with those from 2001 to 2014. As in some previous years, whale calls were monitored at only one offshore site in 2015, as localization of calling whales was not required in 2015. Bearings from the one call-monitoring station to the calling bowheads were determined in 2015 as in prior years using the directional capability of the offshore DASAR (Greene et al. 2004). The methods and results for the 2015 monitoring of Northstar sounds and whale calls are described in Chapters 2 and 3, respectively.

This report is consistent with the annual reporting provisions of regulations and LoAs issued by NMFS to BP for previous years (NMFS 2013, 2014), and with the USACE permit and NSB ordinances applicable to Hilcorp for 2015 and beyond. In 2015, Hilcorp continued the monitoring and reporting practices of other recent years to satisfy USACE and NSB requirements, and to understand and minimize environmental effects of Hilcorp operations.

Based on the Northstar monitoring studies conducted to date, a total of 16 peer-reviewed papers and two additional summary papers have been published in scientific journals or conference proceedings since 2001, with additional papers in preparation (Table 1.1). Copies of most published papers were, with the permission of the relevant journals, included as Appendices to the first and/or second comprehensive report (Richardson, ed., 2008, 2011). In addition, information on various aspects of Northstar monitoring studies has been disseminated through numerous public presentations, e.g., to the annual open-water meetings convened by NMFS until 2013, BP managers, oil field workers, representatives from other energy companies, scientific conferences, universities in Alaska and elsewhere, and, to some degree, in Barrow.

**OVERVIEW OF HILCORP ACTIVITIES, NOVEMBER 2014 – OCTOBER 2015**

This section describes Hilcorp’s activities during the period 1 Nov. 2014 through 31 Oct. 2015. As in previous years, the ice-covered season is defined as the period from 1 Nov. through 15 June, followed by the open-water season from 16 June through 31 Oct.
### TABLE 1.1. Authors and titles of publications and manuscripts resulting from the Northstar marine mammal and acoustic studies program, 1999–2015.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Title</th>
<th>Status</th>
</tr>
</thead>
</table>
### Table 1.1. Concluded.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Title</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galginaitis, M.S. (2013b)^2</td>
<td>Inupiat fall whaling and climate change observations from Cross Island</td>
<td>p. 181-199 In: F.J. Mueter et al. (eds.), Responses of Arctic marine ecosystems to climate change. Alaska Sea Grant, Univ. Alaska Fairbanks.</td>
</tr>
<tr>
<td>Galginaitis, M.S. (2014)^2</td>
<td>An overview of Cross Island subsistence bowhead whaling, Beaufort Sea, Alaska</td>
<td>Alaska J. Anthropol. 12(1) In Preparation (titles and author lists are tentative)</td>
</tr>
<tr>
<td>Richardson, W.J., T.L. McDonald, C.R. Greene Jr, S.B. Blackwell, &amp; B. Streever</td>
<td>Distribution of bowhead whale calls near an oil production island at low and higher-noise times</td>
<td>In prep.</td>
</tr>
</tbody>
</table>

**Transportation To and From Northstar Island**

During the current reporting year, an AW139 helicopter and later a Bell 412 helicopter and a Griffon 2000TD hovercraft were used to transport personnel and equipment to and from Northstar Island during both the ice-covered and the open-water seasons. In addition, 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 a crew boat.

**Helicopters**

The AW139 helicopter is a medium-sized helicopter with two turboshaft engines, a 5-bladed main rotor, and a 4-bladed tail rotor (Fig. 1.2, top). In January 2012, an AW139 replaced the similarly-sized Bell 212 helicopter previously used to service Northstar. In July 2015, the AW139 was replaced with a Bell 412 contracted via Erickson Aviation. The Bell 412 was similarly-sized and also had two turboshaft engines, but was equipped with a 4-bladed main rotor and a 2-bladed tail rotor (Fig. 1.2, bottom).

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^2 Preparation of these papers by M.S. Galginaitis was funded mainly by the U.S. Minerals Management Service (now Bureau of Ocean Energy Management) with supplemental funding from BP as part of the Northstar studies program.
In 2015, as in previous years, helicopters 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 2014/15 reporting period, helicopters made a total of 68 round trips to and from Northstar (Tables 1.2, 1.3). An additional 25 trips involved the helicopter leaving from and returning to Deadhorse Airport without landing at Northstar Island (e.g., pipe inspection, pilot training, and currency flights). Thirty additional flights took place to and from other locations such as Endicott, West Dock, or Northstar Remote Terminal Unit (RTU). Approximately 68% of the year’s helicopter flights to and from Northstar occurred in the month of October 2015. The other “transitional” months of Nov.–Dec. 2014 and Sept. 2015 only had a total of 11 round trip flights (Table 1.2). During most
**TABLE 1.2.** Number of helicopter and hovercraft round trips to Northstar Island for each month during the ice-covered and open-water seasons of 2014/15. A ½ round trip occurred when a helicopter or hovercraft (or other vehicle used for transport) left shore prior to midnight, and returned from the island after midnight or, occasionally, if the vehicle left the shore but did not complete the trip due to weather or other reasons.

<table>
<thead>
<tr>
<th>Month</th>
<th>Ice-covered season</th>
<th>Open-water season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Helicopter</td>
<td>Hovercraft</td>
</tr>
<tr>
<td>November 2014</td>
<td>2</td>
<td>76</td>
</tr>
<tr>
<td>December 2014</td>
<td>4</td>
<td>86.5</td>
</tr>
<tr>
<td>January 2015</td>
<td>1</td>
<td>58.5</td>
</tr>
<tr>
<td>February 2015</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>March 2015</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>April 2015</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>May 2015</td>
<td>2</td>
<td>32.5</td>
</tr>
<tr>
<td>1-15 June 2015</td>
<td>4.5</td>
<td>26.5</td>
</tr>
</tbody>
</table>

**TABLE 1.3.** Total number of helicopter and hovercraft round trips to Northstar Island for each year since 2002/03 during the ice-covered and subsequent open-water seasons. The hovercraft was first tested and used in spring 2003.

<table>
<thead>
<tr>
<th>Year</th>
<th>Ice-covered Season</th>
<th>Open-water Season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Helicopter</td>
<td>Hovercraft</td>
</tr>
<tr>
<td>2002/03</td>
<td>1122</td>
<td>N/A</td>
</tr>
<tr>
<td>2003/04</td>
<td>253</td>
<td>141</td>
</tr>
<tr>
<td>2004/05</td>
<td>118</td>
<td>180</td>
</tr>
<tr>
<td>2005/06</td>
<td>465</td>
<td>249</td>
</tr>
<tr>
<td>2006/07</td>
<td>335</td>
<td>574</td>
</tr>
<tr>
<td>2007/08</td>
<td>222</td>
<td>426</td>
</tr>
<tr>
<td>2008/09</td>
<td>62</td>
<td>539</td>
</tr>
<tr>
<td>2009/10</td>
<td>47</td>
<td>314.5</td>
</tr>
<tr>
<td>2010/11</td>
<td>120.5</td>
<td>374.5</td>
</tr>
<tr>
<td>2011/12</td>
<td>106</td>
<td>462.5</td>
</tr>
<tr>
<td>2012/13</td>
<td>89</td>
<td>300</td>
</tr>
<tr>
<td>2013/14</td>
<td>103</td>
<td>323.5</td>
</tr>
<tr>
<td>2014/15</td>
<td>14.5</td>
<td>280</td>
</tr>
</tbody>
</table>

See caption in Table 1.2 for explanation of ½ round trip.

previous reporting periods, the level of helicopter use was greater during the ice-covered season than during the open-water period. In only three years has this situation been reversed. The 2014/15 recording period was one of these years; the majority of flights took place in October, considered an ice-free month (Table 1.3).
During the various ice-covered seasons since 2002/03, helicopter traffic to and from Northstar was most frequent during the early production period (2002/03) and notably less frequent after 2007/08 (Table 1.3). The level of helicopter traffic to and from Northstar during the 2014/15 reporting period was the lowest on record.

Helicopter routes were negotiated, at an early stage in the planning of the Northstar operations, among the U.S. Fish and Wildlife Service (USFWS), NMFS, and BP to minimize impacts to waterfowl and marine mammals. During regular helicopter operations in 2015, 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.

**Griffon 2000 TD Hovercraft**

A Griffon 2000 TD hovercraft (Fig. 1.3) was also used to transport personnel during both the ice-covered and the open-water periods. The hovercraft made its first test trips in spring 2003, and since then has been used for transport of personnel and supplies. The hovercraft is powered by a 355 hp air-cooled Deutz diesel engine and is 11.9 m (39 ft) in length (Blackwell 2004; Blackwell and Greene 2005). The hovercraft is capable of carrying a payload of 2268 kg (5000 lb). During the 2014/15 reporting period, the hovercraft was used from Nov. 2014 through Jan. 2015, from May through July 2015, and in Oct. 2015. There was no hovercraft activity in Feb. through Apr, when most personnel transport was via pick-up trucks, SUVs, and buses operating on the ice-road; nor in Aug. and Sept. when personnel transport was via crew boat (Table 1.2). Of all hovercraft activity during the 2014/15 reporting period, 20% occurred during the open-water season and 80% during the ice-covered season (Table 1.3). Hovercraft traffic has been variable among years, ranging from 141 to 574 round trips per year during the ice-covered period, and from 72 to 560 round trips per year during the open-water period (Table 1.3).
In 2014/15, hovercraft activity was reduced relative to other recent years both in the ice-covered season (280 trips) and especially in the open-water season (72 trips). The relatively low level of hovercraft use during the open-water season of 2015, as in 2011, resulted from the use of a crew boat during those years. The crew boat was not used in 2012 and hovercraft use returned in 2012 through 2014 to levels similar to those of years prior to 2011 (Table 1.3). The 72 round trips of the hovercraft during the 2015 open-water season was the lowest number for any open-water season since hovercraft operations began in 2003.

**Ice Road Transportation**

As in previous years, an offshore ice road ~12 km (~7.4 mi) in length was built between West Dock and Northstar during the 2014/15 ice-covered season. This was used to transport personnel, equipment, materials, and supplies between the Prudhoe Bay facilities and Northstar Island. Ice-road construction started on 9 Feb. 2015. The first passenger trip on the ice road occurred on 15 March, although Tucker tracked vehicles (not dependent on completion of the ice road) had been used beginning 23 Jan. 2015. The last trip on the ice road in 2015 occurred on 12 May.

*Tucker tracked vehicles* (model 1600 Tucker-Terra; Fig. 1.4) were primarily used, during the 2014/15 reporting period, to transport personnel and materials between West Dock and Northstar during ice-covered periods when the ice road did not permit standard vehicle traffic. These situations occurred mainly in the early-winter months prior to completion of the ice road. Tucker vehicles are capable of carrying 15 people. Tucker tracked vehicles made a total of 108.5 round trips between West Dock and Northstar during the 2014/15 ice-covered season. A large portion of Tucker trips to and from Northstar occurred in Feb. (59 round trips), followed by March (36 round trips) and Jan. (8 round trips). Tucker vehicles were also used occasionally in April (3 trips) and May (2 trips). The level of Tucker use was the third greatest of all years since 2004/05. The only years with more Tucker transits were 2007/08 and 2008/09 (Table 1.4). No detailed records of round trips by Tucker or other tracked vehicles are available for the construction and early production years (2000–2003), but tracked vehicles (Hägglunds) were used frequently in those years.

![FIGURE 1.4. Tucker tracked vehicle powered by a Cummins 6-Qsb 173 HP diesel engine.](image-url)
TABLE 1.4. Number of Tucker tracked vehicle round trips to Northstar Island by year since 2004/05.

<table>
<thead>
<tr>
<th>Year</th>
<th>Tucker Round Trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004/05</td>
<td>25</td>
</tr>
<tr>
<td>2005/06</td>
<td>70</td>
</tr>
<tr>
<td>2006/07</td>
<td>37</td>
</tr>
<tr>
<td>2007/08</td>
<td>111.5</td>
</tr>
<tr>
<td>2008/09</td>
<td>127.5</td>
</tr>
<tr>
<td>2009/10</td>
<td>67</td>
</tr>
<tr>
<td>2010/11</td>
<td>99.5</td>
</tr>
<tr>
<td>2011/12</td>
<td>45.5</td>
</tr>
<tr>
<td>2012/13</td>
<td>49</td>
</tr>
<tr>
<td>2013/14</td>
<td>25</td>
</tr>
<tr>
<td>2014/15</td>
<td>108.5</td>
</tr>
</tbody>
</table>

See caption in Table 1.2 for explanation of ½ round trip.

**Standard vehicles**, including vans, pick-up trucks, and buses, were the main method of transportation for Northstar personnel from 15 March to 12 May 2015. A total of 256 round trips were made with standard vehicles during this period. This is an 11% reduction compared to the 287.5 round trips made in 2014, a result of the later opening of the ice road in 2015.

**Tugs and Barges**

During the 2015 open-water season, supply runs from West Dock to Northstar occurred mainly by tug and barge. The lengths of barges used to transport fuel and cargo to the island were typically ~46–61 m (160–200 ft) and the tug length was ~20 m (65 ft). On days with average levels of background sounds, sounds from tugs maneuvering at Northstar may be detected to a distance of at least 21.5 km (13.4 mi) from Northstar (Blackwell et al. 2009) and possibly further (Blackwell and Greene 2006). A total of 13 tug and barge round trips (i.e., 26 transits) were made between West Dock and Northstar during the 2015 open-water period (Table 1.5). In 2015, barge activity occurred entirely in July and Aug. The total number of barge trips in 2015 was lower than in any year since 2003, although only slightly lower than in 2013–14, the previous minimum (Table 1.6). In the 2003 through 2015 period, the highest level of barge activity occurred in 2003. Barge activity was also relatively high in 2006, 2010, and 2011 (Table 1.6).

TABLE 1.5. Number of round trips to Northstar by tugs/barges and crew boats during the 2015 open-water season, by month. The ½ round trip occurred on 22 Sept., when the crew boat left and returned to Northstar Island without going to another dock.

<table>
<thead>
<tr>
<th>Month</th>
<th>Tugs/Barges</th>
<th>Crew Boats</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 16–30</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>July</td>
<td>10</td>
<td>58</td>
</tr>
<tr>
<td>August</td>
<td>3</td>
<td>79</td>
</tr>
<tr>
<td>September</td>
<td>0</td>
<td>58.5</td>
</tr>
<tr>
<td>October</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>13</td>
<td>195.5</td>
</tr>
</tbody>
</table>
TABLE 1.6. Number of round trips to Northstar Island by tugs/barges, ACS boats and crew boats during the open-water season by year from 2003 through 2015. The trip records of the ACS vessels in 2004 and 2005 are incomplete; they cover only a ~32-day period from late August to early October.

<table>
<thead>
<tr>
<th>Year</th>
<th>Tugs/Barges</th>
<th>ACS boats</th>
<th>Crew Boats</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>82</td>
<td>--</td>
<td>0</td>
</tr>
<tr>
<td>2004</td>
<td>24 (22)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2005</td>
<td>21 (14)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2006</td>
<td>64</td>
<td>106</td>
<td>0</td>
</tr>
<tr>
<td>2007</td>
<td>40</td>
<td>137</td>
<td>0</td>
</tr>
<tr>
<td>2008</td>
<td>45</td>
<td>55</td>
<td>0</td>
</tr>
<tr>
<td>2009</td>
<td>44.5</td>
<td>65</td>
<td>0</td>
</tr>
<tr>
<td>2010</td>
<td>63.5</td>
<td>15</td>
<td>231.5</td>
</tr>
<tr>
<td>2011</td>
<td>61.5</td>
<td>92</td>
<td>488</td>
</tr>
<tr>
<td>2012</td>
<td>30</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>2013</td>
<td>20</td>
<td>0</td>
<td>40.5</td>
</tr>
<tr>
<td>2014</td>
<td>16</td>
<td>0</td>
<td>106</td>
</tr>
<tr>
<td>2015</td>
<td>13</td>
<td>0</td>
<td>195.5</td>
</tr>
</tbody>
</table>

ACS and Crew Boats

Dedicated crew boats were used to transport personnel to and from Northstar during construction and initial operations, but after the hovercraft became available in 2003, a dedicated crew boat was not used again until 2010 and 2011. There was no dedicated crew boat in 2012, but use of a crew boat resumed in 2013 (Table 1.6). In 2015, the M/V Leeway, an 11.5-m (38-ft) aluminum catamaran with twin Yamaha 300 hp outboard motors, was used for personnel transport (Fig. 1.5). From 2003 to 2012, ACS Bay-class boats provided alternative transportation if the hovercraft could not be used. ACS boats were not used after 2012. Even so, crew boats were used less often from 2013 to 2015 than in 2010 and 2011 (Table 1.6).

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. In April 2014, power generation and compressor equipment on the island began to operate using gas produced at Northstar instead of gas imported from Central Gas Facility on the mainland. Now the gas pipeline from the mainland is normally shut off on the island side, but it can be re-opened and is sometimes used for “black start” situations. As in previous years, three Solar® gas turbine generators provided the main power to the island. Emergency diesel generators were also used intermittently during the reporting period as backup 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 used for gas injection into the formations.

Drilling and Pile-Driving

The Northstar drilling rig was removed from the island during the 2010 open-water season and no drilling or pile-driving activity occurred during the current reporting period.
Training Activities

Articulated ARKTOS evacuation craft are used as the island’s emergency escape vehicles (Fig. 1.6). Two ARKTOS vehicles were present up to October 2007, when an additional ARKTOS was added to increase emergency escape capacity and therefore allow for additional personnel on the island. These vehicles can operate both on ice and in water. No ARKTOS training was done in the 2014/15 reporting period.
Training sessions for the Spill Response Team were given every Monday evening, and 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.

**Oil Spill Inspections**

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

**Reportable Spills**

There were no agency-reportable spills during the 2014/15 period, and no clean-up activity was necessary after Northstar flare events.

**Construction and Maintenance Activities**

As a part of ongoing bench inspection, maintenance and repair along the west side of the island, 334 shackles and 38 blocks were removed and replaced in May and June 2015. The newly installed blocks consist of steel and concrete. In July 2015, a bathymetric survey of the submerged slopes of the island was conducted using side scan sonar from a vessel. A strudel scour survey over the pipeline was also performed. One of the Solar® turbines was swapped out and one of the two GE high-pressure compressors was rebuilt, replacing the stage-4 and stage-5 compressors.

**Acoustic and Bowhead Whale Migration Monitoring**

This section provides a summary of the 2015 acoustic and bowhead whale monitoring activities associated with the Northstar project that required use of vessels in waters offshore of Northstar. In addition to bowhead whale calls, calls of some other marine mammals were also recorded. Chapters 2 and 3 describe in detail the methods and results of these monitoring activities. The monitoring program planned and conducted in 2015 resembled that of 2012–14, so the level of boat support required in 2015 was again low compared to the more extensive field efforts of most previous years, especially 2000–2004 and 2008–2009.

Boat-based work in support of this monitoring was conducted on two days: 19 Aug. and 22 Sept. 2015. On 19 Aug., the vessel M/V Leeway was used to deploy five DASARs. Two DASARs were deployed 15 km (9.3 statute mi) northeast of Northstar, and three were deployed ~450 m (~1476 ft) northeast of Northstar. On 22 Sept., all five 2015 DASARs were retrieved using the M/V Leeway. Health checks to confirm recording functionality were performed immediately following DASAR deployment on 19 Aug.

**Non-Northstar Related Activities**

The Bureau of Ocean Energy Management (formerly the Minerals Management Service and, before that, the Bureau of Land Management) has funded and/or conducted aerial surveys of the fall migration of bowhead whales through the central and western Beaufort Sea each year since 1979. Starting in 2007, the Bowhead Whale Aerial Survey Program (BWASP) was coordinated through the National Marine Mammal Laboratory (NMML; Clarke et al. 2011a,b), and in 2008–2015 these surveys also extended across the northeast Chukchi Sea. The purpose was to document marine mammal distribution and movements in Arctic Alaskan waters during the open-water (ice-free) months (Clarke et al. 2011c). Starting in 2012, the Beaufort and Chukchi programs were combined as the Aerial Survey of Arctic Marine Mammals (ASAMM) project.
(Clarke et al. 2014). Information on these programs, including reports and survey data, is available on the NMML website (http://www.afsc.noaa.gov/NMML/cetacean/bwasp/index.php). As summarized there, the ASAMM surveys in the Beaufort Sea during 2015 were conducted from 19 July to 10 Oct.

The research and survey vessel R/V Norseman II conducted operations in the area from 30 July to 7 Aug. as part of the Arctic Nearshore Impact Monitoring in Development Areas (ANIMIDA) program. The Norseman II then transited from Prudhoe Bay to Wainwright from 9 Aug. through 2 Sept. as part of the Arctic Marine Biodiversity Observation Network (AMBON) project.

R/V Sikuliaq took part in an ArcticMix survey to investigate the distribution of heat and salt in the Beaufort Sea. This survey took place off the continental shelf in the Alaskan and Canadian Beaufort from 30 Aug. to 27 Sept. and came within 100 nautical miles of Northstar. Activities included deploying various moored and towed equipment to measure properties of the water column.

The following are seismic applications that were approved by the Alaska Department of Natural Resources for three-dimensional (3D) seismic exploration in 2015. However, we have not confirmed that the activities were completed:

- Geokinetics Inc., near the Colville River as well as Franklin Bluffs on the Sagavanirktok River from 26 Jan. to 31 May 2015.

Various additional shipping operations unrelated to Northstar occur in the Alaskan Beaufort Sea during each open water season. Other non-Northstar industrial activities not addressed here may also have occurred in the general area.

**OBSERVED SEALS**

This section summarizes Northstar seal sightings during the latter part of the ice-covered season and the start of the open-water season for 2005 through 2015. Observations were conducted from the 33-m (109-ft) high process module by Northstar Environmental Specialists on behalf of Hilcorp. The protocol for seal counts was initiated in 2005 and included

- counting the number of basking seals (Fig. 1.7) from 15 May to 15 July on a near-daily basis. Counts were done once each day, usually between 11:00 and 19:00 hr local time, for at least five days per week (when practicable). No counts were made if the cloud ceiling was less than 91 m (300 ft);
- using the roof of the Northstar process module as an elevated platform (33 m or 109 ft above sea level) from which to count seals;
- scanning with the naked eye and using binoculars to confirm suspected seal sightings;
- counting seals within ~950 m (3116 ft) around the entire perimeter of the island, i.e., within an area of landfast ice and varying amounts of open water totaling ~281 ha (695 acres). An inclinometer was used to estimate the distance to observed seals. Seals observed inside the area whose periphery was 2º or more below the horizon were included in the count. (From the height of the observation platform, a 2º depression angle corresponded to a distance of ~950 m or 3116 ft.) If the depression angle was <2º as measured with the inclinometer, then the seal was outside the monitoring area.
Seal observations in 2015 were conducted from 15 May through 15 July as called for by the protocol. A total of 84 seals were observed (including presumed repeat sightings of the same animal on different days; Table 1.7). The total number of seal observations per year ranged from a low of 3 seals in 2007 to a high of 811 seals in 2009. The 2015 seal total count (84) and the mean daily sighting rate (1.4 seals/day) were the median values of all 11 years of the study (Table 1.7). Overall results of the seal counts suggest high inter-annual variability in number of seals sighted and mean daily sighting rates.

### TABLE 1.7. Summary of seal data collected in the period 15 May to 15 July from 2005 through 2015.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total # of seals</th>
<th>Total obs. days</th>
<th>Mean # seals/day</th>
<th>Max. # observed</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>229</td>
<td>42</td>
<td>5.5</td>
<td>124</td>
<td>19.4</td>
</tr>
<tr>
<td>2006</td>
<td>54</td>
<td>48</td>
<td>1.1</td>
<td>4</td>
<td>1.2</td>
</tr>
<tr>
<td>2007</td>
<td>3</td>
<td>62</td>
<td>&lt;0.1</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>2008</td>
<td>415</td>
<td>54</td>
<td>7.7</td>
<td>63</td>
<td>15.1</td>
</tr>
<tr>
<td>2009</td>
<td>811</td>
<td>61</td>
<td>13.3</td>
<td>87</td>
<td>24.6</td>
</tr>
<tr>
<td>2010</td>
<td>185</td>
<td>62</td>
<td>3</td>
<td>18</td>
<td>4.5</td>
</tr>
<tr>
<td>2011</td>
<td>185</td>
<td>62</td>
<td>3</td>
<td>70</td>
<td>10.9</td>
</tr>
<tr>
<td>2012</td>
<td>43</td>
<td>62</td>
<td>0.7</td>
<td>5</td>
<td>1.2</td>
</tr>
<tr>
<td>2013</td>
<td>56</td>
<td>62</td>
<td>0.9</td>
<td>6</td>
<td>1.2</td>
</tr>
<tr>
<td>2014</td>
<td>52</td>
<td>53</td>
<td>1.0</td>
<td>7</td>
<td>1.7</td>
</tr>
<tr>
<td>2015</td>
<td>84</td>
<td>59</td>
<td>1.4</td>
<td>12</td>
<td>2.9</td>
</tr>
</tbody>
</table>
In 2015, the numbers of seals seen in late May and early June were similar, and only 1% of seals observed were recorded after June 15 (Fig. 1.8). In contrast, over the 11-yr period, average sighting rates were highest during the latter half of June, and lower in early June and early July (Fig. 1.8). During most years with data (excluding 2007, when only 3 seal sightings were recorded), the seal sighting rate was low in the latter half of May and increased in early June (Fig. 1.8). This was not the case in 2011, however, when fewer seal sightings were recorded in early June than in late May. In 2008, 2009 and 2011 the seal sighting rate continued to increase during the latter half of June. This was not the case in 2012 when no seal sightings were recorded during the latter half of June, nor in 2015 when only one seal sighting occurred in the latter half of June.

![Graph showing average number of seals observed per day from Northstar Island, by half-month, from 15 May to 15 July during 2005 through 2015.](image)

**Figure 1.8.** Average number of seals observed per day from Northstar Island, by half-month, from 15 May to 15 July during 2005 through 2015. In 2005 observations started on 3 June, so the number of seals in the period 15–31 May 2005 is unknown. Other apparently "missing" bars (1–15 July 2006, 2008, 2013, 2014, and 2015; 16-30 June 2012 and 2015; and all periods in 2007) indicate zero or near zero average numbers during periods when observations were obtained.

In 2015, the seal sightings were fairly evenly split between late May and early June. There was only one sighting in late June and none in July. The relatively high sighting rates in late June of some years are reflected in a high 10-yr average for late June. However, in some other years, including 2015, seal sighting rates declined during the latter half of June and remained low in July (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.

**ACKNOWLEDGEMENTS**

Numerous individuals, including Hunter Ervin, Lori Murray, and Walton Crowell, provided information on Hilcorp activities. Mike Williams, while working with LGL and OASIS Environmental, plus Dr. Bill Streever of BP, designed the seal observation program. Seal observations in 2015 were made by the Northstar Environmental Specialists Phil Hubbard and Hunter Ervin. Bob Rodrigues, Heather Patterson, Mike Williams, and Dr. Lisanne Aerts, with or formerly with LGL, compiled the BP activity and seal data from most previous years. Dr. Katherine Kim (Greeneridge) managed the 2015 monitoring program. Drs. W.J. Richardson (LGL) and K. Kim reviewed and edited the chapter, and Beth Sharp (Hilcorp) provided helpful comments on a draft.
LITERATURE CITED


CHAPTER 2:
UNDERWATER SOUNDS NEAR NORTHSTAR ISLAND,
AUTUMN 2015

by

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ABSTRACT

During the bowhead whale migration in late summer/early autumn 2015, Greeneridge Sciences Inc., on behalf of Hilcorp Alaska LLC, implemented an acoustic monitoring program north-northeast of Hilcorp’s Northstar oil development. Acoustic monitoring in 2015 extended from 19 Aug. through 22 Sept., and focused on determining (1) underwater sound levels and characteristics near Northstar and (2) the relative numbers and bearings to bowhead whale calls near Northstar. The first of these topics is the subject of this chapter.

Underwater sounds associated with Northstar were monitored with bottom-mounted recorders located at two standard sites northeast of the island. The near-island site is ~450 m (1476 ft) northeast, and the offshore site “C/EB” is ~15 km (9 mi) northeast. These acoustic recorders were deployed in 2015 at locations where similar recorders had been deployed during all autumn migration seasons since 2001. Water depths at those sites were ~12 and ~23 m, respectively. Types of acoustic data acquired at both sites were generally consistent with data obtained there in prior years to allow comparison of the 2015 results with those from 2001 to 2014.

As in years past, broadband sound near and offshore of Northstar was characterized by its dependence on wind speed (sea state) and by occurrence of transient high-level “sound spikes” caused by passing vessels. Baseline broadband levels continued to fluctuate approximately in parallel with wind speed. Near-shore and offshore broadband levels in 2015 were within the ranges typical of previous years. One-third octave band levels and spectral density levels were also generally consistent with previous years. As in the previous two years (2013 and 2014), unidentified impulsive transients similar to 2008/2009’s “pop” sounds were detected on the nearshore DASAR in 2015, and no known airgun sounds were received on the offshore DASAR.

INTRODUCTION

A comprehensive report on the results of the initial years of the acoustical and marine mammal monitoring program at Northstar (up to 2004) can be found in Richardson (ed., 2008). Results from continued monitoring in the 2005–2010 period are summarized in a second comprehensive report, Richardson (ed., 2011b). Results of monitoring in 2011–2014 appear in a series of annual reports (Richardson and Kim, eds., 2012–2015). Collectively, these results suggest that (1) ongoing Northstar activities have no measurable effects on seals, and (2) there were—in the 5 seasons of most detailed study—limited but statistically detectable changes in the distribution of localized bowhead whale calls near Northstar as a function of fluctuating levels of underwater sound. The most readily detected effects on distribution of bowhead whale calls may be limited to the southernmost part of the migration corridor during periods with relatively noisy operations (generally boat and barge operations).

Analyses of the 2001–2004 call-location 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 a statistically significant tendency for the southernmost whale calls to be slightly farther offshore (McDonald et al. 2008, 2012; Richardson et al. 2012). 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 in combination. A similar analysis of call-location data from 2009 did not identify a consistent relationship between offshore distance of bowhead whale calls and Northstar sound, possibly because of confounding by reactions of bowhead whales to sound pulses received from a seismic survey that was ongoing far to the east in 2009 (McDonald et al. 2011; Blackwell et al. 2015).
Given the large amount of information about Northstar sounds and Northstar effects available from previous years, the limited nature of those effects, and the results of discussions with regulatory and stakeholder groups, the acoustic monitoring plan implemented in September of 2010–2015 was reduced in scope relative to prior years. Work in September of 2010–2015 involved monitoring for changes, relative to previous late summer/autumn seasons, in (a) levels and characteristics of underwater sounds emanating from Northstar, and (b) the relative numbers of and bearings to bowhead whale calls offshore of Northstar. The current chapter describes the levels and characteristics of underwater sounds near Northstar, and at a recorder located further offshore (location C). Chapter 3 describes the numbers and bearings of whale calls detected at the standard site offshore of Northstar. These two chapters focus mainly on the 2015 results, but also refer to some of the data from previous years.

**Background**

Since development plans for Northstar Island were announced BP Exploration (Alaska) Inc. 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 and/or the whales are especially responsive (see Richardson et al. 1995 for a review). During the planning phase of the acoustic monitoring project for Northstar, it was assumed that construction and especially operational sounds from Northstar, with the exception of vessel-generated sounds, 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 (closest to Northstar) and was designed to detect small-scale effects.

The main goal of the acoustic monitoring program in late summer/early autumn was to understand the relationship between sounds generated by Northstar activities and the distribution of calling bowhead whales in the southern (proximal) portion of the autumn migration corridor. Every year from 2001 to 2015, from late August/early September to late September/early October, acoustic sensors were deployed ~450 m (1476 ft) northeast of the island and also at one or more additional sites farther offshore:

- Cabled hydrophones or seafloor recorders were deployed ~450 m northeast of the island to obtain a continuous record of Northstar (and other) underwater sounds near the island.

- Directional autonomous seafloor acoustic recorders (DASARs, Greene et al. 2004) were deployed offshore at varying numbers of locations to record whale calls and other underwater sounds. The offshore DASARs were deployed as arrays of DASARs at 10 locations (2001–2004 and 2008–2009), as arrays of 3–4 locations (2005–2007, 2012), or in one location (2010–2011, 2013–2015). These offshore DASARs were placed in the southern part of the migration corridor, ~6.5–38.5 km (~4–24 mi) northeast of Northstar. In years when DASARs were deployed at only one offshore location, that location was our site “C/EB”, ~15 km (9 mi) northeast of Northstar. That site was also one of the 3–10 monitoring sites in years with DASARs at multiple offshore sites. The offshore DASAR(s) were used to record and, where possible, locate bowhead whale calls, and to obtain information on calling behavior. They also documented other natural and anthropogenic sounds in offshore waters.

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2 A similar acoustic monitoring effort was done in 2000 as well (Greene et al. 2001), but various technical problems limited the results. The results from 2000 are not further discussed in this report.
As described in Chapter 1, this monitoring effort was conducted for BP in years up to 2014, and was continued in 2015 for Hilcorp Alaska LLC after Hilcorp became the owner and operator of Northstar.

Each year, the acoustic recorders were deployed for ~30 days during late summer/early autumn when bowhead whales were known to migrate past Northstar. Although the whale migration is known to continue well into October, the recorders were retrieved in late September or early October each year before boat-based operations were curtailed by freezeup or incursion of drifting ice.

Analyses of the near-island sound records revealed that vessels were the main contributors to the underwater sound field, as documented in Blackwell and Greene (2006). Vessel activities around Northstar include tug-and-barge operations, crew boats (until 2003 and in 2010–2011 and 2013–2015), a hovercraft (since 2003), and other vessel operations (e.g., oil spill response training) in the 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 sounds produced by these vessels were often detectable as much as ~30 km (19 mi) offshore of Northstar. Without vessels and under calm (sea state ≤1) conditions, i.e., in conditions conducive to detection of sound at long distances, median levels of broadband island sound reached background values 2–4 km (1.2–2.5 mi) from Northstar. This is consistent with results from earlier studies in which most underwater sounds propagating from exploration activities on a gravel island (the same island later developed as Northstar) were quite weak and usually not detectable beyond a few kilometers (Greene 1983; Davis et al. 1985).

Results of previous acoustic monitoring of the westward migration of bowhead whales past Northstar are summarized on p. 2-2. That topic is further addressed in Chapter 3.

Objectives

The overall objectives of the acoustic portion of the ongoing Northstar study are two-fold: acoustic monitoring of (1) Northstar sounds and (2) bowhead whales. In 2015, the specific tasks were as follows:

1. Deploy an acoustic recorder about 450 m (1476 ft) offshore of Northstar, in the same area where underwater sounds have been recorded during each late summer/early autumn season since 2001. This recorder was to be installed for ~30 days in September, corresponding with the deployment period for the offshore recorder (see below). The near-island recorder was to be used to record and quantify sound levels emanating from Northstar. At least one additional acoustic recorder was to be deployed to provide a reasonable level of redundancy.

2. Deploy a DASAR about 15 km or 9 mi offshore of Northstar, consistent with a location used in past years (as far as conditions allow). The data from the offshore recorder were to provide information on the total number of calls detected, the temporal pattern of calling during the recording period, the bearings to calls, and call types. In addition, this recorder was to provide background sound level measurements. These data were to be compared with corresponding data from the same site in previous years (known as location EB in 2001–2007 and C in 2008–2015). A second DASAR was to be deployed at the same location to provide a reasonable level of redundancy.

The methods used and results obtained from these nearshore and offshore DASARs for the monitoring of Northstar sounds are the subject of this chapter. This includes broadband, narrowband, and one-third octave band levels based on data collected at the two locations. It also reports on sounds from other sources, e.g., wind-related ambient sounds and impulsive sounds such as airgun pulses.
METHODS

Instrumentation: DASARs

In this study, sounds were recorded using Directional Autonomous Seafloor Acoustic Recorders (DASARs, see Greene et al. 2004), model C08 (DASAR-C). Each DASAR contains an omnidirectional pressure sensor and a pair of orthogonal sensors from which bearings to sounds can be determined. DASAR design history and hardware specifications are detailed in the monitoring program’s most recent comprehensive report (Richardson, ed., 2011b).

2015 Field Operations

DASAR Deployments and Retrievals

DASARs were deployed as follows: the DASAR was connected to a Danforth anchor by a 110 m (360 ft) ground line. When the vessel was at the target DASAR deployment location, the DASAR was lowered to the seafloor off the stern of the vessel, and a GPS waypoint of the location was obtained. The vessel then moved in a straight line until the end of the ground line was reached, at which point the anchor was deployed and another GPS waypoint was obtained. DASARs were 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.

Five DASARs were installed on 19 Aug. 2015 from the M/V Leeway at two locations mapped in Figure 2.1. Table 2.1 lists the deployment locations and recording start and end times for all DASARs. Two DASARs were deployed at location C, 15 km (9.3 mi) northeast of Northstar, which is the one offshore location where a functional DASAR has been deployed every autumn since 2001. One of the two served as a redundant backup recorder. The role of the offshore DASAR was to provide information on the total number of whale calls detected, the temporal pattern of calling during the recording period, the bearings to calls, and call types, all of which are presented in Chapter 3. It also provided data on ambient and anthropogenic sounds at the offshore location. In addition, three DASARs were deployed ~450 m northeast of Northstar (Fig. 2.2). The primary function of these near-island DASARs was to provide a continuous acoustic record of sounds produced by Northstar and its attending vessels. The three near-island instruments, referred to as DASARs NSa, NSb, and NSc, were located 372 m, 389 m, and 462 m (1222 ft, 1276 ft, and 1517 ft), respectively, from the center of the north shore of Northstar. NSa and NSb were separated by 123 m (402 ft), and NSb and NSc by 132 m (432 ft). Two of the three near-island DASARs were deployed as backups to the third, and it was the DASAR 462 m from Northstar (NSc) whose data were used.

All five DASARs deployed in 2015 were successfully retrieved on 22 Sept. 2015 via the M/V Leeway.

Health Checks

Immediately after DASAR deployments on 19 Aug., health checks were performed on all DASARs. Health checks provide an indication whether the deployed recorders and their software are functioning as expected. A surface-deployed transducer interrogated an acoustic transponder in each recorder, which responded on one channel if it was recording and on another channel if it was not. None of the DASARs reported any health problems on 19 Aug.
FIGURE 2.1. Locations of offshore and near-island DASARs with respect to Northstar Island, Aug.–Sept. 2015. Two DASARs were deployed at location C and three at the near-island location just north of Northstar (see Fig. 2.2). For comparison, DASAR locations used in prior monitoring years are also shown.

**Time and Bearing Calibrations**

On 19 Aug., the day of DASAR deployment, the clock and reference bearings of each DASAR were calibrated. Time and bearing calibrations were also performed on 22 Sept., before DASAR retrievals. *Time calibrations* are conducted because each DASAR’s clock has a small but significant drift. The clock drift must be quantified in order to maintain an accurate time base over the course of the deployment (Greene et
TABLE 2.1. DASAR locations in 2015, 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. Location C in the array is the same as location EB in 2001–2007. DASAR units 36 and 50 were deployed offshore and are redundant of each other, both at location C. DASAR units 37, 48, and 47 were installed close to Northstar and are redundant of each other.

<table>
<thead>
<tr>
<th>Location</th>
<th>Unit #</th>
<th>Installed (Date &amp; time)</th>
<th>Data Start</th>
<th>Data End</th>
<th>Latitude (deg N)</th>
<th>Longitude (deg W)</th>
<th>Depth (m)</th>
<th>Distance from Northstar (km)</th>
<th>Distance from Northstar (mi/ft)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>C (=EB) †</td>
<td>36</td>
<td>19 Aug. 15:13</td>
<td>19 Aug. 14:00</td>
<td>22 Sept. 17:04</td>
<td>70.579</td>
<td>148.391</td>
<td>22.9</td>
<td>14.93</td>
<td>9.28</td>
</tr>
<tr>
<td>C dupl.</td>
<td>50</td>
<td>19 Aug. 15:03</td>
<td>19 Aug. 14:00</td>
<td>22 Sept. 17:15</td>
<td>70.577</td>
<td>148.392</td>
<td>22.6</td>
<td>14.80</td>
<td>9.20</td>
</tr>
<tr>
<td>NSa</td>
<td>37</td>
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<td>19 Aug. 14:00</td>
<td>22 Sept. 17:12</td>
<td>70.495</td>
<td>148.694</td>
<td>12.5</td>
<td>0.37</td>
<td>1222 *</td>
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<tr>
<td>NSb</td>
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<td>19 Aug. 14:00</td>
<td>22 Sept. 17:07</td>
<td>70.494</td>
<td>148.691</td>
<td>12.2</td>
<td>0.39</td>
<td>1276 *</td>
</tr>
<tr>
<td>NSc †</td>
<td>47</td>
<td>19 Aug. 14:04</td>
<td>19 Aug. 14:00</td>
<td>22 Sept. 17:10</td>
<td>70.494</td>
<td>148.688</td>
<td>12.2</td>
<td>0.46</td>
<td>1517 *</td>
</tr>
</tbody>
</table>

*Italicized distances are in feet. † DASAR whose data are used in this report.

FIGURE 2.2. Locations of the three near-island DASARs (■) and their associated ground lines and anchors in relation to Northstar, Aug.–Sept. 2015. The primary function of these DASARs was to provide a continuous acoustic record of sounds produced by Northstar and its attending vessels.

Bearing calibrations are conducted because, during initial deployment, a DASAR’s orientation on the seafloor is random with respect to True North. Also, during inclement weather DASARs have sometimes (in previous years) moved on the seafloor. Directional calibration is therefore necessary to convert bearings to whale calls measured relative to the DASARs to bearings re True North.
Field calibrations (both time and bearing) involve emitting sounds underwater at known times and known locations, and recording these sounds on the DASARs. Calibration procedures in 2015 were similar to those in other years since 2001 (e.g., Blackwell et al. 2011). However, in 2013–2015, boat noise provided the sound source, and the boat’s GPS track provided the known times and known locations. (In previous years, calibration transmissions from a J-9 underwater transducer were projected at six locations around each offshore DASAR site and four locations around the group of near-island DASARs.)

After processing, the collected data allow us to determine each DASAR’s orientation on the seafloor, so the absolute directions of whale calls from the DASARs can be obtained (± a small uncertainty in bearing). The calibration transmissions also allow us to synchronize the clocks in the various DASARs, so that the bearings to a call heard by more than one DASAR can be matched, allowing an estimate of the caller’s position by triangulation. Clock synchronization is also important in other situations, for example when matching a particular industrial sound received on several DASARs.

**Analyses of Acoustic Data from DASARs**

After retrieval of five DASARs on 22 Sept., those DASARs were opened and dismantled. The sampling program was shut down, and the hard drives were removed and hand-carried back to Greenridge Sciences, where they were backed up and copied for analysis. Data were transferred to computers running MATLAB® and custom analysis software and were equalized in post-processing. Equalization is a calibration process that compensates for the fact that the sensitivity curve of a DASAR sensor is not flat across all frequencies, but its shape is known (see Blackwell et al. 2006a). Equalization enables computing calibrated sound pressure levels, both on a spectral density basis and in various frequency bands (e.g., 10–450 Hz or by one-third octave).

Various analyses were performed to address the 2015 study objective of monitoring Northstar sounds. Many of the analyses were the same as in 2008–2014 (Blackwell et al. 2009a,b), and some sound analyses used the same techniques as in 2001–2007, to allow comparisons with previous years. These analyses are described in the following sections:

- Calibration of DASAR time and bearing;
- Broadband, narrowband, and one-third octave band levels of sound; and
- Analyses of other sounds, such as impulsive sounds.

The results from these analyses are presented in the *Results and Discussion* section of this chapter.

**Time and Bearing Calibrations**

The acoustic data from a DASAR consist of three channels (omnidirectional, cosine directional, and sine directional) whose respective time series are combined to determine the magnitude and direction (i.e., bearing) of an incoming signal. For bearing estimation, each DASAR’s orientation with respect to True North must be determined. In previous years, when an array of DASARs was used to localize an incoming signal, it was also necessary to correct for among-DASAR differences in clock drift. Bearing and time calibration analyses were similar in principle to previous years, and are explained in more detail in Chapter 2 and Annex 2.1 of Blackwell et al. (2010a). However, in 2015, as in 2013 and 2014, boat noise was used as the calibration sound source. Thus, instead of applying a matched filter to detect and localize a synthesized calibration transmission, brief periods of high-intensity vessel noise, analogous to previous years’ calibration transmissions at different calibration stations, were manually isolated and localized. Sound samples on the order of a second in duration and of high SNR (signal-to-noise ratio) were selected...
to increase the accuracy of time and bearing estimates. The resulting reference bearing is used to compute the actual bearing to a whale call relative to True North, and the reference time is used to align the DASARs’ clocks.

Broadband, Narrowband, One-third Octave Band, and Minimum Levels

Broadband, narrowband, one-third octave band, and minimum levels of the sounds received by both DASARs were determined using the same methods as applied in previous years to allow between-year comparisons. Details of these analysis methods are presented in Blackwell et al. (2009b, 2011).

Other Sounds

Pop Sounds.—Analyses of the data collected in 2008 and 2009 showed that • pops were only recorded on the three near-island recorders (and not on any offshore array DASARs), • the sounds likely originated from the northeastern corner of the island, and • there was a strong positive association between wind speed and the presence and amplitude of pops (Blackwell et al. 2011). This supported the hypothesis that the pops were produced by movements of an underwater structure. Since 2010, a preliminary manual search of the broadband acoustic records of the three near-island recorders has been conducted annually to identify signal characteristics associated with the pops. This manual search process revealed that there were very few identifiable pops in 2010–2012 (see Kim et al. 2011a, 2012, 2013), and, consequently, no additional systematic analyses were performed to detect and quantify pops in those years. However, in 2013, 2014, and now 2015, broadband level metrics raised suspicions about the presence of pops. Presence of pops was subsequently confirmed by manual search and systematic analyses (see Results/Other Sound Sources), although attempts to identify the source of the pops have been unsuccessful.

Airgun Pulses.—During the 2008 and 2009 field seasons, numerous airgun pulses not associated with Northstar were detected on the acoustic records of the offshore DASARs (Blackwell et al. 2011). Because airgun pulses have energy distributed over our entire analysis band of 10–450 Hz, they are a source of interference in the acoustic records. In addition, bowhead whales have been shown to react to sounds from airguns (e.g., Richardson et al. 1986, 1999; Ljungblad et al. 1988; Blackwell et al. 2013). To obtain a quantitative assessment of the number of airgun pulses received in waters near Northstar during the 2015 field season, we analyzed pulses in the record of DASAR C (the offshore DASAR). As in other recent years, we used software developed by Dr. Aaron Thode of Scripps Institution of Oceanography (see Blackwell et al. 2011).

RESULTS AND DISCUSSION

The overall study objective for acoustic monitoring at Northstar in late summer/early autumn is to assess effects of Northstar production activities, as manifested in underwater sounds, on the distribution and behavior of calling bowhead whales. An important component of this assessment is to understand the sounds produced by the Northstar operation (island and attending vessels) and received by migrating whales, and the changes in these sounds over time both within and among years. These sounds represent the “dose” of sound to which we expect some bowhead whales to react. To meet this objective for 2015, this section presents results from analyses of sounds recorded near and offshore of Northstar in late Aug. to late Sept. 2015. Measurements of underwater sounds generated by Northstar and received within the whale migration corridor, as recorded by a near-island DASAR and an offshore DASAR, respectively, were compared with similar data from previous years. Specifically, the results are presented in the following three subsections:

1. Broadband sound levels near Northstar and offshore;
2. Statistical spectra of sounds near Northstar and offshore, showing percentile one-third octave band and spectral density levels, i.e., the frequency composition of the sounds described in (1); and
3. Other sound sources, for example, impulsive sounds such as airgun pulses.

Broadband Sounds Near Northstar and Offshore

Broadband Sounds Near Northstar

Three DASARs were deployed ~450 m northeast of Northstar, with two of the instruments considered backups to the third. Data from these three recorders were in close agreement, with differences that were well within the variation one might expect based on sound reception at slightly different locations (see Fig. 2.2). As in 2008–2014, and some other previous years, DASAR NSc (southeasternmost) was chosen to be most representative of Northstar sounds because its location was closest to the path taken by tugs and 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). In 2015, NSc was 462 m from the center of the north shore of Northstar Island.

The acoustic signals recorded on DASAR NSc were analyzed to determine the received broadband (10–450 Hz) level of underwater sound based on a 1-min sample every 4.37 min. This is the same descriptive technique used since 2001 (see previous Methods section). Figure 2.3B shows the results for 2015.

![Figure 2.3](image)

**FIGURE 2.3.** Variation in broadband levels of underwater sound near Northstar in relation to date and wind speed for 19 Aug.–22 Sept. 2015. (A) Mean hourly wind speed as recorded by the Prudhoe Bay weather station. (B) Broadband (10–450 Hz) levels of underwater sound (1-min averages) near Northstar vs. time, as recorded by DASAR NSc, located ~450 m northeast of the island. Vertical “spikes” in the sound pressure time series are generally produced by vessels arriving at or departing the island.
The range of broadband levels shown for 2015 is 91–139 dB re 1 µPa, and the variable received levels were correlated with wind speed, which is related to sea state. Figure 2.3A shows mean hourly wind speed as recorded by the Prudhoe Bay weather station, which is at 70.40°N, 148.52°W, on the Westdock causeway, elevation 5 m = 16 ft; 12 km southeast of Northstar. The lowest sound levels in Figure 2.3B are indicative of the quietest times in the water near the island and generally correspond to times with low wind speeds (compare with Fig. 2.3A). Conversely, times of higher wind speed (e.g., 4 or 10–11 Sept.) usually correspond to increased broadband levels in the DASAR record. Mean ± s.d. hourly wind speed in 2015 was 8.0 ± 4.5 m/s (17.9 ± 10.0 mph), calculated over the period 31 Aug.–30 Sept. for historical comparison purposes. When calculated over the entire DASAR deployment period (19 Aug. –22 Sept., e.g., as shown in Fig. 2.3A), wind speeds were somewhat higher, 8.6 ± 4.2 m/s (or 19.2 ± 9.4 mph). The 2015 average wind speed at the Prudhoe Bay weather station was slightly higher than (but within a standard deviation of) the overall average across all 15 years of the study over the same date range (7.3 ± 1.5 m/s). Figure 2.4 summarizes mean wind speed (31 Aug.–30 Sept.) in each year of the Northstar study, as recorded by the Northstar3 (2001–2006) or Prudhoe Bay (2007–2015) weather station.

![Figure 2.4](image)

**Figure 2.4.** Mean wind speed for the period 31 Aug.–30 Sept. in 2001–2015, plus one standard deviation. (For 2014, wind data were unavailable after 19 Sept.) Data for 2001–2006 were collected by the Northstar (N) weather station, whereas data for 2007–2015 were collected by the Prudhoe Bay (PB) weather station.

Figure 2.5 compares broadband levels, as recorded ~450 m northeast of the island, over 15 seasons of monitoring (2001–2015). The number of “vessel spikes”4 in 2015 was higher than during the preceding

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3 The Northstar weather station was dismantled after the 2006 open-water season. The Northstar and Prudhoe Bay weather stations are located about 12 km apart.

4 A “vessel spike” is defined as a relatively rapid increase and then a rapid decrease in received levels, causing a vertical line on long-duration sound pressure time series such as Figures 2.3B and 2.5. The event usually lasts less than 30 min. A vessel approaching and docking at Northstar causes a vessel spike on records from the near-island DASARs.
FIGURE 2.5A. Sound pressure time series (10–450 Hz band; 1-min averages) for the 2001–2008 late summer / early autumn field seasons, as recorded ~450 m north to northeast of Northstar. The recordings used a cabled hydrophone in 2001, 2002, and the first part of 2003, and a DASAR for the second part of 2003 and 2004–2008.
FIGURE 2.5B. Sound pressure time series (10–450 Hz band; 1-min averages) for the 2009–2015 late summer / early autumn field seasons, as recorded ~450 m north to northeast of Northstar. The recorders were DASARs for the years 2009–2015.
three years (2012–2014), and resembled the density of vessel spikes seen in 2010 and 2011 (see Fig. 2.5B). Those were years with similar types and numbers of noise-contributing vessels, notably crewboats (see Tables 1.6 and 1.7; recall that the DASAR recording period covered only 19 Aug.–22 Sept. in 2015). Although ACS Bay-class boats were not utilized in 2013–2015, a dedicated crew boat was used prior to 2003 and again in 2010 and 2011, discontinued in 2012, and again put into service in 2013–2015.

During periods of low wind speed, “baseline” sound levels in 2015 were similar to those for previous production years. Here, “baseline” refers to the lower envelope of the fluctuating sound pressure level (SPL) time series derived by our standard analysis. Baseline levels fluctuate in parallel with wind speed and, therefore, sea state.

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 2.2. Figure 2.6 illustrates how those percentile levels of broadband sound in 2015 compare to previous years (2001–2014). Percentile levels in 2015 were within the ranges of previous years, 2001–2014. The maximum levels in Table 2.2 and Figure 2.6 are mainly associated with the presence of vessels. 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 or could produce a maximum received level between sampling times (which were 1 min every 4.37 min).

**Table 2.2.** Percentile levels, in dB re 1 μPa, of broadband (10–450 Hz; 1-min averages) underwater sound recorded near Northstar Island during late summer / early autumn, 2001–2015. In 2015, data were recorded by DASAR NSc (19 Aug.–22 Sept.). “Range” is the difference (in dB) between maximum and minimum values. All hydrophones were at similar distances (410–550 m or 1345–1804 ft) offshore of Northstar.

<table>
<thead>
<tr>
<th>Year →</th>
<th>2001</th>
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<td></td>
<td>CH #2</td>
<td>CH #2</td>
<td>CH #2</td>
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<td>NSb</td>
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<td>133.1</td>
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<tr>
<td>95th %ile</td>
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<td>110.1</td>
<td>118.2</td>
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<tr>
<td>50th %ile</td>
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<td>103.4</td>
<td>100.5</td>
<td>105.5</td>
<td>98.7</td>
</tr>
<tr>
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<td>87.3</td>
<td>94.8</td>
<td>95.2</td>
<td>91.7</td>
<td>93.7</td>
<td>92.4</td>
<td>91.7</td>
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<tr>
<td>Min</td>
<td>80.8</td>
<td>89.7</td>
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<td>90.4</td>
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<td>88.0</td>
<td>89.8</td>
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<td>59.7</td>
<td>45.3</td>
<td>45.0</td>
<td>40.7</td>
<td>41.1</td>
<td>47.8</td>
<td>41.6</td>
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<td>2011</td>
<td>2012</td>
<td>2013</td>
<td>2014</td>
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<td>NSc</td>
<td>NSc</td>
<td>NSc</td>
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<td>NSc</td>
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<tr>
<td>Max</td>
<td>141.1</td>
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<td>136.4</td>
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<td>95th %ile</td>
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<td>123.0</td>
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<td>123.4</td>
<td>123.9</td>
</tr>
<tr>
<td>50th %ile</td>
<td>103.6</td>
<td>103.9</td>
<td>102.7</td>
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</tr>
<tr>
<td>5th %ile</td>
<td>93.2</td>
<td>89.9</td>
<td>92.3</td>
<td>93.0</td>
<td>92.9</td>
<td>92.0</td>
<td>93.7</td>
</tr>
<tr>
<td>Min</td>
<td>91.0</td>
<td>83.6</td>
<td>90.0</td>
<td>90.3</td>
<td>87.2</td>
<td>90.5</td>
<td>90.0</td>
</tr>
<tr>
<td>Range</td>
<td>50.0</td>
<td>54.3</td>
<td>46.3</td>
<td>46.0</td>
<td>49.2</td>
<td>45.9</td>
<td>49.7</td>
</tr>
</tbody>
</table>
During the 2008 field season, a new popping sound appeared in the recordings from the near-island DASARs. Bearings obtained from the three near-island DASARs suggested that “pops” originated at or close to Northstar (Blackwell et al. 2009b). “Pops” were also detected during the 2009 field season when they were more extensively analyzed (Blackwell et al. 2010b). For 2008 through 2015, to get better estimates of the levels of sound at Northstar in the absence of pops and other specific sounds, a “minimum broadband level” of near-island sound was obtained for each 10-min period. Specifically, for near-island DASAR NSc, we calculated broadband levels (10–450 Hz) over 2-s intervals starting every second (i.e., 50% overlap between samples, see “Methods” section), and retained the lowest value per 10-min period. For the 2015 results, see Fig. 2.7. In 2015, mean received levels were 5.0 dB lower for the 2-s minimum analysis compared to the standard analysis (100.2 dB vs. 105.2 dB re 1 µPa, respectively). As summarized in Table 2.3, such a relatively large difference in mean broadband levels can be indicative of prominent but intermittent pop-like transients. (For additional discussion of 2015 pop-like sounds, see Other Sound Sources later in this chapter.) In 2008, when pop sounds were first identified, the difference in mean broadband levels was 5.9 dB. In 2009, the number of detected pops rose to ~2.5 times that of 2008, and the difference in broadband levels likewise increased. In years when pops were largely absent (2010–2012), this difference was less in 2010 and 2012 but slightly higher in 2011 compared to 2015. Thus, minimum analysis can be a useful tool detecting the presence of pop-like transients but only in cases of large differences in mean broadband levels since some difference in levels is expected due to other transient or fluctuating broadband sounds, such as vessels and some other industrial activities.
FIGURE 2.7. Broadband (10-450 Hz) levels of sound at DASAR NSc in 2015, as calculated two different ways: (1) “Standard method” (black line): average over one min every 4.37 min (from Fig. 2.3); (2) “Minimum method” (orange line): lowest 2-s sample for every 10 min period. See text for more information.

TABLE 2.3. Presence of pop-like transients near Northstar since 2008, and its relation to the difference between mean broadband levels calculated by “standard analysis” and “minimum analysis” methods.

<table>
<thead>
<tr>
<th>Year</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
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<th>2013</th>
<th>2014</th>
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<tr>
<td>Difference in mean broadband levels (dB)</td>
<td>5.9</td>
<td>7.4</td>
<td>4.2</td>
<td>5.2</td>
<td>4.2</td>
<td>7.8</td>
<td>6.6</td>
<td>4.9</td>
</tr>
<tr>
<td>Presence of Pop-like Transients</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Broadband Sounds Offshore

Sounds recorded by the offshore DASAR at location C/EB during 2015 were analyzed in the same two ways as the near-island sounds shown in Figure 2.7, i.e., • average levels over 1 min every 4.37 min (our “standard” analysis), and • minimum level for each 10-min period, based on 2-s averages computed every second (see Blackwell et al. 2011 and 2009b for more details). These two types of broadband (10–450 Hz) levels for DASAR C are shown in Figure 2.8. Recall that DASAR C was 14.9 km (9.3 mi) from Northstar (Table 2.1). At that distance, wind speed and sea state are likely the greatest contributors to “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 includes a different (and lower) baseline. We do not have specific data on wind speed offshore. However, the baseline sound levels in Figure 2.8 generally parallel seasonal variations in wind speed at Prudhoe Bay (Fig. 2.8, top) and, also, the overall shape of the sound pressure time series near the island (Fig. 2.7). The mean broadband level of underwater sound (19 Aug.–22 Sept.) offshore at DASAR C in 2015, based on the standard method, was 99.4 dB re 1 μPa, as compared with 105.2 dB re 1 μPa at the near-island DASAR.
Chapter 2: Underwater Sounds, 2015

2-17

FIGURE 2.8. Variation in broadband levels of underwater sound at offshore DASAR C in relation to date and wind speed for 19 Aug.–23 Sep. 2015. (A) Mean hourly wind speed at the Prudhoe Bay weather station. (B) Broadband (10–450 Hz) levels of underwater sound at offshore DASAR C, located 14.9 km northeast of Northstar. Sound levels were calculated using either the “standard method” (black line, average over one min every 4.37 min) or the “minimum method” (red line, lowest 2-s sample for every 10-min period).

The DASARs deployed in 2001–2015 were laid out in various configurations (see Fig. 2.1). However, one geographic location has included a functional DASAR each field season since 2001: that location was referred to as EB up to 2007 and C since 2008. Comparison of the acoustic records from this location gives us the opportunity to observe the variability in broadband sound levels ~15 km (~9 mi) offshore of Northstar each late summer/autumn season since 2001. This comparison is shown in Figure 2.9. In the 2015 open-water season, vessel spikes in the offshore sound records occurred about as often as in previous years, notwithstanding year-to-year changes in numbers and types of vessel transits (Fig. 2.10).
FIGURE 2.9A. Broadband sound pressure time series (10–450 Hz; 1-min averages) at a DASAR location ~15 km (~9 mi) from Northstar during the first eight of 13 consecutive years, 2001–2008. This DASAR location was known as EB in 2001–2007 and C in 2008–2015. Diamonds indicate sound spikes created by the acoustic crew’s vessel during servicing of the array of DASARs.
FIGURE 2.9B. Broadband sound pressure time series (10–450 Hz; 1-min averages) at a DASAR location ~15 km (~9 mi) from Northstar during the last seven of 13 consecutive years, 2009–2015. This DASAR location was known as EB in 2001–2007 and C in 2008–2015. Diamonds indicate sound spikes created by the acoustic crew’s vessel during servicing of the array of DASARs. There were no mid-season visits to the DASARs in 2010–15.
For each year from 2001 to 2015, Table 2.4 shows percentile levels of broadband sound (maximum, 95th, 50th, and 5th percentile, and minimum) computed over the entire field season for DASAR C/EB. Figure 2.11 shows percentile levels of broadband sound at C/EB in 2015 (the black dots) compared to the range of values in previous years. All percentile levels of broadband sound at C/EB were within the ranges found during previous years, but all were higher than in 2014. The 95th, median, and 5th percentile levels, for example, were 2, 3.1, and 5.2 dB higher than in 2014. A 3 dB difference in received level corresponds to a doubling in sound power. The maximum value in 2015 exceeded the 2014 value by 10.9 dB. However, the maximum value can be determined by a single event, such as a vessel passing near the recorder, so this difference is less noteworthy than the smaller differences for the 5th, 50th and 95th percentiles (Table 2.4).

Figure 2.12 compares broadband sounds near Northstar in 2015 with those recorded simultaneously offshore. Because wind is the most important determinant of baseline sound levels, average hourly wind speed as recorded at the Prudhoe Bay weather station is also shown. Baseline levels at these DASARs tended to parallel the wind speed plot and one another. Generally, the baseline levels near Northstar were higher than those offshore, but this was less so for the early part of the season, until about 11 Sept, than for later dates. Thereafter, there was a larger offset between the near-island vs. offshore values (Fig. 2.12B). Wind noise is less prominent on the seafloor recorders offshore in deeper waters, 23 m at DASAR C, compared to that at 12 m depth at DASAR NSc (Table 2.1). Also, upward excursions of the sound level above the baseline were more frequent and stronger near Northstar, indicative of the greater prominence of transient man-made sounds (e.g., Northstar service vessels) operating near Northstar.
TABLE 2.4. Percentile levels, in dB re 1 µPa, of broadband (10–450 Hz; 1-min averages) underwater sound recorded offshore of Northstar Island during late summer/early autumn, 2001–2015. In 2015, data were recorded on 19 Aug.–22 Sept. by DASAR C (=EB in 2001–2007). “Range” is the difference in dB between maximum and minimum values.

<table>
<thead>
<tr>
<th>Year</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
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<td>144.0</td>
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<td>77.1</td>
<td>78.5</td>
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<tr>
<td>Min</td>
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<td>77.1</td>
<td>74.3</td>
<td>75.6</td>
<td>74.3</td>
<td>75.4</td>
<td>75.8</td>
</tr>
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<td>Range</td>
<td>58.5</td>
<td>47.5</td>
<td>38.4</td>
<td>68.4</td>
<td>54.1</td>
<td>43.4</td>
<td>54.0</td>
</tr>
</tbody>
</table>

FIGURE 2.11. Percentile levels of broadband (10–450 Hz) sound at offshore DASAR C (=EB in 2001–2007) in 2015 (black dot) compared to the range of values at the same site for the period 2001–2014 (gray bar). For each year the minimum, 5th, 25th, 50th, 75th, 95th, and maximum percentiles were calculated using 1-min average values collected over the entire field season (5862–13,973 one-minute samples per year).
FIGURE 2.12. Sounds close to Northstar and offshore in relation to wind speed at Prudhoe Bay. (A) Mean hourly wind speed during the period 19 Aug.–23 Sept. 2015, as recorded by the Prudhoe Bay weather station. (B) Broadband sound pressure time series (10–450 Hz band; 1-min averages) at DASAR NSc, ~450 m northeast of Northstar (in black), and DASAR C/EB, ~15 km or ~9 mi northeast of Northstar (in blue).

**Statistical Spectra of Sounds Near Northstar and Offshore**

To characterize the frequency composition of sounds near Northstar and offshore during the study period in 2015, percentile distributions of one-third octave band levels and spectral density levels were calculated for near-island DASAR NSc and offshore DASAR C. In both cases, the measurements were averages over 1 min, specifically, 1-min periods every 4.37 min, the same data post-processing method used since 2001 and described in Blackwell et al. (2009b, 2011). These plots provide two different ways of looking at the same data: levels for one-third octave bands (Fig. 2.13) are shown mainly because they are more relevant to marine mammal hearing (Richardson et al. 1995), whereas spectral density levels (Fig. 2.14) reveal more details on the frequency composition of the sounds from the island. Overall, the spectra of sounds
FIGURE 2.13. Percentile one-third octave band levels for sounds recorded by DASARs NSc (near-island, top) and C (offshore, bottom) during the period 19 Aug.–22 Sept. 2015. 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. The number of 1-min measurements used was 11,181 for NSc and 11,153 for C.

Recorded near Northstar (top plots in both Figures) are similar to those from previous years\(^5\). As in previous years, spectral peaks were present at 30 Hz and 60 Hz (most evident in Fig. 2.14).

The 60 Hz peak and the weaker 30 Hz peak have been evident every year of monitoring and are associated with generation of 60 Hz power. Also, as in previous years, a peak at 87 Hz again appeared in the minimum, 5th, and 50th percentile data (Fig. 2.14), as it has in the near-island recordings since 2003.

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\(^5\) 2014: Fig. 2.13 and 2.14 in Kim et al. (2015); 2013: Fig. 2.13 and 2.14 in Kim et al. (2014); 2012: Fig. 2.13 and 2.14 in Kim et al. (2013); 2011: Fig. 2.18 and 2.19 in Kim et al. (2012); 2010: Fig. 2.18 and 2.19 in Kim et al. (2011a); 2009: Fig. 3.10 and 3.11 in Blackwell et al. (2010b); 2008: Fig. 3.9 and 3.10 in Blackwell et al. (2009); 2007: Fig. 2.9 in Blackwell et al. (2008); 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).
FIGURE 2.14. Percentile spectral density levels for sounds recorded by DASARs NSc (near-island, top) and C (offshore, bottom) during the period 19 Aug.–22 Sept. 2015. 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. The number of 1-min measurements used was 11,181 for NSc and 11,153 for C.

In the percentile one-third octave spectra (Fig. 2.13), one difference between the top plot (near Northstar) and the bottom plot (offshore) is the presence of a large “hump” in the near-island results near 25–80 Hz as evident in the minimum and 5th percentile curves. Sounds in this frequency band are largely of anthropogenic origin (e.g., aforementioned power generation), at least when ambient noise levels are low. It was this observation that led to the definition of the industrial sound index ISI_5band in 2001 (Blackwell 2003). One-third octave band levels are also elevated near Northstar relative to offshore (Fig. 2.13, top vs. bottom) across the entire frequency range, with especially conspicuous differences in the maximum levels. However, maximum levels can be caused by a single vessel pass and are, therefore, not useful for comparisons.

The same comparison can be made for the percentile spectral density levels shown in Figure 2.14. Ignoring the upper percentiles, which can be heavily influenced by transients such as the closest-point-of-

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6 As defined, ISI_5band includes a slightly narrower range of one-third octave bands, i.e., those centered at 31.5, 40, 50, 63, and 80 Hz and spanning 28–90 Hz.
approach of a single vessel, two aspects distinguish the spectral density data from NSc and DASAR C: (1) elevated percentile values (minimum, 5th, and 50th) near Northstar, and (2) observable tones. At NSc, tones can be identified in the minimum, 5th percentile, and 50th percentile lines, i.e., during quieter times when levels are at or below median values.

**Other Sound Sources**

*“Pop” and Pop-like Sounds*

In 2008 and 2009, an impulsive popping sound was prominent and frequent on the near-island recorders. This sound was of short duration (~0.05 s), but its high amplitude, broad bandwidth, and rate of occurrence were such that it could have some effect on the descriptive statistics of Northstar sound. Pops seem to have been more frequent in 2009—a peak detector applied to near-island (NSb) data from 2009 identified ~2.5 times the number of pops that were detected on the 2008 record. In contrast, a manual search for pops in the near-island records of 2010–2012 revealed few occurrences of signals with the characteristics of the 2008/2009 pops. In 2013, 2014 and 2015, numerous pops were recorded, and the peak detector was again applied to the nearshore DASARs (Table 2.5).

**TABLE 2.5.** Putative “pop” sounds identified by a peak detector applied to nearshore DASAR NSb’s acoustic records from 2008, 2009, 2013, 2014, and 2015. The highest instantaneous peak values are given for the strongest pop in each season’s acoustic record.

<table>
<thead>
<tr>
<th>Year</th>
<th>2008</th>
<th>2009</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
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<tr>
<td># of hours of data analyzed</td>
<td>704.7</td>
<td>801.4</td>
<td>620.0</td>
<td>740.5</td>
<td>799.8</td>
</tr>
<tr>
<td># of pops exceeding 7 Pa threshold*</td>
<td>52,248</td>
<td>131,352</td>
<td>110,410</td>
<td>91,455</td>
<td>65,344</td>
</tr>
<tr>
<td>Highest instantaneous peak (dB re 1 μPa)</td>
<td>149.0</td>
<td>149.3</td>
<td>150.7</td>
<td>150.5</td>
<td>151.6</td>
</tr>
</tbody>
</table>

* A peak pressure of 7 Pa (136.9 dB re 1 μPa) corresponds to the threshold level of the peak detector.

The 2009 pop analyses found a positive association between wind speed and the presence and amplitude of pops in both 2008 and 2009 (Fig. 4.26 in Blackwell et al. 2011). As shown in Figure 2.15, the same association was found in 2013–2015. In 2015, when wind speeds exceeded 7 m/s, hourly maximum pop amplitudes and hourly wind speeds were not as strongly correlated as in previous years ($r = 0.34, n = 296, P < 0.001$). The average wind speed for 31 Aug.–30 Sept. 2015 was 8.0 m/s (± s.d. 4.5 m/s), on par with average wind speeds in other years with pops. However, Figure 2.5 suggests that, at least in 2013–2015, high winds sustained over multiple days may have been necessary before many pops were produced. Bearing estimates from the three nearshore DASARs in 2008, 2009, and 2013 suggested that the pops were likely generated near or slightly offshore of the northeast corner of Northstar. It has been hypothesized that the pops may have been produced by an object or structure underwater, located close to the island, that moved when sea state increased.
FIGURE 2.15. Presence and received sound levels of pops (black dots), the unknown sound source of 2008–2009 and 2013–2015, on records of near-island DASAR NSb in relation to mean hourly wind speed (red line). The threshold level of the peak detector was a peak pressure of 7 Pa (136.9 dB re 1 µPa). Wind speed was measured at the Prudhoe Bay weather station so is only roughly indicative of wind speed near DASAR NSb. In 2013, wind data were absent between 30 Aug., 06:00 AKDT and 7 Sept., 07:00 AKDT, and, in 2014, wind data were absent after 19 Sept., 23:00 AKDT.
Airgun and Other Pulses

No seismic surveys associated with Northstar have been done in recent years, but widely variable numbers of airgun pulses from other seismic survey projects have been detected by DASARs deployed offshore of Northstar. During the 2008 field season, ~147,000 sound pulses produced by airguns were detected via the DASAR deployed farthest from shore that year (known as DASAR J, refer to Fig. 2.2). These pulses came from seismic survey operations not associated with Northstar or other BP operations near Prudhoe Bay. Many of these pulses came from airguns operating relatively nearby, over the continental shelf of the central Alaskan Beaufort Sea, but others came from much longer distances (Thode et al. 2010). The airgun pulses of 2008 constituted a strong confounding factor in achieving the objective of assessing the effects of Northstar sounds on bowhead whale behavior (McDonald et al. 2011). During the 2009 field season, when the monitoring program was very similar to that in 2008, fewer (~65,000) airgun pulses were detected via DASAR J, and their received levels tended to be lower than in 2008. The airgun operations responsible for the generally weak pulses in 2009 were at long distances to the east in the Canadian Beaufort Sea and far to the north in the Arctic Basin (Blackwell et al. 2010b, 2011). Although the contribution of airgun pulses to overall sound levels was smaller in 2009 than it was in 2008, they were taken into account when assessing the effects of Northstar sounds on bowhead call behavior in 2009 (McDonald et al. 2011). In the 2010, 2011, 2013, and 2014 field seasons, notably fewer pulses (2862, 297, 3145, and 1786, respectively) were detected via DASAR C, the only offshore DASAR deployed in those years. In most cases during these four years, the interpulse intervals and bearing tracks for the detected pulses were inconsistent with seismic surveys, and it could not be verified that the pulses originated from airguns (Blackwell et al. 2011; Kim et al. 2012, 2014, 2015).

To obtain a quantitative assessment of pulses received near Northstar during the 2015 field season, automated pulse detection software was applied to DASAR C records of 2015. The same basic software had been used to identify the pulses in DASAR J records of 2008, DASAR J and C records of 2009, and DASAR C records of 2010–2014 (see above). In 2015, only 2080 pulses were detected. Two characteristics of these pulses—their interpulse intervals and bearings from DASAR C—suggest that the pulses did not originate from airguns. As illustrated in Figure 2.16, interpulse intervals were inconsistent, changing rapidly between 7 s and 28 s, and the directions from which the pulses originated also varied significantly from day to day and often within a day. The variation was greater than expected for typical seismic surveys. We conclude that the pulses recorded at DASAR C in 2015 probably were not from a seismic survey; their source(s) are unknown.
ACKNOWLEDGEMENTS

In 2015, HDR Advantage LLC joined the Northstar acoustic monitoring team, and we extend our thanks to M/V Leeway’s Capt. Heather Ronek for her assistance before, during, and after fieldwork. We also are grateful for early discussions with William Britt of Hilcorp and the efforts of Beth Sharp of Hilcorp who provided programmatic leadership, logistical assistance on land prior to fieldwork, assisted at sea with DASAR deployments and retrievals, and reviewed the draft report. Dave Christian and Alex Conrad (Greeneridge Sciences) prepared and tested the DASARs for the field season with their usual enthusiasm. We thank Dr. Bill Streever of BP for facilitating the transition of the monitoring program from BP to Hilcorp. Dr. W. John Richardson of LGL, who managed the contractor team during early years of Northstar monitoring, provided review comments on the draft report and shepherded the report through final production with the assistance of Anne Wright of LGL.
LITERATURE CITED


CHAPTER 3:
ACOUSTIC MONITORING OF BOWHEAD WHALE MIGRATION,
AUTUMN 2015

by

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ABSTRACT

A key objective of the Northstar monitoring is to characterize the westward migration of bowhead whales past Northstar during late summer/autumn, and the possible effects of sound from Northstar on that migration. Since 2001, that has been done primarily by detecting and localizing calls from bowheads in waters offshore of Northstar, and relating those data to measurements of underwater sounds produced by Northstar activities. This chapter describes the detection, classification, and localization of bowhead whale calls recorded by a directional autonomous seafloor acoustic recorder (DASAR) deployed 15 km (9 mi) offshore of Northstar during the 2015 autumn migration. This chapter also characterizes year-to-year and within-season variation in the numbers, types, and distribution (bearings) of calls detected at that offshore location, where acoustic data were acquired every late summer/early autumn season since 2001.

The types and seasonal timing of bowhead whale calls were similar to those in previous years. The average daily call detection rate was 152 calls/day, the fifth lowest in the study’s 15 years. The timing of peak daily call detections was consistent with most previous years, in which peaks occurred around the third week of Sept. In 2015, the two pulses of increased bowhead calling activity occurred during the second and third weeks of Sept. Additional and/or larger pulses might possibly have occurred in the last week of Sept. or thereafter, but early ice formation around Northstar in 2015 forced early retrieval of the DASARs on 22 Sept.

Bearing analyses showed that, in 2015, bowhead whale calls arrived predominantly from the east-northeast relative to DASAR C, consistent with 12 of 15 years of the monitoring program. However, like the year before, the 2015 season had a low offshore/inshore (O/I) ratio (1.2 in 2015), indicating that the numbers of calls “offshore” and “inshore” of the monitoring site were roughly equal. In 2015, bearing metrics such as mean vector length and I/O ratio were similar to those in 2005, possibly due to local heavy ice conditions in both years.

The 2015 season was the fifth year in which the study provided quantitative measures of low-frequency (<450 Hz) call detections from marine mammal species additional to bowhead whales. Bowheads, bearded seals, and unclassified species accounted for 94.5%, 2.1%, and 3.4%, respectively, of marine mammal sounds detected. Man-made sounds detectable at the offshore DASAR—for example, noises attributable to vessels—were also classified and documented in 2015. Sounds classified as unidentifiable constituted the highest percentage of all detected sounds (21.7%) since expanded classification began in 2011. Of the bowhead calls, relative proportions of five different call types in 2015 were similar to those during the previous two seasons, as was the percentage of simple calls in 2015 (93.9%).

INTRODUCTION

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

The overall aim of this study is to assess the effects of Northstar activities, as manifested in underwater sounds, on the distribution and behavior of calling bowhead whales in late summer and early autumn. An acoustical approach is used to locate calling bowhead whales near Northstar (Greene et al. 2004; Blackwell et al. 2007), and dose-response analyses have been applied to previous years’ data to determine whether the distribution of calling whales is related to fluctuations in Northstar sounds. For example, statistical analyses of the 2001 to 2004 data showed that, with increased levels of certain types of Northstar sounds, there was an offshore shift in the locations of whale calls in the southern (inshore) part of the whale migration corridor (McDonald et al. 2008, 2012; Richardson et al. 2008, 2012). This shift could be the result of whales in the southern part of the migration corridor deflecting away from the island or changing their calling rates in response to increased sounds, or some combination of the two. The effect might also be at least partly related to changes in whale headings, given newfound evidence of directionality in bowhead whale calls (Blackwell et al. 2012).

This chapter presents the results from detecting and analyzing bowhead whale calls recorded by a single autonomous seafloor acoustic recorder (DASAR) deployed offshore of Northstar during the late summer/early autumn of 2015. Since 2010, the deployment of a single DASAR, rather than an array of DASARs, precluded the ability to estimate the 2-D positions of calling bowhead whales. However, for the whales whose calls are detected, the directions of the whales from the DASAR can still be determined. Results from the 2001–2004 and 2005–2010 seasons have been summarized previously (Blackwell et al. 2007; Richardson [ed.] 2008, 2011), and results from the 2011–2014 seasons have been presented in subsequent annual reports. This report focuses on the 2015 season, although results from 2001 through 2014 are also summarized here for comparison. This chapter provides information on annual variation in the number, types, and distribution of calls detected offshore of Northstar, and in their bearings from a specific location where acoustic data were acquired every autumn since 2001.

After describing the study’s instrumentation and the methods used to calibrate the recorders, three facets of the Northstar whale call analyses—whale call (1) detection, (2) classification, and (3) bearings—are presented in the Methods and subsequent Results sections.

**METHODS**

As described in Chapter 2, this study is based on recordings of underwater sounds at various locations offshore of Northstar during the late summer/autumn period. In 2001–2010 and 2012, arrays of directional recorders (DASARs) were deployed at varying numbers of sites, providing the ability to detect bowhead whale calls and determine their bearings, from which locations could be estimated. In 2010–11 and 2013–15, offshore DASARs were deployed at only one site — a location where DASARs had been deployed each year since 2001: 14.9 km (9.2 mi) seaward of Northstar at a water depth of 23 m (75 ft). We referred to that site as “EB” up to 2007 and as “C” in 2008–2015. Acoustic data collected by one DASAR at location C are the subject of this chapter.
Instrumentation and Time/Bearing Calibrations

Chapter 2 described the DASARs (see section Instrumentation: DASARs in Methods) and their deployment and subsequent retrievals (see section 2015 Field Operations in Methods). The reader is also referred to Figure 2.1 for a map of the study area depicting the DASAR locations for 2001–2015.

DASAR time and bearing calibrations were also discussed in the Methods section of Chapter 2. Time calibrations are necessary to account for recorder clock drift in order to maintain an accurate time base over the course of the deployment. Bearing calibrations determine each DASAR’s orientation on the seafloor with respect to True North in order to determine the geographic bearing to a detected whale call. Since the transition from the use of arrays of DASARs in earlier years to a single DASAR in 2010–11 and 2013–15, high-precision time calibrations have not been required. Consequently, since 2013, noise generated by the deployment vessel, rather than calibrated transmissions from a J-9 underwater transducer, has served as the sound source for time and bearing calibrations. For detailed procedures for time and bearing calibrations and the estimation of bearings to calls, see the Methods sections in Chapters 4 and 5 of the Northstar monitoring program’s second comprehensive monitoring report, Richardson (ed., 2011).

Whale Call Detection

Analysis of whale calls was performed manually by trained staff, with the assistance of software developed at Greeneridge Sciences • to store and present the acoustic records, and • to extract information about the whale calls once they were manually identified. Detection and classification of each whale call was done by examining spectrograms of the acoustic data, one minute at a time, and listening to recordings of each call or suspected call (see Fig. 3.1). The sounds recorded during a given 1-min interval by a DASAR at site EB/C were analyzed by a single analyst before that analyst moved on to the next 1-min period. Using a computer mouse, analysts delimited the time- and frequency-range of each call by positioning a rectangle on the spectrogram. The software then calculated several parameters including the call’s bearing from that DASAR, duration, signal-to-noise ratio, etc. The call type was also determined by the analyst (see next subsection).

In years with deployments of DASAR arrays, most calls were detected by more than one DASAR, and the aforementioned parameters were determined separately for each DASAR that detected a given call. The classification of call type was done only once regardless of the number of DASARs that detected the call. In earlier years, reception of the call at more than one DASAR allowed for triangulation of the call’s estimated position.

![Image of analysts working with spectrograms.](image-url)
Whale Call Classification

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

- **Simple calls** were frequency-modulated (FM) tonal calls or “moans” in the 50–300 Hz range. We distinguished (1) ascending-frequency or up calls, “/”; (2) descending-frequency or down calls, “\”; (3) constant-frequency calls, “—”; and (4) inflected calls with u-shaped (“∪”) or n-shaped (“∩”) frequency patterns.

- **Complex calls** were infinitely varied and included pulsed sounds, squeals, growls with abundant harmonic content, and combinations of two or more simple and complex segments. Subcategories of complex calls could not be discerned consistently, so all subcategories were pooled.

In addition to sounds from bowhead whales, acoustic records have, in some years, included sounds (10–450 Hz) produced by other marine mammals, such as bearded seals (*Erignathus barbatus*), Pacific walruses (*Odobenus rosmarus divergens*), and gray whales (*Eschrichtius robustus* as well as sounds of anthropogenic origin. As in other years since 2011, non-bowhead calls and anthropogenic sounds were manually classified and tabulated using the analysis software to gain a quantitative assessment of their occurrence.

Bearing Analyses

During the whale call detection and classification process, the bearing from DASAR C to each detected call was determined automatically, using information from the bearing calibrations. After all the calls were classified and bearings to calls were determined, two parameters were calculated based on the bearings from DASAR C to all whale calls detected by that DASAR: the vector mean bearing and the mean vector length (Batschelet 1981). Figure 3.2 shows how to calculate these two parameters using example bearings to nine different calls. The vector mean bearing (α) indicates the average direction from DASAR C to the calls it received that year, while the mean vector length (L) is a measure of the variation of the individual bearings around the vector mean direction. For example, if all the bearings to calls were the same (e.g., 45°), then the vector mean bearing would be 45° and the mean vector length would be 1. If there were equal numbers of calls at 0°, 45° and 90°, the vector mean would again be 45° but the mean vector length would be 0.805. If the bearings were spread evenly in all directions (e.g., 4 bearings at 0°, 90°, 180°, and 270°), then the vector mean bearing would be indeterminate and the mean vector length would be 0.

The proportion of calls “offshore” versus “inshore” (O/I ratio) was also calculated for DASAR C and compared with values from previous years at that location. “Offshore” and “inshore” were defined in relation to the orientation of a line through DASAR C and parallel to the general trend of the coast in the longitude range 146°–150.5°W (see Miller et al. 1999). That part of the coast has an approximate orientation of 108° to 288° True. Offshore calls were defined as those whose bearings from DASAR C were between 288° and 107.9° True (including 360° or equivalently 0°, true north), i.e., offshore of the line. Similarly, inshore calls were defined as those with bearings from C between 108° through 180° (south) to 287.9° (Fig. 3.3).
Figure 3.2. Average bearing calculation. The gray arrows are example bearings from a DASAR. Mean bearing angle $\alpha = \arctan(x, y)$, where $x$ and $y$ are the average cos and sin, respectively, of all bearings obtained at one DASAR during a season. Mean vector length, $L = \sqrt{x^2 + y^2}$, is a measure of the variation of individual bearings around the vector mean direction.

Figure 3.3. Definition of the “offshore” and “inshore” sectors in relation to the general orientation of the coastline and DASAR C’s location (filled circle in center).
RESULTS AND DISCUSSION

After an initial year of partially successful acoustic monitoring operations in 2000 (Greene et al. 2001), the autumn migration of bowhead whales has been monitored acoustically offshore of Northstar Island since 2001. In the four years 2001–2004, we utilized 10 DASARs forming an offshore array to localize whale calls and to estimate the offshore displacement of the distribution of calling bowheads in response to industrial sound produced by Northstar activities. In 2005–2007, the procedure was changed on the basis of the results obtained during 2001–2004. The modified effort involved a smaller array consisting of DASARs at three or four locations; the main function in those years was to count whale calls for comparison with previous years, but bearings of calls from location EB/C were also determined. In 2008 and 2009, a larger array of DASARs was used again, but with the array configuration extending farther offshore than in 2001–2004. The primary objective in 2008–2009 was again to measure the spatial distribution of calling bowhead whales and to relate variation in that distribution to variation in underwater sounds. The offshore extension of the DASAR array in 2008–2009 relative to 2001–2004 was intended to provide data across a larger fraction of the width of the bowhead migration corridor. In 2010–2014, whale calls were monitored at only one offshore site, in keeping with BP’s approved monitoring plan. In 2015, Hilcorp continued the study using the same DASAR configuration as in other recent years. All configurations are shown in Figure 2.1.

Whale Call Activity

Number of Whale Calls Detected

Every year since 2001, there has been a functional DASAR at location C (known as location EB in 2001–2007) during the late summer/early autumn. Call data from this location allow us to compare call counts over 15 years (Table 3.1). That table includes the mean number of calls per day to allow for the fact that DASARs were deployed for varying numbers of days in different years. In years when redundant DASARs were deployed at C/EB, we have only included counts from one DASAR. A total of 5167 bowhead whale calls were detected on the records of DASAR C during the 19 Aug.–22 Sept. period in 2015. The call detection rate in 2015 was on average 152 calls/day, the fifth lowest in the study’s 15 years and similar to results from the 2002 season (Table 3.1).

Hourly call detection rates for DASAR C over the entire 2015 deployment period are shown in Figure 3.4. The highest call detection rate was 219 calls/hour on 13 Sept. between 17:00 and 18:00 AKDT. This maximum hourly rate corresponds to a “pulse” or “wave” of increased daily calling activity that spanned approximately three days, 12 Sept. through 14 Sept. Another pulse of calling activity occurred from 17 Sept. through ~20 Sept. In 2015, DASARs were deployed earlier in the season (19 Aug.), by roughly a week or more, compared to previous years of the study, and we detected little calling activity until the first pulse’s arrival on 12 Sept.

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2 In 2012, DASARs were deployed at two additional sites further offshore than C, but those data were not used for localization of calls (Richardson and Kim [eds.] 2013).
TABLE 3.1. Year-to-year comparison of bowhead whale call counts at DASAR location C (2008–2015) and the equivalent 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 detected calls by the season length, discrepancies in the listed mean number of calls per day may arise from rounding error.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total calls detected at C/EB</th>
<th>Length of DASAR recording season (days)</th>
<th>Mean # calls detected per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001 (EB)</td>
<td>1624</td>
<td>25</td>
<td>65</td>
</tr>
<tr>
<td>2002 (EB)</td>
<td>4317</td>
<td>24</td>
<td>180</td>
</tr>
<tr>
<td>2003 (EB)</td>
<td>21,726</td>
<td>30</td>
<td>724</td>
</tr>
<tr>
<td>2004 (EB)</td>
<td>26,546</td>
<td>27</td>
<td>989</td>
</tr>
<tr>
<td>2005 (EB)</td>
<td>951</td>
<td>29</td>
<td>33</td>
</tr>
<tr>
<td>2006 (EBA)</td>
<td>331</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>2007 (EBA)</td>
<td>9076</td>
<td>36</td>
<td>250</td>
</tr>
<tr>
<td>2008 (C)</td>
<td>39,550</td>
<td>30</td>
<td>1337</td>
</tr>
<tr>
<td>2009 (C)</td>
<td>6859</td>
<td>33</td>
<td>205</td>
</tr>
<tr>
<td>2010 (C)</td>
<td>340</td>
<td>28</td>
<td>12</td>
</tr>
<tr>
<td>2011 (C)</td>
<td>14,440</td>
<td>34</td>
<td>424</td>
</tr>
<tr>
<td>2012 (C)</td>
<td>14,246</td>
<td>42</td>
<td>336</td>
</tr>
<tr>
<td>2013 (C)</td>
<td>21,994</td>
<td>27</td>
<td>807</td>
</tr>
<tr>
<td>2014 (C)</td>
<td>21,634</td>
<td>31</td>
<td>684</td>
</tr>
<tr>
<td>2015 (C)</td>
<td>5,167</td>
<td>34</td>
<td>152</td>
</tr>
</tbody>
</table>

Figure 3.5 compares daily numbers of calls detected by DASARs at location C / EB in 2015 (red line) and in previous years. The pattern at location C in 2015 clearly shows the aforementioned pulses on 13 Sept. and 18 Sept. with peaks of 1085 and 1056 calls/day, respectively. The occurrence of the peak observed call detection rate in mid- to late-Sept. of 2015 was consistent with most previous years; the late-Aug. and early Sept. peaks found in 2008, 2011, and 2014 (Fig. 3.5) were unusual. The largest observed peaks during the 2001–2015 period also occurred around the third week of Sept. in 2003, 2004, 2008, 2012, and 2014, albeit with much higher detection rates: 3819, 4962, 6185, 3997, and 4221 calls/day, respectively. By contrast, in 2005, 2006 and 2010, daily call detection rates were consistently below 200 calls/day; in those years, heavy ice occurred locally in the Northstar area. It should be kept in mind that bowhead whale migration in this region is known to continue well into October, after acoustic monitoring at Northstar ended, and Fig. 3.5 does not show the full duration of the migration season.
Figure 3.4. Hourly detection rate of bowhead whale calls as a function of date and time, 19 Aug.–22 Sept. 2015. Total number of calls detected was 5167. Tick-marks on X-axis represent midnight (local daylight time). The highest hourly call detection rate was 219 calls/hour on 13 Sept. between 17:00 and 18:00 AKDT.

**Bearing Analyses**

Table 3.2 summarizes the main results on bearings to bowhead whale calls. Location C/EB is the one DASAR location for which 15 consecutive years of bearing data exist. Vector mean bearings to the bowhead whale calls detected from that DASAR at location were most often (in 12 of 15 years) offshore within the northeastern quadrant—most commonly to the northeast or east-northeast. The vector mean bearing for 2015 was 80º, consistent with the majority of previous years (Table 3.2). However, the 2015 season, like 2014, exhibited an unusually low O/I ratio — 1.2 in 2015 and 1.0 in 2014, i.e., the number of offshore calls was approximately the same as the number of inshore calls. “Offshore” versus “inshore” calls are distinguished by their bearings relative to the dashed line shown in Figure 3.6. In 2015, 2301 of the 5167 calls originated “inshore” of this line.
FIGURE 3.5. Daily number of bowhead calls detected by a DASAR at location C/EB by date over the 2001–2015 seasons (top panel), replotted below with expanded vertical scale for four years with low call detection rates (2001, 2005, 2006, and 2010). In those four years, the total number of calls detected at location C/EB never exceeded 500 calls/day.
### Table 3.2. Results of the bearing analyses for bowhead whale calls relative to location C (2008–2015) / EB (2001–2007). α is the vector mean bearing in degrees with respect to True North, and L is the length of the mean vector. O/I is the ratio of number of offshore versus inshore calls.

<table>
<thead>
<tr>
<th>Year</th>
<th>α (°)</th>
<th>L</th>
<th>O/I</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>44</td>
<td>0.65</td>
<td>5.7</td>
<td>1624</td>
</tr>
<tr>
<td>2002</td>
<td>64</td>
<td>0.74</td>
<td>13.6</td>
<td>4317</td>
</tr>
<tr>
<td>2003</td>
<td>78</td>
<td>0.55</td>
<td>2.5</td>
<td>21,726</td>
</tr>
<tr>
<td>2004</td>
<td>69</td>
<td>0.42</td>
<td>2.4</td>
<td>26,546</td>
</tr>
<tr>
<td>2005</td>
<td>348</td>
<td>0.14</td>
<td>1.3</td>
<td>951</td>
</tr>
<tr>
<td>2006</td>
<td>33</td>
<td>0.46</td>
<td>4.0</td>
<td>331</td>
</tr>
<tr>
<td>2007</td>
<td>75</td>
<td>0.45</td>
<td>2.9</td>
<td>9076</td>
</tr>
<tr>
<td>2008</td>
<td>59</td>
<td>0.53</td>
<td>5.1</td>
<td>39,550</td>
</tr>
<tr>
<td>2009</td>
<td>65</td>
<td>0.70</td>
<td>5.6</td>
<td>6859</td>
</tr>
<tr>
<td>2010</td>
<td>115</td>
<td>0.24</td>
<td>0.7</td>
<td>340</td>
</tr>
<tr>
<td>2011</td>
<td>77</td>
<td>0.54</td>
<td>4.4</td>
<td>14,440</td>
</tr>
<tr>
<td>2012</td>
<td>68</td>
<td>0.78</td>
<td>16.1</td>
<td>14,246</td>
</tr>
<tr>
<td>2013</td>
<td>51</td>
<td>0.66</td>
<td>26.2</td>
<td>21,994</td>
</tr>
<tr>
<td>2014</td>
<td>115</td>
<td>0.33</td>
<td>1.0</td>
<td>21,364</td>
</tr>
<tr>
<td>2015</td>
<td>80</td>
<td>0.19</td>
<td>1.2</td>
<td>5167</td>
</tr>
</tbody>
</table>

Figure 3.6 shows the percentage distribution of all bearings to bowhead whale calls as obtained by the DASAR at location C / EB in each year from 2001 to 2015. Bearings were grouped into thirty-six 10° bins centered on multiples of 10° (i.e., 355°–4.99°, 5°–14.99°, etc.), expressed as a percentage of all call bearings determined via DASAR C / EB for that season. The 2015 plot shows that, although the vector mean bearing followed the northeast/east-northeast trend of most other years, the bearings were unusually widely distributed in 2015. Consistent with that, the mean vector length of 0.19 was the second lowest of the 15-year study (Table 3.2). In terms of mean vector length and O/I ratio, the 2015 season was very similar to the 2005 season, a year characterized by heavy local ice. Likewise, in 2016, DASAR retrievals took place roughly a week earlier than usual due to the early formation of ice around Northstar.

**Bowhead Call Types and Other Classified Sounds**

Marine mammal calls and certain other sounds detected via the DASAR at location C/EB were tabulated again in 2015. For 2015, as for 2011–2014, we classified and tabulated non-bowhead as well as bowhead sounds, producing a quantitative measure of the detection of bowhead, bearded seal, walrus, unspecified marine mammal, man-made, and unidentified sounds. Although beluga whales and ringed seals occur in or near the Northstar area, beluga vocalizations occur largely above the DASAR’s recording bandwidth and, in addition, few belugas occur over the inner and middle shelf in late summer/autumn. Their main migration corridor is in deep water near and north of the shelf break (Moore et al. 1998; Moore 2000). Ringed seals seldom vocalize in our study area during the summer and early autumn. Classification results are compiled in Table 3.3 below.
FIGURE 3.6. Directional distribution of bearings to bowhead whale calls detected via DASAR C/EB in 2001–2015. Results for each 10° sector are expressed as a percentage of all bearings to bowhead whale calls obtained via the DASAR at location C/EB that year. Note the larger scale for percentage of bearings for 2010 and 2011. The approximate orientation of the coast is shown as a dashed line through each DASAR. Sample sizes vary widely, from 331 in 2006 (over 18 days) and 340 in 2010 (28 days) to 39,550 in 2008 (30 days).
As noted in Table 3.1, the total number of bowhead calls detected at C/EB in Aug.–Sept. 2015 was 5167. Other sounds, as listed in Table 3.3, added another 2310 detections at C/EB, for a total of 7477 detected sounds in 2015. Note that these values need to be interpreted cautiously. Most types of mammal calls were discrete and were generally counted individually. However, when a series of repetitive walrus calls was detected (as has occurred in past years, although not in 2015), it would be classified as a single detection. Also, man-made sounds often continued for an extended period and such sounds were typically counted only once.

Bowhead whales, bearded seals, and unclassified species accounted for 94.5%, 2.1%, and 3.4%, respectively, of marine mammal calls detected. In 2011–2013, relatively small numbers of walrus call-sequences were detected (6, 50, and 4, respectively), but none were detected in 2014 and 2015. Man-made sounds, for example, noises attributable to vessels or identifiable industrial activity, comprised 5.2% of all detections. In 2015, the number of unidentifiable sounds—sounds that could not be positively classified as originating from marine mammals or anthropogenic sources—constituted 21.7% of all detections, by far the highest proportion unidentifiable sounds in the five years of extended Northstar sound classification. Unidentifiable sounds in 2011–2014 constituted, respectively, 16.1%, 2.0%, 0.3%, and 0.4% of the classified sounds.

Figure 3.7 shows a percentage breakdown of all bowhead whale calls detected by DASARs at location C/EB by call type for 2001–2015. Calls are broken down into two main categories: simple calls and complex calls. Simple calls are further broken down into four sub-categories: upsweeps, downsweeps, constant frequency calls, and undulated calls. Until 2007, undulated calls were split into ∪-shaped and ∩-shaped undulated calls, but some undulated calls fit neither of these categories. Consequently, a third category of “other” undulated calls was created. To facilitate comparison among years, undulated calls are treated here as one category.

The call type analysis (Fig. 3.7) showed that the proportional use of different call types in 2015 was within the range of previous years, with the relative percentages of call types quite similar to those in the previous two years. In 8 of the study’s 15 years, simple calls comprised 80 to 90% of calls. In 2015, as in most study years, simple calls predominated (Fig. 3.8) but in 2015, much like the previous two years, they comprised virtually all (93.9%) of the 5167 bowhead calls detected. Changes in the percentage use
**FIGURE 3.7.** Percentage breakdown by call type in 2001–2015 for calls detected by DASARs at location C/EB. Simple calls include upsweeps, downsweeps, constant calls, and undulations.

**FIGURE 3.8.** Percentage of simple (black bars) vs. complex (gray bars) call types in 2001–2015. As in most study years, simple calls predominated in 2015 and accounted for 93.9% of bowhead calls in 2015.
of different call types from one year to the next are difficult to interpret because little is known about the behavioral significance of specific types of bowhead calls. Some studies suggest that complex calls, which comprised 6.1% of the calls detected in 2015, are related mostly to social behavior (Würsig and Clark 1993; Richardson et al. 1995a,b).

**Bowhead Call Summary**

The bowhead call detection rate at location C/EB in 2015 was the fifth lowest in the study’s 15 years, with an average daily call detection rate of 152 calls/day. Despite relatively low call numbers, the periods of peak daily call detection in 2015 were consistent with previous years in terms of seasonal timing. This was so even in comparison with high-call-count seasons, e.g., 2003, 2004, 2008, and 2012, when the largest peak occurred around the third week of Sept. In 2015, additional and/or larger peaks might possibly have occurred in the last week of Sept., when the Northstar monitoring period historically concludes, but encroaching ice around Northstar forced early retrieval of the DASARs on 22 Sept.

Bearing analyses showed that, in 2015, calls originated at widely scattered bearings relative to location C/EB. Even so, the average bearing in 2015 was to the east-northeast. That was consistent with 12 of the study’s 15 years, in which the mean bearing was in the northeastern quadrant relative to DASAR C. However, like 2014, the 2015 season was noteworthy in its unusually low O/I ratio, with roughly equal numbers of calls “offshore” and “inshore”. In 2015, bearing metrics such as mean vector length (short) and I/O ratio (near 1.0) were similar to 2005, possibly due to local heavy ice conditions in both years.

The 2015 season was the fifth year in which the study provided quantitative measures of call detections from marine mammal species additional to bowhead whales. Bowheads, bearded seals, and unclassified species accounted for 94.5%, 2.1%, and 3.4%, respectively, of marine mammal sounds detected. Man-made sounds—for example, noises attributable to vessels—were also classified and documented in 2015. Sounds classified as unidentifiable were at their highest percentage (21.7% of all detected sounds) since expanded classification began in 2011. Relative proportions of five different call types in 2015 were similar to those during the previous two seasons, as was the percentage of simple calls in 2015 (93.9%).

**ACKNOWLEDGEMENTS**

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Chapter 3: Acoustic Monitoring of 2015 Bowhead Migration


