NORTHEASTERN CHUKCHI SEA
JOINT ACOUSTIC MONITORING PROGRAM 2012–2013

Prepared for

ConocoPhillips Company
Anchorage, Alaska

Shell Exploration & Production Company
Anchorage, Alaska

Statoil USA E&P, Inc.
Anchorage, Alaska

Final Report

Document 00808

November 2014

Prepared by

JASCO Applied Sciences (Canada) Ltd.

Report Authors

Julien Delarue

Jeff MacDonnell

Bruce Martin

Xavier Mouy

David Hannay

Suggested citation:

Delarue, J., J. MacDonnell, B. Martin, X. Mouy, and D. Hannay. 2014. Northeastern Chukchi Sea Joint Acoustic Monitoring Program 2012–2013. JASCO Document #00808. Technical report by JASCO Applied Sciences for ConocoPhillips Company, Shell Exploration & Production Company, and Statoil USA E&P, Inc.

Cover photos, bottom left clockwise: JASCO Autonomous Multichannel Acoustic Recorder G2 (Julien Delarue, JASCO); bearded seal (U.S. Fish and Wildlife Service); bowhead whale (Fisheries and Oceans Canada); and Pacific walrus (Eric Lumsden, JASCO).

Contents

Figures

Tables

1. Introduction

This report presents the results of the winter 2012–2013 and summer 2013 seasons of the Acoustic Monitoring Program in the northeastern Chukchi Sea. ConocoPhillips Company and Shell Exploration & Production Company (Shell) began baseline acoustic monitoring in the Chukchi Sea in summer 2006 as a key component of their arctic marine mammal research programs. Statoil USA Exploration and Production, Inc. (Statoil) became a sponsoring member of the programs in summer 2010. The Bioacoustics Research Program (BRP), based at the Cornell Laboratory of Ornithology, made the first acoustic measurements in summer 2006 and participated in the program in summer 2008 (BRP 2010). JASCO Applied Sciences Ltd. (JASCO) has conducted consecutive summer and winter acoustic recording periods since summer 2007.

1.1. Objectives of the Acoustic Monitoring Program

The objectives are to:

1. Document baseline ambient noise conditions.
2. Characterize sounds produced by oil and gas exploration activities.
3. Examine the spatial and temporal distribution of marine mammals based on acoustic detections of their vocalizations[1].

These objectives are being achieved through a dedicated study based on acoustic measurements made with autonomous acoustic recording systems deployed on the seabed for long periods of time across large areas of the northeastern Chukchi Sea. The data acquired under this program cover a continuous period of more than six years at multiple locations. In terms of temporal and spatial coverage, the data represent one of the largest and most comprehensive set of acoustic recordings and include millions of marine mammal calls and thousands of hours of vessel noise, seismic survey noise, and weather and ice-related sounds.

Ambient noise conditions are discussed in Section 3.1. Anthropogenic sound characterizations, specifically related to seismic exploration and vessel traffic, are discussed in Sections 3.2 and 3.3 respectively.

The majority of this report addresses Objective 3. The Acoustic Monitoring Program was partly designed to gather information about several marine mammal species' spatial and temporal distributions, habitat usage, calling behaviors, and migration paths. A particular focus is localizing vocalizing bowhead whales (*Balaena mysticetus)* in offshore areas near oil and gas exploration leases. The bowhead migration patterns close to the Alaskan coast are well understood by local subsistence whalers. Migration in offshore areas, however, was poorly understood at the outset of this program in 2006. In parallel with results from tagging studies led by the Alaska Department of Fish and Game (see e.g., Quakenbush et al. 2010), the results of the

[1] Although many sounds made by marine mammals do not originate from vocal cords, the term "vocalization" is used as a generic term to cover all sounds produced by marine mammals that are discussed in this report. The term "call" is used synonymously for brevity.

passive acoustic monitoring studies have and still are greatly improving our understanding of bowhead fall migration routes. For instance, recently collected data (winter 2011–2012 and 2012–2013) from recorders deployed north of Hanna Shoal provided new insights into migration behaviors in previously unsampled areas where data collection by means other than acoustic recordings is difficult to achieve.

A program component of Objective 3 is to increase information about walrus (*Odobenus rosmarus*) habitat use in the northeastern Chukchi Sea. In parallel with the results from tagging studies led by the U.S. Geological Survey (see e.g., Jay et al. 2012), the 2007 to 2009 recorder deployments provided new information about walrus presence and migration timing (Martin et al. 2009, Delarue et al. 2010a, Martin et al. 2010). Large terrestrial haul-outs, primarily near Point Lay, were identified acoustically in several years' data. The collected data also showed walrus moved between these haul-outs and the Hanna Shoal foraging areas. In addition, the 2010 deployments yielded data showing seismic surveys possibly affect walrus communications (Delarue et al. 2011a).

Objective 3 also aims to document the occurrence of beluga whales in offshore areas. The acoustic data indicated that some beluga whales migrated through the lease areas in spring, but they are generally not heard in the northeastern Chukchi Sea in summer. Fall recordings within the lease areas yielded far fewer detections than spring recordings, which suggest that a portion of the animals transiting through the Chukchi Sea in spring are either absent from the area or are quiet during their fall migration. The acoustic data collected north of Hanna Shoal also did not detect belugas, which might mean the animals migrate well outside the study area or they substantially reduce their vocal activity during their fall migration.

1.2. Overview of Main Results Relevant to Marine Mammals

The Acoustic Monitoring Program identified vocalizations from the following marine mammal species:

- Bowhead whale (*Balaena mysticetus*)
- Beluga whale (*Delphinapterus leucas*)
- Gray whale (*Eschrichtius robustus*)
- Fin whale (*Balaenoptera physalus*)
- Killer whale (*Orcinus orca*)
- Minke whale (*Balaenoptera acutorostrata*)
- Humpback whale (*Megaptera novaeangliae*)
- Walrus (*Odobenus rosmarus*)
- Bearded seal (*Erignathus barbatus*)
- Ribbon seal (*Histriophoca fasciata*)
- Ringed seal (*Pusa hispida*)

Some low-frequency sounds, possibly produced by fish, were also detected, but have not yet been classified.

Winter acoustic data (mid-October 2012 through July 2013):

- Provided insight into the timing of bowhead and beluga fall and spring migrations.
- Correlated annual variations in the migration schedule to ice conditions.
- Documented the prevalence of belugas and bowhead whales in coastal leads during the spring migration, even though some individuals migrated offshore through the lease areas.
- Documented the continuous presence of ringed and bearded seals, the occasional presence of walrus, and ribbon seal fall migration.

Summer acoustic data (August 2013 through mid-October 2013):

- Provided information on the presence of several marine mammal species during the ice-free season, a time of increased species diversity and anthropogenic activity in the northeastern Chukchi Sea.
- Confirmed the study area’s importance to walrus, including walrus transitioning from offshore Hanna Shoal to shore haul-outs in late August 2007, and, subsequently, in 2010 and 2011.
- Consistently demonstrated the relatively limited acoustic presence of bowheads and belugas in the northeastern Chukchi Sea in July and August, and their return to a more prominent acoustic presence in late September and October coinciding with the onset of the fall migration in the area.
- Illustrated that vocalizing bowheads follow a fall migration corridor centered along the 71st parallel latitude as they move west past Barrow.
- Documented the annual recurrence of non-Arctic species including killer, fin, minke, and humpback whales, albeit these detections were low overall.

1.3. Recorder Deployment History 2006-2013

In summer 2006 the Cornell Lab of Ornithology’s Bioacoustics Research Program ran the Acoustic Monitoring Program. Marine Autonomous Recording Units (MARUs) were deployed in two phases:

1. 6 recorders from mid-July to mid-August 2006 sampled acoustic data on a duty cycle at 10 kHz sampling rate.
2. 22 recorders from mid-August to mid-October 2006 sampled continuously at 2 kHz sampling rate.

Since July 2007 JASCO has conducted consecutive summer and winter passive acoustic studies with Autonomous Multichannel Acoustic Recorders (AMARs) and Autonomous Underwater Recorders for Acoustic Listening (AURALs), which sample at 16000 and 16384 Hz, respectively, (Figure 1). This sampling rate allows acoustic sound frequencies of up to 8 kHz to be recorded. The summer sessions included four lines of recorders starting from Cape Lisburne, Point Lay, Wainwright, and Barrow and extending up to 135 miles off the coast. Additional clusters of recorders were deployed near Shell's, ConocoPhillips', and Statoil's current lease blocks and previously established well sites as follows:

- Summer 2008: Cornell deployed clusters of 13 MARUs each around the Klondike and Burger well sites.
- Summer 2009: JASCO deployed clusters of 12 AMARs each around the Klondike and Burger well sites.
- Summer 2010: JASCO deployed clusters of seven AMARs each around the Klondike and Burger well sites, and in the Statoil lease area.
- Summer 2011: JASCO deployed a single AMAR at the Klondike and Burger well sites, and near in the Statoil lease area.
- Summer 2012: JASCO deployed one AMAR near the Klondike well site and in the Statoil lease area, and seven AMARs around the Burger well sites.
- Summer 2013: JASCO deployed one AMAR near the Klondike well site and in the Statoil lease area, and eleven AMARs around the Burger well sites. A greater focus was placed on the Burger lease area because Shell carried out drilling activity there in 2012.

During the winter session, recorders were deployed in mid-October and retrieved the following year in July or August. The recorders typically operated for 7–10 months, limited mainly by battery life. Between 2007 and 2011, five to nine recorders were deployed throughout the program area. Starting in 2011, the winter program included six AURALs deployed on the northern side of Hanna Shoal, resulting in 15 winter recorders. This deployment scheme continued during winter 2012–2013, but was replaced for the 2013–2014 winter by three inshore recorders to document nearshore passages of bowhead and beluga whales during their spring migrations. In summer 2014 JASCO retrieved seven of its eight winter recorders (the eighth recorder will be retrieved later).

The recorders used in winter sessions had the following duty cycles:

- Winter 2007–2008: 5 recorders set to a 20% duty cycle.
- Winter 2008–2009: 7 recorders set to a 17% duty cycle.
- Winter 2009–2010: 8 recorders set to a 17% duty cycle.
- Winter 2010–2011: 8 recorders set to a 17% duty cycle.
- Winter 2011–2012: 9 recorders set to a 17% duty cycle and 6 recorders at Hanna Shoal set to a 12.5% duty cycle.
- Winter 2012–2013: 9 recorders set to a 17% duty cycle and 6 recorders at Hanna Shoal set to a 12.5% duty cycle.
- Winter 2013–2014: 8 recorders set to a 17% duty cycle.

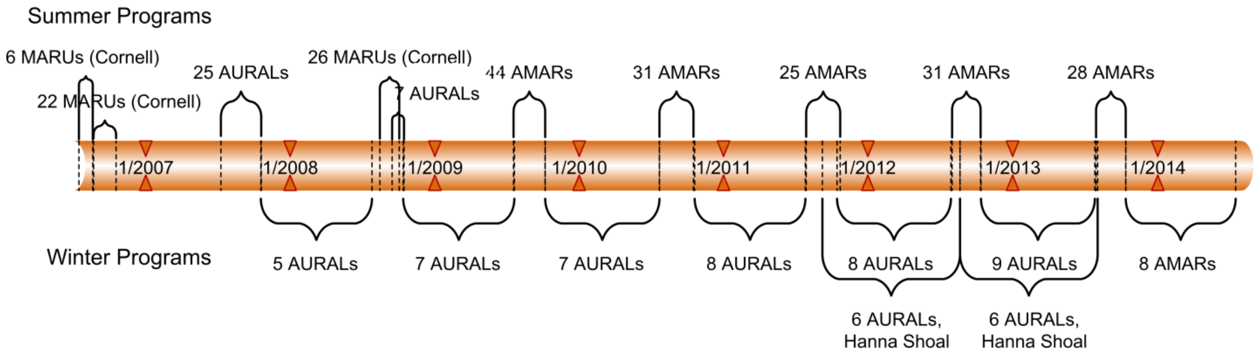

Figure 1. Timeline of Chukchi Sea Acoustic Monitoring Program, 2006 to 2014.

The acoustic data acquired in 2012–2013 were analyzed to quantify ambient sound levels, the presence of anthropogenic activity, and the acoustic presence of marine mammals. The ambient noise measurements add to the growing knowledge of underwater Arctic soundscape baseline conditions, thus providing information for inter-annual comparisons. Noise from seismic surveys conducted by TGS and Shell noise from vessel traffic were quantified. Although Objective 3 focused on bowhead whales, walrus, and beluga whales, this report also discusses the acoustic presence of other detected species.

2. Methods

2.1. Data Acquisition

2.1.1. Winter 2012–2013 Recording Period

Acoustic data for the winter 2012–2013 recording period were acquired in two phases: six AURALs Model 2 (Multi-Electronique Ltd.) were deployed to the North, East, and West of Hanna Shoal, and nine AURALs were deployed offshore of Cape Lisburne, Point Lay, Wainwright, and Barrow in fall (Figure 2). All recorders but one (WN60) were retrieved during summer 2013. Further retrieval attempts will be made in 2014.

Each AURAL has a single omnidirectional hydrophone and is powered by 64 D-cell alkaline batteries. Acoustic data were recorded on an internal 160 GB hard drive at 16-bit resolution and 16 384 samples per second. Each AURAL was fitted with an HTI−96 hydrophone (−160 dB re 1 V/µPa nominal sensitivity) and set for a gain of 22 dB. The spectral density of the electronic background noise of the AURALs in this configuration is approximately 45 dB re 1 µPa^2/Hz, a broadband noise level of 86 dB re 1 µPa and the usable bandwidth is 10–7700 Hz. The nine recorders deployed off Cape Lisburne, Point Lay, Wainwright, and Barrow were set to record for 40 min of every 4 h (i.e., a 17% duty cycle); the six Hanna Shoal recorders were set to record for 30 min of every 4 h (i.e., a 12.5% duty cycle). Because the AURALs have limited data storage and battery power capacity, duty cycling was required for the recordings to span the entire deployment.

Each AURAL was deployed on the seafloor with a rectangular frame that kept the top of the recorder and its hydrophone secured off the seafloor. A sinking ground line about 2.5 times the water depth connected the recorder to a small weight for grapple retrieval (Figure 3). The six Hanna Shoal recorders were deployed 10–13 Sep 2012 and retrieved 3 Aug to 13 Oct 2013. The nine winter recorders were deployed 6–14 Oct 2012 and retrieved 30 Jul through 16 Oct 2013, except for WN60 (Table 1). Differences in battery lives led to large differences in recording duration between stations, with recording end dates varying from 28 Jun to 9 Sep 2013. The mean recording duration was 314 days (range: 262-362; Table 1).

Wind speed and air temperature data were acquired from the Barrow station of the US Climate Reference Network (Barrow in Figure 2; Mefford and Dutton 2003). Ice cover data were obtained from the Interactive Multisensor Snow and Ice Mapping System (NOAA 2008) with a nominal resolution of 4 km (6144 × 6144 grid); however, this system does not provide numeric values for ice concentration.

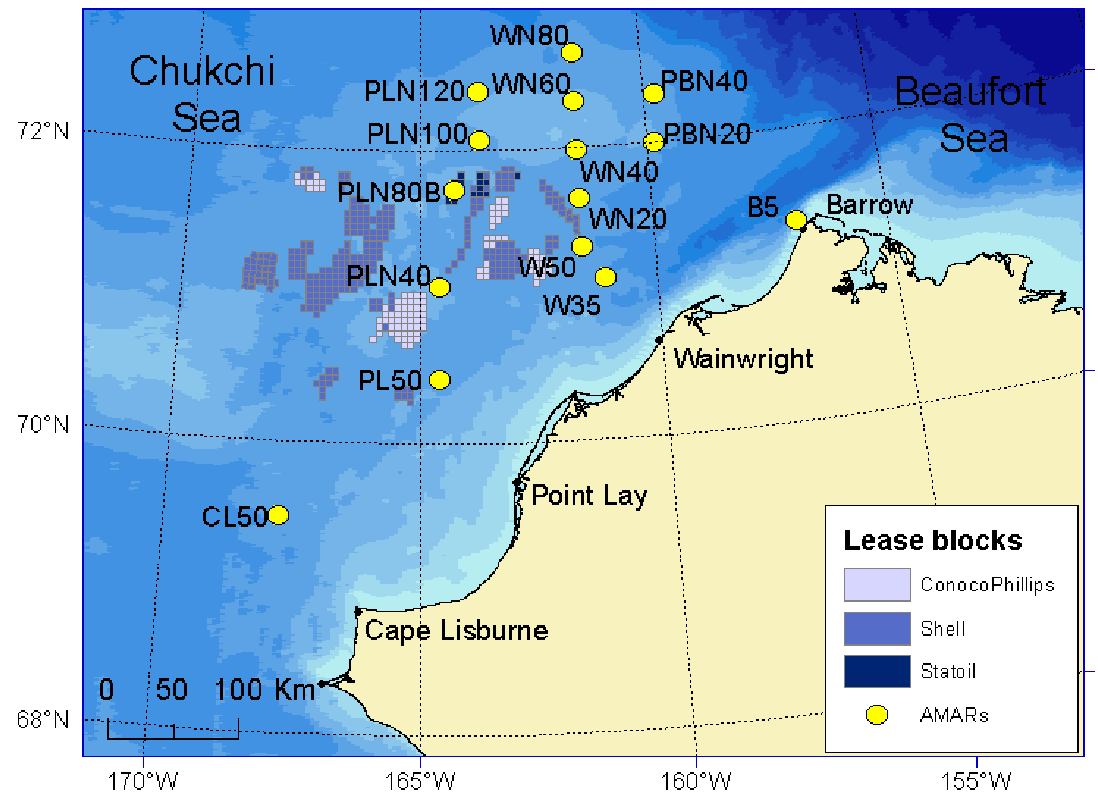

Figure 2. Winter 2012–2013 stations of the Acoustic Monitoring Program in the northeastern Chukchi Sea. Shades of blue represent water depth. Station WN60 was not recovered.

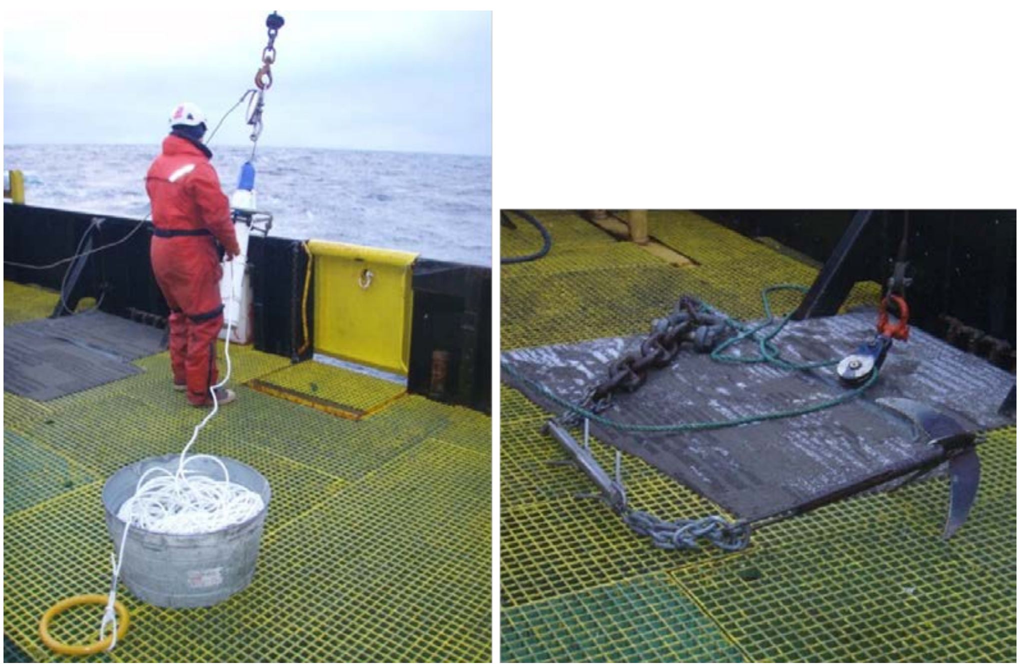

Figure 3. (Left) An AURAL Model 2 being deployed from the *Norseman II* in the northeastern Chukchi Sea. (Right) Grapple recovery gear.

Table 1. Recorder locations (see Figure 2) and recording periods for the winter 2012–2013 Acoustic Monitoring Program in the northeastern Chukchi Sea. The AURALs operated on 12.5-17% duty cycles (recording 30 or 40 min of every 4 h) from deployment to record end. Time is in UTC.

Station	Latitude (°N)	Longitude (°W)	Deployment 2012	Record end 2013	Recording days
B5	71.35770	-156.94917	11 Oct 04:31	6 Aug 12:20	299.3
CL50	69.48337	-167.75905	14 Oct 04:07	30 Jul 02:30	288.9
PBN20	71.98595	-159.82650	10 Sep 23:03	4 Sep 02:08	358.1
PBN40	72.31650	-159.73210	12 Sep 01:26	28 Aug 04:46	350.1
PL50	70.43665	-164.59172	13 Oct 15:28	30 Jul 16:55	290.1
PLN100	72.06277	-163.69210	13 Sep 00:49	2 Jul 15:02	292.6
PLN120	72.39490	-163.69215	12 Sep 20:02	9 Sep 06:34	361.4
PLN40	71.06630	-164.58662	13 Oct 10:25	24 Jul 20:41	284.4
PLN80	71.72405	-164.23923	9 Oct 03:08	28 Jun 02:05	262.0
W35	71.09425	-161.07078	13 Oct 01:19	14 Aug 11:30	305.4
W50	71.31107	-161.54005	6 Oct 03:12	10 Aug 14:30	308.5
WN20	71.64197	-161.53935	10 Oct 03:37	10 Aug 05:52	304.1
WN40	71.97488	-161.54295	10 Oct 20:36	1 Sep 21:15	326.0
WN60	72.30694	-161.53833	11 Sep 05:41	Not retrieved	N/A
WN80	72.63853	-161.53860	12 Sep 08:33	9 Sep 11:34	362.1

2.1.2. Summer 2013 Program

Acoustic data from the summer 2013 recordings were acquired with 28 AMARs (JASCO Applied Sciences). Each AMAR had a single omnidirectional hydrophone and was powered by 48 D-cell alkaline batteries. Acoustic data were recorded continuously on 384 GB of internal flash memory at 24-bit resolution and 16 000 samples per second. Each AMAR was fitted with a GTI−M8E hydrophone (−164 dB re 1 V/µPa nominal sensitivity) and set to 0 dB gain. The spectral density of the electronic background noise of the AMARs in this configuration was ~25 dB re 1 µPa^2/Hz, the broadband noise floor was 67 dB re 1 µPa, and the usable bandwidth is 10 Hz to 7.6 kHz.

Like the AURALs, each AMAR was deployed with a supporting metal frame to keep the hydrophone off the seafloor (Figure 4). A sinking ground line about 2.5 times the water depth connected the recorder to a 15 lb weight so it could be retrieved by grappling. Four stations north of W50 and one northwest of B15 could not be deployed because of ice conditions. All deployed recorders were successfully retrieved.

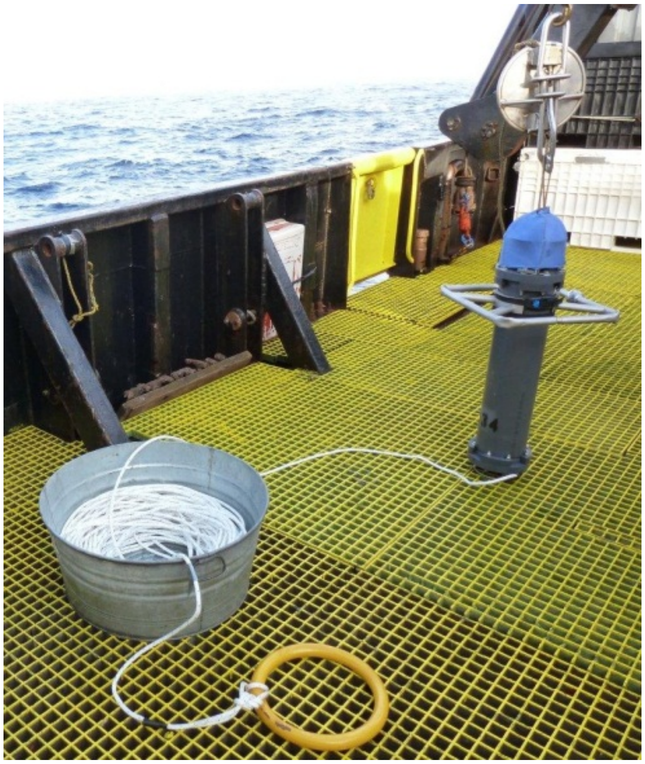

Figure 4. An AMAR ready to be deployed in the northeastern Chukchi Sea.

The summer 2013 recording period consisted of a regional array of 15 AMARs—11 AMARs around the Burger drill site and 1 AMAR near each of the Klondike and Statoil lease areas (Figure 5). From 2006 through 2012, the regional array recorders were deployed in a consistent pattern along lines extending offshore from Cape Lisburne, Point Lay, Wainwright, and Barrow. The lines extended perpendicularly from the coastline for 50 nautical miles (mi) and then northward to about 120 mi offshore (Figure 5). Similar to the 2009–2012 recording periods, the northernmost Cape Lisburne stations, CLN90 and CLN120, were shifted east of the line to overlap the Shell lease areas. All recorders were deployed between 29 Jul and 23 Aug 2013 and retrieved between 11 and 21 Oct 2013 (Table 2); they recorded data over the entire deployment.

Wind, water temperature, and current speeds were recorded on two meteorological buoys operated by Shell and the University of Alaska Fairbanks, located at 70.87° N, 165.25° W (Buoy 1, near KL01) and 70.03° N, 166.07° W (Buoy 2, between CL50 and PL30). In winter, ice cover data were obtained from the Interactive Multisensor Snow and Ice Mapping System (NOAA 2008) with a nominal resolution of 4 km (6144 × 6144 grid).

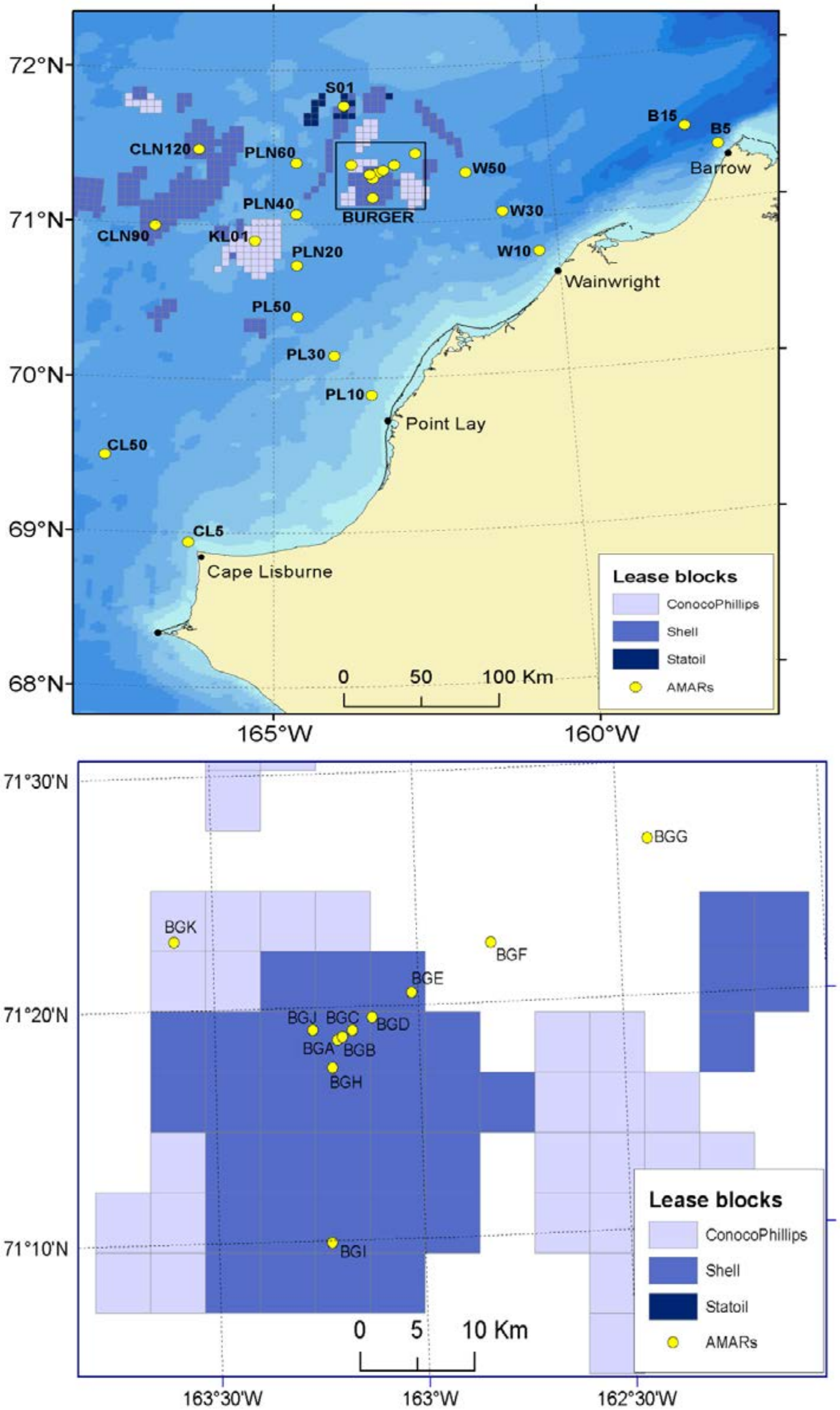

Figure 5. Recorder stations for the summer 2013 program in the northeastern Chukchi Sea: (top) the regional array and (bottom) the recorders at the Burger lease area. Shades of blue represent water depth.

Table 2. Recorder locations (see Figure 5) and recording durations for the summer 2013 Acoustic Monitoring Program in the Chukchi Sea. The Autonomous Multichannel Acoustic Recorders (AMARs) recorded continuously from deployment to retrieval. Stations are listed alphabetically.

Station	Latitude (°N)	Longitude (°W)	Deployment (UTC)	Retrieval (UTC)	Recording days
B15	71.50270	-157.49780	6 Aug 14:39	11 Oct 19:24	66.2
B5	71.36370	-156.93750	6 Aug 12:42	11 Oct 16:09	66.1
BGA	71.31037	-163.20030	5 Aug 08:39	15 Oct 21:55	71.6
BGB	71.31247	-163.18837	5 Aug 08:27	15 Oct 22:16	71.6
BGC	71.31695	-163.16337	5 Aug 08:14	15 Oct 22:41	71.6
BGD	71.32560	-163.11460	5 Aug 07:55	15 Oct 23:15	71.6
BGE	71.34230	-163.01500	5 Aug 07:29	16 Oct 23:54	72.7
BGF	71.37605	-162.81748	5 Aug 06:49	16 Oct 00:53	71.8
BGG	71.44575	-162.42415	5 Aug 05:37	15 Oct 18:52	71.6
BGH	71.29048	-163.21400	5 Aug 11:47	13 Oct 18:46	69.3
BGI	71.16560	-163.22490	5 Aug 12:55	13 Oct 20:05	69.3
BGJ	71.31770	-163.25990	5 Aug 11:20	13 Oct 18:11	69.3
BGK	71.38290	-163.59540	5 Aug 10:02	13 Oct 16:49	69.3
CL5	68.94180	-166.37380	29 Jul 19:34	21 Oct 09:27	83.6
CL50	69.49700	-167.78600	30 Jul 02:52	20 Oct 02:17	82.0
CLN120	71.48580	-166.34880	1 Aug 12:51	16 Oct 19:07	76.3
CLN90	70.98845	-167.09865	31 Jul 12:52	18 Oct 12:15	79.0
KL01	70.89720	-165.32830	31 Jul 08:28	17 Oct 20:09	78.5
PL10	69.88910	-163.35050	29 Jul 22:37	19 Oct 02:02	81.1
PL30	70.14690	-163.96100	30 Jul 19:50	18 Oct 22:57	80.1
PL50	70.40365	-164.58550	30 Jul 17:08	19 Oct 08:19	80.6
PLN20	70.73490	-164.58660	31 Jul 06:02	18 Oct 02:50	78.9
PLN40	71.06680	-164.58775	2 Aug 20:50	17 Oct 23:14	76.1
PLN60	71.39860	-164.58860	2 Aug 17:41	16 Oct 14:13	74.9
S01	71.76500	-163.69760	3 Aug 11:10	13 Oct 13:17	71.1
W10	70.77600	-160.32595	7 Aug 02:35	11 Oct 04:33	65.1
W30	71.04580	-160.92600	4 Aug 21:36	15 Oct 12:21	71.6
W50	71.31015	-161.53620	23 Aug 13:04	15 Oct 08:10	52.8

2.2. Data Analysis Overview

Data analysis was performed using a combination of automated and manual techniques. Total ocean sound levels and the proportion to which anthropogenic activities contributed were quantified using automated procedures (Sections 2.4.1 through 2.4.3).

Marine mammal calls were detected and classified both manually and with JASCO's automated acoustic analysis software suite. Because of their conservation status and their importance to the Alaska North Slope communities, calls of three species—bowhead and beluga whales (Section 2.4.5) and walrus (Section 2.4.6)—were more thoroughly analyzed with both manual and specialized automated approaches than those of other species (Table 3). Due to their relatively simple structure and highly stereotyped presentation, minke whale calls were accurately identified by a specialized automated detector. Bearded seal calls were detected with a generic automated detector (Section 2.4.4) and by manually analyzing the calls. Calls of other species were detected by manually analyzing 5% of the recorded data. Marine mammal call rates vary among individuals and over time, and could depend on the calling animal's age and sex. Furthermore, several individuals might call at the same time. Thus, the numbers of recorded calls of a species do not accurately represent the relative abundance of animals of that species.

Aside from establishing the acoustic occurrence of members of a species, manual analysis (Section 2.3) was performed to identify call types and to evaluate automated detector performance and classification methods. The automated detection and classification suite processed the entire dataset; it was the primary method used to estimate the magnitude, in number of detected calls, of acoustic calling activity as a function of time at each recorder station. Individual seismic pulses were identified and seismic signal and ambient sound levels calculated based on the results of the automated detector.

Table 3. Endangered Species Act (ESA) conservation status (Department of the Interior US Fish and Wildlife Service 2002) of marine mammal species in the northeastern Chukchi Sea and their generalized occurrence and tendency to vocalize. The first four species are of special interest for this report.

Species	ESA conservation status	Period	Occurrence	Vocalization tendency	Analysis method	
					Automated	Manual
Bowhead whales	Endangered	Apr–Jun	Common	High, decreasing	✓	✓
		Jul–Aug	Rare	Low		
		Sep–Dec	Common	High, increasing		
Walrus	–	Jun–Oct	Abundant	High	✓	✓
		Nov–Dec	Rare	High		
Beluga whales	–	Apr–Jun	Common	High	✓	✓
		Jul–Dec	Low	Moderate		
Bearded seals	Threatened	Nov–Jun	Abundant	High	✓	✓
		Jul–Oct	Abundant	Low, increasing		
Fin whales	Endangered	Aug–Oct	Rare	Low		✓
Gray whales	De-listed in 1994; Not threatened	Jul–Oct	Common	Low		✓
Humpback whales	Endangered	Aug–Sep	Rare	Low to moderate		✓
Killer whales	–	Jul–Oct	Rare	Low		✓
Minke whales	–	Aug–Oct	Low	Low	✓	✓
Ribbon seals	–	Sep–Nov	Occasional	Low		✓
Ringed seals	Threatened	All year	Abundant	Low		✓
Spotted seals	–	All year	Abundant	Unknown		

2.3. Manual Data Analysis

JASCO’s SpectroPlotter, a custom software tool, standardizes annotations and approaches among analysts. Seven trained analysts visually examined spectrograms in SpectroPlotter and, when needed, by simultaneously listening to audio playbacks. Four analysts had several years of experience classifying Arctic marine mammal vocalizations in previous Chukchi Sea datasets. The other three analysts had little to no previous experience identifying Arctic marine mammal sounds, but received training with a standard set of vocalizations from all species detected in previous years and verified their detections with the lead analyst.

The purpose of the manual analysis was to:

- Detect and classify marine mammal calls within a subset of the data.
  This would allow us to assess performance of the automated classifiers. Precision and recall methods, were used to quantitatively assess performance by comparing outputs of the automated classifiers with the manual classifications for each species.
- Review a fraction of the data through the entire recording period.
  This would allow us to assess where and when the target species (bowhead whales, walrus, beluga whales, and bearded seals) are acoustically present in the Chukchi Sea.
- Identify non-target and extralimital species.
  In previous years several species, such as killer whales and fin whales, were recorded occasionally. Acoustic detections of such species are valuable because they help us understand these animals' current habitat use in the Chukchi Sea and to describe changes in habitat use over time, the latter which could result from environmental changes, including changes in ice conditions and prey availability. Manual analysis is especially important in this context because automated classifiers are not configured and tested for these species.

The probability of detection by this protocol is discussed in Appendix A, Automated Detection and Classification of Marine Mammal Vocalizations and Anthropogenic Noise. The probability is dependent on the number of calls in a file. The 5% manual analysis protocol was assessed to be a reasonable compromise between the cost of the analysis and the probability of detecting the target species.

2.3.1. Manual Analysis Protocol

Five percent of the winter 2012–2013 and summer 2013 data from all operational recorders were analyzed manually.

The winter acoustic data were acquired on a duty-cycle, recording for either 30 min (Hanna Shoal stations) or 40 min (all other stations) of every 4 h, yielding six files per day. The middle 2 min sample of each data file was manually analyzed. Analysts annotated one call per species per sample for all files and stations to record each species in the dataset. In addition, analysts annotated all marine mammal calls in one sample per day for all days and stations. A different sample was fully annotated each day, selecting consecutive samples for successive days. Automated detector performance was evaluated with these fully-annotated samples (see Appendix A.6).

The summer acoustic data were acquired continuously and stored in 30 minute files, which yielded 48 files per day. The middle 90 s of each 30 min file were manually analyzed. Analysts annotated one call per species per sample. In contrast to the winter acoustic data treatment, analysts annotated all identified marine mammal vocalizations in two samples of each day for 15 of the 28 recorders deployed during that period. This protocol generated enough fully-annotated samples to evaluate the performance of the automated detectors.

2.3.2. Analysis Validation

The lead analyst, Julien Delarue, reviewed a random subset of annotations from all analysts to ensure calls were accurately classified, to give the analysts feedback on their classifications, and to help classify calls that were difficult to attribute to a known call type. The lead analyst consulted with external researchers when new or unknown call types were detected.

The annotation review entailed verifying a sample of annotations of target (bowhead whales, walrus, beluga whales, and bearded seals) and non-target species, specifically focusing on annotations of less common species or those outside the expected range or residency period of common species, and identifying species tagged as “Unknown” by reviewing sample sounds. Unknown sounds for which analysts indicated a possible source were prioritized, especially if the source was possibly one of the target species and had not yet been detected on that date.

2.4. Automated Data Analysis

To accurately analyze the 8.64 TB of acoustic data collected during the summer and winter programs, we used a specialized computing platform operating approximately 700 times faster than the recording duration (i.e., 700 h of recorded data could be analyzed in 1 h of computation time). The system allows automated analysis of total ocean noise, seismic survey sounds, vessel noise, and possible marine mammal calls. Figure 6 shows a block diagram outlining the stages of the automated analysis. Walrus, bowhead, and beluga whale calls were detected and classified with algorithms coded in MATLAB programming software (Mathworks Inc.) and executed separately on the computing platform (described in Sections 2.4.5 and 2.4.6).

Appendix A, Automated Detection and Classification of Marine Mammal Vocalizations and Anthropogenic Noise, contains detailed descriptions of the algorithms and an analysis of the classifiers’ precision and recall.

In addition to the analyses conducted until now, new computational processes were implemented this year to better classify the dominant sound source in each minute of data as Vessel, Seismic, or Ambient. To minimize the influence of anthropogenic sources on ambient source sound level estimates, we defined Ambient as any minute of data that does not have an anthropogenic detection within two hours of that minute. This resulted in more accurate estimates of daily cumulative sound exposure levels from each class of sources, cumulative distribution functions of sound pressure levels, and exceedance spectra for each source.

First performed in 2012, per-minute noise levels predicted bowhead whale detection ranges for each minute of data (Appendix D, Estimating the Detection Range of Bowhead Moans). We used this measurement to convert the call counts into call densities, which revealed slightly different migration paths than the simple call count data (Section 2.4.9).

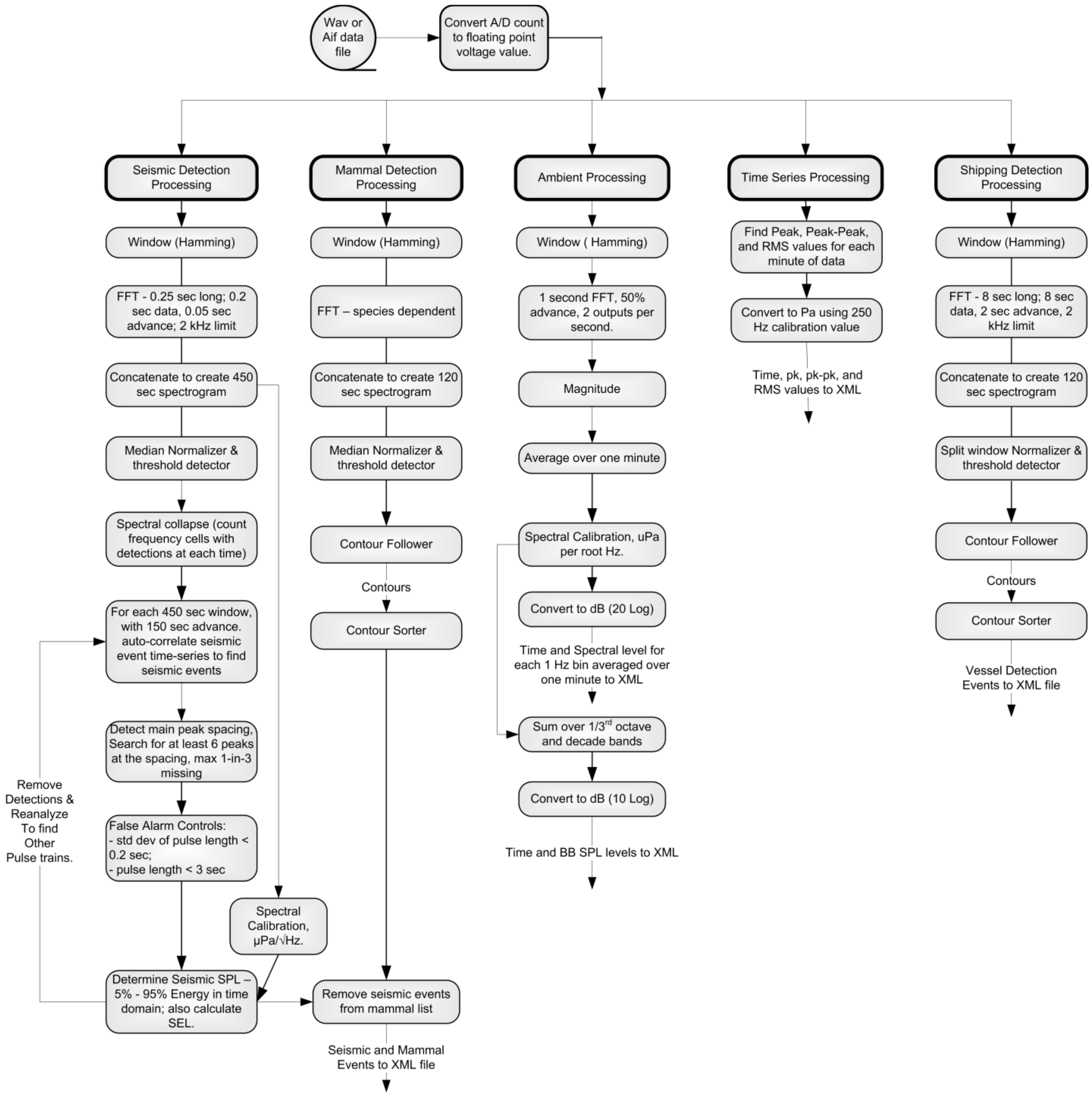

Figure 6. Major stages of JASCO's automated acoustic analysis software suite.

2.4.1. Total Ocean Noise and Time Series Analysis

The total ocean noise levels were quantified at a 1 Hz frequency resolution and were averaged to produce sound pressure density values for each 1 Hz step of the recorded bandwidth over each minute of recording. Further analyses yielded 1/3-octave-band, which corresponds to hearing filter bandwidth in terrestrial mammals, and decade band, a logarithmic filter bandwidth, sound pressure levels for each minute of data. Appendix B, Ambient Noise Results, provides more details about this.

2.4.2. Vessel Noise Detections

Vessel detection was performed in two steps. During the first step, narrowband tones (tonals) produced by the ship's propulsion system and other rotating machinery (Arveson and Vendittis 2000) were detected in each file (See details in Appendix A.10, Vessel Noise Detection).

During the second step, the sound pressure levels assessed once per minute as root-mean-square sound pressure levels (rms SPL) within a frequency band typical for large vessel noise 40-315 Hz) and measured in consecutive digital sound files, were combined to detect ship passages. Background estimates of the shipping band rms SPL and the total rms SPL are compared to their median values over the 12 h window, centered on the current time. Shipping is detected when the rms SPL in the shipping band is at least 3 dB above the median, at least 5 shipping tonals are present, and the rms SPL in the shipping band is within 8 dB of the total rms SPL (Figure 7).

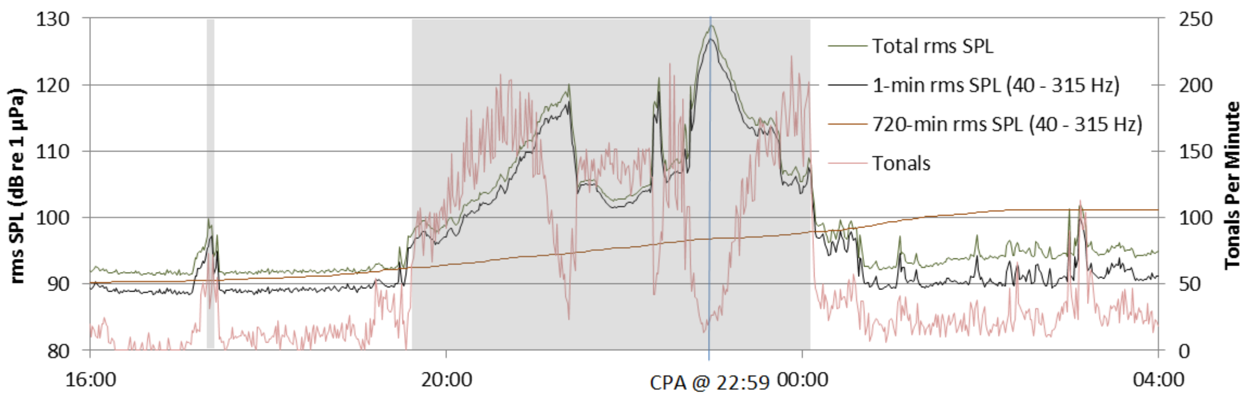

Figure 7. Example of broadband and in-band root-mean-square sound pressure level (rms SPL) and the number of 0.125 Hz wide tonals detected per minute as a ship approached a recorder, stopped, and then departed. The shaded area is the period of shipping detection. All tonals are from the same vessel. Fewer tonals are detected at the ship's closest points of approach (CPA) at 22:59 because of the broadband cavitation noise at the CPA and the Doppler shift of the tonals.

2.4.3. Seismic Survey Event Detections

Seismic pulse sequences were detected using correlated detections in spectrogram contours. A 300 s long spectrogram was created using a 4 Hz frequency resolution and a 0.05 s time resolution (Reisz window). Each frequency bin was normalized to the median bin value over the 300 s window. The detection threshold was three times the median value. Contours were created by joining the detected time and frequency bins in the frequency range of 7–1000 Hz using a 5 × 5 kernel. Any contour 0.2–6 s with a bandwidth of at least 60 Hz was kept for further analysis.

An "event" time series is created by summing the normalized value of the frequency bins at each time bin that contains detected contours. The event time series is auto-correlated to look for repeated events. The correlated data space is normalized to its median and a detection threshold of 3 is applied. Peaks larger than their two nearest neighbors are identified and the peaks list is searched for entries with a set repetition interval. The spacing between the minimum and maximum time peaks is appropriately set, typically at 4.8 and 65 s, to allow for the normal range of seismic pulse periods, which are between 5 and 60 s. If at least six regularly spaced peaks occur, the original event time series is searched for all peaks that match the repetition period within a tolerance of 0.25 s. The duration of the 90% rms SPL window of each peak is determined from the originally sampled time series, and pulses more than 3 s long are rejected (see Appendix A.11, Seismic Survey Detection for details on minimizing false alarms and measuring noise levels).

The performance of the seismic detector was evaluated on seismic airgun data from PLN80 in summer 2010 and determined to be highly precise $P = 0.9997$; $R = 0.9949$), where precision (P) and recall (R) are explained in Section 2.4.8.

2.4.4. Generic Marine Mammal Call Detections

A specialized detector identified calls from bowhead whales, beluga whales, and walrus. The generic detector was mainly used to identify bearded seal calls

Similar to seismic survey detection, automated detection of marine mammal vocalizations is achieved by comparing contour features in the frequency spectrum of signals. Appendix A.4, Bearded Seal Call Detection has details of the analysis.

2.4.5. Bowhead and Beluga Whale Call Detections

Bowhead moans and beluga whistles were automatically detected and separately classified in two steps:

1. Time-frequency contours are detected and extracted from a normalized spectrogram using a tonal detector developed by Mellinger et al. (2011).
2. Each contour is represented by 46 features and presented to two-class random forest classifiers (i.e., bowhead whale vs. “other”, beluga whale vs. “other”).

Random forest classifiers are trained using the manually annotated calls. See Appendix A.2, Bowhead and Beluga Call Detection and Classification, for a full technical description of the process and an evaluation of the performance of these classifiers.

The bowhead calls that can be detected include a variety of simple moans, as described by Clark and Johnson (1984) and Ljungblad et al. (1982). Although many song notes are structurally different and more complex than the moans targeted by the detector, most songs incorporate some moans in at least one of their phrases (Delarue et al. 2009), which makes this method ideal for detecting songs. Songs are a dominant component of the bowhead acoustic repertoire in fall, winter, and spring (Delarue et al. 2009).

2.4.6. Walrus Grunt Detections

The steps below detail the process used to quantify walrus calls using the walrus grunt detector/classifier, which is based on time-frequency representation of the acoustic signal:

1. The spectrogram was calculated and then segmented into time-frequency objects.
2. For each object, a set of contour features that represented salient grunt characteristics were extracted from the 20–1000 Hz frequency band of the spectrogram. Features included, but

were not limited to, minimum frequency, maximum frequency, frequency distribution, and frequency and amplitude modulation indices.

3. Extracted features for each object were then presented to a five-class random forest classifier to determine the class of the sound in the analyzed frame (i.e., walrus grunt, bowhead, seismic, bearded seal, or "other").

A full technical description of the detection/classification process is given in Appendix A.3, Walrus Grunt Detection and Classification.

2.4.7. Minke Whale Boing Call Detections

Minke whale "boing" sounds (Rankin and Barlow 2005) were detected automatically in recordings using a spectrogram correlation method based on Mouy et al. (2009):

1. The spectrogram was computed and normalized, and then the data binarized (set to zero or one) using the local variance and the normalized energy.
2. A set of synthetic binary time-frequency templates representing typical minke whale boing calls was created as successions of linear time-frequency segments defined by their start and end frequencies, sound duration, frequency width, frequency span, and duration of silence before and after the call.
3. Each time-frequency template was cross-correlated with the binarized spectrograms to identify sounds matching the defined boing templates in the recording.

A full technical description of the detection process is given in Appendix A.5, Minke Whale Detection. Given the small quantity of boing calls present in recordings, the performance of the detector could not be accurately evaluated. Analysts used the automated detection results in their manual analysis to ensure they did not miss any minke whale vocalizations.

2.4.8. Detector and Classifier Performance Evaluation

The performance of the marine mammal detectors/classifiers was assessed by comparing the automated detections/classifications with manual detections for all fully-annotated, manually analyzed recordings. For the winter 2012–2013 data, the analysis protocol (see Section 2.3.1) yielded a test dataset of 3149 fully-annotated, two-minute long samples, covering 11 stations. For the summer 2013 data, manual analysis yielded a test dataset of 1732 fully-annotated, 1.5 min samples.

Detector and classifier performance was measured by calculating the precision (P) and recall (R) indices (see Appendix A.6.3, Precision and Recall). These values characterize the relationship between the detector/classifier and the dataset. R describes the proportion of calls detected; P measures the proportion of accurate classifications. P and R were calculated separately for different signal-to-noise ratios: < 0 dB, 0–5 dB, > 5–10 dB, and > 10 dB. Those results are presented in Appendix A, Automated Detection and Classification of Marine Mammal Vocalizations and Anthropogenic Noise. The P and R values are then used to correct the number of automated detections and to estimate call counts (see Appendix A.6, Performance Evaluation). Table 4 summarizes the performance of the detectors used for each species for all detected vocalizations, with the majority of signal-to-noise ratios being 0–5 dB.

Table 4. Performance of the automated detectors and classifiers (precision, *P*, of winter periods and recall, *R*) applied to the winter 2012–2013 and summer 2013 datasets.

Species	Winter 2012–2013		Summer 2013	
	P	*R*	*P*	*R*
Bowhead	0.72	0.47	0.70	0.35
Walrus	0.42	0.65	0.50	0.65
Beluga	0.53	0.38	0.65	0.35
Bearded seal	0.96	0.16	0.96	0.16

2.4.9. Noise-Independent Call Densities

Noise levels influence the area within which animals can be acoustically detected. This area varies in time and is different for each location. Consequently, the number of calls detected at a given time and location is highly dependent on noise conditions. An increase in the number of detected calls could potentially be due to a decrease in noise levels (leading to a larger detection area) rather than an increase in vocal activity. Appendix D, Estimating the Detection Range of Bowhead Moans, provides more details on this, specifically Figure D–4, which shows the detection area of bowhead calls at each location of the summer 2013 monitoring program.

To help people understand the acoustic data, we estimated call density (in calls/km^2) by dividing the number of detections by the detection area. Call density is a noise-independent vocal activity index.

The vocal activity index was computed as follows:

1. The number of detections from the automatic detector was summed for each 30 min recording. So false positives from the detectors were not included, detections were only used if the manual analysts confirmed bowhead sounds were present.
2. The number of detections, N_{detect}, was then weighted with the precision, *P*, and recall, *R*, indices to estimate the call count N_{calls} : $N_{calls} = N_{detect} (P/R)$. (Appendices A.5, Minke Whale Detection, and A.6, Performance Evaluation).
3. The estimated call count for each 30 min recording was divided by the size of the area in which the calls were detected, estimating the call density for that area. Given the flat bathymetry of the northeastern Chukchi Sea, we assumed the detection range, r ,was the same for all azimuths (Figure D-2). Hence, the area of detection (A) was defined as $A = \pi r^2$. Detection ranges were calculated for each minute of recording (Appendix D, Estimating the Detection Range of Bowhead Moans). The range value used for each 30 min recording was the median of all the 1 min range values.

To produce call density maps for the entire recording period, all estimated call densities were summed at each station and interpolated spatially using a Kriging algorithm (see Appendix E, Interpolation Techniques).

A successful calculation of detection areas depends on knowing details about source levels of the calls of interest. MacDonnell and Martin (2011) calculated the source levels of bowhead moans using more than 100 localized calling bowhead whales at the Burger prospect (Appendix D, Estimating the Detection Range of Bowhead Moans, Figure D-1). The literature has not yet defined source levels of walrus grunts. Consequently, estimated call densities were only calculated for bowhead calls.

2.4.10. Bowhead Whale Call Localization

The localization processing approach, which was used on these data, assumes that cetacean vocalizations from the same individual are simultaneously detected on several hydrophones of an array of nearby sensors. Because underwater sound travels at a finite speed, the vocalizations arrive sooner at nearby hydrophones than at more distant ones. Under certain conditions, the differences in arrival times of calls to three or more hydrophones can be used to determine the position of the calling animal.

The Burger array of recorders was suitable for localizations because recorders were relatively close together (see Figure 5) and BGA, BGB, BGC, BGD, BGE, BGH, and BGJ were all configured to record sound frequencies up to 32 kHz (64,000 samples per second).

The analysis used a 3-D localization processor with multiple hydrophones previously designed and tested with MATLAB programming software, and implemented to process large data sets with JASCO's Acoustic Analysis software suite (AA). The methods consisted of four main stages: (1) Recorder clock synchronization; (2) Event detection; (3) Event localization; (4) Consolidation.

1. *Recorder clock synchronization*. The synchronization stage determined absolute time shift and the clock drift rate between the reference recorder (BGA) and each of the other recorders' clocks using identifiable pings from a seismic exploration ship as synchronization events (Table 5). Cross-correlation was used to compute the relative arrival times of these signals at each recorder relative to BGA; these signals were used to synchronize the recorders. The speed of sound in water was used to calculate the source emission times based on known positions of the sources. An intermediate record of both the time drift factors and the acoustic data segments, which were used to compute the cross-correlations, were produced.
2. *Event detection.* Bowhead calls were identified with output from JASCO's automatic bowhead detector at recorders BGA, BGB, BGC, BGD, BGE, BGH, and BGJ, totaling 115,059 detection instances. Each record included the start time, duration, lower frequency bound, and bandwidth of the detected bowhead localization.
3. *Event localization.* Call detections were localized by adjusting detection times on all recorders to the common timeframe of recorder BGA. The relative detection arrival times on multiple recorders were used to triangulate the source position. This was accomplished through a time difference of arrival (TDOA) method, implemented as follows: The timespan extracted from each recording was centered on the detection time, and also extended before and after the detection by the maximum sound propagation time between recorders. A 7 × 7 matrix of TDOAs was created based on cross-correlations between each pair or recorders. Each row in the matrix represented the computed TDOAs between one recorder and each of the other six. Diagonal values were set to zero because they correspond to a recording's delay relative to itself. The strength of each matrix row was scored by summing the magnitude of its three strongest correlations. TDOAs from the row with the highest score were used to calculate the localization using its three strongest correlations. See Appendix F, Localization Techniques for details. Some cross-correlations were weak because the signal to noise ratio (SNR) was too high or a bowhead vocalization was not recorded by

enough recorders. which were then adjusted to account for the difference in distances from the ship to each recorder.

4. *Consolidation.* Localizations from all recorders were combined and any duplicate localizations, defined as those whose common timeframe reference times were within 1 s of each other, were discarded; 70,116 unique localizations were retained. Table 5 summarizes the localization counts from detection through to consolidation.

Table 5. Summary of localization step results.

Step	Count
Total bowhead vocalization detections	115059
Number of detections localized	95954
Detections after duplicates removed	70116

3. Results

3.1. Received Ocean Sound Levels

The received ocean sound levels at one representative recording station, PLN40, are used here to illustrate the acoustic characterization methods applied to all stations. The received sound levels at all other stations are provided in Appendix B, Ambient Noise Results.

3.1.1. Winter 2012–2013 Recording Period

The total received broadband sound levels at PLN40 varied between 88 dB and 133 dB re 1 µPa (Figure 8, top). Noise levels from 12 Oct to 15 Nov, which was the ice-free period, were consistently between 100–110 dB re 1 µPa (see Appendix B, Ambient Noise Results). The period when ice covered the area lasted from approximately 15 Nov to 12 Jul near PLN40. For the whole study area, freeze-up began 1 Nov and was complete by 20 Nov. Ice began retreating around mid-June, lasting until mid-Aug, although some ice remained near Hanna Shoal into September. When ice was present and temperatures began to fall, localized high intensity ice-cracking impulses occurred (Figure 8, bottom). Scattering at the rough under-ice surface highly attenuates sound propagation under ice at frequencies above 200 Hz (Greene and Buck 1964, Diachok 1976, Roth 2012). This phenomenon caused low sound levels above 200 Hz for most of the deployment period (Figure 8, bottom).

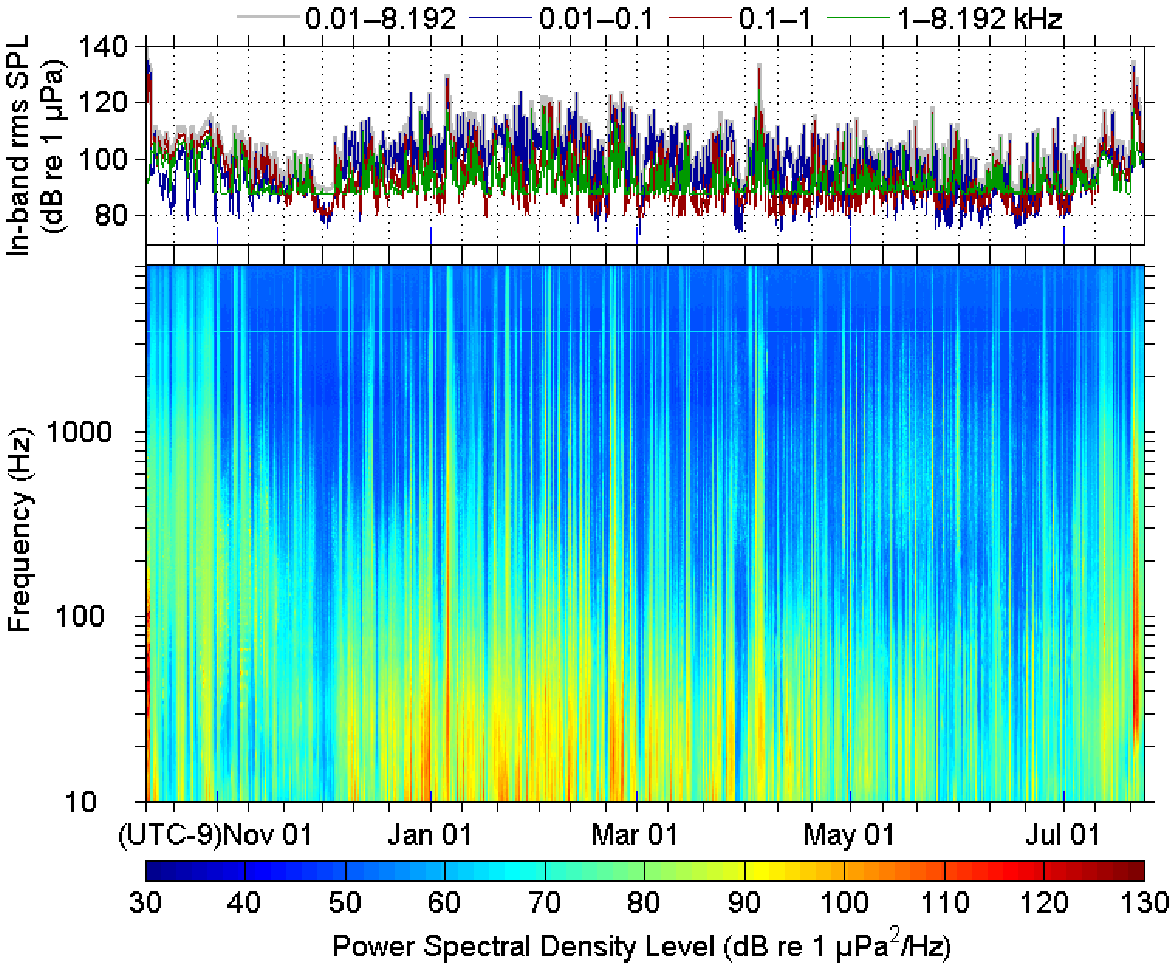

Figure 8. (Top) Broadband and decade-band sound pressure levels (SPL) for winter 2012 Station PLN40. (Bottom) Spectrogram of underwater sound over the recording period from October 2012 to July 2013.

The 1/3-octave mean SPL values (over time) are consistently about 20 dB higher than the 1/3-octave median SPL values calculated over the entire recording period (Figure 9). This large difference is attributed to a large number of brief but high intensity ice-cracking events that contribute to the mean but have little influence on the median. The L_{50}–L_{95} spectral levels are all limited by the AURAL recorder's self noise above 1 kHz. The spectral levels above 1 kHz were less than about 50 dB re 1 µPa/Hz for more than at least half of the time (Figure 9).

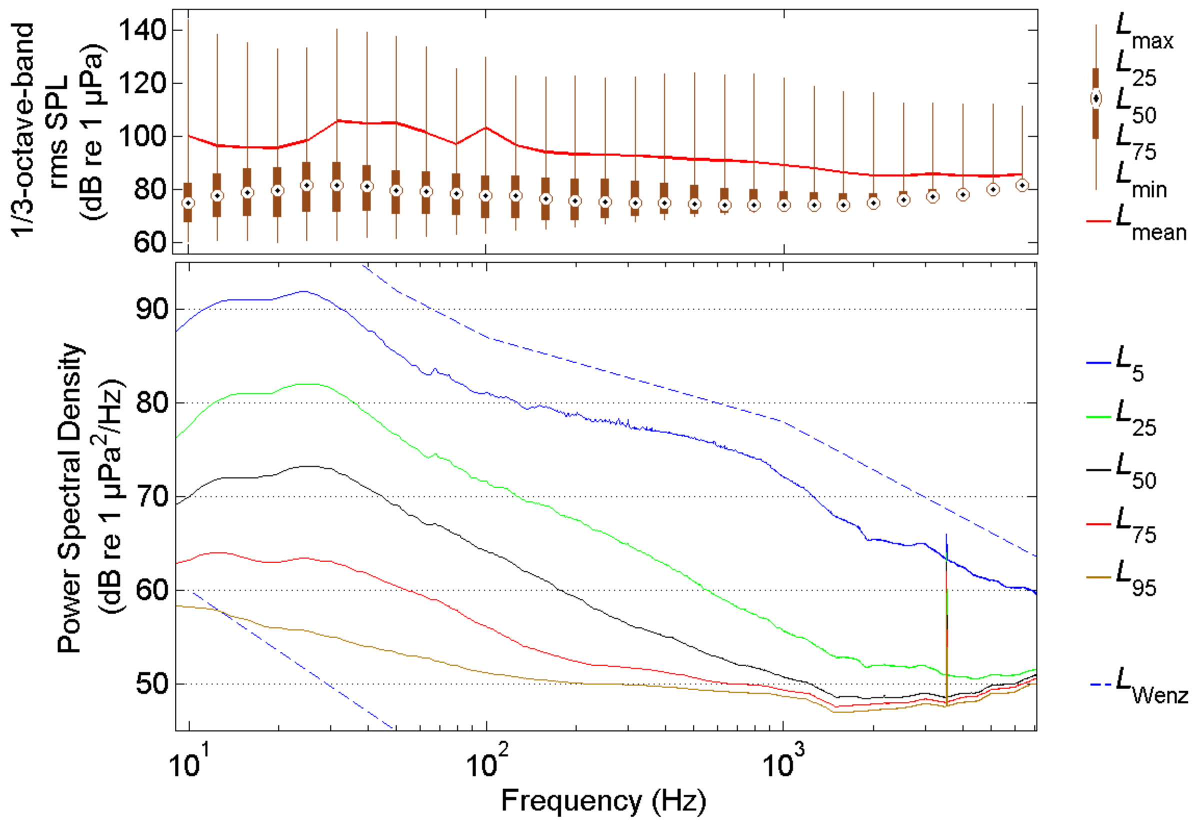

Figure 9. (Top) Distribution of 1/3-octave-band sound pressure levels (SPL) for winter Station PLN40. The red line indicates the root-mean-square (rms) level over the recording period from October 2012 to July 2013. (Bottom) Percentile exceedance levels of the power spectral density. The spike at 3.5 kHz is caused by the AURAL's electronic background noise. The dashed lines are the limits of prevailing noise from the Wenz curves.

3.1.2. Summer 2013 Program

Received sound levels at PLN40 ranged from 81–147 dB re 1 µPa (Figure 10). Periods with higher sound pressure levels were associated with seismic survey noise (e.g., 10 Sep) and shallow hazards surveys, operated by TGS and Shell, respectively.

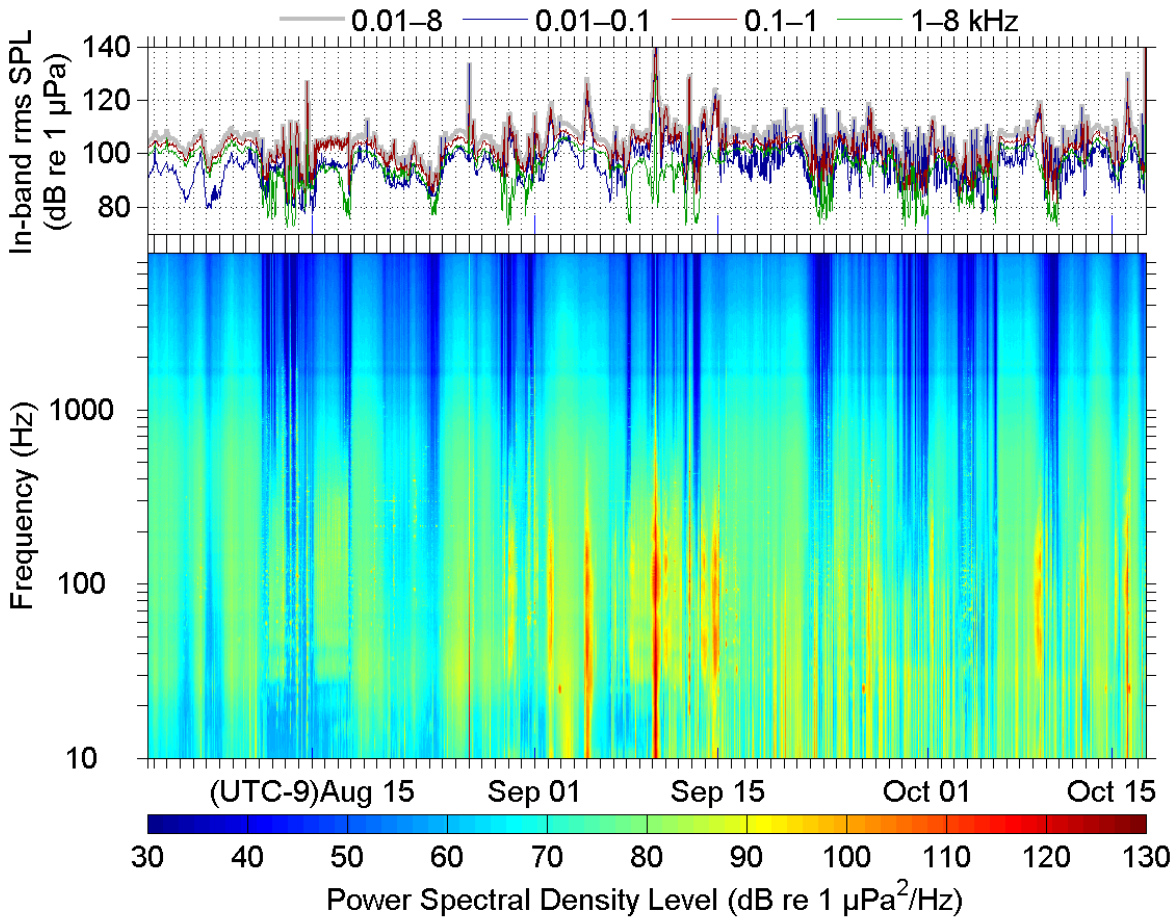

Figure 10. Broadband and decade-band sound pressure levels (SPL) for (top) summer 2013 Station PLN40 and (bottom) spectrogram of underwater sound August to October 2013.

Above 100 Hz, the 1/3-octave-band mean SPL and median SPL decrease as the frequency increases (Figure 11). Generally, the spectral levels decrease for frequencies above 500 Hz, which is a common characteristic of ambient noise spectra (Wenz 1962). The L_{50} curve falls from 70.4 to 53.3 dB re 1 µPa^2/Hz between 500 and 5000 Hz, a decrease of 17.1 dB/decade. This is a typical roll-off for wind driven noise spectra (Ma and Nystuen 2005). The electronic background noise of the AMARs is 23 dB re 1 µPa^2/Hz so sound levels below 500 Hz reflect the true ambient noise conditions. Spectral exceedance levels remain within the Wenz limits of prevailing noise (Figure 11) except for the L_{95} from 80–200 Hz. The increased levels between 20 and 500 Hz were due to the presence of seismic survey activity, which is discussed in Section 3.2.2.

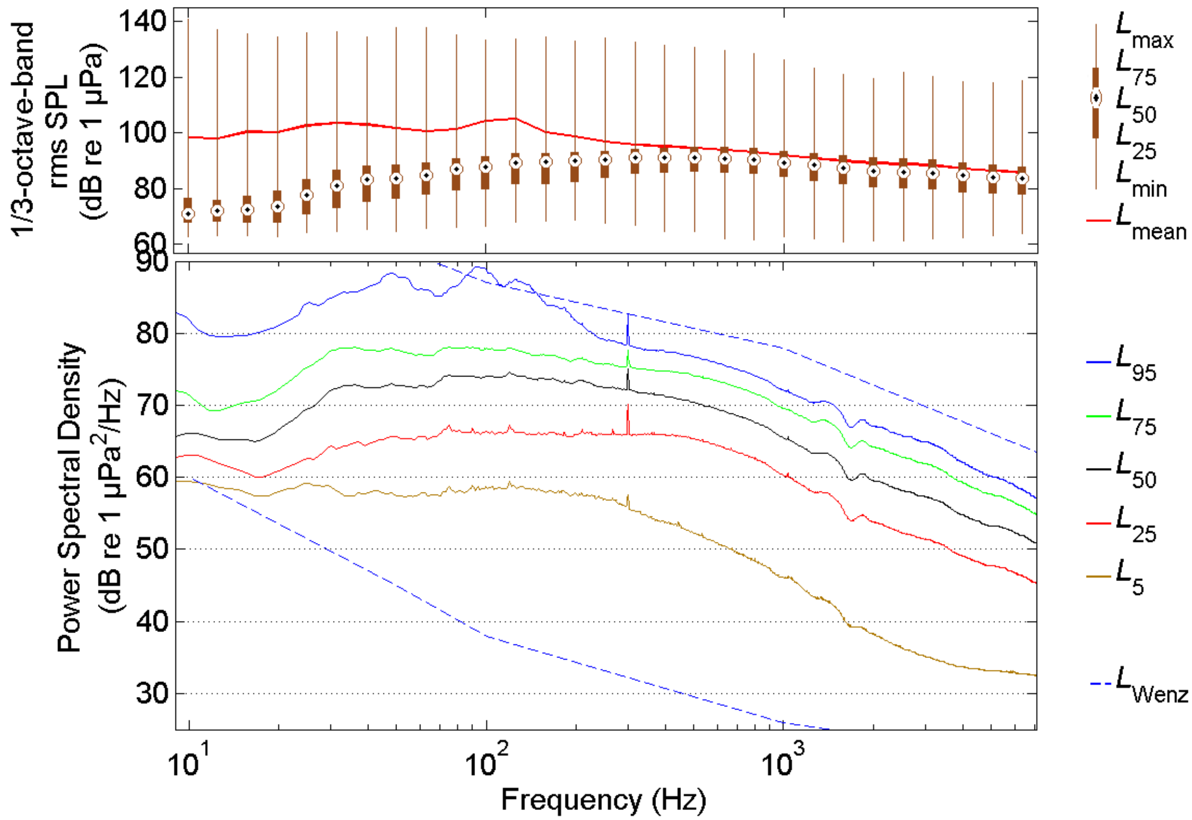

Figure 11. (Top) Box plot showing 1/3-octave-band sound pressure levels (SPL) for summer 2013 Station PLN40. The red line indicates the root-mean-square (rms) level over the recording period from August to October, 2012. (Bottom) Percentile 1 min power spectral density levels. The dashed lines are the limits of prevailing noise from the Wenz curves.

The distribution of sound exposure levels (SELs) was measured for each station; PLN40 is shown in Figure 12. Sound sources were classified; see Sections 2.4.2 and 2.4.3 for details. The peak daily cumulative SEL (SEL (24 h)) occurred on 10 Sep and was associated with a nearby seismic survey, which shows as a peak in Figure 10. The median of the total received sound energy at each station was Kriging-interpolated (see Appendix E, Interpolation Techniques) for the entire summer recording period (Figure 13); it showed median SPL between 98.7 and 105.5 dB re 1 µPa. The median SEL (24 h) was Kriging-interpolated (Figure 14); it showed values between 148.7 and 155.0 dB re 1 µPa^{2}s. Station PLN60 and the Burger cluster recorded higher sound pressure levels associated with seismic survey activity. Station CL50 reported higher levels due to wind and wave noise and strong prevailing currents (Appendix B, Ambient Noise Results).

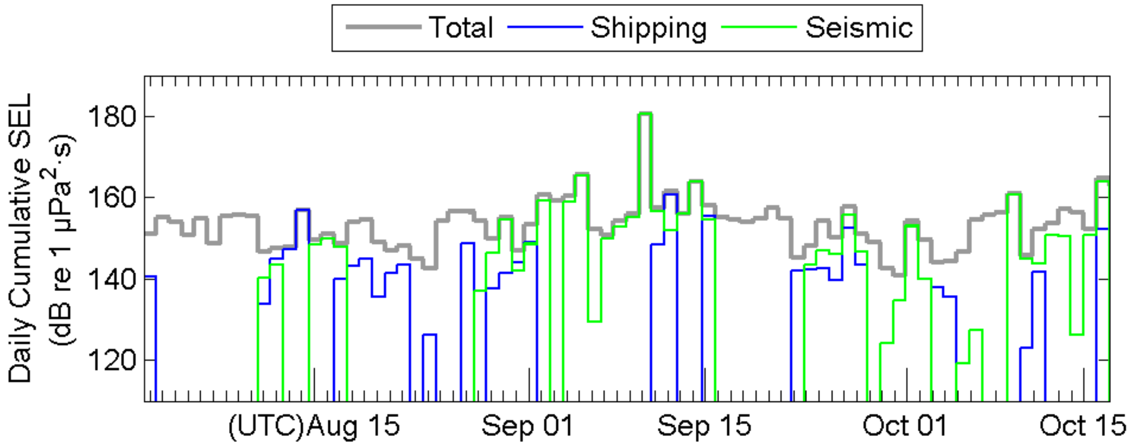

Figure 12. Daily cumulative sound exposure level (SEL (24 h)) distributions at PLN40 summer 2013. The data are divided into total, shipping, and seismic classes.

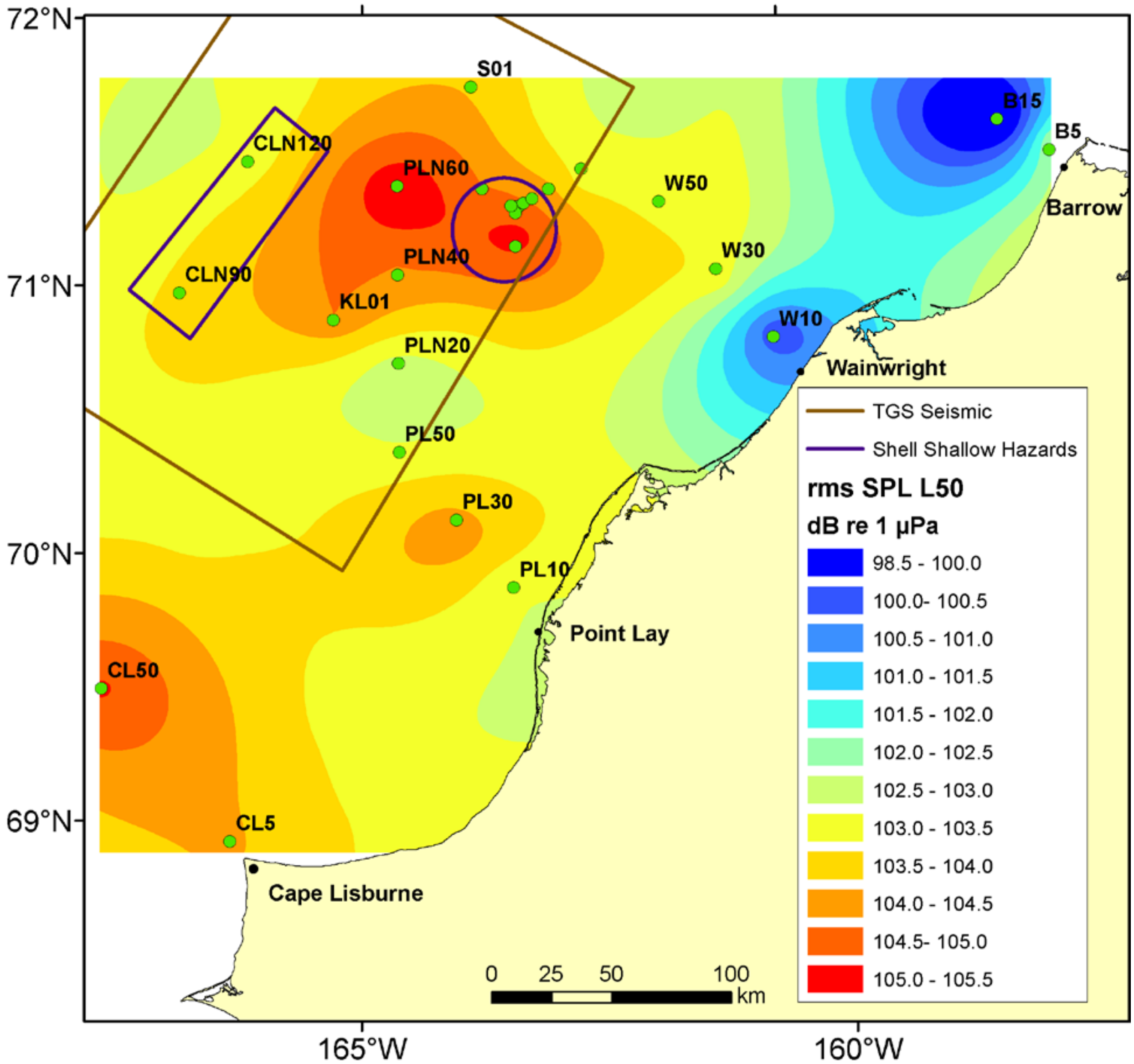

Figure 13. Median of the total sound pressure levels (Kriging-interpolated) received during summer 2013. The SPL are between 98.7 and 105.5 dB re 1 µPa.

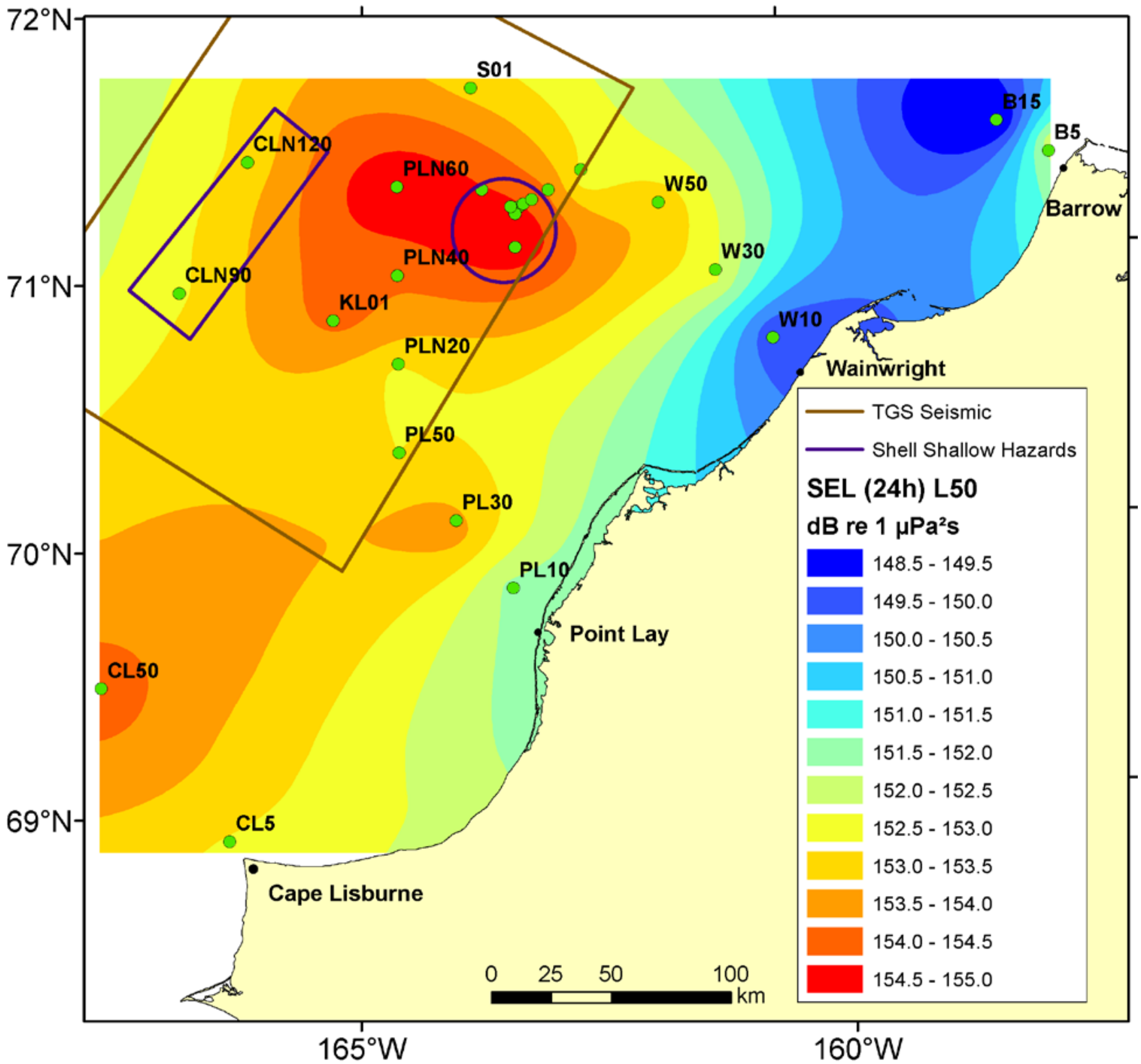

Figure 14. Median of the Kriging-interpolated daily cumulative sound exposure levels (SEL (24 h)) received during the summer period 2013. The SEL (24 h) are between 148.7 and 155.0 dB re 1 µPa^{2}s.

3.2. Seismic Survey Event Detections

3.2.1. Winter 2012–2013 Program

A few seismic events from surveys related to country-dependent claims under the United Nations Convention on the Law of the Sea, by Canada, the US, and Russia, were detected in September 2012 at PBN40 and WN40. All other detections throughout the winter deployment were triggered by sea ice noise (Figures B–12 to B–16).

3.2.2. Summer 2013 Program

Seismic survey source sounds were detected using the automated detection algorithm described in Section 2.4.3. Detections were made of seismic shots from TGS's 2-D seismic survey, which ran from 29 Aug to 29 Oct, and from Shell's shallow hazards seismic survey, which ran from 18 Jul to 28 Sep. Seismic survey noise was prominent in the northwestern part of the study area (Stations KL01, CLN90, and CLN120), but was detected on all stations to some degree (Figures 15 through 17). A spectrogram of seismic survey activity is shown in Figure 18. Seismic survey noise with approximately 10 s pulse intervals came from a nearby survey. Distant seismic survey noise was also present, but with pulse intervals of approximately 3 s.

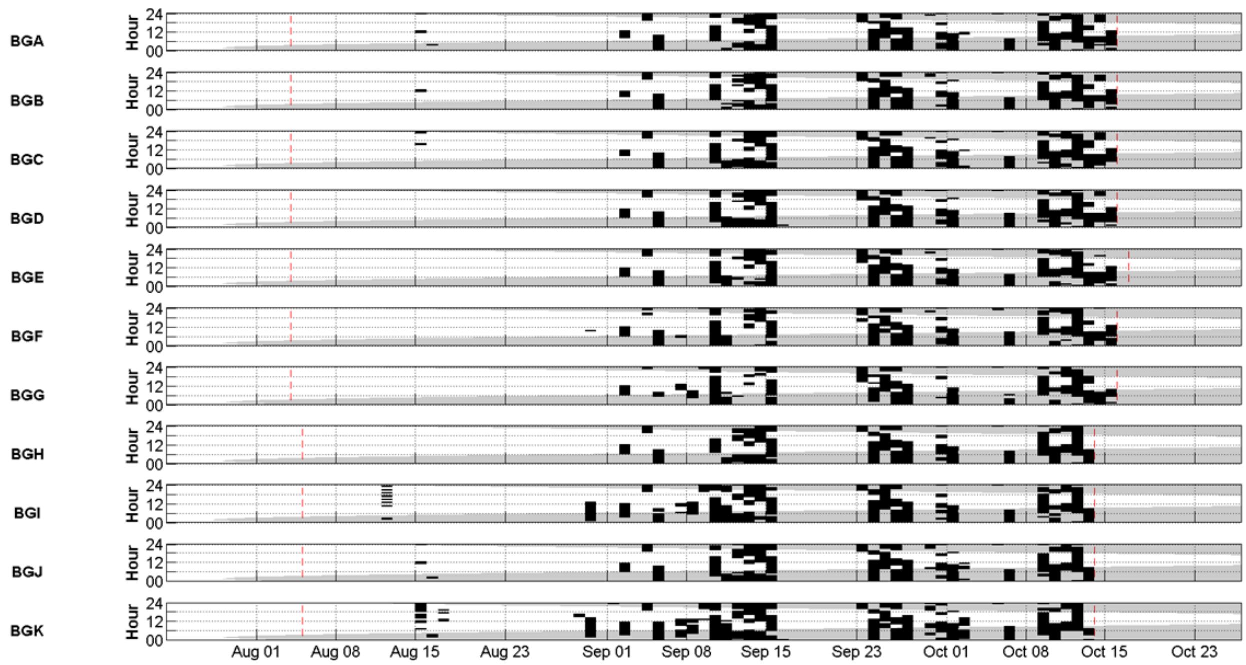

Figure 15. Seismic survey detection presence each hour (vertical axis) versus date (horizontal axis) at 11 Burger recording stations, 25 Jul to 26 Oct 2013. The grey areas indicate hours of darkness. Vertical dashed lines indicate AMAR deployment and retrieval dates.

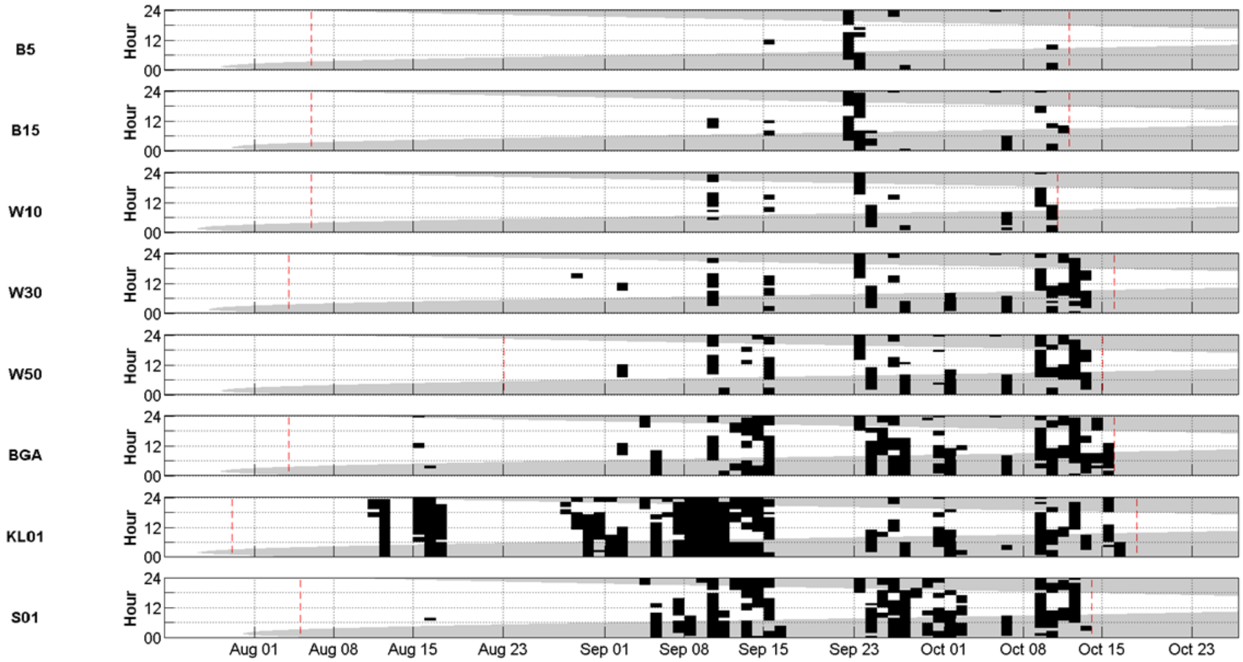

Figure 16. Seismic survey detection presence each hour (vertical axis) versus date (horizontal axis) at eight stations—B5, B15, W10, W30, W50, BGA, KL01, and S01—25 Jul to 26 Oct 2013. The grey areas indicate hours of darkness. Vertical dashed lines indicate AMAR deployment and retrieval dates.

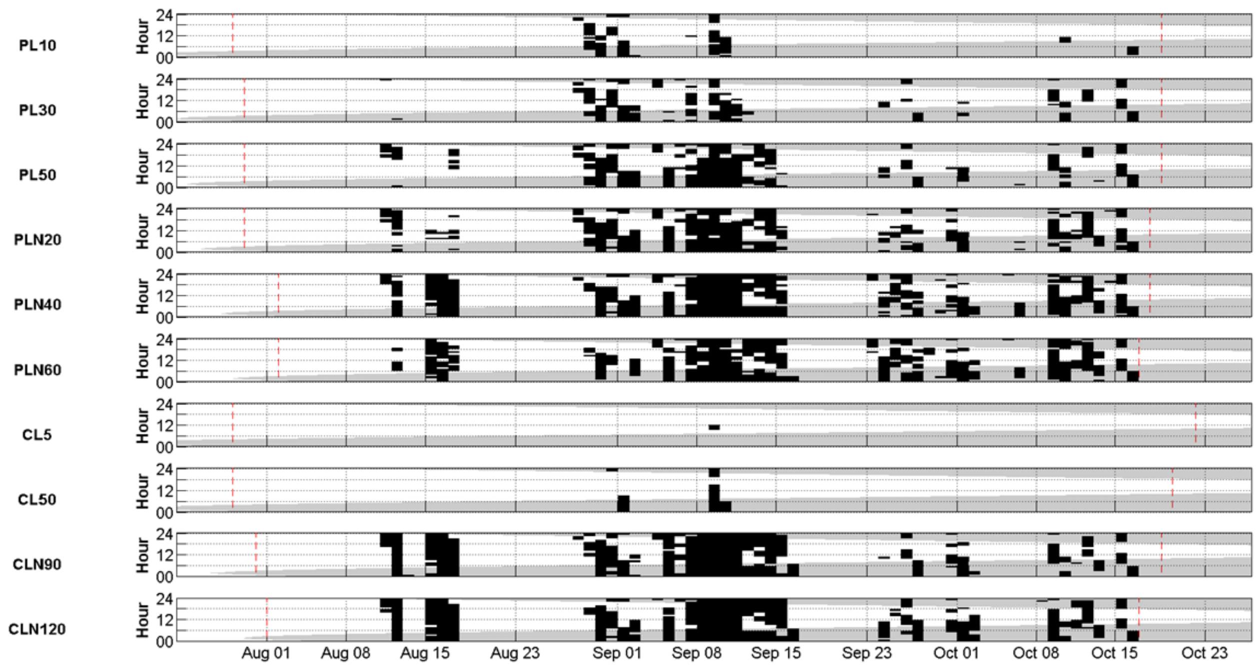

Figure 17. Seismic survey detection presence each hour (vertical axis) versus date (horizontal axis) at 10 stations—PL10, PL30, PL50, PLN20, PLN40, PLN60, CL5, CL50, CLN90, and CLN120—25 Jul to 26 Oct 2013. The grey areas indicate hours of darkness. Vertical dashed lines indicate AMAR deployment and retrieval dates.

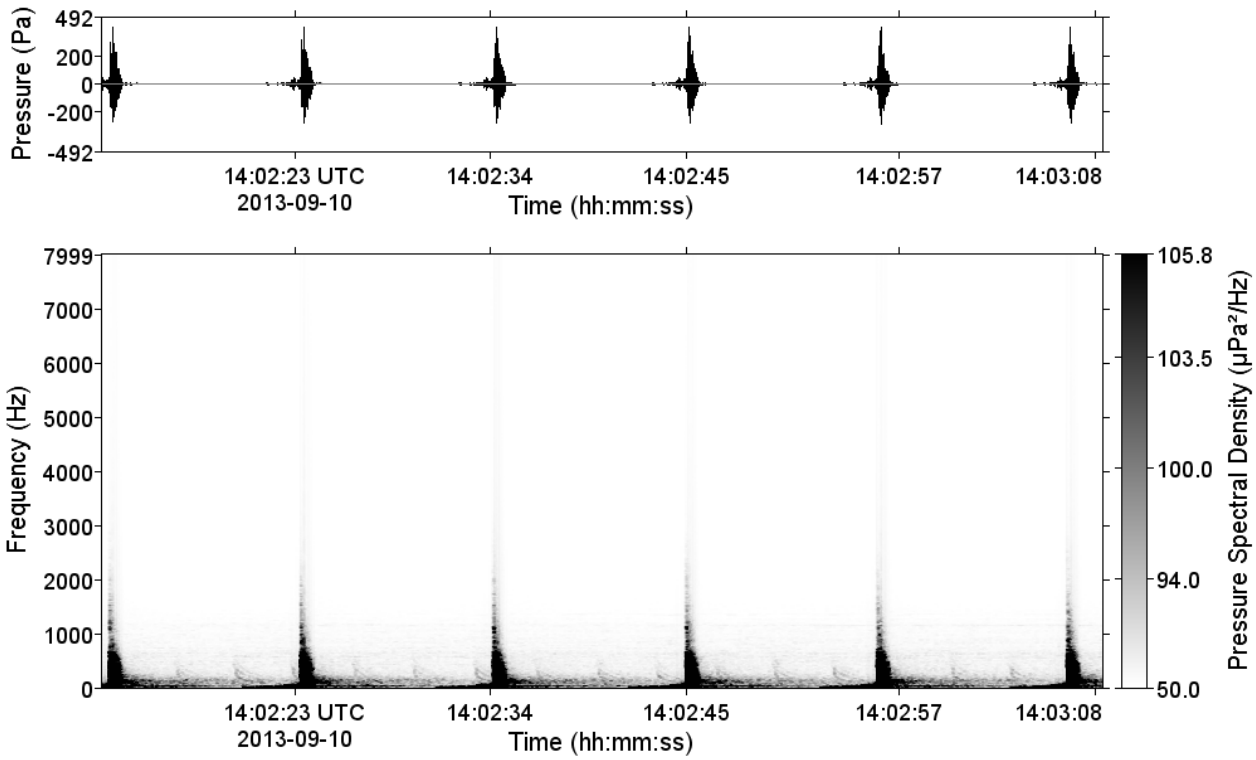

Figure 18. (Top) Pressure signature and (bottom) spectrogram of seismic pulses from an airgun array, 10 Sep 2013 at summer Station PLN40 (Frequency resolution: 0.5 z; Frame length: 0.25 s; Hamming window).

3.3. Vessel Noise Detections, Summer 2013 Program

Vessel detection presence results indicate a vessel's passage through the closest point of approach (CPA) to the recorder station, by hour (Figures 19 through 21). Station BGI had the most daily vessel passages with an average of five per day during summer. The mean vessel passages for each station were Kriging-interpolated to produce Figure 22, which, as expected, shows that the majority of vessel activity was near the Burger site, where some seismic survey operations took place and therefore support vessels were likely in the area. Vessel activity was also detected near Barrow, which was likely due to traffic in and out of the village and to a lesser extent traffic between the Beaufort and Chukchi Seas.

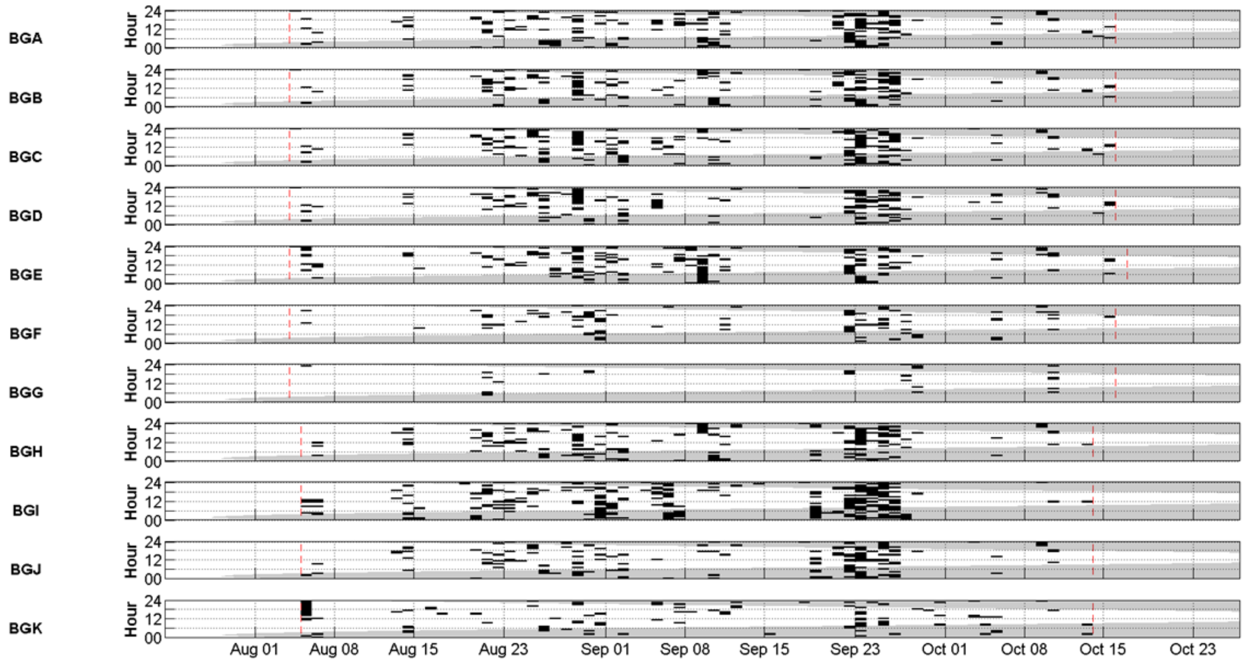

Figure 19. Vessel detections at Burger stations each hour (vertical axis) versus date (horizontal axis)—28 Jul to 21 Oct 2013. The grey areas indicate hours of darkness. Vertical dashed lines indicate AMAR deployment and retrieval dates.

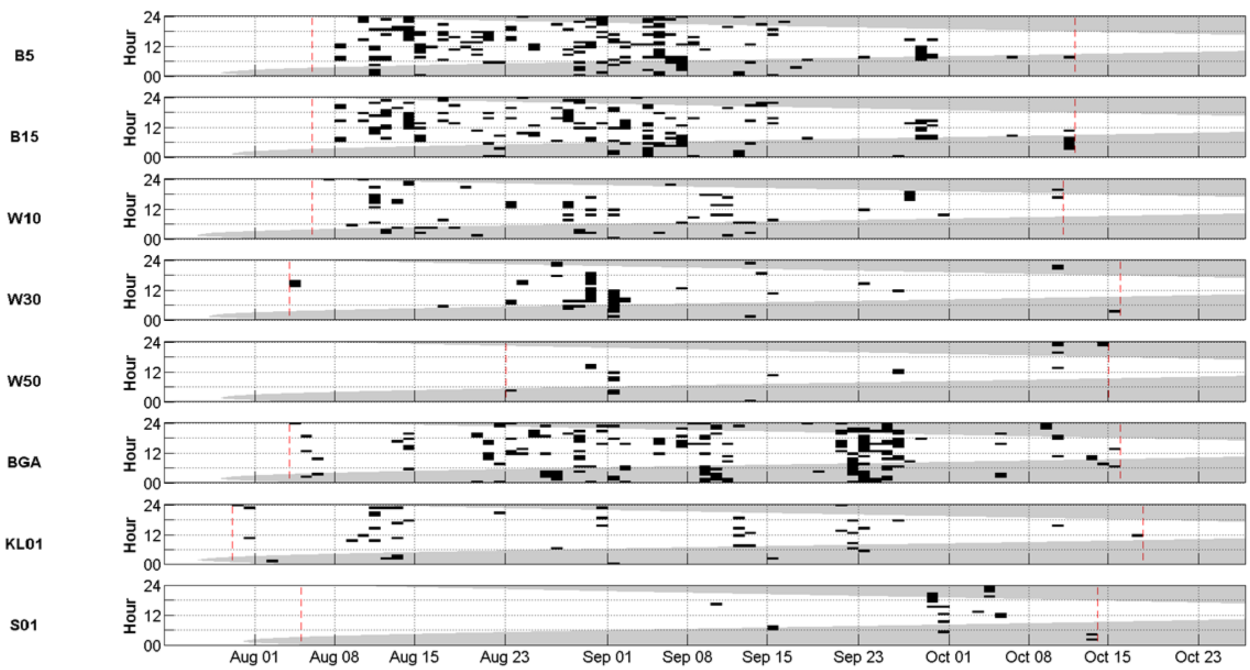

Figure 20. Vessel detections each hour (vertical axis) versus date (horizontal axis) at eight stations—B5 to S01—28 Jul to 21 Oct 2013. The grey areas indicate hours of darkness. Vertical dashed lines indicate AMAR deployment and retrieval dates.

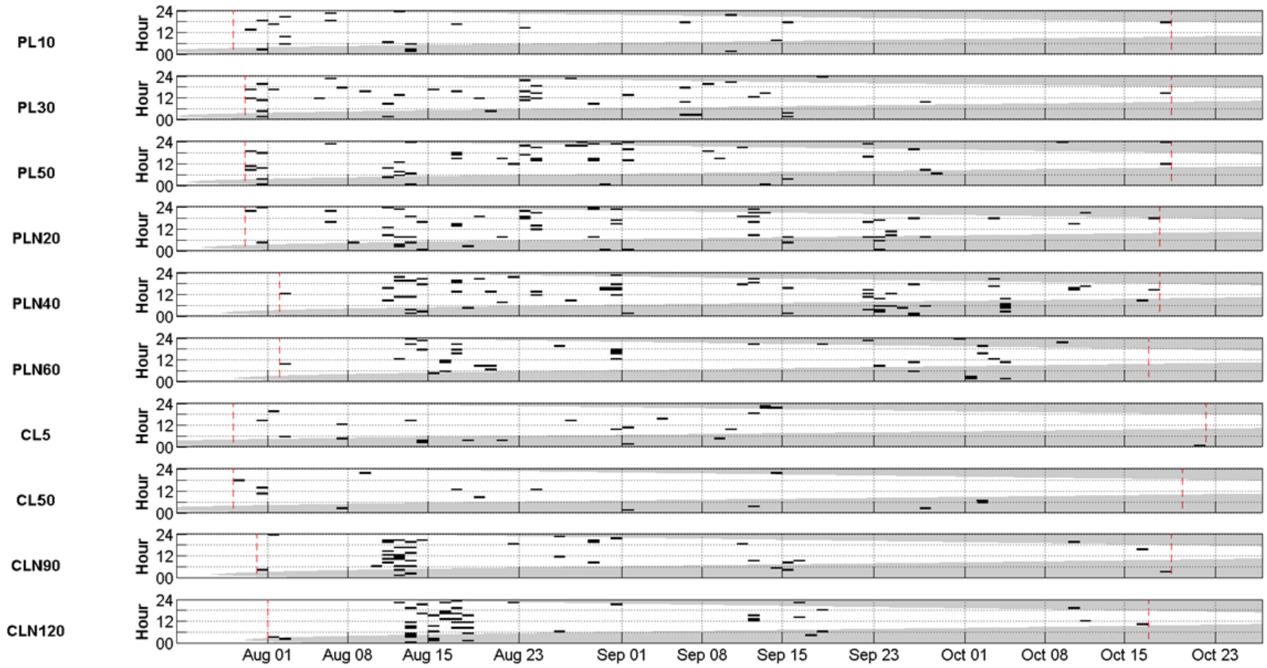

Figure 21. Vessel detections each hour (vertical axis) versus date (horizontal axis) at eight stations—PL10 to CLN120—28 Jul to 21 Oct 2013. The grey areas indicate hours of darkness. Vertical dashed lines indicate AMAR deployment and retrieval dates.

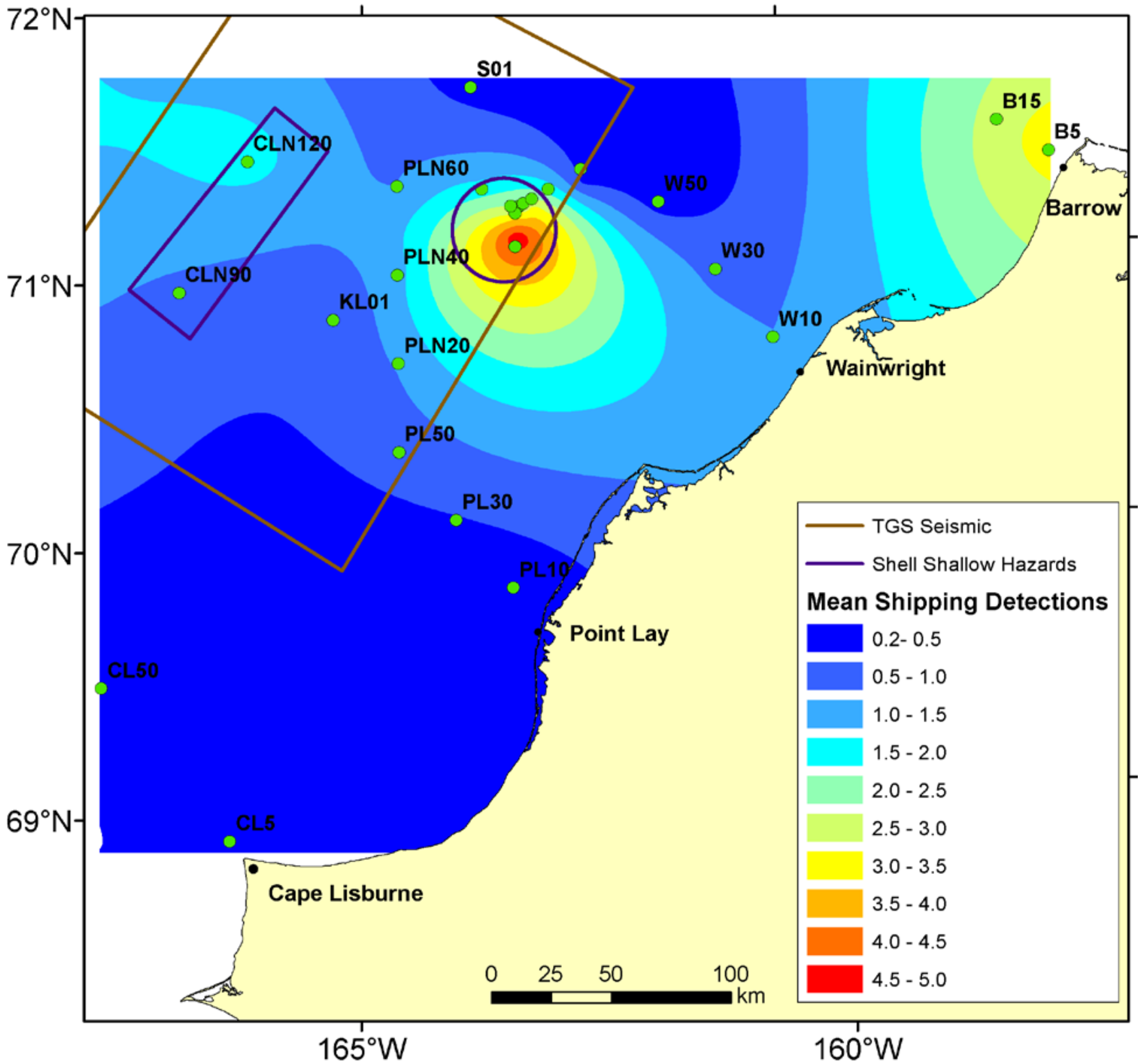

Figure 22. Summer 2013: Mean of the detected daily vessel closest points of approach levels (Kriging-interpolated). The mean values are between 0.2 and 5.0 detections per day.

3.4. Marine Mammal Call Detections

The numbers of detected vocalizations in the winter and summer datasets are presented below by species, in the order of importance of target species. Calls from these species were detected by manual analyses and by automated detector/classifiers. Vocalizations by other cetaceans (except minke whale) and pinnipeds were detected manually only; these detections are presented alphabetically by the animals' common names.

Marine mammal acoustic occurrence at each station is presented as the daily proportion of 40 min or 30 min sound files (Hanna Shoal winter and summer, respectively) with manual detections for each species. Stations that did not have at least one detection were omitted from the plots (see Tables 7 and 8).

Species-specific call count estimates are presented as the number of automated detections corrected by performance indicators (See Appendix A.7, Call Count Estimation) over various periods. These are shown as either bubble plots (winter data: bowhead whales, beluga whales, walrus, and bearded seals; Table 6), interpolated contour plots, or a combination of both (summer data: bowhead whales, beluga whales, walrus, and bearded seal; Table 6). The contour plots were produced using radial basis interpolation method (see Appendix E, Interpolation Techniques). The automated detections used for both plot types were compiled based on manual detection results, i.e., automated detections for a given file were counted only if a call was manually detected within that file for a given species. The corrected numbers of automated detections more closely represent the actual number of vocalizations for a given species; these were summed over a given period (Table 6) and mapped to produce call count estimate plots. Given the relatively large distances that separated each of the recorders, the interpolated contour plots only reflect large-scale patterns. Local occurrence at increasing distance from the recorders might differ from the plots.

Table 6. Periods over which the numbers of acoustic detections (or the proportion of days with detections) were summed for each species for which bubble or interpolated contour plots were created.

Species	Fall 2012	Spring 2013	Summer 2013
Bowhead whale	Monthly[a]	Monthly[a]	2-4 weeks[bc]
Walrus	1-2.5 months[ac]	Monthly[a]	Variable[bc]
Beluga whale	Monthly[a]	Monthly[a]	Variable[bc]
Bearded seal	Monthly[a]	Monthly[a]	Variable[bc]

[a] Bubble plot.
[b] Mixed plot.
[c] Summation period adjusted to reflect trends in detections.

3.4.1. Summary of Manual Call Detections

In the winter 2012–2013 data, 57,849 sounds were annotated manually, of which 54,572 were classified as marine mammal calls (Table 7). In the summer 2013 data, 46,053 sounds were annotated manually, of which 41,061 were classified as marine mammal calls (Table 8).

During the winter session, Station WN20 had the most marine mammal call detections, mostly due to the many combined bearded seal and walrus calls. Bearded seals were by far the most commonly detected species in the winter dataset, accounting for 61% of all identified annotations, followed by walrus (20%), and bowhead whales (15%). Minke and gray whales and ringed and ribbon seals represented a small number of annotations (0.75% combined).

In the summer 2013 data, walrus calls accounted for 64.4% of all identified calls. Bowhead whale, bearded seal, and beluga whale calls accounted for 28.6, 3.1, and 2.8% of the annotations, respectively. The contributions of other species were negligible.

Table 7. Winter 2012–2013 call detections: Marine mammal annotations resulting from the manual analysis of 5% of the data from each recording station.

Station	Bowhead whale	Walrus	Beluga whale	Bearded seal	Ringed seal	Ribbon seal	Minke whale	Gray whale	Unknown	**Total**
B5	718	66	209	2057	4				52	**3106**
CL50	415	247	77	1735	12	15	40		125	**2666**
PBN20	232	202	9	2240	17				165	**2865**
PBN40	509	74	38	2204	12				233	**3070**
PL50	494	272	212	1541	27				100	**2646**
PLN100	1262	309	75	4105	2	49			265	**6067**
PLN120	948	1865	62	2674	13				115	**5678**
PLN40	506	314	47	1761	7				126	**2761**
PLN80B	701	43	9	2891	8	1			130	**3783**
W35	789	284	77	2752	57			1	292	**4251**
W50	550	1063	248	3438	11	2			838	**6150**
WN20	465	3152	59	3027	59				443	**7205**
WN40	321	935	87	1767	29				181	**3320**
WN80	514	2105	109	1296	44				212	**4280**
Total	**8424**	**10931**	**1318**	**33488**	**302**	**67**	**40**	**1**	**3277**	**57849**

Table 8. Summer 2013 call detections: Marine mammal annotations resulting from the manual analysis of 5% of the data from each recording station. No spotted seal sounds were detected due to a lack of knowledge about their calls (see Section 3.4.13). BW: bowhead whale; WA: walrus; WW: beluga whale; BS: bearded seal; GW: gray whale; KW: killer whale; MW: minke whale; HW: humpback whale; FW: fin whale; RS: ringed seal; RB: ribbon seal; UN: unidentified sounds.

Station	BW	WA	WW	BS	GW	KW	MW	HW	FW	RS	RB	UN	**Total**
B15	1509	64	142	65						11		110	**1901**
B5	1322	34	168	21				4		1		116	**1666**
BGA	312	1271	34	38						3	2	300	**1960**
BGB	321	1239	36	34							4	264	**1898**
BGC	417	1446	33	63						4	3	154	**2120**
BGD	334	1334	36	61								163	**1928**
BGE	405	1381	26	84								299	**2195**
BGF	361	1333	40	56								240	**2030**
BGG	340	2682	68	29								104	**3223**
BGH	239	511	32	27								17	**826**
BGI	158	432	35	26								4	**655**
BGJ	450	2010	17	72						3		56	**2608**
BGK	359	960	46	37								94	**1496**
CL5		925		1						4		192	**1122**
CL50		137	1	48		7	4	4	58	13		82	**354**
CLN120	568	373	59	16	1	7		1		3		91	**1119**
CLN90	423	401	93	16	4	23			3			81	**1044**
KL01	281	146	13	40	3	4		6		5		113	**611**
PL10		3895	5	6	2		3			1		154	**4066**
PL30	82	453	6	22	6		15	2		3		169	**758**
PL50	160	159	29	50	25	4	8	5		8		190	**638**
PLN20	415	350	44	65	15	2	1	4		4		265	**1165**
PLN40	514	295	20	51	4	1				2		391	**1278**
PLN60	387	344	24	50						2	1	151	**959**
S01	277	2350	16	48	1						2	230	**2924**
W10	568	198	8	108	47	2				4		347	**1282**
W30	847	408	14	80	15	3						334	**1701**
W50	759	1343	58	70	14					1		281	**2526**
Total	**11808**	**26474**	**1103**	**1284**	**137**	**53**	**31**	**26**	**61**	**72**	**12**	**4992**	**46053**

3.4.2. Bowhead Whale Call Detections

3.4.2.1. Winter 2012–2013 Program

Bowhead whale fall detections were distributed over two main periods. The first period began on 18 to 21 Sep, except for PBN40 where the first detection was a week earlier on 12 Sep, and lasted until the end of October. This was the onset of the first area-wide detection period recorded during the 2013 summer program (Delarue et al. 2013b; Appendix C, Marine Mammal Detection Results: Figure C–1 and Table C–1). The nine winter recorders that started recording between 6 and 14 Oct captured the end of the first detection period. Increasing detections with increasing distance from shore along the Point Lay and Wainwright deployment lines of recorders (Figure C–1) illustrate that detections were more numerous offshore than inshore, both in terms of the daily proportion of sound files with detections and the number of days with detections.

The second period of detections started around 1 Nov at all stations except PL50 and CL50, where it started a week later. We noted a tendency toward a later onset of detections with decreasing distance from shore, particularly along the Point Lay deployment line (Figure C–1). The last calls clearly occurred later inshore than offshore (Table C–1). The last fall detection occurred on 5 Dec at PL50. Call count estimates suggest that the core of the migration corridor is centered between 71 and 72° N, with decreasing occurrence to the north and south (Figure 23, Figures C–3 and C–4). Call counts increased substantially from September to November (Figures C–2 through C–4).

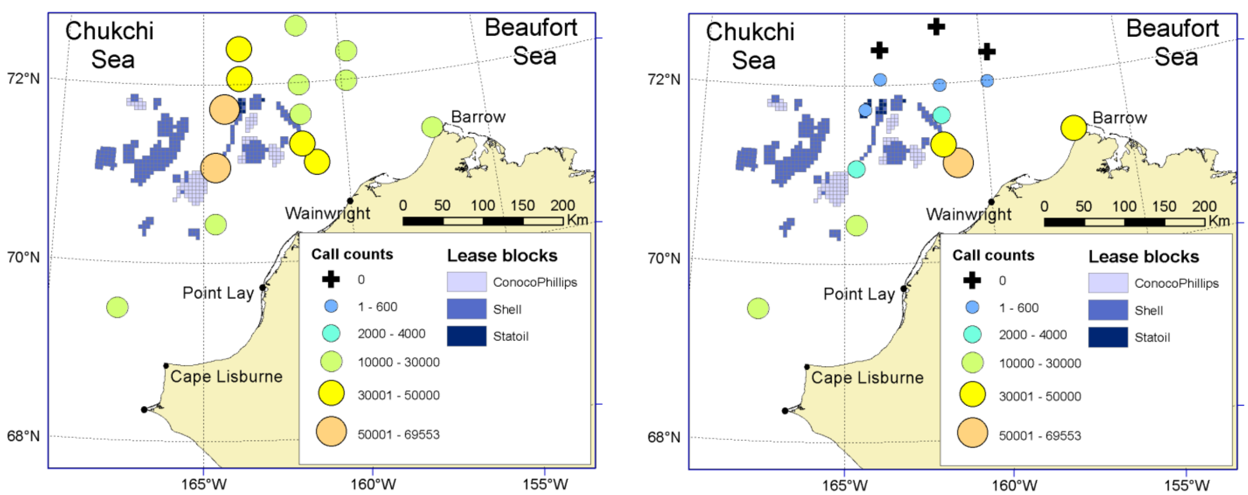

Figure 23. Bowhead whale call count estimates* at winter 2012–2013 stations in the Chukchi Sea (radial basis interpolated). (Left) Fall migration 14 Oct to 31 Dec 2012. (Right) Spring migration 1 Apr to 28 Jun 2013.

* Corrected sum of automated call detections in all files with manual detections.

Spring call detections started on 11 Apr at CL50 and on 12 Apr at PL50, W35, and B5. There was a clear delay in the onset of the first detections with increasing distance from shore off Point Lay and Wainwright (Table C–1). Similarly, the number of detection days and the number of calls decreased strongly with increasing distance from shore (Figure 23, Figures C–5 to C–7). W35 had the highest number of detected calls (Figure 23) despite having the same number of detection days as B5 (Table C–1); previously this station recorded the highest number of calls.

Station W50 spring call counts were similar to those from B5, but with 25 less detection days. This suggests that the main migration corridor was potentially further offshore than in previous years. Vocal activity in the study area had largely stopped by mid-June with the exception of B5 where it continued at a moderate level until mid-July. Offshore stations PLN100, PLN120, PBN40, and WN80 detected sporadic call activity in July and August (Figures C–8 and C–9).

Most bowhead calls that we detected consisted of frequency-modulated narrowband moans (typically without harmonics), moans with harmonic structure, and the complex calls defined as broadband, pulsed, and often strident (Ljungblad et al. 1982, Clark and Johnson 1984). By fall, these calls became increasingly organized into stereotyped sequences called songs (Delarue et al. 2009). From the second week of November, detections at all stations consisted almost exclusively of songs. The early spring detections were also usually songs but typically less stereotypical than those in November. Songs became increasingly disorganized as the spring migration progressed. By June, most detections consisted of non-stereotyped moans and/or complex call sequences. Calling rates decreased after June (see Appendix A.8, Detector/Classifier Performance).

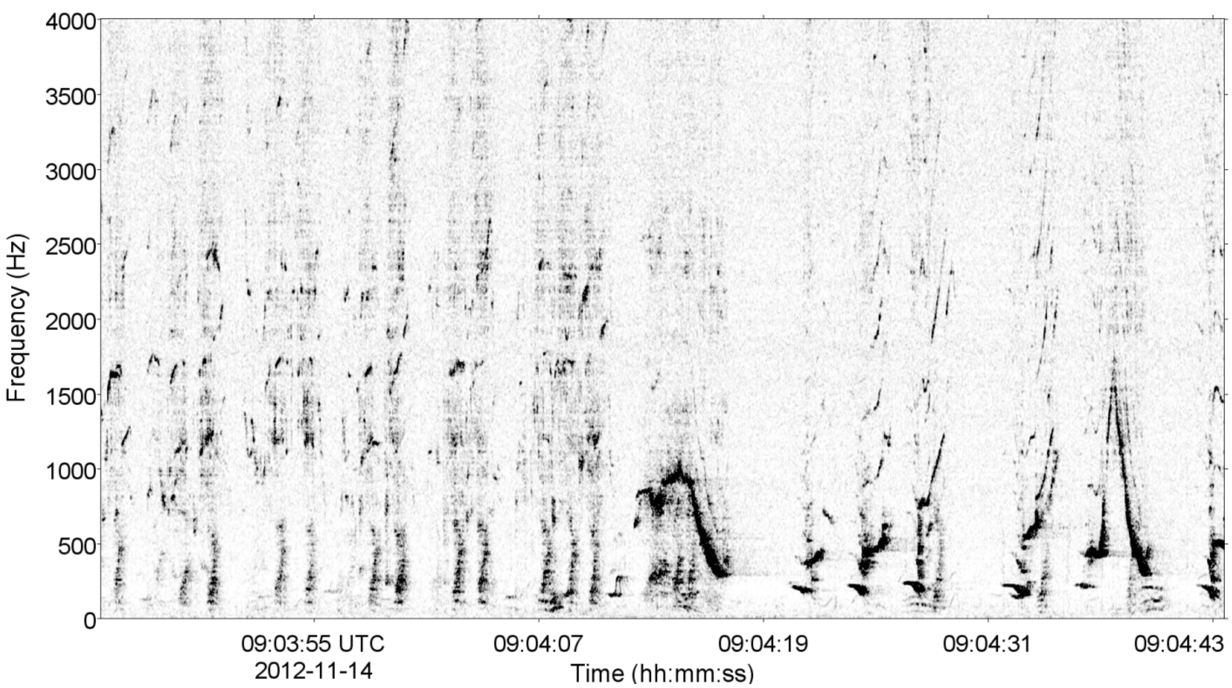

Figure 24. Spectrogram of complex bowhead calls recorded at Station W35, 14 Nov 2012 (Frequency resolution: 2 Hz; Frame size: 0.128 s; Advance: 0.032 s; Hamming window).

3.4.2.2. Summer 2013 Program

Bowhead vocalizations were manually detected in the recordings from summer 2013 at all analyzed stations except PL10, CL5, and CL50 (Appendix C, Marine Mammal Detection Results: Table C–2 and Figures C–10 and C–11). The proportion of days with detections at each analyzed station ranged from 6% (PL30) to 87% (B15), with a mean of 41.5% (Table C–2).

Three distinct detection periods were identified:

1. 5 Aug to 3 Sep 2013: Detections were concentrated in the northern half of the study area at stations north of 71° N and off Point Barrow (Figure C–12). Call counts at the northern stations were substantially lower than near Barrow. Excluding PL10, PL30, PL50, CL5, CL50 that had no detections, and excluding the Barrow stations that had very high detection counts, bowhead detections occurred on 21.5% of days between 5 Aug and 3 Sep. An area-wide peak in detections occurred from 24–26 Aug when a maximum of 78% of active stations recorded bowhead calls (Figure C–15).
2. 4 to 21 Sep 2013: This period was characterized by an absence of detections throughout the western and central parts of the study area, a continuation of intense call activity off Barrow, and the onset of call activity at the inshore Wainwright stations (W10 and W30). There were also a few sporadic detections at the northernmost station (S01) and in the Burger lease area (Figure C–13).
3. 22 Sep to mid-October 2013 (Figure C–14): Except at B15, where detections occurred uniformly until the instrument was retrieved, detections at most stations occurred in temporal waves presumably associated with the movements of fall migrating whales. Detections at Burger occurred in one single wave between 29 Sep to 6 Oct, with only sporadic call activity before and after (Figure C–11). Although 85% of active stations recorded this early October detection peak, shorter peaks separated by 2 to 3 days with few or no detections happened before and after the extended peak throughout the study area. Along the Point Lay deployment line, the intensity of each detection peak decreased with decreasing distance from shore; PL30 and PL50 lacked any peaks (Figure C–10). The proportion of active stations with detections dropped from 7–8 Oct, possibly due to a weather event with sustained wind speeds of 20–25 kts for 48 hrs (Figure C–15) although a pause in the migration or a combination of environmental and biological factors cannot be excluded as contributing factors.

The number of calls recorded off Barrow was two times higher than at any other station. Aside from Barrow, the area off Wainwright and to a lesser degree an area along a line running from the Burger lease area to CLN120 (Figure C–14), were also considered high-detection areas. Similarly, the majority of sightings made during visual surveys occurred in these areas (Aerts et al. 2014; Figure 26). Most acoustic detections occurred north of 71° N except for stations W10 and those between PL30 and KL01 (Figure 25); the latter recorded far fewer calls than elsewhere north of 71° N.

The detected calls consisted mostly of simple moans (Figure 26) although an increasing proportion of complex calls was noticed near the end of the recording period.

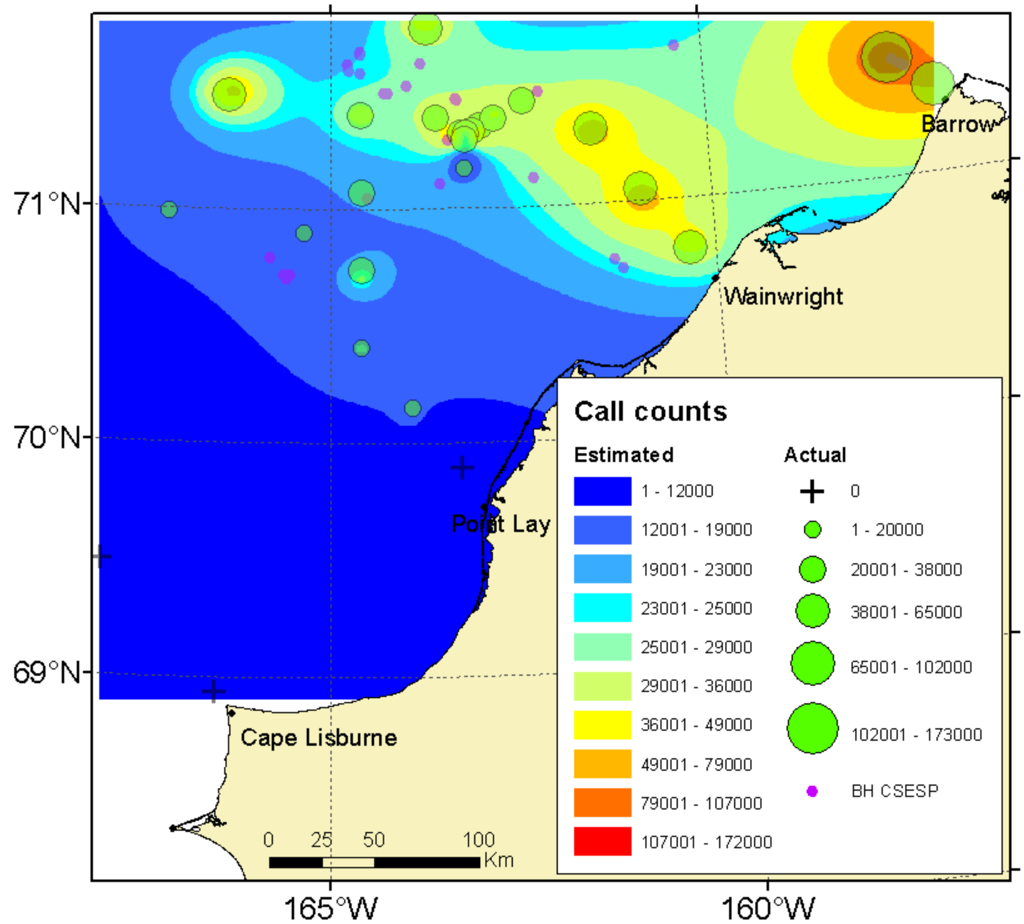

Figure 25. Interpolated (radial basis function) and actual bowhead whale call counts based on the sum of automated call detections in all files with manual detections for 5 Aug to 11 Oct (period when all 28 recorders were deployed) at all summer 2013 stations in the northeastern Chukchi Sea. Bowhead whale sightings recorded during the Chukchi Sea Environmental Science Program are also displayed (Aerts et al. 2014).

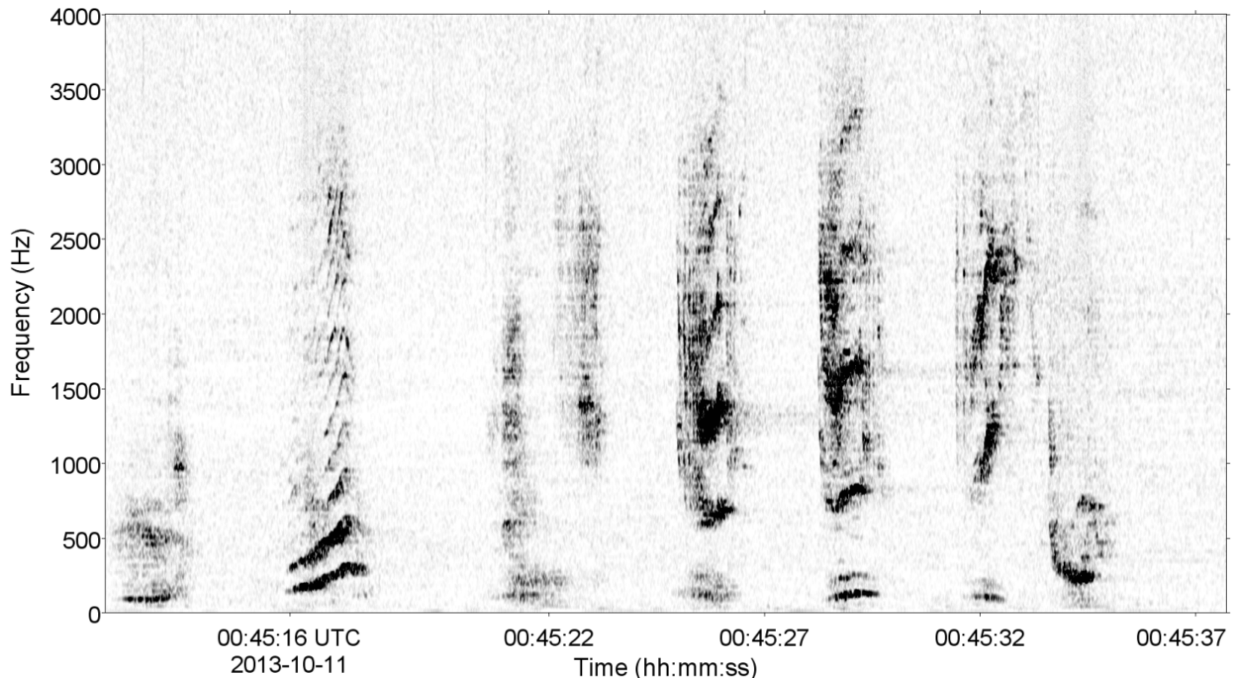

Figure 26. Spectrogram of bowhead moans at Station W50, 11 Oct 2013 (Frequency resolution: 1 Hz; Frame size: 0.06 s; Advance: 0.006 s; Hamming window).

3.4.3. Walrus Call Detections

3.4.3.1. Winter 2012–2013 Program

The bulk of the fall 2012 walrus call detections occurred in recordings from Hanna Shoal between 10 Sep and 7 Oct (Figure 27). The highest number of calls was recorded at WN80. From 14 Oct onward, only half of the stations detected calls. The rather abrupt disappearance of detections at the Hanna Shoal stations appears to be linked with the beginning of the walrus fall migration, which takes them first inshore and then southwest toward Point Hope. This theory is supported by sporadic call activity, concentrated over a few days, at WN20 and W35. No calls were recorded at B5 and CL50 during the fall and early winter. Stations PBN20, WN20, WN40, and PLN120 recorded walrus calls sporadically from late January to mid-March 2013 (Figure C–16).

The first spring call detection occurred on 21 May at PL50, but the bulk of detections did not start until mid-June, with a general progression from southwest to northeast and inshore to offshore (Figure C–16; Table C–3). Detections in the southwestern part of the study area (CL50, PL50, and PLN40) were brief and spread over 2 to 3 weeks. On the other hand, calling activity at stations closer to Hanna Shoal began in earnest quickly after the first detections.

Detected walrus calls consisted predominantly of a variety of grunt-like sound; knocks and bell sounds were detected intermittently (Stirling et al. 1983, Stirling et al. 1987, Schusterman and Reichmuth 2008).

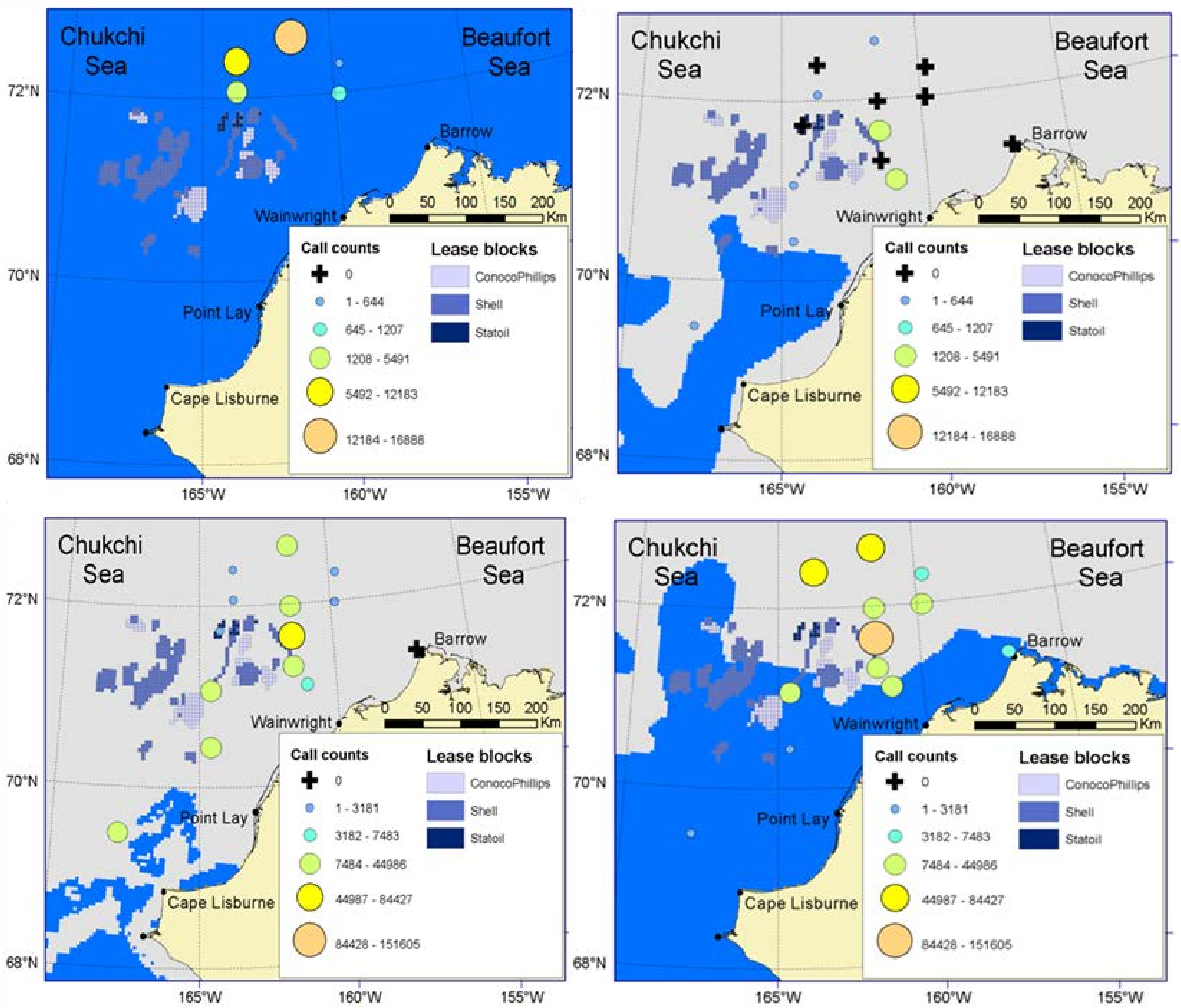

Figure 27. Walrus call count estimates* at all winter 2012–2013 recording stations in the Chukchi Sea. (Top left) from 10 Sep to 13 Oct 2012; (Top right) from 14 Oct to 31 Dec 2012; (Bottom left) June 2013; (Bottom right) July 2013. The blue background indicates ice-free areas. Gray areas represent ice coverage for the middle of each period (NOAA 2008).

* Corrected sum of automated call detections in all files with manual detections.

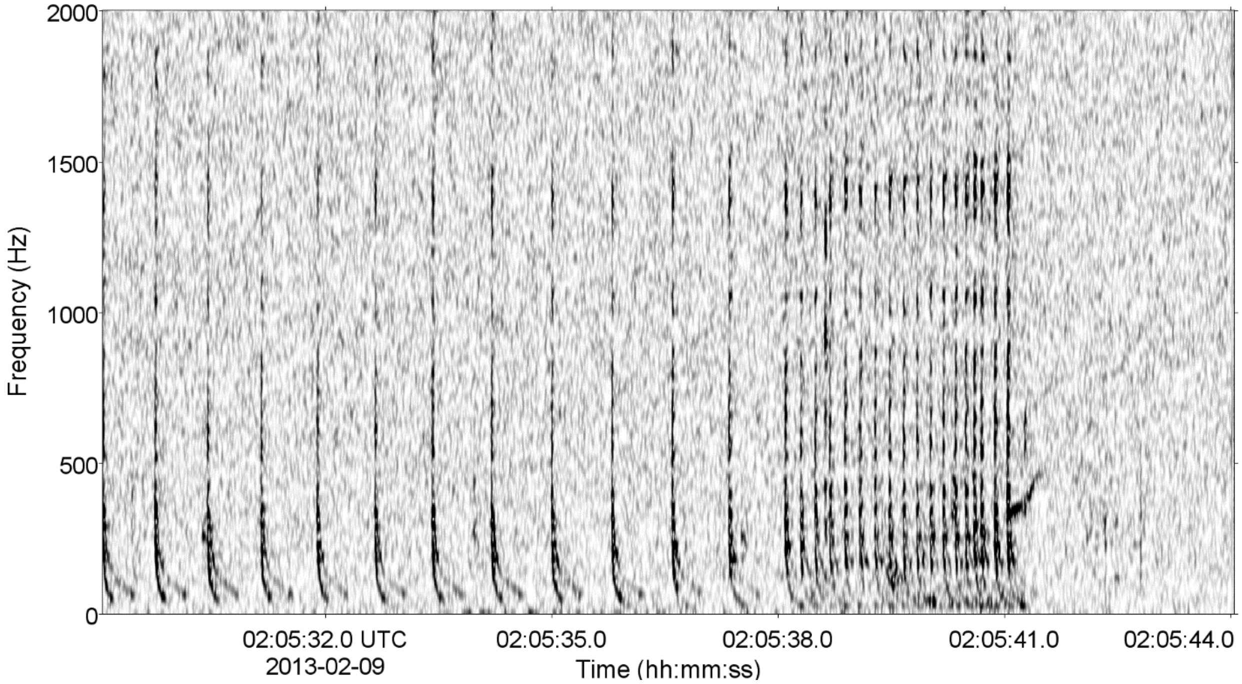

Figure 28. Spectrogram of walrus grunts recorded at Station PLN120, 9 Feb 2012 (Frequency resolution: 4 Hz; Frame size: 0.05 s; Advance: 0.01 s; Hamming window).

3.4.3.2. Summer 2013 Program

Walrus calls were detected at all stations and on every day during the summer 2013 recording period (Figure C–17 and C–18). The mean proportion of days with detections at each recorder was 54% (range: 9–92%; Table C–4). Call activity until the end of August was largely concentrated at stations around Hanna Shoal, with greater detections and west and northwest of the shoal than in other years (Figure C–20). Station S01, northwest of the shoal, recorded the highest number of calls over that period.

Relatively fewer detections occurred from the end of August to 11 Sep than before or after. The mean proportion of stations with detections fell to about 30% during this period but the spatial distribution was similar to that in early August. Call counts at PL10, however, doubled in late August and early September relative to mid-August (Figure C–21).

From 11 Sep onward, there was an increase in the number of stations where calls were detected (Figure C–19); call detections peaked in late September/early October, a few weeks later than usual, with calls recorded at over 80% of stations. This period was characterized by a shift of the highest call activity from the northern stations to an inshore area off Point Lay (PL10). At the same time, walrus acoustic presence remained strong in the Burger lease area and near Station S01. Call counts also increased considerably at southwestern station CL5 (Figure C–22). The large and rapid drop in the proportion of stations with detections from Oct 7-8 (from ~85% to 27%) appears to be correlated with inclement weather (20–25 kts sustained wind for 48 hrs; Figure C–19). Overall, the distribution of visual sightings is well correlated with the areas of highest acoustic occurrence (Aerts et al. 2014; Figure 29). The lack of sightings near PL10 or CL5 was related to lower visual effort around those stations.

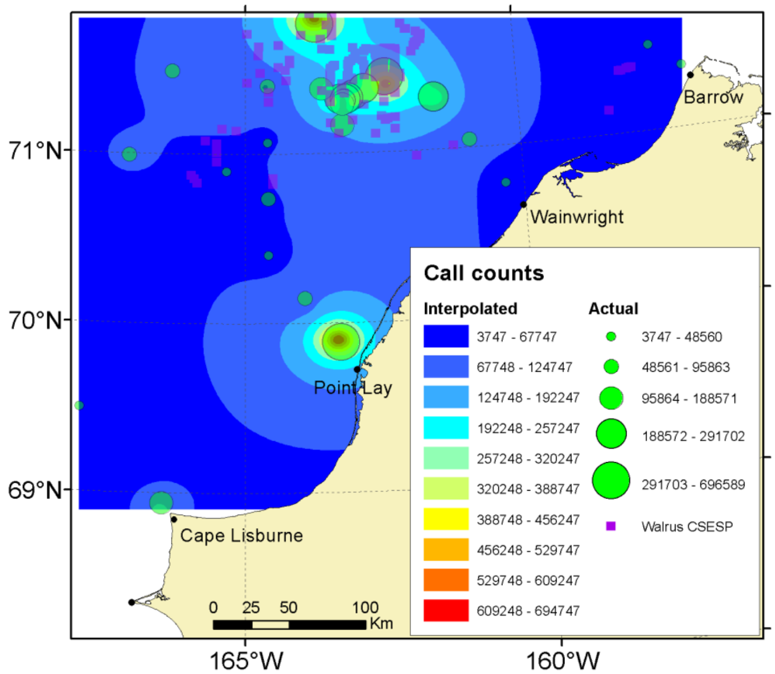

Figure 29. Interpolated (radial basis function) and actual walrus call counts based on the sum of automated call detections in all files with manual detections for 5 Aug to 11 Oct (period when all 28 recorders were deployed) at all summer 2013 stations in the northeastern Chukchi Sea. Walrus sightings recorded during the Chukchi Sea Environmental Science Program are also displayed (Aerts et al. 2014).

Manually-detected walrus calls included various grunts as well as knocks and bell calls, as described by Stirling et al. (1983), Stirling et al. (1987), and Schusterman and Reichmuth (2008). The automated call detector targeted grunts because they are more frequent and have a longer detection range than the other call types (JASCO unpublished data; Figure 30).

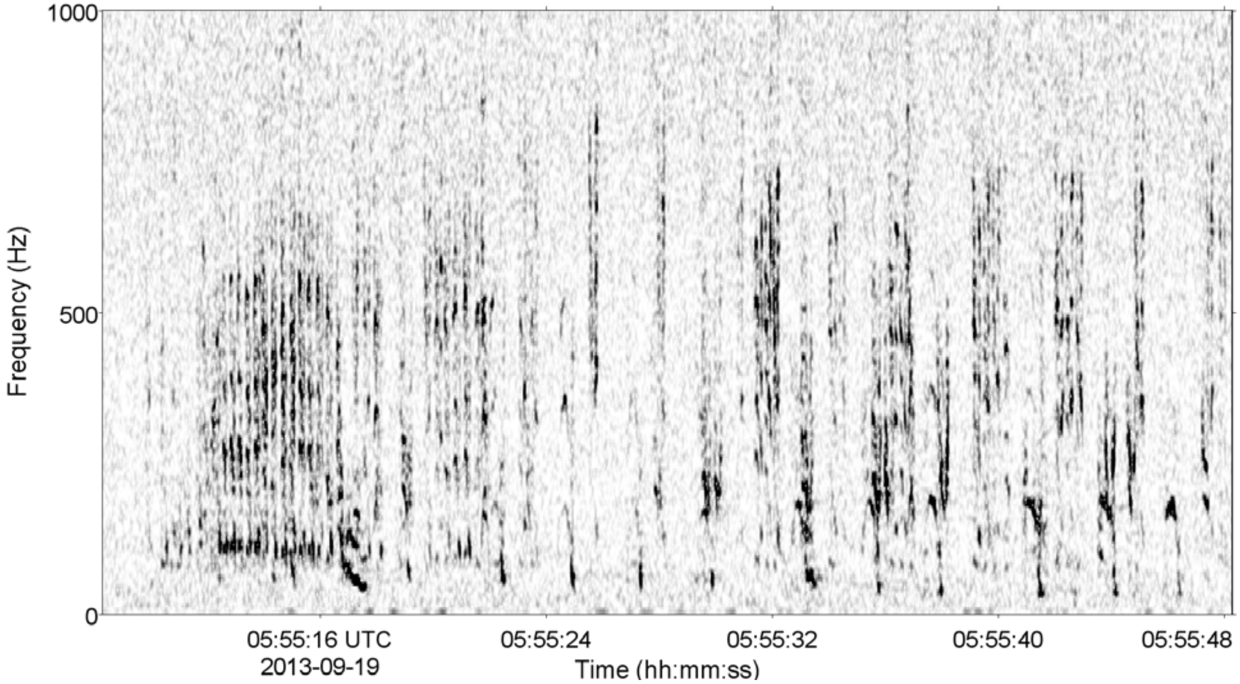

Figure 30. Spectrogram of walrus grunts, knocks, and bell sounds recorded at Station CLN120, 10 Aug 2012 (Frequency resolution: 4 Hz; Frame size: 0.16 s; Advance: 0.04 s; Hamming window).

3.4.4. Beluga Whale Call Detections

3.4.4.1. Winter 2012–2013 Recording Period

Beluga whale call activity during the fall migration was generally infrequent although detections occurred at all stations except WN20. Calls were detected at Station B5 from 1 to 14 days of recording, with a mean of 4 days across all stations. Seventy percent of the detections occurred in November. Isolated beluga calls were detected at PBN20 on 24 Jan 2013, well past the end of the usual fall migration period (Table C–5; Figure C–23 to C–25). Across the study area there were more calls detected south of 72° N (Figure 31) and at stations closer to shore (Figure C–25).

During the spring migration, beluga calls were detected at all stations; the number of detection days ranged from 5 (PBN20) to 34 (PL50) with a mean of 15.8 days. Calls were detected for 25 days at Station B5, which had the highest annual number of detection days in all previous years. W35 had fewer days with detections (n = 21) than W50 (n = 29), the latter being 15 mi further offshore (Table C–5). In contrast results from previous winter sessions have shown that the number of detection days decreases as the distance from shore increases (Delarue et al. 2013b). Fewer bowhead whale detections, might be because their migration corridor was further offshore in 2013 than in previous years.

Detections started early—19 Mar at CL50—and continued until 29 Apr at PLN80. Ninety-two percent of all detections occurred before 1 Jun. A few detections occurred offshore in late July/early August (Figure C–29). During the main migration period, call counts decreased as the distance from shore increased, except for W50 (Figure 31, Figures C–26 and C–27).

The detected beluga calls included a variety of whistles, buzzes, chirps, and other high-frequency calls previously described for that species (Figure 33; Karlsen et al. 2002, Belikov and Bel'kovich 2006, Belikov and Bel'kovich 2008).

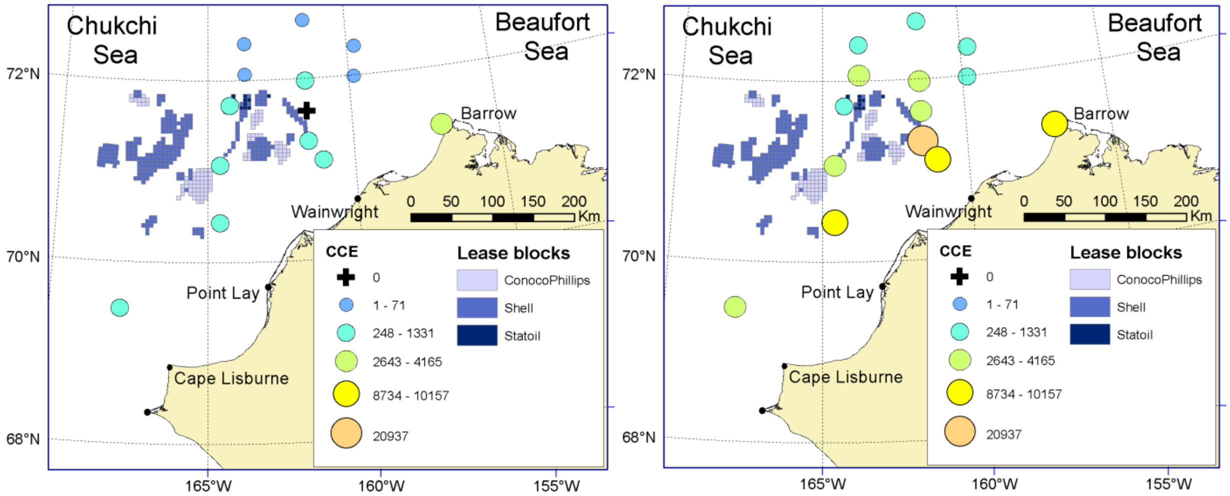

Figure 31. Beluga whale call count estimates* in the Chukchi Sea at all winter 2012–2013 recording stations. (Left) from 14 Oct to 31 Dec 2012; (right) 27 Mar to 28 Apr 2013.

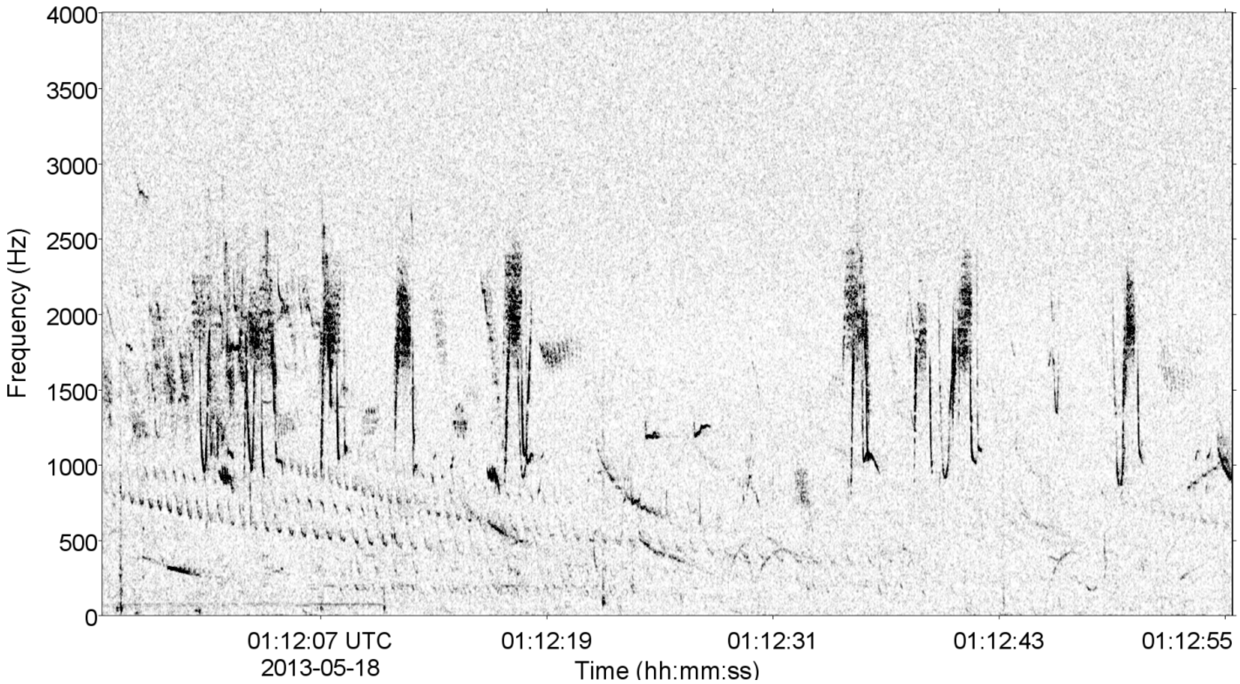

Figure 32. Spectrogram of beluga calls recorded 18 May 2012 at Station W50. (Frequency resolution: 2 Hz; Frame size: 0.128 s; Advance: 0.032 s; Hamming window).

* Corrected sum of automated call detections in all files with manual detections.

3.4.4.2. Summer 2013 Recording Period

Beluga whale calls were detected at all stations except for CL5. The proportion of days with detections ranged from 1.2% at CL50 to 30.1% at B5 with a mean of 7.8%.

Detections were concentrated in two periods:

1. From 1 to 21 Aug most calls were detected off Barrow, but calls were recorded sporadically throughout the whole study area, including CLN90 and CLN120 (Table C–6; Figure 33 and Figure C–30). There were no detections between 25 Aug and 25 Sep, except for one at BGF on 31 Aug.
2. From late September to mid-October, detections were widespread with up to 82% of stations reporting calls. Pronounced spikes of detections occurred from 3-4 Oct in the Burger lease area (Figure 34 and Figure C–31). Generally more detections occurred offshore than inshore (Figure 35).

Detected signals included a mixture of whistles and pulsed calls (Figure 36). Some echolocation clicks were also detected at the Burger recorders that had been set to higher sampling rates (64 kHz instead of 16 kHz).

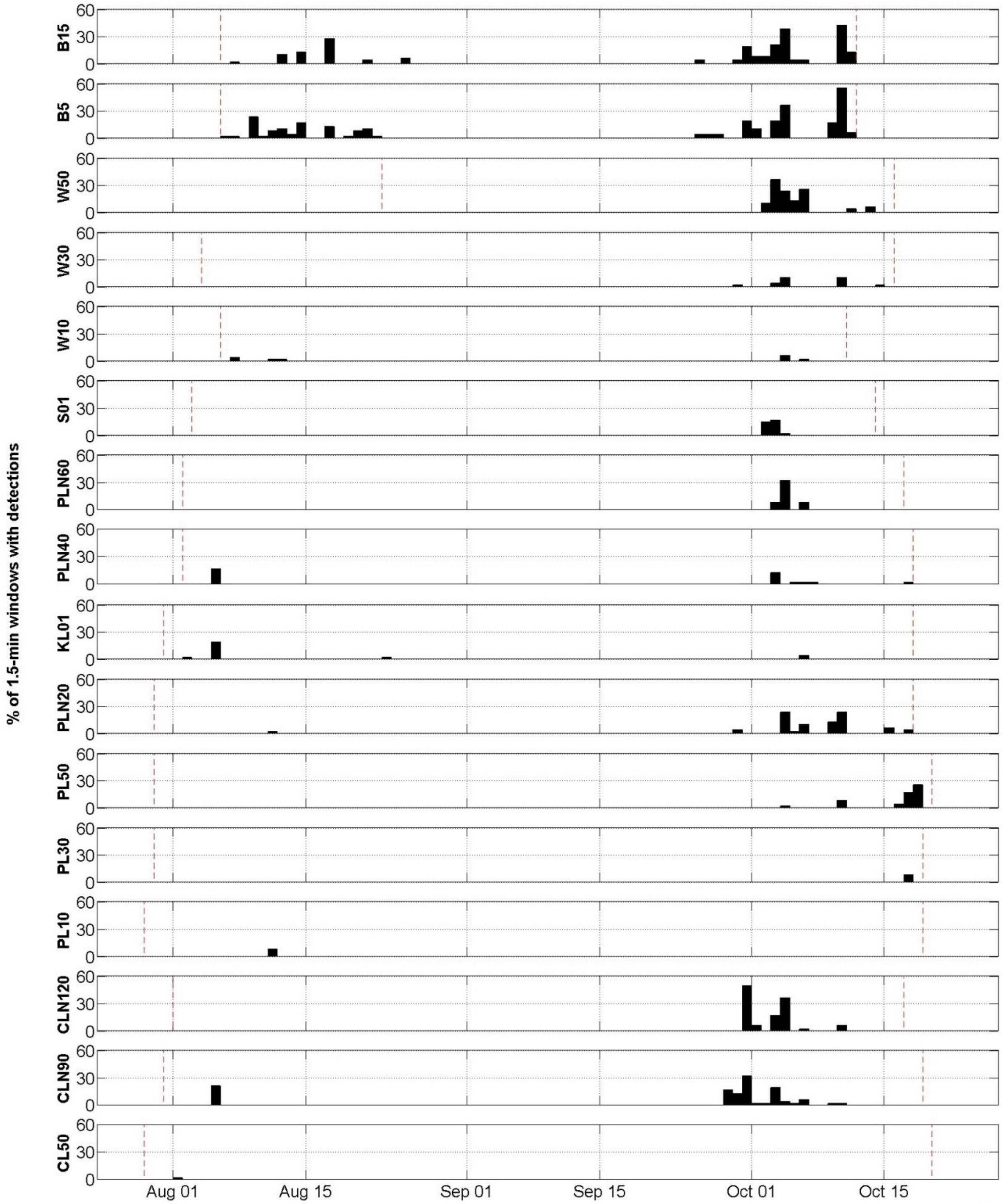

Figure 33. Summer 2013 daily beluga call detections in the northeastern Chukchi Sea: Daily proportion of sound files with detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2013. Forty-eight sound files were recorded each day. Vertical dashed lines indicate recording start and end. Stations are ordered northeast (top) to southwest (bottom). Stations without call detections were omitted.

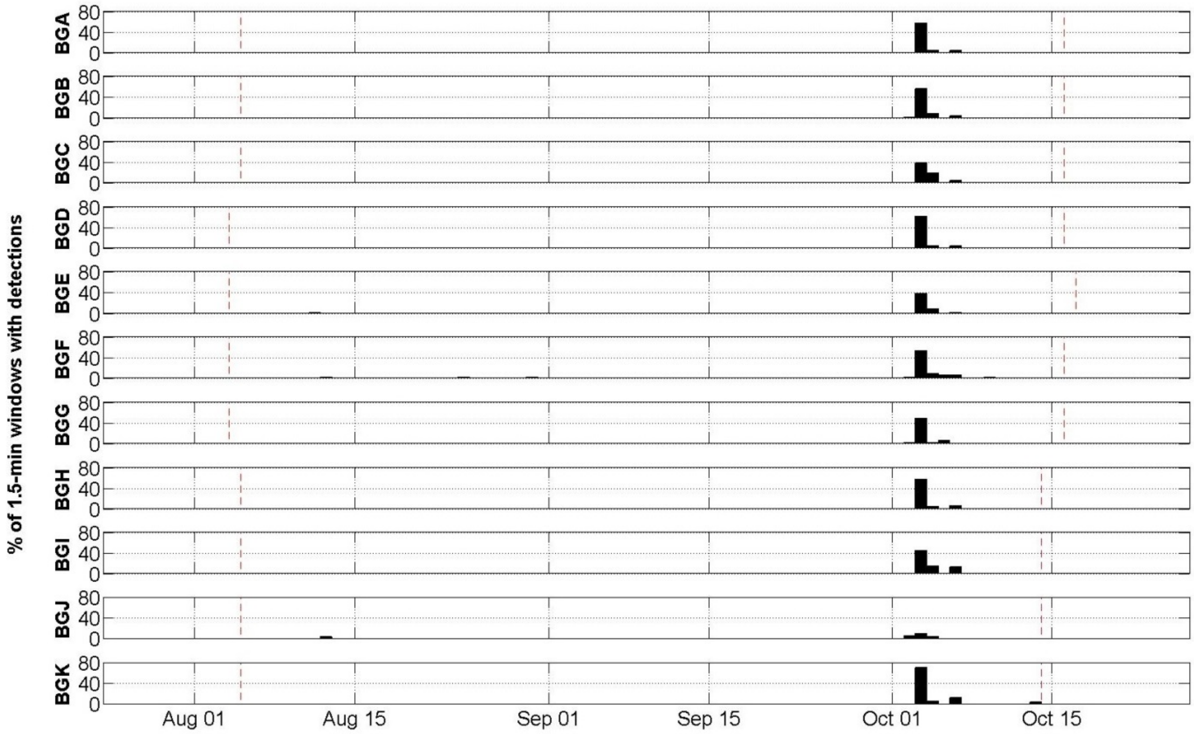

Figure 34. Summer 2013 daily beluga call detections in the Burger lease area: Daily proportion of sound files with detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2013. Forty-eight sound files were recorded each day. Vertical dashed lines indicate recording start and end. Stations are ordered northeast (top) to southwest (bottom). Stations without call detections were omitted.

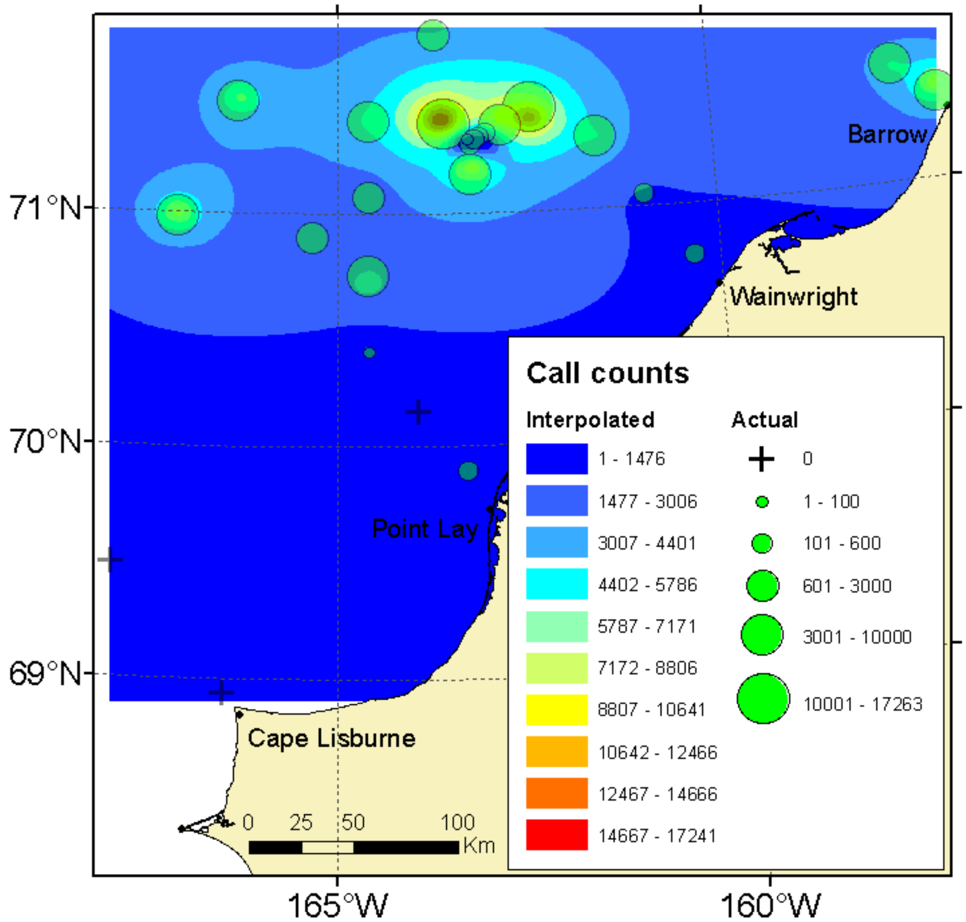

Figure 35. Interpolated (radial basis function) and actual beluga call counts based on the sum of automated call detections in all files with manual detections for 5 Aug to 11 Oct (period when all 28 recorders were deployed) at all summer 2013 stations in the northeastern Chukchi Sea.

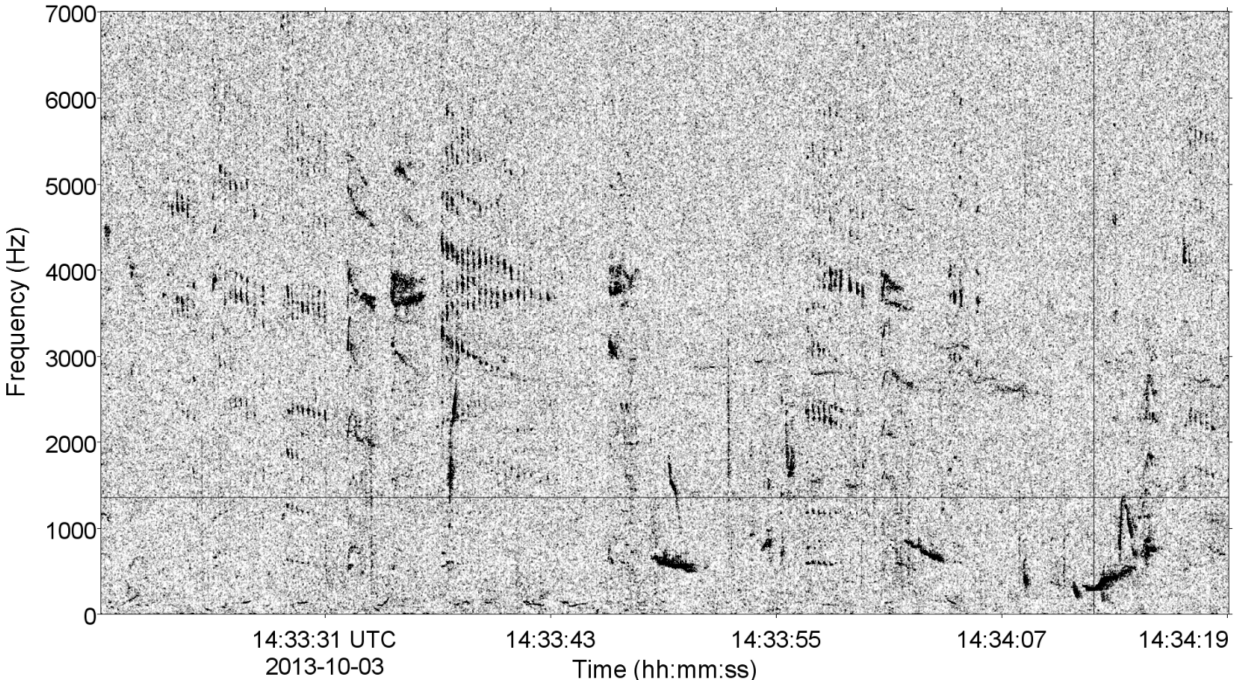

Figure 36. Beluga calls detected at Station BGB on 3 Oct 2013 (Frequency resolution: 2 Hz; Frame size: 0.128 s; Advance: 0.032 s; Hamming window).

3.4.5. Bearded Seal Call Detections

3.4.5.1. Winter 2012–2013 Recording Period

During winter 2012–2013, all stations detected bearded seal calls. There was an average of 197 detection days across stations ranging from 171 at WN80 to 234 at PLN80 (Table C–7). Detections were infrequent before November, except at PLN100, PLN80, and PBN40 where in October detections became fairly regular (Figure C–32). Call activity increased gradually from November onward, however, gaps of a few days without detections were not atypical, especially around mid-January at PLN100 and PLN120 (Figure 37; Figures C–33 to C–35). Continuous acoustic activity—defined as calls detected in every file—started in early March at the three Wainwright stations closest to shore (W35, W50, and WN20), around mid-March at the offshore Point Lay stations, and in April at other stations. All stations reported continuous detections until late June/early July 2013 except at CL50 and PL50 where detections stopped on 18 and 20 June, respectively (Figure 37 and Figures C–36 to C–41). Acoustic activity at all stations ceased quickly over 2-3 days.

Seasonal variations in call counts are consistent with the trends in detection days described above. Call counts increased moderately from October to February and significantly in March. Although calls were essentially detected in every file from April to June, call counts per file continued to increase in April, peaked in May, and then began to decrease in June, although only marginally at W35 and W50 where counts were the highest across all stations in June (Figures C–32 to C–41).

Looking at the entire winter 2012–2013 recording period, locations with sustained bearded seal acoustic detections included Stations W35, W50, and PLN100 (Figure 38). Station WN80 reported about a third of the detections as each of W35, W50, and PLN100. Stations along a corridor between Wainwright and Station PLN100 experienced higher call counts than stations elsewhere (Figure 38).

The detected calls consisted primarily of upsweeping and downsweeping trills (Figure 39; Van Parijs et al. 2001).

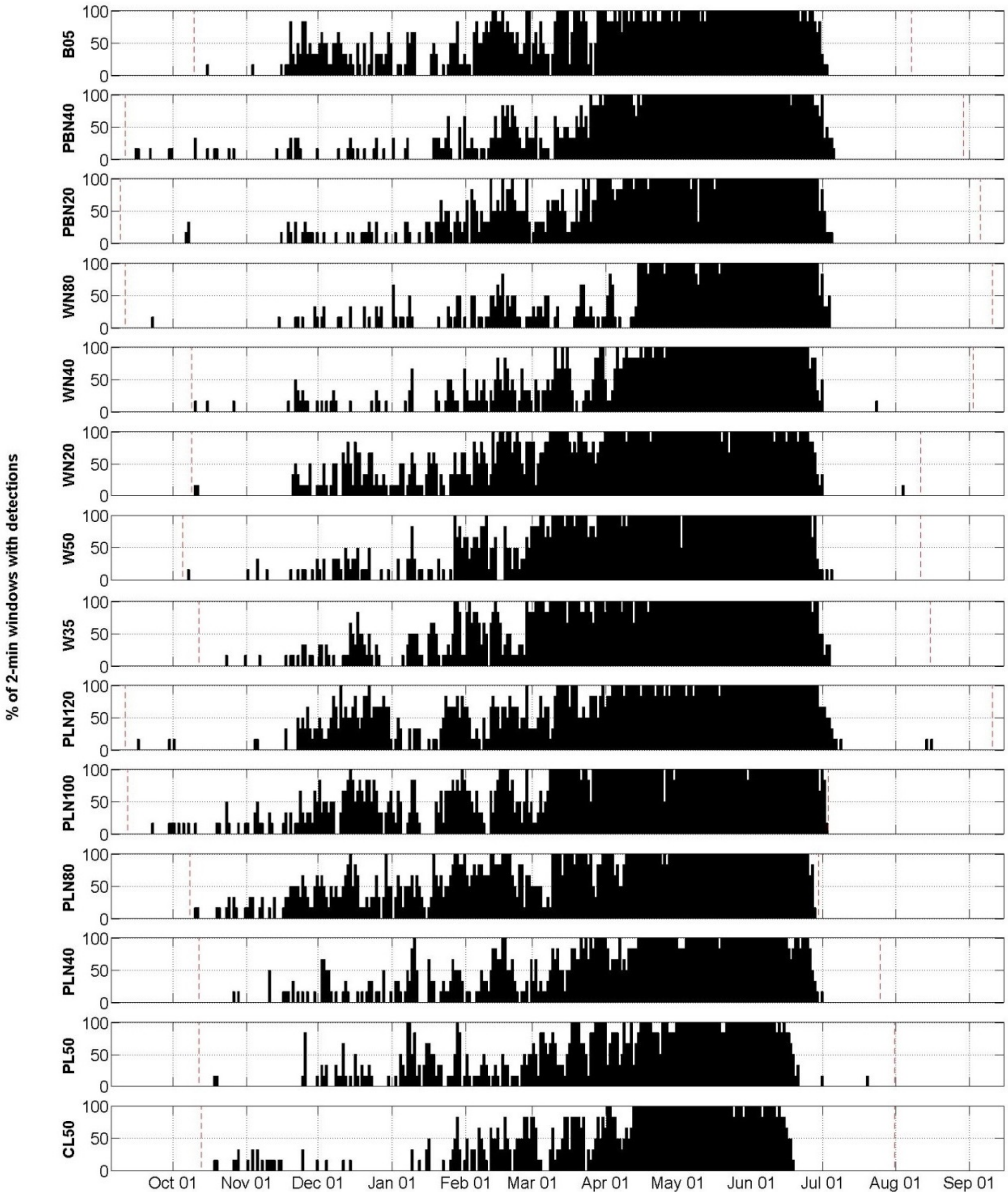

Figure 37. Winter 2012–2013 daily bearded seal call detections: Daily proportion of sound files with call detections based on the manual analysis of 5% of the acoustic data recorded early September 2012 through late August 2013 in the northeastern Chukchi Sea for each station. Six sound files lasting 30 or 40 min were recorded each day every four hours. Stations are ordered from northeast (top) to southwest (bottom). The vertical dashed lines indicate the recording start and end dates.

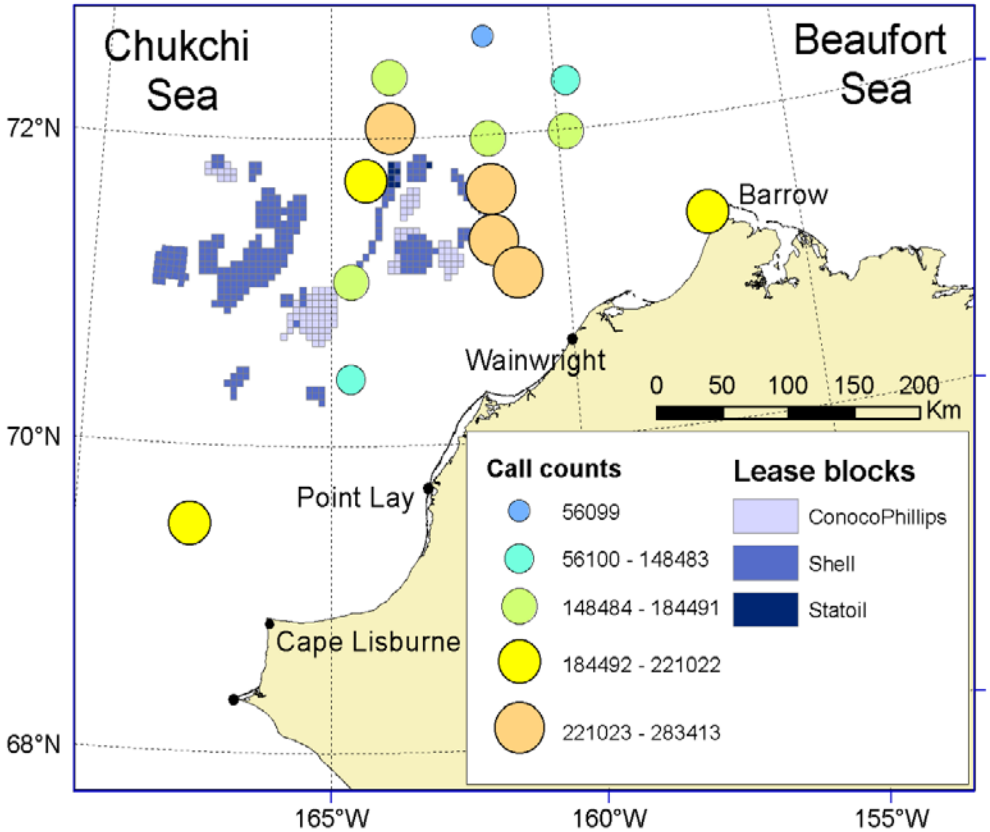

Figure 38. Bearded seal call count estimates* in the Chukchi Sea from 10 Sep 2012 through 9 Sep 2013 at all winter 2012–2013 recording stations.

* Corrected sum of automated call detections in all files with manual detections.

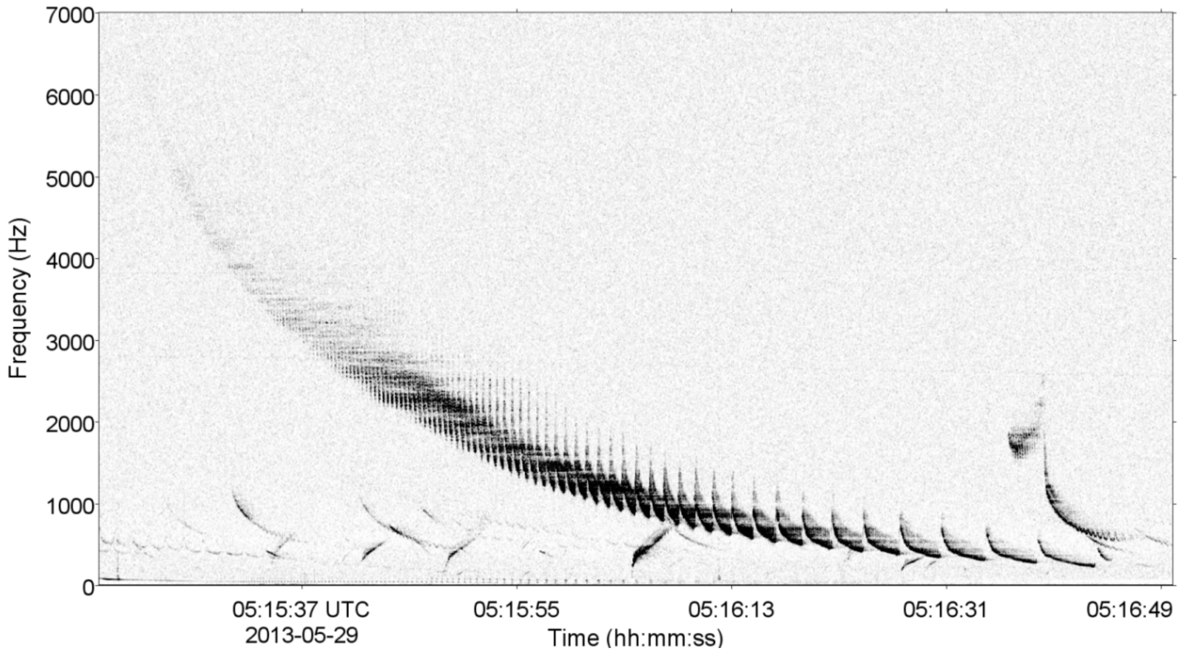

Figure 39. Spectrogram of bearded seal calls recorded 29 May 2013 at Station WN20 (Frequency resolution: 2 Hz; Frame size: 0.128 s; Advance: 0.032 s; Hamming window).

3.4.5.2. Summer 2013 Recording Period

Bearded seals were detected at all stations. Detection days represented between 1% at CL5 to 50% at W10 of the number of recording days. Detections were infrequent from the start of the session until the beginning of September. The highest number of calls during that period was recorded at PL50 (Figures C–42 to C–44). Detections began increasing in September at B5, W10, and some stations on the Point Lay line (PL50 and further north; Figure C–45). Detections across most stations peaked between 29 Sep and 6 Oct (Figure C–46), but steadily declined thereafter. Call counts in September and October were highest within an arc ranging from Wainwright to PLN60, passing through the Burger lease area (Figure 40). The sightings recorded by the Chukchi Sea Environmental Science Program (CSESP; Aerts et al. 2014) were largely within that arc, with the exception of sightings recorded along the coast between Wainwright and Barrow. While the overlap in visual and acoustic detections is at least partly due to the distribution of survey effort, it illustrates how the two survey methods can complement one another.

The recorded short sequences of irregularly occurring bearded seal calls had more temporal variability and were easily distinguishable from the long, complex spiraling songs common during the spring breeding season (Ray et al. 1969).

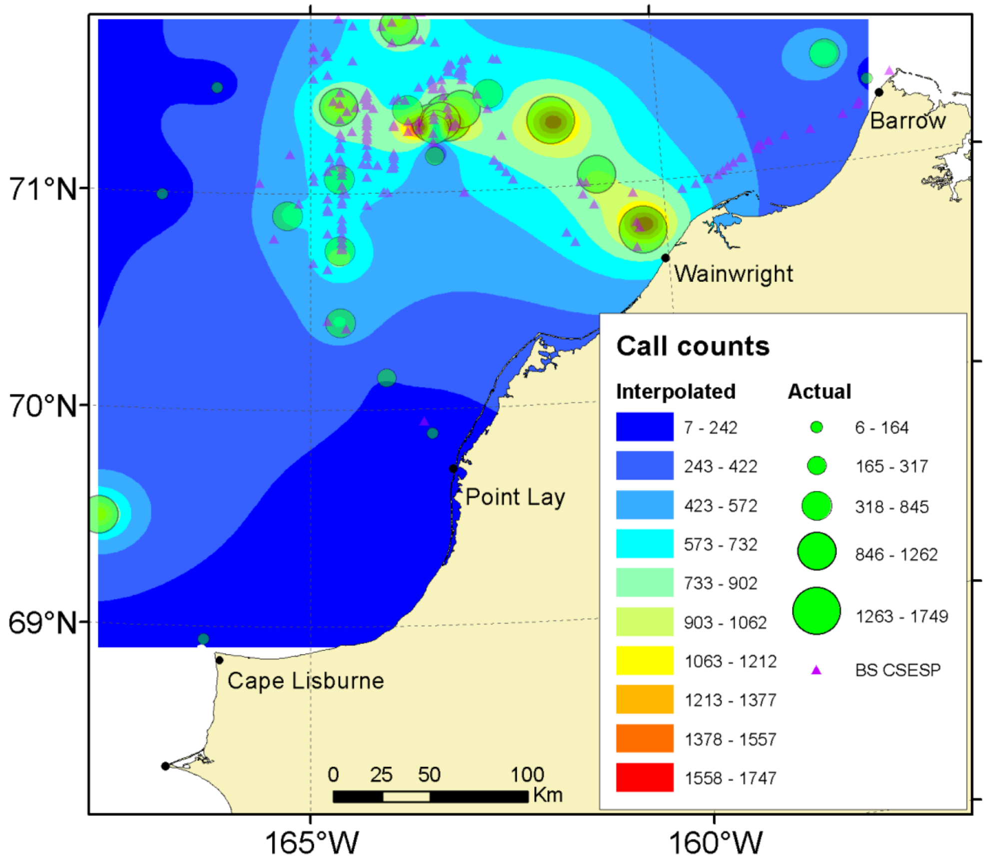

Figure 40. Interpolated (radial basis function) and actual bearded seal call counts based on the sum of automated call detections in all files with manual detections for 5 Aug to 11 Oct (period when all 28 recorders were deployed) at all summer 2013 stations in the northeastern Chukchi Sea.

3.4.6. Fin Whale Call Detections

3.4.6.1. Winter 2012–2013 Recording Period

No fin whale calls were detected in the winter 2012–2013 dataset.

3.4.6.2. Summer 2013 Recording Period

Fin whale calls were detected at CL50 and CLN90 between 4 Aug and 11 Oct 2013. Most detections occurred before 15 Sep 2013 at CL50 (Figure 41 and Table C–9). Most calls were broadband signals sweeping from 20 to 50 Hz (Figure 42).

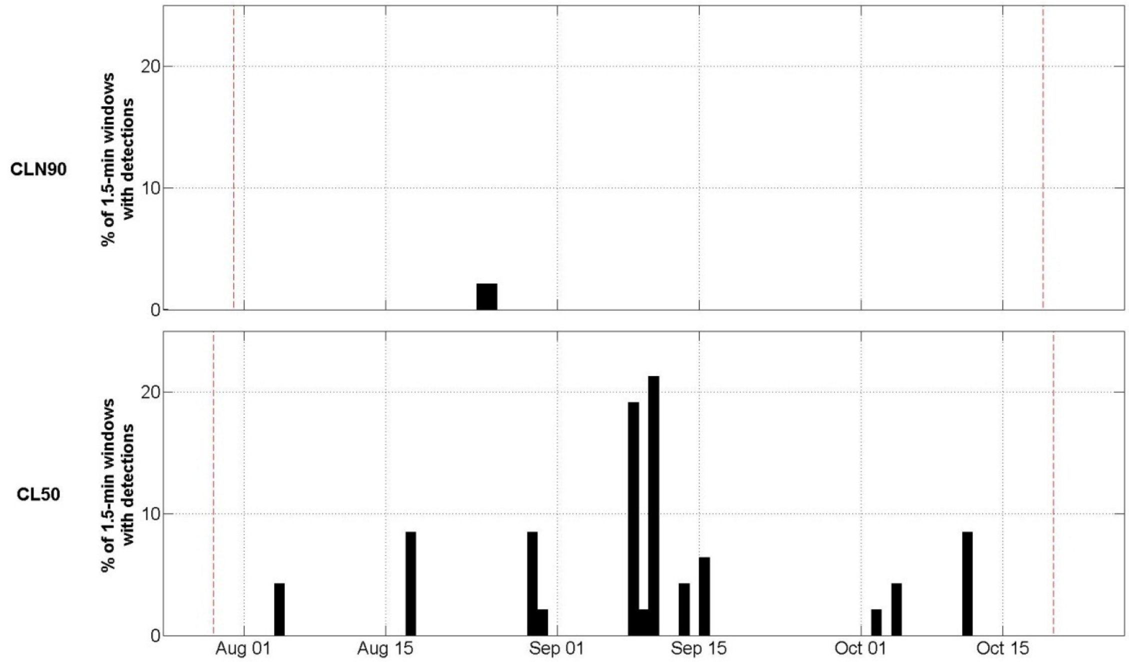

Figure 41. Summer 2013 fin whale call detections: Daily proportion of 30 min sound files with call detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2013. Forty-eight sound files were recorded daily. Vertical dashed lines indicate recording start and end. (Top) Station CLN90 is northeast. (Bottom) Station CL50 is southwest. Stations without call detections were omitted.

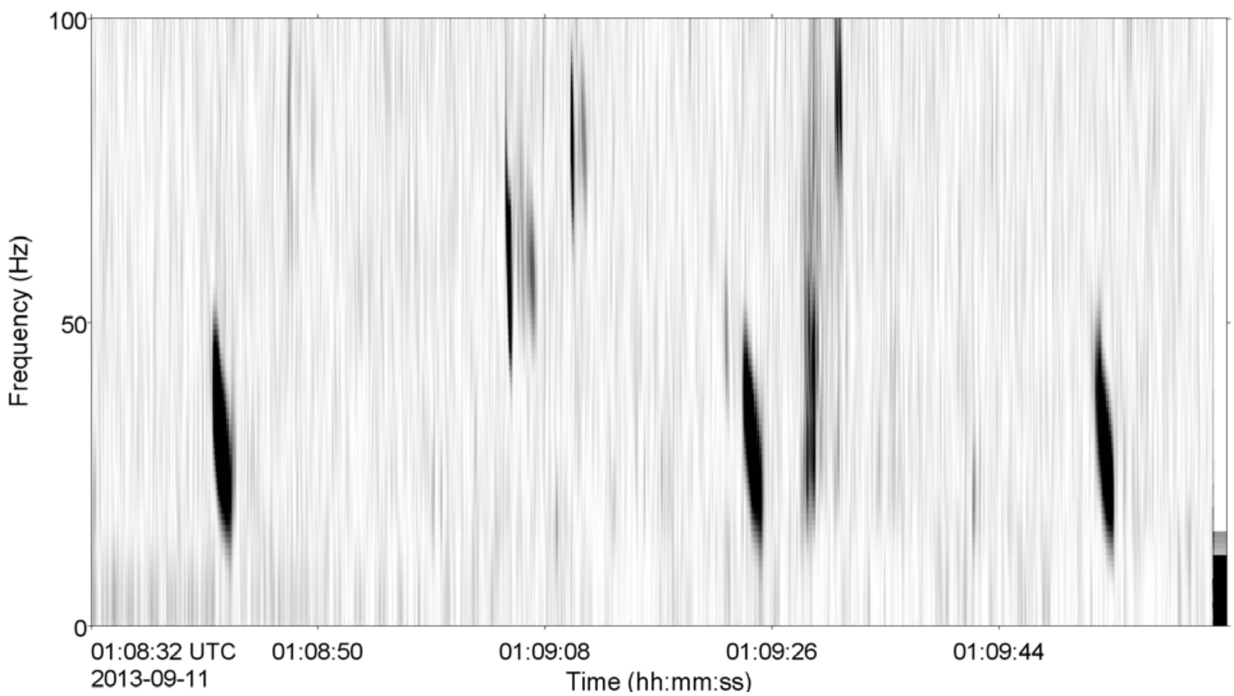

Figure 42. Spectrogram of fin whale calls recorded at Station CL50 on 11 Sep 2013 (Frequency resolution: 1 Hz; Frame size: 0.1 s; Advance: 0.01 s; Hamming window).

3.4.7. Gray Whale Call Detections

3.4.7.1. Winter 2012–2013 Recording Period

Gray whale calls were detected once on 29 Jun 2013 at W35.

3.4.7.2. Summer 2013 Recording Period

Gray whale calls were detected at 12 of the 28 stations. The proportion of days with detections was lowest (1.3%) at the offshore stations (e.g., CLN120 and S01) and KL01, and highest off Wainwright, particularly at W10 (29.2%) (Table C–10; Figure 43). Acoustic activity was recorded throughout the study period. Off Wainwright, detections shifted from being more concentrated inshore before 15 Sep 2013 to more concentrated offshore toward W30-W50 thereafter.

Gray whale calls were rare. Most of the detections were low-frequency moans (Figure 44), with additional contributions from pulses and bonging signals (Crane and Lashkari 1996).

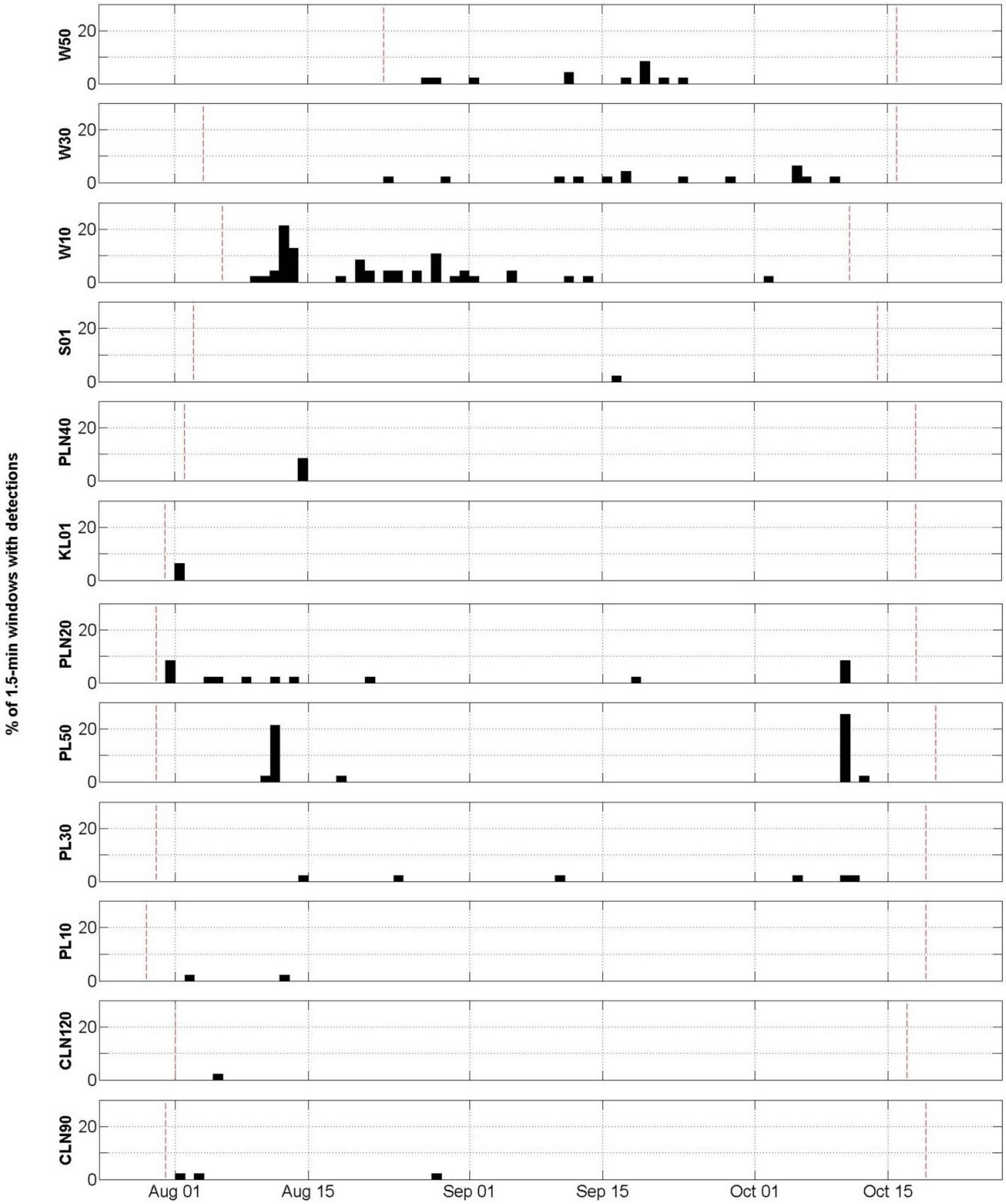

Figure 43. Summer 2013 daily gray whale call detections: Daily proportion of sound file with detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2013 in the northeastern Chukchi Sea. Forty-eight sound files were recorded daily. Stations without detections were omitted. Vertical dashed lines indicate recording start and end.

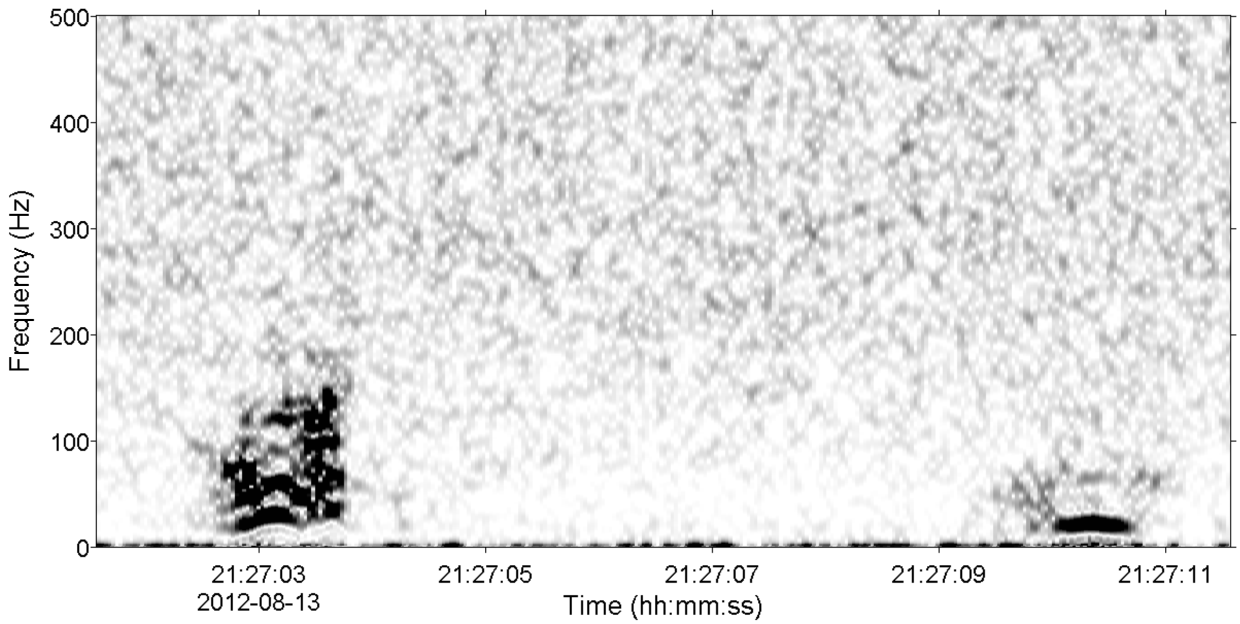

Figure 44. Gray whale moans recorded on 13 Aug 2012 at Station CLN90 (Frequency resolution: 1 Hz; Frame size: 0.128 s; Advance: 0.032 s; Reisz window).

3.4.8. Humpback Whale Call Detections

3.4.8.1. Winter 2012–2013 Recording Period

No humpback whale calls were detected in the winter 2012–2013 data.

3.4.8.2. Summer 2013 Recording Period

Humpback whale calls were detected at six stations located off Cape Lisburne and Point Lay, between 30 and 135 mi from shore. The detections were concentrated over two short periods: 31 Jul through 2 Aug and 8–11 Sep 2013. The number of detections at each station was low (Table C–11; Figures 45 and 46).

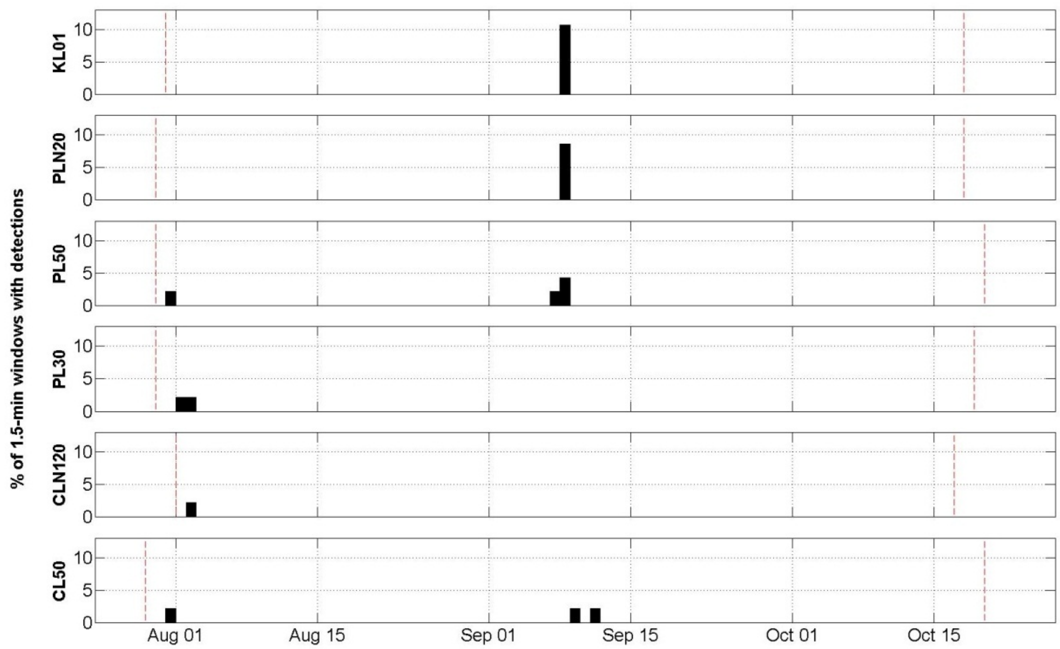

Figure 45. Summer 2013 humpback whale call detections: Daily proportion of 30 min sound files with call detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2013. Forty-eight sound files were recorded daily. Vertical dashed lines indicate recording start and end. Stations are ordered from northeast (top) to southwest (bottom). Stations without call detections were omitted.

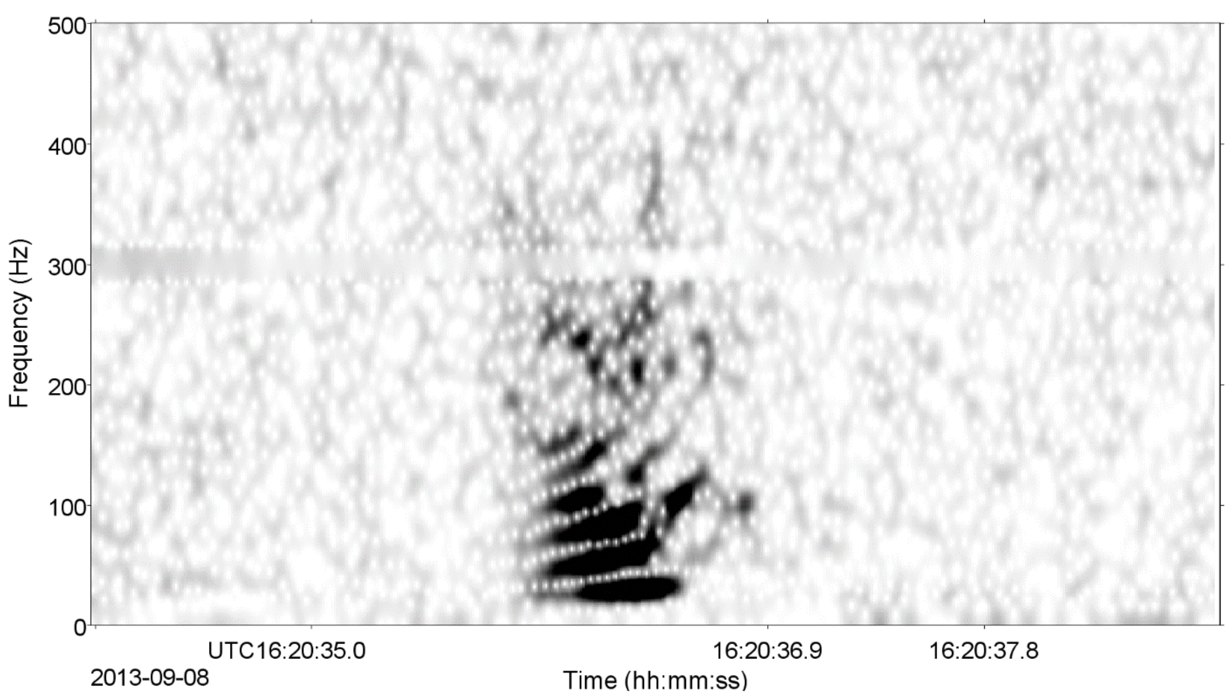

Figure 46. Spectrogram of humpback whale call recorded at Station KL01 on 8 Sep 2013 (Frequency resolution: 1 Hz; Frame size: 0.1 s; Advance: 0.01 s; Hamming window).

3.4.9. Killer Whale Call Detections

3.4.9.1. Winter 2012–2013 Recording Period

No killer whale calls were detected in the winter 2012–2013 data.

3.4.9.2. Summer 2013 Recording Period

Killer whale calls were detected at nine stations between 17 Aug and 3 Oct 2013 (Figure 47; Table C–12). There were one to four detection days at each station (CL50 and CLN90). Most detections occurred offshore of Cape Lisburne and Point Lay, but killer whales were also detected on two occasions within 30 mi of shore. The detected calls consisted mostly of pulsed calls and whistles (Ford 1989).

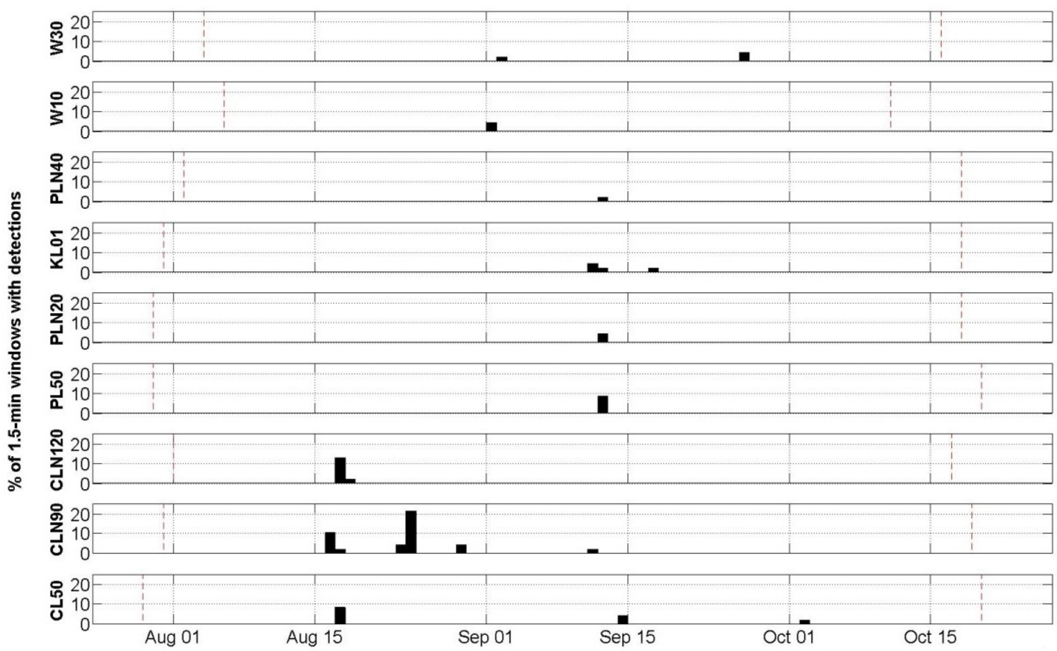

Figure 47. Summer 2013 killer whale call detections: Daily proportion of 30 min sound files with call detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2013. Forty-eight were recorded daily. Vertical dashed lines indicate recording start and end. Stations are ordered from northeast (top) to southwest (bottom). Stations without call detections were omitted.

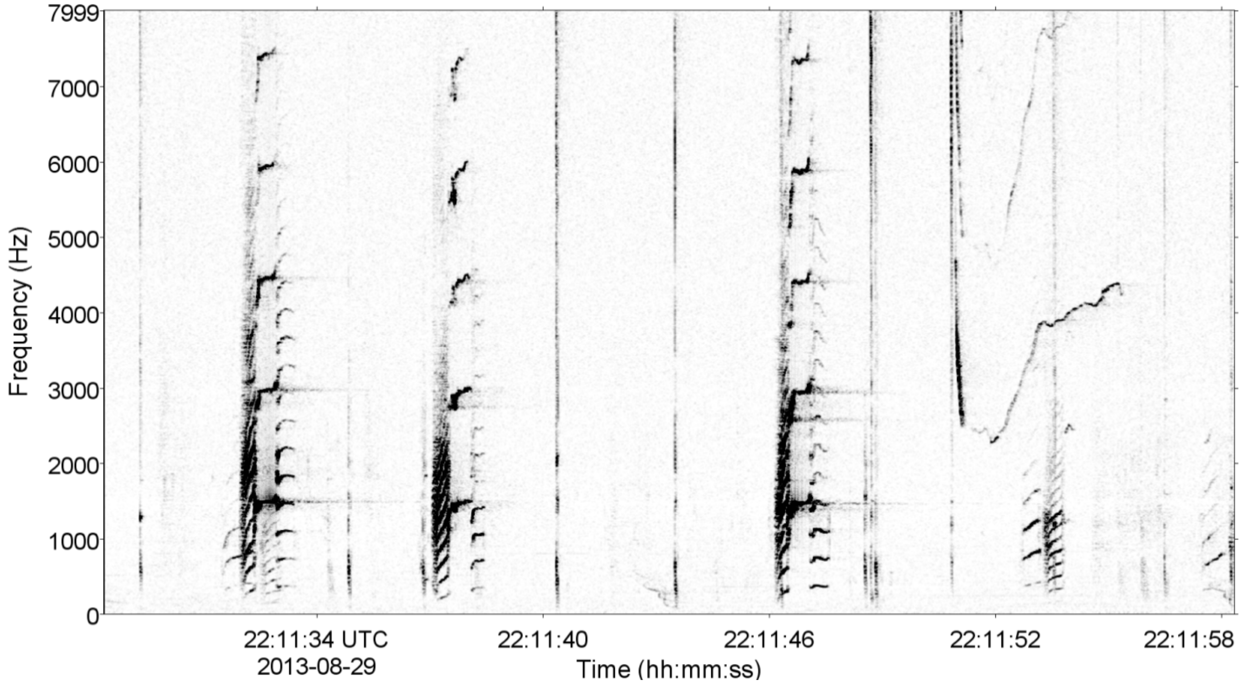

Figure 48. Killer whale call spectrogram from detection at Station CLN90, 29 Aug 2013 (Frequency resolution: 4 Hz; Frame size: 0.1 s; Advance: 0.01 s; Hamming window).

3.4.10. Minke Whale Call Detections

3.4.10.1. Winter 2012–2013 Recording Period

Minke whale boing calls were detected on five different days between 23 Oct and 1 Nov 2012, and on 4 Jul 2013 at CL50.

3.4.10.2. Summer 2013 Recording Period

Between 28 Sep and 18 Oct 2013, minke whale boing calls (Rankin and Barlow 2005) were detected at five stations although there was an isolated detection on 8 Sep at CL50. Most detections occurred 10–55 mi northwest from Point Lay. There were only 1–5 detection days at each station (Table C–13; Figure 50).

Results from the automated minke whale boing detector were also used to examine if any minke whale encounters were missed during the manual analysis. We found that all calls identified by the boing call detector were also detected during the manual analysis. Both methods provided similar results.

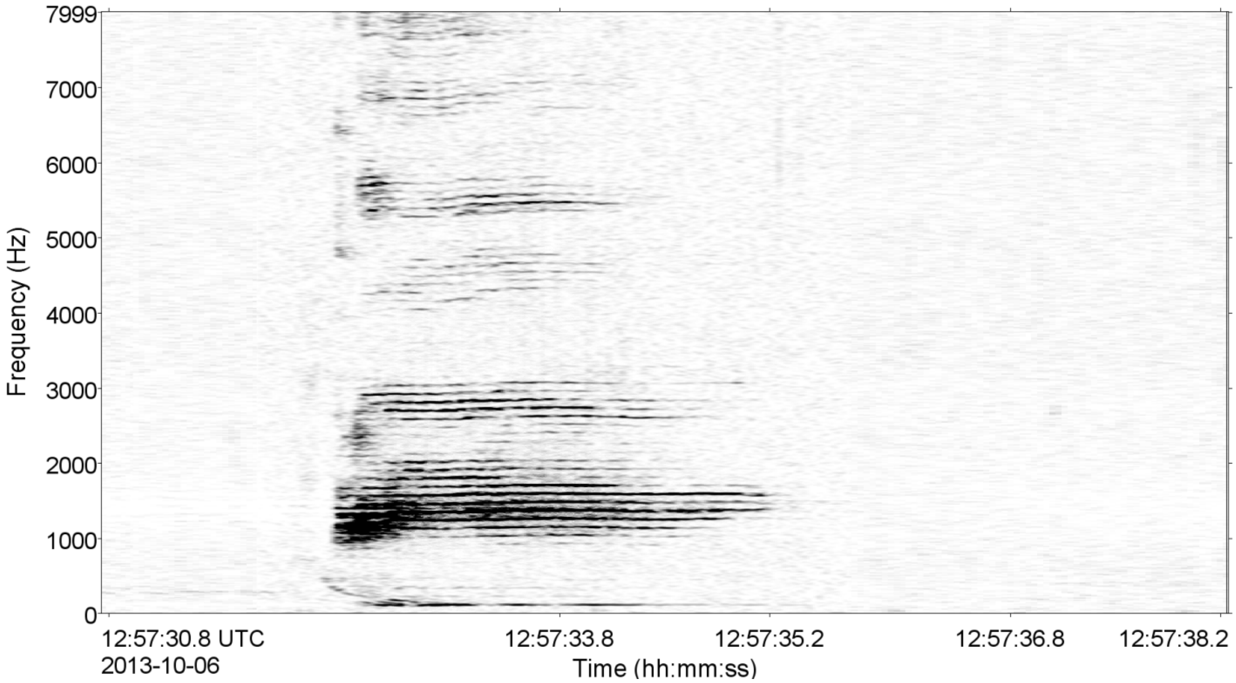

Figure 49. Minke whale boing calls recorded 6 Oct 2013 at Station PL30 (Frequency resolution: 1 Hz; Frame size: 0.1 s; Advance: 0.01 s; Hamming window).

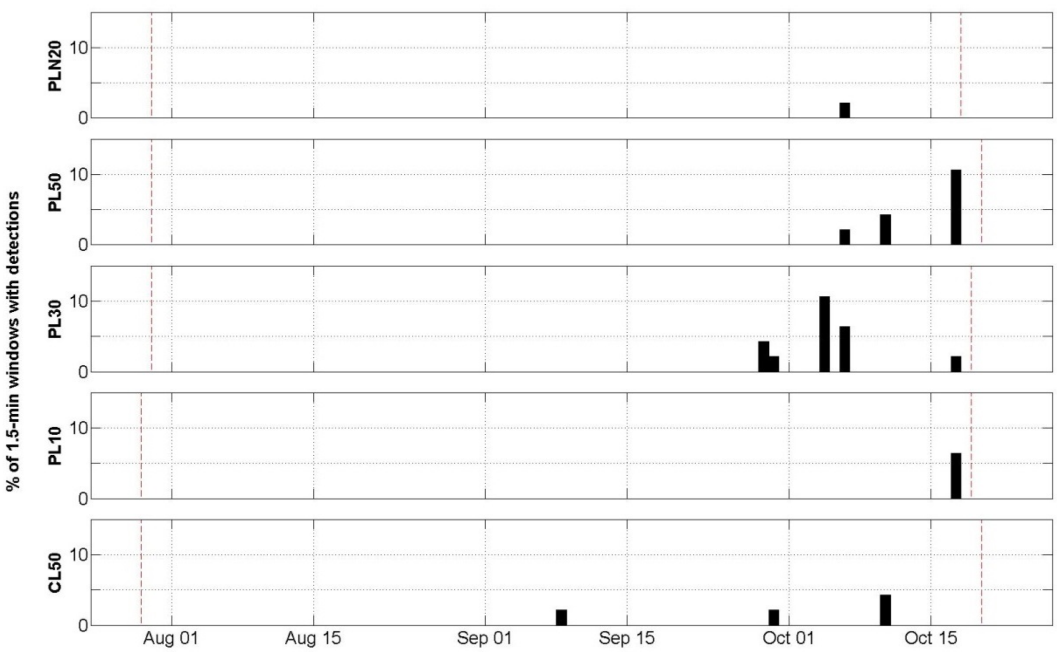

Figure 50. Summer 2013 minke whale call detections: Daily proportion of 30 min sound files with call detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2013. Forty-eight sound files were recorded daily. Vertical dashed lines indicate recording start and end. Stations are ordered from northeast (top) to southwest (bottom). Stations without call detections were omitted.

3.4.11. Ribbon Seal Call Detections

3.4.11.1. Winter 2012–2013 Program

Ribbon seal calls were detected at five stations between 18 Oct and 19 Nov 2012. Four stations had only 1–2 detection days, but at CL50 calls were recorded on ten different days (Table 9). Two types of ribbon seal calls were detected: loud downsweeping signals, with or without harmonics, corresponding to the short and medium sweeps, and loud puffing sounds as described by Watkins and Ray (1977; Figure 51).

Table 9. Winter 2012–2013 ribbon seal call detection periods: Dates of first and last call detections and number of days on which a call was detected for each recording station in the northeastern Chukchi Sea. Stations without call detections were omitted.

Station	Record start	First detection	Last detection	Record end	Detection days
W50	6 Oct	16 Nov	16 Nov	10 Aug	1
PLN120	12 Sep	19 Oct	19 Oct	9 Sep	1
PLN100	13 Sep	5 Nov	13 Nov	2 Jul	2
PLN80	9 Oct	24 Oct	24 Oct	28 Jun	1
CL50	14 Oct	18 Oct	19 Nov	30 Jul	10

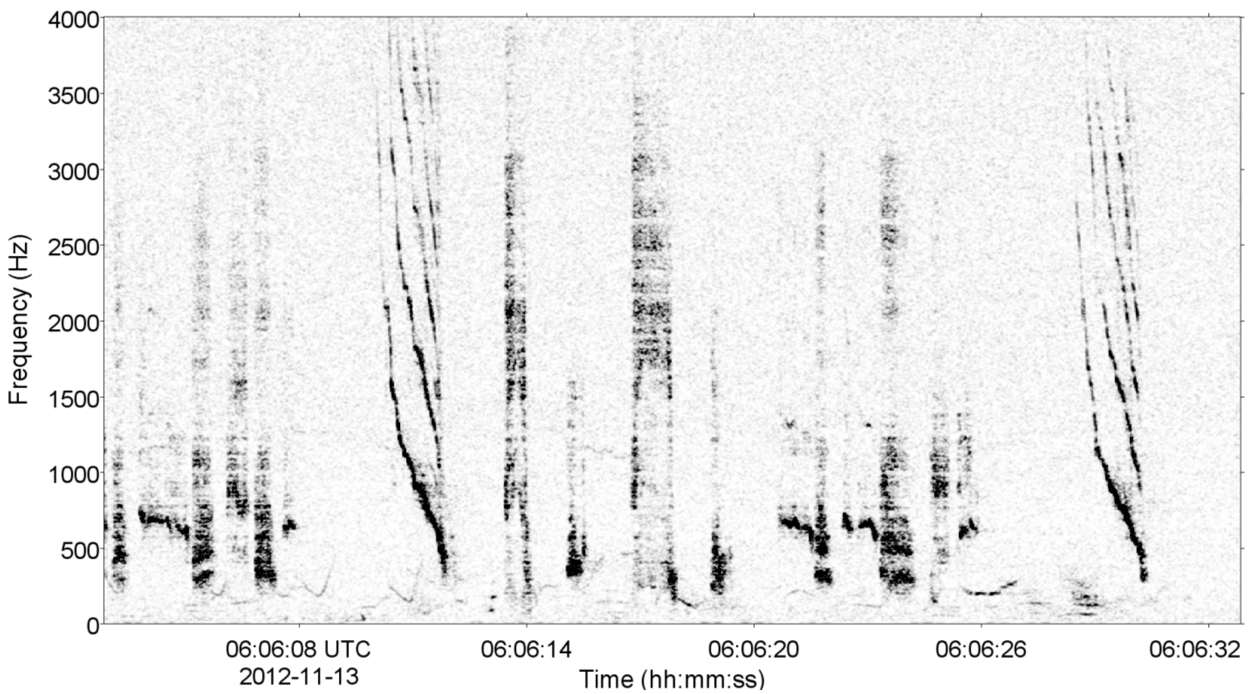

Figure 51. Spectrogram of ribbon seal calls recorded 13 Nov 2012 at Station PLN100 (Frequency resolution: 2 Hz; Frame size: 0.128 s; Advance: 0.032 s; Hamming window).

3.4.11.2. Summer 2013 Recording Period

Ribbon seal calls (Figure 51) were detected between 3 and 5 Oct 2013 at three Burger stations as well as at PLN60 and S01 (Table 10).

Table 10. Summer 2013 ribbon seal call detection periods: Dates of first and last call detections and the number and proportion of days on which a call was detected for each recording station in the northeastern Chukchi Sea. Stations without call detections were omitted.

Station	Record start	First detection	Last detection	Record end	Detection days	% Days with detection
BGA	5 Aug	3 Oct	4 Oct	15 Oct	2	2.8
BGB	5 Aug	3 Oct	4 Oct	15 Oct	2	2.8
BGC	5 Aug	3 Oct	4 Oct	15 Oct	2	2.8
PLN60	2 Aug	3 Oct	3 Oct	16 Oct	1	1.3
S01	3 Aug	5 Oct	5 Oct	13 Oct	1	1.4

3.4.12. Ringed Seal Call Detections

3.4.12.1. Winter 2012–2013 Recording Period

Ringed seal calls were detected at all stations during the winter 2012–2013 session (Figure 52; Table C–14). The number of days with detections ranged from 2 (PLN100) to 21 (WN40) with a mean of 9.4 days. Although there were no obvious trends in the spatial distribution of call detections, they occurred almost exclusively from December to May.

The manual detection analysts mainly identified barks and yelps as described by Stirling (1973; Figure 53). Ringed seals likely produce other call types, but the published descriptions of most of those are inadequate to identify them with high confidence. Nevertheless, recent work on several captive ringed seals in Japan (Mizuguchi et al. 2013) described series of thumps, apparently linked to their mating behavior. Our data had similar sounds (Figure 54), which we have tentatively assigned to ringed seals based on their similarities with sound clips of the thump sequences provided to us by the authors of that study. Figure 55 shows compares the occurrence of known ringed seal calls and thumps at four stations. The thumps were most common in April and May, which corresponds to ringed seal breeding season; the thumps occurred in conjunction with barks and yelps, although barks and yelps were detected far less frequently during that period. This evidence supports our hypothesis that ringed seals might have produced these thumps. Differences between calls in our data and those produced by the young captive animals in the Japanese study (mainly numbers of thumps series), which were captured in the Sea of Okhotsk, might be due to geographic differences. Differences in thump structure (sequence) could also have been due to the animals having been removed from their natural habitat when they were immature, meaning they were young enough as to be physically unable to perform and had not yet been exposed to the calls of breeding adults.

In previous years, we showed that the detection probability for ringed seal barks and yelps during the 5% data manual analysis was low (22%; see Appendix A in Delarue et al. 2013b) , which means that the results presented here under-represent the occurrence of ringed seal calls. If we included the thumps together with other poorly described calls and the majority of identified calls targeted by analysts, the detection probability for that species would increase greatly.

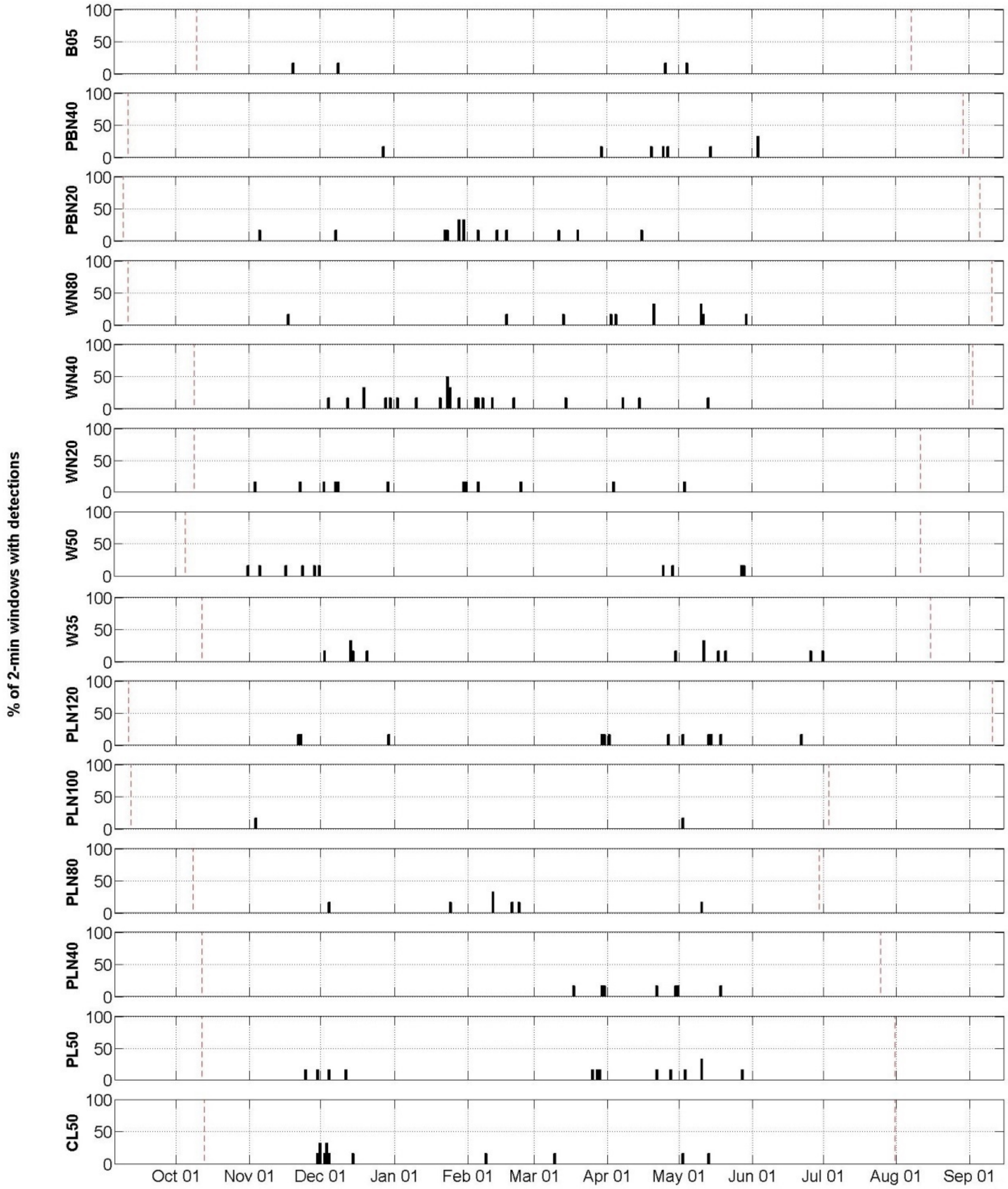

Figure 52. Winter 2012–2013 daily ringed seal call detections: Daily proportion of sound files with call detections based on the manual analysis of 5% of the acoustic data recorded early September 2012 through late Aug 2013 in the northeastern Chukchi Sea for each station. Six sound files lasting 30 or 40 min were recorded each day every four hours. Stations are ordered from northeast (top) to southwest (bottom). The vertical dashed lines indicate the recording start and end dates.

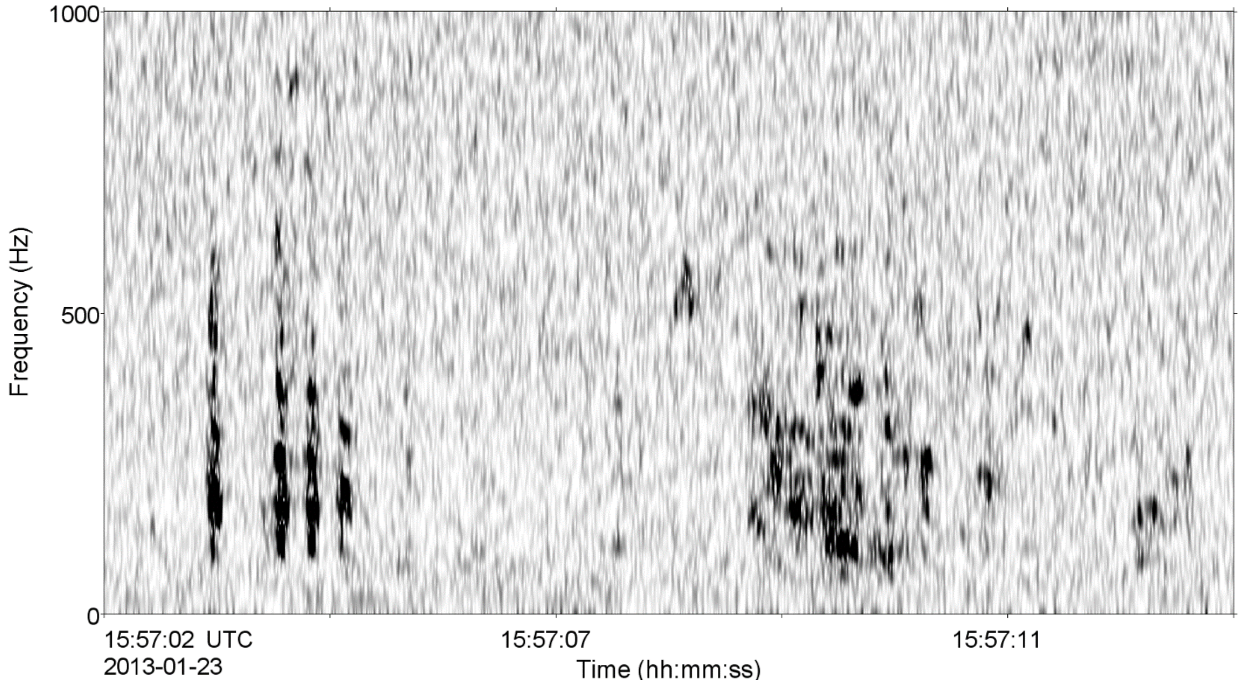

Figure 53. Spectrogram of ringed seal calls recorded 23 Jan 2013 at Station CL50 (Frequency resolution: 1 Hz; Frame size: 0.1 s; Advance: 0.01 s; Hamming window).

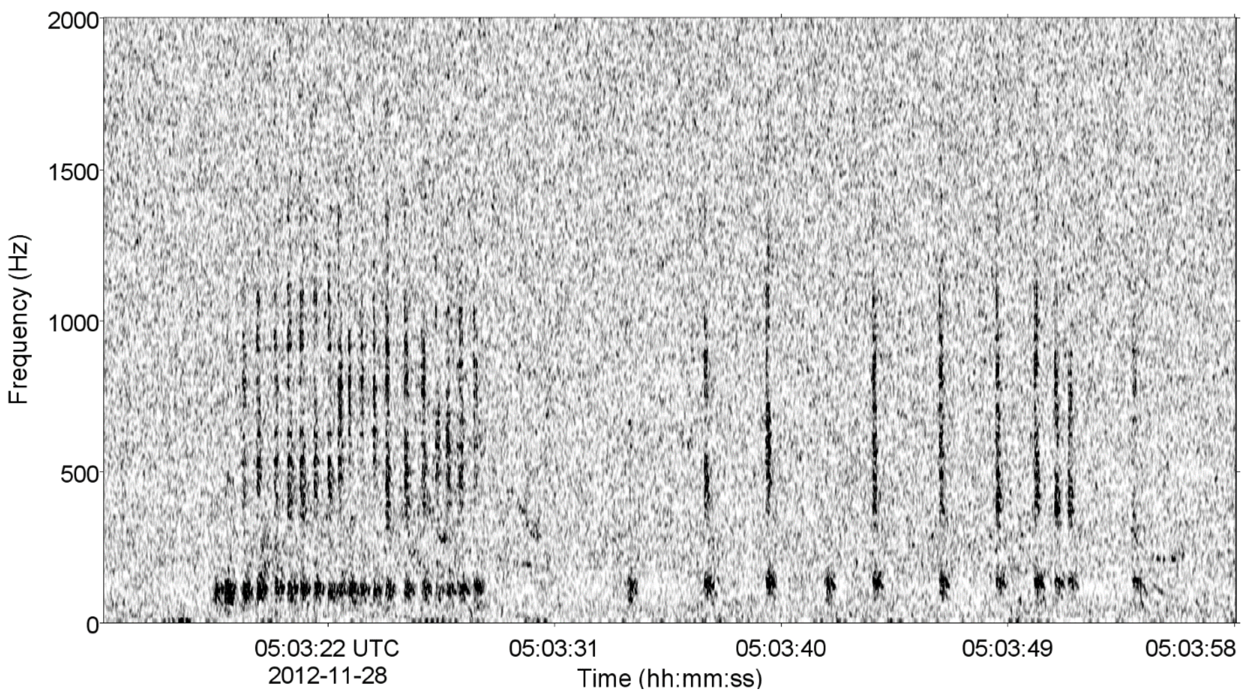

Figure 54. Spectrogram of thumps presumably produced by ringed seals recorded 28 Nov 2012 at Station CL50 (Frequency resolution: 4 Hz; Frame size: 0.1 s; Advance: 0.01 s; Hamming window).

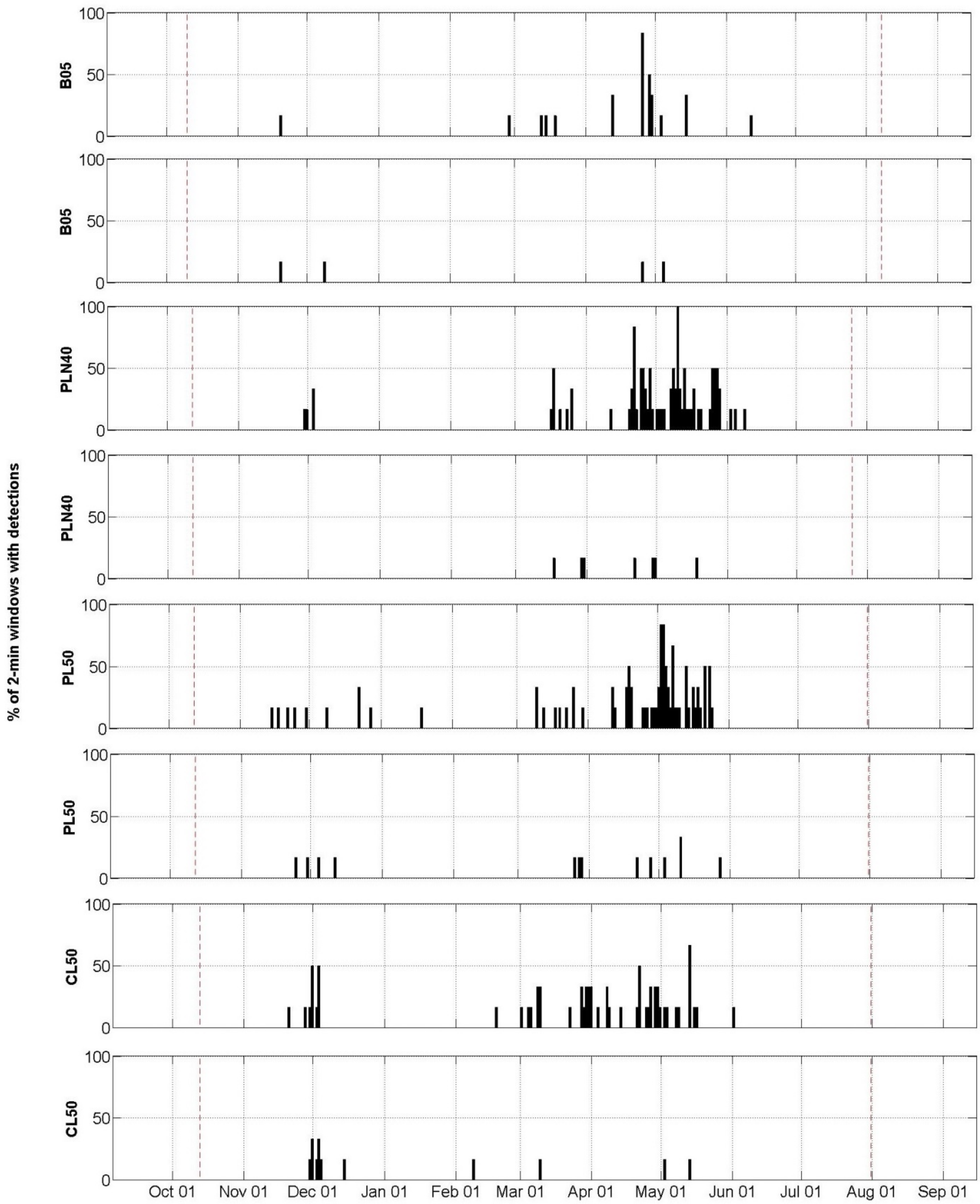

Figure 55. Daily ringed seal call detections based on different call types. For each pair of plots, (top) shows the proportion of sound files with detections of “double thumps”; (bottom) shows the proportion of sound files with detections of calls used in this study (e.g., bark, yelps, etc.). Six sound files lasting 30 or 40 min were recorded each day every four hours. The vertical dashed lines indicate the recording start and end dates.

3.4.12.2. Summer 2013 Recording Period

Ringed seal calls were detected at 17 stations. Calls were recorded on one to four days per station (Table C–15). Detections were sporadic throughout the study area. No temporal or spatial patterns were observed (Figure 56).

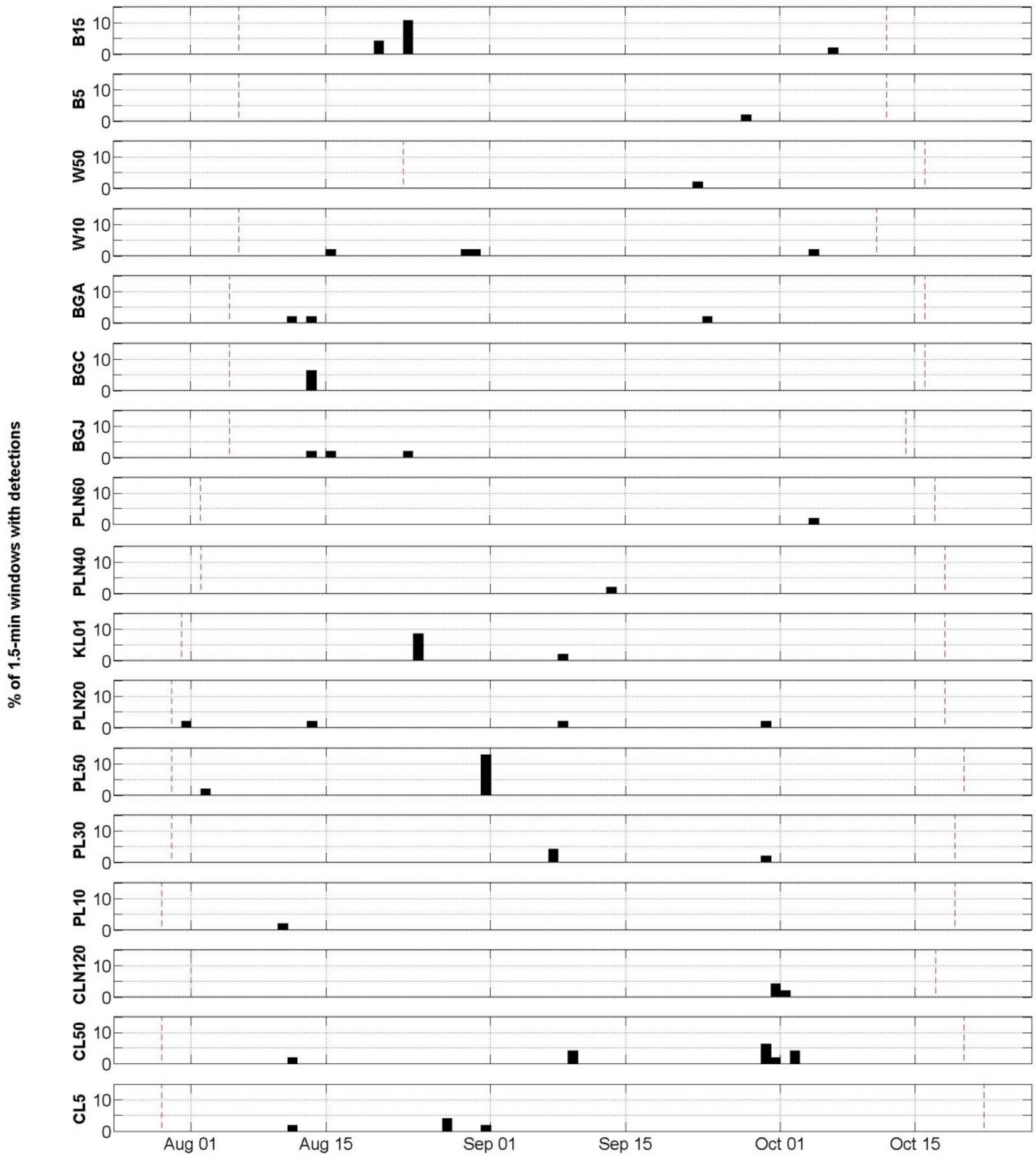

Figure 56. Summer 2013 daily ringed seal call detections: Daily proportion of 30 min sound files with call detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2013. Forty-eight files were recorded daily. Vertical dashed lines indicate recording start and end. Stations are ordered from northeast (top) to southwest (bottom). Stations without call detections were omitted.

3.4.13. Spotted Seal Call Detections

No spotted seal calls were detected manually in the winter 2012–2013 or summer 2013 datasets, not because they were necessarily absent from the program area, but owing to a lack of knowledge about their calls. Spotted seals are regularly seen in the program area in summer (e.g., Aerts et al. 2013). Recorders placed near known spotted seal summer haul-outs (e.g., in Kasegaluk Lagoon passes; Frost et al. 1993) could help researchers better understand spotted seal calls and assess the feasibility of acoustically surveying this species.

3.5. Bowhead Call Localization

Bowhead whale moans were detected and localized near the Burger array (Figure 57). Locations beyond 6 km from the center of the array (Station BGC) were excluded to present only those with high location accuracy. This reduced the number of localizations from 70,116 to 31,703. There were no noticeable location biases (e.g., skews) in the distribution of localized calls around the array. Similarly, we did not observe any skewed distribution of calls relative to the array between days or selected periods (Figures C–47 to C–58).

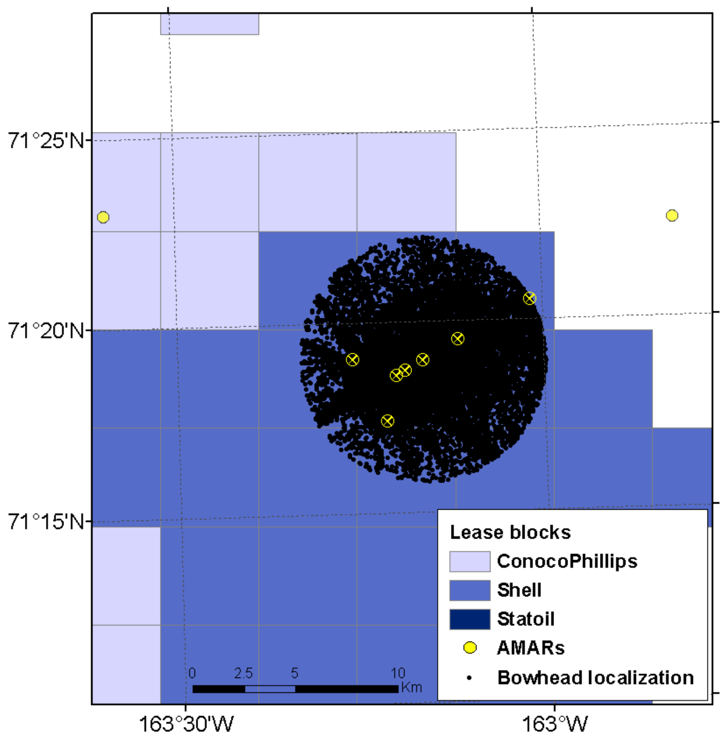

Figure 57. Localized bowhead calls in the Burger lease area between 12 Aug and 13 Oct 2013. The yellow crossed circles represent the recorders used for localization purposes. Localizations beyond 6 km from the center of the array were excluded.

4. Discussion: 2007–2013 Trends

4.1. Received Ocean Noise

Ambient noise is comprised of sounds produced by wind, waves, ice-cracking events, geological seismic events, and from biological sources—in the Chukchi Sea marine mammals are the main contributors, but fish can be important contributors in some areas. Although anthropogenic sounds contribute to the total underwater sound field, they are generally considered separately from ambient noise.

Because the natural soundscape is part of the environment in which marine life is evolving, it is appropriate to assume that marine animals adapt alongside this noise. Nevertheless, this assumption does not mean that ambient noise does not constitute a cost for marine animals while they forage, socialize, and find mates. Anthropogenic noise is a much more recent addition to the underwater soundscape, especially in remote regions and has led to the assumption that marine life might not be well adapted to certain anthropogenic sounds: those that are not part of the natural spectral composition of ambient sounds or those that add sound pressure to the spectral composition of the natural soundscape that is significant enough to negatively affect marine mammals' lives.

The ambient sound levels at Station PLN40 throughout the summer and the winter deployments are compared from 2007 through 2013. Ambient sound levels for summer 2013 are compared across several stations. This discussion addresses both natural and anthropogenic sounds.

4.1.1. Station PLN40 Multi-Year Analysis

The 2007–2013 summer recordings produced similar ambient sound profiles for the Chukchi Sea. The ambient sound levels were within the expected range indicated by the Wenz curves, with local variations that were correlated with weather, marine mammal acoustic activity, vessel activity, and seismic exploration. The 50th percentile power spectral density (PSD) levels are plotted in Figure 58 from Station PLN40 for all recordings from summer 2007 to summer 2013. Station KL11 was substituted for summer 2009 because PLN40 was not deployed that year. We've grouped spectrograms for the recordings into summer and winter sessions to make them easier to compare (Figures 59 and 60).

The noise levels measured during summer 2013 were elevated relative to previous years' levels in the 30 to 400 Hz band. This difference can be attributed to greater seismic survey activity near station PLN40 in 2013. Above 400 Hz, the levels are similar to previous years.

In summer 2012, ambient noise levels below 1 kHz increased in mid-September (Figure 59). That increase was likely due to higher wind speeds during that time. Tonals from distant shipping were present in recordings between mid-August and early September 2012.

Two periods of increased broadband noise in mid-August and mid-September 2011 were attributed to wind and wave-break noise and partially to water movement against the hydrophone. Tonal noise, present from early August to mid-September, was associated with a loud vessel operating near the Statoil lease area. Figure 58**,** a spectrogram, shows seismic survey activities during summer 2010 as noise in the lower frequency bands (up to 200 Hz), which can also be seen as an elevation in the spectral levels.

The summer 2008 recording period was much shorter than in other years, but contains moderate broadband noise, which was attributed to bowhead whales calling during migration, and to early fall weather. The relatively high noise levels that year are also due to the recording period extending later in the season, which means recordings picked up storms with high wind speeds. Anthropogenic influences on the soundscape during summer 2009 were similar to those during summer 2008, with a restricted period of shallow hazards seismic activity.

During summer 2007, the PLN40 recorder was deployed until 14 Sep. Because August was very quiet and the recorder was retrieved early, the power spectral density curve (Figure 58) which depicts sound levels over PLN40's entire deployment, shows very low summer levels despite an extensive seismic survey program in September.

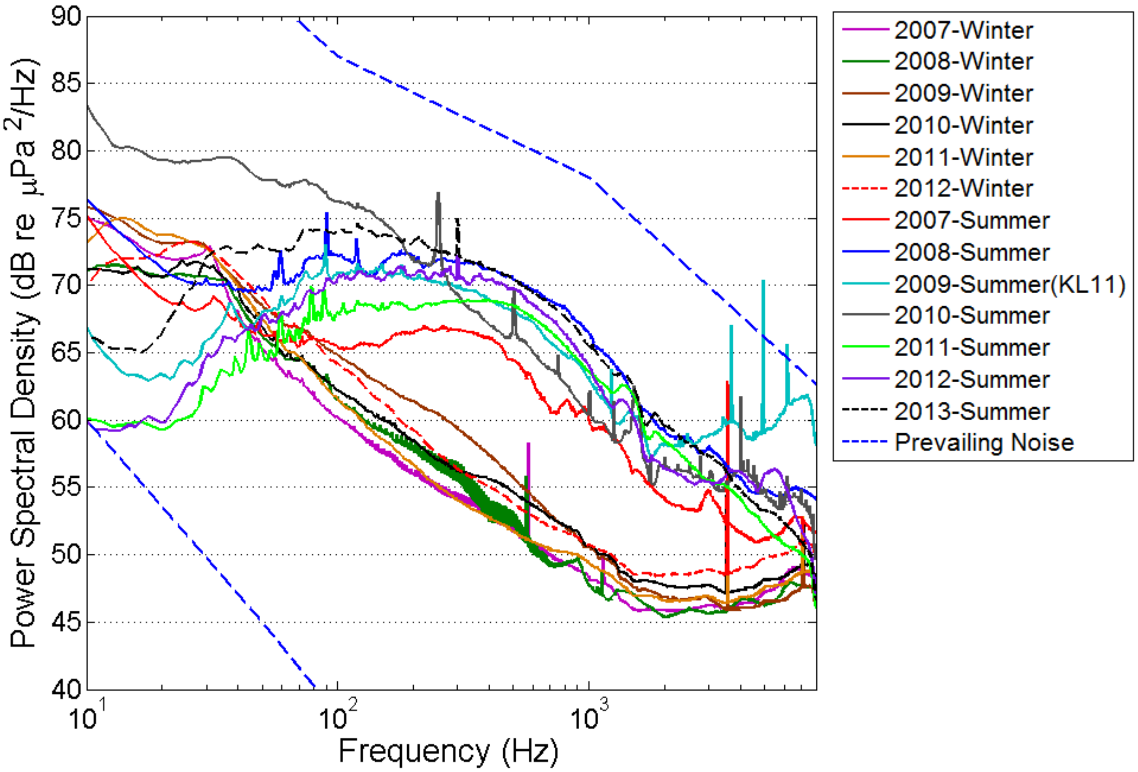

Figure 58. Percentile 1 min power spectral density levels at PLN40, for the recording periods from summer 2007 and winter 2007 through summer 2013. Station KL11 results are shown for summer 2009 because PLN40 data are unavailable for that year.

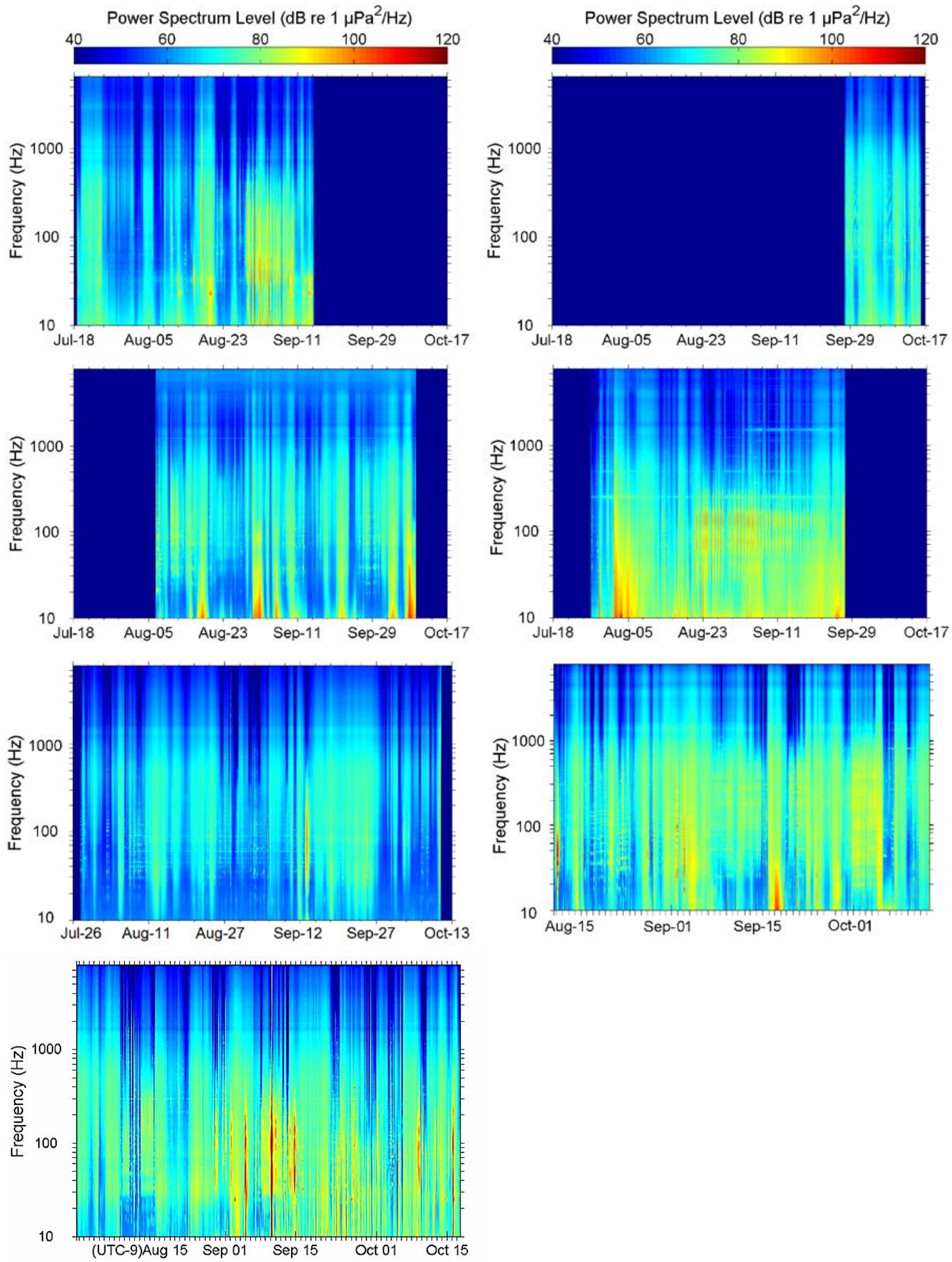

Figure 59. Spectrogram of underwater sound at Station PLN40 for the summer deployments for (top left) 2007, (top right) 2008, (upper middle left) 2009, (upper middle right) 2010, (lower middle left) 2011, (lower middle right) 2012, and (bottom left) 2013. Station KL11 was used for summer 2009 because the PLN40 data are unavailable for that period.

The spectral density percentiles (Figure 58) and spectrograms (Figure 59) both indicate that sound levels are higher at low frequencies (< 1 kHz) than at higher frequencies. When integrated over decade-bands, however, the in-band SPL show that the total sound levels from 10–100 Hz are generally the lowest compared to the 100–1000 and 1000–8000 Hz bands (Table 11). In fact, the sound levels in the 100–1000 Hz band are generally the highest, which indicates that wind-generated surface noise is the dominant noise source in the Chukchi during summer months.

Table 11. Median decade-band sound pressure levels (dB re 1 µPa) for summer 2009, 2010, 2011, 2012, and 2013 at Station PLN40.

Year	Median decade-band SPL (dB re 1 µPa)		
	10–100 Hz	100 Hz to 1 kHz	1–8 kHz
2009	88.2	97.1	98.4
2010	95.8	96.2	92.6
2011	88.2	99.5	97.0
2012	86.4	98.0	94.2
2013	92.1	100.2	95.7

Ambient noise levels from the 2007 to 2010 winter periods show a linear decrease from 40 Hz to 2 kHz. The winter 2011 recording period was much quieter than the other recording periods; winter 2012 was louder than the other periods (Figures 58 and 60). The loudest periods of all six winter deployments correspond with ice formation and break up. The relatively high levels below 100 Hz are attributed to wind noise propagating through the ice.

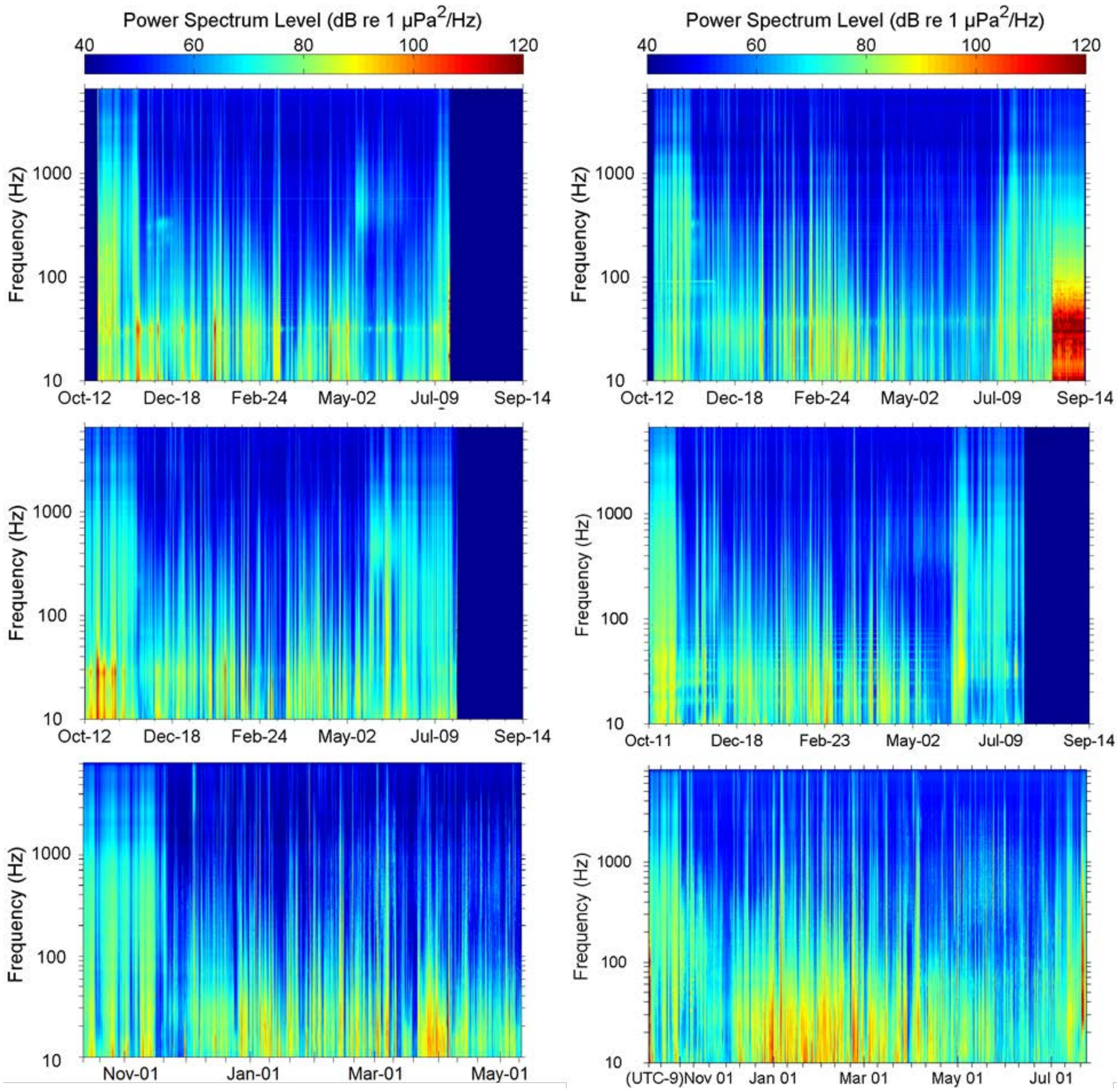

Figure 60. Spectrogram of underwater sound at Station PLN40 for the winter programs for (top left) 2007–2008, (top right) 2008–2009, (middle left) 2009–2010, (middle right) 2010–2011, (bottom left) 2011–2012, (bottom right) 2012–2013.

4.1.2. Summer 2013 Recording Period

The 50th percentile power spectral density levels from the summer 2013 recordings are plotted for stations along a line roughly going east to west (Figure 61); the corresponding spectrograms for the recordings are shown in Figure 62. Low frequency sound levels at Station PLN60 were elevated up to 3 dB above sound levels at other stations because it was closer to seismic survey activity. Station B15 had considerably lower sound levels than the other stations due to the greater distance to the seismic survey activity.

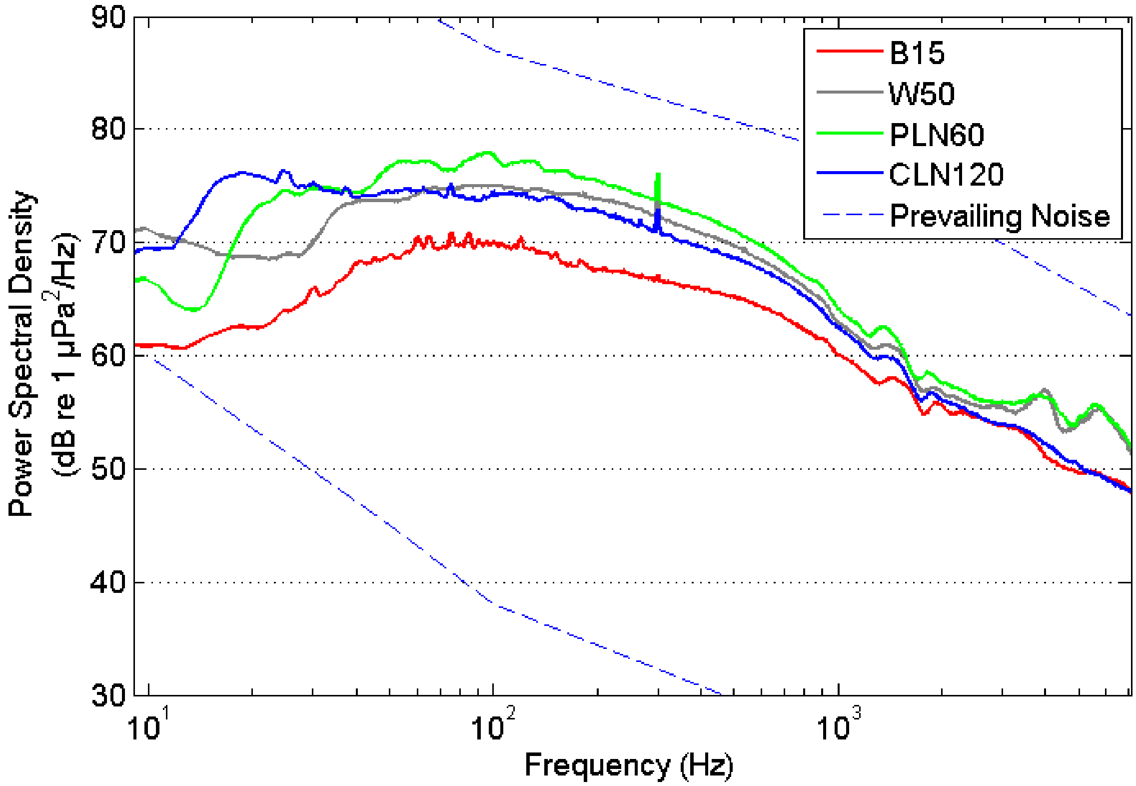

Figure 61. Percentile 1 min power spectral density levels at stations along a roughly east-west line across the Chukchi Sea for summer 2013.

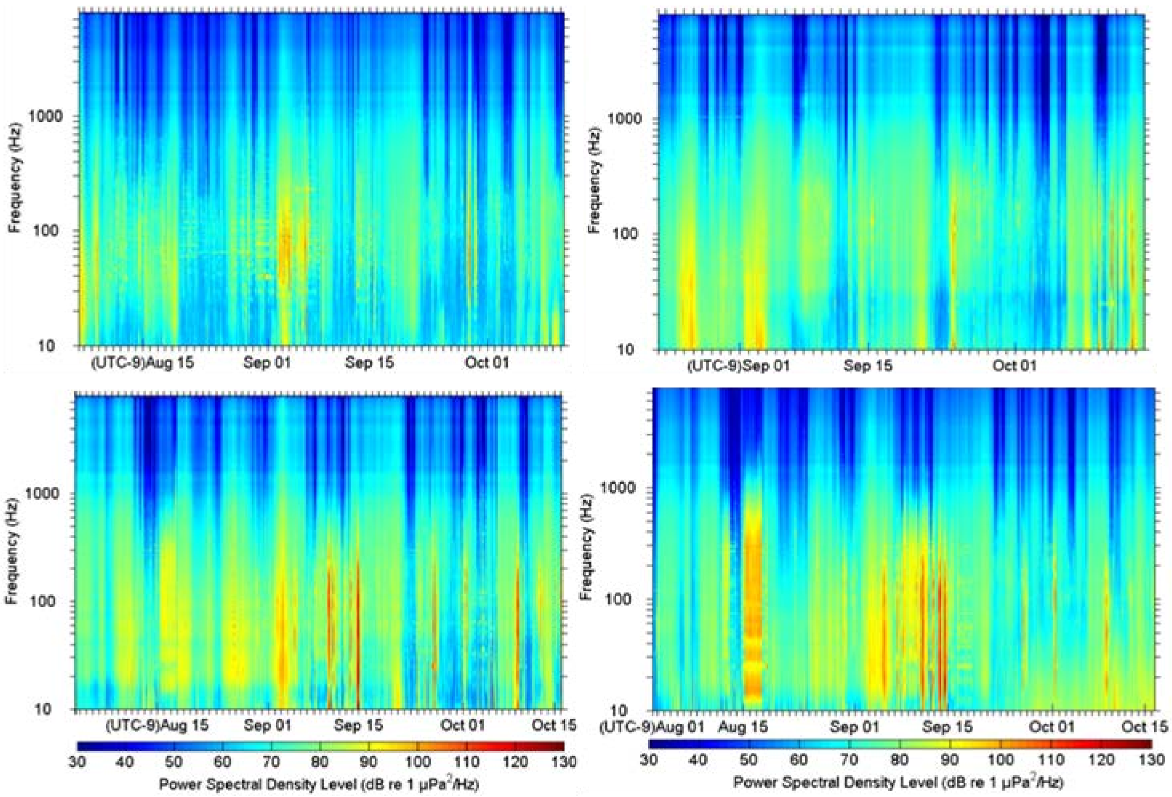

Figure 62. Spectrogram of underwater sound at (top left) B15, (top right) W50, (bottom left) PLN60, and (bottom right) CLN120 for the summer 2013 program.

4.2. Marine Mammal Call Detections

Because recorders have been deployed at the same or similar locations each year since 2007, we were able to compare data collected over the years and draw conclusions based on similarities in the data collection. This discussion does not include the 2008 summer data because only five recorders were deployed that year and only late in the season (26 Sep to 16 Oct 2008). Because the summer 2007 (first deployment) and winter 2007–2008 data were not analyzed using the standardized protocol, which was first applied to the winter 2008–2009 data, these two datasets were not directly comparable to later datasets. Furthermore, differences in deployment scenarios influenced our ability to compare the results between locations and years. For example, the Burger and Klondike cluster arrays were first deployed in summer 2009. In summer 2010, a third cluster array was added at the Statoil lease area. In summer 2011, all of the arrays were removed, but a single recorder was retained at each array location to continue monitoring the three lease areas. A modified version of the Burger cluster array was reinstalled in summer 2012. The number of recorders in the winter program increased from five in 2007–2008 to fifteen in 2011–2012.

4.2.1. Bowhead Whale Call Detections

4.2.1.1. Comparison of Winter Acoustic Recording Periods

The detections made during fall 2012 were generally consistent, both spatially and temporally, with results from previous years. The substantial increase in call counts (one order of magnitude) from September to November is mostly due to an increase in vocal activity associated with the onset of singing in males (e.g., Delarue et al. 2009). The highest call counts were reported at stations located between 71° and 72° N, but high call counts also occurred north of 72° N, which indicates that bowhead whale movements are not restricted to a corridor but have a tendency to occur north of 71° latitude. Lower call counts at CL50 and PL50 confirm earlier suggestions that bowheads primarily migrate on a westerly trajectory after leaving the Barrow-Wainwright area and then likely head toward the northern Chukotka coast where they feed in fall (Quakenbush et al. 2010).

In contrast to prior years' observations, bowheads left the Chukchi Sea earlier in 2012; they were last detected acoustically on 5 Dec, 2012 (50% of all detections happened before 24 Nov). This is the earliest complete departure on record since the beginning of the winter recording program in 2007. Bowheads typically leave the central part of the study area, including the lease areas, by the end of November, but some whales tend to linger until the middle or end of December and sometimes into January in the southwestern part of the study area. Results of a satellite tagging study showed that most tagged whales traversed the lease areas in less than a week, however, one whale remained there for 30 days (Quakenbush et al. 2010). Late migrants or individuals on a hiatus from their migration could take advantage of foraging opportunities due to lower competition for food in the Chukchi Sea instead of traveling to the Chukotka coast where most of the whales are in late November and December (Quakenbush et al. 2010).This late migration phenomenon should be considered when planning work in the lease areas beyond the open-water season. Heavy ice conditions presumably prompted all whales to depart early in 2012.

The spring migration in 2013 occurred at approximately the same time as in previous years. Bowhead call detections in the offshore lease areas tended to occur later than detections closer to shore. Detection frequency decreased with increasing distance of recorders from shore, confirming earlier suggestions (Braham et al. 1984) that bowheads migrate predominantly close to shore even though some individuals transit through the offshore lease areas. However, compared to the previous spring migrations, Station B5, the station closest to shore, did not report the highest call counts in 2013. The configuration of coastal leads in the ice usually funnels whales entering the Beaufort Sea toward this station. Persistent westerly winds kept the nearshore lead mostly closed during spring 2013, disrupting the spring hunt in Barrow (Alaska Dispatch, May 30 2013, http://www.alaskadispatch.com/article/20130530/arctic-alaska-barrow-whaling-crews-still-waiting-open-water). Bowheads likely migrated further offshore, leading to a lower than usual call count at B5. In contrast, Station W35, which is located 30 mi further offshore, had the highest call count during the spring migration (April to June).

4.2.1.2. Comparison of Summer Acoustic Recording Periods

Similar to what we witnessed over the last two summers, acoustic activity was registered in the central and northern parts of the study area (including the Burger lease area) in August 2013, peaking during the last week of that month. During the same period, however, call counts off

Barrow were one to two orders of magnitude higher suggesting a much larger and denser aggregation of whales there. In comparison, the same period in 2009 and 2010 was characterized by only 1–2 sporadic detections within the monitored area and those were tentatively linked to tagged individuals moving between the Beaufort Sea and the Chukotka coast.

Bogoslovskaya et al. (1982) reported that whales arrive regularly near Cape Schmidt and Cape Billings along the Chukotka coast in late August and early September. This suggests that some whales might have summered in the western Chukchi or left the Beaufort Sea earlier than the rest of the animals. The latter movement pattern would explain increases in acoustic detections during late August. It is unclear whether the similar spatial distribution of acoustic detections in August 2013 and during the fall migration (i.e., oriented in an east-west direction, mostly north of 71° N) should be interpreted as evidence that the August detections represent migrating bowheads (Figures A–12 and A–14; Delarue et al. 2011b, Delarue et al. 2013b).

Mid-summer detections from 2011–2013 could be associated with bowheads foraging in the study area. Bowhead whales' most important prey items are euphausiids and copepods (Lowry et al. 2004) and both are present in the northeastern Chukchi Sea during summer (Hopcroft et al. 2014) with copepods being far more abundant than euphausiids. The annual distribution pattern of bowhead call detections, however, does not coincide with annual peaks of copepod abundance and biomass, which increase from August to September (Hopcroft et al. 2014). The current evidence does not support foraging as the main explanation for bowhead whale presence in the Chukchi Sea because bowhead whale calls were essentially absent the first three weeks of September, except near Barrow and Wainwright. Because bowheads often aggregate near Barrow to feed before migrating across the Chukchi Sea (Lowry et al. 2004, Moore et al. 2010), zooplankton sampling program off Barrow and Wainwright could help explain why detection counts are much higher in these areas in summer months.

Bowhead whales were historically present in the Chukchi Sea in August (Braham et al. 1984) , as shown by the large number of reported catches in our study area. Whether these individuals were caught during their migration through the area or whether they summered in the Chukchi Sea remains unclear. When commercial hunting started, however, bowhead whales were caught from spring to autumn in the Bering Sea, which suggests that at least a segment of the population was non-migratory and that another segment of the population perhaps summered in the Chukchi Sea (Bockstoce and Burns 1993). The western Arctic bowhead population is has likely recovered to its historical size (George et al. 2004), which could mean that due to pressure on food supply in the Beaufort Sea this population expands its summer range into areas of historical presence, including the Chukchi Sea. An increase of bowhead whales in the Chukchi Sea should be monitored closely to assess possible interactions between them and humans.

As in 2012, September was characterized by high call counts at the inshore Barrow and Wainwright stations, possibly indicating that bowheads were present throughout Peard Bay. This finding is consistent with previous reports of bowhead sightings in this area in summer (Moore 1992) and bowhead feeding aggregations near Barrow (Moore et al. 2010). The fall concentration of bowheads off Wainwright could interact with future developments in the area, such as pipe-laying activities. If oil and gas prospects are developed, this potential bowhead feeding area should be assessed.

Bowhead migration through the Chukchi Sea started around 22 Sep 2013. As in previous years, most detections were concentrated north of 71° N, with much less acoustic activity between 70°

and 71° N northwest of Point Lay. Call detection distributions vary little over the years, meanings a preferred migration corridor might be present (Figure 63). Migration timing is, however, more likely to vary due to ice conditions.

In 2013, call counts off Barrow were the highest recorded since the beginning of the summer monitoring programs (Figure 63). Highest call counts at stations other than those off Barrow were in the range of the maxima reported in 2009, 2010, and 2012. Higher call counts might be correlated with a population increase (George et al. 2004), which could be responsible for the increase in residency within the study area. Very low call counts in 2011 are likely due to recorders being retrieved before the peak of the bowhead migration, which was delayed across the Chukchi Sea that year.

Call densities (Figure 64) illustrate the acoustic occurrence of bowhead whales while controlling for differing detection ranges at separate stations due to varying noise conditions. Call densities generally follow the same spatio-temporal trends as those observed for call counts: they are highest off Barrow and Wainwright, presumably because migrating bowheads concentrate to feed in these areas before migrating across the Chukchi Sea. Individuals fan out as they migrate, leading to lower spatial and call densities. In 2013, Station B15 reported the highest recorded call densities since 2009. Call densities in the rest of the study area were similar to previous years, except for those reported in 2011, which were lower due to fewer call detections.

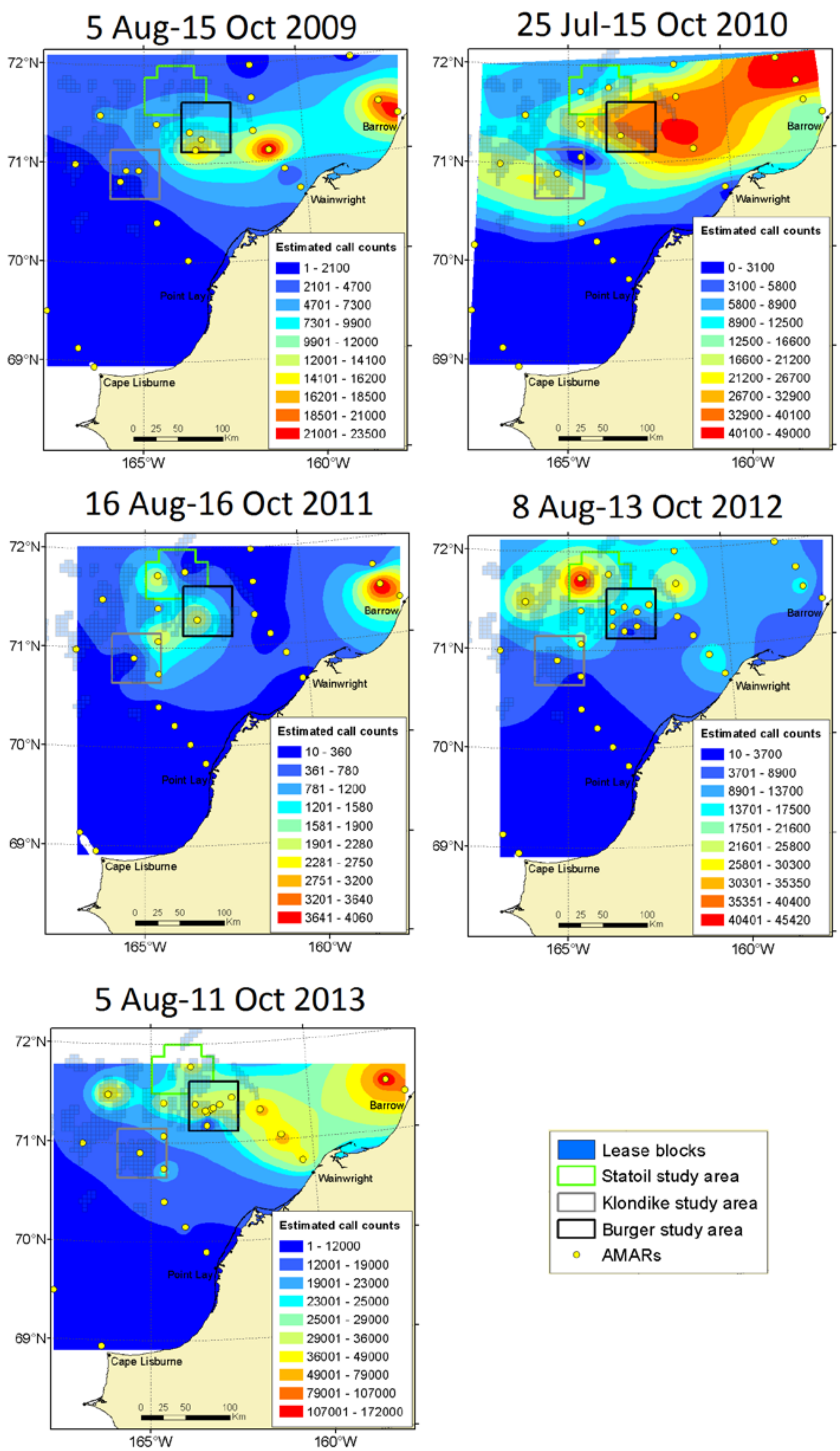

Figure 63. Summer bowhead whale call counts in 2009, 2010, 2011, 2012, and 2013: Radial basis interpolated call counts based on the sum of automated call detections in all files with manual detections at all summer recording stations in the northeastern Chukchi Sea.

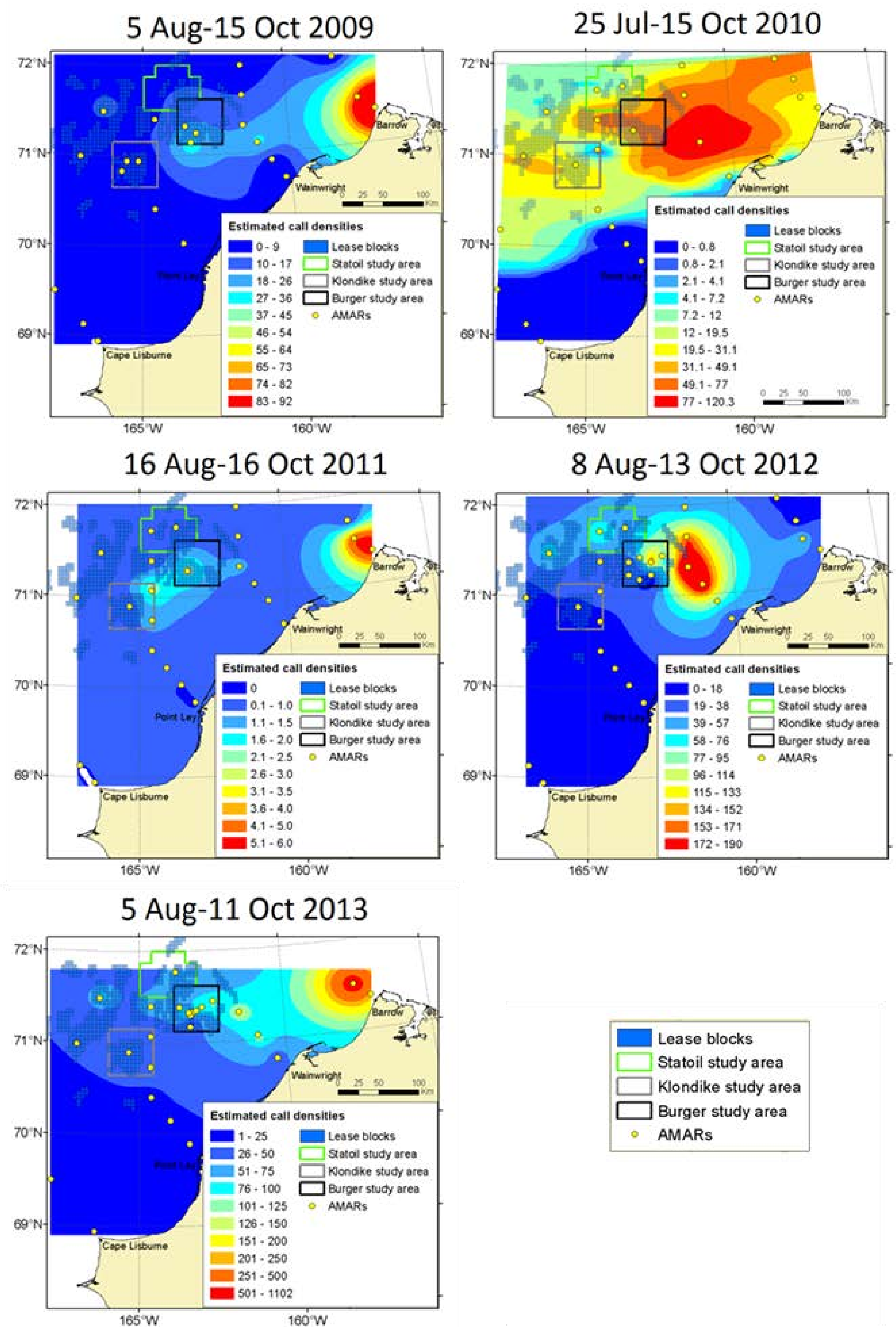

Figure 64. Summer bowhead whale call densities in 2009, 2010, 2011, 2012, and 2013: Radial basis-interpolated call densities based on the sum of automated call detections in all files with manual detections at all summer recording stations in the northeastern Chukchi Sea.

4.2.2. Walrus Call Detections

4.2.2.1. Winter Acoustic Recording Periods

The acoustic data from recorders deployed on the north side of Hanna Shoal for the second consecutive year confirmed the presence of walrus in this area until early October, with a peak in detections in the north-central part of the Shoal (WN80). The number of detections reported over the rest of fall was similar to previous years, i.e., rare and concentrated over a few days. Walrus calls were also detected in the middle of winter at four stations surrounding Hanna Shoal. These sporadic winter detections, which were more frequent during the 2012–2013 session, might be linked to the presence of polynyas, which form when deep-keeled ice ridges become grounded on Hanna Shoal (Stringer and Groves 1991).

The spatio-temporal distribution of call detections in spring 2013 was consistent with past patterns. Walrus calls were first detected in early June. Detections lasted only 2–3 weeks in the southwestern part of the study area when animals were travelling through the area toward Hanna Shoal. Detections started slightly later off Wainwright but continued without interruption (Jun-Sep) until the recordings stopped at most stations in the northeastern part of the study area.

4.2.2.2. Summer Acoustic Recording Periods

The frequency of summer detections in 2013 has been similar to that of previous years (Figure 65). This was surprising because ice conditions prevented the deployment of recorders north and south of Hanna Shoal where walrus spend much of their time foraging (Jay et al. 2012). Call activity was highest in the Statoil lease area, located on the western edge of Hanna Shoal until early September. At Station S01, calls occurred daily in more than 80% of sound files, a vocalization rate that no other stations reported until mid-September. Call counts were also high within the Burger lease area.

A general trend showed increasing call counts with decreasing distance to Hanna Shoal. In previous years, detections outside of the coastal Point Lay area, which was formerly an important haul-out area, were highest between stations W50 and WN20 on the southern edge of Hanna Shoal. In 2013, detections were highest at BGG, located approximately between W50–WN20 and the Burger 2012 drill site (eastern edge of Burger lease area, Figure 65), highlighting the importance of the Burger lease area as walrus habitat. The high density and biomass of benthic organisms found within, and increasing densities toward the northeast of the Burger lease area (Blanchard and Knowlton 2013), might explain the higher detection rate of walrus calls.

From mid-September, call counts remained high in the Statoil and Burger lease areas but the highest call counts were reported at PL10 in the vicinity of a terrestrial haul-out at Point Lay (Christman et al. 2013). From 2010 to 2013, total call counts were highest from PL5–PL10, which were closest to the haul-out sites. This was true in 2012 as well even though no animals were visually detected at any of the potential haul-outs near Point Lay. In 2009, animals established a coastal haul-out near Icy Cape, which might explain the relatively high call counts reported from stations near Wainwright. Once call activity was registered near haul-outs, detections occurred continuously until the recorder was retrieved. Such sustained call activity could correspond to animals regularly transiting to and from the haul-out site or indicate that animals foraged near shore instead of returning to Hanna Shoal after resting onshore. Nevertheless, studies of the benthic fauna have shown that bivalve and polychaete worms were more common in offshore areas frequented by walrus (Blanchard and Knowlton 2013). Nearshore foraging could occur if higher foraging success offshore is offset by the energetic costs of travel between coastal haul-outs and offshore foraging grounds.

The increase in call counts at CL5 in mid-September is consistent with previous years and marks the beginning of the fall migration toward the northern Chukotka coast.

The extent of walrus' spatial distribution fluctuated a lot during summer 2013. Some of the peaks in the number of stations with detections in August might reflect the broader distribution of sea ice, which was prevalent in the area in 2013, available for walrus to rest upon. Spatial distribution of call detections reached its peak after 23 Sep when walrus were heard at 80–90% of active stations. At that time, walrus could be more widely dispersing because the sea ice was disappearing from Hanna Shoal, a time when animals begin migrating back to the northern Chukotka coast where they typically aggregate in fall.

The remarkable consistency in the distribution of walrus call detections in summers across years could be due to two factors: low inter-annual variability in the distribution of their benthic prey, and the availability of suitable haul-out sites near Point Lay.

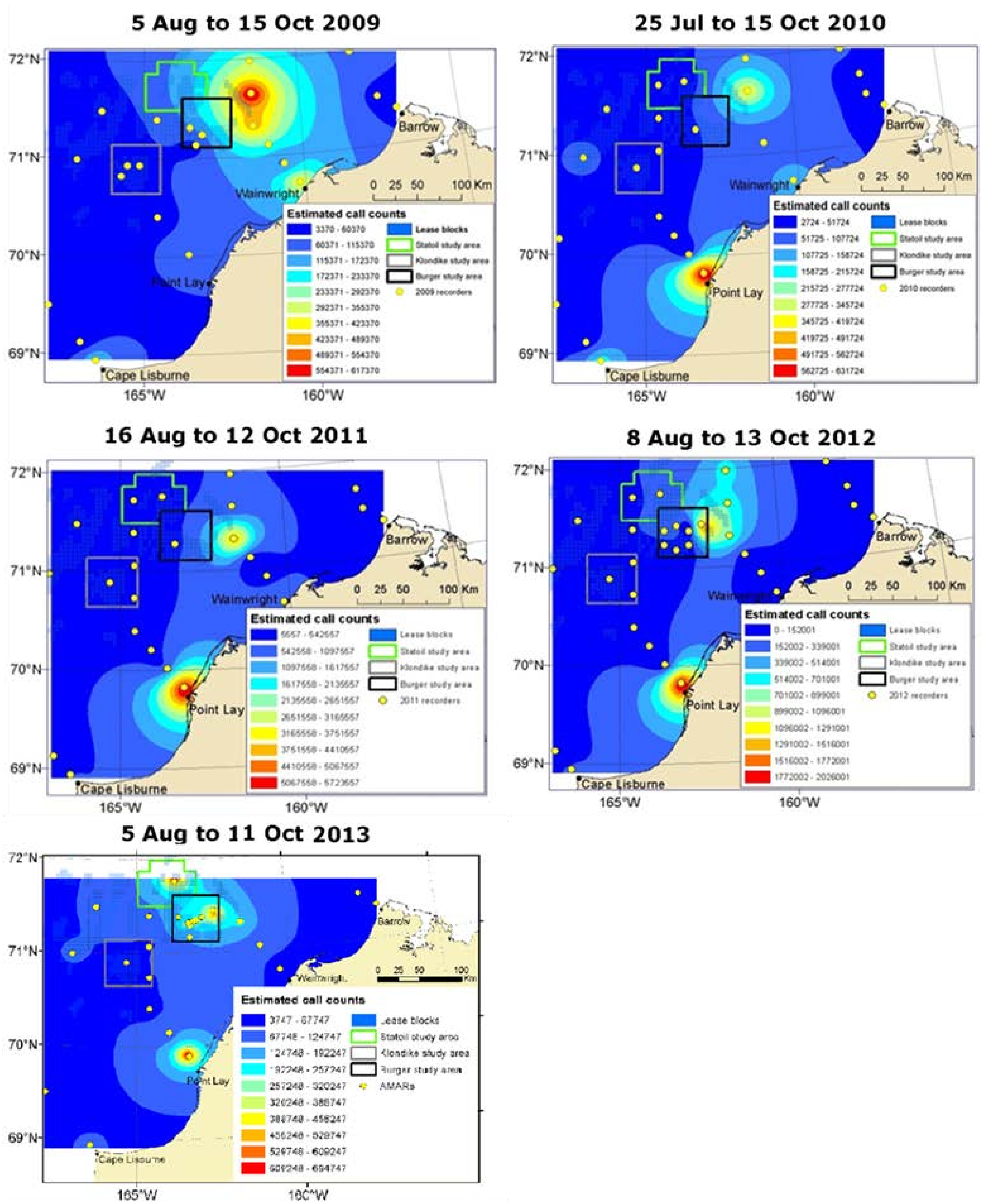

Figure 65. Summer walrus call counts in 2009, 2010, 2011, 2012, and 2013: Radial basis-interpolated call counts based on the sum of automated call detections in all files with manual detections at all summer recording stations in the northeastern Chukchi Sea.

4.2.3. Beluga Whale Call Detections

4.2.3.1. Winter Acoustic Recording Periods

The spatial and temporal distribution of beluga whale call detections during winter 2012–2013 was generally consistent with the trends observed in previous years within the main part of the study area. B5, near Barrow, had the most consistent and predictable rate of detections during fall, presumably because belugas transit via Barrow canyon on their way back from the northern Chukchi and Beaufort Seas. There were fewer detections at stations farther west and detections were farther apart, possibly because belugas spread out over a larger area after leaving Barrow canyon. Alternatively, whales might prefer to migrate closer to shore where recorders were not deployed until this year. Data from inshore recorders deployed in fall 2013 should help us test this hypothesis.

One of the reasons we deployed recorders on the north side of Hanna Shoal was to capture the Eastern Beaufort Sea beluga stock fall migration. Belugas have been shown to migrate through the northern Chukchi Sea, along the shelf break, in September (Richard et al. 2001). The complete absence of beluga call detections in September and rare detections in October 2012 strongly suggest that the recorders surrounding Hanna Shoal were not in the migration path of the Eastern Beaufort Sea belugas. Recorders deployed to intercept the fall migration of that stock might be better placed in the deep waters of the Chukchi basin. The recorded fall detections are therefore most likely from animals of the Eastern Chukchi beluga stock.

The number and distribution of spring detections were generally comparable to those from previous years. Beluga call counts were higher inshore than offshore but the number of detections reported from the offshore lease areas remained substantial despite virtually 100% ice coverage. As discussed for bowheads, Station B5 typically yielded the highest number of detection days and call counts. In 2013, PL50 and W50 both reported more detection days than B5. Call counts at W50 were higher than at B5 in both April and May, the main migration months. This is likely due to ice conditions at B5 where consistent westerly spring winds kept the coastal lead closed, forcing animals to migrate further offshore and away from the recorder than they might have otherwise.

With few exceptions, acoustic activity stopped at the end of May. Whether both stocks of belugas migrated simultaneously or sequentially could not be determined. The absence of a second detection peak in June or July cannot be interpreted as both stocks migrating together because Eastern Chukchi belugas might be following the coastline and thus not detected on offshore recorders. The inshore recorders deployed in fall 2013 will provide better information on this possibility.

4.2.3.2. Summer Acoustic Recording Periods

The acoustic data from summer 2013 were characterized by more widespread detections than in previous years at all stations except CL5. Over the last years, detections have always been concentrated in or near Barrow canyon in August where Eastern Chukchi belugas appear to forage before heading north into the northern Chukchi and Beaufort Seas (Suydam et al. 2005, Delarue et al. 2011b). Sporadic detections west and north of Kasegaluk Lagoon suggest that belugas dispersed more broadly in summer 2013, a phenomenon that could have been triggered by the comparatively high sea ice cover and a concurrent greater availability of Arctic cod, which is generally associated with sea ice and is the main prey of belugas (Moore et al. 2000).

A widespread wave of detections occurred in late September/early October. In contrast, beluga calls were only detected at a few stations during the same period in previous years. Belugas were seen once near PLN40 on 3 Oct 2013 by CSESP marine mammal observers (MMOs, Aerts et al. 2014), which likely corresponds to the peak in detections at Burger. During Aerial Surveys for Arctic Marine Mammals (ASAMM), beluga sightings in August 2013 mostly occurred inshore between Point Lay and Barrow, except for one offshore sighting north of Wainwright. Several sightings occurred on 30 Sep about 220 km northwest from Point Lay (Clarke et al. 2014). Acoustic detections occurred in the same general area (CLN90) in late September/early October. A few more sightings occurred in October along a line heading west from Barrow.

4.2.4. Bearded Seal Call Detections

4.2.4.1. Winter Acoustic Recording Periods

Bearded seal call presence during winter 2012–2013 was similar to that of previous years. The recordings made from 2011–2012 showed that most bearded seals in the northeastern Chukchi Sea were concentrated in the north of the study area, near stations PLN80 and PLN100. Detections were typically less frequent on either side of these two stations. In 2012–2013, the area near PLN100 was also rife with acoustic activity, as was an area between W35 and WN20. Summer data previously showed that bearded seals show an affinity to the waters off Wainwright (Figure 66).

Typically calling rates steadily increase from October until peaking in May/June, which coincides with the mating season. The rate and timing of the increase leading to the peak varies between stations. Call detections usually seize abruptly in late June/early July, with very sporadic, or no detections thereafter. Bearded seals are the most common acoustically detected marine mammal species during winter.

4.2.4.2. Summer Acoustic Recording Periods

Summer detections typically consist of a few sporadic calls in late July and August, then acoustic activity steadily increases into September, and peaks in October. Bearded seal calls are present mainly at the offshore stations during summer, particularly near CLN90, CLN120, and PLN80-S01. In some years, a second area of higher vocal activity occurs off Wainwright (e.g., 2009).

Detection rate and distribution during summer 2013 were generally comparable to those of previous years (Figure 66). Bearded seal calls were most commonly recorded along an arc ranging from Wainwright to PLN20 via S01. The CSESP bearded seal sightings coincided with the acoustic detections and were also concentrated inside that arc (Aerts et al. 2014). The steady increase in calling rate from September to May, which might be due to changing vocal behavior, makes it difficult to compare estimated call counts to relative abundance. We think it’s likely that the low number of detections in July and August is also likely due to vocal bearded seal vocal behavior and does not necessarily mean there are fewer animals present. Call counts were generally lower in 2013 than in previous years (Figure 66), but the range of values is not large enough to draw any meaningful conclusions. Densities derived from visual observations in 2013, however, are the highest since the program began (Aerts et al. 2014).

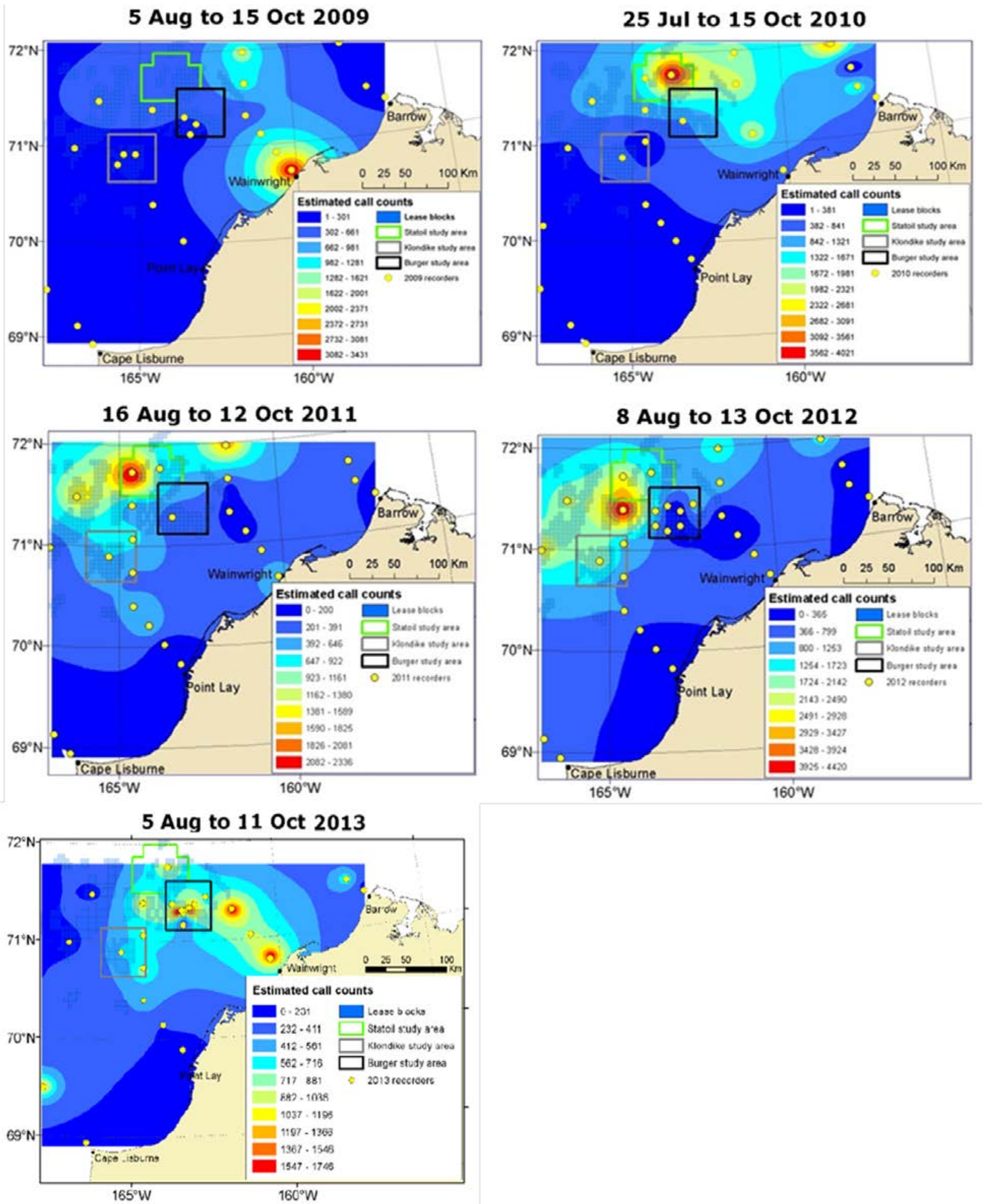

Figure 66. Summer bearded seal call counts in 2009, 2010, 2011, 2012, and 2013: Radial basis-interpolated call counts based on the sum of automated call detections in all files with manual detections at all summer recording stations in the northeastern Chukchi Sea.

4.2.5. Fin Whale Call Detections

Fin whale calls detected in the summer datasets from 2009 to 2011 confirmed that fin whales, which were first recorded in 2007 (Delarue et al. 2013a), occur occasionally in summer in the northeastern Chukchi Sea. In all years, fin whales were only detected at the offshore Cape Lisburne stations as well as Station PL50. The number of detections decreased sharply between 2007 and 2009 and remained low thereafter, indicating that fin whale visits to the northeastern Chukchi Sea are still a rare occurrence. After being acoustically absent in 2012, fin whale calls were detected on 13 days at CL50 between early August and mid-October. These acoustic observations are consistent with visual observations in summer 2013. Three fin whales were sighted during the ASAMM surveys and two by MMOs of the CSESP program off Cape Lisburne (Aerts et al. 2014, Clarke et al. 2014).

4.2.6. Gray Whale Call Detections

In 2011 and 2012 gray whale detections were concentrated off Wainwright, a feature that was apparent again in 2013, coinciding with gray whale distribution patterns established via aerial surveys (Clarke and Ferguson 2010). The 2013 sightings from both the ASAMM (Clarke et al. 2014) and CSESP (Aerts et al. 2014) were also concentrated inshore, mainly between Barrow and Wainwright, with a slight offshore extension off Wainwright. The number of detection days in 2013 was similar to 2012. An analysis of the detection probability of gray whale calls in 2012 showed that the currently applied analysis protocol underestimates the acoustic occurrence of gray whales. Assuming that the vocal repertoire of gray whales is similar across the study area, the spatial distribution is likely correctly depicted by the current analysis protocol while the occurrence (i.e., proportion of hours with detections) of gray whales at each station could be underestimated. Gray whales' preference for the area off Wainwright is linked to the area's high density of amphipods (Blanchard and Knowlton 2013).The densest amphipod beds are 20 to 30 mi offshore, which is where call detections were highest. Gray whale's affinity to the Wainwright area should be considered when planning future work there, in particular pipe-laying activities if the Burger prospect is developed to the point of industrial production.

4.2.7. Humpback Whale Call Detections

Humpback whales were first detected in summer 2010 and calls have been recorded every year since. The spatial extent of the 2013 detections is the highest to date, with six stations involved. Closely timed detections at widely separated stations indicate that multiple individuals were present in the northeastern Chukchi Sea during summer 2013. The ASAMM reported two humpback whale sightings between Cape Lisburne and Point Lay (Clarke et al. 2014).

4.2.8. Killer Whale Call Detections

Killer whales were acoustically detected in summers 2009–2013; they were first recorded in 2007 (Delarue et al. 2010b). In 2013, as in past years, detections were concentrated off Cape Lisburne and Point Lay with Wainwright stations having fewer detections. Calls were recorded predominantly at offshore stations (50 mi offshore and beyond), except off Wainwright. Fewer stations overall recorded calls than in prior years; in past years, detections at nearshore stations were more common. CSESP MMOs did not see killer whales (Aerts et al. 2014), nor were these animals noticed during the ASAMM aerial survey (Clarke et al. 2014). Fewer observations in

2013 might reflect the natural annual variability in killer whale occurrence, variations in prey distribution, and/or differences in sea ice cover. Further analysis of the 2007 data revealed that mammal-eating killer whales, called transients, were the sources of the detected calls (Delarue et al. 2010b). This is consistent with visual observations of killer whale predation on marine mammals in the Chukchi Sea (George and Suydam 1998). Transient killer whales generally vocalize at low rate except after a kill (Deecke et al. 2005), which could explain the low detection rate for transients in the Chukchi Sea.

4.2.9. Minke Whale Call Detections

Minke whales have been regularly detected in late October/November in the winter recordings from CL50 and this was again the case in 2013. This species was also detected in the 2011, 2012, and 2013 summer recordings with detections concentrated off Cape Lisburne and Point Lay. Visual observations (one CSESP minke whale sighting northeast of Wainwright; Aerts et al. (2014) and five ASAMM sightings along the shore between Cape Lisburne and Icy Cape (Clarke et al. 2014) confirmed the presence of the species. Most of the sightings occurred in July and August while most acoustic detections occurred from mid-September onward, suggesting that minke whales are not vocally active during summer. The increase in minke whale calling rate in fall is consistent with the increase in baleen whale vocal activity over this period, which is associated with the onset of their reproductive cycle (e.g. Stafford et al. 2007, Stafford et al. 2012).

4.2.10. Ringed Seals

4.2.10.1. Winter 2012–2013

Acoustic presence of ringed seals during winter 2012–2013 was consistent with that of previous winters. Ringed seals were detected sporadically at all stations. This is attributed to the low production rate of calls by this species. In a similar study conducted along the continental slope north of our study area from 2006 to 2009, Jones et al. (2014) found that ringed seal calls were present from December to May, a pattern very similar to that observed in this program.

4.2.10.2. Summer 2013

The summer 2013 detections were similar to previous years in that they were distributed throughout the study area and occurred sporadically at all stations, with no obvious areas of higher acoustic occurrence. Low calling rates combined with the analysis protocol underestimates the true occurrence of ringed seals.

5. Conclusion

5.1. Winter 2012–2013 Recording Period

The recordings made during the winter 2012–2013 session of the Acoustic Monitoring Program provided information about ambient noise levels and marine mammal vocalizations in the northeastern Chukchi Sea from September 2012 to August 2013.

Key findings and conclusions:

- As expected, ambient sound levels were influenced by weather (wind and waves), ice presence, and marine mammal vocalizations. The ambient sound spectral levels were within the ranges described by the Wenz curves.
- Bearded seal sounds were a major contributor to the soundscape from April to June. They were detected from October until early July. Bowhead whale calls were the predominant marine mammal recorded from mid-October until 1 Dec 2012.
- The last fall detection of bowhead calls was the earliest end of vocalizations recorded to date, even though detections in the lease areas stopped around 20–25 Nov based on when call periods ended in years previous. Beluga and walrus detections in fall 2012 were similar to previous years with respect to both timing and spatial distribution.
- The frequency and distribution of the bowhead and beluga whale spring detections were similar to previous years except that Station B5 did not record the highest number of calls. Whales of these two species presumably migrated further offshore probably due to persistent westerly winds that kept the coastal lead near Barrow closed during almost all spring. The “inshore” (within 50 mi) stations near Wainwright saw a marked increase in detections compared to other spring migrations, surpassing the number of detections at Barrow in April and May.
- Walrus acoustic presence in fall 2012 was consistently strong on the Hanna Shoal recorders until mid-October, but dropped off throughout the study area thereafter. Mid-winter detections of walrus were reported from four offshore stations over seven different days, a marked increase compared to previous years. Spring detections in 2013 followed the pattern observed in previous years of the study. Mid-winter detections might be linked to offshore polynya presence, which form when deep-keeled ice ridges become grounded on Hanna Shoal (Stringer and Groves 1991).
- Ringed seal calls were detected throughout the recording period with no obvious spatio-temporal trends. As in previous years, the occurrence of ringed seal calls might have been underestimated because ringed seals have a low overall calling rate, and only 5% of data was reviewed. A new call type tentatively assigned to that species revealed strong acoustic activity in April and May during the breeding season. It will be integrated into the analysis next year and should improve the detectability of this species.

5.2. Summer 2013 Recording Period

The summer 2013 recordings of the Acoustic Monitoring Program in the northeastern Chukchi Sea revealed the presence of marine mammals, vessels, and seismic airgun operations. The results of the acoustic analysis were compared with results from previous years.

Key findings and conclusions:

- Median sound pressure levels in the Chukchi Sea at frequencies below 1000 Hz varied by up to 20 dB between 2010 and 2013. These large differences can be attributed to the presence of 3-D seismic surveys in 2007, 2008, and 2010, and 2-D seismic surveys in 2013.
- Bowhead whales: A wave of bowhead call detections occurred during the second half of August 2013 in the central and western part of the study area. A similar wave was observed in 2011 and 2012. Call activity off Barrow was consistently high during the entire summer recording period. Calls were first detected off Wainwright in the southwest of the study area during the first half of September. Detections in the study area started around 20 Sep, then increased and spread westward, continuing until the recorders were retrieved in mid-October.
- With the exception of a few detections at stations located between PLN20 and PL30, bowhead call activity west of Wainwright was concentrated north of 71° N, as was observed in previous years.
- Walrus: As in prior years, walrus were the most commonly detected species in the Chukchi Sea in summer 2013. The highest call counts were recorded at Station S01 located near Statoil's lease areas during the first half of the summer session and at Station PL10 from mid-September onward. These later detections coincided with walrus hauling-out near Point Lay. The eastern edge of the Burger area (i.e., Hanna Shoal) was also characterized by high call activity.
- Beluga whales: The 2013 data contained the highest number of beluga detections of all summer sessions in the program. Beluga call detections were widely dispersed in August, indicating that belugas spread out more widely than in other years after they left the coastal lagoons. This trend remained stable into fall when beluga calls were detected at all but one station.
- Minke whales: Minke whale calls were detected at six stations off Cape Lisburne and Point Lay in summer 2013. This detection distribution is similar to that from the previous two study years. Minke whale acoustic presence therefore appears to be restricted to the southwestern parts of the study area.
- Killer whales: Detections were less widely distributed than in previous years, but occurred mainly in the same general area off Cape Lisburne and Wainwright.
- Gray whale: Gray whale detections were largely concentrated within 20 mi of Wainwright. The area around PLN20, which was characterized by the second highest number of detections in 2011 and 2012, had fewer gray whale calls in summer 2013.
- Bearded seal: Bearded seal acoustic detections were concentrated in an arc ranging from Wainwright to PLN20 via Station S01 and within the Burger lease area.

- Ribbon seal calls were only detected over three days in October. Ringed seal calls were widely dispersed, but occurred only sporadically. These results, however, might still underestimate ringed seal calls because of their low overall calling rate and the limited manual review of just 5% of acquired data.
- Fin, minke, and humpback whales occur regularly in the study area in summer, perhaps benefiting from reduced Arctic ice conditions (see for instance Moore and Huntington 2008). Annual trends in acoustic presence have not been assessed because the detection rates for these species are low.

Acknowledgments

The authors acknowledge Dr. Julie Oswald for her contribution to the development of the bowhead and beluga call detectors. Del Leary provided support and advice throughout the development of the bowhead and walrus detectors and wrote the algorithm used to perform the detection probability analysis. Briand Gaudet and Trent Johnson were instrumental in developing and maintaining the software used to complete the manual analyses. Briand Gaudet also performed the bowhead localization analysis. Many thanks to the manual data analysts: Craig Evans, Frederic Paquet, Alain Carpentier, Karen Hiltz, Scott Trivers, Ben Rooker, and Eric Lumsden. Thanks also to the crew of the Westward Wind for their assistance with field operations and Sheyna Wisdom and her team for logistical support. And lastly, to Katherine Williams for several detailed report reviews.

Abbreviations & Glossary

2-D	two-dimensional
90% rms	root-mean-square pressure within the time window containing the center 90% (from 5% to 95%) of the pulse energy
AM	amplitude-modulated
AMAR	Autonomous Multichannel Acoustic Recorder (by JASCO Applied Sciences)
ASAMM	Aerial Surveys for Arctic Marine Mammals
AURAL	Autonomous Underwater Recorder for Acoustic Listening Model 2 (by Multi-Electronique)
BB	broadband
BG01	the Burger lease recorder Station
Buoy	meteorological buoy operated by Shell
BWi	bandwidth index
B*XX*	regional array recorder Station *XX* mi from Barrow
CL*XX*	regional array recorder Station *XX* mi from Cape Lisburne
CLN*XX*	regional array recorder Station *XX* mi north of Station CL50
CSESP	Chukchi Sea Environmental Studies Program
DP	detection probability
E	event
$\overline{E}$	non-event
ESA	Endangered Species Act of 1973 (US)
FFT	fast Fourier transform
FM	frequency-modulated
FN	false negative
FP	false positive
GB	gigabyte (1GB = 10243 bytes)
h	hour
HF	high frequency
in^3	cubic inches
JASCO	JASCO Applied Sciences
KL01	the Klondike lease recorder Station
LF	low frequency
M/V	motor vessel
MARU	Marine Autonomous Recording Unit

mi	statute mile
min	minute
NASA	National Aeronautics and Space Administration (US)
NSIDC	National Snow and Ice Data Center
P	precision
P_n	noise power
P_s	signal power
PL*XX*	regional array recorder Station, *XX* mi from Point Lay
PLN*XX*	regional array recorder Station, *XX* mi north of Station PL50
pt(s)	point(s)
R	recall
rms	root-mean-square
ROC	receiver operating characteristic
SEL	sound exposure level (dB re 1 µPa^2·s)
Shell	Shell Exploration and Production Company
SNR	signal-to-noise ratio
S01	the Statoil lease recorder Station
SPL	sound pressure level (dB re 1 µPa)
Statoil	Statoil USA Exploration and Production Inc.
STFT	short-time Fourier transform
TB	terabyte (1TB = 10244 bytes)
Ti	duration index
TP	true positive
TPR	true-positive rate
TN	true negative
USCRN	United States Climate Reference Network
UTC	Coordinated Universal Time
W*XX*	regional recorder Station *XX* mi from Wainwright
WN*XX*	regional recorder Station *XX* mi north of Station W50

Literature Cited

[BRP] Bioacoustics Research Program. 2010. *Passive Acoustic Monitoring of Marine Mammals in the Chukchi Sea 9 September – 14 October 2008*. Document Number Final Report. Technical Report 10-04 by The Cornell Lab of Ornithology for ConocoPhillips Alaska, Inc. https://companyweb.jasco.com/LibraryCatalogue/Holdings/0000000-corne------2010-monitoring-marine-mammals-Chukchi.pdf.

[NOAA] National Oceanic and Atmospheric Administration. 2008. IMS daily Northern Hemisphere snow and ice analysis at 4 km and 24 km resolution. National Snow and Ice Data Center. http://dx.doi.org/10.7265/N52R3PMC

Aerts, L.A.M., W. Hetrick, S. Sitkiewicz, C. Schudel, D. Snyder, and R. Gumtow. 2013. *Marine mammal distribution and abundance in the northeastern Chukchi Sea during summer and Early fall, 2008-2012*. Final Report prepared by LAMA Ecological for ConocoPhillips Company, Shell Exploration and Production Company and Statoil USA E&P, Inc.

Aerts, L.A.M., C.L. Christman, C. Schudel, W. Hetrick, and D. Snyder. 2014. *Marine mammal distribution and abundance in the northeastern Chukchi Sea during summer and early fall, 2008-2013*. LAMA Ecological, ConocoPhillips Company, Shell Exploration and Production Company and Statoil USA E&P, Inc. 81 pp.

Arveson, P.T. and D.J. Vendittis. 2000. Radiated noise characteristics of a modern cargo ship. *Journal of the Acoustical Society of America* 107(1): 118-129.

Belikov, R. and V. Bel'kovich. 2006. High-pitched tonal signals of beluga whales (*Delphinapterus leucas*) in a summer assemblage off Solovetskii Island in the White Sea. *Acoustical Physics* 52(2): 125-131.

Belikov, R.A. and V.M. Bel'kovich. 2008. Communicative pulsed signals of beluga whales in the reproductive gathering off Solovetskii Island in the White Sea. *Acoustical Physics* 54(1): 115-123. http://dx.doi.org/10.1134/S1063771008010168.

Blanchard, A.L. and A.L. Knowlton. 2013. *Chukchi Sea Environmental Studies Program 2008-2012: Benthic Ecology of the Chukchi Sea*. ConocoPhillips Company, Shell Exploration and Production Company and Statoil USA E & P, Inc.

Bockstoce, J.R. and J.J. Burns. 1993. Commercial whaling in the North Pacific sector. *The bowhead whale* 2: 563-577.

Bogoslovskaya, L., L. Votrogov, and I. Krupnik. 1982. The bowhead whale off Chukotka: migrations and aboriginal whaling. *Report of the International Whaling Commission* 32: 391-399.

Braham, H.W., B.D. Krogman, and G.M. Carroll. 1984. Bowhead and white whale migration, distribution, and abundance in the Bering, Chukchi, and Beaufort Seas, 1975-1978. US Department of Commerce. *NOAA Technical Report. NMFS SSRF-778*.

Christman, C.L., A.A. Brower, and M.C. Ferguson. 2013. *Pacific walrus (Odobenus rosmarus divergens) haulouts along the northwestern Alaskan coastline, summer and fall 2009-2013*. *Alaska Marine Science Symposium*, Anchorage.

Clark, C.W. and J.H. Johnson. 1984. The sounds of the bowhead whale, *Balaena mysticetus*, during the spring migrations of 1979 and 1980. *Canadian Journal of Zoology* 62: 1436-1441.

Clarke, J.T. and M.C. Ferguson. 2010. Aerial surveys of large whales in the northeastern Chukchi Sea, 2008-2009, with review of 1982-1991 data. *IWC Scientific Committee*. Volume SC/62/BRG13. 1-18 pp.

Clarke, J.T., A.A. Brower, C.L. Christman, and M.C. Ferguson. 2014. *Distribution and Relative Abundance of Marine Mammals in the Northeastern Chukchi and Western Beaufort Seas, 2013*. Annual Report, OCS Study BOEM 2014-018. National Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way NE, F/AKC3, Seattle, WA 98115-6349.

Crane, N.L. and K. Lashkari. 1996. Sound production of gray whales, *Eschrichtius robustus*, along their migration route: A new approach to signal analysis. *Journal of the Acoustical Society of America* 100(3): 1878-1886.

Deecke, V., J. Ford, and P. Slater. 2005. The vocal behaviour of mammal-eating killer whales: communicating with costly calls. *Animal Behaviour* 69: 395-405. <Go to ISI>://000226586700017

Delarue, J., M. Laurinolli, and B. Martin. 2009. Bowhead whale (*Balaena mysticetus*) songs in the Chukchi Sea between October 2007 and May 2008. *Journal of the Acoustical Society of America* 126(6): 3319-3328. http://link.aip.org/link/?JAS/126/3319/1.

Delarue, J., B. Martin, X. Mouy, J. MacDonnell, D. Hannay, N. Chorney, and J. Vallarta. 2010a. *Northeastern Chukchi Sea Joint Acoustic Monitoring Program 2008-2009*. Technical report for ConocoPhillips Company, Shell Exploration & Production Company, and Statoil USA E&P, Inc. by JASCO Applied Sciences Ltd. 156 plus appendices (84) pp. http://www.chukchiscience.com/Downloads/tabid/253/Default.aspx.

Delarue, J., H. Yurk, and B. Martin. 2010b. *Killer whale acoustic detections in the Chukchi Sea: Insights into their ecology and stock affiliation*. *Alaska Marine Science Symposium*, Anchorage, AK.

Delarue, J., M. Laurinolli, and B. Martin. 2011a. Acoustic Detections of Beluga Whales in the Northeastern Chukchi Sea, July 2007 to July 2008. *Arctic* 64(1): 15-24.

Delarue, J., B. Martin, X. Mouy, J. MacDonnell, J. Vallarta, and N. Chorney. 2011b. *Northeastern Chukchi Sea Joint Acoustic Monitoring Program 2009-2010*. *In*: Hannay, D. (ed.). Technical report for ConocoPhillips Company, Shell Exploration & Production Company, and Statoil USA E&P, Inc. by JASCO Applied Sciences, Dartmouth, NS. 156 pp. http://www.chukchiscience.com/Downloads/tabid/253/Default.aspx.

Delarue, J., B. Martin, D. Hannay, and C.L. Berchok. 2013a. Acoustic occurrence and affiliation of fin whales detected in the Northeastern Chukchi Sea, July to October 2007–10. *Arctic* 66(2): 159-172. http://arctic.synergiesprairies.ca/arctic/index.php/arctic/article/view/4287.

Delarue, J., J. Vallarta, H. Frouin-Mouy, J. Wladichuk, B. Martin, X. Mouy, and D.H. Hannay. 2013b. *Northeastern Chukchi Sea Joint Acoustic Monitoring Program 2011-2012*. Document Number 00533 Version 3.0. Technical report for ConocoPhillips Company, Shell Exploration & Production Company, and Statoil USA E&P, Inc. by JASCO Applied Sciences.

[ESA] Endangered Species Act of 1973 as Amended. 2002. United States Pub. L. No. 93–205, 87 Stat. 884, 16 U.S.C. 1531 (Dec 28, 1973) as amended by Pub. L. No. 107–136 (Jan 24, 2002). http://www.nmfs.noaa.gov/pr/pdfs/laws/esa.pdf.

Diachok, O.I. 1976. Effects of sea-ice ridges on sound propagation in the Arctic Ocean. *Journal of the Acoustical Society of America* 59(5): 1110-1120.

Ford, J.K.B. 1989. Acoustic behavior of resident killer whales (*Orcinus orca*) off Vancouver Island, British Columbia. *Canadian Journal of Zoology* 67(3): 727-745.

Frost, K.J., L.F. Lowry, and G. Carroll. 1993. Beluga whale and spotted seal use of a coastal lagoon system in the northeastern Chukchi Sea. *Arctic* 46: 8-16.

George, J.C. and R. Suydam. 1998. Observations of killer whale (*Orcinus orca*) predation in the Northeastern Chukchi and Western Beaufort Seas. *Marine Mammal Science* 14(2): 330-332.

George, J.C., J. Zeh, R.S. Suydam, and C.W. Clark. 2004. Abundance and population trend (1978-2001) of western Arctic bowhead whales surveyed near Barrow, Alaska. *Marine Mammal Science* 20(4): 755-773.

Greene, C.R. and B.M. Buck. 1964. Arctic Ocean Ambient Noise. *Journal of the Acoustical Society of America* 36(6): 1218-1220. http://scitation.aip.org/content/asa/journal/jasa/36/6/10.1121/1.1919192.

Hopcroft, R.R., J. Questel, and C. Clarke-Hopcroft. 2014. *Oceanographic assessment of the planktonic communities in the northeastern Chukchi Sea: Report for Survey year 2013*. Institute of Marine Science, University of Alaska Fairbanks, ConocoPhillips, Shell Exploration & Production Company and Statoil USA Exploration & Production Inc.

Jay, C.V., A.S. Fischbach, and A.A. Kochnev. 2012. Walrus areas of use in the Chukchi Sea during sparse sea ice cover. *Marine Ecology Progress Series* 468: 1-13.

Jones, J.M., B.J. Thayre, E.H. Roth, M. Mahoney, I. Sia, K. Merculief, C. Jackson, C. Zeller, M. Clare, et al. 2014. Ringed, Bearded, and Ribbon Seal Vocalizations North of Barrow, Alaska: Seasonal Presence and Relationship with Sea Ice. *Arctic* 67(2): 203–222.

Karlsen, J., A. Bisther, C. Lydersen, T. Haug, and K. Kovacs. 2002. Summer vocalisations of adult male white whales (*Delphinapterus leucas*) in Svalbard, Norway. *Polar Biology* 25(11): 808-817. http://www.researchgate.net/publication/226011456_Summer_vocalisations_of_adult_male_white_whales_(Delphinapterus_leucas)_in_Svalbard_Norway/file/60b7d5298991b7cd05.pdf.

Ljungblad, D.K., P.O. Thompson, and S.E. Moore. 1982. Underwater sounds recorded from migrating bowhead whales, *Balaena mysticetus*, in 1979. *Journal of the Acoustical Society of America* 71(2): 477-482.

Lowry, L.F., G. Sheffield, and J.C. George. 2004. Bowhead whale feeding in the Alaskan Beaufort Sea, based on stomach contents analyses. *Journal of Cetacean research and Management* 6(3): 215-223.

Ma, B.B. and J.A. Nystuen. 2005. Passive acoustic detection and measurement of rainfall at sea. *Journal of Atmospheric and Oceanic Technology* 22(8): 1225-1248.

MacDonnell, J. and B. Martin. 2011. Estimating bowhead whale communications space using measured and modeled data. *Journal of the Acoustical Society of America* 129(4): 2574-2574. http://scitation.aip.org/content/asa/journal/jasa/129/4/10.1121/1.3588494.

Martin, B., D. Hannay, M. Laurinolli, C. Whitt, X. Mouy, and R. Bohan. 2009. Chukchi Sea Acoustic Monitoring Program. (Chapter 5) *In* Ireland, D.S., D.W. Funk, R. Rodrigues, and W.R. Koski (eds.). *Joint Monitoring Program in the Chukchi and Beaufort Seas, open water seasons, 2006-2007*. LGL Alaska Report P971-2. Report from LGL Alaska Research Associates Inc., LGL Ltd., JASCO Research Ltd., and Greeneridge Sciences Inc. for Shell Offshore Inc., ConocoPhillips Alaska Inc., National Marine Fisheries Service (US), and US Fish and Wildlife Service. 485 plus appendices pp.

Martin, B., D. Hannay, C. Whitt, X. Mouy, and R. Bohan. 2010. Chukchi Sea Acoustic Monitoring Program. (Chapter 5) *In* Funk, D.W., D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.). *Joint Monitoring Program in the Chukchi and Beaufort Seas, open water seasons, 2006–2008*. LGL Alaska Report P1050-2. Report from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research Ltd., for Shell Offshore, Inc., other industry contributors, National Marine Fisheries Service (US), and US Fish and Wildlife Service. 506 plus appendices pp.

Mefford, T. and E. Dutton. 2003. *Barrow Alaska Climate Monitoring and Diagnostics: Meteorology and Radiation Data*. National Snow and Ice Data Center, Boulder, Colorado USA.

Mellinger, D.K., S.W. Martin, R.P. Morrissey, L. Thomas, and J.J. Yosco. 2011. A method for detecting whistles, moans, and other frequency contour sounds. *Journal of the Acoustical Society of America* 129(6): 4055-4061. http://dx.doi.org/doi/10.1121/1.3531926.

Mizuguchi, D., M. Tsunokawa, and S. Koshima. 2013. *Estimated function of underwater vocalization of ringed seals (Phoca hispida) in captivity*. *20th Biennial Meeting of the Society for Marine mammalogy*, Dunedin, NZ.

Moore, S.E. 1992. Summer records of bowhead whales in the northeastern Chukchi Sea. *Arctic and Alpine Research* 45(4): 398-400. http://pubs.aina.ucalgary.ca/arctic/arctic45-4-398.pdf.

Moore, S.E., D.P. DeMaster, and P.K. Dayton. 2000. Cetacean habitat selection in the Alaskan Arctic during summer and autumn. *Arctic* 53(4): 432-447. http://daytonlab.ucsd.edu/publications/Mooreetal00.pdf.

Moore, S.E. and H.P. Huntington. 2008. Arctic marine mammals and climate change: Impacts and resilience. *Ecological Applications* 18(sp2): S157–S165. http://www.esajournals.org/doi/abs/10.1890/06-0571.1.

Moore, S.E., J.C. George, G. Sheffield, J. Bacon, and C.J. Ashjian. 2010. Bowhead whale distribution and feeding near Barrow, Alaska, in late summer 2005–06. *Arctic* 63(2): 195-205.

Mouy, X., M. Bahoura, and Y. Simard. 2009. Automatic recognition of fin and blue whale calls for real-time monitoring in the St. Lawrence. *Journal of the Acoustical Society of America* 126(6): 2918-2928. <Go to ISI>://000272838800015.

Quakenbush, L.T., J.J. Citta, J.C. George, R.J. Small, and M.P. Heide-Jørgensen. 2010. Fall and winter movements of bowhead whales (*Balaena mysticetus*) in the Chukchi Sea and within a potential petroleum development area. *Arctic* 63(3): 289–307. http://arctic.synergiesprairies.ca/arctic/index.php/arctic/article/view/1493.

Rankin, S. and J. Barlow. 2005. Source of the North Pacific “boing” sound attributed to minke whales. *Journal of the Acoustical Society of America* 118(5): 3346-3351.

Ray, C., W.A. Watkins, and J.J. Burns. 1969. The underwater song of *Erignathus barbatus* (Bearded seal). *Zoologica* 54: 79-83.

Richard, P.R., A.R. Martin, and J.R. Orr. 2001. Summer and autumn movements of belugas of the Eastern Beaufort Sea stock. *Arctic* 54: 223-236.

Roth, E.H. 2012. Underwater ambient noise on the Chukchi Sea continental slope from 2006-2009. *Journal of the Acoustical Society of America* 13(1): 104-110.

Schusterman, R.J. and C. Reichmuth. 2008. Novel sound production through contingency learning in the Pacific walrus (*Odobenus rosmarus divergens*). *Animal Cognition* 11(2): 319-27. NLM.

Stafford, K.M., D.K. Mellinger, S.E. Moore, and C.G. Fox. 2007. Seasonal variability and detection range modeling of baleen whale calls in the Gulf of Alaska, 1999–2002. *Journal of Acoustical Society of America* 122(6): 3378-3390.

Stafford, K.M., S.E. Moore, C.L. Berchok, O. Wiig, C. Lydersen, E. Hansen, D. Kalmbach, and K.M. Kovacs. 2012. Spitsbergen's endangered bowhead whales sing through the polar night. *Endangered Species Research* 18: 95-103.

Stirling, I. 1973. Vocalization in the ringed seal (*Phoca hispida*). *Journal of the Fisheries Board of Canada* 30(10): 1592-1594.

Stirling, I., W. Calvert, and H. Cleator. 1983. Underwater vocalizations as a tool for studying the distribution and relative abundance of wintering pinnipeds in the high Arctic. *Arctic* 36(3): 262-274. http://arctic.synergiesprairies.ca/arctic/index.php/arctic/article/download/2275/2252.

Stirling, I., W. Calvert, and C. Spencer. 1987. Evidence of stereotyped underwater vocalizations of male Atlantic walruses (*Odobenus rosmarus rosmarus*). *Canadian Journal of Zoology* 65(9): 2311-2321.

Stringer, W.J. and J. Groves. 1991. Location and areal extent of polynyas in the Bering and Chukchi Seas. *Arctic* 44: 164-171.

Suydam, R.S., L.F. Lowry, and K.J. Frost. 2005. *Distribution and movements of beluga whales from the eastern Chukchi Sea stock during summer and early autumn*. OCS Study MMS2005-035. www.boem.gov/BOEM-Newsroom/Library/Publications/.../2005_035.aspx.

Van Parijs, S.M., K.M. Kovacs, and C. Lydersen. 2001. Spatial and temporal distribution of vocalising male bearded seals-implications for male mating strategies. *Behaviour* 138(7): 905-922.

Watkins, W.A. and G.C. Ray. 1977. Underwater sounds from ribbon seal, *Phoca (Histriophoca) fasciata*. *Fishery Bulletin* 75: 450-453. https://darchive.mblwhoilibrary.org/bitstream/handle/1912/6185/Watkins_Ray_1977%20ribbon%20seal%20vocalizations.pdf?sequence=1.

Wenz, G.M. 1962. Acoustic ambient noise in the ocean: Spectra and sources. *Journal of the Acoustical Society of America* 34(12): 1936-1956.