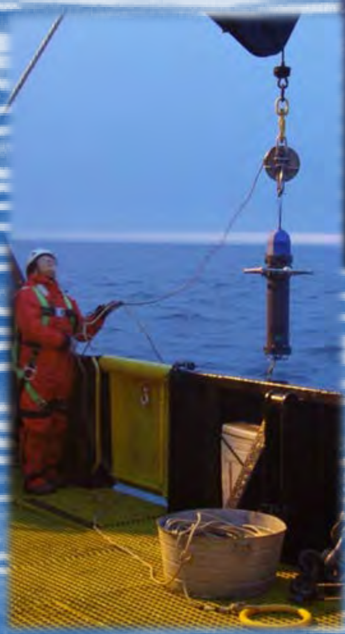
NORTHEASTERN CHUKCHI SEA JOINT ACOUSTIC MONITORING PROGRAM 2013–2014



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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

1. Introduction

This report presents the results of the winter 2013–2014 and summer 2014 seasons of the acoustic monitoring program in the northeastern Chukchi Sea, collected for the multi-year Chukchi Sea Environmental Science Program (CSESP). These data extend the CSESP acoustic dataset through summer 2014 using methods and study locations that are consistent with those from previous years of the program. Funding of the 2013–2014 program was provided by Shell Exploration & Production Company and ConocoPhillips Oil Company.

Shell began baseline acoustic monitoring in the Chukchi Sea in summer 2006 and 2007 as a component of their Arctic marine mammal research programs. In 2007, ConocoPhillips initiated sponsorship of CSESP that included an acoustic monitoring component. Shell and ConocoPhillips jointly sponsored CSESP in 2008 and both companies have contributed support through 2014. Statoil USA Exploration and Production, Inc. contributed to joint sponsorship from 2010 to 2012. 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. JASCO Applied Sciences Ltd. (JASCO) has conducted consecutive summer and winter acoustic recording studies since summer 2007 and has presented program results in yearly reports similar to this one.

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].

The acoustic monitoring program is meeting these objectives using autonomous acoustic recording systems deployed on the seabed for long periods, across a large area of the northeastern Chukchi Sea. The data acquired under this program cover a continuous period of more than seven years (2007 to present) at multiple locations. In terms of temporal and spatial coverage, the data represent one of the largest and most comprehensive sets of underwater acoustic recordings and includes 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 survey 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

[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.

distributions, habitat usage, calling behaviors, and migration paths. One emphasis of the study was to localize vocalizing bowhead whales (*Balaena mysticetus)* in offshore areas near oil and gas exploration leases because bowheads are an important food source to subsistence hunters in the area.

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 passive acoustic monitoring studies have and continue to improve our understanding of bowhead fall migration routes and timing. For instance, passive acoustic data collected from recorders deployed north of Hanna Shoal in winter 2011–2012 and 2012–2013 helped us better understand migration behavior by gathering information from areas that were not sampled, because data collection by means other than acoustic recordings is difficult to achieve. The difficulties arise due to the frequently adverse weather conditions, ice presence, and remoteness.

Objective 3 includes the gathering of more 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 acoustic recorder deployments provided new and significant information about walrus presence and migration timing (Martin et al. 2009, Delarue et al. 2010a, Martin et al. 2010). Calls from walruses near large terrestrial haul-outs, primarily near Point Lay, were identified acoustically in several years. These data also showed walruses moving between on-shore haul-outs and the Hanna Shoal foraging areas, indicating that the haul-outs could be important feeding areas in low ice years. The 2010 deployments yielded data showing seismic survey noise might affect walrus communications (Delarue et al. 2011a).

Objective 3 also aims to document the occurrence of beluga whales in offshore areas. Large numbers of CSESP acoustic detections in spring indicate that beluga whales seasonally migrate through the lease areas of the northeastern Chukchi Sea. Low detection numbers in summer are consistent with the moderate overlap between the summer range of the eastern Chukchi Sea beluga population with the acoustic array (Hauser et al. 2014) and the small size of that population (Allen and Angliss 2013). Fall recordings within the lease areas also yielded far fewer detections than spring recordings, which suggest that the fall migration path does not pass through the same areas, or that belugas are vocalizing less during the fall. Some have speculated that the fall migration might occur north of Hanna Shoal, but belugas were not detected in acoustic data collected more northern stations in 2012. Recent analyses of telemetry data suggest that the largest stock of belugas (Beaufort Sea) generally migrates even further north in the fall, circumnavigating the acoustically instrumented study area. Eastern Chukchi Sea belugas, however, migrated through our monitoring area. The low fall detection rate reflects a small population that likely calls less frequently than in spring and travels through a large study area with relatively sparse recorder coverage.

1.2. Overview of Marine Mammals Results

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 as of yet been classified.

Winter acoustic data (mid-October through July):

- Provided important information on migration timing and distribution of bowhead and beluga whales during their fall and spring migrations.
- Documented the prevalence of beluga and bowhead whales in coastal leads during the spring migration, even though some individuals migrated further offshore through the lease areas.
- Documented the yearlong occurrence of ringed and bearded seals, the return of walruses in the spring and gray whales in early summer, and sporadic detections of ribbon seals and minke whales in the fall.

Summer acoustic data (August through mid-October):

- 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 walruses that transitioned from Hanna Shoal to shore haul-outs starting in late August 2007 and most years after that.
- Consistently demonstrated the scarce acoustic presence of bowheads and belugas in the northeastern Chukchi Sea in July and August, and their return 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 Deployments 2006–2014

In summer 2006, the Cornell Lab of Ornithology's Bioacoustics Research Program carried out an acoustic monitoring program for Shell. 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 16,000 and 16,384 Hz, respectively (Figure 1), a sampling rate that allows acoustic sound frequencies of up to 8 kHz to be recorded. The summer recording periods included four lines of recorders starting at Cape Lisburne, Point Lay, Wainwright, and Barrow and extending up to 135 miles off the coast. Additional clusters of recorders were deployed near lease blocks and well sites as follows:

- Summer 2008: Cornell deployed one cluster of 13 MARUs around the Klondike and one around the 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 both the Klondike and Burger well sites, and one near the Statoil lease area.
- Summer 2012: JASCO deployed one AMAR each 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 one in the Statoil lease area, and eleven AMARs around the Burger well sites. We focused more on the Burger lease area as a continuation of the 2012 monitoring effort, which was when Shell carried out drilling activity.
- Summer 2014: JASCO deployed one AMAR near the Klondike well site, and six AMARs around the Burger well sites even though no drilling activities occurred there in this year.

During the winter recording periods, 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 total. These stations were redeployed for winter 2012–2013 but not subsequently. Three nearshore recorders were deployed in winter 2013–2014 to document passages of bowhead and beluga whales during their migrations, particularly in the spring.

The winter session recorders had the following duty cycles:

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

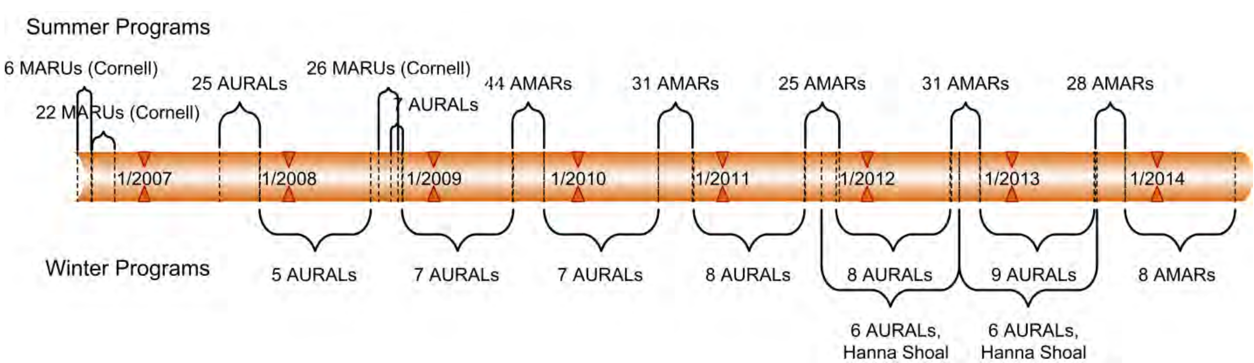

Figure 1. Timeline of Chukchi Sea Acoustic Monitoring Program, 2006 to 2014.The acoustic data acquired in 2013–2014 were analyzed to quantify ambient sound levels, the presence of anthropogenic activity, and the acoustic presence of marine mammals. The ambient noise measurements add to the growing knowledge of underwater Arctic soundscape baseline conditions, thus providing information for inter-annual comparisons. 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. Acoustic Recorders

All acoustic data were recorded using AMARs (JASCO Applied Sciences). Each AMAR had a single omnidirectional hydrophone and was powered by two D-cell alkaline battery packs: one with 9 cells and one with 48 cells. Acoustic data were recorded continuously on 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.

Each AMAR 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 2).

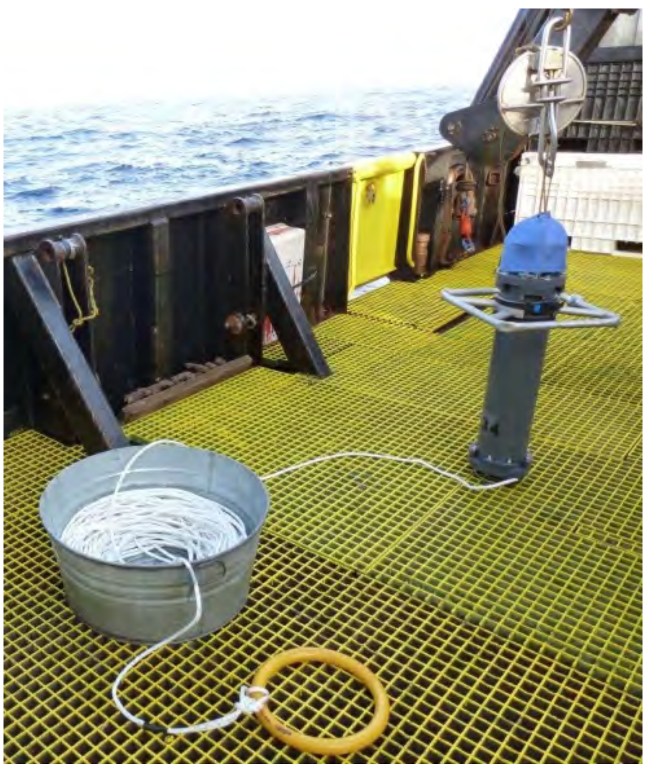

Figure 2. An AMAR just before it was deployed in the northeastern Chukchi Sea.

2.1.2. Winter 2013–2014 Recording Period

Acoustic data for the winter 2013–2014 recording period were acquired using eight AMARs deployed offshore of Cape Lisburne, Point Lay, Wainwright, and Barrow (Figure 3). These recorders were set to record at 16 ksps for 5 min of every 30 min (i.e., a 17% duty cycle) due to battery limitations.

The winter AMARs were deployed from 11–20 Oct 2013. Two recorders (B5 and PL10) stopped prematurely. Five recorders performed as intended and acquired data from 203 to 342 days (Table 1). Many attempts made by two vessels to retrieve the recorder at Station PLN40 in fall 2014 were unsuccessful. The recorder was retrieved in fall 2015 with data intact, but these data have not yet been analyzed or included here.

Ice concentration data were obtained from the Ocean and Sea Ice SAF website (http://osisaf.met.no/p/ice/). The grid size for these data is 10 km.

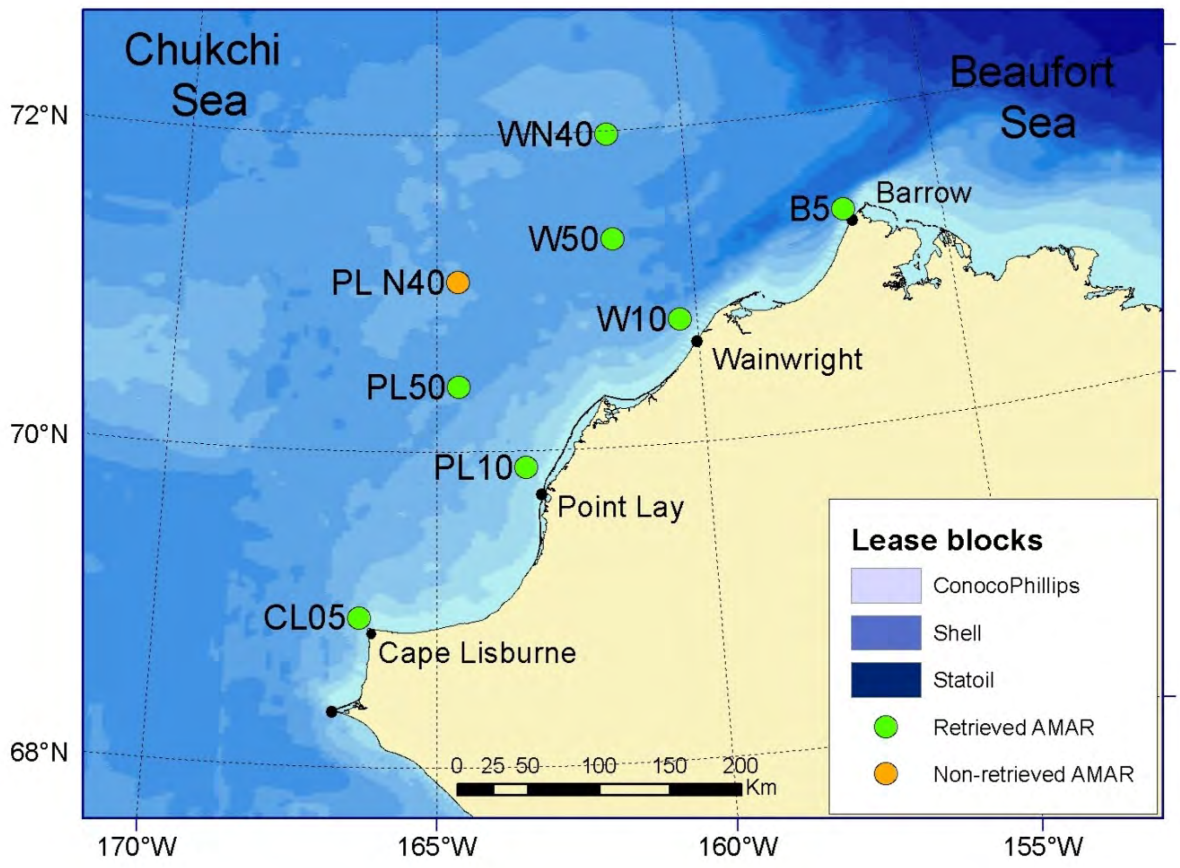

Figure 3. Winter 2013–2014 stations of the Acoustic Monitoring Program in the northeastern Chukchi Sea. Shades of blue represent water depth.

Table 1. Recorder locations (see Figure 3) and recording periods for the winter 2013–2014 Acoustic Monitoring Program. The AMARs operated on 17% duty cycles (recording 5 min of every 30 min) from deployment to record end. Dates are in UTC.

Station	Latitude (°N)	Longitude (°W)	Deployment	Record end	Recording days
B5	71.36338	-156.93705	11 Oct 2013	26 Dec 2013	77
CL05	68.94133	-166.37435	20 Oct 2013	11 Jun 2014	203*
PL10	70.77598	-160.32813	18 Oct 2013	27 Jan 2014	58*
PL50	71.31060	-161.53740	19 Oct 2013	2 Aug 2014	299
W10	69.88850	-163.35412	11 Oct 2013	2 Aug 2014	307
W50	70.40300	-164.58722	15 Oct 2013	21 Sep 2014	342
WN40	71.31060	-161.53740	12 Oct 2013	18 Sep 2014	342

* Data gaps occurred throughout the recording period.

2.1.3. Summer 2014 Recording Period

Acoustic data for the summer 2014 were acquired with 28 AMARs. Twenty-two AMARS were deployed along four 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 4). Six AMARs were deployed in an array around the Burger drill site. The recorders at Station BGF and B5 were set to record 770 s at 16 ksps and 130 s at 375 ksps for a total cycle length of 15 min. All other recorders recorded continuously at 16 ksps.

Twenty-two recorders were deployed between 31 Jul and 6 Aug 2014. Six were deployed between 21 Aug and 2 Sep because of ice conditions. Most recorders were retrieved between 9 and 17 Oct 2014 (Table 2). The recorders at Stations B5, B15, and CL50 were left behind because of scheduling delays; they were retrieved in summer 2015. All recorders, except the following, were still recording upon retrieval and yielded complete datasets. The recorder at Station BGA yielded no data, the one at BGD stopped recording early, recorders at Stations B5, B15, and CL50 recorded until the second week of November, whereas the one at WN60 had noise issues and thus its data could not be analyzed.

Wind speeds were acquired from the meteorological buoys deployed as part of the CSESP.

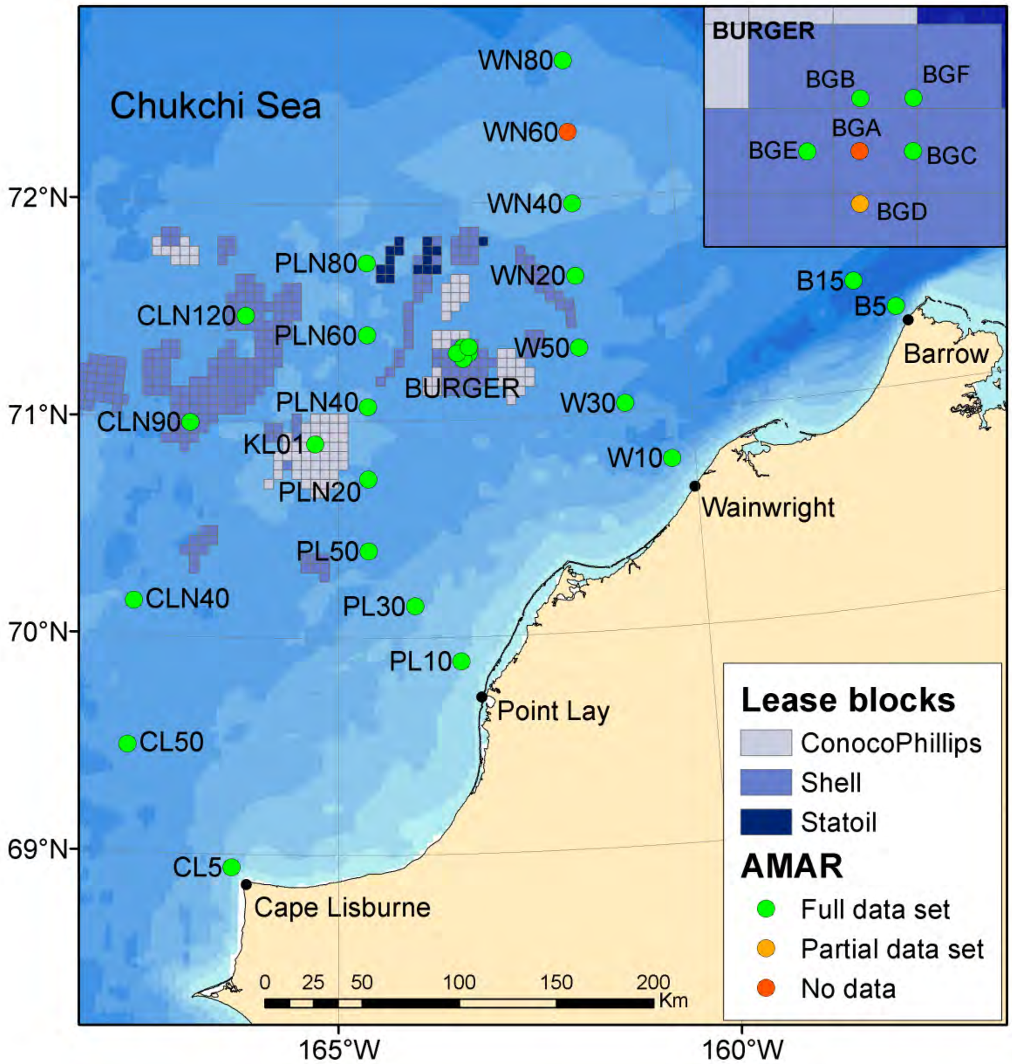

Figure 4. Recorder stations for the summer 2014 program in the northeastern Chukchi Sea. The inset map shows detail of the Burger array. Shades of blue represent water depth.Table 2. Recorder locations (see Figure 4) and recording durations for the summer 2014 Acoustic Monitoring Program. Stations are listed alphabetically.

Station	Latitude (°N)	Longitude (°W)	Deployment	Record end	Recording days
B5	71.36311	-156.93723	6 Aug 2014	9 Nov 2014	95
B15	71.50413	-157.50105	6 Aug 2014	13 Nov 2014	99
BGA	71.30875	-163.21277	5 Aug 2014	14 Oct 2014	No data
BGB	71.33572	-163.20930	5 Aug 2014	14 Oct 2014	70
BGC	71.30793	-163.12788	5 Aug 2014	15 Oct 2014	71
BGD	71.28178	-163.21452	5 Aug 2014	18 Aug 2014	14
BGE	71.30942	-163.29640	5 Aug 2014	14 Oct 2014	70
BGF	71.33517	-163.12437	5 Aug 2014	14 Oct 2014	70
CL5	68.94177	-166.37450	30 Jul 2014	17 Oct 2014	79
CL50	69.49562	-167.78368	31 Jul 2014	6 Nov 2014	98
CLN40	70.15907	-167.78297	31 Jul 2014	8 Oct 2014	70
CLN90B	70.98843	-167.09870	31 Jul 2014	10 Oct 2014	71
CLN120B	71.48605	-166.34962	31 Jul 2014	11 Oct 2014	71
KL01	70.89692	-165.32815	1 Aug 2014	10 Oct 2014	70
PL10	69.88887	-163.35122	2 Aug 2014	9 Oct 2014	69
PL30	70.14685	-163.96267	2 Aug 2014	9 Oct 2014	69
PL50	70.40333	-164.58762	2 Aug 2014	9 Oct 2014	69
PLN20	70.73500	-164.58708	1 Aug 2014	10 Oct 2014	69
PLN40	71.09058	-164.58398	4 Aug 2014	13 Oct 2014	70
PLN60	71.39890	-164.58848	5 Aug 2014	13 Oct 2014	69
PLN80	71.73082	-164.58823	21 Aug 2014	11 Oct 2014	51
W10	70.77595	-160.32613	3 Aug 2014	15 Oct 2014	74
W30	71.04405	-160.92947	6 Aug 2014	15 Oct 2014	70
W50	71.31118	-161.54887	2 Sep 2014	16 Oct 2014	44
WN20	71.64330	-161.53560	2 Sep 2014	16 Oct 2014	44
WN40	71.97653	-161.52323	2 Sep 2014	12 Oct 2014	41
WN60	72.30695	-161.52285	2 Sep 2014	12 Oct 2014	41*
WN80	72.63832	-161.53598	2 Sep 2014	12 Oct 2014	41

* Recordings were contaminated with noise so they were not analyzed.

2.2. Data Analysis Overview

Acoustic data were analyzed using a combination of automated and manual techniques. Ocean sound levels and the proportion to which anthropogenic activities contributed to them 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 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 throughout the year 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 necessarily represent the abundance of animals of that species. Call counts indicate relative abundance of animals between stations, but they assume the study area populations are similar in age and sex.

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 Jul–Aug Sep–Dec	Common Occasional Common	High, decreasing Low High, increasing	✓	✓
Walrus	Candidate for listing	Jun–Oct Nov–Dec	Abundant Occasional	High High	✓	✓
Beluga whales	–	Apr–Jun Jul–Dec	Common Occasional	High Moderate	✓	✓
Bearded seals	–	Nov–Jun Jul–Oct	Abundant Abundant	High Low, increasing	✓	✓
Fin whales	Endangered	Aug–Oct	Occasional	Low		✓
Gray whales	De-listed in 1994; Not threatened	Jul–Oct	Common	Low		✓
Humpback whales	Endangered	Aug–Sep	Occasional	Low to moderate		✓
Killer whales	–	Jul–Oct	Occasional	Low		✓
Minke whales	–	Aug–Oct	Occasional	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

Seven trained analysts used JASCO's SpectroPlotter software to visually examine spectrograms and to listen to audio playbacks as necessary. The software provided a consistent set of tools for documenting the duration and bandwidth of each marine mammal call. Four analysts had several years of experience classifying arctic marine mammal vocalizations in previous Chukchi Sea datasets. Two other 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:

- 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 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 possibly stemming 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.
- Assess how well automated classifiers perform. Precision and recall methods were used to quantitatively assess performance by comparing outputs of the automated classifiers with the manual classifications for each species.

The probability of detection by our 5% manual analysis 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. This protocol was determined 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 2013–2014 and summer 2014 data from all operational recorders were analyzed manually.

The winter acoustic data were acquired on a duty-cycle, recording for 5 min every 30 min, yielding 48 sound files per day. The middle 30 s sample of every other data file was manually analyzed. Analysts annotated one call per species for all extracted 30 s samples and stations to record each species in the dataset. In addition, analysts annotated all marine mammal calls in a subset of samples randomly selected across days and stations. 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 sound files, which yielded 48 files per day. The middle 90 s sample of each 30 min file was manually analyzed. Analysts annotated one call per species per sample. Similar to the winter acoustic data treatment, analysts annotated all identified marine mammal vocalizations in a subset of samples randomly selected across days and stations 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 8.04 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 5 shows a block diagram outlining the stages of the automated analysis. Walrus, bowhead, minke, 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 sound level estimates, we defined ambient levels from individual minutes of data that did 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. The methods and results are described in Appendix D (Estimating the Detection Range of Bowhead Moans).

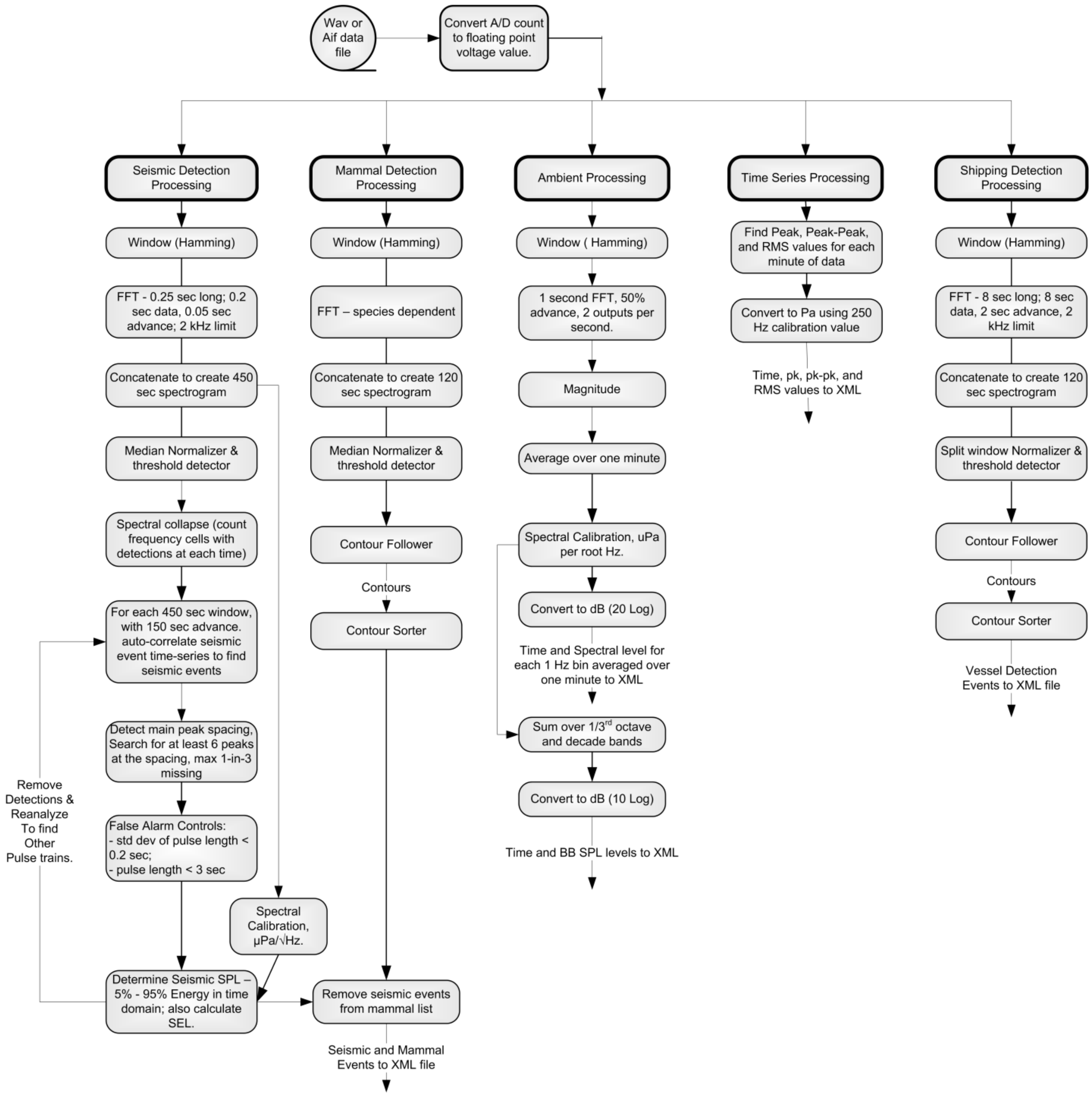

Figure 5. Major stages of JASCO's automated acoustic analysis software suite.

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 levels, which corresponds approximately with the hearing filter bandwidth in terrestrial mammals, and decade band, a logarithmic filter bandwidth, sound pressure levels for each minute of data. More details about noise analysis methods and results are provided in Appendix B, Ambient Noise Results.

2.4.2. Vessel Noise Detection

Vessel detection was performed in two steps. In the first step, constant, narrowband tones produced by the ship's propulsion system and other rotating machinery (Arveson and Vendittis 2000) were detected in each file (Appendix A.10, Vessel Noise Detection). These are also referred to as tonals.

During the second step, the root-mean-square sound pressure levels (rms SPL) were assessed once per minute within the 40-315 Hz frequency band typical for large vessel noise. Background estimates of the shipping band rms SPL and the total rms SPL were compared to their median values over the 12 h window, centered on the current time. Shipping detections were defined by three criteria: 1.) the rms SPL in the shipping band was at least 3 dB above the median, 2.) at least 5 shipping tonals (0.125 Hz bandwidth) were present, and 3.) the rms SPL in the shipping band was within 8 dB of the total rms SPL (Figure 6).

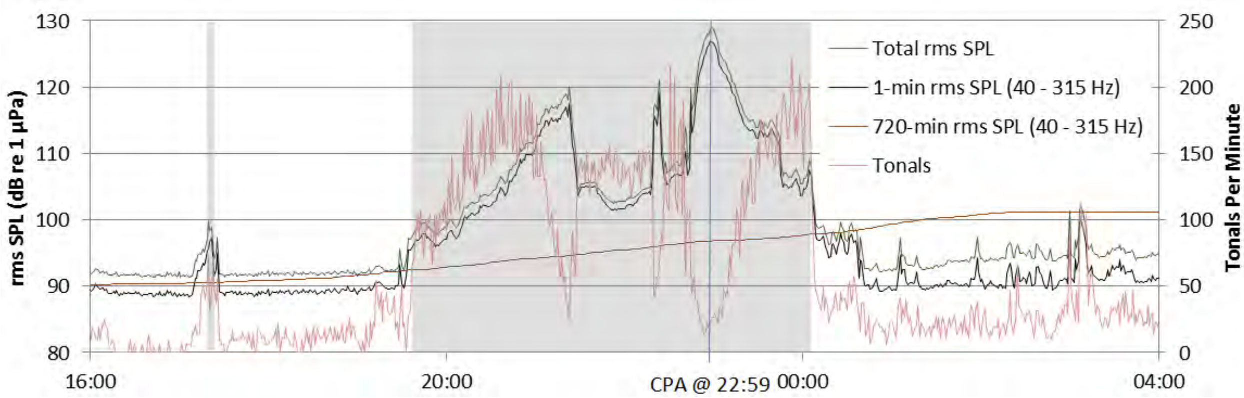

Figure 6. Example of broadband and in-band root-mean-square sound pressure level (rms SPL) and the number of tonals detected per minute as a ship approached a recorder, stopped, and then departed. The shaded area is the period of shipping detection. Fewer tonals are detected at the ship's closest point of approach (CPA) at 22:59 because of masking by broadband cavitation noise and due to Doppler shift that shifts the tone frequencies.

2.4.3. Seismic Survey Event Detection

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 Detection

A specialized detector identified calls from walruses and from bowhead, beluga, and minke whales. 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 Detection

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 Detection

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 Detection

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 2013–2014 data, the analysis protocol (see Section 2.3.1) yielded a test dataset of 186 fully annotated samples. For the summer 2014 data, manual analysis yielded a test dataset of 138 fully annotated 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 2013–2014 and summer 2014 datasets.

Species	Winter 2013–2014		Summer 2014	
	P	*R*	*P*	*R*
Bowhead	0.74	0.30	0.81	0.39
Walrus	0.72	0.28	0.52	0.88
Beluga	0.56	0.55	0.68	0.55
Bearded seal	0.77	0.65	0.84	0.58
Minke whale	0.95	0.50	-	-

3. Results

Tables and figures in this section that are preceded by a letter refer to tables and figures in the appendices.

3.1. Received Ocean Sound Levels

The received ocean sound levels at Station PLN40, a representative station, illustrate the acoustic characterization methods applied to all stations. The winter 2013–2014 recorder at PLN40 was not retrieved in time for this analysis, thus data from W50 are used as a surrogate for PLN40 for winter 2013–2014. The received sound levels at all other stations are in Appendix B, Ambient Noise Results.

3.1.1. Winter 2013–2014 Recording Period

The total received broadband sound levels at W50 varied between 79 dB and 149 dB re 1 µPa (Figure 7, top). From 29 Oct to 23 Nov, while the area was ice-free, sound levels were 90–115 dB re 1 µPa. Bowhead whale calls increased sound levels in the 100–1000 Hz band in early December. Station W50 was covered with sea ice from approximately 23 Nov 2013 to 16 Jul 2014. For the whole study area, freeze-up began in late October and was complete by the end of November. Ice began retreating around late May, lasting until mid-August. When ice was present and temperatures began to fall, localized high intensity ice-cracking impulses occurred (Figure 7, 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 recording period (Figure 7, bottom).

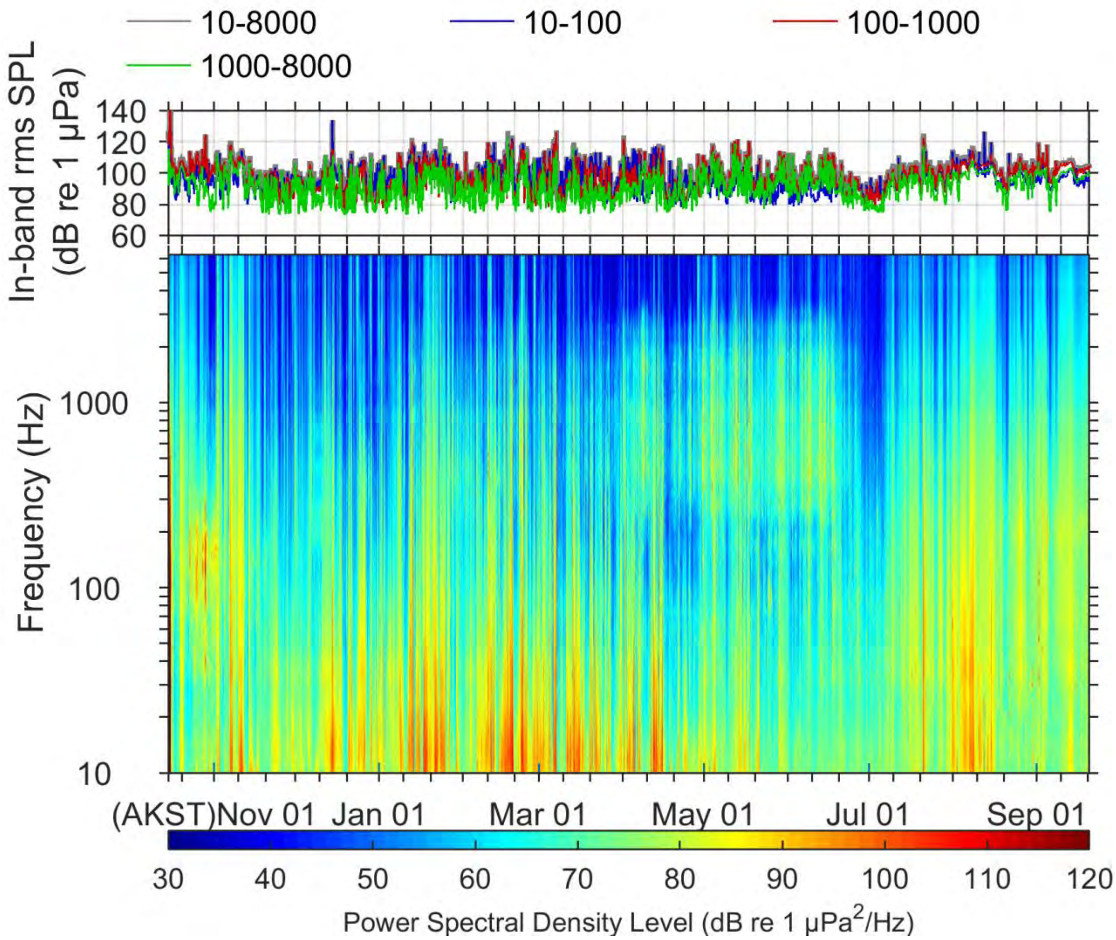

Figure 7. (Top) Broadband and decade-band sound pressure levels (SPL) for winter 2013 Station W50. (Bottom) Spectrogram of underwater sound recorded from October 2013 to August 2014. Bowhead calls are apparent in late-October between 80 Hz and 200 Hz. Bearded Seal calls are apparent between April and mid-June between 300 Hz and 3 kHz.

The 1/3-octave mean SPL values (over time) were consistently about 15 dB higher than the 1/3-octave median SPL values calculated over the entire recording period (Figure 8). 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} spectral levels consistently decreased by approximately 10 dB/decade over the entire frequency range. AMARs were used in place of AURALs for winter deployments in 2013–2014 for the first time. The AMAR’s lower noise floor produced lower winter ambient noise measurements above 1 kHz, that had been previously masked by AURAL self-noise. This effect is detailed in Section 4.1.1.

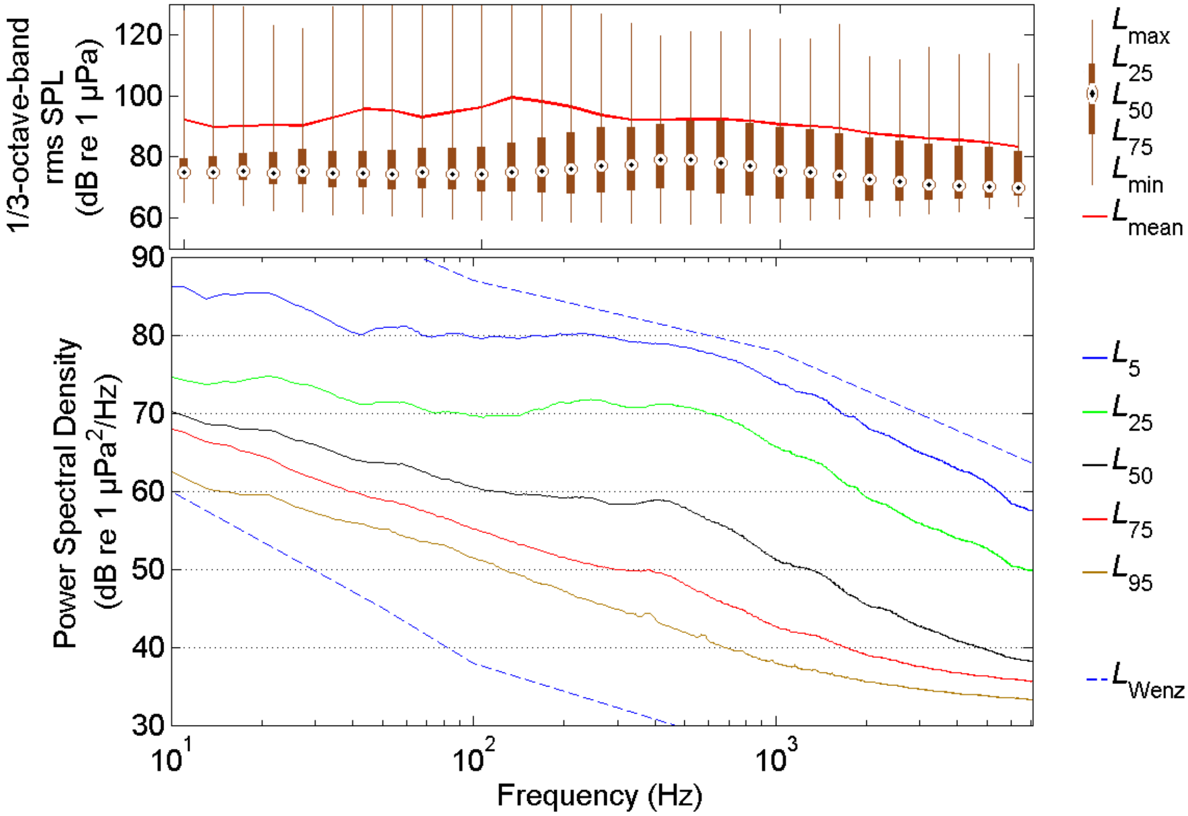

Figure 8. (Top) Distribution of 1/3-octave-band sound pressure levels (SPL) at winter Station PL50. The red line indicates the root-mean-square (rms) level recorded from October 2013 to August 2014. (Bottom) Percentile exceedance levels of the power spectral density. The dashed lines are the limits of prevailing noise from the Wenz curves.

3.1.2. Summer 2014 Recording Period

Broadband received sound levels at PLN40 ranged from 81–125 dB re 1 µPa (Figure 9). Broadband rms SPL were highly correlated ($r^2 = 0.859$, $p < 0.0001$) with wind speed (Figure 10).

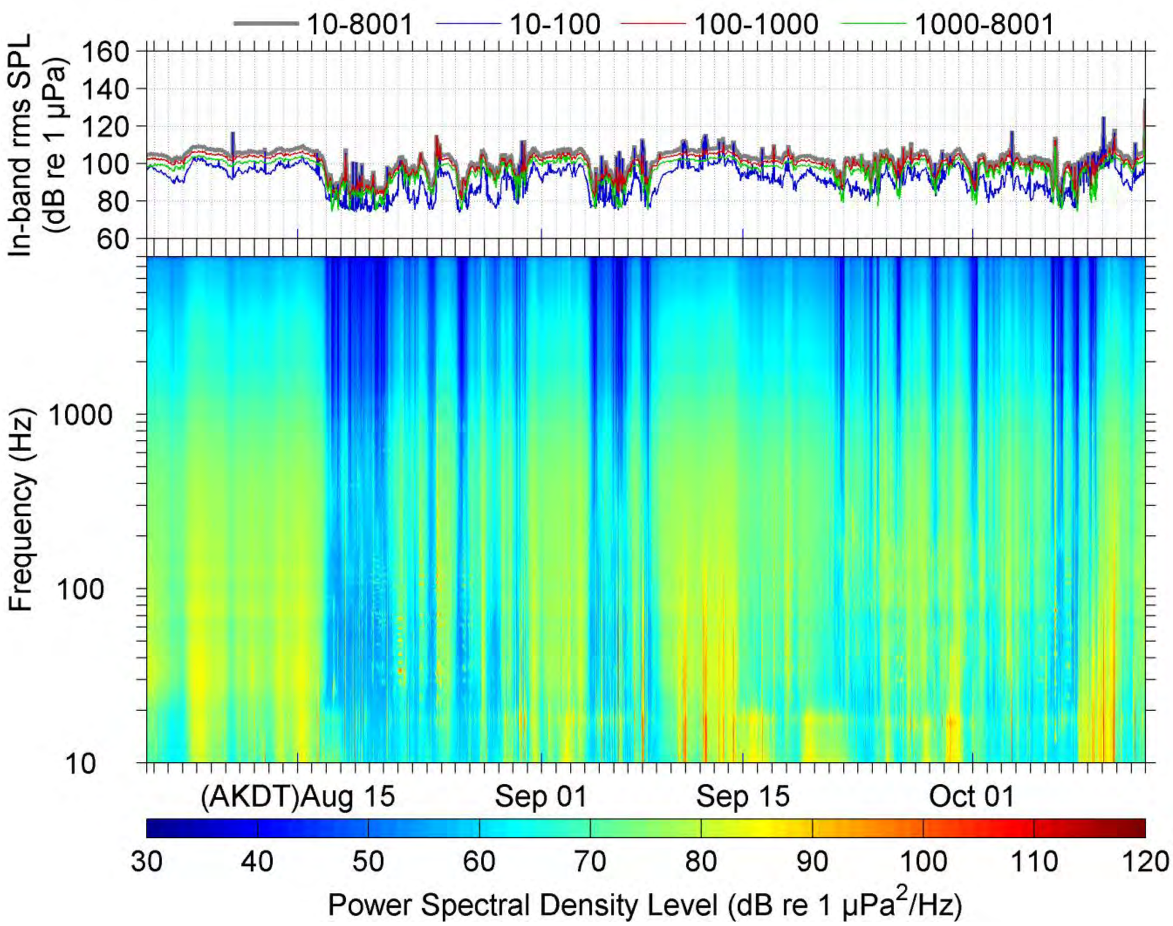

Figure 9. (Top) Broadband and decade-band sound pressure levels (SPL) for summer 2014 Station PLN40 and (bottom) spectrogram of underwater sound August to October 2014.

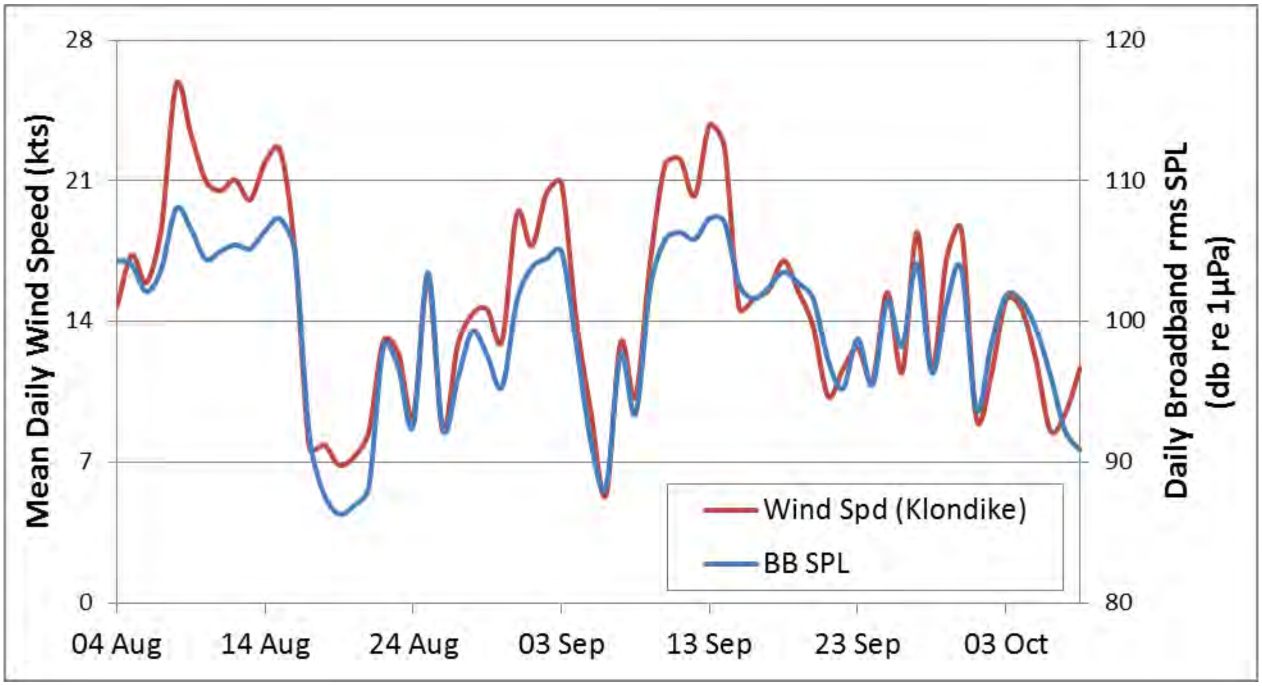

Figure 10. Mean daily wind speed recorded at Klondike and mean daily broadband rms SPL measured at Station PLN40 located 32 km away from Klondike.

Above 300 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} spectra decrease from 70.9 to 55.1 dB re 1 µPa^2/Hz over the frequency range 500 to 5000 Hz, a decrease of 15.8 dB/decade. This is typical for wind driven noise spectra (Ma and Nystuen 2005). Because the electronic background noise of the AMARs is 23 dB re 1 µPa^2/Hz, sound levels below 500 Hz reflect the true ambient noise conditions. Spectral exceedance levels remain within the Wenz limits of prevailing noise.

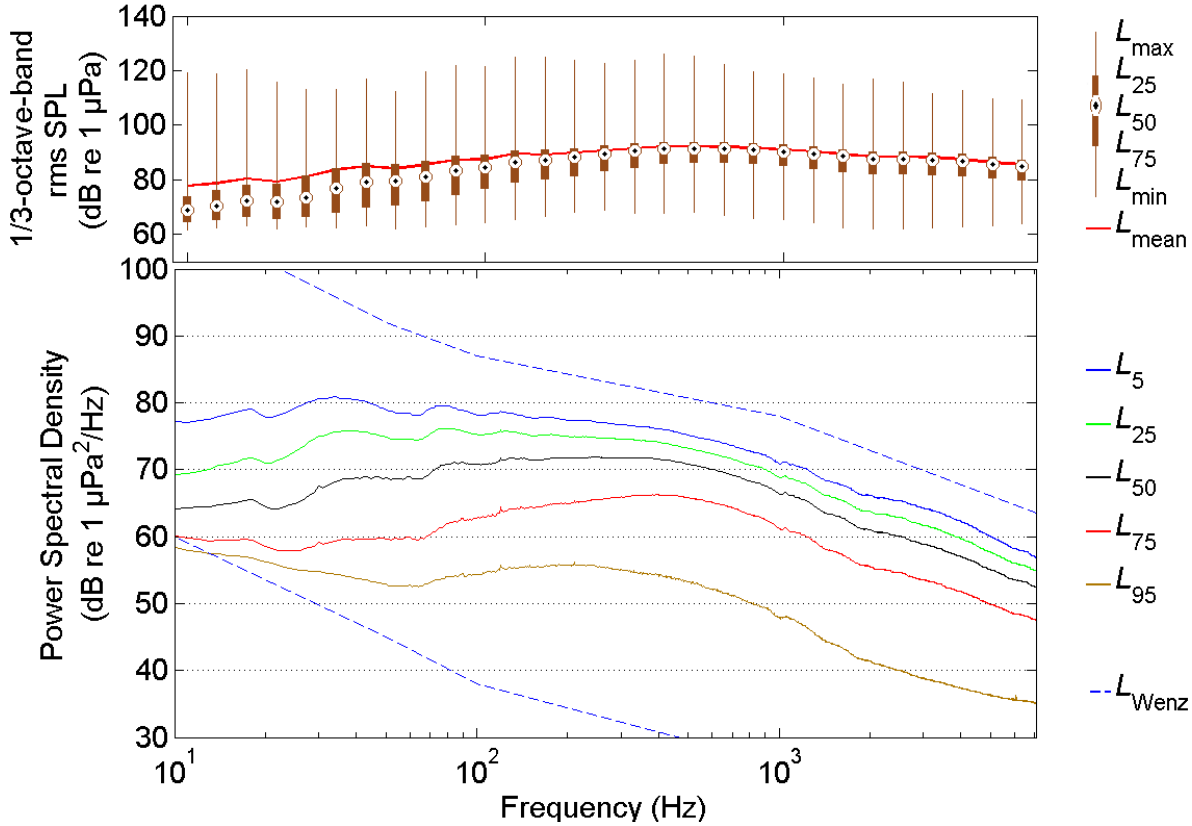

Figure 11. (Top) Box plot showing 1/3-octave-band sound pressure levels (SPL) for summer 2014 Station PLN40. The red line indicates the root-mean-square (rms) level recorded from August to October 2014. (Bottom) Percentile 1 min power spectral density levels. The dashed lines are the limits of prevailing 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 SEL (SEL 24 h) occurred on 8 Aug and was associated with a weather event. Daily SEL plots for the other stations are shown in Appendix B, Ambient Noise Results.

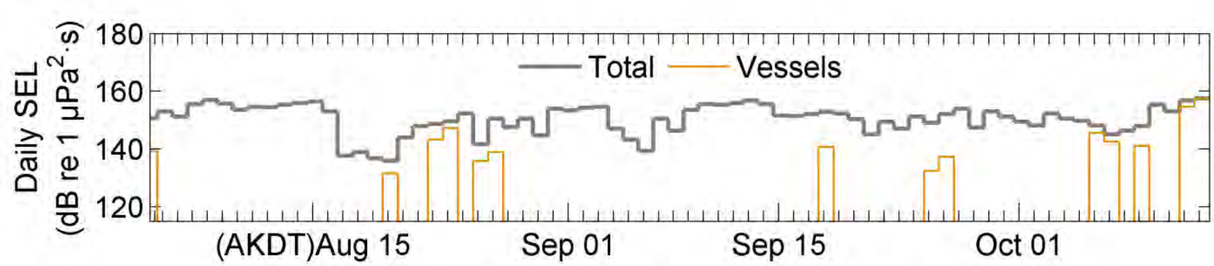

Figure 12. Daily cumulative sound exposure level (SEL 24 h) distributions (10 Hz – 8 kHz) at PLN40 summer 2014. The data were divided into total, vessel, and seismic classes; however, seismic survey sounds were not detected. Note 24 h Leq is 49.4 dB less than daily SEL.

3.2. Seismic Survey Event Detections

3.2.1. Winter 2013–2014 Recording Period

In October 2013, a few seismic airgun pulses were detected at all stations except B5 and CL5. Seismic events at W50 are shown in Figure 13. The other stations SEL plots are shown in Appendix B.

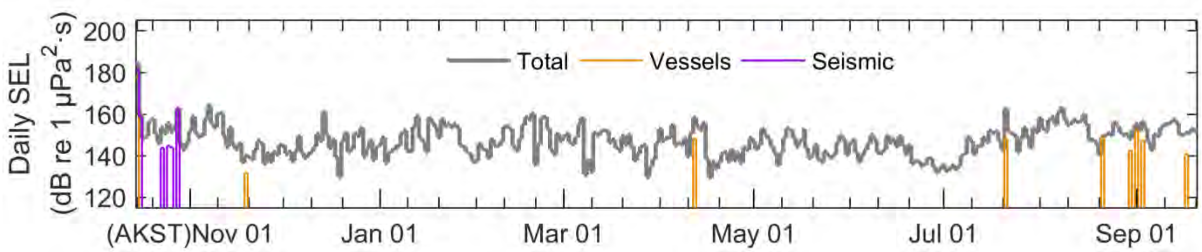

Figure 13. Daily sound exposure level (SEL 24 h) distributions (10 Hz – 8 kHz) at W50 winter 2013, divided into total, vessel, and seismic classes. Note 24 h Leq is 49.4 dB less than daily SEL.

3.2.2. Summer 2014 Recording Period

Seismic survey source sounds were detected using the automated detection algorithm described in Section 2.4.3. Because the only seismic survey sounds that we detected (8–11 Sep at WN80) had a very low signal to noise ratio, they did not contribute significantly to the daily SEL (Figure 14). Figure 15 is a spectrogram of a seismic survey sounds.

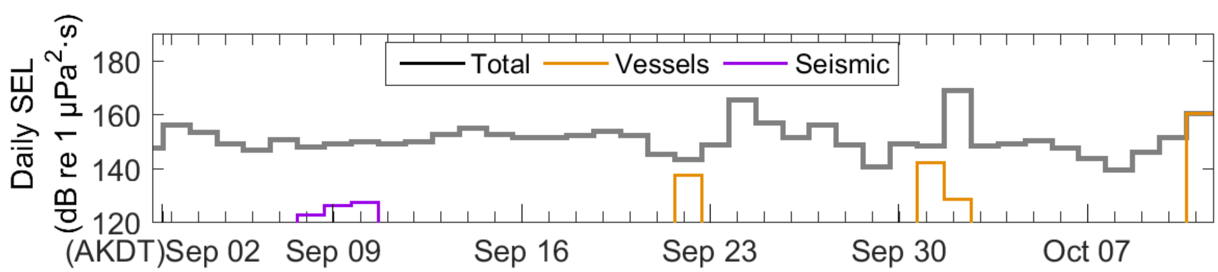

Figure 14. Daily sound exposure level (SEL 24 h) distributions (10 Hz – 8 kHz) at WN80 summer 2014, divided into total, vessel, and seismic classes. Note 24 h Leq is 49.4 dB less than daily SEL.

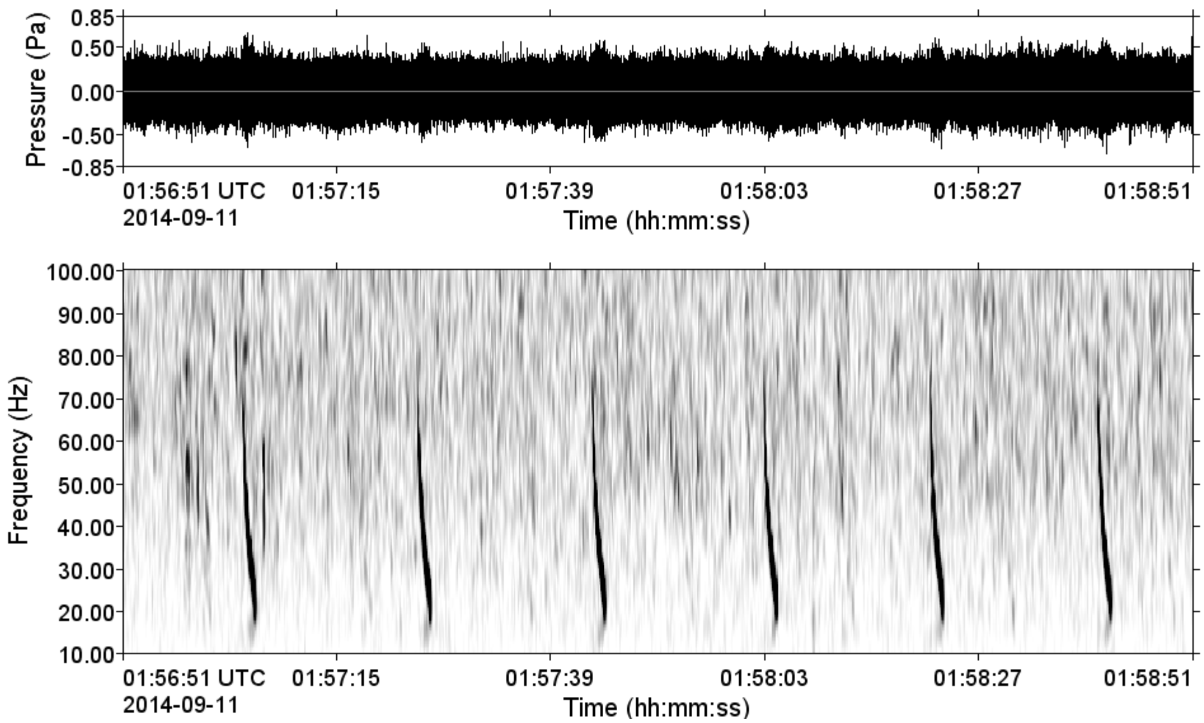

Figure 15. (Top) Pressure signature and (bottom) spectrogram of seismic pulses from an airgun array, at summer Station WN80 on 11 Sep 2014. (Frequency resolution: 1 Hz; Frame size: 0.06 s; Advance: 0.006 s; Hamming window).

3.3. Vessel Noise Detections, Summer 2014 Recording Period

The results from detected vessels showed each vessel's passage through the closest point of approach (CPA) to the recorder station, by hour. Vessel detections were lowest at the Burger, Cape Lisburne, and Point Lay stations (Figure 16, Figure 17, B–25, and B–26) and highest at Barrow and Wainwright. The detections at the two latter sites decreased with distance from shore. Station B5 had the most daily vessel passages with an average of 1.4 per day during summer, likely due to vessel traffic into and out of the village. Overall, there were fewer vessels detected in the Chukchi in summer 2014 than in previous years.

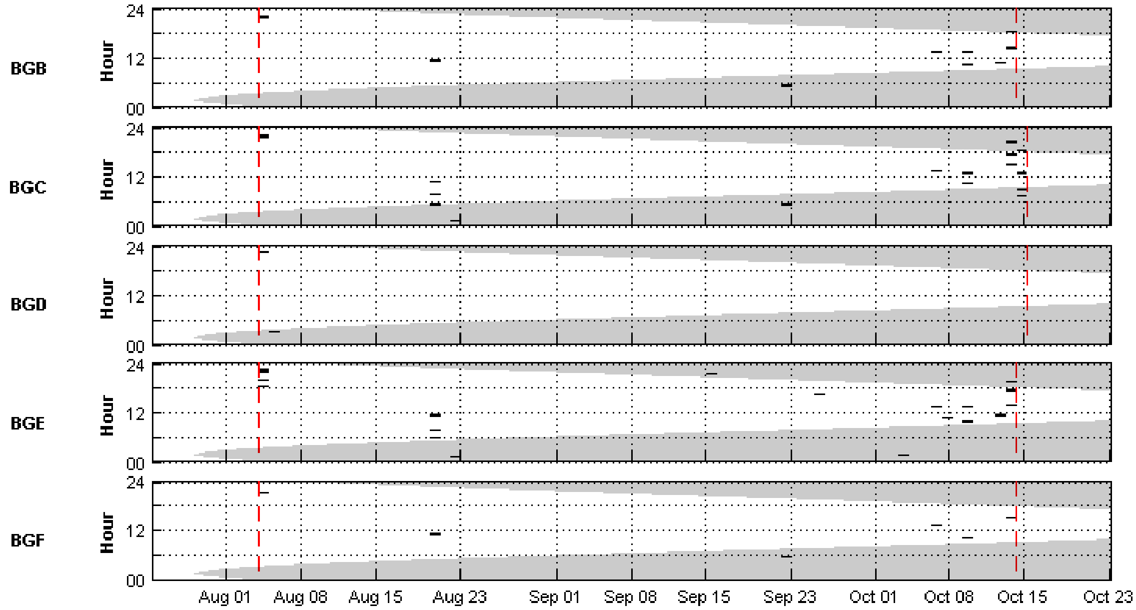

Figure 16. Vessel detections each hour (vertical axis) versus date (horizontal axis) at five stations—BGB to BGF—25 Jul to 23 Oct 2014 The grey areas indicate hours of darkness. Vertical dashed lines indicate AMAR deployment and retrieval.

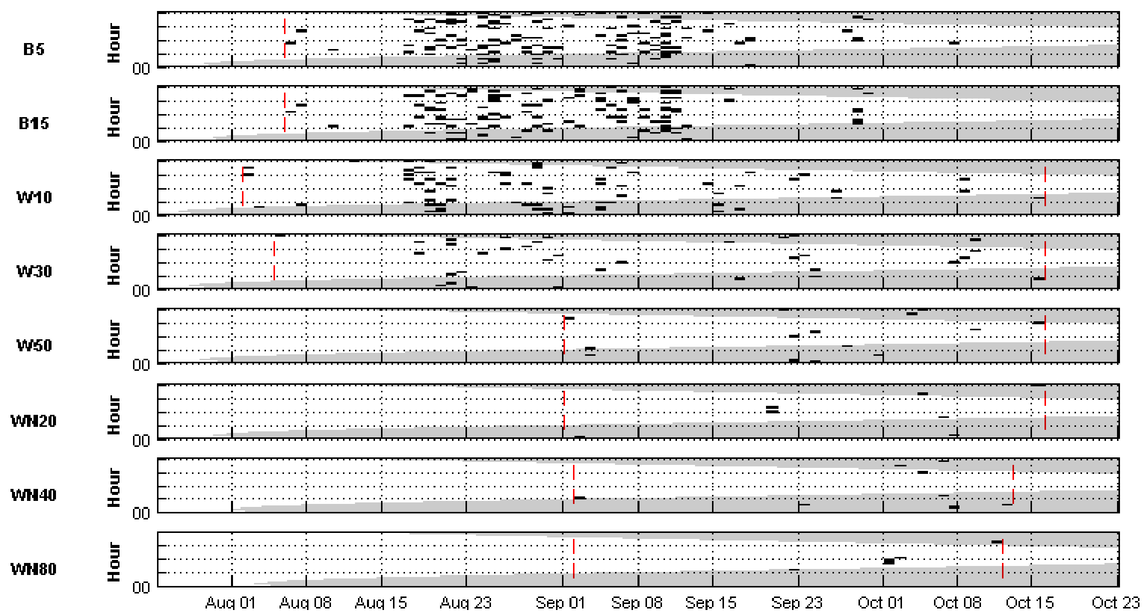

Figure 17. Vessel detections each hour (vertical axis) versus date (horizontal axis) at eight stations—B5 to WN80—25 Jul to 23 Oct 2014. The grey areas indicate hours of darkness. Vertical dashed lines indicate AMAR deployment and retrieval.

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 using a combination of manual analyses and 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 5 min or 30 min sound files (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 5 and 6).

Species-specific detections are described using the daily average number of automatic detections corrected by performance indicators (See Appendix A.7, Call Count Estimation) or the sum of call counts per period. The automated detections 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 represented the actual number of vocalizations for a species. Call counts were then averaged over periods that reflected temporal trends in detections, and subsequently mapped.

3.4.1. Summary of Manual Call Detections

In the winter 2013–2014 data, 20,509 sounds were annotated manually, of which 18,978 were classified as marine mammal calls (Table 5). In the summer 2014 data, 34,492 sounds were annotated manually, of which 28,577 were classified as marine mammal calls (Table 6).

Station W10 accounted for more than half of all winter call detections, the result of high numbers of bearded seal calls there. Bearded seals were the most commonly detected species in the winter dataset, accounting for 47% of all identified annotations, followed by bowhead whales (21%). Walrus and ringed seals accounted for 13% and 11% of identified annotations. There were fewer detections at PL10 and B5 because these recorders operated for shorter times than the other winter recorders.

In the summer recording period, walrus and bowhead whale calls accounted for 60.2% and 28.6% of all identified calls, respectively; other species contributed negligibly (5% or less). Station BGD, which was only deployed for a short time, and Stations PL30, PL50, CLN40, and KL01 had few annotations overall. The number of walrus annotations at each station strongly influenced the total number of marine mammal annotations. Stations B5 and B15 were the only stations where the high number of summer marine mammal annotations were driven by bowhead whale, not walrus, calls. Factors in the marked differences in the number of unknown calls between stations could be attributed to differences in environmental noise between stations and/or the data analyst's experience identifying calls.

Table 5. Winter 2013–2014 call detections: Marine mammal annotations resulting from the manual analysis of 5% of the data from each station, listed in order of increasing total detections.

Station	Bearded seal	Bowhead whale	Walrus	Ringed seal	Beluga whale	Gray whale	Minke whale	Ribbon seal	Killer whale	Unknown	**Total**
PL10	196	3	51	8			6			12	**276**
B5	94	706		1	36			12	3	11	**863**
PL50	480	773	231	528	143	3	7	15		300	2,684
WN40	1,073	142	1,367	129	28	1				64	2,804
W50	1,387	503	533	607	212	4		9		149	3,405
CL05	2,387	1,109	48	398	270		56			548	4,816
W10	3,173	831	279	493	290	148				447	5,661
Total	**8,790**	**4,067**	**2,509**	**2,164**	**979**	**156**	**69**	**36**	**3**	**1,531**	**20,509**

Table 6. Summer 2014 call detections: Marine mammal annotations resulting from the manual analysis of 5% of the data from each station, listed in order of increasing total detections. No spotted seal sounds were detected due to a lack of knowledge about their calls (see Section 3.4.13). WA: walrus; BW: bowhead whale; BS: bearded seal; WW: beluga whale; GW: gray whale; RS: ringed seal; KW: killer whale; FW: fin whale; RB: ribbon seal; HW: humpback whale; MW: minke whale; MM: marine mammal; UN: unidentified sound.

Station	WA	BH	BS	WW	GW	RS	KW	FW	RB	HB	MW	MM	UN	**Total**
BGD	67	1	1		2							71	45	**116**
PL50	84	23	15	14	13	19	5	5				178	115	**293**
PL30	290		10		3	7		3				313	193	**506**
CL50	79	51	33	6	2	6	6	51				234	273	**507**
KL01	107	318	11	15	4	6	16	3				480	81	**561**
CLN40	266	19	23	11	3	3				1	1	327	390	**717**
CL5	810				1		1					812	19	**831**
PLN80	454	381	62	53	14							964	82	**1046**
PLN20	295	240	59	31	4	37	4	3				673	378	**1051**
PLN60	264	396	76	21	23	2	2	1				785	408	**1193**
W10	295	222	98	29	81	5						730	467	**1197**
CLN90B	376	387	17	47	4	1	35					867	337	**1204**
PLN40	322	635	54	10	8	5	1					1035	227	**1262**
W30	534	428	99	112	9	3	2					1187	120	**1307**
CLN120B	571	629	27	68	3	8	11		2			1319	110	**1431**
WN40	1,134	240	83	19	1							1,477	95	**1,572**
WN80	1,234	308	19	5		2						1,568	71	**1,639**
BGC	1,134	268	108	52	9	7	5	2				1,585	162	**1,747**
B5	25	1,035	93	366	33	11						1,563	207	**1,770**
W50	1,345	254	65	46	2							1,712	79	**1,791**
BGE	1,345	218	108	30	1		1	11				1,714	198	**1,912**
WN20	1,229	258	98	7	6							1,598	315	**1,913**
BGB	1,384	237	102	10	2		9					1,744	171	**1,915**
PL10	1,946		2		1		2					1,951	85	**2,036**
B15	53	1,374	170	151		25						1,773	290	**2,063**
BGF	1,547	248	97	22	2	1						1,917	995	**2,912**
Total	**17,190**	**8,170**	**1,530**	**1,125**	**231**	**148**	**100**	**79**	**2**	**1**	**1**	**28,577**	**5,913**	**34,492**

3.4.2. Bowhead Whale Call Detections

See Appendix C: Marine Mammal Detection Results for detailed technical information about bowhead whale call detection methods.

3.4.2.1. Winter 2013–2014 Recording Period

Bowhead whale calls were detected at all stations during the fall migration, although calls were only detected at PL10 for five days. The highest number of detection days (n = 65) occurred at W50 (Table C–1). The area with the highest mean daily call counts shifted from the Barrow-Wainwright stations in October to the Cape Lisburne-Point Lay area in December (Figures C–2 to C–4). This shift generally coincides with ice formation and is consistent with the westerly heading of migrating bowhead whales in fall. Overall, call counts were highest at W50 and PL50 during the fall migration (Figure 18). Detections at the Wainwright stations, and to a lesser extent at B5, occurred in succession, whereas detections were more uniformly distributed temporally at PL50 and CL5 (Figure 19). Except at WN40 and PL10, detections generally lasted until mid-December and up to early January at CL50.

The first spring detections occurred on 4 Apr at PL50. The date of CL5's first detection (9 Apr) is likely not the first migrating bowhead whale; recording was interrupted at this station from mid-March until 9 Apr. Spring detections at B5 and PL10 are zero because these recorders had stopped recording earlier. Bowhead whale calls were not detected at WN40 (Table C–1). Most detections stopped in early June with few detections after that, except for a small detection peak in early July at PL50 and W10 (Figure 19). Mean daily call counts were highest at W10, followed closely by PL50 (Figure 18). In April, call counts were higher at stations closer to shore, where ice concentrations were slightly lower than offshore (Figure C–5). In May, detections at PL50 were more than twice that of any other stations; ice concentrations were lower throughout the area (Figure C–6). In June, most call counts occurred nearshore at W10 (Figure C–7).

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 throughout the spring migration, particularly from June onward (see Appendix A.8, Detector/Classifier Performance).

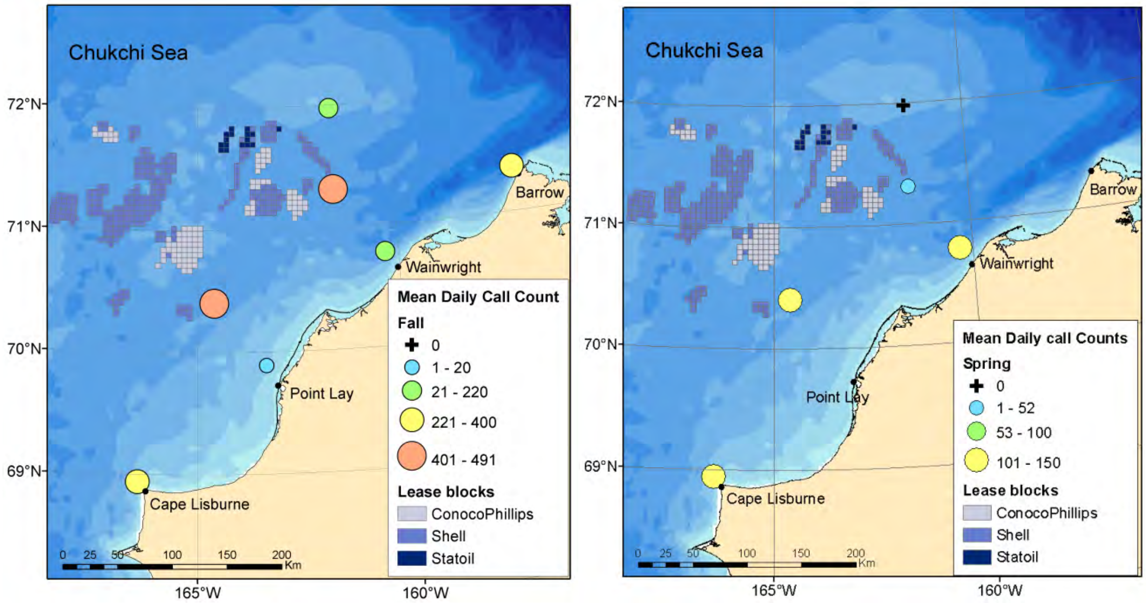

Figure 18. Bowhead whale mean daily call count[2] at winter 2013–2014 stations in the Chukchi Sea. (Left) Fall migration 10 Oct 2013 to 4 Jan 2014. (Right) Spring migration 4 Apr to 31 Jul 2014.

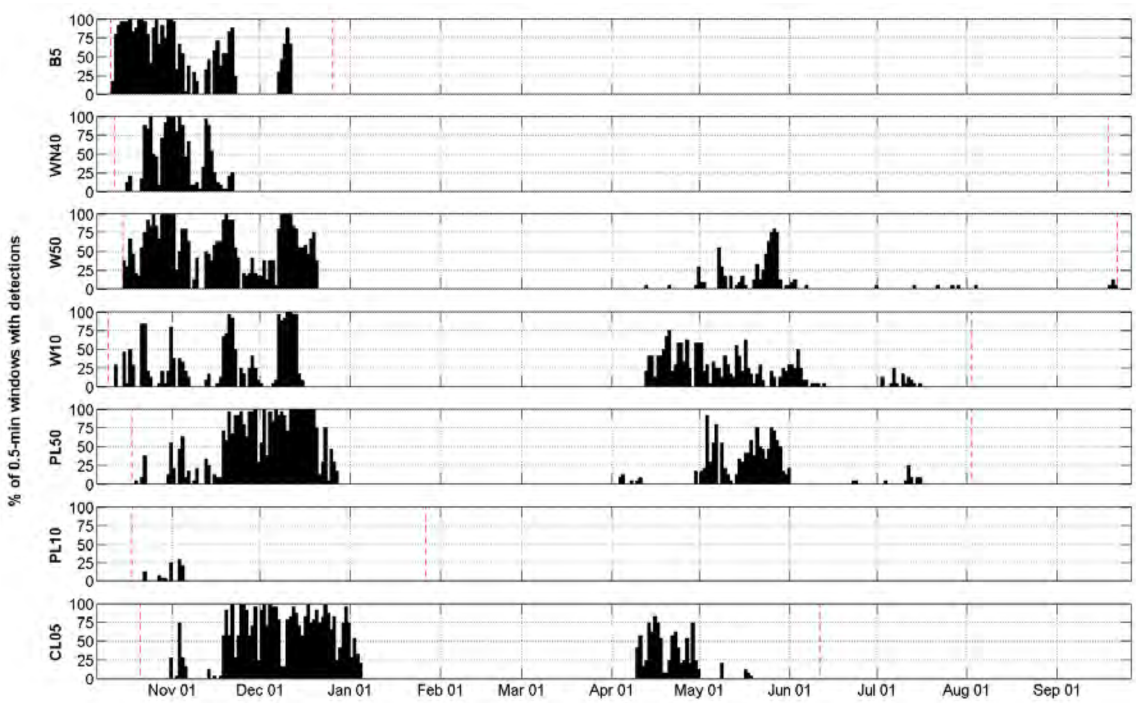

Figure 19. Winter 2013–2014 daily bowhead call detections: Daily proportion of sound files with call detections based on the manual analysis of 5% of the acoustic data recorded early October 2013 through late September 2014 in the northeastern Chukchi Sea for each station. Forty-eight sound files lasting 5 min were recorded each day, spaced every 30 min. Stations are ordered from (top) northeast to (bottom) southwest. The vertical red dashed lines indicate the recording start and end dates.

[2] Corrected sum of automated call detections in all files with manual detections divided by number of active recording days.

3.4.2.2. Summer 2014 Recording Period

Bowhead whale calls were detected at all active stations except CL5, PL10, and PL30. The proportion of recording days with detections ranged from 7% to 72% and averaged 35% across all stations (Table C–2), but these detections were not uniformly distributed. Detections can be split into two time periods with a nearly complete absence of calls between:

1. August 9 through 27: Three distinct detection peaks are visible at Stations B5 and B15, the last being on 24 Aug. A few sporadic detections occurred before 25 Aug at other stations, but most detections were concentrated on 26 and 27 Aug, predominantly at Burger and the northern Point Lay stations (Figure 21; Appendix C).
2. September 13 through November 3: Fall detections started on 13 Sep off Barrow, on 16 Sep at the nearshore Wainwright stations, and across the study area from 21 Sep. Detections continued fairly steadily after that except for a notable gap at the nearshore Wainwright stations in late September and early October. Detections during the fall migration often occur in distinct waves, which was apparent off Barrow and Wainwright. Detections further west were more uniformly distributed in time. The bulk of fall detections off Barrow (94% at B5 and B15) ended on 16 Oct, with moderate detections continuing until 3 Nov (Figure 21; Appendix C).

Mean daily call counts were highest near or north of 71° N (Figure 20). The highest call count detections occurred at B15, followed by PLN40, PLN80, and CLN120. There were few detections south of 70.5° N. Detections in the Burger lease areas were lower than at stations east and west of Burger. Mean daily call counts at W50, WN20, WN40, and WN80 are inflated relative to the other stations because their shorter deployment period almost completely overlapped with the period of bowhead whale acoustic occurrence.

We investigated the influence of ambient noise on bowhead detections. This analysis was focused on the fall detection period, from the first detection until the end of the recording period for four representative stations. Bowhead detections at PLN40, CLN120, and B15 were slightly negatively correlated correlations were not significant. Detections at W30 were strongly negatively correlated with broadband rms SPL ($r^2 = 0.3$, $p = 0.0015$; Figure 22), which was likely driven by the prolonged period of noise levels above 100 dB re 1 µPa. Call counts appeared to follow the opposite trends from broadband rms SPL at PLN40, particularly when noise levels approached or surpassed 100 dB re 1 µPa.

The detected calls consisted mostly of simple moans (Figure 23), although an increasing proportion of complex calls occurred near the end of the recording period.

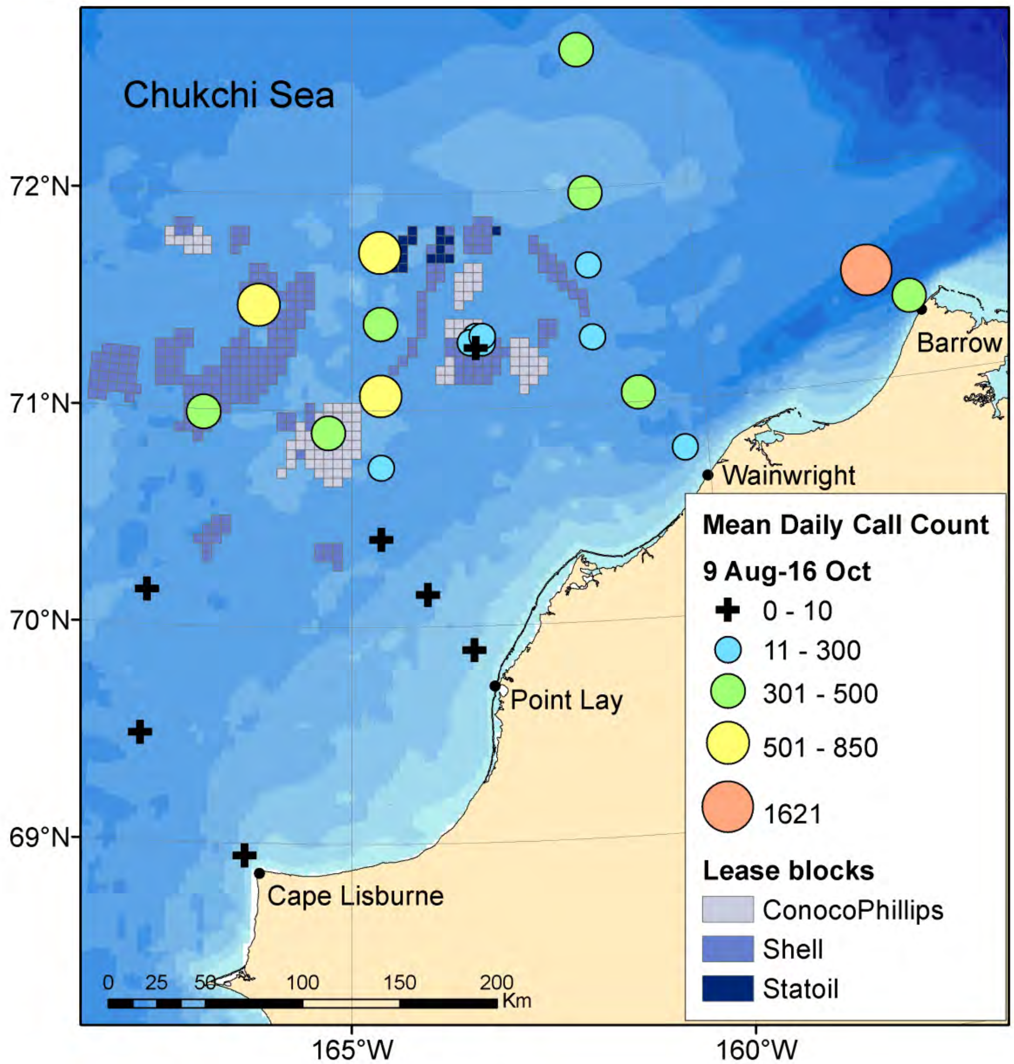

Figure 20. Mean daily bowhead whale call counts (calculated as the sum of automated call detections in all files with manual detections divided by the number of active recording days) for 9 Aug to 16 Oct at all summer 2014 stations in the northeastern Chukchi Sea.

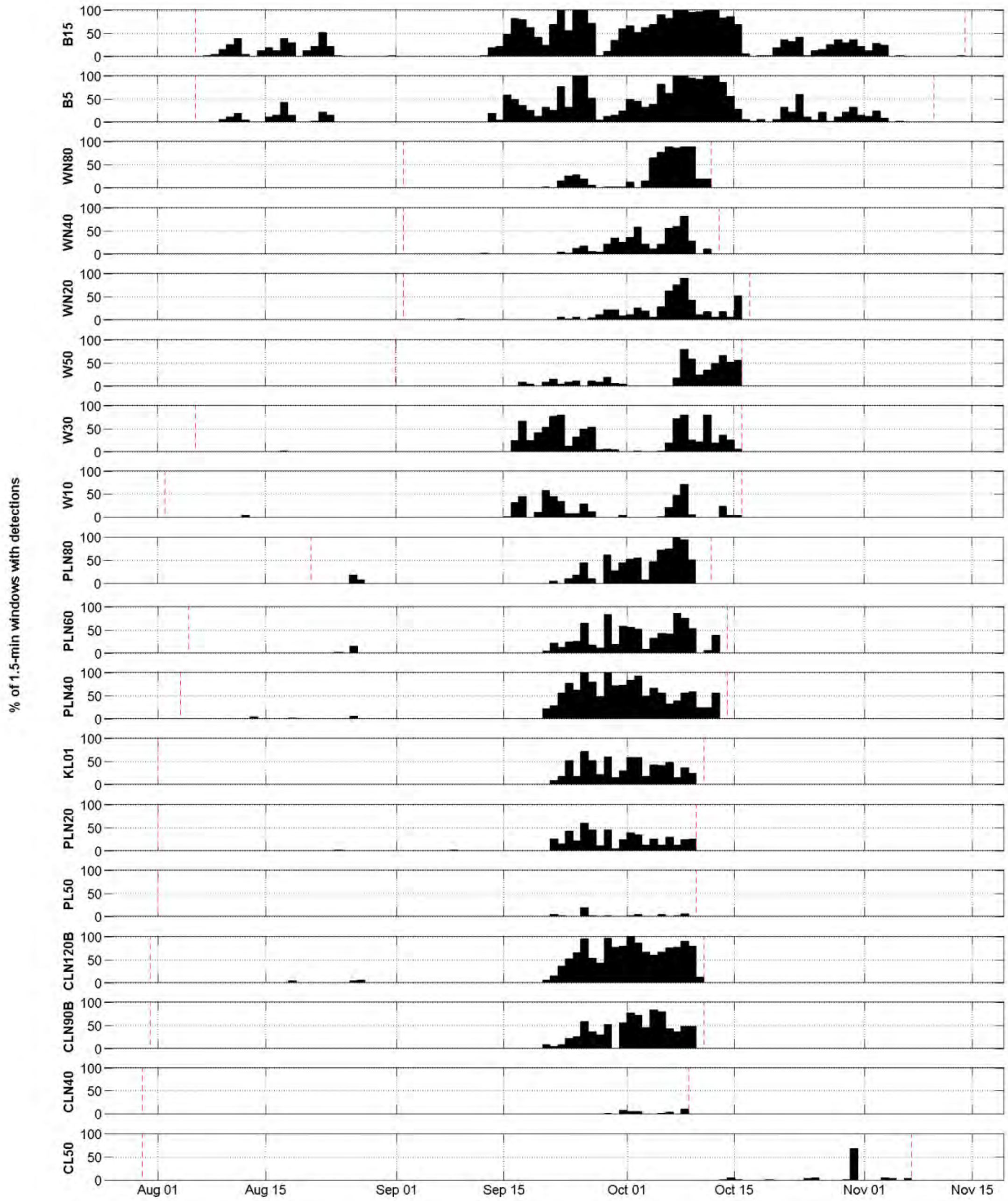

Figure 21. Summer 2014 daily bowhead call detections in the northeastern Chukchi Sea: Daily proportion of sound files with call detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-November 2014. Forty-eight sound files were recorded each day. Vertical red dashed lines indicate record start and end. Stations are ordered from (top) northeast to (bottom) southwest. Stations without call detections are omitted.

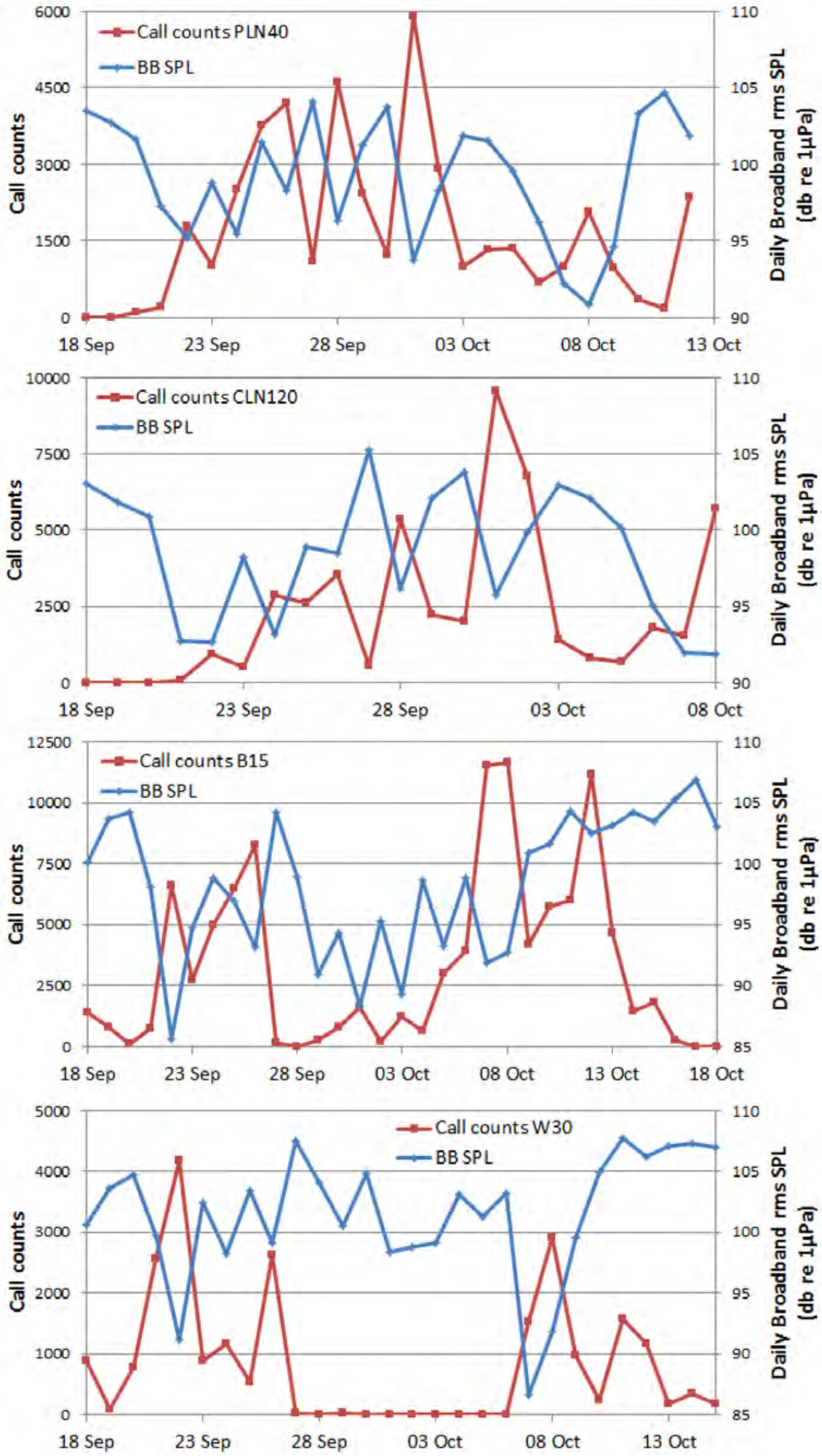

Figure 22. Time series of daily bowhead whale call counts and broadband rms SPL (from top to bottom) at PLN40, CLN120, B15, and W30.

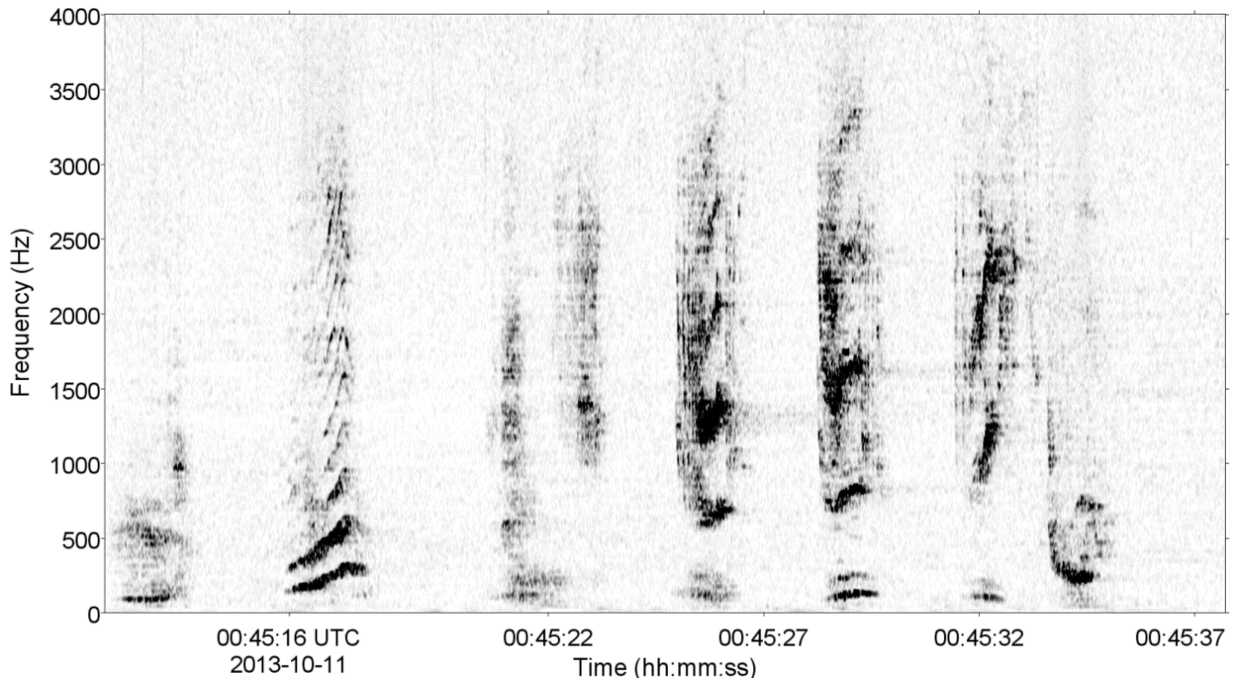

Figure 23. Spectrogram of bowhead vocalizations at Station W50, 11 Oct 2013 (Frequency resolution: 1 Hz; Frame size: 0.06 s; Advance: 0.006 s; Hamming window).

3.4.3. Walrus Call Detections

3.4.3.1. Winter 2013–2014 Recording Period

There were few fall walrus call detections and no winter detections. The number of detection days ranged from 0 (B5 and W50) to 4 at PL10 and PL50. Most fall detections occurred before the end of October (Table C–3).

Spring detections started on 5 Jun at W50 and generally occurred every day thereafter. At PL50, detections spread over 32 days but were most concentrated over two weeks in late June-early July. The low number of detections during the last week of recording at PL50 suggests that walruses only transited through this area. On the other hand, detections occurred consistently at W50 and WN40 until September when the recorders were retrieved. There were no spring detections at CL5, B5, and PL10 because these recorders were inactive when walruses were in the study area.

Call counts were highest at W50 in June and at WN40 from early July onward. WN40 was near the ice edge starting early July. Call detections were lowest at the stations closer to shore (W10) and further from Hanna Shoal (PL50) (Figure 24).

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

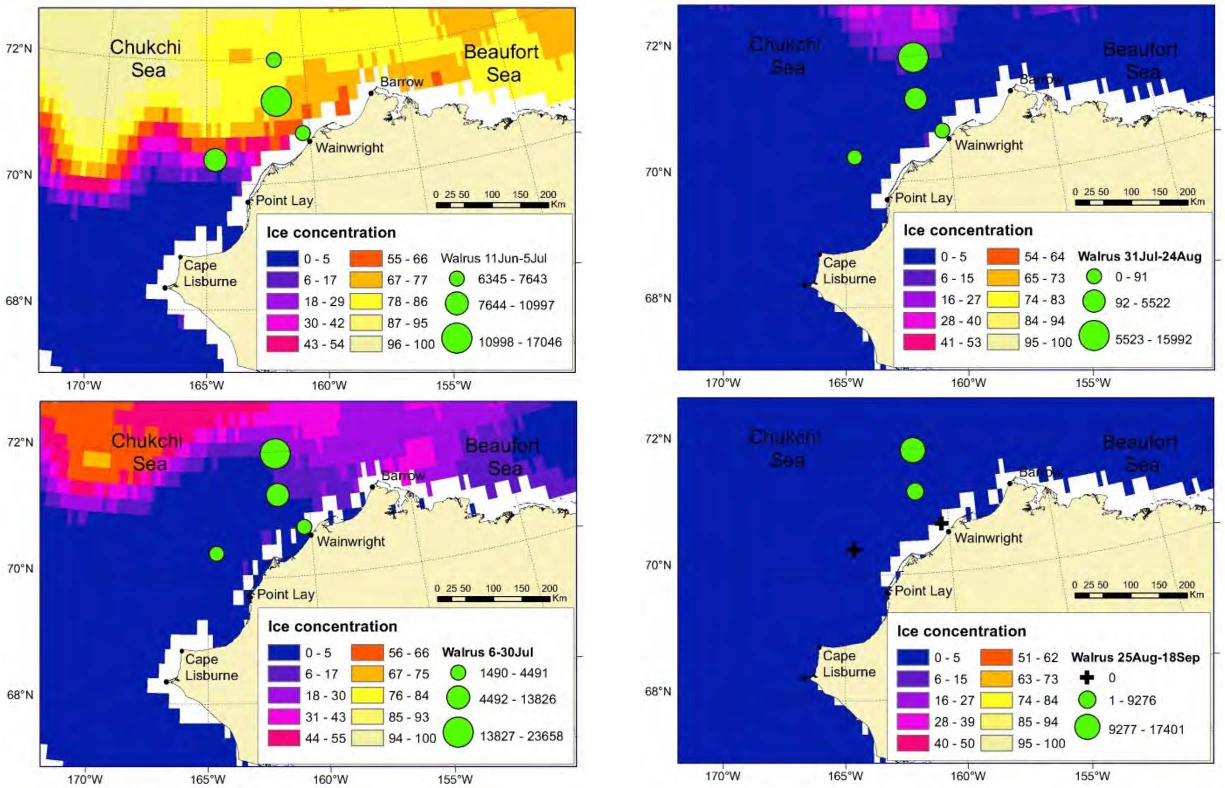

Figure 24. Walrus call count estimates[3] at all winter 2013–2014 stations in the Chukchi Sea. (Top left) from 11 Jun to 5 Jul 2014; (Top right) from 6–30 Jul 2014; (Bottom left) 31 Jul to 24 Aug 2014; (Bottom right) 25 Aug to 18 Sep 2014.

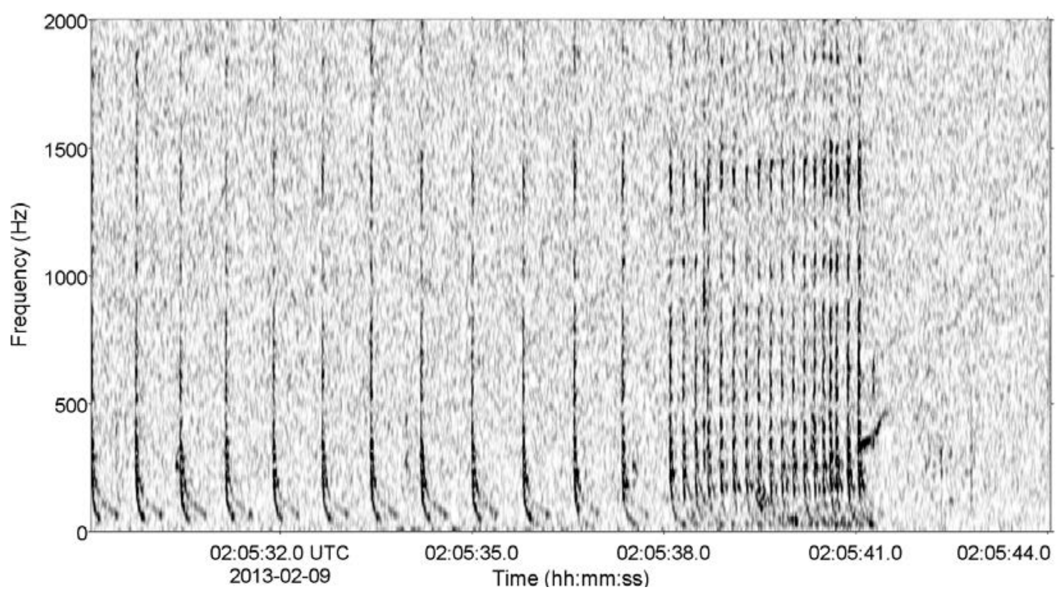

Figure 25. Spectrogram of walrus grunts recorded at Station PLN120, 9 Feb 2013 (Frequency resolution: 1 Hz; Frame size: 0.06 s; Advance: 0.006 s; Hamming window).

[3] Corrected sum of automated call detections in all files with manual detections.

3.4.3.2. Summer 2014 Recording Period

Walruses were detected at all stations in summer 2014. In summer, 30.2–97.6% of recording days had detections, with an average of 64% across all stations (Table C–4). Walruses were most often detected at the northern Wainwright stations and at PL10. At the latter, walruses were detected almost continuously after the second week of September. At most other stations, detections were concentrated in peaks that occurred simultaneously across the area. The most prominent peaks occurred in the third week of August, the first and third weeks of September, and the second week of October (Figure 26; Appendix C).

An analysis into the effects of ambient noise levels on walrus detections revealed that at some stations call counts were strongly negatively correlated with broadband rms SPL (BGB: $r^2 = 0.54$, $p < 0.00001$; PLN40: $r^2 = 0.29$, $p < 0.00001$). On the other hand, the slight negative correlation between call counts and rms SPL observed at WN20 was not significant ($p = 0.36$) (Figure 27). Noise levels were not as closely correlated to wind speed at this station; walrus calls were possibly driving noise levels in some periods (e.g., early September). Higher walrus densities and their proximity to the recorders compared to other areas could explain these differences.

Mean daily call counts were highest at PL10, followed by the Hanna Shoal and Burger stations. Call counts were generally low west of a line running from Burger to Point Lay, except at CLN120 and CL5 (Figure 28). In the first two weeks of August, walrus mean daily call counts were highest at the offshore Cape Lisburne stations. From there on, call count maxima occurred at PL10. Other detection hotspots included Burger in the second half of August and the offshore Wainwright stations in September (Appendix C).

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 29).

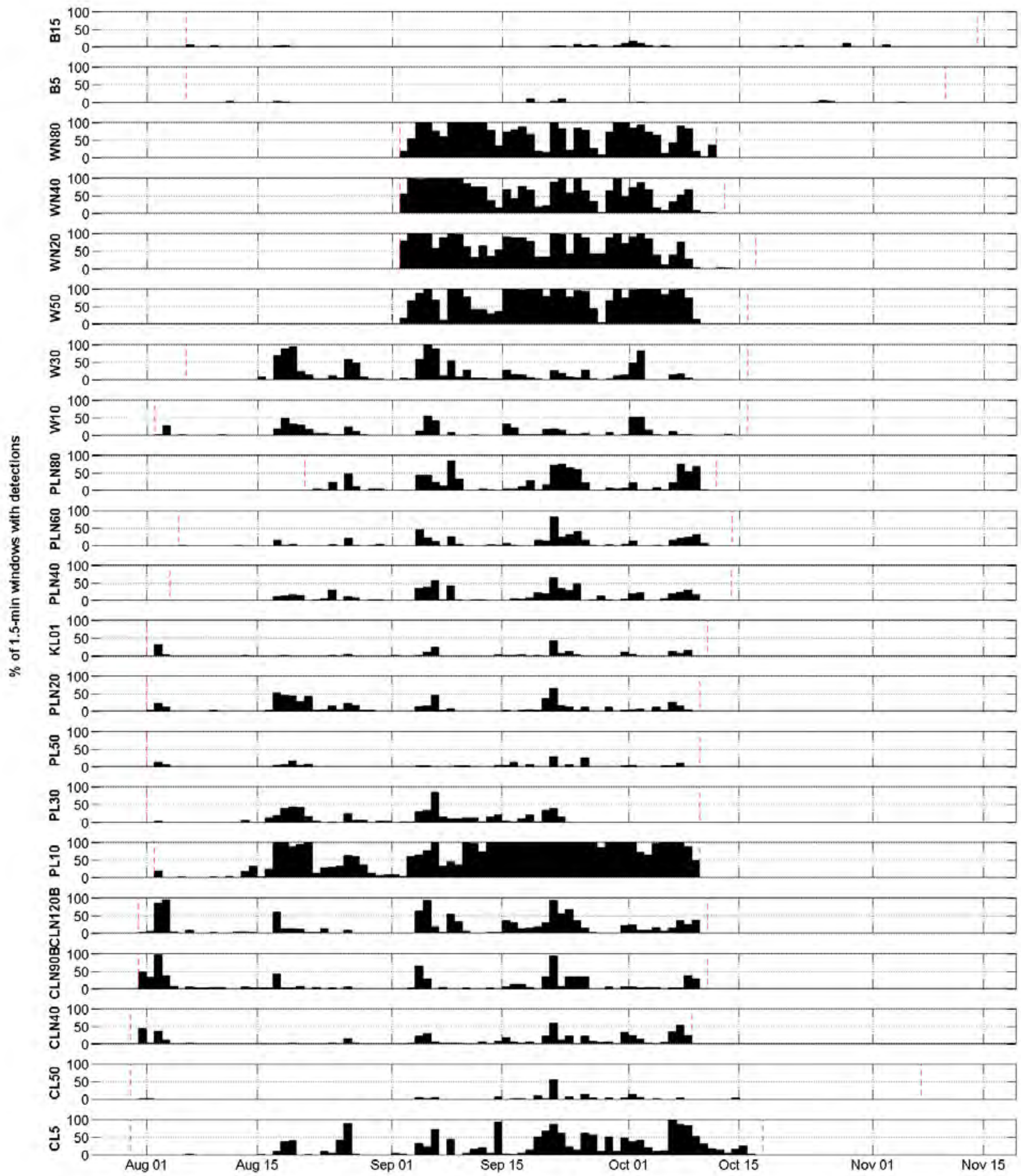

Figure 26. Summer 2014 daily walrus call detections: Daily proportion of sound files with call detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-November 2014. Forty-eight sound files were recorded each day. Vertical red dashed lines indicate record start and end. Stations are ordered from (top) northeast to (bottom) southwest.

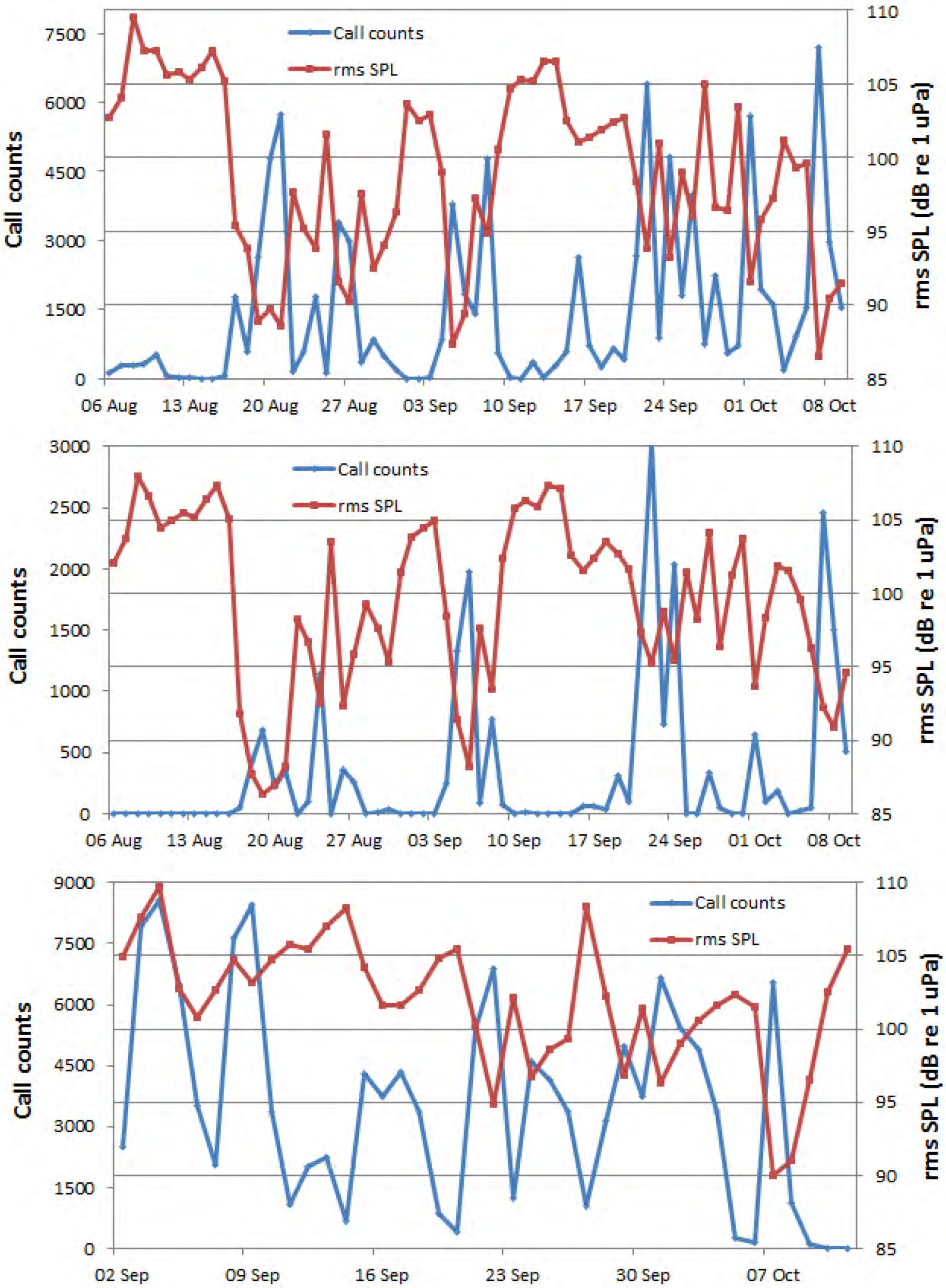

Figure 27. Time series of daily walrus call counts and mean broadband rms SPL at (top) Station BGB, (middle) PLN40, and (bottom) WN20.

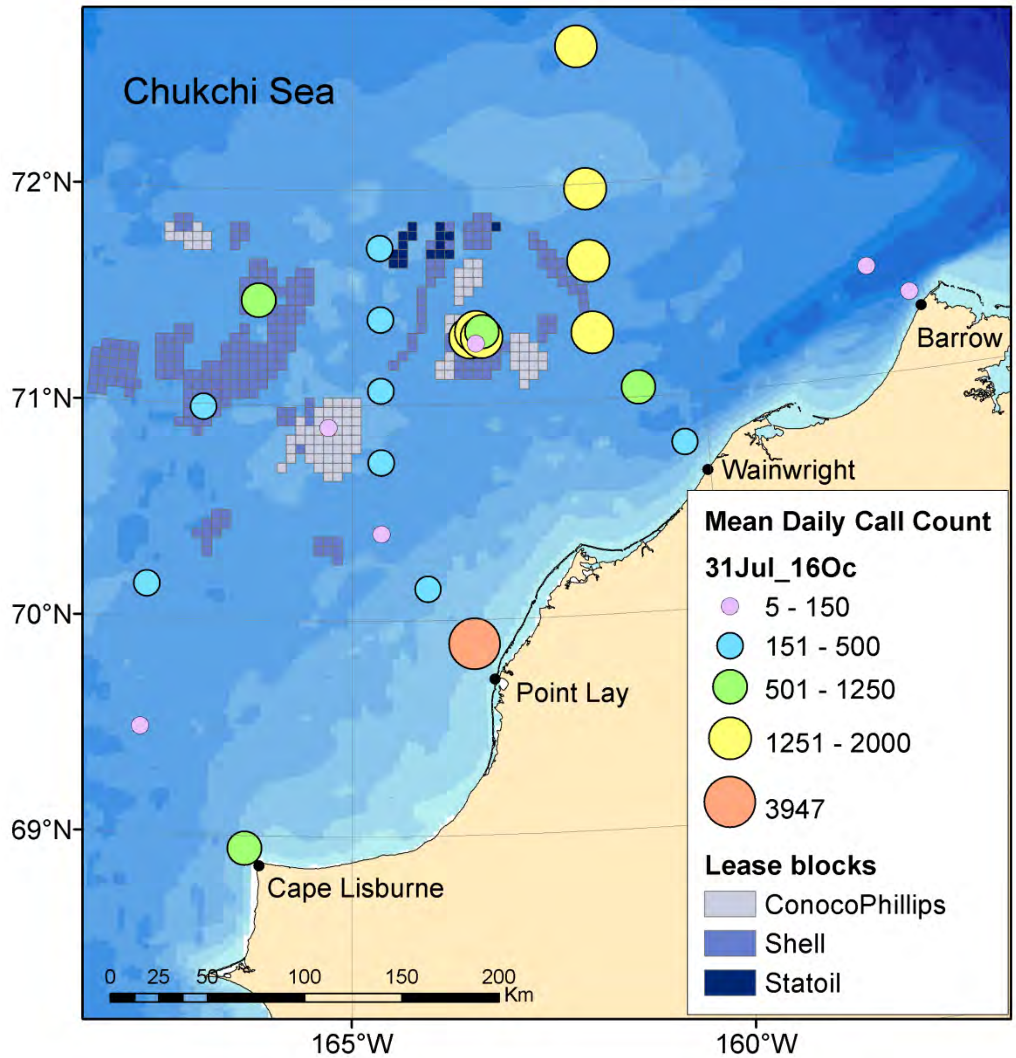

Figure 28. Mean daily walrus call counts (calculated as the sum of automated call detections in all files with manual detections divided by the number of active recording days) for 31 Jul to 16 Oct at all summer 2014 stations in the northeastern Chukchi Sea.

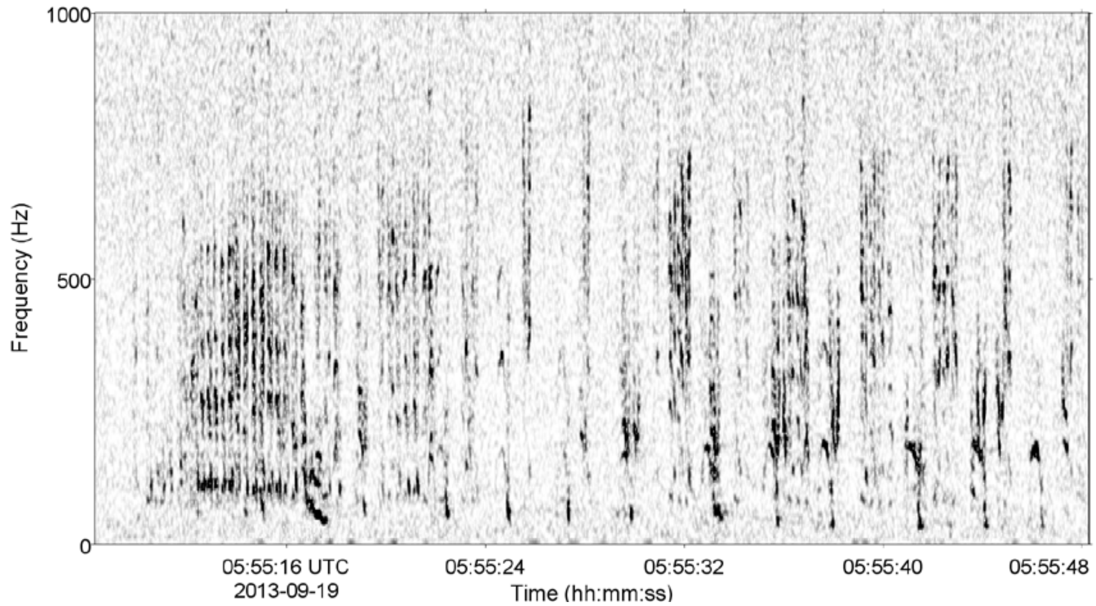

Figure 29. Spectrogram of walrus grunts, knocks, and bell sounds recorded at Station CLN120, 19 Sep 2013 (Frequency resolution: 1 Hz; Frame size: 0.06 s; Advance: 0.006 s; Hamming window).

3.4.4. Beluga Whale Call Detections

3.4.4.1. Winter 2013–2014 Recording Period

Beluga calls were detected between one (WN40) and twelve (B5) days in the fall 2013. The first detections occurred on 15 Oct; the last on 18 Dec. Detection days were generally not clustered with the exception of B5, where most detections occurred in late October-early November (Table C–5; Figure C–14). The highest call counts occurred at B5 and PL50, but these were 1-2 orders of magnitude lower than in the spring.

Spring detections started on 4 Apr at W10 and PL50. Most detections occurred before the end of May-early June, although at W50 detections were low but consistent until early June. The highest call counts were recorded at CL5, followed by W10, and PL50. 87% of calls were recorded in April at CL50, but there were about twice as many detections in May compared to April at W10 and PL50 (Figure C–14). Along the Wainwright line, call counts decreased as distance from shore increased (Figure 30).

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).

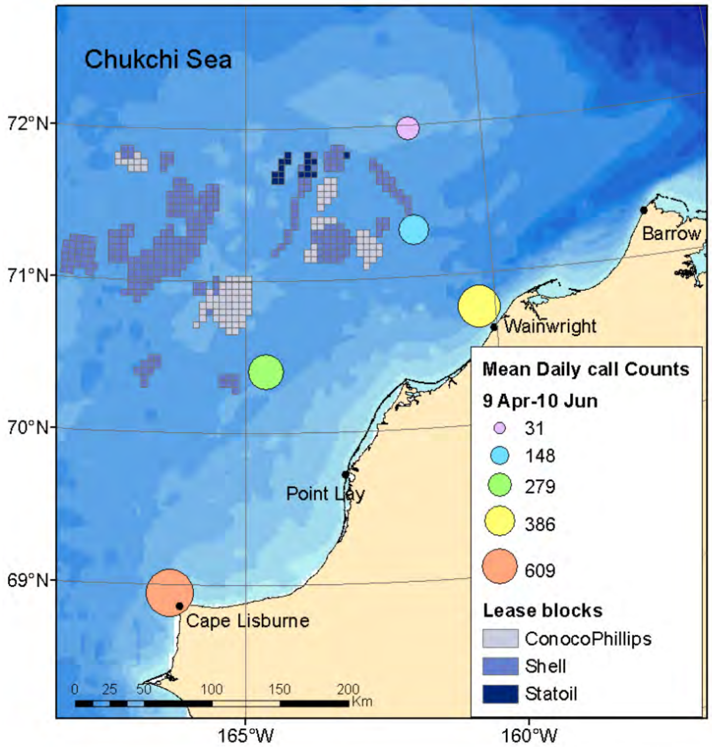

Figure 30. Beluga whale mean daily call counts[4] in the Chukchi Sea at all active winter 2013–2014 stations from 9 Apr to 10 Jun 2014.

[4] Corrected sum of automated call detections in all files with manual detections divided by the number of recording days.

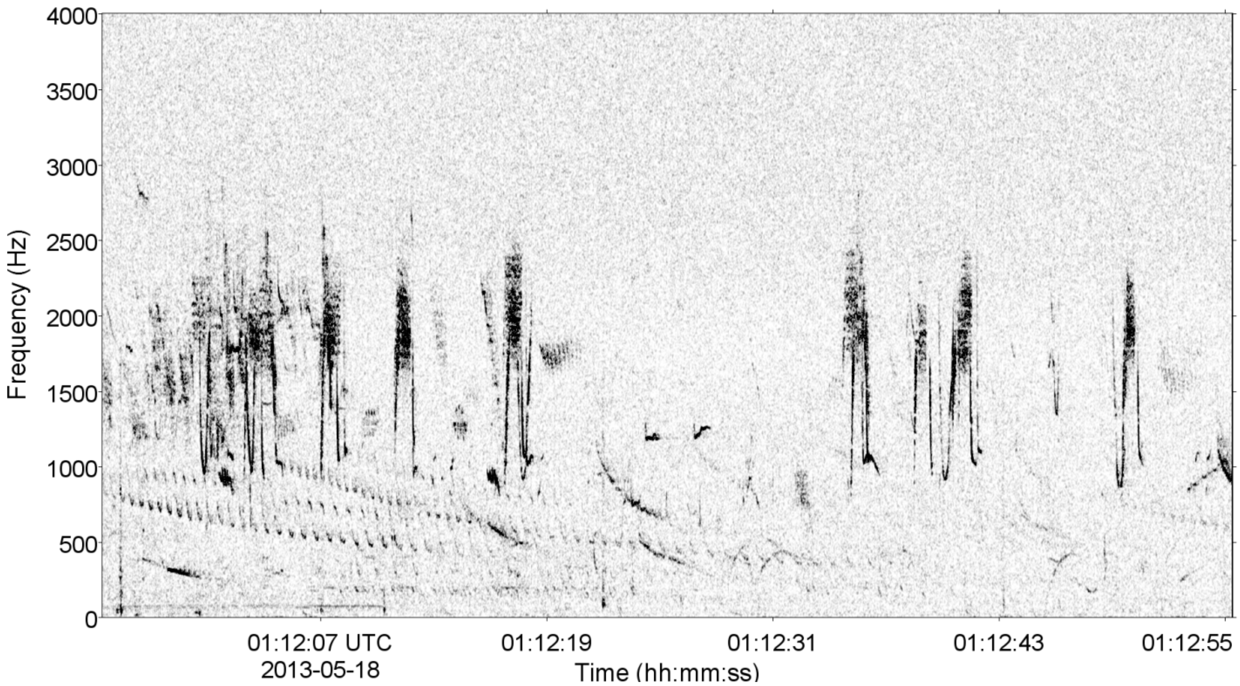

Figure 31. Spectrogram of beluga calls recorded 18 May 2013 at Station W50. (Frequency resolution: 1 Hz; Frame size: 0.06 s; Advance: 0.006 s; Hamming window).

3.4.4.2. Summer 2014 Recording Period

Beluga whale calls were detected at all stations except CL5, PL10, and PL30. The proportion of days with detections ranged from 1.5% at PL50 to 49% at B15 with a mean of 14.1% (Table C–6). Stations W30, B15, and B5 had the highest call counts. Off Barrow, 30% of detections occurred in August—64% between 18 Sep and 15 Oct and the rest between 24 Oct and 10 Nov.

In the rest of the study area, detections occurred sporadically throughout the summer, including in the Burger lease area (Figure C–18), but were concentrated at the end of the first week of October at all stations. Call count rates after 15 Sep were highest at W30, CLN90, CLN120, and PLN80 (Table C–6; Figure 32; Figure 33). Overall, 95% of all recorded calls at stations other than Barrow occurred after 15 Sep.

By configuring Station B5 and BGF to record on a duty cycle with a sampling rate alternating between 16 and 250 ksps, we were able to detect echolocation clicks produced by beluga whales while they foraged. Figure 34 contrasts detections of tonal calls and clicks at these two stations. Click detections showed that belugas occurred more commonly in the Burger lease area than indicated by the manual analysis of lower-frequency whistle calls alone. On the other hand, manual detections of lower frequency calls occurred over 46 days while clicks were detected only on 25 days.

Detected signals included a mixture of whistles and pulsed calls (Figure 35).

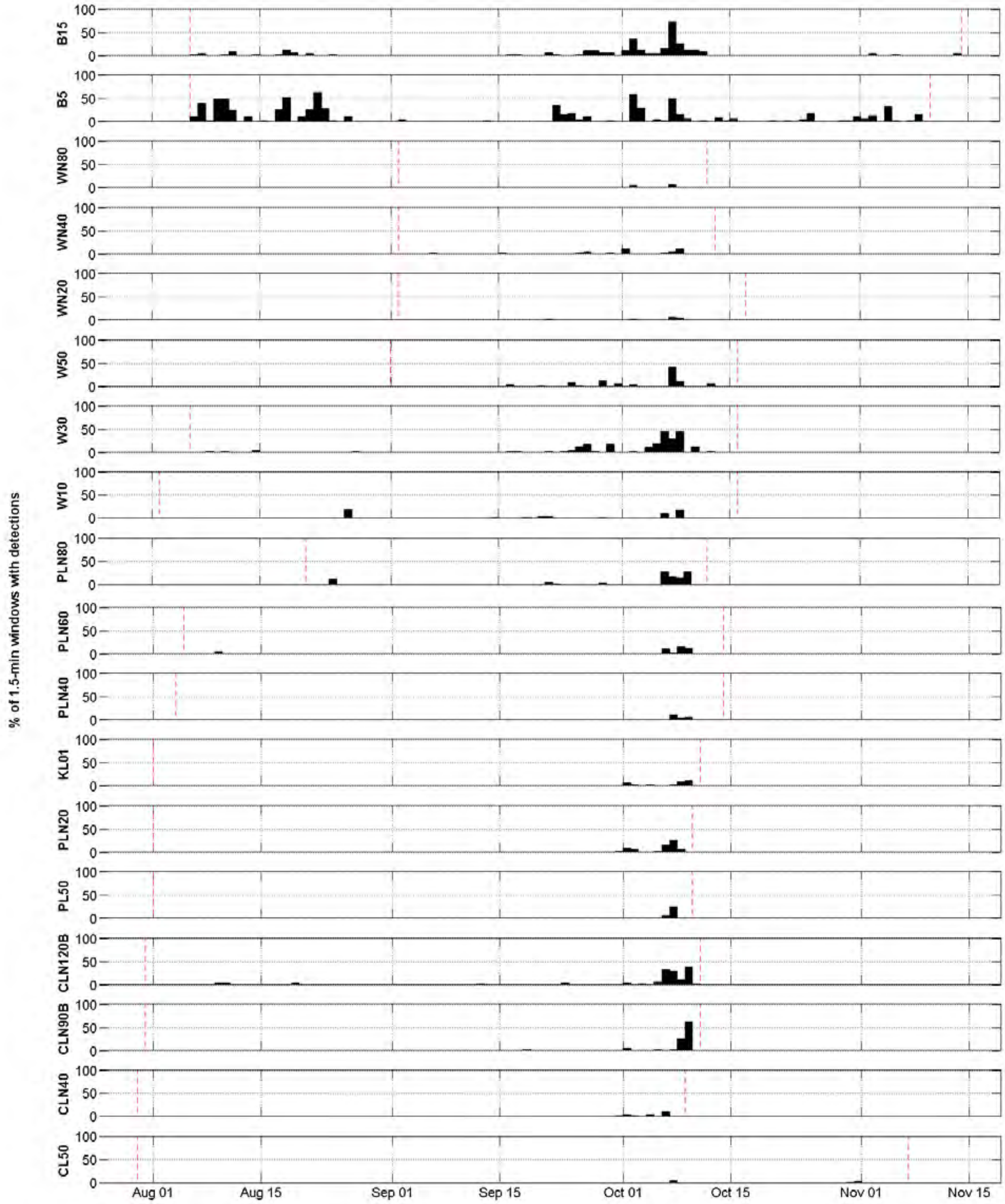

Figure 32. Summer 2014 daily beluga call detections in the northeastern Chukchi Sea: Daily proportion of sound files with detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2013. Forty-eight sound files were recorded each day. Red dashed lines indicate record start and end. Stations are ordered from (top) northeast to (bottom) southwest. Stations without call detections were omitted.

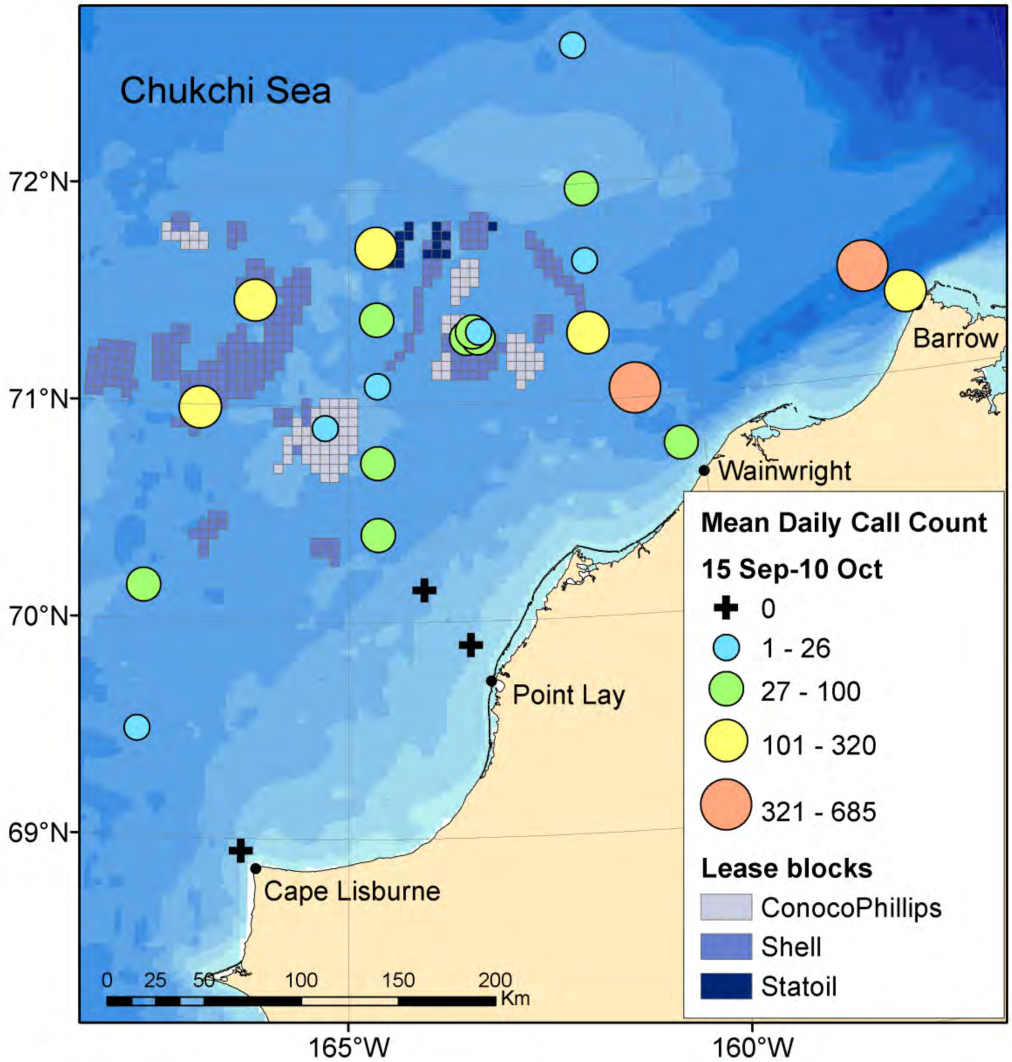

Figure 33. Mean daily beluga call counts (calculated as the sum of automated call detections in all files with manual detections divided by the number of active recording days) for 15 Sep to 10 Oct at all summer 2014 stations in the northeastern Chukchi Sea.

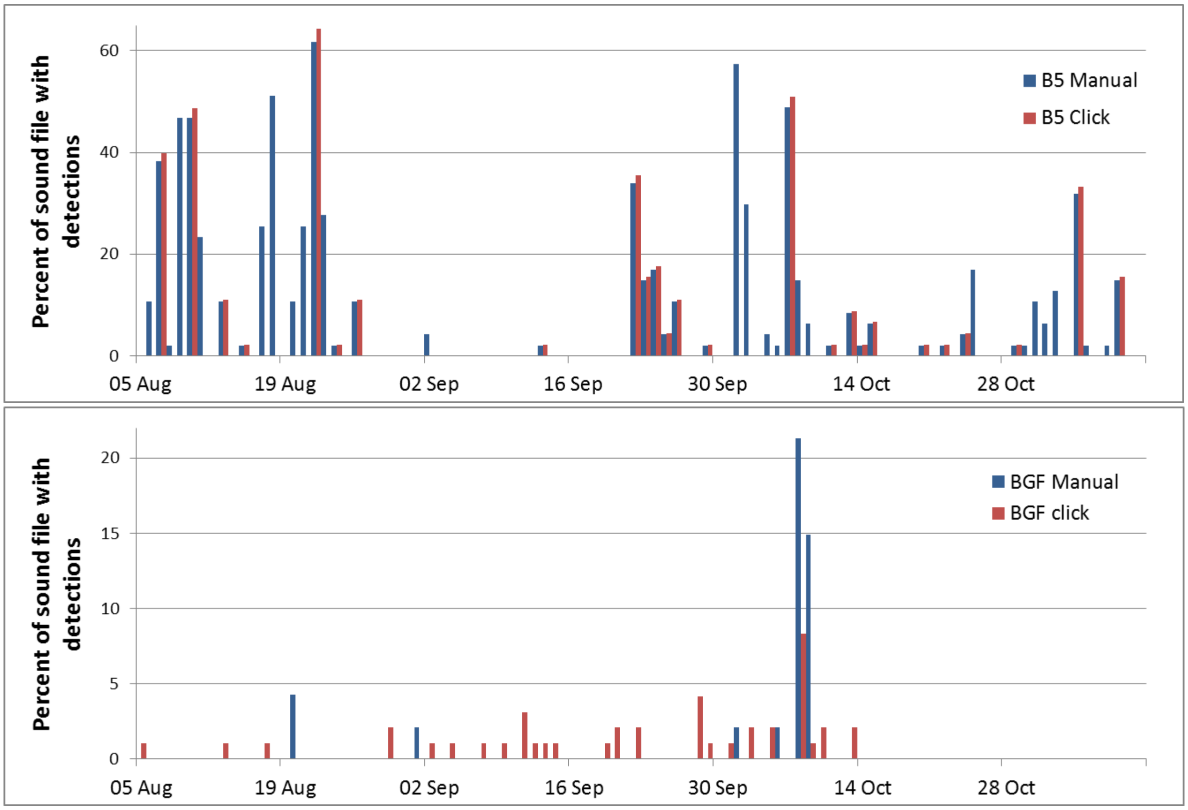

Figure 34. Summer 2014 daily percent of manual and automatic click beluga detections at (top) Station B5 and (bottom) BGF from 5 Aug through mid-November 2014.

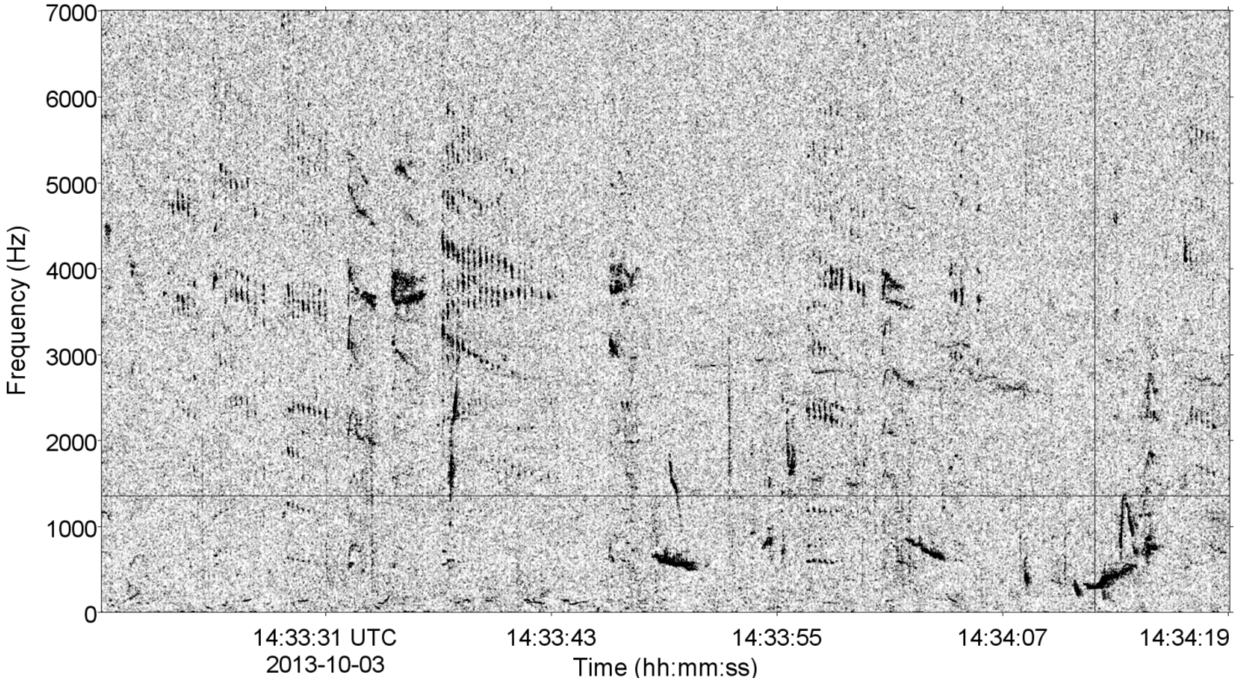

Figure 35. Beluga calls detected at Station BGB on 3 Oct 2013. (Frequency resolution: 1 Hz; Frame size: 0.06 s; Advance: 0.006 s; Hamming window).

3.4.5. Bearded Seal Call Detections

3.4.5.1. Winter 2013–2014 Recording Period

Bearded seals were detected at all stations. The number of detection days ranged from 22 at B5 to 226 at W50 (Table C–7). Detections were rare in October and November and started increasing in December and January. In the second half of January, all stations that were still active had one to two weeks with no or few detections, but resumed thereafter continuing to increase and peaking between April and June, depending on the stations. At WN40, detections peaked in May and June, but did not increase significantly until late March. The gap in detections at CL5 between mid-March and early Apr is due to a recorder's malfunction. Detections decreased rapidly and stopped completely over a few days at all stations. The last detection occurred between mid-June and early July, depending on stations. Detections continued longer at stations farther northeast (Figure 36).

Call counts overall were highest at W50 (Figure 37). Monthly call counts were similar across stations in November and December (Figures C–19 and C–20). Call counts varied most widely between stations in January after which time call counts rose in parallel at all stations, but were consistently lower at WN40, except in May when all stations had similarly high call counts. June counts were highest at stations farther northeast, although this is at least partly due to the recorder stopping early at CL5 (Figures C–21 to C–26).

The detected calls consisted primarily of upsweeping and downsweeping trills (Figure 38; Van Parijs et al. 2001).

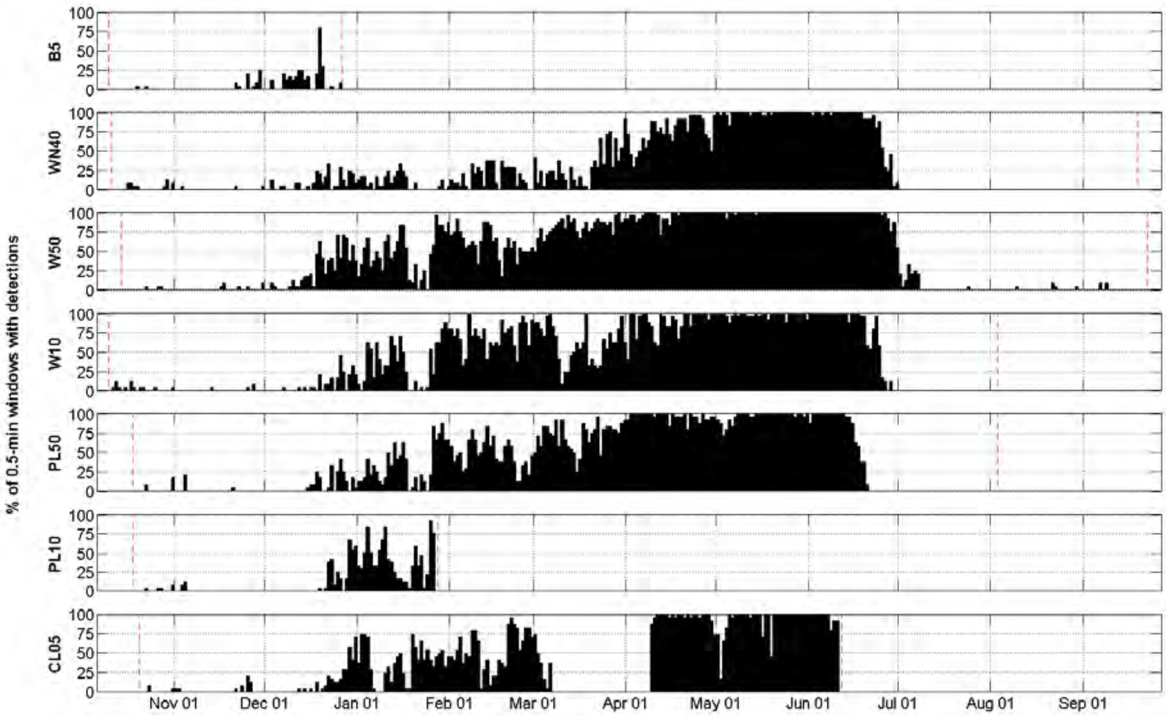

Figure 36. Winter 2013–2014 daily bearded seal call detections: Daily proportion of sound files with call detections based on the manual analysis of 5% of the acoustic data recorded early September 2013 through September 2014 in the northeastern Chukchi Sea for each station. Forty-eight sound files lasting 5 min were recorded each day every 30 min. Stations are ordered from (top) northeast to (bottom) southwest. The red dashed lines indicate the record start and end dates.

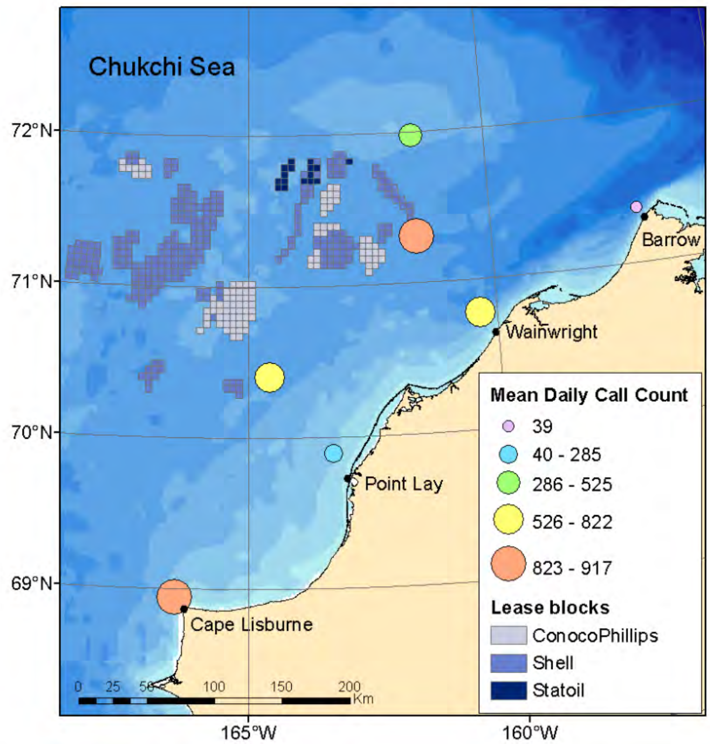

Figure 37. Bearded seal mean daily call counts[5] in the Chukchi Sea from Oct 2013 through July Sep 2014 at all winter 2013–2014 stations.

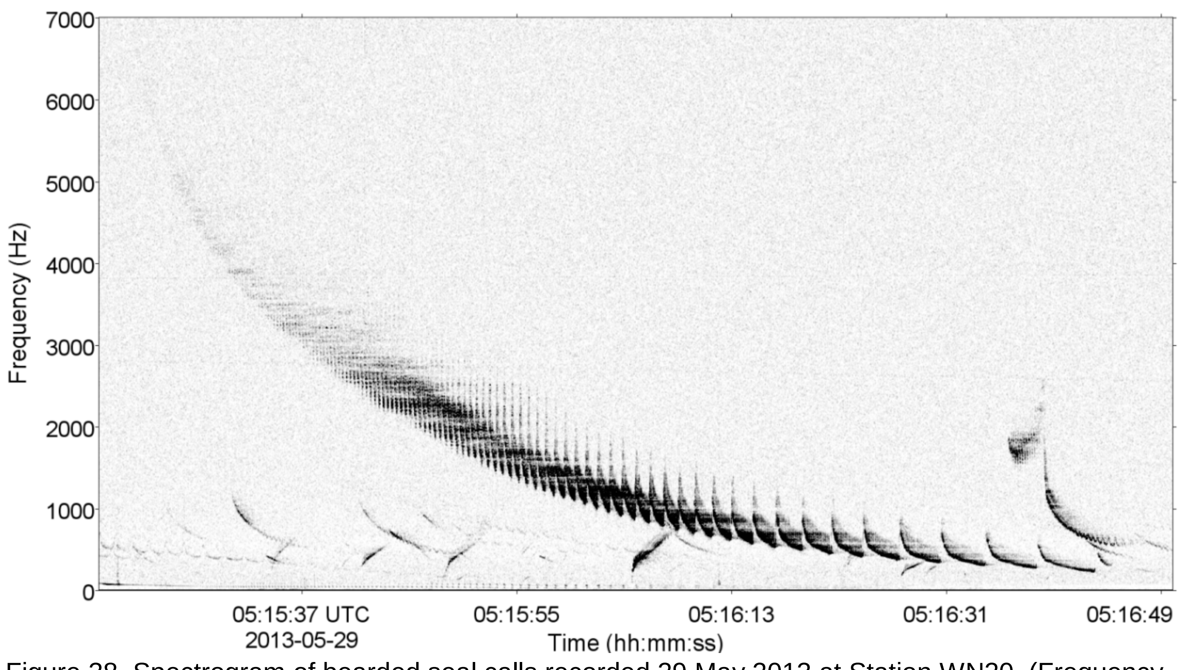

Figure 38. Spectrogram of bearded seal calls recorded 29 May 2013 at Station WN20. (Frequency resolution: 1 Hz; Frame size: 0.06 s; Advance: 0.006 s; Hamming window).

[5] Corrected sum of automated call detections in all files with manual detections divided by the number of recording days.

3.4.5.2. Summer 2014 Recording Period

Bearded seal calls were detected at all stations except CL5 and CL20. The proportion of recording days with detections ranged from 2.9 to 72.9% with a mean of 37% across stations (Table C–8). Detections were evenly distributed throughout the recording period, even though detections increased progressively starting in late Sep. There were few detections before 15 Aug (Figure 39).

Mean daily call counts were highest north of 71° N—the northernmost stations—particularly at B15, WN80, PLN60, and PLN80. Call counts were low along and west of a line running from Point Lay through Klondike to CLN120 (Figure 40) and generally increased with increasing distance from shore. Nevertheless, call count maxima occurred near Wainwright in the first half of the deployment, possibly indicating an offshore shift in distribution of calling bearded seals from summer to fall (Figures C–28 and C–29).

In summer bearded seal calls exhibited more temporal variability and were easily distinguishable from the long, complex spiraling calls common during the spring breeding season (Ray et al. 1969).

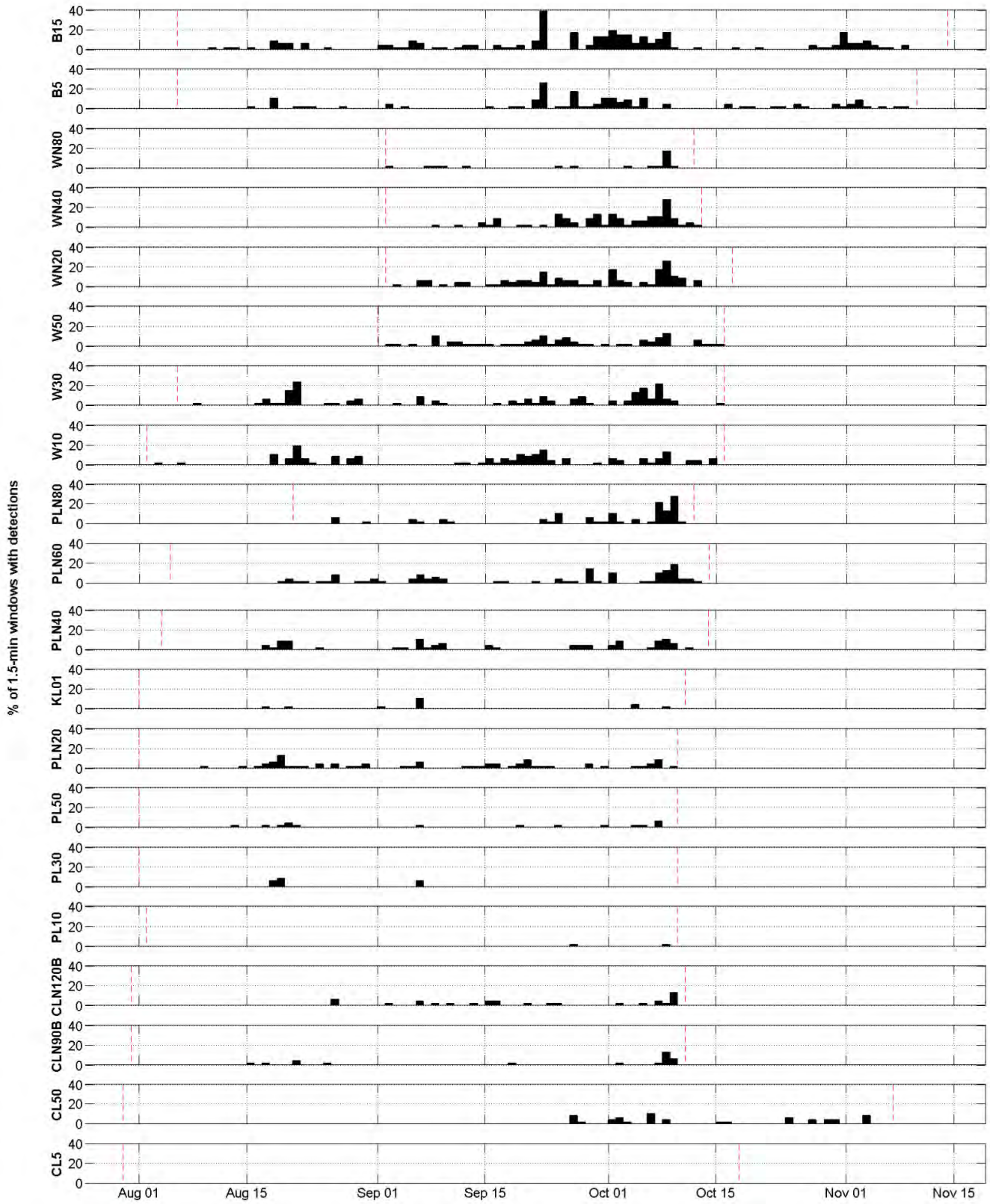

Figure 39. Summer 2014 daily bearded seal call detections: Daily proportion of sound files with call detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-November 2014.

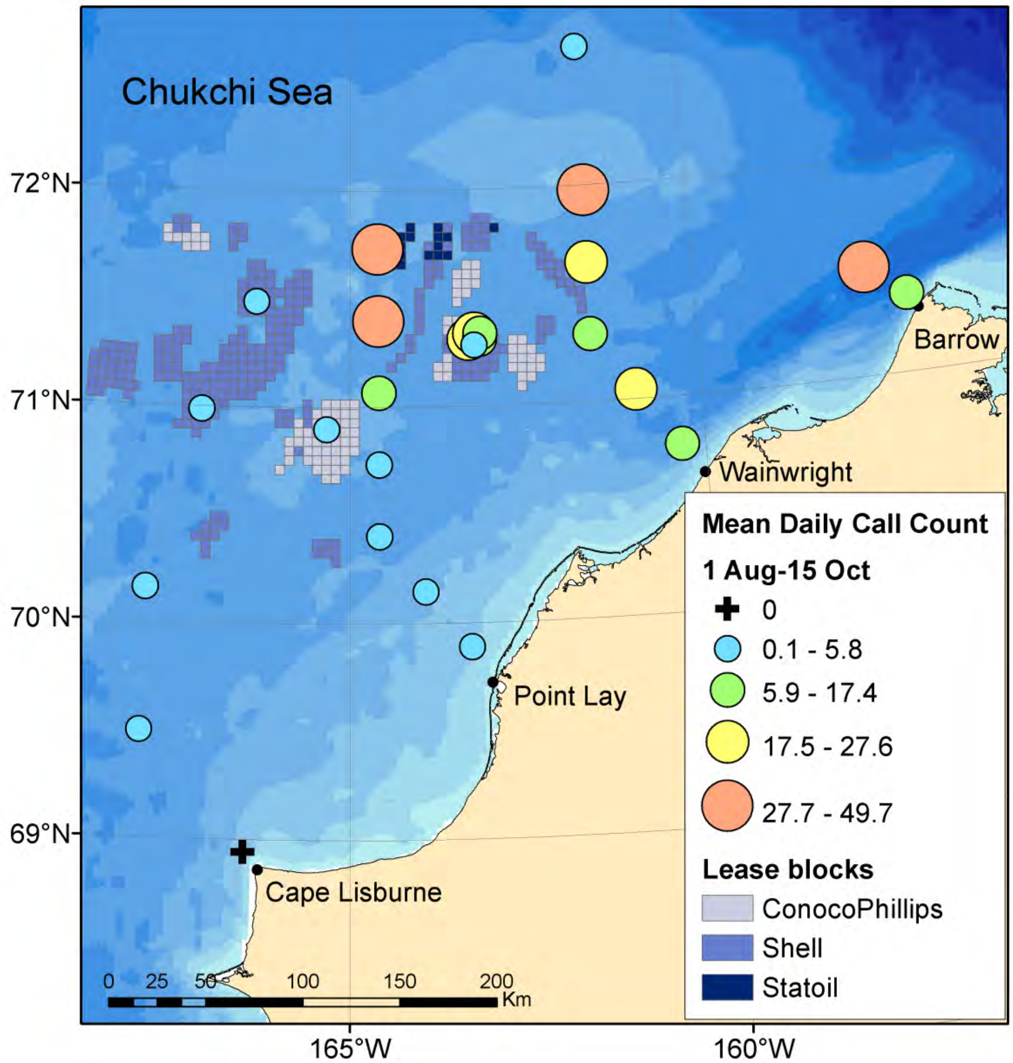

Figure 40. Mean daily bearded seal call counts (calculated as the sum of automated call detections in all files with manual detections divided by the number of active recording days) for 1 Aug to 15 Oct at all summer 2014 stations in the northeastern Chukchi Sea.

3.4.6. Fin Whale Call Detections

3.4.6.1. Winter 2013–2014 Recording Period

No fin whale calls were detected in the winter 2013–2014 dataset.

3.4.6.2. Summer 2014 Recording Period

Fin whale calls were detected at three Point Lay stations and in Klondike on 24 Aug and at PLN60 on 27 Aug (Table 7). CL50 had nine days of detections between 16 Aug and 21 Sep. Most calls were broadband signals sweeping down from 50 to 20 Hz (Figure 41).

Table 7. Summer 2014 fin whale call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the number and percentage of days on which a call was detected 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
KL01	1 Aug	24 Aug	24 Aug	10 Oct	1	1.4
PLN60	1 Aug	27 Aug	27 Aug	10 Oct	1	1.4
PLN20	1 Aug	24 Aug	24 Aug	10 Oct	1	1.4
PL50	2 Aug	24 Aug	24 Aug	9 Oct	1	1.5
PL30	2 Aug	24 Aug	24 Aug	9 Oct	1	1.5
CL50	31 Jul	16 Aug	21 Sep	6 Nov	9	9.3

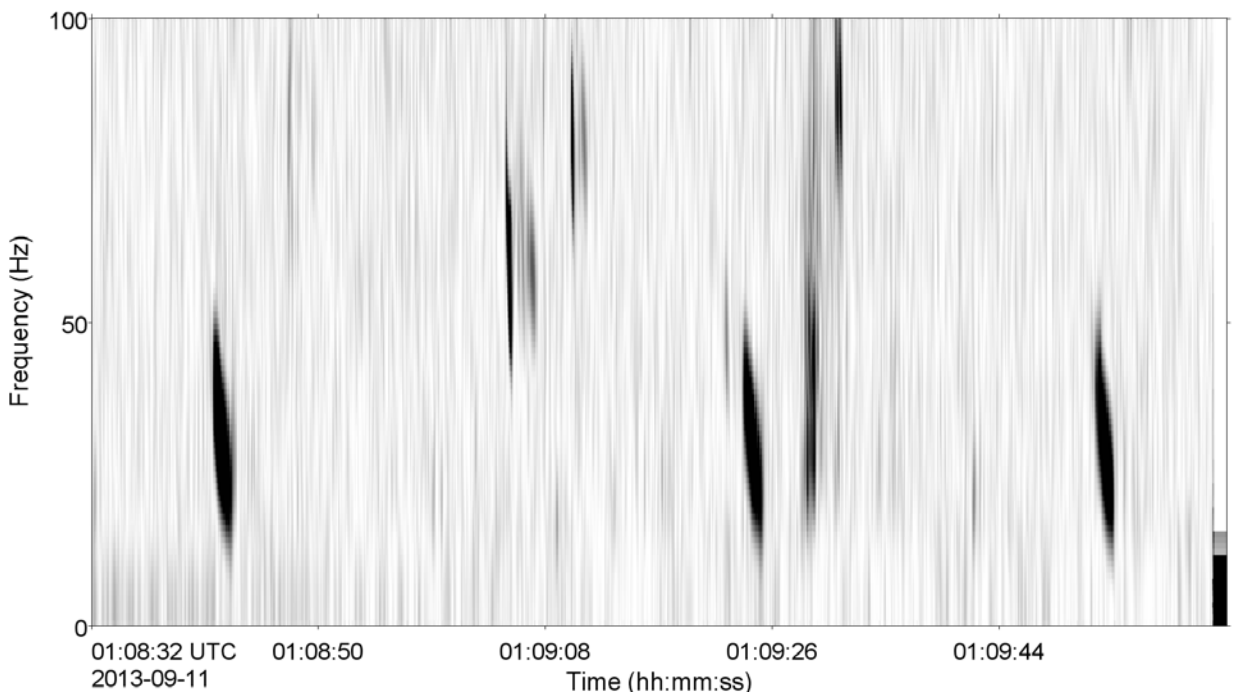

Figure 41. Spectrogram of fin whale calls recorded at Station CL50 on 11 Sep 2013. (Frequency resolution: 1 Hz; Frame size: 0.06 s; Advance: 0.006 s; Hamming window).

3.4.7. Gray Whale Call Detections

3.4.7.1. Winter 2013–2014 Recording Period

Gray whale calls were detected at four stations. WN40 had one mid-August 2014 detection. W50 had three early August detections. PL50 and W10 each had one detection in November. The earliest spring detection occurred at PL50 on 22 Jun. Gray whale calls were detected on 27 out of 33 possible days between 28 Jun and 31 Jul 2014 (Table 8).

Table 8. Winter 2013–2014 gray whale call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the number of days on which a call was detected manually for each station in the northeastern Chukchi Sea. The recorders operated for 5 min every 30 min.

Station	Record start	First detection	Last detection	Record end	Detection days	% Days with detection
WN40	12 Oct	17 Aug	17 Aug	18 Sep	1	0.3
W50	15 Oct	3 Aug	7 Aug	21 Sep	3	0.9
W10	11 Oct	19 Nov	31 Jul	2 Aug	28	9.5
PL50	19 Oct	4 Nov	26 Jul	2 Aug	3	1.0

3.4.7.2. Summer 2014 Recording Period

Gray whale calls were detected at all stations except CL20 and PL10. The proportion of recording days with detections was low on average (7.5%), but as high as 35.3% at W10 (Table C–9). At W10, detections were generally concentrated in August. There were few detections past mid-September in the study area (Figure 42).

Most of the detections were low-frequency moans (Figure 43), with additional contributions from pulses and bonging signals (Crane and Lashkari 1996).

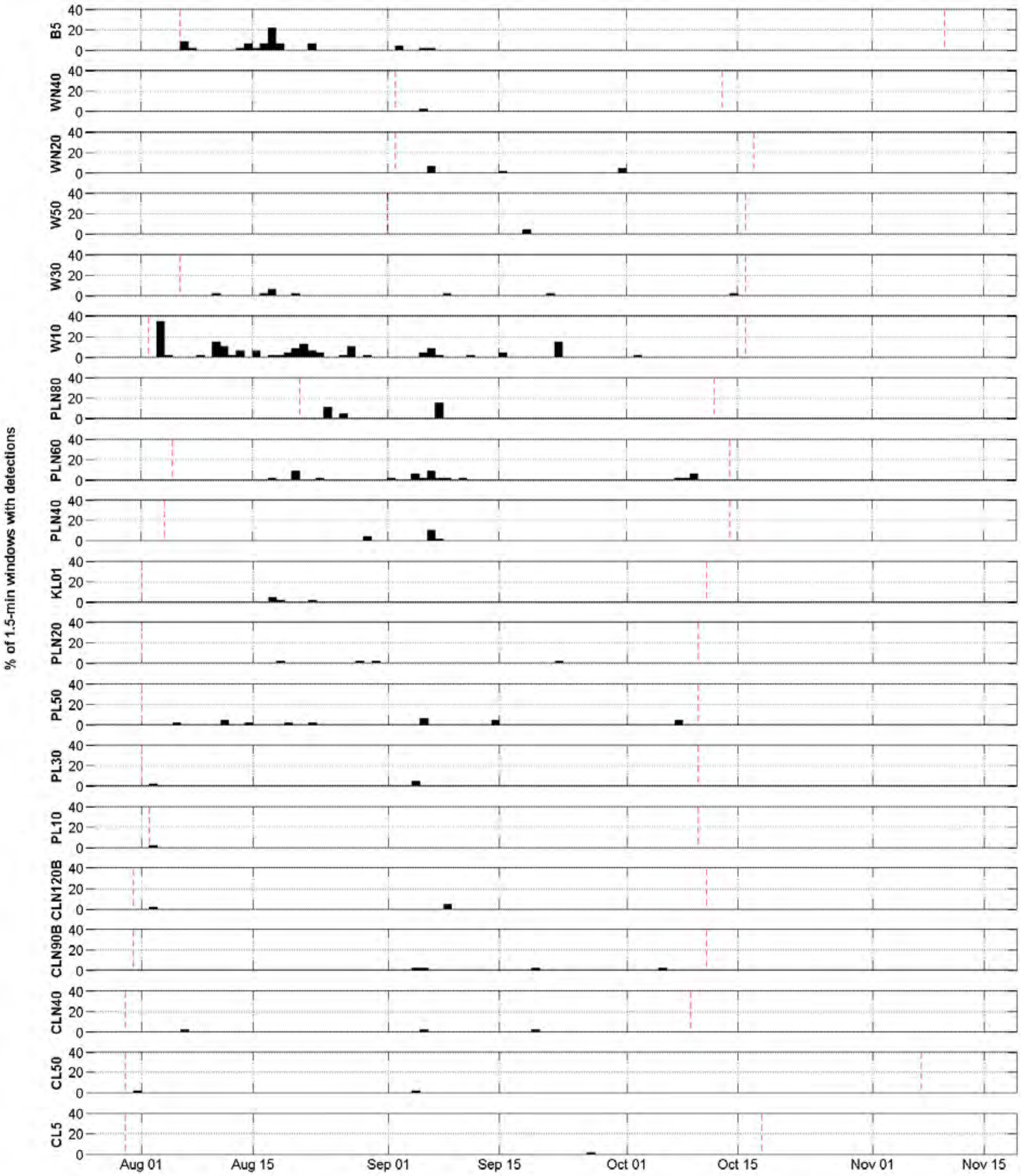

Figure 42. Summer 2014 daily gray whale call detections: Daily proportion of sound files with detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2014 in the northeastern Chukchi Sea. Forty-eight sound files were recorded daily. Stations without detections were omitted. Vertical dashed lines indicate recording start and end.

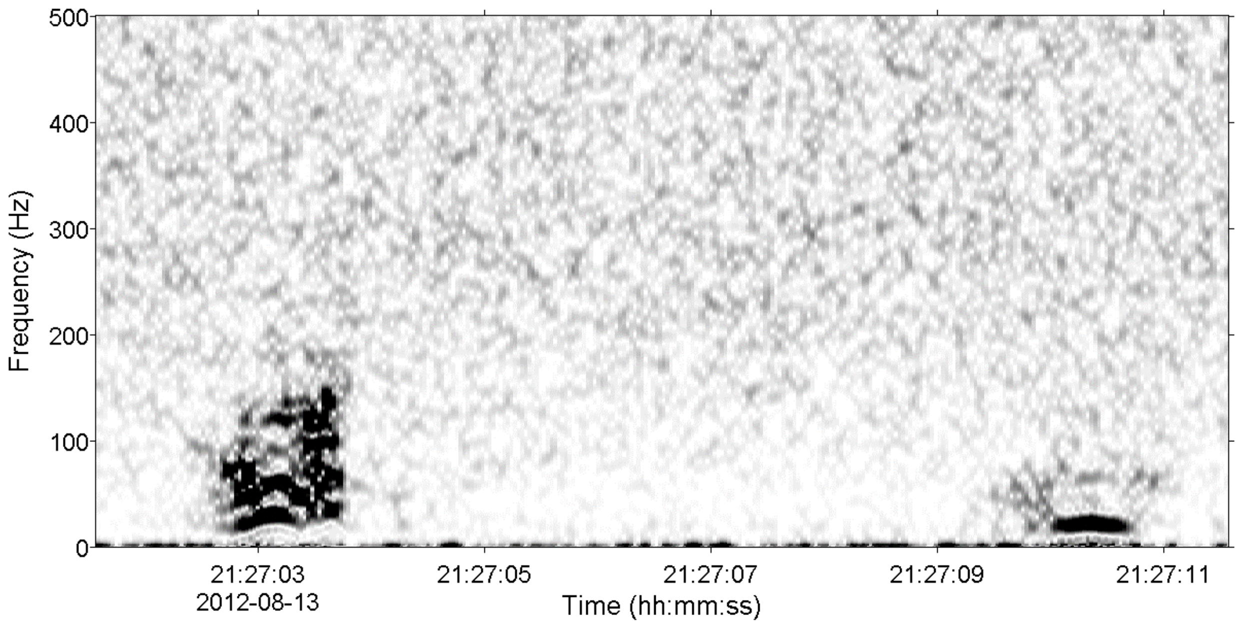

Figure 43. Spectrogram of gray whale moans recorded on 13 Aug 2012 at Station CLN90. (Frequency resolution: 1 Hz; Frame size: 0.06 s; Advance: 0.006 s; Hamming window).

3.4.8. Humpback Whale Call Detections

3.4.8.1. Winter 2013–2014 Recording Period

No humpback whale calls were detected in the winter 2013–2014 data.

3.4.8.2. Summer 2014 Recording Period

Humpback whale calls were detected once on 31 Jul 2014 at CLN40.

3.4.9. Killer Whale Call Detections

3.4.9.1. Winter 2013–2014 Recording Period

No killer whale calls were detected in the winter 2013–2014 data.

3.4.9.2. Summer 2014 Recording Period

Killer whale calls were detected between one and three days at 13 different stations. All detections occurred southwest of a line extending from W30 to Burger. Most detections occurred at multiple stations during two peaks—19 to 20 Aug and 7 to 8 Oct (Figure 44; Table C–10). Detections were more common at offshore than inshore stations. The detected calls consisted mostly of pulsed calls and whistles (Ford 1989).

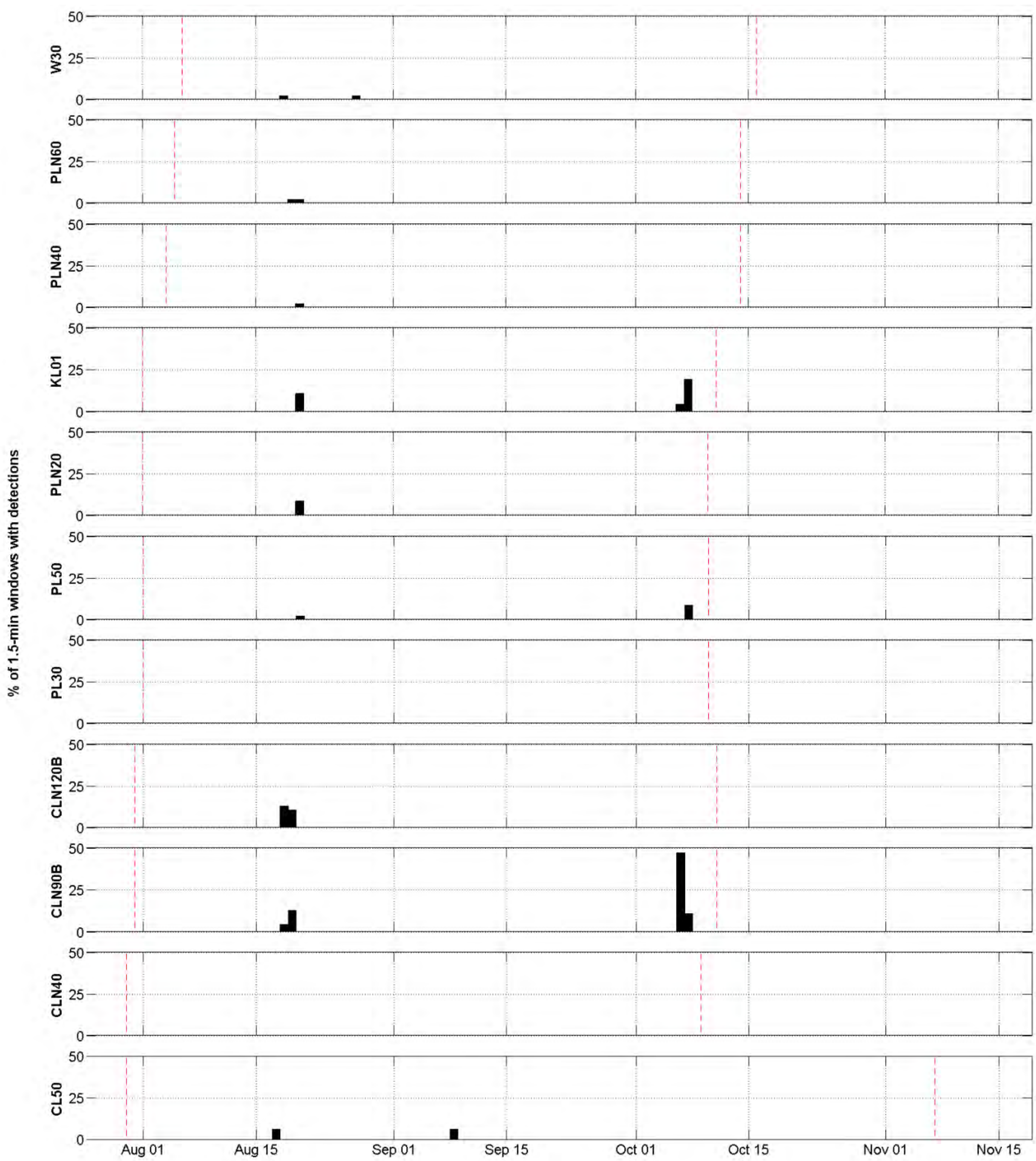

Figure 44. Summer 2014 killer whale call detections: Daily proportion of 30 min sound files with call detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2014. Forty-eight sound files were recorded daily. Vertical dashed lines indicate recording start and end. Stations are ordered from (top) northeast to (bottom) southwest. Stations without call detections were omitted.

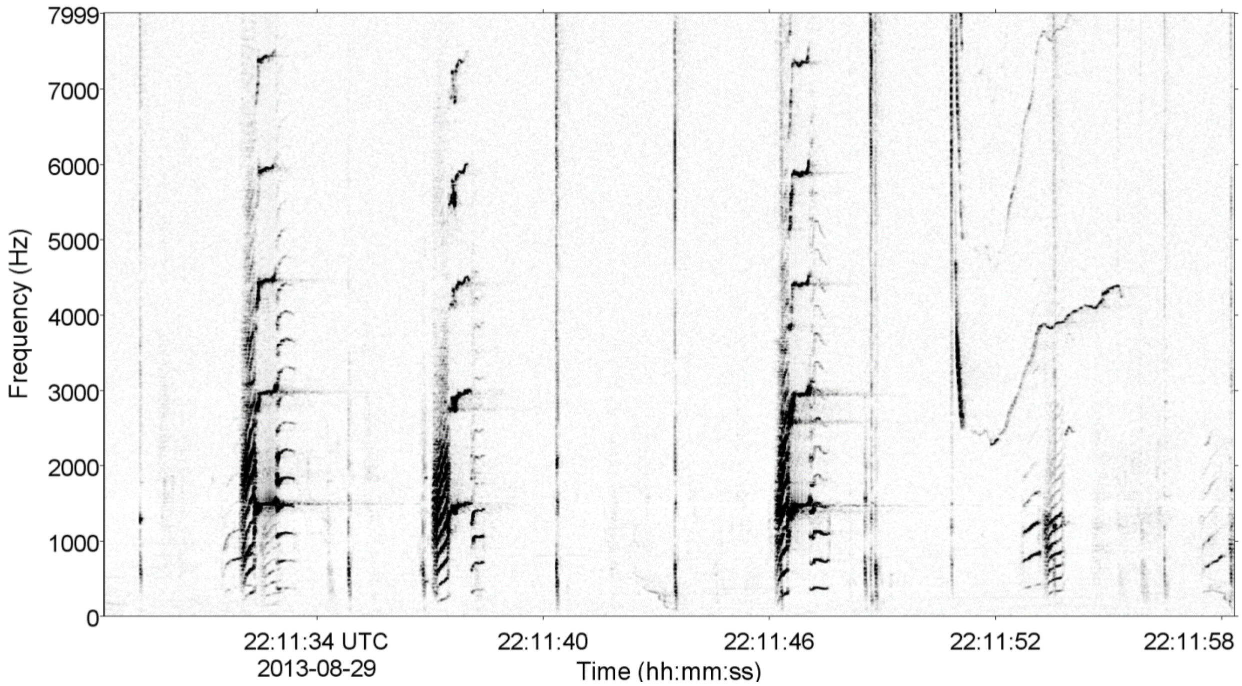

Figure 45. Killer whale call spectrogram from detections at Station CLN90, 29 Aug 2013. (Frequency resolution: 1 Hz; Frame size: 0.06 s; Advance: 0.006 s; Hamming window).

3.4.10. Minke Whale Call Detections

3.4.10.1. Winter 2013–2014 Recording Period

Minke whale boing calls were detected between 22 Oct and 6 Nov 2013 at PL50, PL10, and CL5. At PL10 detections occurred on a single day; at PL50 detections occurred over four days; at CL5 detections occurred over five days.

3.4.10.2. Summer 2014 Recording Period

Minke whale boing sounds were detected once at CLN40 on 5 Sep 2014.

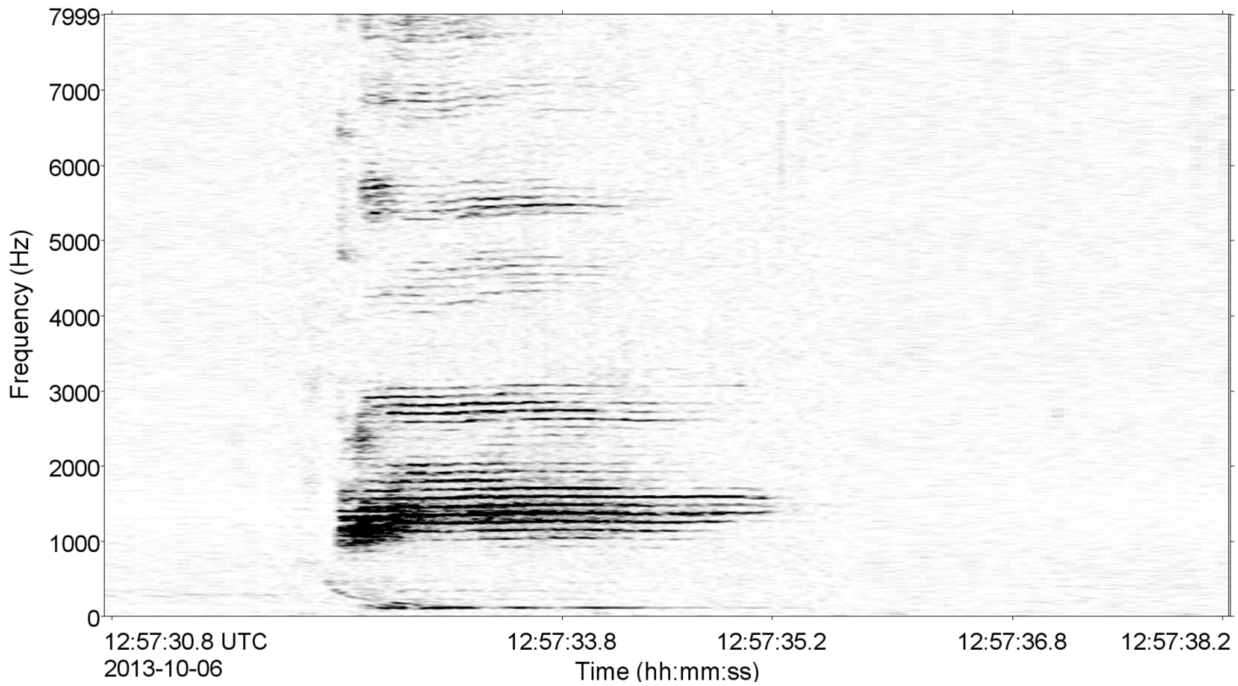

Figure 46. Minke whale boing calls recorded 6 Oct 2013 at Station PL30. (Frequency resolution: 1 Hz; Frame size: 0.06 s; Advance: 0.006 s; Hamming window).

3.4.11. Ribbon Seal Call Detections

3.4.11.1. Winter 2013–2014 Recording Period

Ribbon seal calls were detected at three stations between 19 Oct and 20 Nov 2013. Four detection days occurred between 19 Oct and 3 Nov at B5; five detection days occurred at PL50 between 1 and 20 Nov; three detection days occurred at W50 between 1 and 5 Nov.

Two types of ribbon seal calls were detected: loud downsweeping signals, with or without harmonics, which corresponded to the short and medium sweeps, and loud puffing sounds as described by Watkins and Ray (1977; Figure 47).

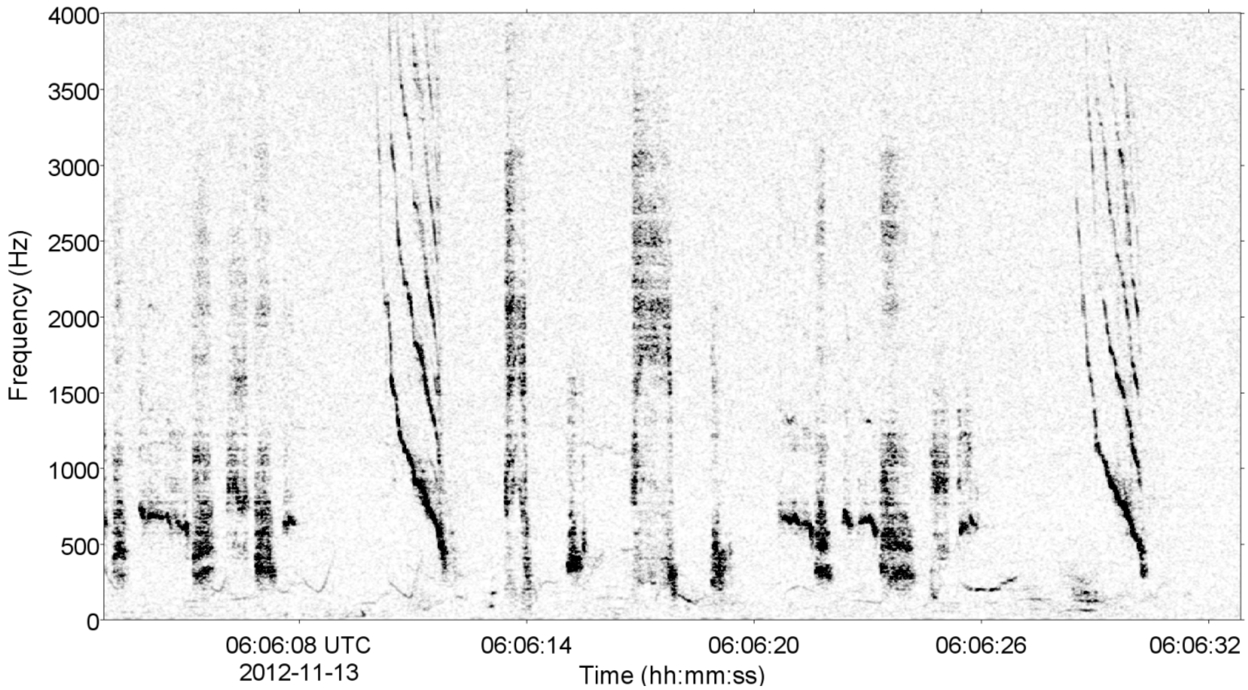

Figure 47. Spectrogram of ribbon seal calls recorded 13 Nov 2012 at Station PLN100. (Frequency resolution: 1 Hz; Frame size: 0.06 s; Advance: 0.006 s; Hamming window).

3.4.11.2. Summer 2014 Recording Period

Ribbon seal calls (Figure 47) were detected once at CLN120 on 8 Oct 2014.

3.4.12. Ringed Seal Call Detections

3.4.12.1. Winter 2013–2014 Recording Period

Ringed seal calls were detected at all stations during the winter 2013–2014 deployment. The number of days with detections ranged from 1 or 2 days at B5 and PL10 (presumably due to their short recording duration) to 125 and 127 days at PL50 and W50 (Table C–11). Station W50 and PL50 had similar temporal detection patterns: detections occurred almost daily, but at low levels in November and December. There were no detections in January at either station. Calls were detected in a few files on most days in February and March. Detections increased and peaked in April and May before stopping at the end of May. The pattern was somewhat similar at W10 except that detections were absent before February. Detections at CL5 did not follow any clear temporal pattern, whereas detections at WN40 were generally rare before mid-April except for a bout of detections in late December early January (Figure 48).

In previous years, we showed that the detection probability for ringed seal barks and yelps using a 5% manual data analysis protocol was low (22%; see Appendix A in Delarue et al. (2013b)). Including thumps (see Delarue et al. 2014) in the set of targeted calls definitely raised the detection probability although we did not quantify the associated increase. By including thumps, we feel that the results better represent the true acoustic occurrence of ringed seals in the Chukchi Sea.

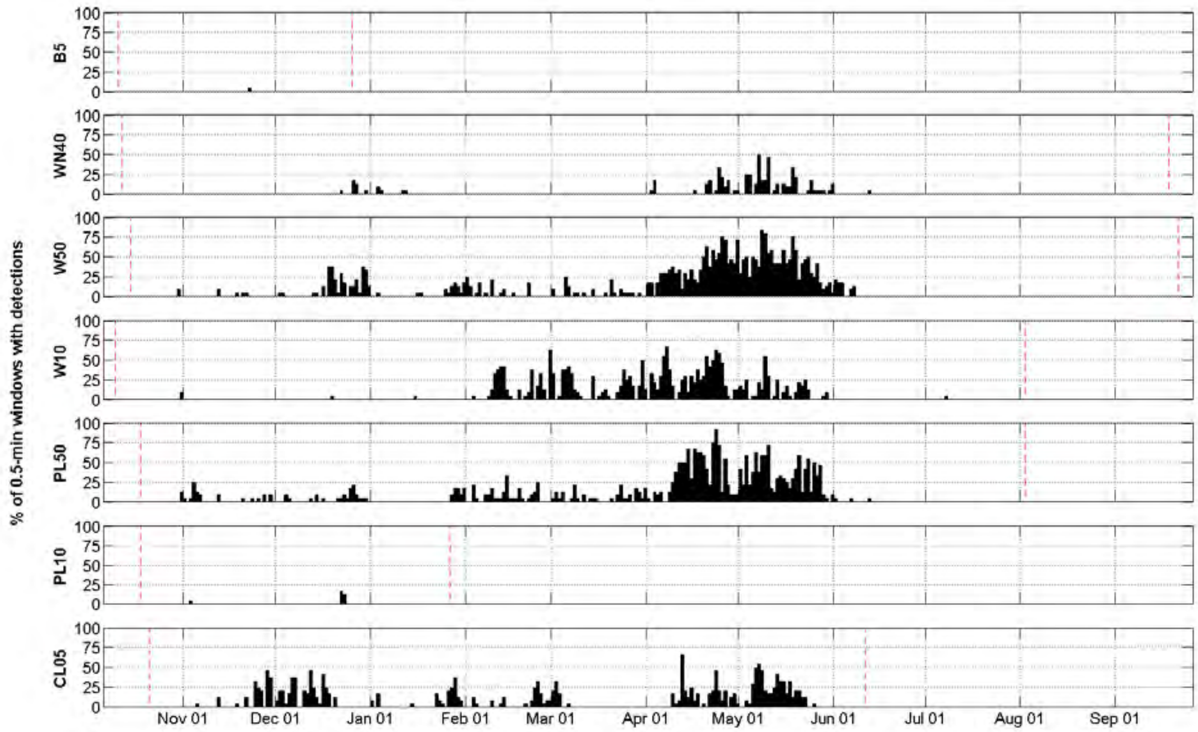

Figure 48. Winter 2013–2014 daily ringed seal call detections: Daily proportion of sound files with call detections based on the manual analysis of 5% of the acoustic data recorded early September 2013 through Sep 2014 in the northeastern Chukchi Sea for each station. Six sound files lasting 30 or 40 min were recorded each day every four hours. Stations are ordered from (top) northeast to (bottom) southwest. The vertical dashed lines indicate the recording start and end dates.

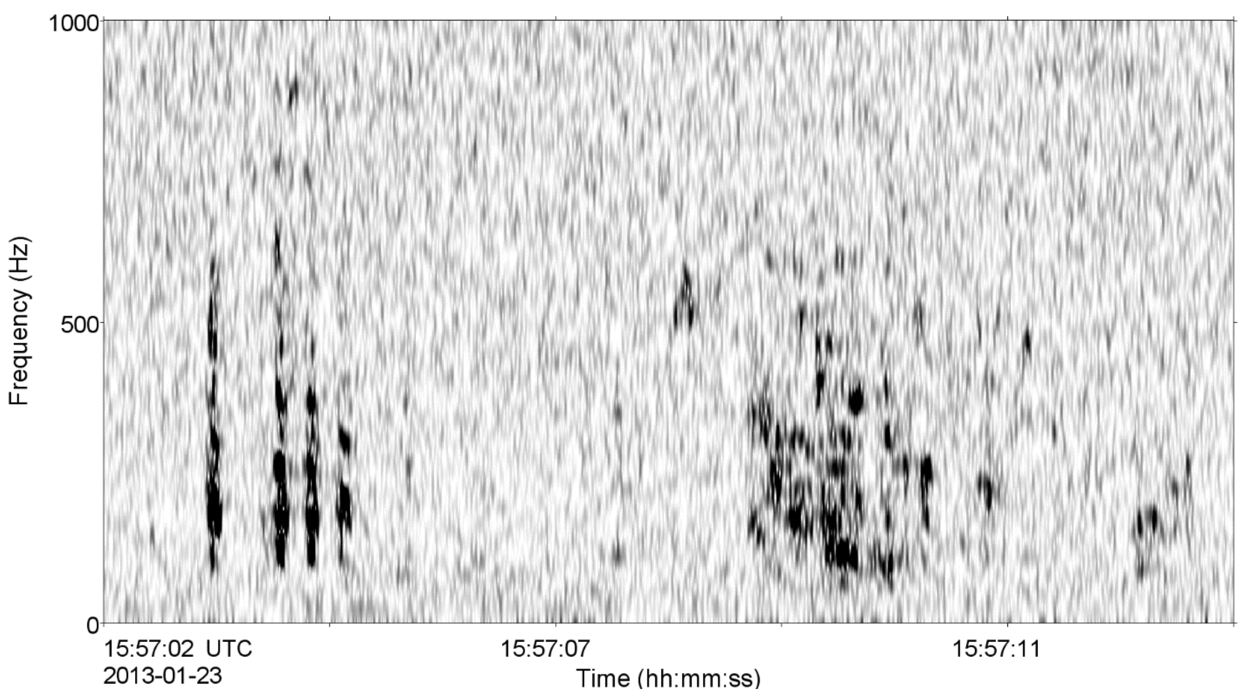

Figure 49. Spectrogram of ringed seal calls recorded 23 Jan 2013 at Station CL50. (Frequency resolution: 1 Hz; Frame size: 0.06 s; Advance: 0.006 s; Hamming window).

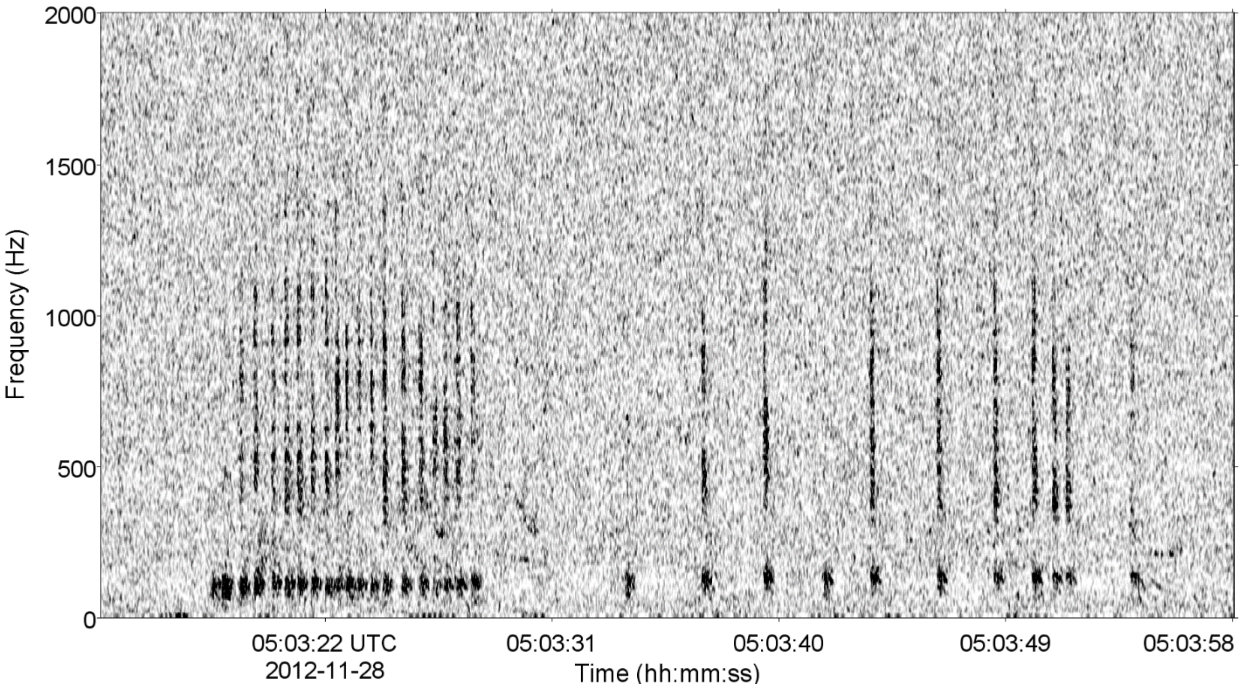

Figure 50. Spectrogram of thumps produced by ringed seals recorded 28 Nov 2012 at Station CL50. (Frequency resolution: 1 Hz; Frame size: 0.06 s; Advance: 0.006 s; Hamming window).

3.4.12.2. Summer 2014 Recording Period

Ringed seal calls were detected at 17 stations during summer 2014. Calls were recorded on one to 13 days per station (Table C–12). Detections were sporadic throughout the study area. No temporal or spatial patterns were observed (Figure 51).

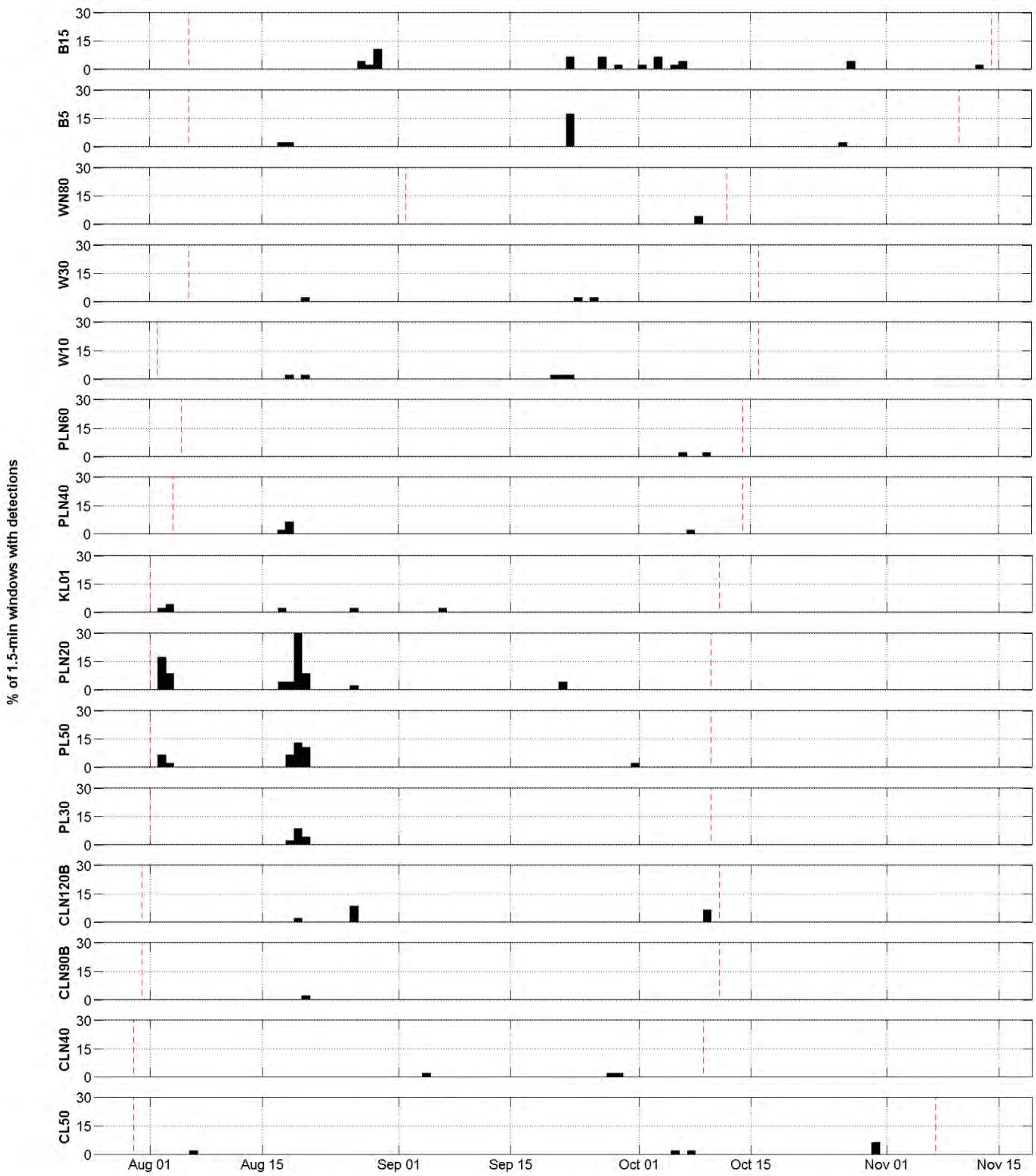

Figure 51. Summer 2014 daily ringed seal call detections: Daily proportion of 30 min sound files with call detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2014. Forty-eight files were recorded daily. Vertical dashed lines indicate recording start and end. Stations are ordered from (top) northeast to (bottom) southwest. Stations without call detections were omitted.

3.4.13. Spotted Seal Call Detections

Spotted seals were not manually or automatically detected in the winter 2013–2014 or summer 2014 datasets, likely because we do not have a good representation of their call types. Spotted seals are regularly seen in the program area in summer (e.g., Aerts et al. 2013). It would be worthwhile to document their calls to improve this analysis. One way to do that would be to place recorders near known spotted seal summer haul-outs (e.g., in Kasegaluk Lagoon passes; Frost et al. 1993).

4. Discussion: 2007–2014 Trends

4.1. Received Ocean Noise

Ambient noise consists 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 has been part of the environment in which marine life has evolved, it is appropriate to assume that marine animals have adapted to 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 like the Chukchi Sea. Marine fauna are likely less well adapted to deal with anthropogenic sounds that differ in temporal and spectral character from natural sounds. One of the goals of this study is to characterize natural and anthropogenic sounds in the Chukchi Sea environment and to determine when and where it exceeds the natural ambient noise.

The ambient sound levels measured at Station PLN40 throughout the summer and the winter deployments are compared from seasons 2007 through 2014. Ambient sound levels for summer 2014 are also compared between several stations. This discussion addresses both natural and anthropogenic sounds.

4.1.1. Station PLN40 Multi-Year Analysis

The 2007–2014 summer ambient noise measurements were consistent with each other and with previous years' measurements of this program. Local variations were correlated with weather, marine mammal acoustic activity, vessel activity, and seismic exploration. The 50th percentile (median) power spectral density (PSD) levels are presented in Figure 52 from Station PLN40 for from summer recording periods from 2007 to 2014. Station KL11 was substituted for summer 2009 because PLN40 was not deployed that year. Winter session PSDs from 2007 to 2013 are plotted in Figure 53. Station W50 was substituted for winter 2013-2014 because the recorder at Station PLN40 was not retrieved until fall 2015. We have displayed spectrograms for the summer and winter periods separately because of their different spectral characteristics (Figures 54 and 55).

The 2013–2014, winter dataset is the first one monitored using AMARs; all prior winter measurements were made with AURALs. The AMAR has a lower noise floor than the AURAL and thus this type of recorder captured true ambient levels above 1500 Hz that were obscured by AURAL self-noise (Figure 53). At 8 kHz, the AMAR shows a median PSD of approximately 35 dB re $\mu Pa^2/Hz$, approximately 15 dB lower than measured by the AURALs. While this is a low level, it is still well above the corresponding lower Wenz curve range of 20 dB re $\mu Pa^2/Hz$.

Summer 2014 noise levels at PLN40 were similar to previous years' but spectral levels from 300 Hz to 4 kHz were about 3 dB above the multi-year mean. These elevated levels are attributed to noise produced a relatively large number of weather events this year.

Summer 2013 noise spectral levels in the 30 to 400 Hz band were approximately 5 dB above the multi-year mean. This difference can be attributed to greater seismic survey activity in 2013 near Station PLN40. The spectral levels above 400 Hz are similar to other years.

In summer 2012, ambient noise levels below 1 kHz increased in mid-September (Figure 54). 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.

In summer 2011, two periods of increased broadband noise in mid-August and mid-September 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 52.

In summer 2010 there was substantial seismic survey activities that resulted in the highest spectral levels below 150 Hz of all years. Sound levels at higher frequencies were among the lowest of the multi-year measurements. That may have been due to calmer weather conditions.

The summer 2009 ambient noise spectral levels were similar to those in other years. There was a restricted period of shallow hazards seismic activity captured in this recording but it did not significantly affect the time-averaged levels. The elevated levels above 3 kHz in these data are likely due to recorder self-noise.

The summer 2008 recording period showed spectral levels were slightly elevated relative to the multi-year mean. Even though this recording period was much shorter than other years, it extended later in the season when wind and weather conditions were worse.

During summer 2007, the PLN40 recorder was deployed only until 14 Sep. Because Aug and early Sep experienced calm weather, the spectral levels are low relative to other years. This is despite an extensive seismic survey program that occurred in September.

The spectral density percentiles (Figure 52) and spectrograms (Figure 54) both indicate that sound levels are higher at lower frequencies (< 1 kHz) than at higher frequencies. When integrated over decade-bands, however, the in-band SPLs show that the total sound levels from 10–100 Hz are much lower than those in the 100–1000 and 1000–8000 Hz bands (Table 9). Generally, sound levels in the 100–1000 Hz band are the highest, which indicates that wind-generated surface noise is the dominant noise source in the Chukchi summer.

Table 9. Median decade-band sound pressure levels (dB re 1 µPa) for summers 2009 through 2014 at Station PLN40.

Year	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
2014	92.0	100.3	95.2

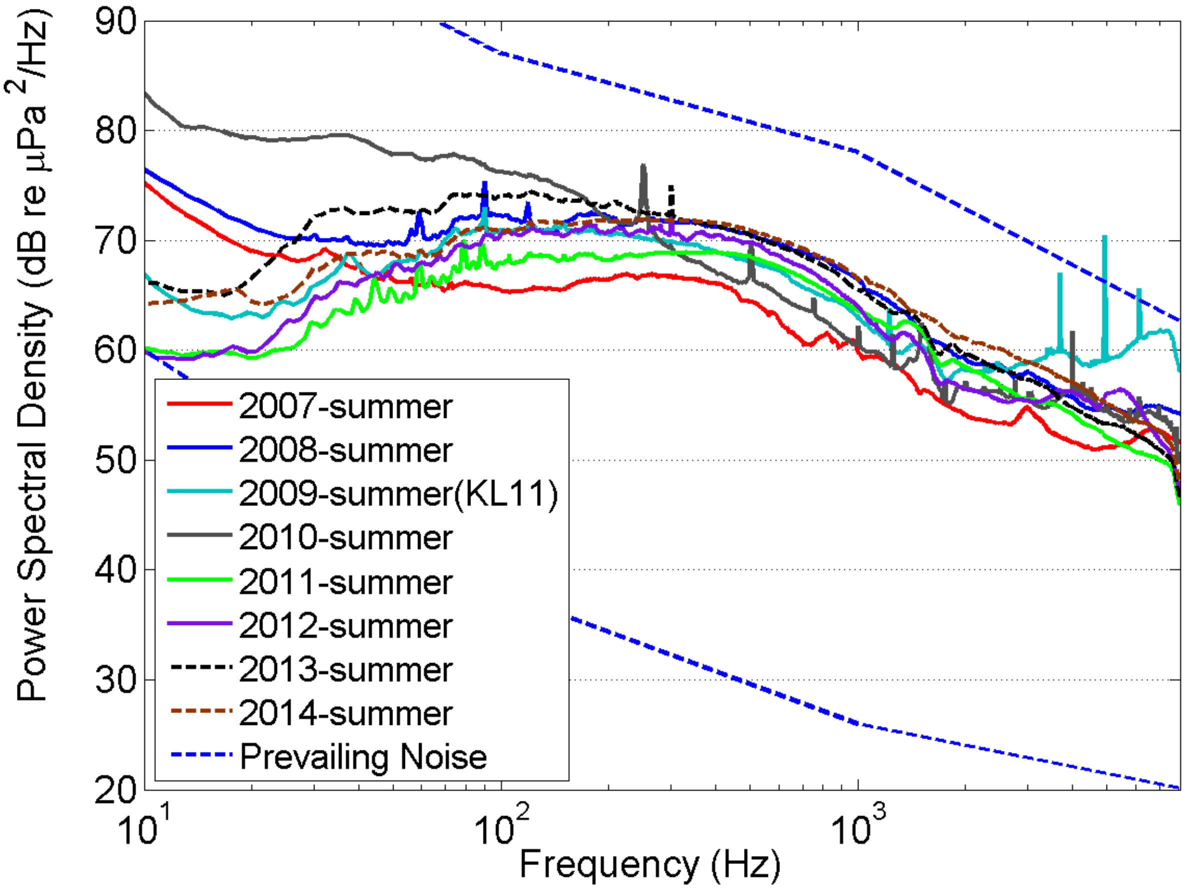

Figure 52. Percentile 1 min power spectral density levels at PLN40, for the recording periods from summer 2007 through 2014. Station KL11 results are shown for summer 2009 because PLN40 data are unavailable for that year.

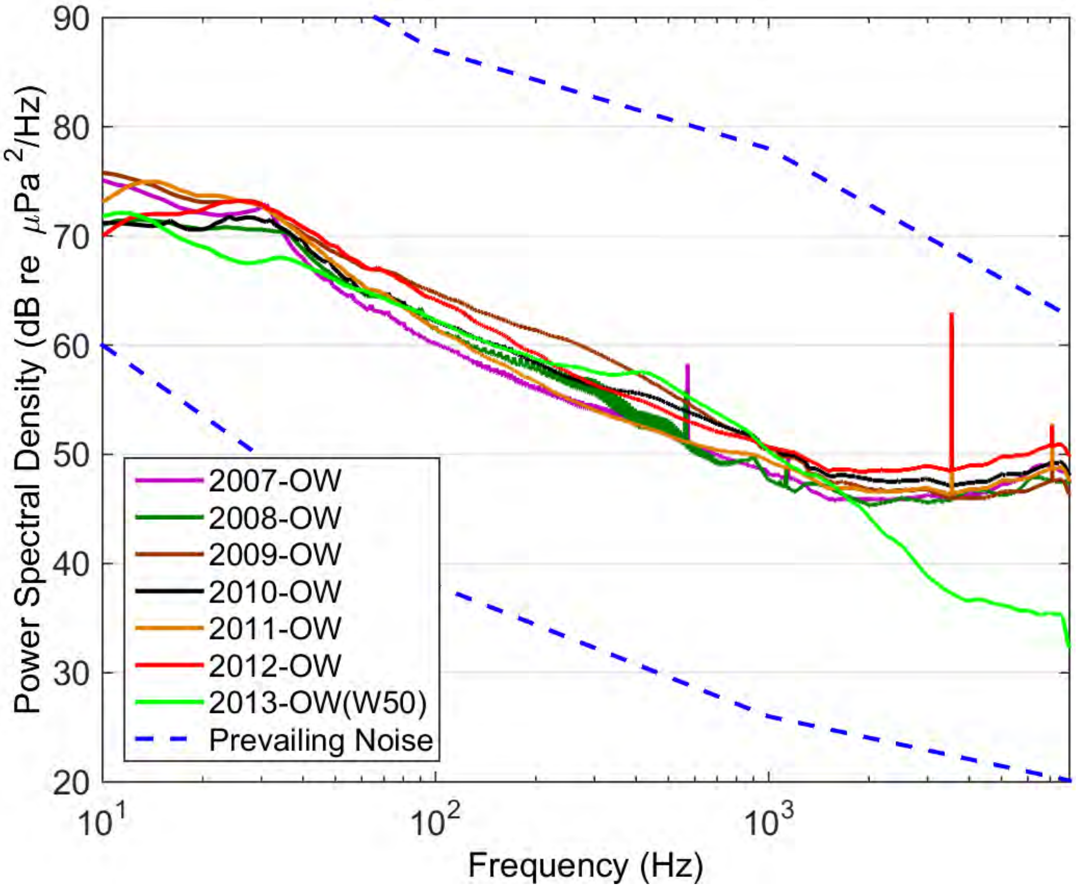

Figure 53. Percentile 1 min power spectral density levels at PLN40, for the recording periods from winter 2007 through 2013. Station W50 results are shown for winter 2013 because PLN40 has not yet been retrieved.

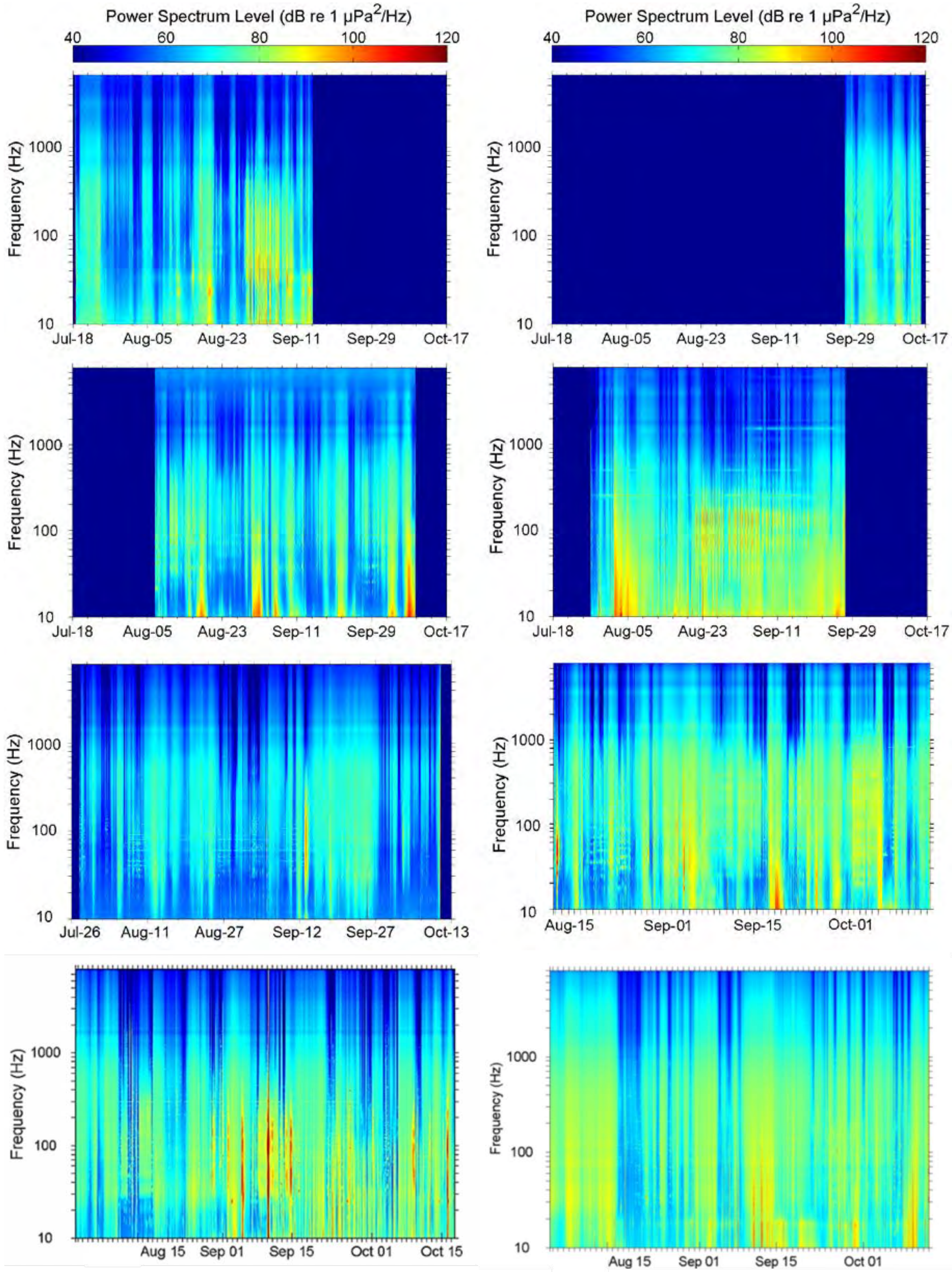

Figure 54. Spectrogram of underwater sound at Station PLN40 for summer deployments (top left) 2007, (top right) 2008, (upper middle left) 2009, (upper middle right) 2010, (lower middle left) 2011, (lower middle right) 2012, (bottom left) 2013, and (bottom right) 2014.

Ambient noise spectral levels from the 2007 to 2010 winter periods decrease linearly over the frequency range 40 Hz to 2 kHz. The winter 2011 recording period was much quieter than the other recording periods; winter 2012 was louder than the others (Figures 53 and 55). Due to the lower noise floor of the AMAR, the winter 2013 median data are lower for frequencies above 2 kHz. Below 2 kHz, PSD levels are similar to previous years, with the exception of a small increase between 400 and 700 Hz, which was likely caused by bearded seals that were more prominent on W50 than PLN40. The loudest periods correspond with ice formation and break up. The relatively high spectral levels below 100 Hz are attributed to wind noise propagating through the ice.

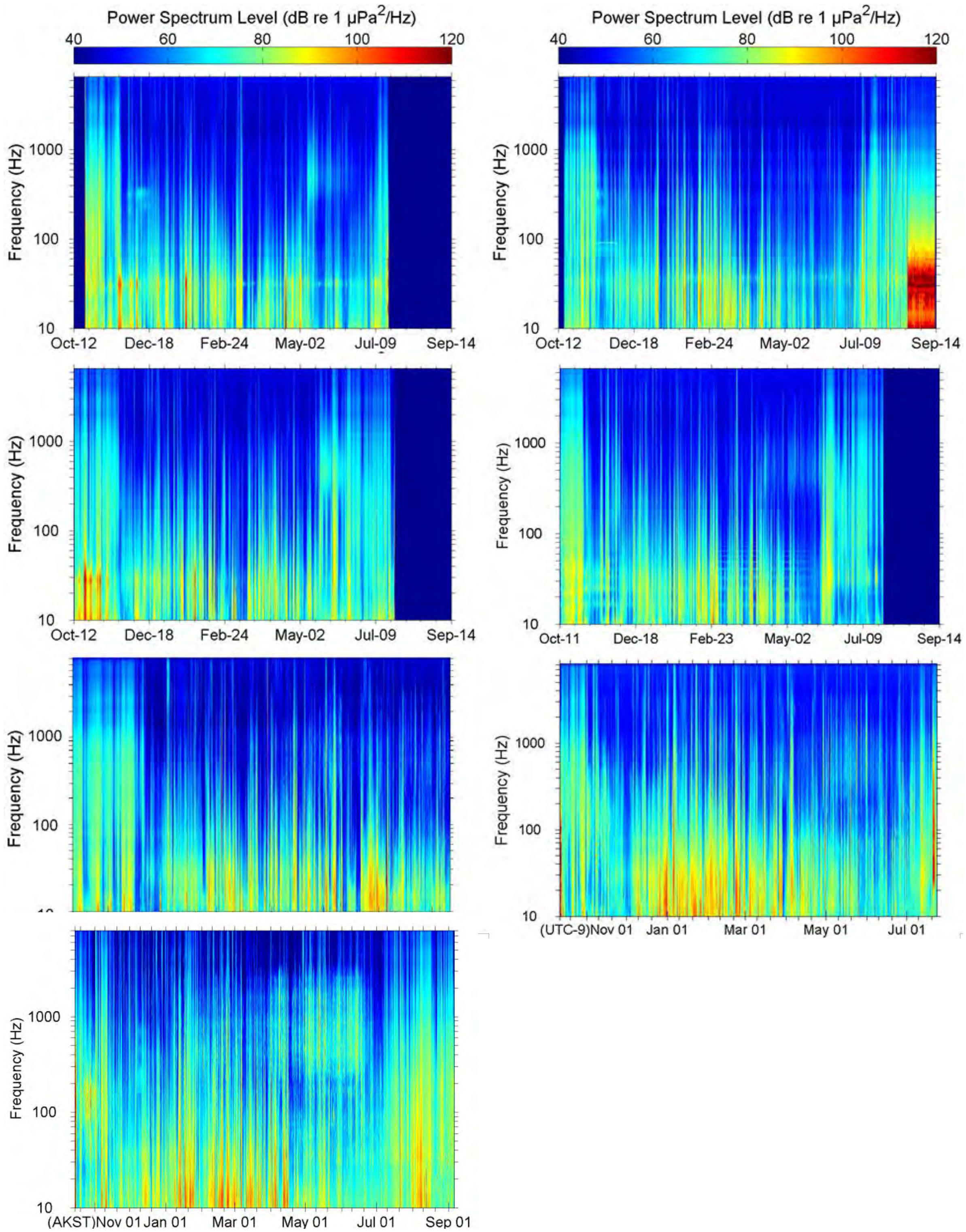

Figure 55. Spectrogram of underwater sound at Station PLN40 for the winter programs for (top left) 2007–2008, (top right) 2008–2009, (upper middle left) 2009–2010, (upper middle right) 2010–2011, (upper middle left) 2011–2012, (upper middle right) 2012–2013, and (bottom) 2013–2014. Station W50 results are shown for winter 2013–2014 because PLN40 has not yet been retrieved.

4.1.2. Summer 2014 Recording Period

The 50th percentile power spectral density levels from the summer 2014 recordings are plotted for stations along a line roughly going east to west (Figure 56); the corresponding spectrograms for the recordings are shown in Figure 57. Sound levels below 1 kHz at Stations PLN60 and W50 were higher than other stations due to biological noise.

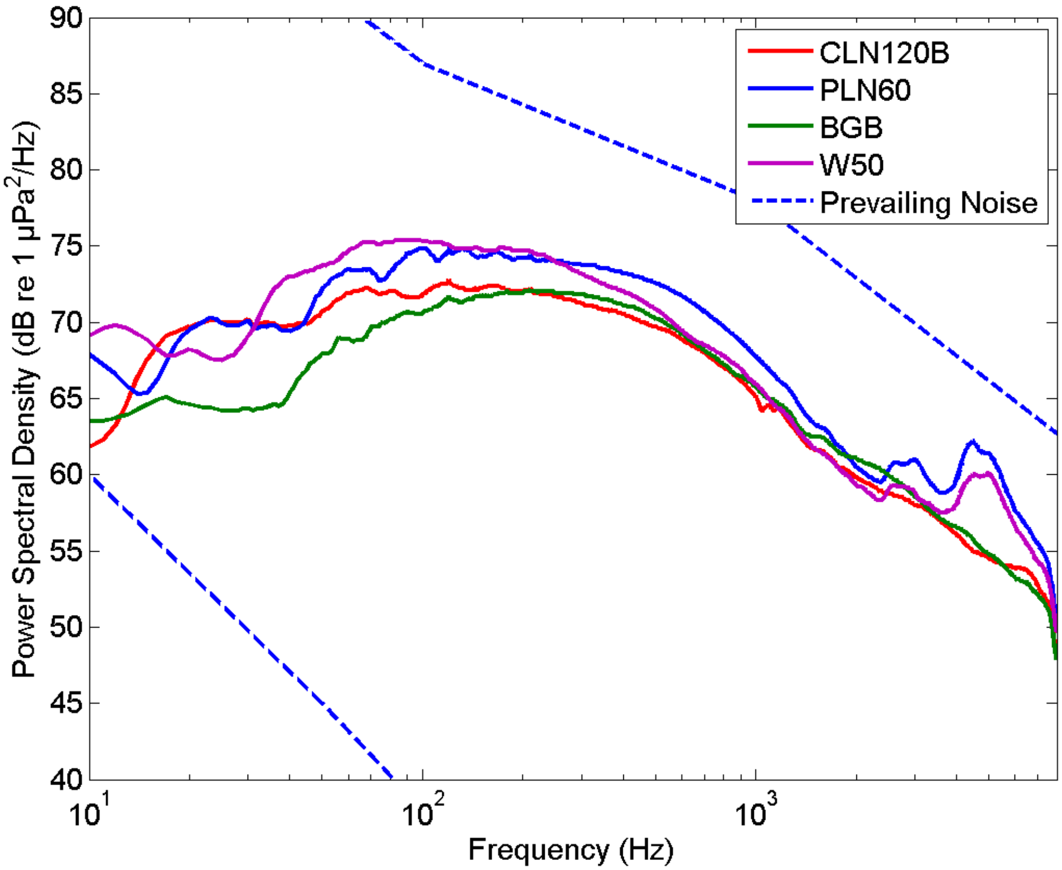

Figure 56. 50th percentile (median) 1 min power spectral density levels at stations along a roughly east-west line across the Chukchi Sea for summer 2014.

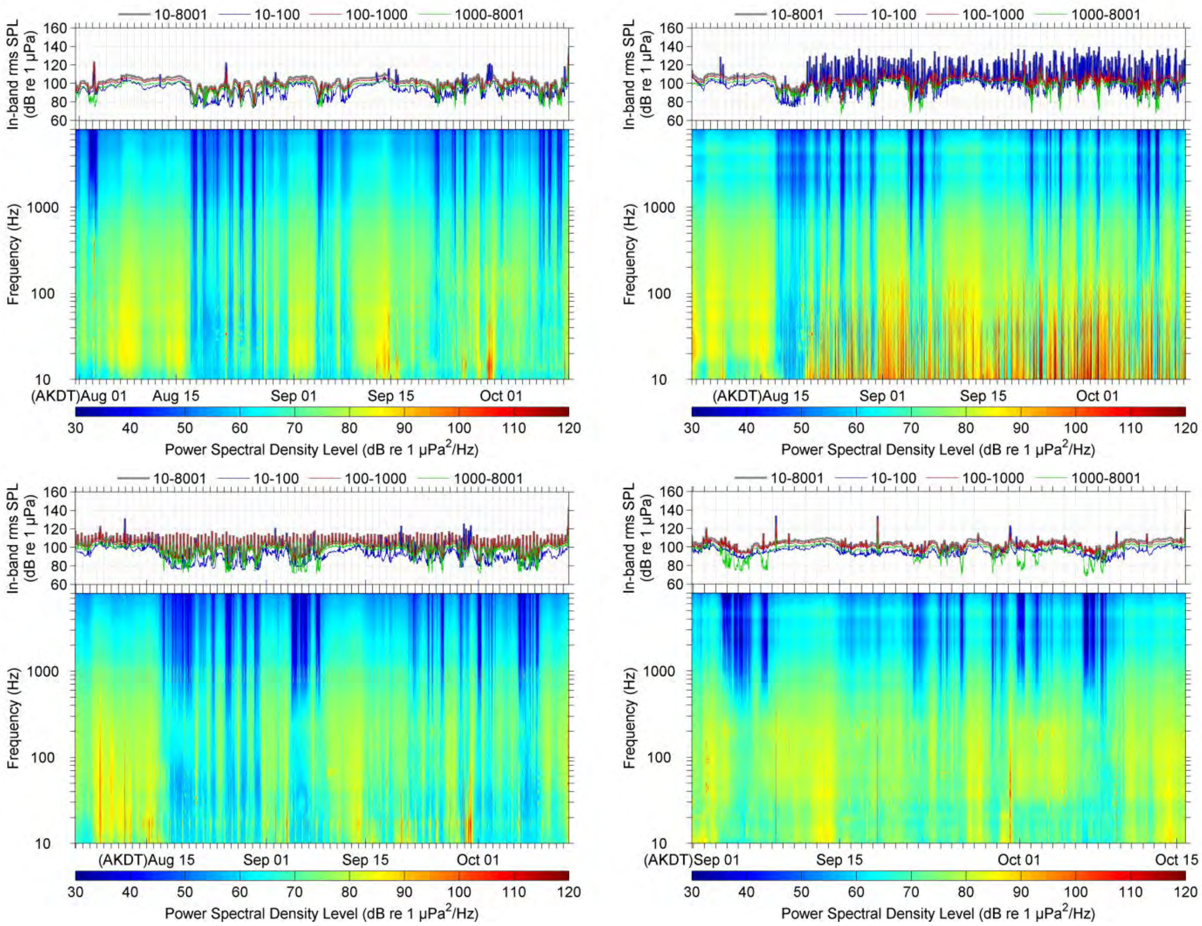

Figure 57. Spectrogram of underwater sound at (top left) CLN120, (top right) PLN60, (bottom left) BGB, and (bottom right) W50 for the summer 2014 program.

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 multiple years. This discussion does not include the 2008 summer data that was acquired with just five recorders late in the season (26 Sep to 16 Oct 2008). The datasets for the first deployment in summer 2007 and winter 2007–2008 were not analyzed using the standardized protocol described in this report and first applied to the winter 2008–2009 data. Because these initial datasets are not directly comparable to later ones, they are omitted from this discussion. The sections below compare 2014 results to prior recording periods.

4.2.1. Bowhead Whale Call Detections

4.2.1.1. Comparison of Winter Acoustic Recording Periods

Bowhead whale detections during fall 2013 extended later into the fall than in prior years. In contrast, the fall 2012 data revealed the earliest complete departure on record since the winter recording program began in 2007. In the central part of the study area (W50–PL50), detections usually stop in the last week of November. December detections are generally restricted to stations off Cape Lisburne. In 2013, detections at Stations W50 and PL50 lasted until mid to late December, whereas detections at CL5 lasted until 4 Jan 2014. The increase in call counts from October to December is mostly due to an increase in vocal activity associated with the onset of singing (e.g., Delarue et al. 2009). The lowest call counts occurred at Station PL10, which confirms previous findings that bowheads migrate predominantly west after reaching Barrow or Wainwright. The high call counts at CL5 are probably due to bowheads arriving from the north to forage, finding more open water areas, or both.

Results of a satellite tagging study showed that most tagged whales traversed the lease areas in less than a week; however, one whale remained in the lease areas for 30 days (Quakenbush et al. 2010). Foraging opportunities in areas with lower bowhead whale densities compared to known fall aggregation sites such as the Chukotka coast in November (Quakenbush et al. 2010) may explain why individuals choose to spend more time near the lease areas during the fall. Planners should consider this late residency pattern for any work in the lease areas outside of the open-water season. Favorable ice conditions may also have allowed some bowhead whales to extend they stay in the Chukchi Sea in 2013, but other factors may be at play.

The spring migration in 2014 occurred generally at the same time as previous years. Bowhead call detections at stations near the lease areas (PL50, W50) occurred about two weeks later than at stations closer to shore. Detections decreased with increasing distance from shore, confirming earlier suggestions (Braham et al. 1984) that spring migrating bowheads prefer inshore areas. We were unable to fully assess the extent of the spring migration inshore compared to offshore because three recorders either stopped before spring migration began (PL10, B5) or were not retrieved (PLN40)[6].

4.2.1.2. Comparison of Summer Acoustic Recording Periods

Summer detections in 2014 were comparable with the patterns observed over the last three years. Sporadic detections occurred in August, mostly in the central part of the study area. Interestingly, these detections immediately followed the last of three detection peaks off Barrow in August, which strongly suggests that some bowheads foraging off Barrow transit through the Chukchi Sea ahead of the typical fall migration.

Detections resumed in mid-September after a three week hiatus; first off Barrow, three days later off Wainwright, and then increasing throughout the study area. This pattern is consistent with those observed in previous years, with the only exception being a short gap in detections at the nearshore Wainwright stations, which appears to be linked to elevated levels of noise that likely masked calls.

Because the recorders at Barrow recorded longer than in previous years—this year until early November, but most years around the middle of October—we were able to better evaluate the fall migration. Detections in fall 2014 off Barrow peaked in the first two weeks of October, then stopped rather abruptly, and then resumed at much lower levels from late October until early

[6] The winter 2013-2014 recorder at Station PLN40 was retrieved in fall 2015, just prior to this report being completed and thus its data were not included.

November, which suggests that a large proportion of the migrating population transits through the Chukchi Sea before or around the middle of October. This finding agrees with tagging-derived occupancy data (Quakenbush et al. 2010), which shows minimal presence in the Chukchi Sea past October. Assuming that 2014 is representative of previous survey years, the information presented until now on the spatio-temporal occurrence of bowhead whales in the Chukchi Sea using acoustic data from the summer programs can be used to describe the whole migration, not just individuals present during the recording period.

Figure 58 shows the annual average of mean daily bowhead whale call counts from 2009 to 2014. These results show that few bowhead whales occur south of a line running west from Wainwright. Stations to the south of that line had consistently low detections (low standard deviation) while those to the north recorded more calls and experienced more inter-annual variability in the number of detected calls, particularly off Wainwright and Barrow. The higher variability in the number of detected calls in areas of greater acoustic presence could be because they are feeding areas. Productivity in these areas is driven by oceanographic conditions, which vary annually to some extent. Figure 59 shows that inter-annual variations in mean daily call counts are greatest off Barrow and Wainwright and lowest at Burger and PLN60, which are father west. This suggests a more predictable occurrence associated with the steady transit of migrating bowhead whales near stations in the western half of the study area.

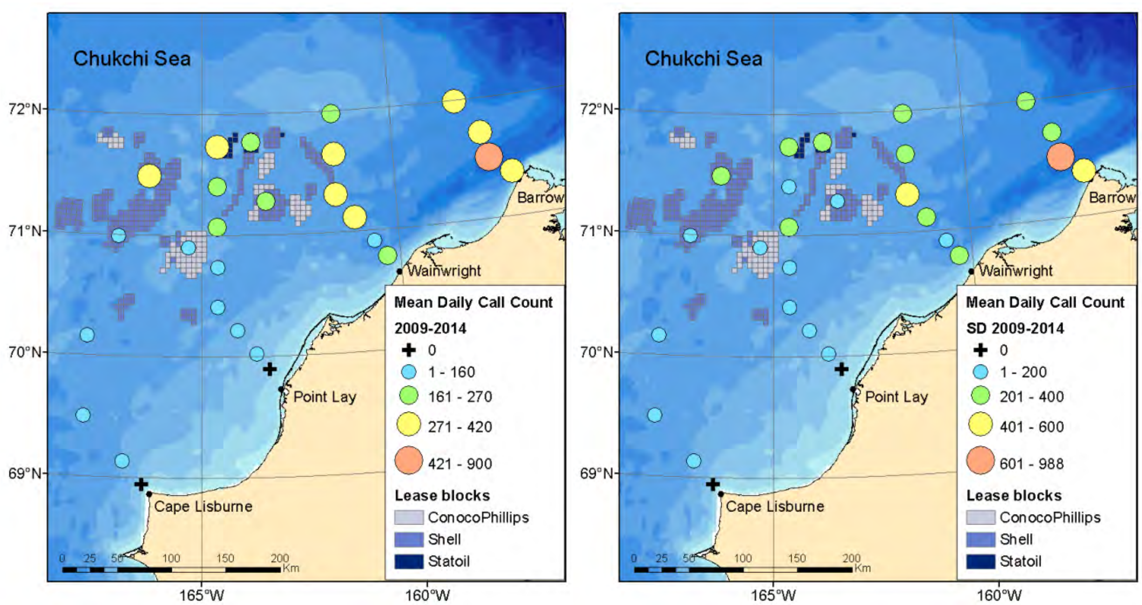

Figure 58. (Left) annual average and (right) standard deviation of mean daily bowhead whale call counts calculated as the sum of automated call detections in all files with manual detections divided by the number of active recording days from 2009 to 2014 at all summer stations deployed twice or more in the northeastern Chukchi Sea.

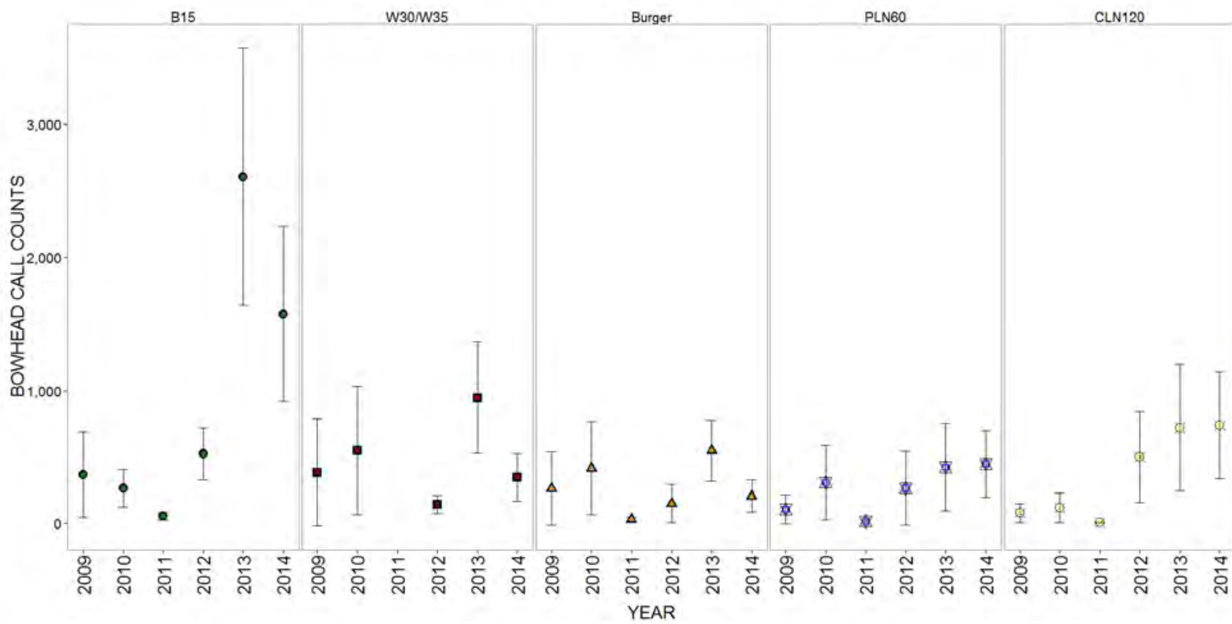

Figure 59. The mean daily bowhead whale call count and 95% confidence intervals from 2009 to 2014 at five stations.

Figure 60 shows the number of years bowhead whale calls were detected during the summer programs (~1 Aug to ~15 Oct) between 2009 and 2014 for five representative stations. All stations recorded calls every day in at least half the years beginning approximately between 8 and 20 Sep depending on the location. Figure 60 also highlights a consistently timed fall migration onset in the study area. Before mid-September, detections occurred in at least one year on most days at B15 and Burger, but were more sporadic at PLN60, CLN120, and W30/W35.

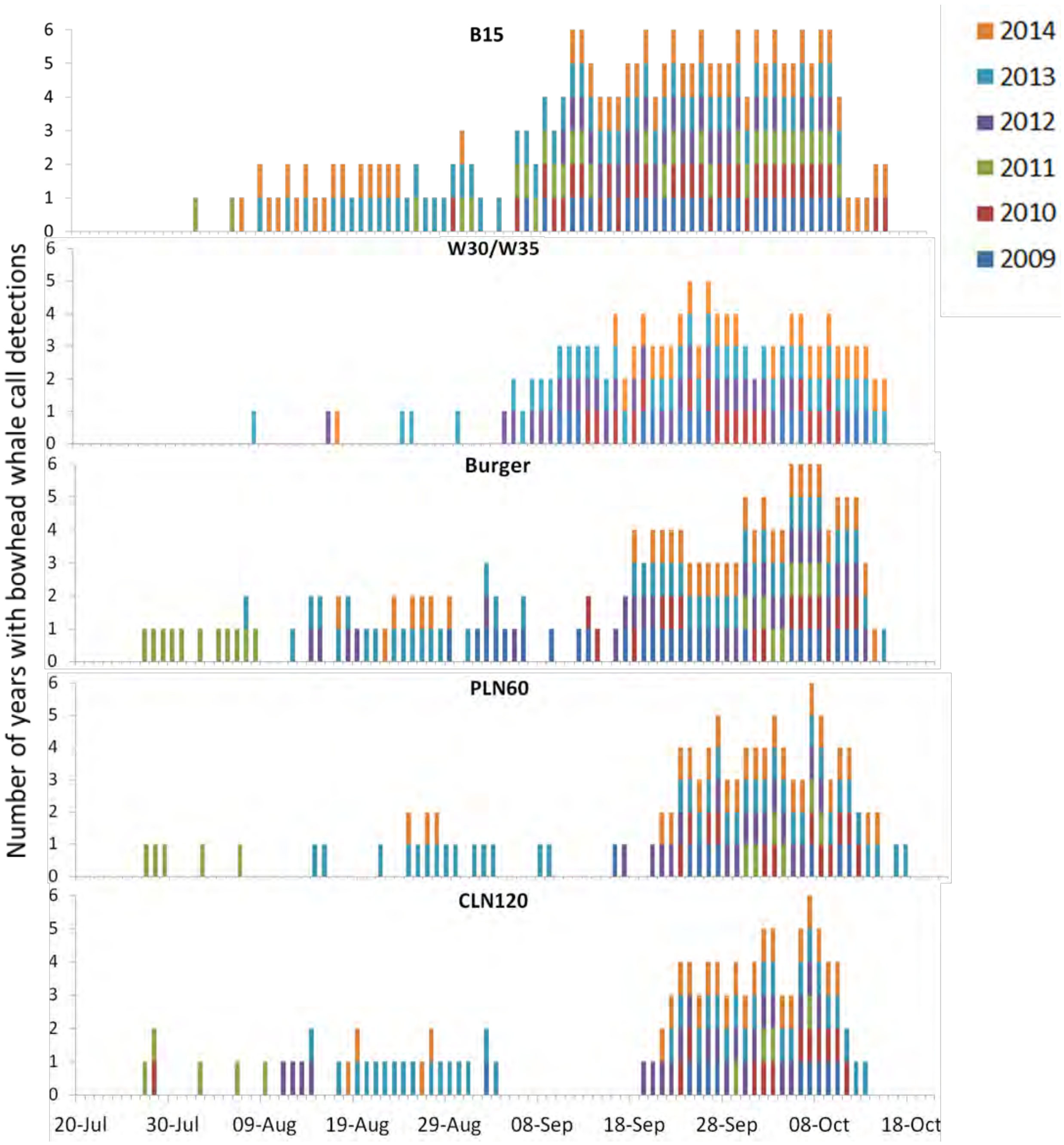

Figure 60. Number of years with daily bowhead whale call detections between late July and mid-October (maximum duration of summer Acoustic Monitoring Programs) at five stations.

4.2.2. Walrus Call Detections

4.2.2.1. Comparison of Winter Acoustic Recording Periods

Walrus detections during the winter programs are noticeable because of their regularity. Although they vary more in the fall, they are consistently low and few detections occur after October. In the spring, walruses are almost systematically detected for the first time in the first week of June. Calls are progressively detected farther northeast until walruses reach stations at or near Hanna Shoal. Detections at stations in the southwestern part of the study area only last about two weeks, but persist near Hanna Shoal once they start, confirming that this is the final migration destination for walruses.

4.2.2.2. Comparison of Summer Acoustic Recording Periods

Walrus summer detections show a high consistency in occurrence over time. Six years of data indicate that Point Lay, where walruses have hauled out in large numbers in recent years, consistently has the most walrus detections. The Hanna Shoal area (W50–WN40), and to a lesser extent Burger, also had many call detections (Figure 61). Except for CL5, the rest of the stations had low call counts. The regularity by which walruses use Hanna Shoal and Burger areas highlights their strong affiliation to these areas for foraging. These areas tend to be the last ones with sea ice cover in summer. However, sea ice disappeared completely from the entire Chukchi Sea shelf as early as late August in recent years, forcing walruses to make extensive movements between Hanna Shoal and coastal haul outs along the coast.

Walruses are the most commonly acoustically detected species in the northeastern Chukchi Sea. Most stations within the core of walrus habitat had detections each day from 1 Aug to 15 Oct on at least one, and often multiple, study years (Figure 62). Mean daily call counts were quite stable at most stations except WN20 and off Point Lay (Figure 63). Inter-annual variations in call counts at Point Lay are likely driven by differences in when walruses arrive at the haul out sites, the proximity of these sites to the recorders, and the number of walruses present.

The high detection rate of walrus calls in the Burger and Hanna Shoal areas is best explained by their high density and biomass of benthic organisms. Densities increase between Burger and Hanna Shoal (Blanchard and Knowlton 2013), which correlates well with the observed gradient in call counts between these areas. The high consistency in the distribution of walrus call detections in summers across years could be due to two factors: their benthic prey's distribution does not vary much over the years, and there are many suitable haul out sites near Point Lay.

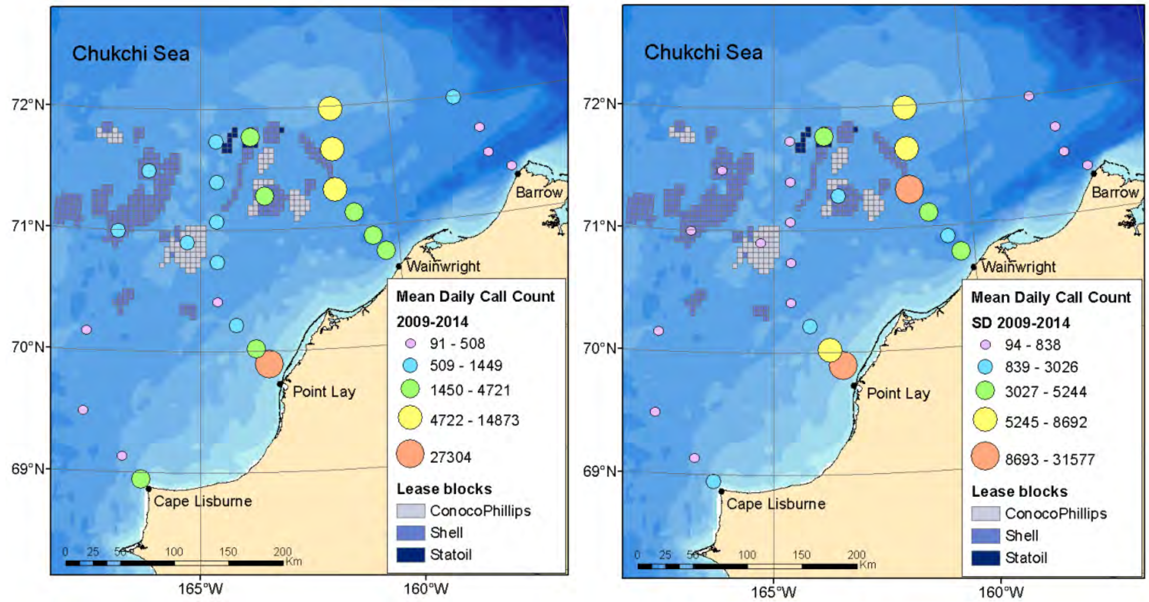

Figure 61. (Left) Annual average and (right) standard deviation of mean daily walrus call counts (calculated as the sum of automated call detections in all files with manual detections divided by the number of active recording days) from 2009 to 2014 at all summer stations deployed at least twice throughout the recording program in the northeastern Chukchi Sea.

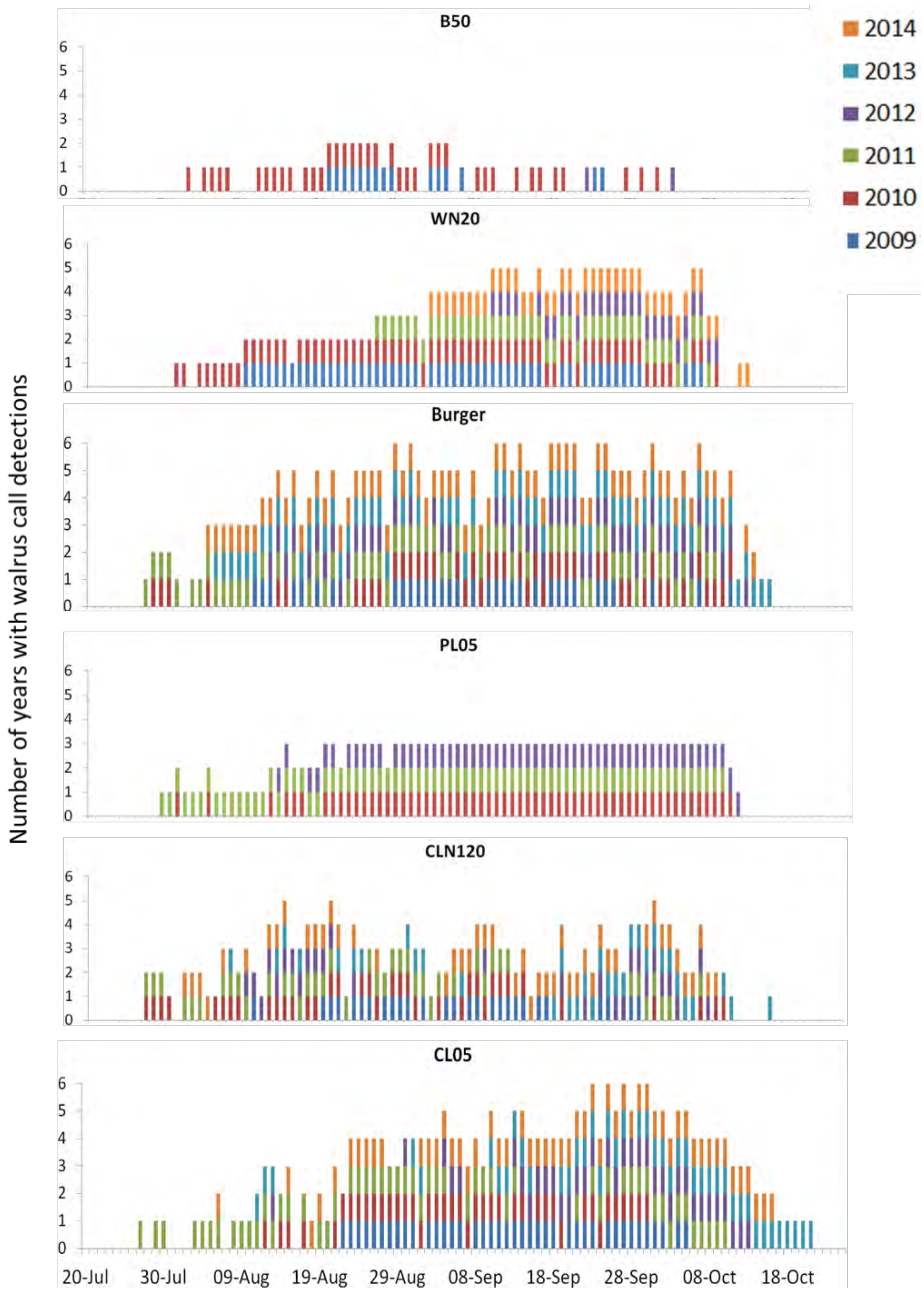

Figure 62. Number of years with daily walrus call detections between late July and mid-October (maximum duration of summer Acoustic Monitoring Programs) at six stations.

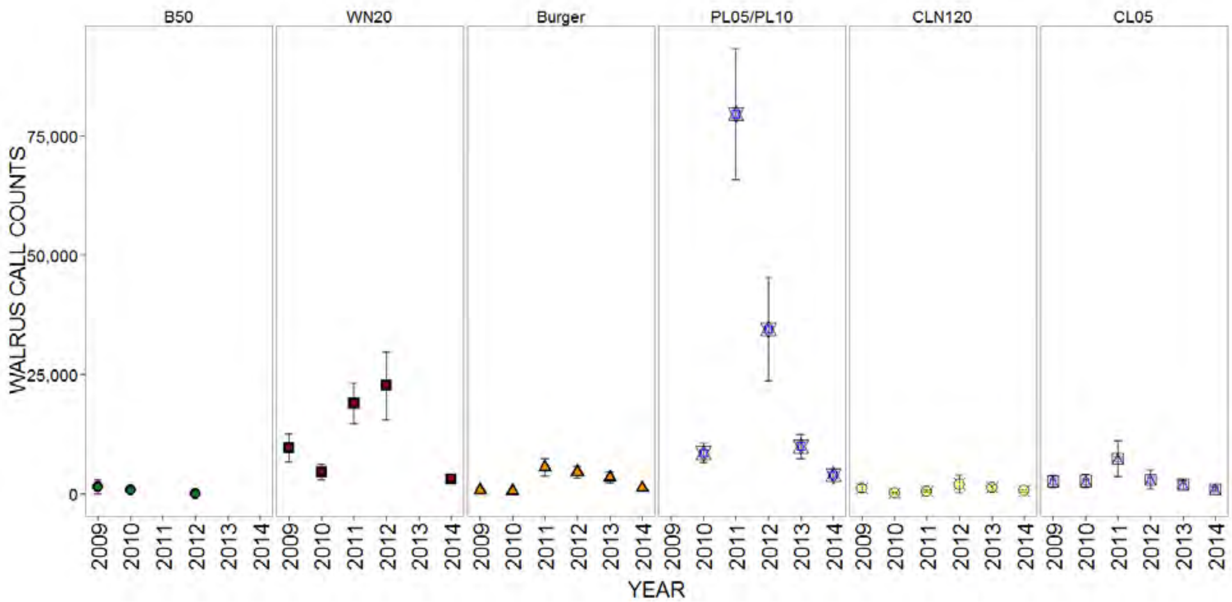

Figure 63. Whisker plot of the mean daily walrus call count and 95% confidence interval from 2009 to 2014 at stations B50, WN20, Burger, PL05/PL10, CLN120 and CL05.

4.2.3. Beluga Whale Call Detections

4.2.3.1. Comparison of Winter Acoustic Recording Periods

The spatial and temporal distribution of beluga whale call detections during winter 2013–2014 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. Stations farther west had fewer detections and those were separated more in time, possibly because belugas spread out over a larger area after leaving Barrow canyon. Although we previously speculated that the low number of detections in the fall could be due to belugas migrating inshore where no recorders were deployed in previous years, neither the lack of detections at PL10 nor the few detections at CL5 at inshore stations support this hypothesis. The discrepancy in the number of detections between fall (low) and spring (high) seems best explained by the fact that only the eastern Chukchi Sea belugas, which are far fewer in number than eastern Beaufort Sea belugas, migrate past our recorders in the fall, yielding fewer detections.

The number and distribution of spring detections were generally comparable to those from previous years. Beluga call counts were higher inshore than offshore. We had hoped that information gathered by inshore recorders would answer whether both stocks of belugas migrate simultaneously or sequentially in the spring. However, because PL10 stopped recording before the spring migration and CL5 stopped around mid-June, there was no clear answer. Thus, the sporadic detections in June at W50 and July at W10 could represent late Eastern Beaufort Sea belugas, eastern Chukchi Sea belugas, or a combination of both. A single, well-defined detection period that generally ended at the end of May was observed at W10, W50, and PL50. Unless eastern Chukchi belugas begin migrating long before they aggregate in the coastal lagoons, this first detection period likely represents eastern Beaufort belugas.

4.2.3.2. Comparison of Summer Acoustic Recording Periods

The acoustic detections from summer 2014 were similar to those from summer 2013: detections occurred at most stations and were generally concentrated in early October. Belugas were detected off Barrow through most of the deployment period, excluding late August through mid-September. Before 2013, detections had always been concentrated in or near Barrow canyon in August where Eastern Chukchi belugas are known to forage before heading north into the northern Chukchi and Beaufort Seas (Suydam et al. 2005, Delarue et al. 2011b), and at the end of the recording period as they start migrating back toward the Bering Sea (Figure 64).

Worth noting is the synchrony between bowhead and beluga August detections off Barrow. Detections of both species stopped on the same day (25 Aug). In September, beluga detections resumed after bowhead detections, but followed similar temporal patterns after that. In the fall, bowhead detections were generally higher at B15, whereas beluga detections were higher at B5.

Automatic click detections at station BGF resulted in twice the number of detection days relative to manual detections of whistles only. On the other hand, manual whistle detections at B5 were higher than click detections, which always occurred simultaneously with whistles. Differences in animal density between both areas may explain the observed differences. Eastern Chukchi Sea belugas forage predictably in Barrow Canyon in summer. Belugas are comparatively scarce offshore in the Chukchi Sea before the fall migration. Higher densities of belugas off Barrow could present more opportunities for social interaction and, in turn, more contact calls, such as whistles and complex calls. On the other hand, low sighting and detection rates as observed at Burger, suggest low beluga densities. The lone animals or small groups present might not have any or many opportunities for social interactions and thus produce social calls at lower rates in comparison to foraging echolocation clicks.

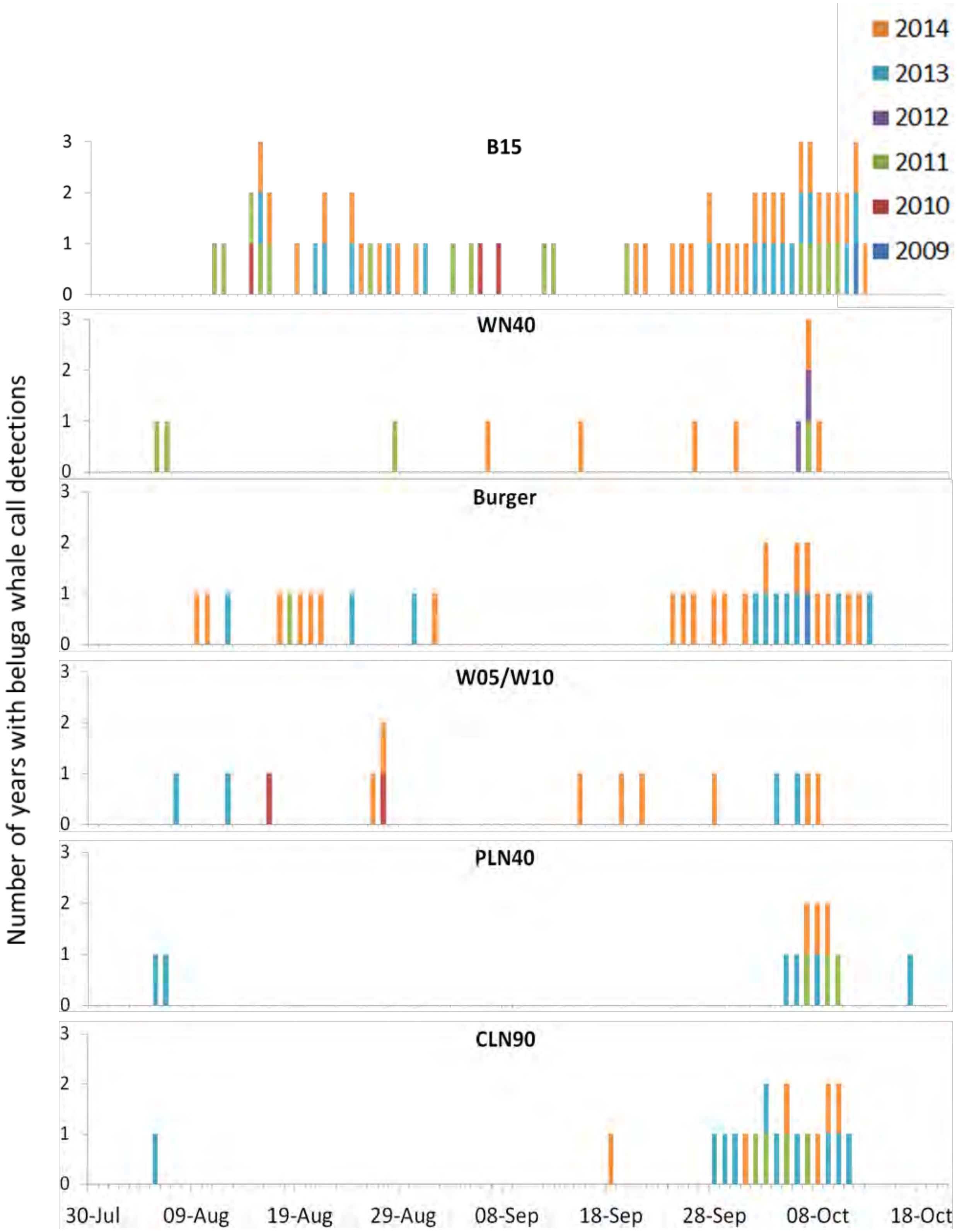

Figure 64. Number of years with daily beluga whale call detections between late July and mid-October (maximum duration of summer Acoustic Monitoring Programs) at six stations.

4.2.4. Bearded Seal Call Detections

4.2.4.1. Comparison of Winter Acoustic Recording Periods

Bearded seal call presence during winter 2013–2014 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. In 2012–2013, the area near PLN100 was also rife with acoustic activity, as was an area between W35 and WN20. No recorders were deployed in the 2013–2014 recording period in the areas that yielded the highest call counts in past years. W50 ranked highest for call counts, which is consistent with bearded seal affinity for the Wainwright area shown in previous winters and summers.

Detections in late January decreased and sometimes stopped across the area. Acoustic data showed a similar trend in detection rates during previous winters around the same period. Noise levels do not appear to be a factor in the 2014 area-wide drop in detections. We observed a similar decrease in detections throughout January for ringed seals.

4.2.4.2. Comparison of Summer Acoustic Recording Periods

Summer detections typically consist of a few sporadic calls in late July and August. Acoustic activity steadily increases into September, and peaks in October (Figure 65). Bearded seal calls are detected at some stations throughout the summer, but the likelihood of a call occurring on any given day increases after the beginning of September. Calls were generally absent off Barrow and near WN40 before the end of August.

The steady increase in bearded seal calling rates from September to May is the result of seasonal changes in vocal behavior, which complicates estimates and comparisons of abundance throughout the year. This behavioral change results in a low number of detections in July and August, which does not indicate the seals are not in the area because they are regularly sighted in summer in the Chukchi Sea.

Because seasonal changes in calling behavior occur at the same rate across the area, acoustic detections can be used to assess the relative occurrence of bearded seals between stations. Detections were higher offshore and off Wainwright and lowest west of Wainwright and south of 71° N (Figure 66).

Inter-annual variations in mean daily call counts (Figure 67) occurred at all stations. We noted previously that the location and magnitude of detection peaks varied annually. This might be related to the diverse diet of bearded seals, which means they forage where it is most energetically rewarding instead of being tied to productive, yet geographically restricted, patches of prey, as do walruses who prey on bivalves in the Chukchi Sea.

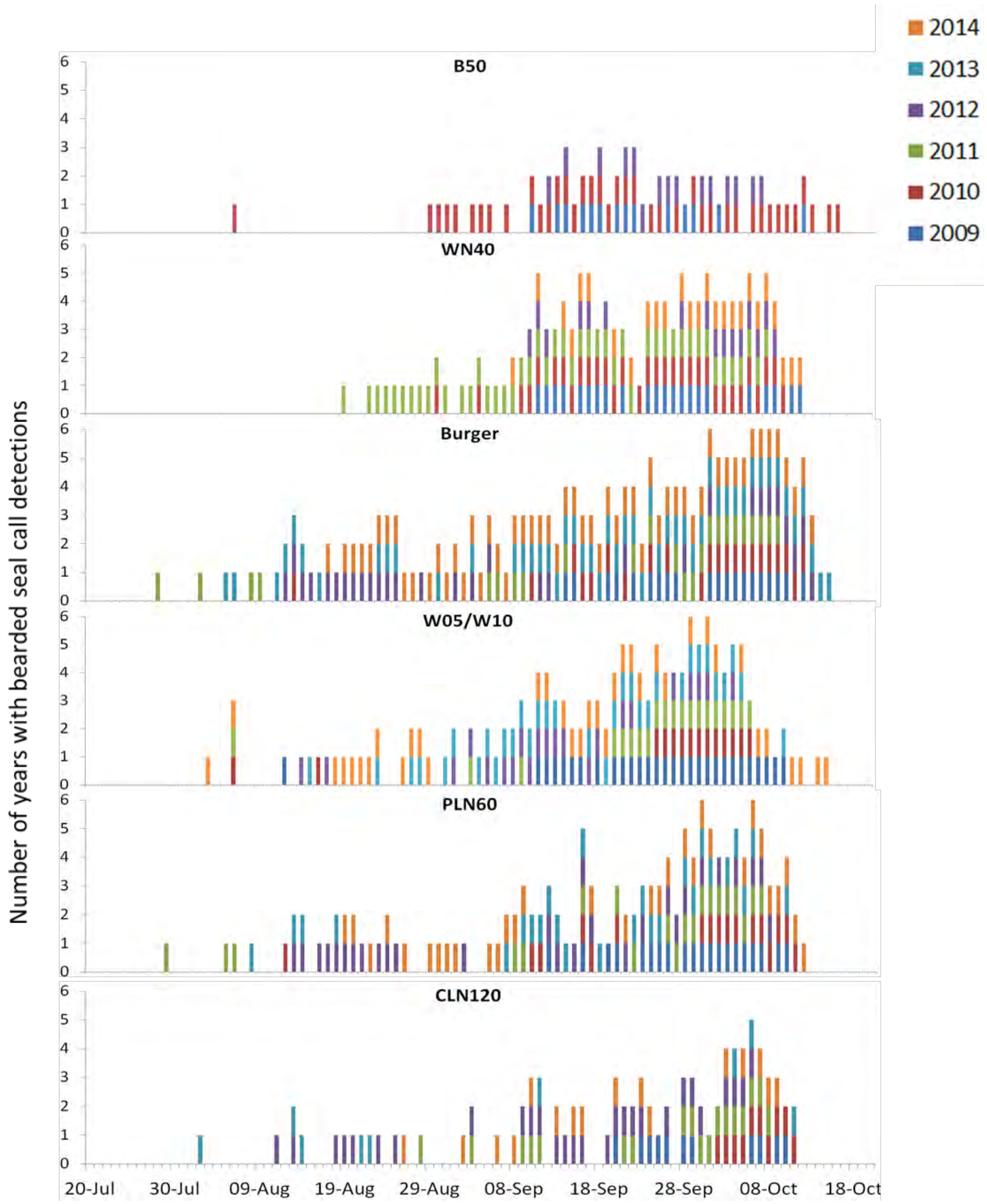

Figure 65. Number of years with daily bearded seal call detections between late July and mid-October (maximum duration of summer Acoustic Monitoring Programs) at five representative stations.

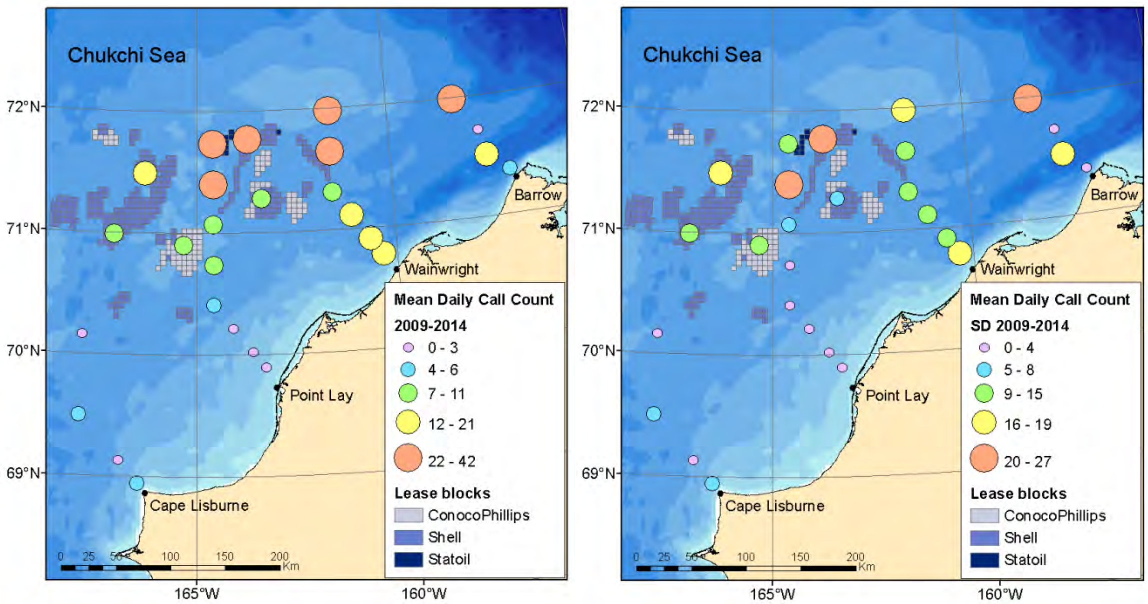

Figure 66. (Left) annual average and (right) standard deviation of mean daily bearded seal call counts calculated as the sum of automated call detections in all files with manual detections divided by the number of active recording days from 2009 to 2014 at all summer stations deployed twice or more in the northeastern Chukchi Sea.

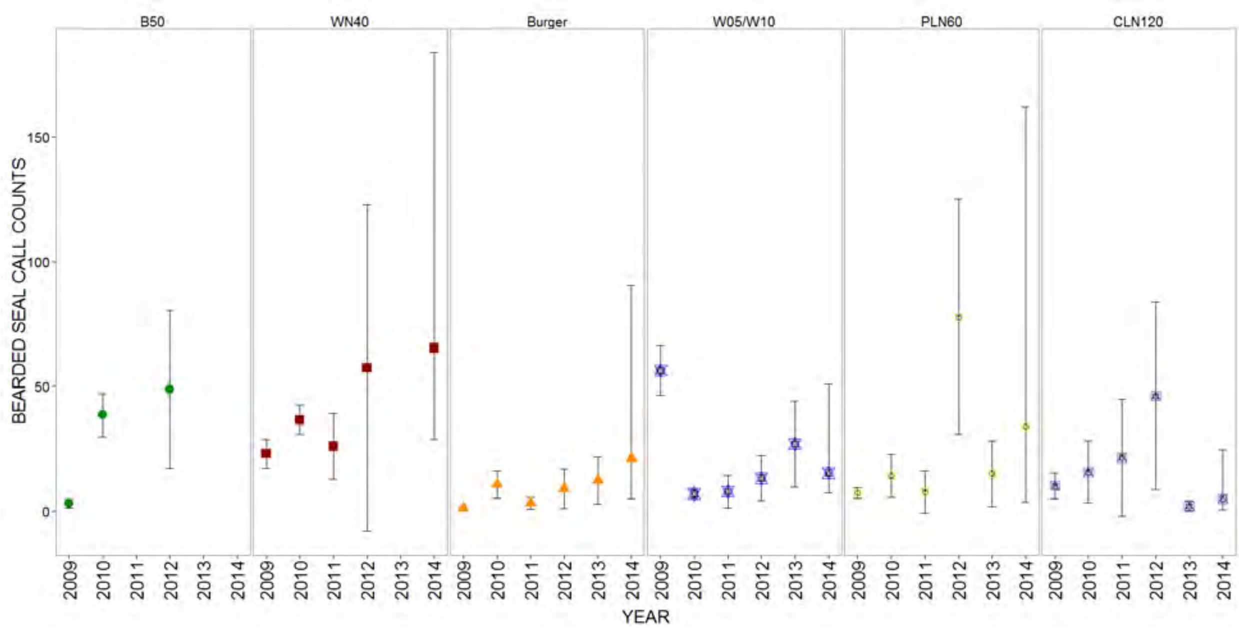

Figure 67. Mean daily bearded seal call count and 95% confidence interval from 2009 to 2014 at six stations.

4.2.5. Fin Whale Call Detections

Fin whale calls were first recorded in 2007 (Delarue et al. 2013a) and were detected in all years since 2009, except in 2012, over which time they were only detected at the offshore Cape Lisburne stations and Station PL50. The number of detections decreased sharply between 2007, a year with an unusually high number of detections, and 2009. Detections have remained low thereafter, indicating that fin whale visits to the northeastern Chukchi Sea are still a rare occurrence. This is consistent with the handful of visual sightings (e.g., five combined sightings by boat and aerial surveys in 2013 (Aerts et al. 2014, Clarke et al. 2014); there were no sightings in 2014 (Christman et al. 2015).

4.2.6. Gray Whale Call Detections

Gray whales have an affinity for the waters off Wainwright, particularly in August. They occur sporadically in other areas throughout the summer (Figure 68). These detections coincide 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. There were few shipboard visual sightings in 2014 (Christman et al. 2015).

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 might be underestimated.

Gray whales’ preference for the area off Wainwright is linked to the area’s high amphipod density (Blanchard and Knowlton 2013). The densest amphipod beds are 20 to 30 mi offshore, which is where call detections were highest.

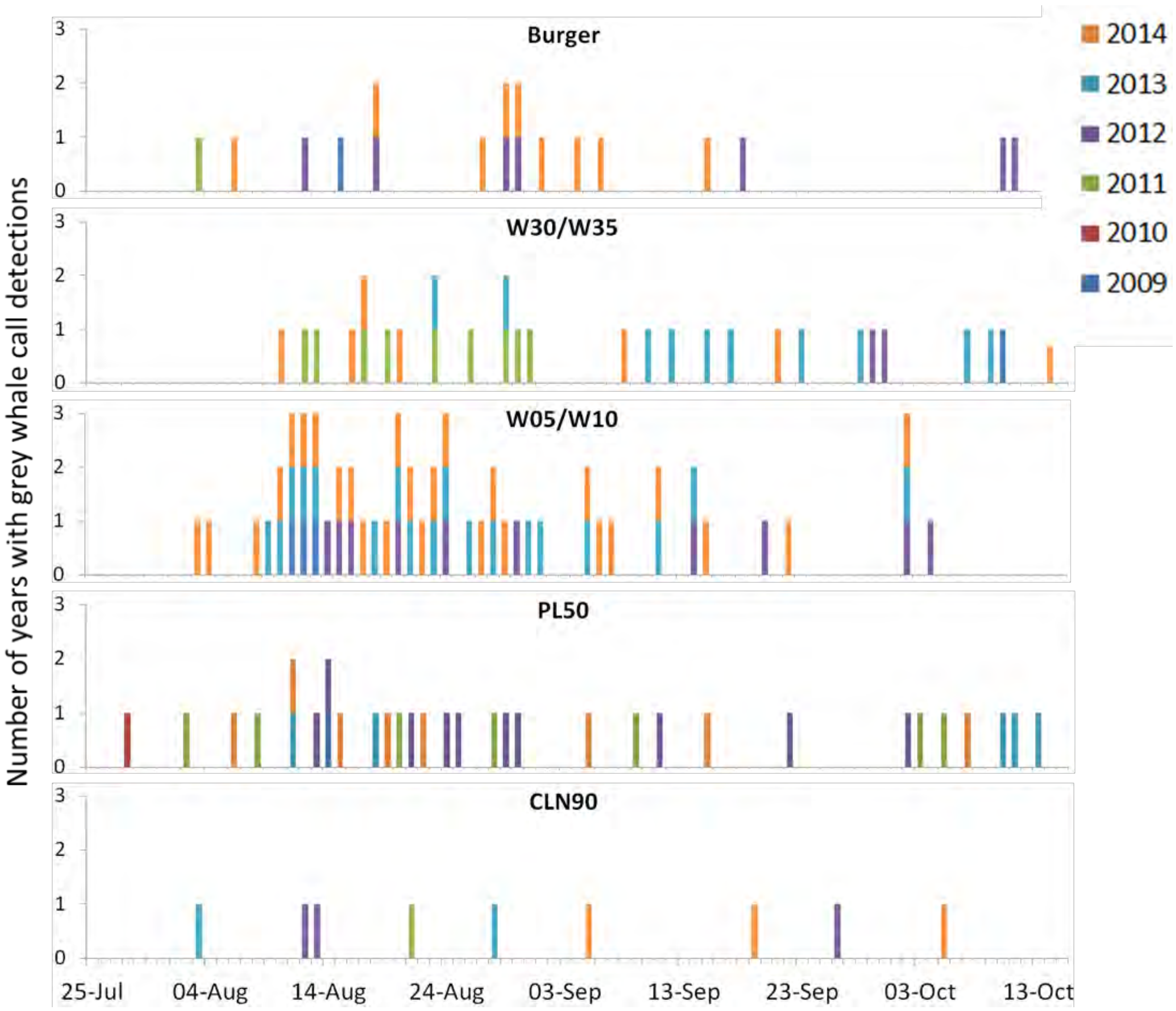

Figure 68. Number of years with daily gray whale call detections between late July and mid-October (maximum duration of summer Acoustic Monitoring Programs) at five stations.

4.2.7. Humpback Whale Call Detections

Humpback whales were first detected in summer 2010 and calls have been recorded every year since. Humpback whale calls were only detected once in 2014, which indicates this species only occurs at low densities in the northeastern Chukchi Sea, or that they do not actively vocalize.

4.2.8. Killer Whale Call Detections

Killer whales were first recorded in 2007 (Delarue et al. 2010b) and acoustically detected in all summers from 2009–2014. Further analysis of the 2007 data revealed mammal-eating killer whales 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).

Detections in 2014 were concentrated over two short periods. Interestingly, these pseudo-synchronous calls (relative to the duration of the summer programs) were detected at stations that are very distant from each other considering the time required for killer whales to move between these stations at average swim speed. Further analysis of these calls to look for matches could allow determining if these detections are the result of rapid, area-wide movements by individuals of the same pod or if there were other contributing factors. Because of the quiet nature of mammal-eating killer whales (Deecke et al. 2005), it is likely that the results underestimate the true occurrence of this killer whale ecotype, even though they are in line with the limited number of visual observations.

CSESP MMOs did not see killer whales (Aerts et al. 2014, Christman et al. 2015), nor was this species recorded during the ASAMM aerial survey (Clarke et al. 2014) in 2013. 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.

Killer whales can occur throughout the study area any time during the summer, even though detections are more concentrated from mid-August to mid-September and within any year their presence will be infrequent (Figure 69). Killer whales may have increased presence in the arctic if the recent occurrences of longer open water periods, relative to historic averages, continue.

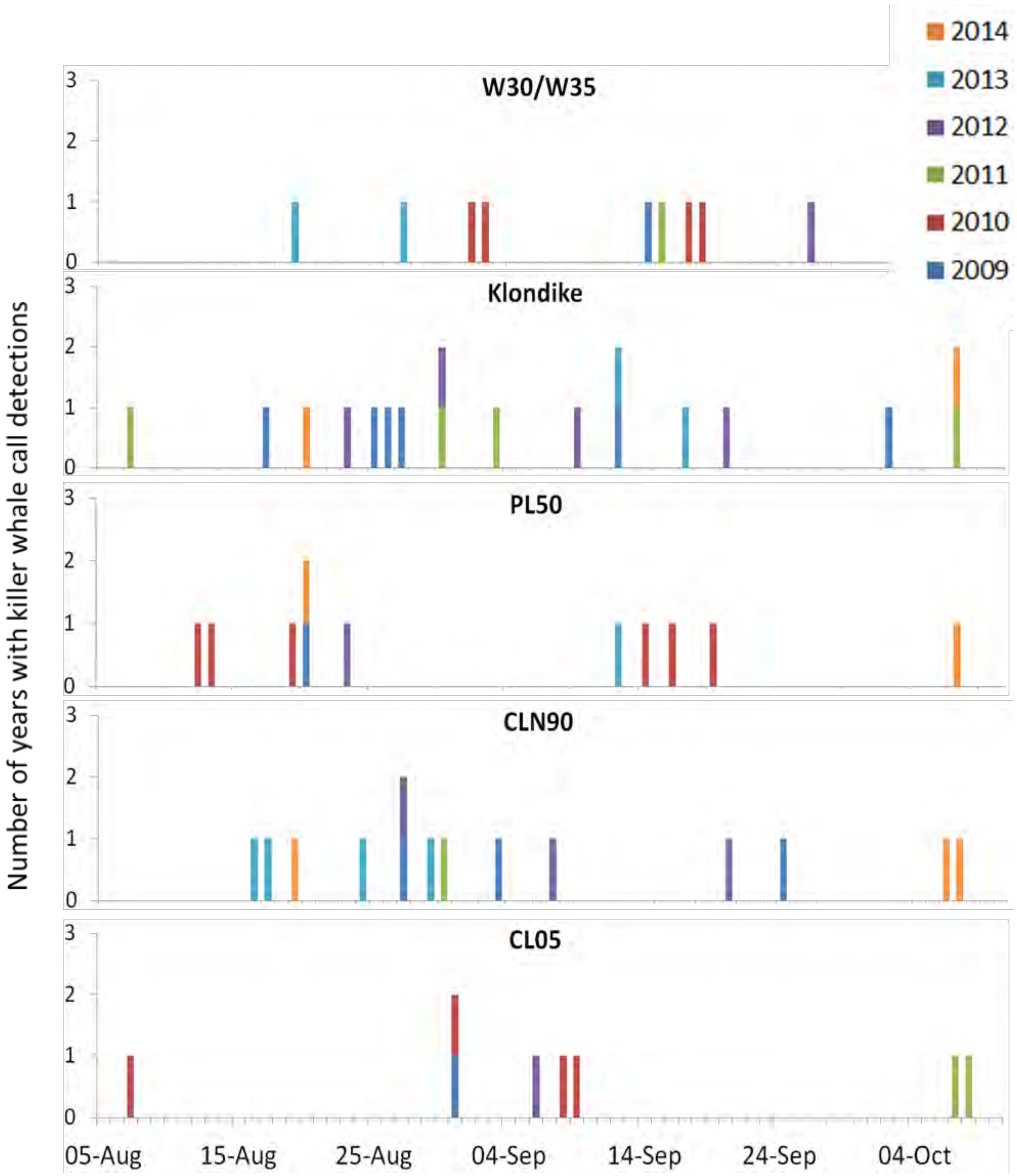

Figure 69. Number of years with daily killer whale call detections for each day between late July and mid-October (maximum duration of summer Acoustic Monitoring Programs) at five stations.

4.2.9. Minke Whale Call Detections

Minke whales have been regularly detected in all years of the Acoustic Monitoring Program in late October/November in the winter recordings at station CL50. This species was also detected in the summer recordings from 2011 onward, with detections concentrated off Cape Lisburne and Point Lay. Visual observations in 2013 (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 this species. Most of the sightings occurred in July and August while most acoustic detections occurred from mid-September onward, suggesting that minke whales in this region may be less 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). The lack of detections in summer therefore does not mean minke whales are absent.

4.2.10. Ringed Seal Call Detections

4.2.10.1. Comparison of Winter Acoustic Recording Periods

By including a new call type in the set of target calls, ringed seals had a higher detection probability compared to previous winters. A peak in detections that occurred in April and May coincides with this species' breeding period. This is consistent with the acoustic behavior of other pinnipeds, such as bearded seals, whose calling activity also peaks around the breeding season.

These results show unequivocally that some ringed seals winter in the Chukchi Sea and presumably mate there in the spring. Detections were most common 50 nmi from shore and generally lower at shorter and longer distances from shore. Throughout most of January detections were absent at all stations, a pattern similar to what was observed in bearded seals.

4.2.10.2. Comparison of Summer Acoustic Recording Periods

The summer 2014 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 or lower acoustic occurrence. Low calling rates combined with the analysis protocol presumably underestimates the true occurrence of ringed seals.

5. Conclusions

5.1. Winter 2013–2014

- The bowhead whale 2013 fall migration extended later than in previous years, particularly in the central part of the study area. The spring 2014 migration was well defined between early April and early June.
- Walrus 2013 fall detections were rare; spring 2014 detections were highly consistent with previous years, i.e., starting in the first or second week of June and progressively moving toward Hanna Shoal.
- Beluga calls were detected sporadically in the fall of 2013. The lack of detections at the inshore recorders suggests that beluga do not migrate preferentially inshore in the fall, as hypothesized previously. Spring detections started in early April 2014 with the main wave lasting until early June. Only sporadic detections occurred after that.
- Ringed seals were detected from November 2013 through May 2014, with a peak in April and May, corresponding to their breeding season. As with bearded seals, the post-mating season was followed by an almost complete absence of detections.
- Gray whales were detected of Wainwright starting in late June 2014 off Point Lay. They were detected almost daily off Wainwright in July.

5.2. Summer 2014

- Humpback and minke whales as well as ribbon seals were each detected once or twice in summer 2014, consistent with their sporadic acoustic occurrence in the northeastern Chukchi Sea. Fin whales were detected over several days off Cape Lisburne.
- Ringed seals were detected sporadically throughout the summer without any clear spatial pattern. Bearded seal call detections increased at the end of the recording periods (early Oct 2014) and were most common offshore, with the exception of nearshore waters off Barrow.
- Beluga detections were common off Barrow in August and otherwise concentrated over 2–3 days at the end of the first week of October 2014 at most stations. Echolocation click detections were more common than whistles and non-click calls in Burger; the opposite was true off Barrow, possibly due to differences in densities and social interactions between both areas.
- Walrus were once again the most commonly detected species overall, with core areas on Hanna Shoal and just off Point Lay. Detections were generally rare in other areas, except during sporadic peaks. These area-wide peaks occurred at most stations simultaneously, which could be because of synchronous movements by many walruses across the area.
- Bowhead detections occurred in August off Barrow. These were followed immediately by detections in the central part of the study area, suggesting early movements across the

Chukchi Sea before the fall migration. The onset of the 2014 bowhead fall migration occurred during third week of September. Calls of migrating bowhead whales were once again concentrated north of 71° N.

6. 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
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)
BG*XX*	the Burger lease station
B*XX*	regional array recorder Station *XX* statute mi from Barrow
CL*XX*	regional array recorder Station *XX* statute mi from Cape Lisburne
CLN*XX*	regional array recorder Station *XX* statute mi north of Station CL50
CSESP	Chukchi Sea Environmental Studies Program
E	event
$\overline{E}$	non-event
FFT	fast Fourier transform
FM	frequency-modulated
FN	false negative
FP	false positive
h	hour
KL*XX*	the Klondike lease recorder Station
M/V	motor vessel
mi	statute mile
min	minute
P	precision
PL*XX*	regional array recorder Station, *XX* mi from Point Lay
PLN*XX*	regional array recorder Station, *XX* mi north of Station PL50
R	recall
rms	root-mean-square
SEL	sound exposure level (dB re 1 $\mu Pa^2 \cdot s$)
SEL 24 h	24 h sound exposure level
SNR	signal-to-noise ratio
S01	the Statoil lease recorder Station
SPL	sound pressure level (dB re 1 µPa)

STFT short-time Fourier transform

TB terabyte (1TB = 10244 bytes)

Ti duration index

TP true positive

TPR true-positive rate

TN true negative

UTC Coordinated Universal Time

W*XX* regional recorder Station *XX* mi from Wainwright

WN*XX* regional recorder Station *XX* mi north of Station W50

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