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NORTHEASTERN CHUKCHI SEA
JOINT ACOUSTIC MONITORING PROGRAM 2011–2012

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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 (Department of Fisheries and Oceans Canada); and Pacific walrus (Eric Lumsden, JASCO).

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1. Introduction

This report presents the results for the winter 2011–2012 and summer 2012 Joint Acoustic Monitoring Programs in the northeastern Chukchi Sea. ConocoPhillips Company and Shell Exploration & Production Company (Shell) began baseline Acoustic Monitoring Programs in the Chukchi Sea in summer 2006 as a key component of their arctic marine mammal research studies. Statoil USA Exploration and Production, Inc. (Statoil) became a sponsoring member of the programs in summer 2010. The Bioacoustics Research Program (BRP), based at the Cornell Laboratory of Ornithology, performed Acoustic Monitoring Programs in summer 2006 and summer 2008. JASCO Applied Sciences Ltd. (JASCO) has conducted consecutive summer and winter programs since summer 2007 and continues to do so.

1.1. History and Overview of the Joint Acoustic Monitoring Programs

The Joint Acoustic Monitoring Programs document baseline ambient noise conditions, characterize sounds produced by oil and gas exploration, and examine the spatial and temporal distribution of marine mammals based on acoustic detections of their vocalizations[1]. The Acoustic Monitoring Programs are performed with autonomous acoustic recording systems deployed on the seabed for extended periods over large areas of the northeastern Chukchi Sea. Acoustic monitoring studies measure marine mammal sounds that can be detected in acoustic recordings.

The Joint Acoustic Monitoring Programs address knowledge gaps about spatial and temporal distributions, habitat use, calling behavior, and migration paths of several Chukchi Sea marine mammal species. One goal of the Acoustic Monitoring Programs is to provide information about the locations of vocalizing bowhead whales (*Balaena mysticetus*) in offshore areas that have been the focus of oil and gas exploration. The bowhead migration patterns close to the Alaskan coast are well known by local bowhead whalers. Migration patterns in farther offshore areas, however, were poorly understood until the onset of this program. The program, in parallel with tagging efforts led by the Alaska Department of Fish and Game (see e.g., Quakenbush et al. 2010), has greatly improved our understanding of bowhead fall migration routes. It continues to do so, for instance with the deployment of recorders in the winter 2011–2012 in previously unsampled areas north of Hanna Shoal.

A second goal of the program is to augment the sparse information about walrus (*Odobenus rosmarus*) habitat use in the northeastern Chukchi Sea. The 2007 program (Martin et al. 2009) provided new information about walrus presence and migration timing; the 2008 (Hannay et al. 2009) and 2009 (Delarue et al. 2010*b*) programs contributed to that information. The 2010 program provided new information on the possible effects of seismic surveys on walrus communications (Delarue et al. 2011*a*). The 2011 program confirmed the 2010 findings on the

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

location of large terrestrial haul-outs, primarily near Point Lay, in absence of sea ice and movements between these and the Hanna Shoal foraging areas.

A third goal of the program was to document the occurrence of beluga whales in offshore areas. This program has shown that some beluga whales migrate throughout the lease areas in the spring and are essentially absent from the northeastern Chukchi Sea during summer months. The deployment of winter recorders north of Hanna Shoal was intended, in part, to investigate whether some beluga whales migrate north of the lease areas. Indeed, the fall recordings have until now yielded far fewer detections than spring recordings, which suggests that a portion of the animals transiting through the Chukchi Sea in the spring is unaccounted for in the fall.

The Acoustic Monitoring Programs have successfully 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 hispid*a)

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

The Acoustic Monitoring Programs continue to provide new information about marine mammal presence in the Chukchi Sea:

Winter 2007–2008 program:

Provided insight into the timing and distribution of bowhead and beluga spring migrations.

Winter 2009–2010 program:

Identified the earliest calls by spring migrating bowhead and beluga whales.

Confirmed the spring migration routes are not restricted to coastal leads.

Winter 2010–2011 program:

Detected bowhead and beluga whales and walrus later in the season than any other program to date.

The winter programs continue to provide information about bearded and ringed seal presence and vocalizations in winter and spring.

Summer programs:

Target marine mammals present during the ice-free season, a time of increased species diversity and anthropogenic activity in the northeastern Chukchi Sea.

Have established this area's importance to walrus in summer, including acoustically monitoring the transit of walrus from Hanna Shoal to shore haul-outs in late August 2007, and, subsequently, in 2010 and 2011.

Consistently demonstrated the relatively limited acoustic occurrence of bowheads and belugas in the northeastern Chukchi Sea in July and August, and their return in late September and October with the onset of the fall migration in the area.

Have shown vocalizing bowheads follow a fall migration corridor approximately centered around 71° N as they move west past Barrow.

This report provides the results from the winter 2011–2012 and summer 2012 Acoustic Monitoring Programs. Winter data were obtained from two deployments: six Autonomous Underwater Recorders for Acoustic Listening, Model 2 (AURALs) deployed to the north, east and west of Hanna Shoal in late August 2011; and nine AURALs deployed offshore of Cape Lisburne, Point Lay, Wainwright, and Barrow in mid-October 2011 as a continuation of the previous winter programs.

In addition, the report presents the results of a detailed study on bearded seal acoustic detections and behavior based on data recorded since 2008. This analysis describes the seasonal and diel patterns of bearded seal call detections and variations in call type use before, during, and after the spring mating season (see Appendix D).

Summer data were acquired with 31 Autonomous Multichannel Acoustic Recorders (AMARs) deployed from early August through mid-October 2012 throughout the northeastern Chukchi Sea. Twenty-two AMARs were deployed in a regional array along four lines extending offshore from Cape Lisburne, Point Lay, Wainwright, and Barrow. Two single AMARs were deployed within the Klondike and Statoil lease areas. A greater focus was placed around the Burger lease area because of the presence of the drill ship Noble Discoverer and numerous associated vessels. The drill location was surrounded by seven AMARs.

The acquired acoustic data were analyzed to quantify ambient sound levels, presence of anthropogenic activity (such as vessels and seismic surveys), and the acoustic presence of marine mammals. The program focus remains on bowhead whales, walrus, and beluga whales, but many other detected species are discussed in the results.

1.3. Acoustic Monitoring Program Instrumentation History

The first Joint Acoustic Monitoring Program was run by the Cornell Lab of Ornithology's Bioacoustics Research Program in summer 2006. Since July 2007, JASCO has conducted consecutive summer and winter programs with AMARs and AURALs, respectively, sampling at 16 ksps (Figure 1).

Marine Autonomous Recording Units (MARUs) were deployed in two phases:

1. 6 recorders deployed from mid-Jul to mid-Aug 2006, sampling on a duty cycle at 10 kHz
2. 22 recorders deployed from mid-Aug to mid-Oct 2006, sampling continuously at 2 kHz.

The summer Acoustic Monitoring Programs include four lines of recorders extending up to 230 km off the coast from Cape Lisburne, Point Lay, Wainwright, and Barrow. These lines were augmented with clusters of recorders near Shell, ConocoPhillips and Statoil's lease blocks and historic well sites as follows:

- Summer 2008, Cornell deployed clusters of 13 MARUs each around the Klondike and Burger well sites.
- Summer 2009, JASCO deployed clusters of 12 AMARs each around the Klondike and Burger well sites.
- Summer 2010, JASCO deployed clusters of seven AMARs each around the Klondike and Burger well sites, and in the Statoil lease area.
- Summer 2011, JASCO deployed a single AMAR at the Klondike and Burger well sites, and near in the Statoil lease area.
- Summer 2012, JASCO deployed one AMAR near the Klondike well site and in the Statoil lease area, and seven AMARs around the Burger well site.

The winter program recorders are deployed in mid-October and retrieved in July or August of the following year. The recorders typically operate for 7–10 months, limited mainly by battery life.

The winter Acoustic Monitoring Programs have included five to nine recorders deployed throughout the program area. JASCO performed the winter programs from 2007 to 2011. For the first time, the 2011 winter program included deployment of six AURALs at Hanna Shoal. A 2012 winter program, also including a Hanna Shoal component, is underway; JASCO will retrieve 15 recorders in summer 2013.

The winter programs employed recorders set to duty cycles as follows:

- Winter 2007–2008, five recorders set to a 20% duty cycle.
- Winter 2008–2009, seven recorders set to a 17% duty cycle.
- Winter 2009–2010, eight recorders set to a 17% duty cycle.
- Winter 2010–2011, eight recorders set to a 17% duty cycle.
- Winter 2011–2012, nine recorders set to a 17% duty cycle and six recorders set to a 12.5% duty cycle (Hanna Shoal).

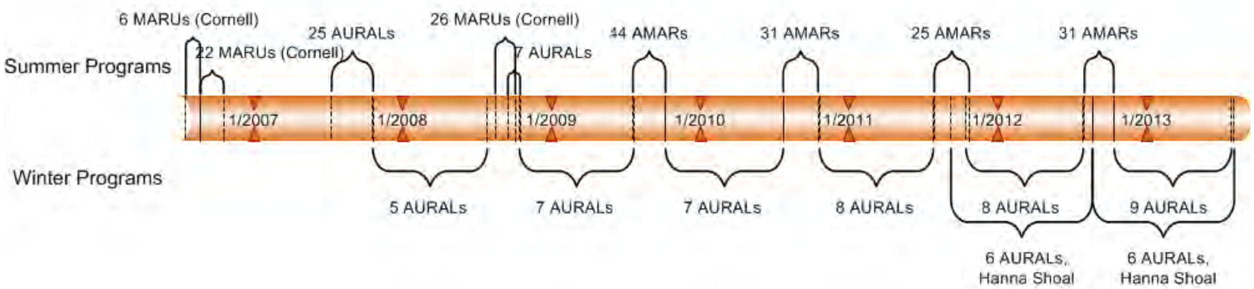


Figure 1. Timeline of Chukchi Sea Acoustic Monitoring Programs, 2006 to 2012. JASCO conducted all but three of the programs; the Bioacoustics Research Program, Cornell Lab of Ornithology ran the remaining three programs (BRP 2010).

2. Methods

2.1. Data Acquisition

The winter 2011–2012 Acoustic Monitoring Program deployed Autonomous Underwater Recorders for Acoustic Listening, Model 2 (AURALs, Multi-Electronique Ltd.) at 15 regional stations. The summer 2012 Acoustic Monitoring Program deployed Autonomous Multichannel Acoustic Recorders (AMARs, JASCO Applied Sciences Ltd.) at 22 regional stations and 9 lease area stations.

2.1.1. Winter 2011–2012 Program

Acoustic data for the winter 2011–2012 program were acquired in two phases: six AURALs were deployed to the north, east, and west of Hanna Shoal in late August 2011, and nine AURALs were deployed offshore of Cape Lisburne, Point Lay, Wainwright, and Barrow in mid-October 2011 as a continuation of the previous winter programs (Figure 2). All recorders were retrieved during the summer 2012. Each AURAL has a single omnidirectional hydrophone and is powered by 64 D-cell alkaline batteries. Acoustic data were recorded on an internal 160GB hard drive at 16-bit resolution and 16 384 samples per second. Each AURAL was fitted with an HTI-96 hydrophone (−160 dB re 1 V/µPa nominal sensitivity) and set for a gain of 22 dB. The spectral density of the electronic background noise of the AURALs in this configuration is approximately 45 dB re 1 $\mu Pa^2/Hz$, a broadband noise level of 86 dB re 1 µPa and the usable bandwidth is 10–7700 Hz. The recorders were set to record for 40 min of every 4 h (i.e., a 17% duty cycle). Because the AURALs have limited data storage and battery power capacity, duty cycling was required for the recordings to span the entire deployment.

Each AURAL was deployed to the seafloor with a rectangular frame secured near the top to keep the hydrophone off the seafloor. A sinking ground line about 2.5 times the water depth connected the recorder to a small weight for grapple retrieval (Figure 3). All recorders were retrieved successfully, leaving no material on the seafloor. The six Hanna Shoal recorders were deployed 27–29 Aug 2011 and retrieved 10–13 Sep 2012. The nine winter recorders were deployed 8–13 Oct 2011 and retrieved 10 Aug through 16 Oct 2012 (Table 1). The recording duration varied greatly between stations, with end dates between 31 Dec 2011 to 1 Aug 2012. The average last day of recording was 1 May 2012 (Table 1).

Wind speed and air temperature data were acquired from the Barrow station of the US Climate Reference Network (Barrow in Figure 2; NCDC 2012). Ice cover data were obtained from the Interactive Multisensor Snow and Ice Mapping System (NOAA 2012) with a nominal resolution of 24 km (1024 × 1024 grid). It does not provide ice concentration values.

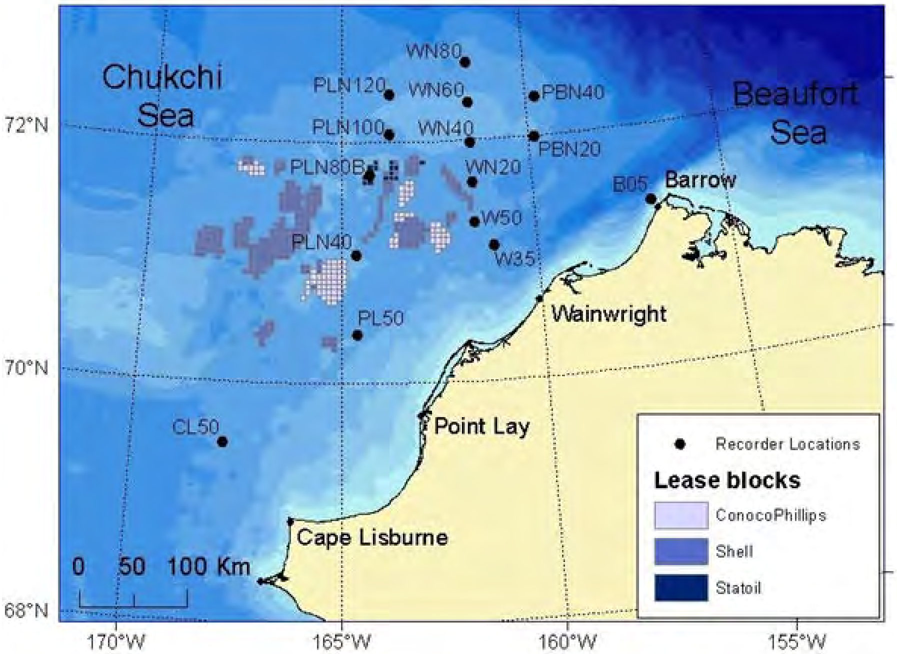


Figure 2. Recorder stations for winter 2011–2012 of the Joint Acoustic Monitoring Program in the northeastern Chukchi Sea. Shades of blue represent water depth.

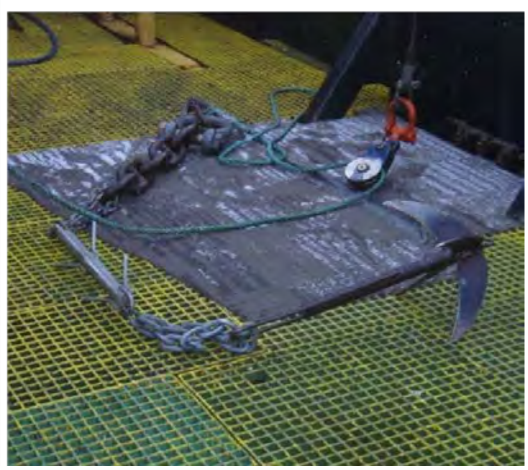


Figure 3. (Left) An Autonomous Underwater Recorder for Acoustic Listening, Model 2 (AURAL) ready for deployment from the *Norseman II* in summer 2012 in the northeastern Chukchi Sea. (Right) Grapple recovery gear ready for use on the *Norseman II*.

Table 1. Recorder locations (see Figure 2) and recording periods for the winter 2011–2012 Acoustic Monitoring Program in the northeastern Chukchi Sea. The AURALs operated on a 17% duty cycle (recording 40 min of every 4 h) from deployment to record end.

Station	Latitude (°N)	Longitude (°W)	Deployment (UTC)	Record End	Recording Days
B05	71.36105	156.91677	13-Oct-11	01-Aug-12	293
CL50	69.49632	167.78955	11-Oct-11	14-Mar-12	155
PBN20	71.98591	159.82624	29-Aug-11	31-Dec-11	124
PBN40	72.31660	159.73247	29-Aug-11	14-Jun-12	290
PL50	70.40247	164.58802	09-Oct-11	17-May-12	221
PLN100	72.06276	163.69191	28-Aug-11	03-Jul-12	310
PLN120	72.39466	163.69191	28-Aug-11	23-Jun-12	300
PLN40	71.06740	164.58842	11-Oct-11	10-May-12	212
PLN80	71.72472	164.23820	11-Oct-11	02-Jun-12	235
W35	71.10998	161.07150	12-Oct-11	05-May-12	206
W50	71.31080	161.53395	12-Oct-11	30-Apr-12	201
WN20	71.64280	161.53237	08-Oct-11	07-May-12	212
WN40	71.97462	161.54132	08-Oct-11	15-Feb-12	130
WN60	72.30676	161.53758	27-Aug-11	26-Jan-12	152
WN80	72.63877	161.53776	27-Aug-11	01-Jun-12	279

2.1.2. Summer 2012 Program

Acoustic data for the summer 2012 program were acquired with 31 Autonomous Multichannel Acoustic Recorders (AMARs, JASCO Applied Sciences). Each AMAR incorporates a single omnidirectional hydrophone and is powered by 48 D-cell alkaline batteries. Acoustic data were recorded continuously on 384GB of internal flash memory at 24-bit resolution and 16 000 samples per second. Each AMAR was fitted with a GTI-M8E hydrophone (−164 dB re 1 V/µPa nominal sensitivity) and set for a gain of 0 dB. The spectral density of the electronic background noise of the AMARs in this configuration is ~25 dB re 1 µPa^2/Hz, the broadband noise floor is 67 dB re 1 µPa, and the usable bandwidth is 10 Hz to 7.6 kHz. Because the AMARs do not use hard drives, they generate less background noise and require less power than other recording technologies, so they were set to record continuously for the full deployment period.

Like the AURALs, each AMAR was deployed with a metal frame secured near the top to keep the hydrophone off the seafloor (Figure 4). A sinking ground line about 2.5 times the water depth connected the recorder to a 15 lb weight for grapple retrieval. All recorders were retrieved successfully, leaving no material behind.

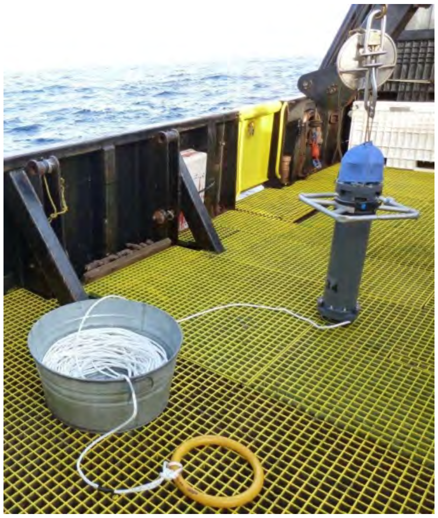
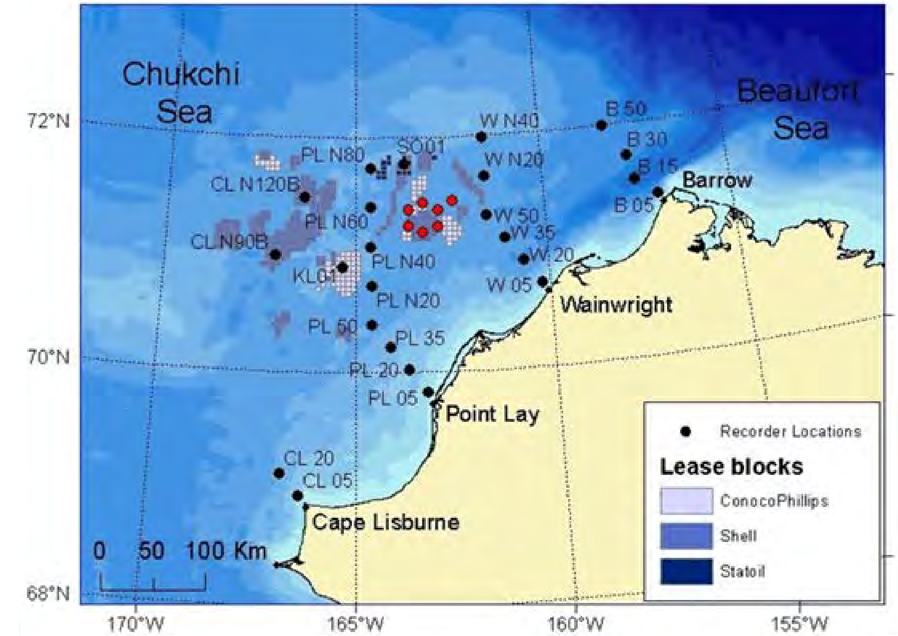


Figure 4. An Autonomous Multichannel Acoustic Recorder (AMAR) ready for deployment in summer 2012 in the northeastern Chukchi Sea.

The summer 2012 program consisted of a regional array of 22 AMARs, 7 AMARs around the Burger drill site, and 1 AMAR near each of the Klondike and Statoil lease areas (Figure 5). The regional array recorders were deployed along lines off Cape Lisburne, Point Lay, Wainwright, and Barrow, in a geographic configuration similar to those of the 2006 through 2011 summer regional programs. These lines extended perpendicularly from the coastline for 50 nautical miles (nmi) then continued northward to about 120 nmi offshore (Figure 5). Similar to 2009–2011, the northernmost Cape Lisburne stations, CLN90B and CLN120B, were shifted east of the line to the Shell lease areas. All recorders were deployed between 8 Aug and 11 Sep 2012 and retrieved between 5 and 14 Oct 2012 (Table 2). All recorders operated from deployment to retrieval, except S01, which was flooded.



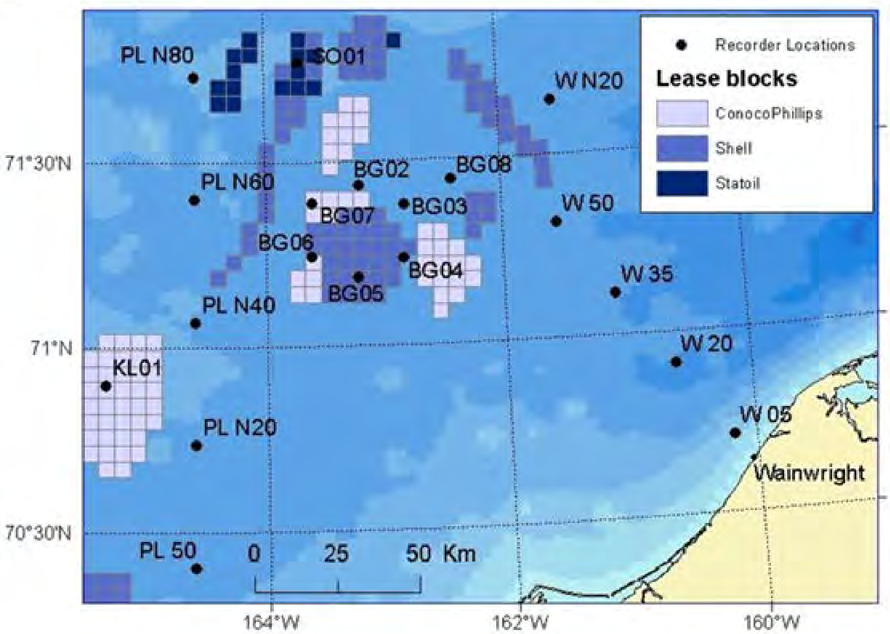


Figure 5. Recorder stations for the summer 2012 program in the northeastern Chukchi Sea: (top) the regional array and (bottom) the recorders at the lease areas. Shades of blue represent water depth.

Table 2. Recorder locations (see Figure 5) and recording durations for the summer 2012 Acoustic Monitoring Program in the Chukchi Sea. The Autonomous Multichannel Acoustic Recorders (AMARs) recorded continuously from deployment to retrieval. Stations are listed alphabetically.

Station	Latitude (°N)	Longitude (°W)	Deployment (UTC)	Retrieval (UTC)	Recording Days
B05	71.36311	156.93723	11-Aug-12	11-Oct-12	61
B15	71.50413	157.50105	11-Sep-12	11-Oct-12	30
B30	71.71164	157.64861	11-Sep-12	11-Oct-12	30
B50	71.98851	158.23675	11-Sep-12	11-Oct-12	30
BG02	71.43276	163.20045	12-Aug-12	7-Oct-12	56
BG03	71.37619	162.81678	12-Aug-12	13-Oct-12	62
BG04	71.23283	162.83286	12-Aug-12	13-Oct-12	62
BG05	71.18441	163.22335	12-Aug-12	13-Oct-12	62
BG06	71.24015	163.60442	12-Aug-12	13-Oct-12	62
BG07	71.38356	163.59406	09-Aug-12	13-Oct-12	65
BG08	71.44296	162.41884	12-Aug-12	13-Oct-12	62
CL05	68.94155	166.37507	8-Aug-12	14-Oct-12	67
CL20	69.12757	166.83663	8-Aug-12	14-Oct-12	67
CLN90B	70.98820	167.10000	9-Aug-12	8-Oct-12	60
CLN120B	71.48573	166.35000	9-Aug-12	8-Oct-12	60
KL01	70.89727	165.32875	12-Aug-12	7-Oct-12	56
PL05	69.82358	163.20332	13-Aug-12	11-Oct-12	59
PL20	70.01798	163.65623	13-Aug-12	11-Oct-12	59
PL35	70.21118	164.11766	13-Aug-12	11-Oct-12	59
PL50	70.40313	164.58782	13-Aug-12	11-Oct-12	59
PLN20	70.73507	164.58763	13-Aug-12	11-Oct-12	59
PLN40	71.06700	164.58763	12-Aug-12	13-Oct-12	62
PLN60	71.39892	164.58782	12-Aug-12	8-Oct-12	57
PLN80	71.73084	164.58820	11-Aug-12	9-Oct-12	59
S01*	71.76513	163.69650	10-Aug-12	9-Oct-12	–
W05	70.70824	160.18007	14-Aug-12	5-Oct-12	52
W20	70.91015	160.62339	14-Aug-12	5-Oct-12	52
W35	71.11097	161.07581	14-Aug-12	6-Oct-12	53
W50	71.31065	161.53758	10-Aug-12	5-Oct-12	56
WN20	71.64270	161.53750	10-Sep-12	10-Oct-12	30
WN40	71.97473	161.53750	10-Sep-12	10-Oct-12	30

* Flooded

Wind speed and water temperature were recorded on two meteorological buoys, operated by Shell, located at 72.15° N, 161.52° W (Buoy 1, near WN40) and 70.87° N, 165.24° W (Buoy 2, near KL01; see Figure 5). As with winter, summer ice coverage data were obtained from the Interactive Multisensor Snow and Ice Mapping System (NOAA 2012).

2.2. Data Analysis Overview

Data analysis was performed using a combination of automated and manual techniques. Quantification of total ocean sound levels and the contribution of anthropogenic activities to the sound levels were performed with automated methods (Sections 2.4.1, 2.4.2, and 2.4.3).

Researchers detected and classified marine mammal calls 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, three species—bowhead and beluga whales (Section 2.4.5) and walrus (Section 2.4.6)—were more thoroughly analyzed with manual and specialized automated approaches than were other species (Table 3). Bearded seal calls were detected with a generic automated technique (Section 2.4.4) and manual analysis. Calls of other species were only manually detected based on a fraction of the dataset. Marine mammal call rates can vary among individuals and over time, and may depend on age and sex class. Thus, the numbers of calls per species do not necessarily represent the relative abundance of the animals.

Manual analysis (Section 2.3) was performed on a fraction of the data to establish the acoustic occurrence of marine mammal species, and to characterize call types to evaluate the performance of the automated detection and classification methods. The automated detection and classification suite processed the entire dataset to estimate the magnitude (in number of detected calls) of acoustic calling activity as a function of time at each station. The automated suite also yielded results not easily achieved with manual analysis such as detecting individual seismic pulses and calculating seismic signal levels and ambient sound levels.

Table 3. Endangered Species Act (ESA) conservation status (Endangered Species Act of 1973 as Amended 2002, USFWS 2012) of marine mammal species in the northeastern Chukchi Sea and their (generalized) occurrence and tendency to vocalize. The first four species are of special interest for this report.

Species	ESA Conservation Status	Period	Occurrence	Vocalization Tendency	Analysis Method	
					Automated	*Manual*
Bowhead whales	Endangered	Apr–Jun	Common	High, decreasing	✓	✓
		Jul–Aug	Rare	Low		
		Sep–Dec	Common	High		
Walrus	–	Jun–Oct	Abundant	High	✓	✓
		Nov–Dec	Rare	High		
Beluga whales	–	Apr–Jun	Common	High	✓	✓
		Jul–Nov	Low to moderate	Moderate		
Bearded seals	Threatened	Sep–Jun	Abundant	High	✓	✓
		Jul–Aug	Abundant	Low		
Fin whales	Endangered	Aug–Oct	Rare	Low		✓
Gray whales	De-listed in 1994; Not threatened	Jul–Oct	Common	Low to moderate		✓
Humpback whales	Endangered	Aug–Sep	Rare	Low to moderate		✓
Killer whales	–	Jul–Oct	Rare	Low		✓
Minke whales	–	Aug–Oct	Low to moderate	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 manually analyzed data by visually examining spectrograms and listening to audio playbacks. Two analysts had more than four years' experience; two others had two years' experience classifying arctic marine mammal vocalizations in previous Chukchi Sea datasets. The other three analysts had little to no experience identifying arctic marine mammal sounds. The lead analyst trained the latter three analysts with a standard set of vocalizations from all species detected in previous year's Chukchi Sea acoustic dataset.

The objectives of the manual analysis were to:

1. Detect and classify marine mammal calls within a subset of the data to allow performance assessments of the automated classifiers. Precision and recall methods, described in Appendix A, were used to quantitatively assess performance by comparing outputs of the automated classifiers with the manual classifications for each species.
2. Review a fraction of the data through the entire recording period to assess where and when the target species (bowhead whales, walrus, beluga whales, and bearded seals) are acoustically present in the Chukchi Sea. This identifies periods and stations with significant or unexpected detections of marine mammals, which might then require further analysis.
3. Identify non-target and extra-limital species. Previous programs recorded several species such as killer whales and fin whales that are observed less frequently in the Chukchi Sea. Acoustic detections of such species are valuable because they help us understand their present habitat use as well as changes in habitat use over time, which may indicate environmental changes, including changes in ice conditions and availability of prey. Manual analysis is especially important in this context because automated classifiers are not configured and tested for these species.

2.3.1. Manual Analysis Protocol

Five percent of the winter 2011–2012 data from all 15 recorders were analyzed manually. The winter acoustic data were acquired on a duty-cycle, recording for either 30 min (Hanna Shoal stations) or 40 min (all other stations) of every 4 h, yielding six files per day. The first 2 min sample of each data file was manually analyzed by visually examining spectrograms and listening to audio playbacks. Analysts annotated one call per species per sample for all files and stations to record each species in the dataset. In addition, analysts annotated all marine mammal calls in one sample per day for all days and stations. Analysts fully annotated a different sample each day, selecting consecutive samples for successive days. Automated detector performance was evaluated with these fully-annotated samples (see Appendix A.5).

Five percent of the summer 2012 data from all 30 operational recorders were analyzed manually. The summer acoustic data were acquired continuously and stored in 30-minute long files yielding 48 files per day. The first 90 s of each 30 min file per station each day were sampled for manual analysis. Analysts annotated one call per species per sample for all files and stations to record each species in the dataset. For 26 of the 30 recorders, analysts annotated all identified marine mammal vocalizations in two samples of each day. Full-annotation sample selection alternated between the 1st and 25th samples on one day and the 13th and 37th samples the next day. This corresponds to analyzing 4% (2/48) of the 90-second samples at a high level of detail and 96% (46/48) of the samples at a moderate level of detail for these ten stations. This protocol generated enough fully-annotated samples to evaluate the performance of the automated detectors. For the other four stations, analysts annotated one call per species per sample for all 48 samples of each day.

In case of doubt regarding species identification within a sample, the source file of the sample was examined for the presence of more easily identifiable calls within the same time window. A custom software tool (JASCO's SpectroPlotter) that provides standardized annotations and a consistent approach among analysts, was used to manually analyze data. Calls were identified by species and call type (Table 4). For bowhead whales, analysts annotated individual sounds, but did not distinguish or characterize songs (see for example, Delarue et al. 2009).

Table 4. Call types by species annotated during manual analysis of the winter 2011–2012 and summer 2012 datasets. Abbreviations: AM=amplitude-modulated, FM=frequency-modulated, HF=high-frequency, LF=low-frequency.

Species	Call Type	Description
Bowhead whale	Upsweep	Upsweeping FM tonal, usually below 600 Hz.
	Downsweep	Downsweeping FM tonal, usually below 600 Hz.
	Constant	Relatively flat FM tonal, usually below 600 Hz.
	Convex	Inflected FM tonal, increasing then decreasing in frequency. Usually below 600 Hz.
	Concave	Inflected FM tonal, decreasing then increasing in frequency. Usually below 600 Hz.
	Complex	FM moans with more than one inflection point and/or with harmonics. Any FM and AM calls extending above 600 Hz.
	Overlap	Overlapping calls produced concurrently by several individuals.
	Other	Bowhead calls outside the above categories.
Walrus	Knock	Broadband impulsive sounds typically occurring in long series.
	Bell	Tonal calls centered around 450 Hz and typically associated with knocks.
	Chimp	Two-part call reminiscent of chimpanzee vocalizations and often produced in long sequences. Sometimes repeated without interruption between consecutive units. Second part higher in frequency than first part.
	Grunt	Grunting sound. Often produced in pairs or triads repeated in long sequences.
	Bark	Often produced in pairs or triads repeated in long sequences. Similar to grunts, but higher in frequency (400 Hz).
	Snort	Snorting/burping sound typically increasing in frequency. Typically not produced in sequence.
	Tone	LF tonal calls, typically flat or downsweeping. Usually around 100–200 Hz. Similar to bowhead moans but shorter (< 0.5 s).
	Low-frequency downsweep	A short call (< 0.5 s) with features intermediate between a grunt and tone; fast downward sweep rate; less than 100 Hz and emphasis on LF (< 50 Hz)
	Overlap	Overlapping calls produced by several animals concurrently.
	Other	Walrus calls outside the above categories.
Beluga whale	Low whistle	FM calls without harmonics below 2500 Hz.
	High whistle	FM calls without harmonics above 2500 Hz.
	Buzz	Broadband buzzing sounds.
	Chirp	Very short, HF sound. Reminiscent of small-bird chirps.
	Click	Broadband clicks, presumably echolocation related.
	Overlap	Overlapping calls produced by several animals concurrently.
	Other	Beluga calls outside the above categories.

Species	Call Type	Description
Bearded seal	Long trill	Downsweeping trills longer than 6 s.
	Short trill	Downsweeping trills shorter than 6 s.
	Upsweeping trill	All upsweeping trills.
	Constant trill	Flat trills.
	Complex trill	Trills containing both up- and downsweeping segments.
	Overlap	Overlapping calls produced by several animals concurrently.
	Other	Bearded seal calls outside the above categories.
Fin whale	20 Hz pulse	Pulse downsweeping from 25 to 18 Hz, about 1 s long.
	Broadband downsweep	Same bottom frequency as 20 Hz pulse, but top frequency can extend up to 50 Hz or above.
	Other	Calls that do not match the above categories.
Gray whale	Knock	Knocking sounds. No frequency modulation.
	Click	Series of impulsive sounds similar to knocks but varying in pitch throughout the series.
	Grunt-like knock	Superposition of knocks and grunts.
	Moan/growl	Moans with harmonic. Very LF (fundamental near 100 Hz) with growly texture. Sometimes mixed with grunt-like knocks.
	Other	Calls outside the above categories.
Humpback whale	Grunt/snort, wop	AM calls often ascending in frequency at the end (e.g., Thompson et al. 1986, Dunlop et al. 2007).
	Other	Calls outside the above categories (e.g., moans, cries, etc.).
Killer whale	Pulsed call	Characterized by harmonic structure. Fundamental frequency usually around 800–1000 Hz. Expect repetitions of stereotyped calls within files.
	Whistle	FM calls usually without harmonics.
	Other	Calls outside the above categories.
Minke whale	Boing	Pulsed call with fundamental frequencies and harmonics around 1200–1500 Hz, 1–2 s long.
Ribbon seal	Medium downsweep	FM calls, sometimes with harmonic, downsweeping from 2–5 kHz to 100 Hz, usually < 2 s. Metallic texture and sonority.
	Other	Primarily contains the puffing sounds described by Watkins and Ray (1977). Includes other uncategorized calls.
Ringed seal	Bark	Short barking/grunting sounds below 1 kHz and produced in series; often alternating with yelps.
	Yelp	Short yelping sounds between 600–1000 Hz; can occur alone or in mixed sequences with barks.
	Other	Ringed seal calls outside the above categories.
Unknown	Undescribed	Any biological sound that cannot be classified as one of the above species; includes isolated calls that cannot be assigned to a species based on context. Most presumed ice seal calls were likely logged here.
	Grunt	Any grunt-like calls not likely produced by walrus.

2.3.2. Analysis Validation

The lead analyst, Julien Delarue, helped the other analysts classify calls that were difficult to attribute to a known call type. Delarue reviewed a random subset of annotations from all analysts to ensure accurate classification of calls by species and to provide feedback to the analysts, who fixed any incorrect classifications. The lead analyst consulted with external researchers when new or unknown call types were detected.

The annotation review consisted in verifying a sample of annotations of the target (bowhead whale, walrus, beluga whale, and bearded seal) and non-target species, particularly annotations that referred to less common species or those outside the expected range or residency period of common species; and reviewing a sample of sounds tagged as "Unknown" to resolve species identity. Priority was given to unknown sounds for which analysts indicated a possible source on days with no or few detections, especially if the possible source was one of the target species.

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

2.4. Automated Data Analysis

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

An overview of ambient, seismic and vessel noise analysis, and bowhead whale, walrus, beluga whale, and bearded seal call detection and classification is provided below. Appendix A contains detailed descriptions of the algorithms and an analysis of the classifiers' precision and recall.

An extension of the previous years' processing chains was implemented this year to better classify the dominant sound source in each minute of data as vessels, seismic, or ambient. To minimize anthropogenic sources from affecting the ambient source sound level estimates, we define ambient as any minute of data that does not have an anthropogenic detection within two hours of that minute. The results of this analysis estimate the daily cumulative sound exposure level from each class of source, the cumulative distribution function of the sound pressure levels, and exceedance spectra for each source.

An additional extension, performed in 2012, used the per-minute noise levels to predict the detection range for bowhead whales for each minute of data (Appendix E.). We used this measurement to convert the call counts into call densities, which revealed slightly different migration paths than the simple call count data (Section 2.4.8). A Generalized Linear Model was built to investigate whether the drilling noise levels around Burger in fall 2012 may have masked our ability to detect bowhead calls (Section 2.4.9).

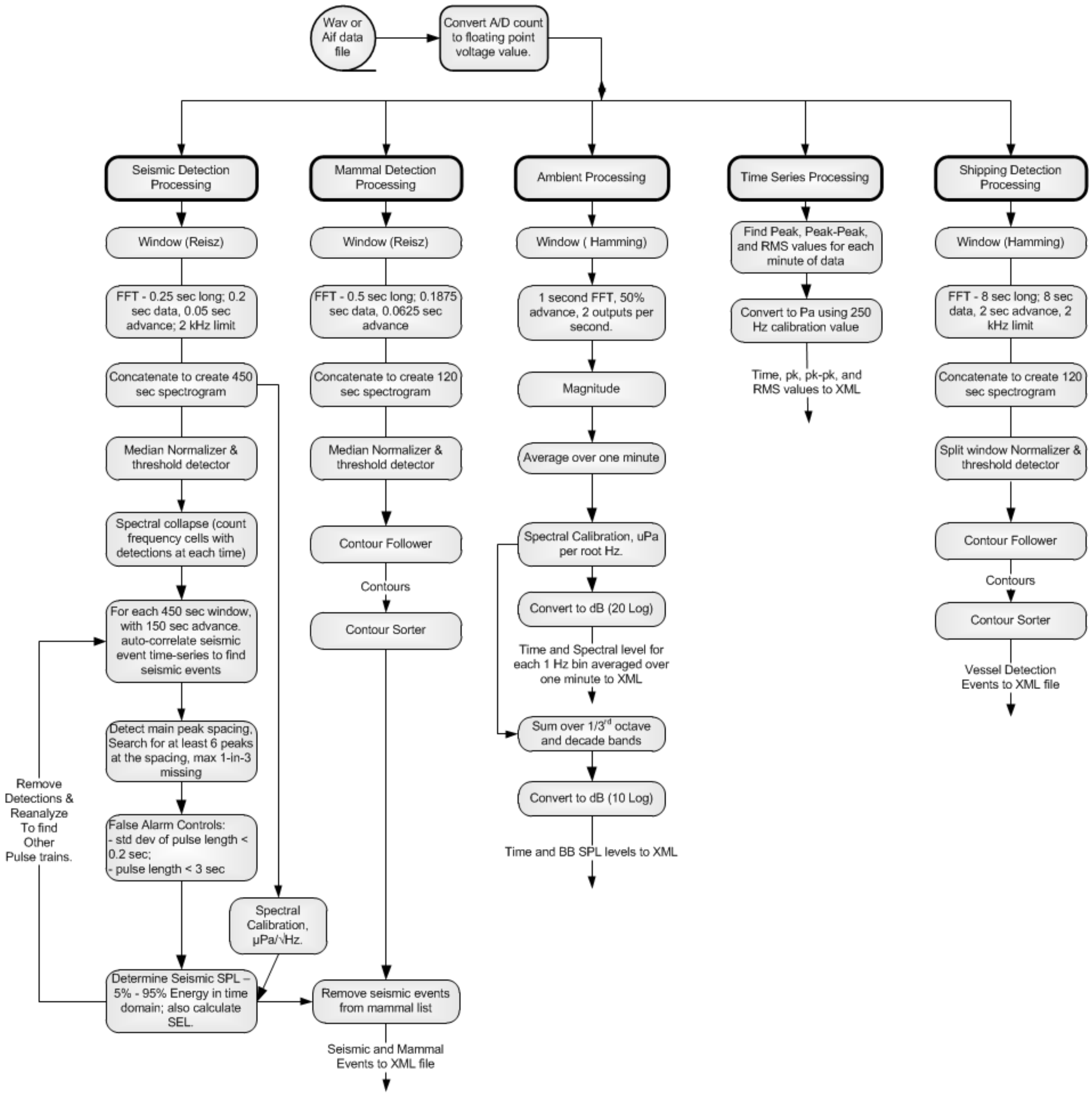


Figure 6. Major stages of JASCO's automated acoustic analysis software suite, SpectroPlotter.

2.4.1. Total Ocean Noise and Time Series Analysis

The total ocean noise levels were quantified using a 1 Hz resolution frequency domain analysis; results were averaged to produce spectral density values for each minute of recording. These values directly compare to the Wenz curves (Figure 7), which represent typical sound levels in the ocean. The ambient analysis also yields 1/3-octave-band and decade-band sound pressure levels for each minute of data. See Appendix B for more information.

The Time Series processing tool chain analyzes the ocean sound in the time domain. This tool finds peak amplitudes, peak-to-peak amplitudes, and rms amplitudes of the time series for each minute of data. Results are computed and stored for each second and each minute of data.

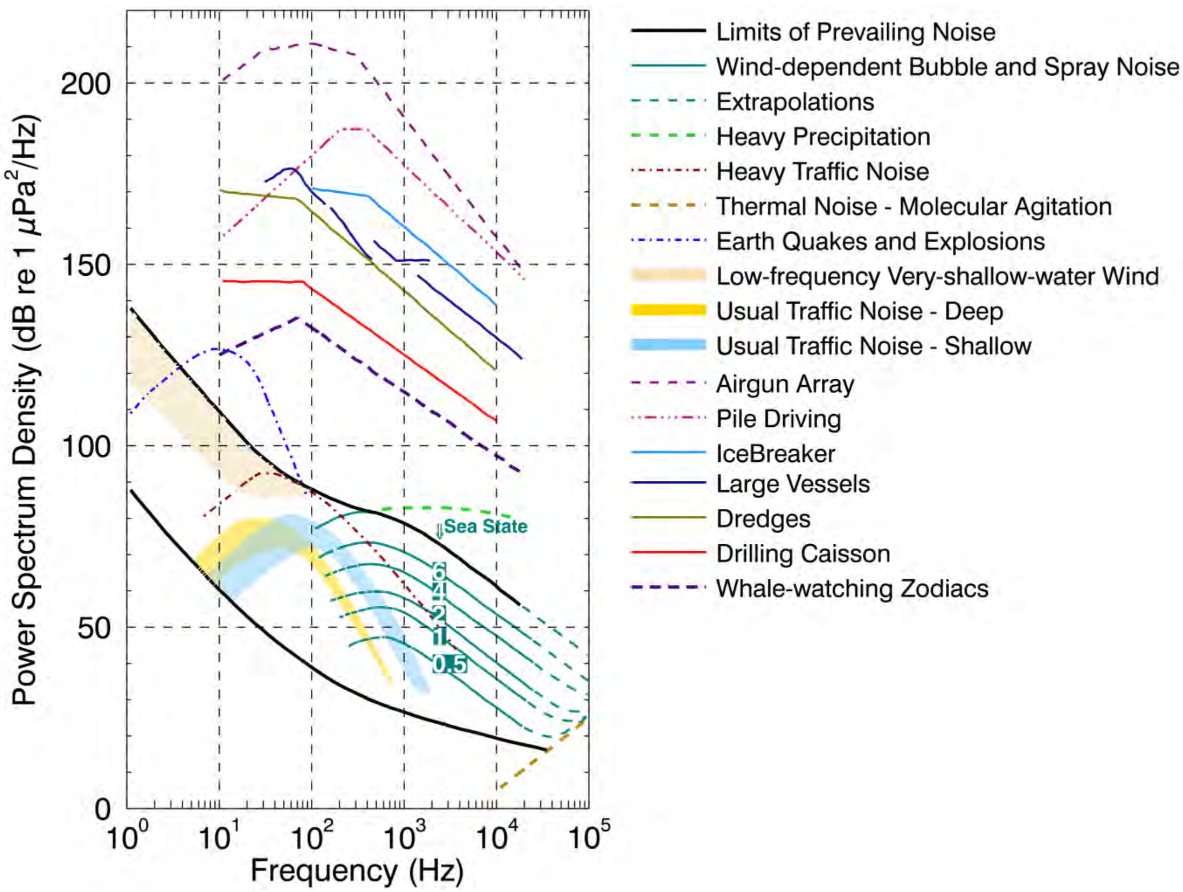


Figure 7. Wenz (1962) curves of typical ocean noise and typical source spectra for anthropogenic noise sources (Ross 1976, Urick 1983, Scrimger and Heitmeyer 1991, Erbe and Farmer 2000, Erbe 2002, 2009).

2.4.2. Vessel Noise Detections

Ships produce narrowband sinusoidal tones from the propulsion and other rotating machinery, as well as broadband energy from propeller cavitation (Arveson and Vendittis 2000). JASCO implemented a shipping detector based on overlapped FFTs. The number of seconds of data input to the FFT determines its spectral resolution. JASCO uses 0.125 Hz resolution by using 8 s of real data with a 2 s time step. This frequency resolution separates the tones from each other for easy detection, and the 2 s time step provides suitable temporal resolution. Higher frequency resolutions can reduce detectability of shipping tones, which are often unstable within 1/16 Hz for long periods.

Tonal detection is performed on the 30-minute WAV files. A 120 s-long spectrogram is created with 0.125 Hz frequency resolution and 2 s time step (131 072-point FFTs, 128 000 real data points, 32 000-point advance (time step), Hamming window). A split-window normalizer (Struzinski 1984) selects the tonal peaks from the background (16-point window, 6-point notch, and detection threshold of 4 times the median). The peaks are joined with a 5 × 5 kernel to create contours. Associations in frequency are then made if contours occur at the same time. The event time and number of tones for any event at least 20 s long and 40 Hz in bandwidth are recorded for further analysis.

The short-range vessel noise detection is performed on the combined results from each WAV file. We define a shipping band of 40–315 Hz and obtain a root-mean-square (rms) sound pressure level (SPL) for the band once per minute. Background estimates of the shipping band rms SPL and the total rms SPL are compared to their median values over the 12-hour window centered on the current time. Shipping is detected when the rms SPL in the shipping band is at least 3 dB above the median, at least 5 shipping tonals are present, and the rms SPL in the shipping band is within 8 dB of the total rms SPL. When these conditions are true, the total per-minute rms SPL is attributed to shipping. The shipping post-processor also performs a search for broadband shipping sound. If the rms SPL in the shipping band is greater than 105 dB, the 1/3-octave-band SPL at 630 Hz exceeds the SPL at 6300 Hz by at least 10 dB, and there were tonals detected within half an hour of the current time, then broadband shipping is detected. The 10 dB constraint between 1/3-octave-bands separated by a decade in frequency is equivalent to the 20 dB/decade slope discussed in Wenz (1962).

2.4.3. Seismic Survey Event Detections

Seismic pulse sequences are detected using correlation detection on spectrogram contours. A 300 s long spectrogram is created with 4 Hz frequency resolution and 0.05 s time step (4096-point FFT, 3200 real data points, 800-point time step, Reisz window). Each frequency bin is normalized to the median bin value over the 300 s window. The detection threshold is 3 times the median value. Contours are created by joining the detected time/frequency bins in the frequency range of 7–1000 Hz using a 7×7 kernel. Any contour between 0.2 and 6 s long with a bandwidth of at least 60 Hz is 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 on each side are identified and the peaks list is searched for entries with a set repetition interval. The minimum and maximum time spacing of the peaks are appropriately set, typically at 4.8 s and 65 s, to allow for the normal range of seismic pulse periods of 5–60 s. If at least 6 peaks occur with a regular spacing, 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. To minimize false alarms, especially from biological sources, sequences with a duration standard deviation greater than 0.2 + (number of pulses)/30 seconds are rejected. Finally the 100% sound exposure level (SEL) is computed by adding 0.46 dB to the SEL computed over the 90% rms SPL window, and the pulse time, duration, 90% rms SPL, and SEL are stored for later use. The detected peaks are removed from the event time series and the process is repeated to look for weaker sequences or changes in sequence timing.

This detector does not handle some situations well. For instance, if the pulse period is unstable by more than 0.25 s, the detector cannot lock on. Also, the detector misses pulses if there are fewer than six pulses at the beginning or end of a WAV file at a particular repetition rate. We applied post-processing to address these issues and smooth the results. If at least 8 out of 20 min have seismic detections, then the other 12 min may have missing seismic. Tests for possible missed seismic events include a standard deviation of less than 2 in the number of shots per minute, the rms SPL in the period is stable within 3 dB and is greater than 125 dB, and the 1-minute seismic SEL for the minutes with seismic is within 6 dB of the total 1-minute SEL.

Seismic is declared missing for the minutes that meet these criteria. The missing minutes are filled in using the 1-minute rms SPL and SEL from the ambient computations minus the mean difference between the 1-minute seismic SEL and the 1-minute ambient SEL.

The performance of the seismic detector has been evaluated on seismic airgun data from PLN80 in summer 2010; the detector had high precision ($P = 0.9997$) and recall ($R = 0.9949$).

2.4.4. Generic Marine Mammal Call Detections (Except Bowhead Whale, Beluga Whale, and Walrus)

Similar to seismic survey detection, automated detection of marine mammal vocalizations is accomplished with contours in the frequency domain. The analysis used FFT parameters, which depend on the type of signal detected (see Appendix A).

The adjacent time-frequency bins above the detection threshold were joined using a 5 × 5 kernel to create contours using a contour-following algorithm. The contours were then sorted to classify the probable type of call. A user-defined call definition file configured the contour sorter. The effectiveness of the contour sorter can be evaluated by comparing the precision and recall of the sorter against the truth data from manual analysis of selected data sets. Appendix A provides further details on the contour follower and sorter.

This technique was reliably used for bearded seal, fin, and killer whale calls; it was also configured for bowhead, beluga, and minke whale calls, as well as ringed seal calls. This approach was only used to guide the manual analysts; all detailed reporting results were based on manual analysis.

2.4.5. Bowhead and Beluga Whale Call Detections

Bowhead moans and beluga whistles are auto-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 for a full technical description of the detection and classification process and an evaluation of the performance and recall 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 the detector targeted, most songs incorporate some moans in at least one of their phrases (Delarue et al. 2009), which makes this method ideal for detecting them. The ability to detect songs is important because songs are a dominant component of the bowhead acoustic repertoire in fall, winter, and spring (Delarue et al. 2009).

2.4.6. Walrus Grunt Detections

The walrus grunt detector/classifier is based on time-frequency representation of the acoustic signal. The spectrogram is calculated and then analyzed in consecutive 0.7 s time windows (frames) overlapping by 50%. For each frame, a set of features representing salient characteristics of the spectrogram are extracted in the frequency band 50–800 Hz. Features included, but were not limited to, spectral entropy, harmonicity, frequency distribution, and frequency and amplitude modulation indices. Extracted features for each frame were then presented to a two-class random forest classifier to determine the class of the sound in the analyzed frame (i.e., walrus grunt or "other"). A full technical description of the detection/classification process is given in Appendix A.

2.4.7. Detector/Classifier Performance Evaluation

The performance of the marine mammal detectors/classifiers was assessed by comparing the automated detection/classifications with manual detections for all fully-annotated manually analyzed recordings. For the winter 2011–2012 data, marine mammal calls were fully-annotated in one sample per day for all days and stations. Analysts fully annotated a different sample each day, selecting consecutive samples for successive days, providing complete diurnal coverage of the data. This yielded a test dataset of 3005 fully-annotated, two-minute long samples, covering nine stations. For the summer 2012 data, marine mammal calls were fully manually annotated 26 of the 30 recorders. Full-annotation sample selection alternated between the 1st and 25th samples on one day and the 13th and 37th samples the next day. This yielded a test dataset of 2758 fully-annotated, 1.5-minute long samples. The performances of the detectors were measured by calculating the precision (P) and recall (R) indices (see Appendix A.5.3). These values characterize the relationship between the detector/classifier and the dataset, where P measures exactness, and R measures completeness. P and R were also calculated separately for vocalizations with signal-to-noise ratios of < 0 dB, 0–5 dB, >5–10 dB, and > 10 dB and those results are presented in Appendix A. These values are further used to correct the number of automated detections and estimate call counts (see Appendix A.6). Table 5 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 5. Performance of the automated detectors/classifiers (precision, P and recall, R) applied to the winter 2011–2012 and summer 2012 datasets.

Species	Winter 2011–2012			Summer 2012		
	P (%)	R (%)	Detector/ Classifier	P (%)	R (%)	Detector/ Classifier
Bowhead	66	34	Tonal detector + Random forest classifier	73	44	Tonal detector + Random forest classifier
Walrus	62	10	Grunt detector	43	19	Grunt detector
Beluga	42	40	Tonal detector + Random forest classifier	–	–	–
Bearded seal	45	62	Contour follower/sorter	74	25	Contour follower/sorter

2.4.8. Noise-Independent Call Densities

Noise levels influence the area within which animals can be acoustically detected (Appendix E). This area varies in time and is different for each location. Consequently, the number of calls detected at a given time and location is highly dependent on noise conditions. An increase in the number of detected calls could potentially be due to a decrease in noise levels (leading to a larger detection area) rather than an increase in vocal activity. Figure E.2 shows the detection area of bowhead calls at each location of the summer 2012 monitoring program.

To facilitate the interpretation of the acoustic data, the number of detections was divided by the detection area to provide a noise-independent vocal activity index. Because the number of detections was divided by an area, this index is referred to as the estimated call density (in calls/km^2). Its computation is performed as follows:

1. The number of detections from the automatic detector was summed for each 30-min recording. To avoid taking into account false positives from the detectors, detections were only used if the manual analysts confirmed the presence of bowhead sounds.
2. The number of detections N_{detec} was then weighted with the precision P and recall R indices to provide an estimated call count N_{calls} : $N_{calls} = N_{detec}\ (P/R)$. (Sections A.5 and A.6).
3. The estimated call count for each 30-minute recording was divided by the area of detection of the calls of interest to obtain an estimate of the call density. Given the flat bathymetry of the northeastern Chukchi Sea it was considered that the detection range r was the same for all azimuths (Figure E.2). Hence, the area of detection A was defined as $A = \prod r^2$. Detection ranges were calculated for each minute of recording (Appendix E). The range value used for each 30-minute recording was the median of all the one-minute range values.

To produce call density maps for the entire monitoring period, all estimated call densities were summed at each station and interpolated in space using a kriging algorithm (see Section 2.4.9).

Calculating the detection areas requires knowing the source levels of the calls of interest (Appendix E). MacDonnell et al. (2011) calculated the source levels of bowhead moans using more than 100 localized calling bowhead whales at the Burger prospect (Figure E.1). Source levels of walrus grunts have not yet been defined in the literature. Consequently, estimated call densities were only calculated for bowhead calls.

2.4.9. Interpolation Techniques

There are two main groupings of interpolation techniques used to create surfaces maps from measured points:

- Deterministic–Based on either the extent of similarity or the degree of smoothing of the measured points.
- Geostatistical–Uses the statistical properties of the measured points.

Radial basis function is a deterministic interpolation technique that creates a surface from measured points, based on the degree of smoothing. It calculates predictions from the measured points based on the assumption that the interpolating surfaces should be influenced by a function of their radial distance from a grid point and that the surface must pass through each measured sample value.

There are five different basis functions:

- Thin-plate spline
- Spline with tension
- Completely regularized spline
- Multiquadric function
- Inverse multiquadric function

Each basis function has a different shape and results in a different interpolation surface. Each of the functions has a parameter that controls surface smoothness through a series of elevation samples. Its default value is equal to the average point spacing, assuming the samples are uniformly distributed. The radial basis function used was the inverse multiquadric, given by the equation:

$$B(h) = \frac{1}{\sqrt{h^2 + R^2}}$$

where h is the anisotropically scaled distance from the interpolant to the node and R^2 is the kernel parameter that controls surface smoothness. Smoother maps are generated from lower parameter values.

Ordinary kriging is a geostatistical interpolation technique that relies on both statistical and mathematical methods to create surfaces and assess the uncertainty of the predictions. Ordinary kriging assumes the model:

$$Z(s) = \mu + \varepsilon(s)$$

where μ is an unknown constant and ε represent errors associated with μ. Ordinary kriging requires the form and parameter values of the spatial dependence of the spatial process in terms of a *semivariogram* model. In spatial statistics the theoretical *semivariogram* is a function (e.g., linear, exponential, Gaussian, and spherical) describing the degree of spatial dependence of a spatial random field or stochastic process. Typically the *semivariogram* model is not known in advance, and therefore must be estimated, either visually or by an estimation method. The appropriate model must fit the empirical values by matching the shape of the curve of the experimental variogram to the shape of the curve of the mathematical function.

This list summarizes the main steps in creating a geostatistical model:

1. Examine the data.
2. Calculate the experimental semivariogram.
3. Fit a theoretical model.
4. Generate the matrices of kriging equations.
5. Solve the matrices to obtain a predicted value and its associated error for each location in the output surface.

Surface map plots were generated with IDL programming software version 8.2.0, MATLAB version 8.1.0, and ArcGIS version 10.1.

3. Results

3.1. Received Ocean Sound Levels

The received ocean sound levels at one representative recording station, PLN40, illustrate the sound conditions during the program. The received sound levels for all other stations are provided in Appendix B. The power spectral density levels can be compared to the Wenz curves (see Figure 7). The dashed lines in the percentile plots are the limits of prevailing noise from the Wenz curves.

3.1.1. Winter 2011–2012 Program

The total received sound level varied between the Aural M2 recorder noise floor of 86 dB and 136 dB re 1 µPa (Figure 8, top). Noise levels from 11 Oct to 15 Nov were consistently between 100–110 dB re 1 µPa, which was the ice-free period (see Appendix B). During the ice-covered period (15 Nov–10 May) ice cracking during periods of falling temperatures created localized high intensity impulses with high frequency content (Figure 8, bottom). Sound propagation under ice at frequencies above 200 Hz is highly attenuated by scattering at the rough under-ice surface (Buck and Greene 1964, Diachok 1976, Roth 2012), resulting in low sound levels above 200 Hz for most of the deployment (Figure 8, bottom).

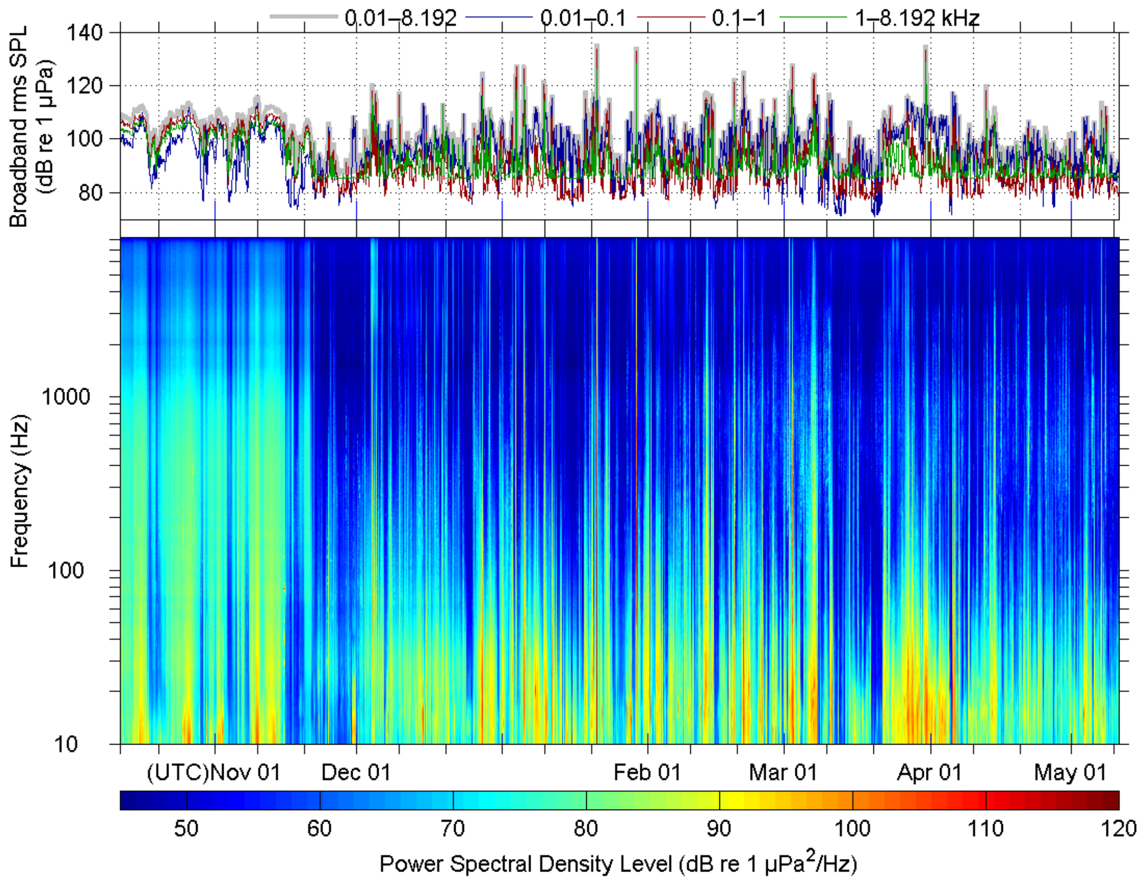


Figure 8. (Top) Broadband and decade-band sound pressure levels (SPLs) for winter 2011 Station PLN40. (Bottom) Spectrogram of underwater sound over the recording period from October 2011 to May 2012.

The 1/3-octave-band median SPL remained constant near 100 dB re 1 µPa and the 1/3-octave-band mean SPL remained constant near 80 dB re 1 µPa when averaged over the entire recording (Figure 9). The large difference between the median and the mean is attributed to the high intensity ice cracking events. The L_{50}–L_{95} spectral exceedance levels are all self-noise limited above 1 kHz, confirming that there was little high frequency noise propagating under ice (Figure 9).

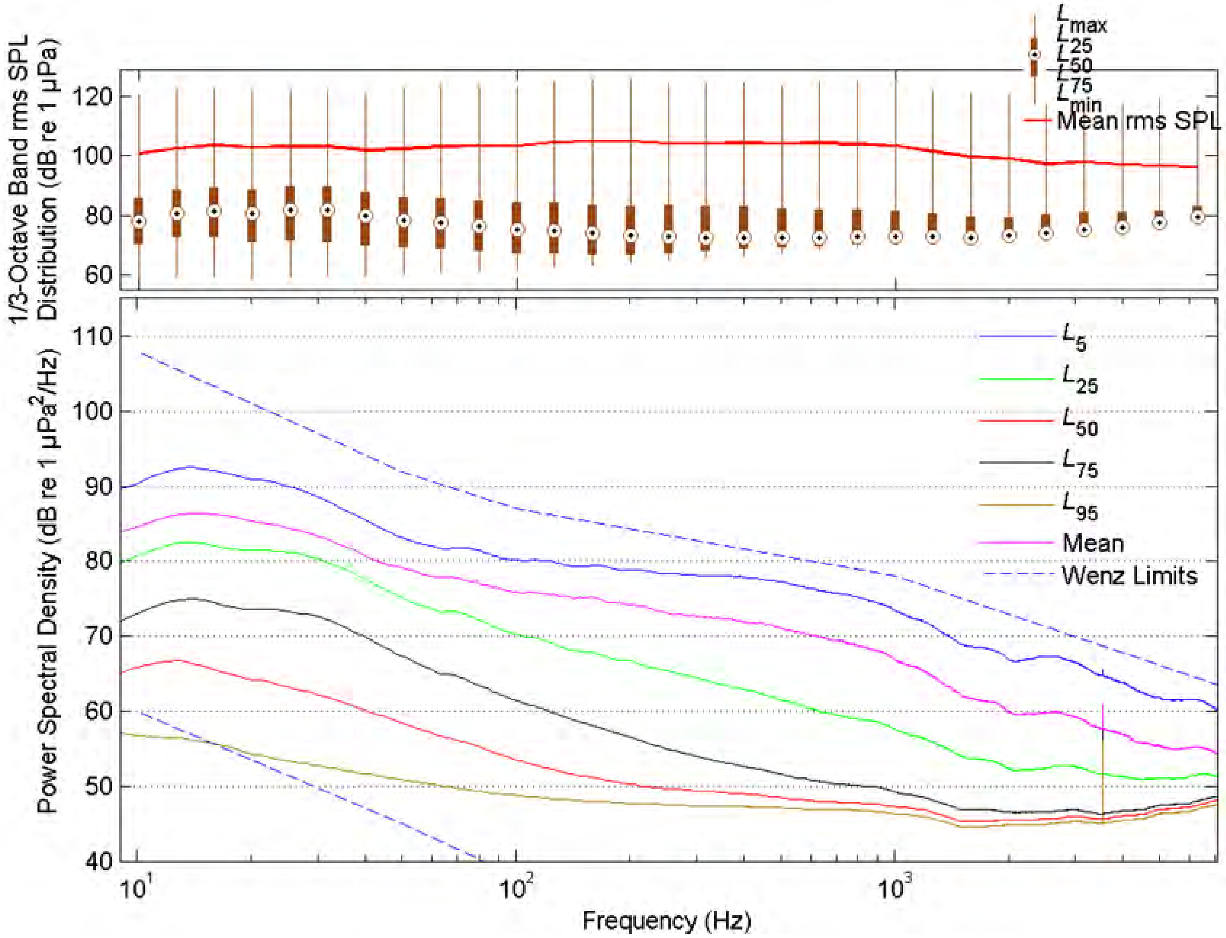


Figure 9. (Top) Distribution of 1/3-octave-band sound pressure levels (SPLs) for winter Station PLN40. The red line indicates the root-mean-square (rms) level over the recording period from October 2011 to May 2012. (Bottom) Percentile exceedance levels of the power spectral density. The spike at 3.5 kHz is caused by the AURAL's electronic background noise. The dashed lines are the limits of prevailing noise from the Wenz curves (see Figure 7).

3.1.2. Summer 2012 Program

Total received sound levels at PLN40 ranged from 87–124 dB re 1 µPa (Figure 10). Periods of higher sound levels were associated with wind and wave action (e.g., Sep 18), or drilling activity at the Burger drill site 35 km northeast of PLN40 (e.g., 1–5 Oct). In general, increased wind speed is associated with higher sound levels in shallow water (Greene and Buck 1979).

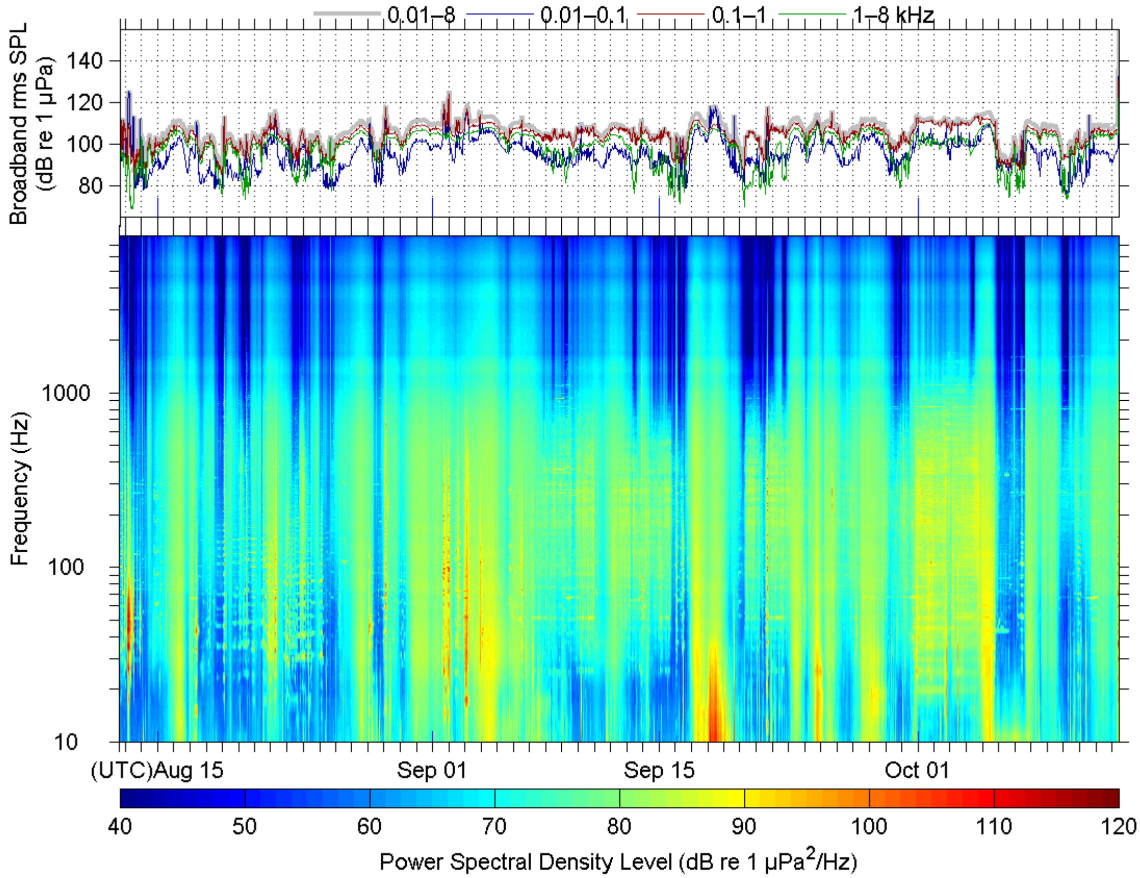


Figure 10. Broadband and decade-band sound pressure levels (SPLs) for (top) summer 2012 Station PLN40 and (bottom) spectrogram of underwater sound August to October 2012.

Unlike the winter station, 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 L50 curve falls from 74.5 to 57.3 dB re 1 μPa^2/Hz between 500 and 5000 Hz, a decrease of 17.2 dB/decade. This is a typical roll-off for wind driven noise spectra (Ma and Nystuen 2005). The electronic background noise of the AMARs is 23 dB re 1 μPa^2/Hz so sound levels below 500 Hz reflect the true ambient noise conditions. All spectral exceedance levels remain within the Wenz limits of prevailing noise (Figure 7, Figure 11).

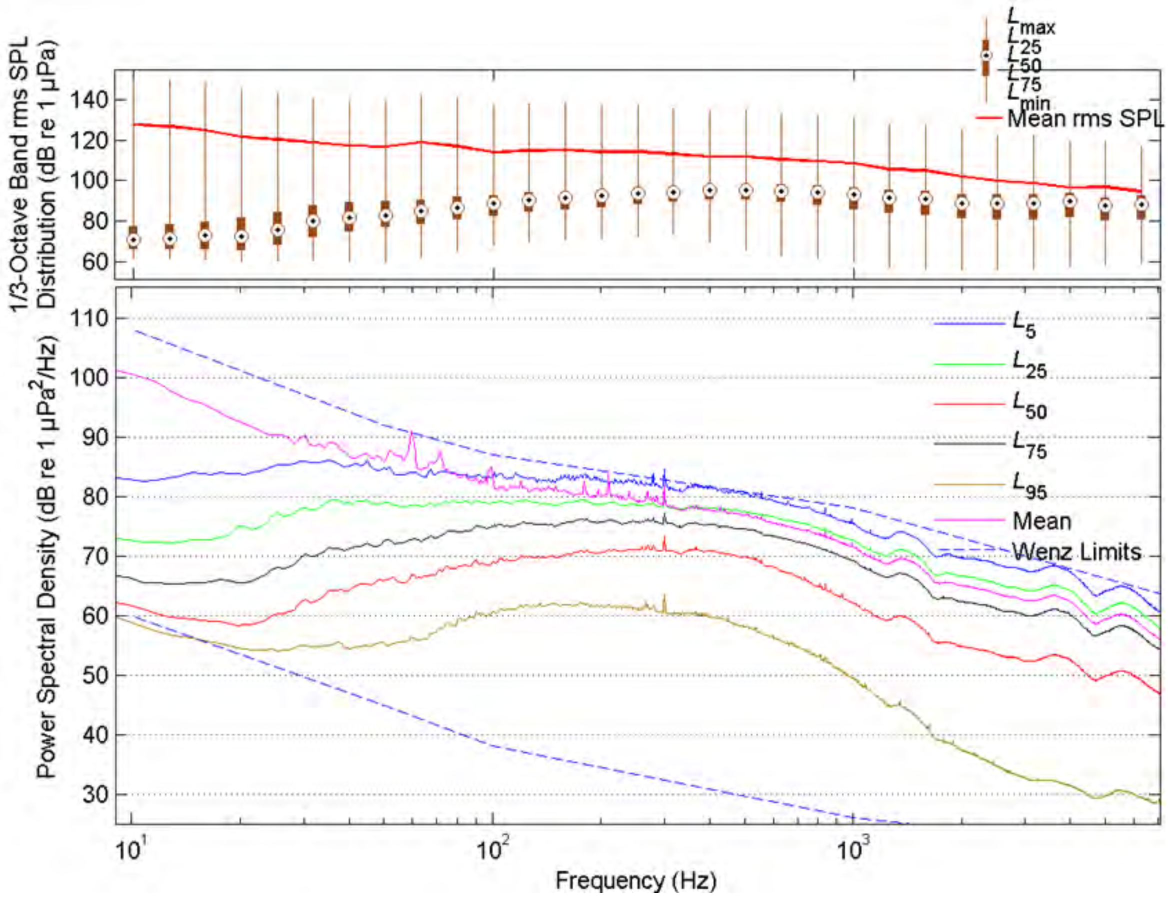


Figure 11. (Top) Box plot showing 1/3-octave-band sound pressure levels (SPLs) for summer 2012 Station PLN40. The red line indicates the root-mean-square (rms) level over the recording period from August to October, 2012. (Bottom) Percentile 1-min power spectral density levels. The dashed lines are the limits of prevailing noise from the Wenz curves (see Figure 7).

The distributions of sound levels were measured for each station (Figure 12). The median of the total received sound energy at each station was kriging interpolated (see Section 2.4.9) for the summer program (Figure 13), with median SPLs between 98 and 109.9 dB re 1 µPa. Stations W35 and the Burger cluster received higher sounds levels associated with the Shell drilling program. The elevated levels at Station PL05 were driven predominantly by walrus. Noise at Station CL05 was mainly associated with weather and wave noise.

The maximum daily cSEL was measured (Appendix B) at station CL05 on 24 Sep during an intense weather period. The unweighted value was 181.3 dB re 1 µPa^2·s (180.1 lf M-weighted, 166.4 mf M-weighted, 169.9 pinniped M-weighted). No other days had cSELs above 170 dB re 1 µPa^2·s. The maximum daily cSEL due to anthropogenic activity was measured at W35 on 26 Sep. The unweighted value was 175.4 dB re 1 µPa^2·s (174.7 lf M-weighted, 172.7 mf M-weighted, 173.7 pinniped M-weighted). Four other days had cSELs above 170 dB re 1 µPa^2·s at W35. The maximum daily cSEL due to marine mammal calls was measured at PL05 on 28 Sep. The unweighted value was 178.6 dB re 1 µPa^2·s (176.5 lf M-weighted, 167.9 mf M-weighted, 169.7 pinniped M-weighted). Three other days had cSELs above 170 dB µPa^2·s at PL05.

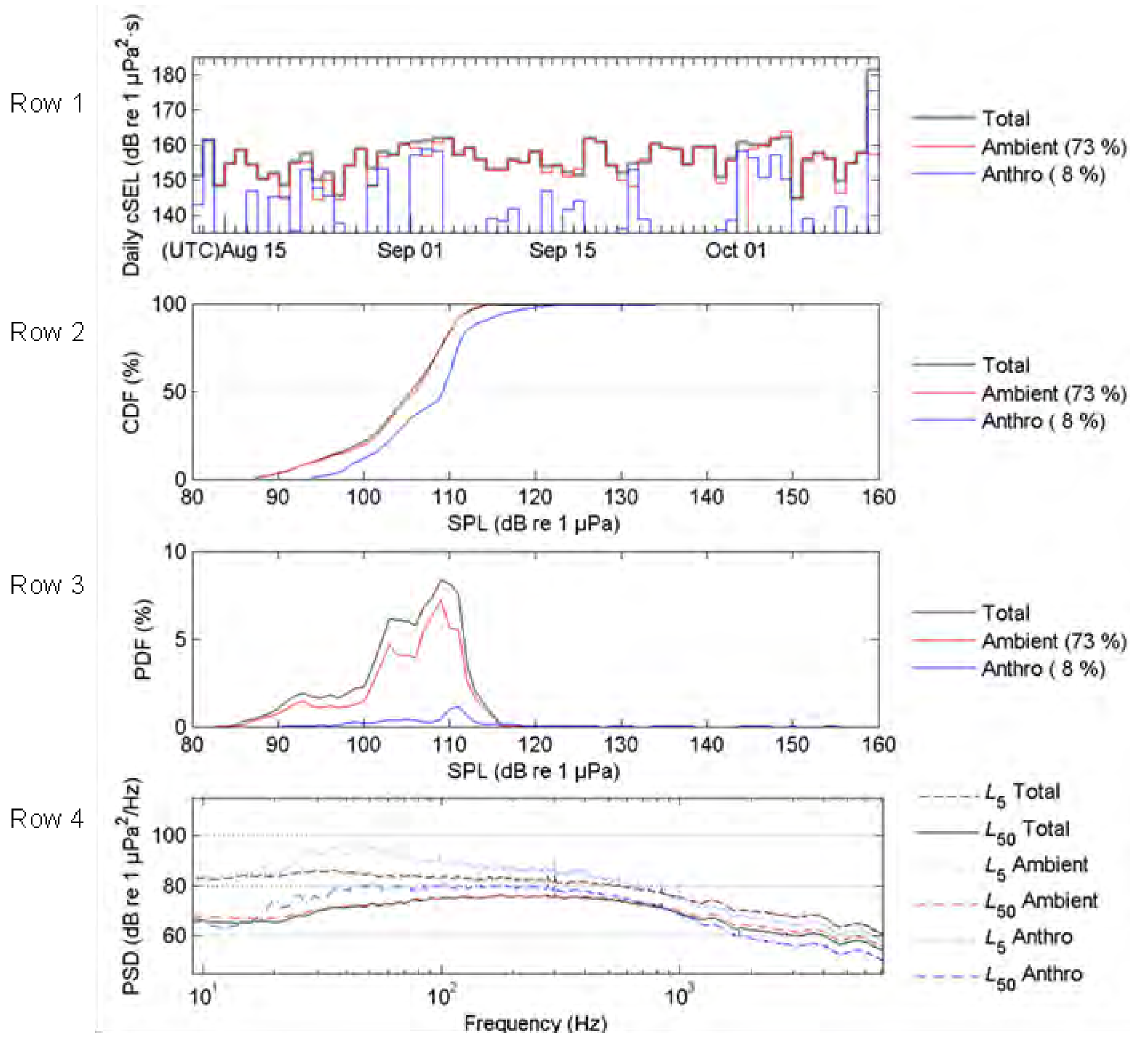


Figure 12. Sound distributions at PLN40 summer 2012. For each figure, the data is divided into total, ambient, and anthropogenic classes. The ambient class is composed of all data that do not have an anthropogenic detection within 2 hours; this excludes undetected anthropogenic sound. (Row 1) Daily cumulative sound exposure level (cSEL). (Row 2) Cumulative distribution function for each class. The 50% value is representative of typical levels for each class. (Row 3) Probability distribution function for each class. (Row 4) 50% and 5% exceedance spectra for each class.

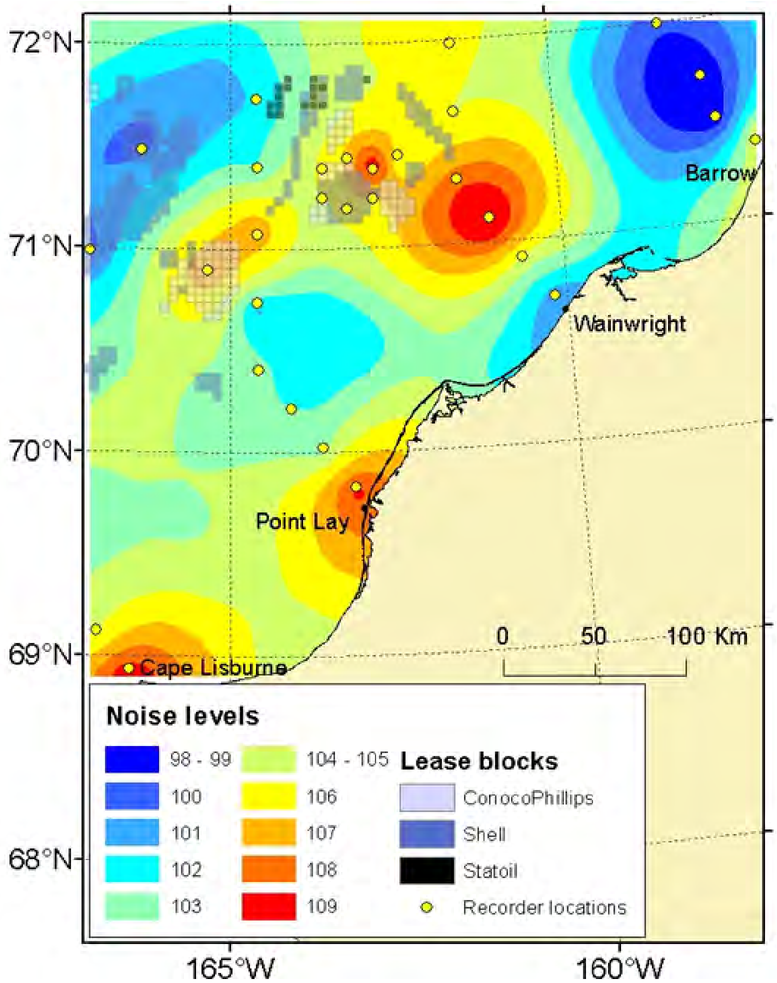


Figure 13. Median of the total sound pressure levels (kriging-interpolated) received during the summer period 2012. The SPLs are between 98 and 109.9 dB re 1 µPa.

3.2. Seismic Survey Event Detections

3.2.1. Winter 2011–2012 Program

No seismic survey events were detected manually or automatically in the winter program data, which spanned early October 2011 through May 2012.

3.2.2. Summer 2012 Program

Seismic survey sources were detected only from United Nations Convention on the Law of the Sea surveys performed by Canada, the US, and Russia in September 2012. Most seismic shots were detected at B50. Stations B30, CL20, and CLN90B detected a few scattered shots. Figure 14 shows the daily cSEL, cumulative distribution function (CDF), and the median of the pressure spectral density of seismic pulse events detected at B50 (Figure 15). The CDF shows that seismic survey events were detected only in very quiet conditions (median rms SPL of 90 dB re 1 µPa, 6 dB lower than the overall median).

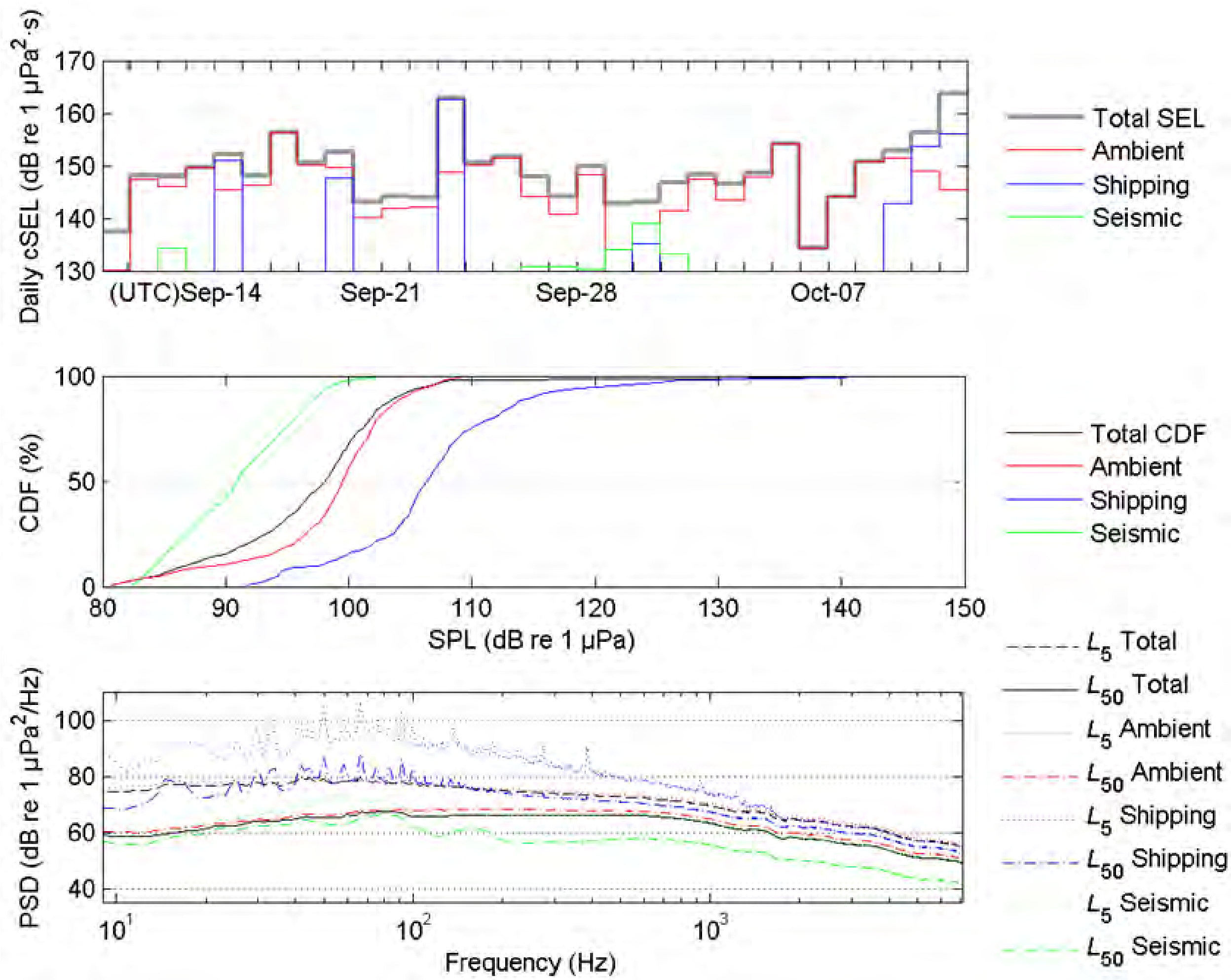


Figure 14. (Top) Daily cumulative sound exposure level (cSEL) with seismic survey event detections in summer 2012 at B50. (Middle) Cumulative density function (CDF). (Bottom) The 5th and 50th (median) percentiles of the pressure spectral density (PSD). Maximum cSELs from seismic activity were below 140 dB re 1 μPa^2·s (30 Sep 2012).

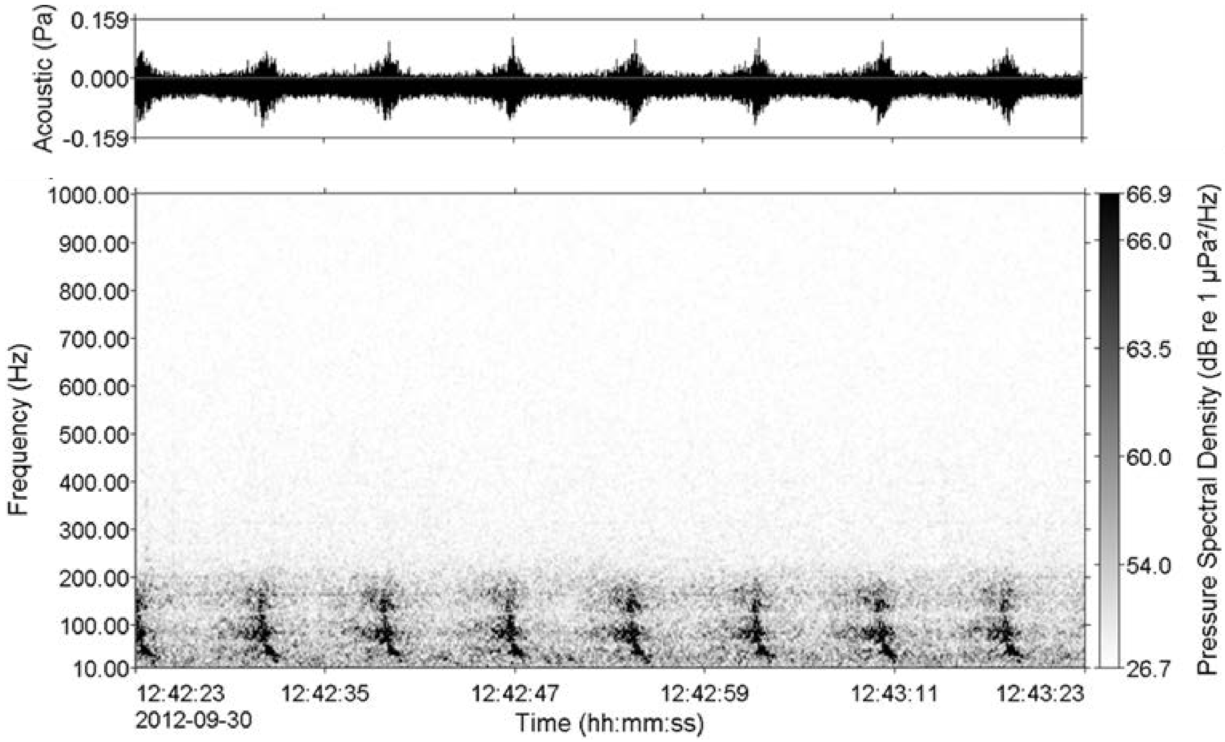


Figure 15. (Top) Pressure signature and (bottom) spectrogram of seismic airgun shots from an unknown airgun array, 30 Sep 2012 at summer Station B50 (16 000 pt FFT, 1800 pts real data).

3.3. Vessel Noise Detections, Summer 2012 Program

The outputs from the vessel noise detector include the percentage of the deployment during which vessels were a significant noise source, and how much the median vessel noise exceeds the median ambient noise (Figure 16). The median percentage of time that vessels were detected throughout the Chukchi array was 5.1%, with a median of 31.2% around the Burger drill site. The median difference between the vessel and ambient rms SPLs was 3.5 dB through the Chukchi array, and 12.1 dB around the Burger drill site. As in other years, B05 had many vessel detections—18.9% of the deployment. Appendix B provides the cSEL/CDF plots (Figure 14) for all stations.

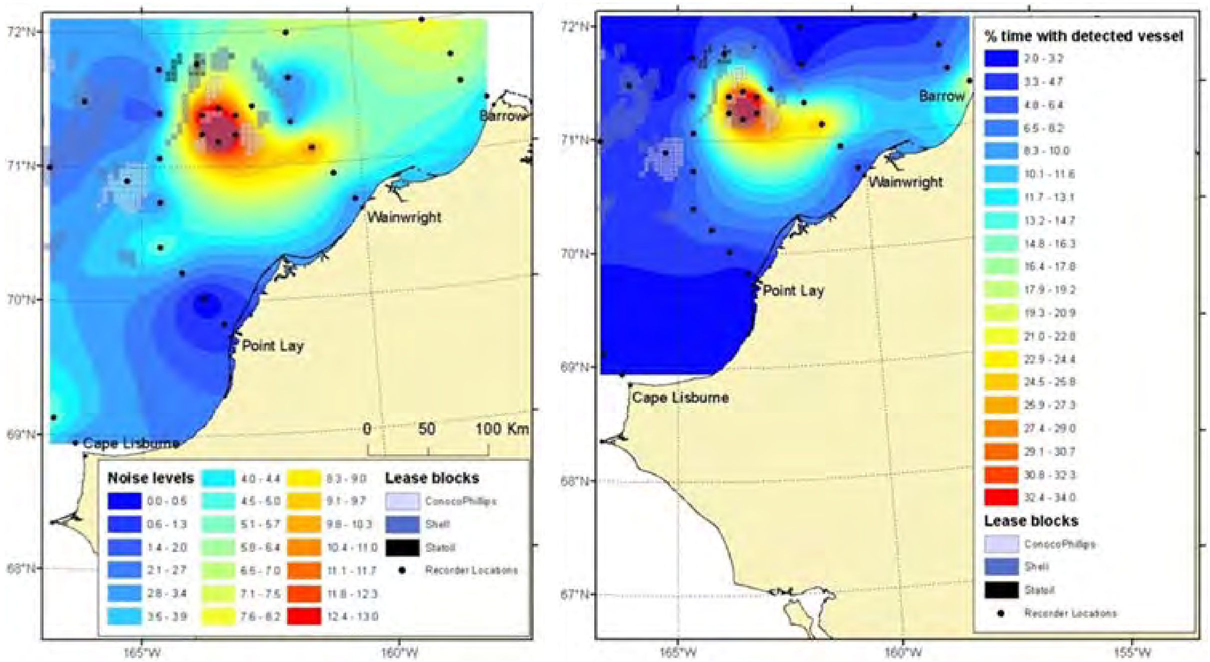


Figure 16. (Left) Difference between the median of vessel and ambient noise levels (kriging-interpolated) throughout the Chukchi Sea, summer 2012. (Right) Fraction of time that vessels were detected (kriging-interpolated) in the Chukchi Sea, summer 2012. The peak value is 33.9% at BG03.

3.4. Marine Mammal Call Detections, Summer 2012 Program

The vocalization[2] detections in the winter and summer datasets are presented by species, led by bowhead whale, walrus, beluga whale, and bearded seal. Calls from these species were detected by both manual analysis and the automated detector/classifiers. Vocalizations by other whale and pinniped species were detected manually, and the detections are presented alphabetically by their common names.

Marine mammal acoustic occurrence at each station is presented as the daily number of 40 min/30 min sound files (winter/Hanna Shoal and summer, respectively) with manual detections for each species. Stations without at least one detection of a given species were omitted from the plots (see Tables 7 and 8).

Species-specific call count estimates are presented as the corrected number of automated detections, as an index of abundance, over various periods. No automated detector was available for gray whales so the proportion of days with detections is shown instead. These are shown as either bubble plots (winter data: beluga, walrus, and bearded seals (January onward); Table 6), interpolated contour plots (summer data: bowheads, gray whales, walrus, and bearded seals) or a combination of both (winter data: bowhead and bearded seals [Fall]); Table 6). The contour plots

[2] 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.

were produced using radial-basis interpolation method (see Section 2.4.9). The automated detections used as input for both plot types were compiled based on manual detection results: automated detections for a given file were counted only if a call was manually detected within that file for the given species. The resulting automated detection numbers were corrected using P and R to account for detector false alarms and missed calls (see Appendix A.6). The corrected numbers of automated detections represent more closely the actual number of vocalizations for a given species and were summed over a given period (Table 6) and mapped to produce call count estimate plots. Given the relatively large distances separating each recorder, the interpolated contour plots should only be read to reflect large-scale patterns. Local occurrence at increasing distance from the recorders may differ from that shown by the plots.

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

Species	Fall 2011	Spring 2012	Summer 2012
Bowhead whale	1 month[b]	–[a]	Every 3 weeks[c]
Walrus	1.5–2.5 month[d]	–[a]	Every 3 weeks[c]
Beluga whale	Every 3 weeks[d]	Monthly[d]	–[a]
Bearded seal	2.5 months[b]	Monthly[d]	Every 3 weeks[c]
Gray whale	–[a]	–[a]	All season[c]

a Not detected/not enough detections.
b Mixed plot.
c Interpolated contour plot.
d Bubble plot.

3.4.1. Summary of Manual Call Detections

In the winter 2011–2012 data, 33,736 sounds were annotated manually, of which 32,163 (Table 7) were classified as marine mammal calls. In the summer 2011 data, 33,234 sounds were annotated manually, of which 28,196 (Table 8) were classified as marine mammal calls. From the winter program, Station B05 had the most marine mammal call detections, largely driven by large combined number of bowhead whale, beluga whale and bearded seal calls as well as Station B05 having the longest deployment duration. Bearded seals were by far the most commonly detected species in the winter dataset, accounting for 61% of annotations, followed by bowhead whales at 17%. The low number of detections at WN40 and PBN20 were caused by the recordings ended early.

In the summer 2012 data, walrus calls accounted for 76.3% of the manual annotations. Bowhead whale and bearded seal calls accounted for 18% and 3.1% of the annotations, respectively. The contributions of other species were negligible. Stations BG08 and PL05 had the most manual annotations due to the high numbers of walrus calls.

Table 7. Winter 2011–2012 call detections: Marine mammal annotations resulting from the manual analysis of 5% of the data from each recording station.

Station	Bowhead whale	Walrus	Beluga whale	Bearded seal	Ringed seal	Gray whale	Minke whale	Unknown	**Total**
B05	1474	127	632	2213	4	3		314	**4767**
PBN40	216	664		1132	23			64	**2099**
PBN20	80	638	1	38	6			45	**808**
WN80	156	411	75	660	24			100	**1426**
WN60	139	1754	2	77	10			33	**2015**
WN40	100	2		52	9			41	**204**
WN20	144	320	2	1332	5			73	**1876**
W50	493	17	6	1236	10			60	**1822**
W35	545	11	30	1445	16			110	**2157**
PLN120	154	578	12	2590	3			46	**3383**
PLN100	104	183	18	2822	18			72	**3217**
PLN80	210	35	78	2912				60	**3295**
PLN40	526	28	220	1877	1			62	**2714**
PL50	801	21	96	1406	21	2		441	**2788**
CL50	558	11	50	490	2		2	52	**1165**
Total	**5700**	**4800**	**1222**	**20282**	**152**	**5**	**2**	**1573**	**33736**

Table 8. Summer 2012 call detections: Marine mammal annotations resulting from the manual analysis of 5% of the data from each recording station. No spotted seal sounds were detected due to a lack of knowledge about their calls (see Section 3.4.13). Because fin and humpback whale calls were only tentatively identified, they are not reported.

Station	Bowhead whale	Walrus	Beluga whale	Bearded seal	Gray whale	Killer whale	Minke whale	Ribbon seal	Ringed seal	**All mammals**	Unknown
B05	130	38	37	24	14	4			2	**249**	140
B15	409			20		3			2	**434**	90
B30	315			12					7	**334**	100
B50	350	2	15	35					5	**407**	59
BG02	311	1025		26	1	2				**1365**	255
BG03	180	645		10		2			2	**839**	260
BG04	127	301		9	9	47			4	**497**	119
BG05	123	89		19	13	10	1	3	5	**263**	184
BG06	280	168		20	2	8		2	4	**484**	185
BG07	302	1407		42	1	5				**1757**	92
BG08	234	5658		8	2					**5902**	126
CL05		1435		11	6	51			2	**1505**	260
CL20		135		26	13	25	7		1	**207**	206
CLN120B	412	1083		83	3			1	15	**1597**	214
CLN90B	103	1137		75	7	20				**1342**	168
KL01	105	225		66	10	7				**413**	120
PL05		3385		5		1				**3391**	126
PL20	4	339		7	35	13	3		1	**402**	601
PL35	2	258		23	61	3	14			**361**	137
PL50		147		48	63	5	15			**278**	85
PLN20	39	349		61	35	3			1	**488**	181
PLN40	268	430		71	10			2		**781**	363
PLN60	186	882		102	1			1	22	**1194**	218
PLN80	479	1717		73	3					**2272**	561
W05	214	23		56	33	8				**334**	189
W20	310	28		57	51	2				**448**	982
W35	264	317		7	20	5				**613**	110
W50	324	1385			10	1			1	**1721**	129
WN20	322	1792		17					2	**2133**	181
WN40	199	974	12	30	7			1		**1223**	269
Total	**5992**	**25374**	**64**	**1043**	**410**	**225**	**40**	**10**	**76**	**33234**	6710

3.4.2. Bowhead Whale Call Detections

3.4.2.1. Winter 2011–2012 Program

The winter 2011–2012 program began in late Aug 2011 with the deployment of six recorders on the western, northern and eastern sides of Hanna Shoal. Only sporadic bowhead whale *(Balaena mysticetus*) detections (Figure C.1) occurred until nine additional recorders were deployed 8–13 October. Bowhead were however detected further south on the summer 2011 recorders from September until mid-October (Delarue et al. 2012). Starting around mid-Oct, detections occurred throughout the area (Figure C.1). The fall migration during the recording period can be split into two main phases. The first ran from 12 Oct to 15 Nov. During this phase, a decrease in call count with increasing distance from shore was observed (Figure 17). Bowhead whales appeared to migrate predominantly from Barrow (Station B05) west toward stations W35 to W50 and PLN40, although some detections occurred further north from that line. Detections at station B05 stopped at the end of this phase; there were few detections at CL50 during this phase. Ice formed in the study area near the end of the first phase. The second phase started on 15 Nov with a strong pulse that was visible at all stations, including those furthest to the north (Figure C.1). This pulse lasted until about 20 Nov at all stations north and east of PLN80, and no bowhead calls were detected later on at these stations, with the exception of one isolated detection on 29 Nov at W50. Detections on the Point Lay line recorders lasted until 1 Dec (except 22 Nov at PLN120). The last detections in the study area occurred on 16 Dec at CL50. An interpolated call count isopleth seems to indicate that the migration heading during the second phase was predominantly southwest, roughly parallel to the advancing ice edge and the coast (Figure 17).

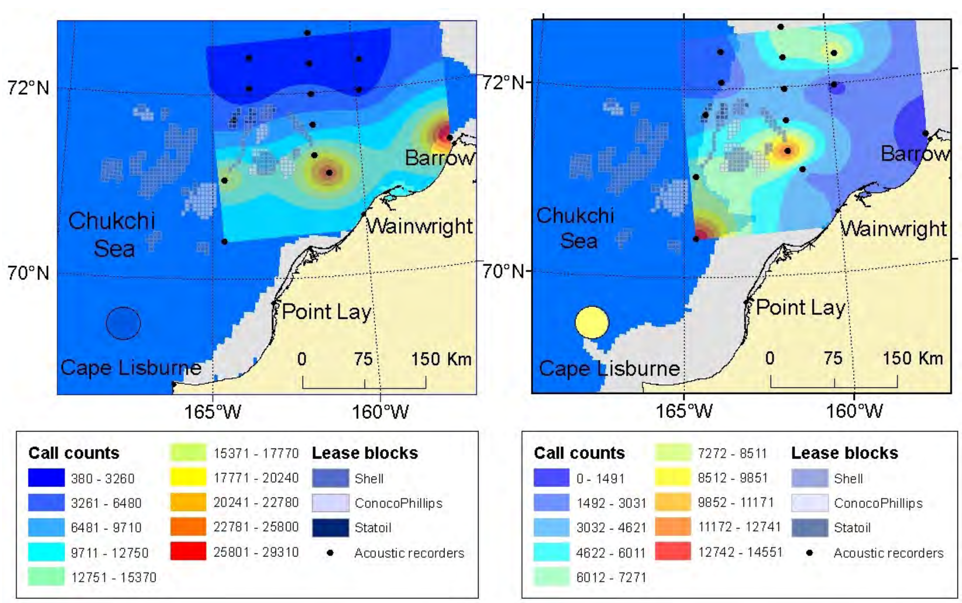


Figure 17. Bowhead whale call count estimates* on winter 2011–2012 stations in the Chukchi Sea (radial basis interpolated). (Left) 12 Oct to 15 Nov 2011; (right) 15 Nov to 16 Dec 2011. Areas of complete ice coverage are shown in gray for the mean detection dates (2 and 18 Nov 2011, NOAA 2012). The color of the circle off Cape Lisburne follows the call count scale. *Corrected sum of automated call detections in all files with manual detections.

Few stations recorded bowhead whale calls during the spring migration (Figure C.2) although this is at least partly explained by a number of recorders being inactive during the migration peak in May (Table C.1). The first bowhead whales were detected on 14 and 15 Apr at B05 and W35, respectively. The core of the migration was over by 15 Jun, but isolated detections occurred until 22 July at Station B05. Of the seven recorders located beyond 50 nmi from shore that were still active at least until 7 May 2012 (Table C.1), only Station PBN40 recorded bowhead whale calls.

Most detected bowhead calls consisted of frequency-modulated narrowband moans (typically without harmonics), moans with harmonic structure, and the complex calls defined as broadband, pulsed, and often strident (Figure 18; Ljungblad et al. 1982, Clark and Johnson 1984). In fall, these calls became increasingly organized into stereotyped sequences, called songs, as the migration progressed (Delarue et al. 2009). From mid-November, detections at all stations consisted almost exclusively of songs. The early spring detections were usually songs. These songs were typically less stereotyped than those in late November and December with an increasingly disorganized structure. By June, most detections consisted of non-stereotyped moans and/or complex call sequences. Calling rates decreased after June (see Appendix A.8).

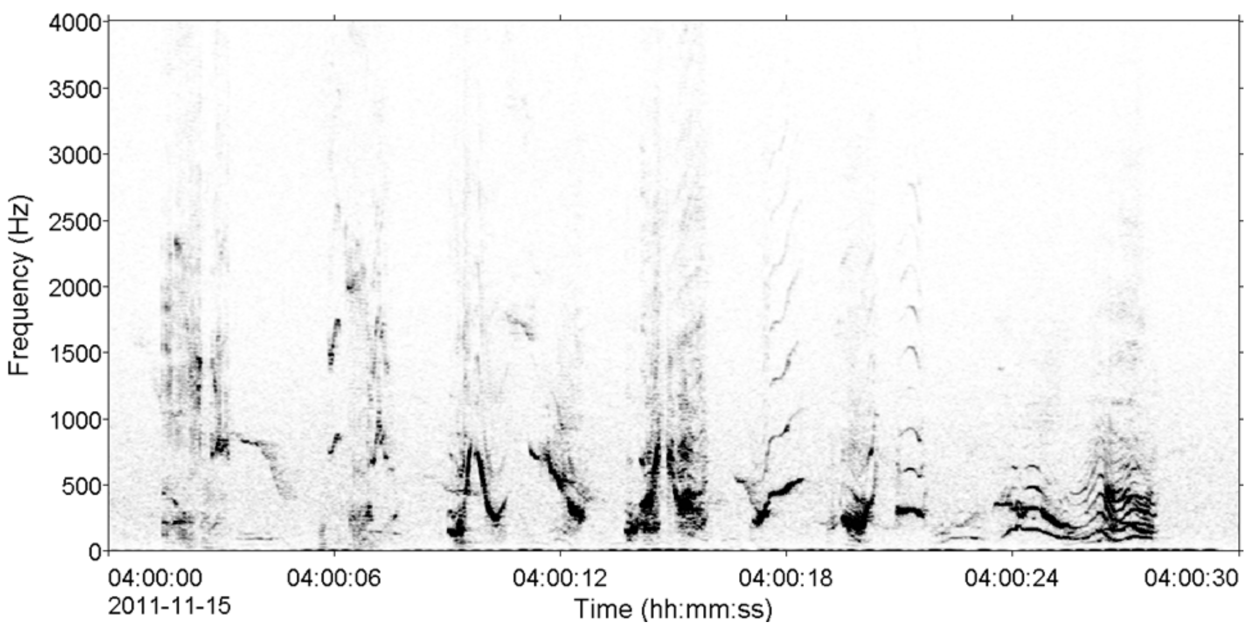


Figure 18. Spectrogram of complex bowhead calls recorded at Station PL50, 15 Nov 2011 (Frequency resolution: 2 Hz; Frame size: 0.128 s; time step: 0.032 s; Reisz window).

3.4.2.2. Summer 2012 Program

Bowhead vocalizations were manually detected in the summer 2012 dataset at all analyzed stations except PL05, PL50, CL05, and CL20 (Appendix C). A first detection period occurred between 11 and 16 Aug. Detections were most abundant at CLN120 and CLN90 but a few bowhead calls were also detected in the Burger and Klondike study areas, along the Point Lay line south of PLN40 and at W20 and W35 (Appendix C). Detections resumed around 3 Sep, primarily at station B05. As this short 5-day peak subsided, another started on 9 Sep at the inshore Wainwright stations.

Detections were strong for six days before declining. During that time, detections started at all Barrow stations (12 Sep) and gradually spread throughout the study area. This first area-wide detection period lasted between 16 and 24 Sep. Call count isopleths (Appendix C) indicate that bowhead acoustic occurrence was highest between Barrow and Wainwright. Although bowhead whale calls were recorded at most stations, call counts were lower in the Burger study area. With the exception of two isolated detections at PL20 and PL35, there were no detections south of a line running along 70.71° N between Stations W05 and PLN20.

A gap in the migration was noticeable on 25 Sep, with only 16% of active stations reporting detections, down from 46% the day before and increasing to 60% four days later (Appendix C). Detections resumed on 26 Sep off Barrow and three days later throughout the study area. Detections declined at the inshore Barrow stations (B05 and B15) from early October, but remained strong at B30 and more particularly B50 as well as in the rest of the study area. The highest area-wide call counts were recorded on 6 and 7 Oct (Appendix C). The locations of highest call counts shifted from Peard Bay to stations north and west of the Burger study area. The Burger study area itself appeared split in half with call counts close to three times higher in its northwest section compared to the southeast (Appendix C). Figure 19 summarizes the acoustic detection over the entire study area during the period when all recorders were deployed.

The detected calls consisted mostly of simple moans (Figure 20) although an increasing proportion of complex calls were detected near the end of the recording period.

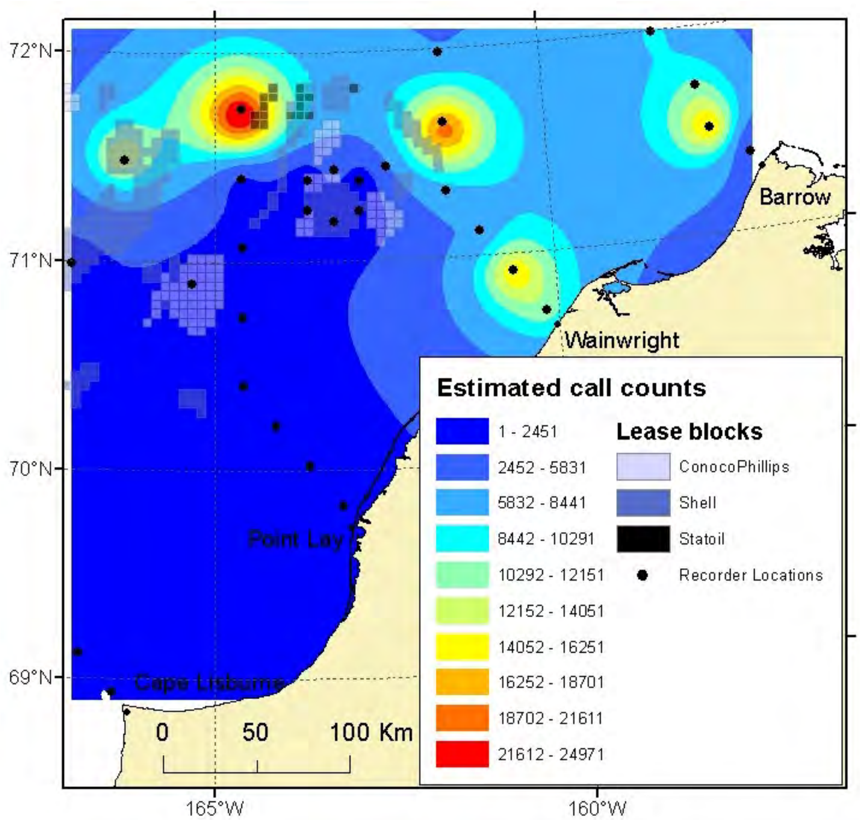


Figure 19. Interpolated bowhead whale call counts based on the sum of automated call detections in all files with manual detections for 11 Sep to 5 Oct (only period when all 30 recorders were deployed) at all summer 2012 stations in the northeastern Chukchi Sea.

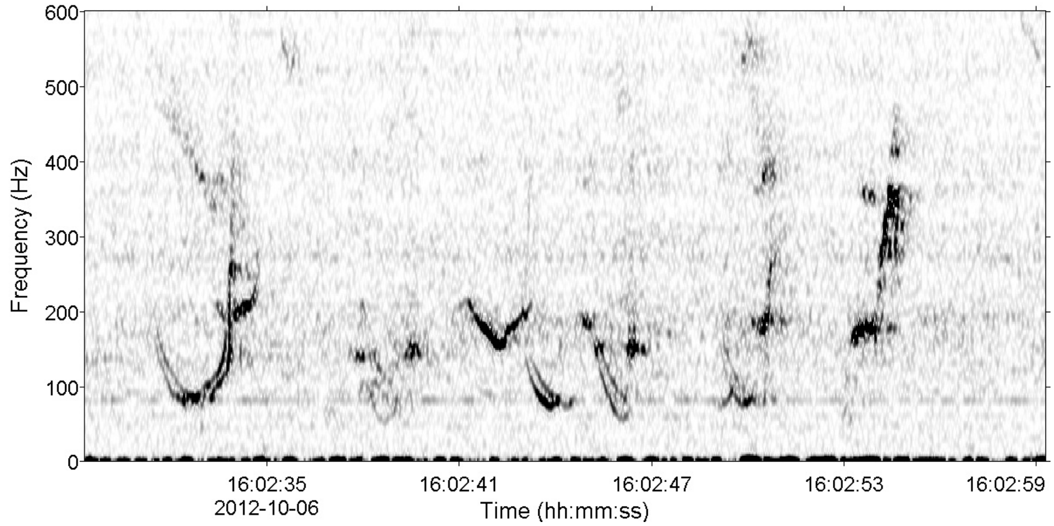


Figure 20. Spectrogram of bowhead moans at Station BG06, 6 Oct 2012 (Frequency resolution: 2 Hz; Frame size: 0.128 s; time step: 0.032 s; Reisz window).

3.4.3. Walrus Call Detections

3.4.3.1. Winter 2011–2012 Program

The bulk of fall 2011 walrus detections occurred on the six Hanna Shoal recorders between late August and 10 October (Figure 21). Of the nine winter recorders deployed around 10 Oct, only WN20 had a significant number of detections, which lasted until the end of October. Calls were almost completely absent in October at WN40, 20 nmi further north. Call counts were also lower further south, at W50 and W35. A short wave of detections on 17–19 Oct occurred at W35, W50, PLN40, PL50, and CL50. The last detection of 2011 occurred on 20 Dec at PLN120 (Appendix C). During the first detection phase (Hanna Shoal only), call counts were highest at WN60 and decreased on the northern, eastern, and western flanks of the Shoal (Figure 21). After the deployment of the winter recorders, the southwesterly shift in the distribution of call detections suggests walrus moving out of the area (Figure 21).

Because most recorders stopped working before walrus typically return to the study area (~15 Jun), walrus were only detected six days in July (at B05) and three days in late June/early July (at PLN100). Most detected walrus calls consisted of a variety of grunt-like sounds; knocks and bell sounds were detected intermittently (Figure 22; Stirling et al. 1983, 1987, Schusterman and Reichmuth 2008).

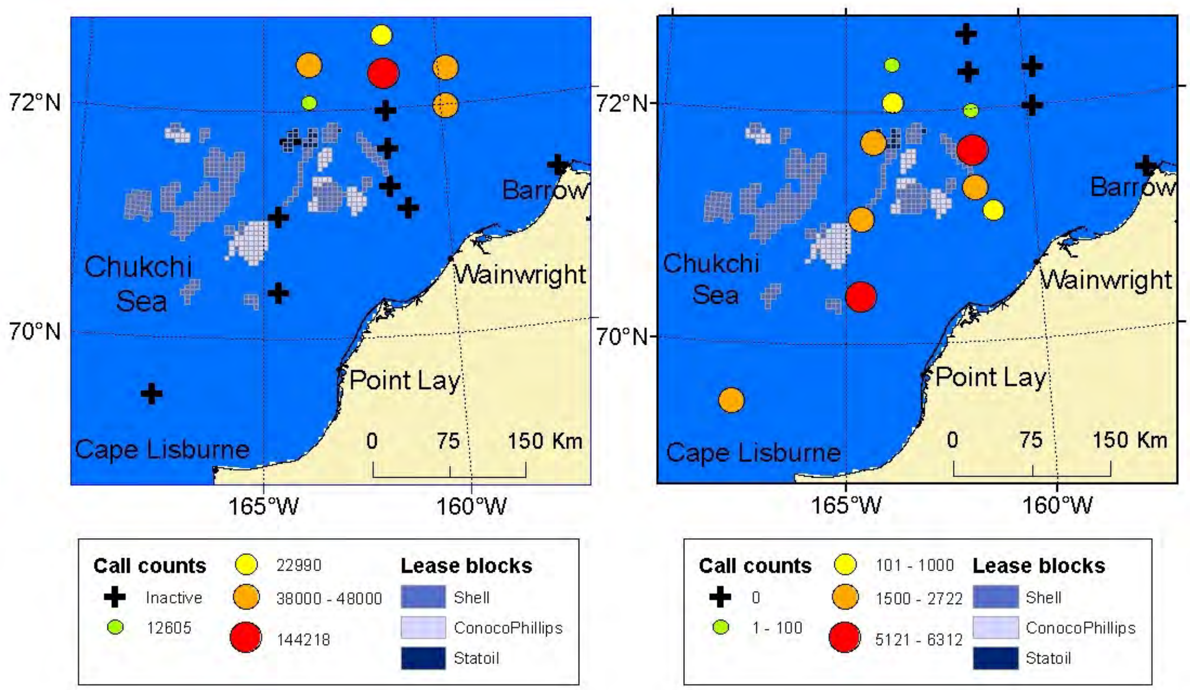


Figure 21. Walrus call count estimates* in the Chukchi Sea at all winter 2011–2012 recording stations. (Left) from 29 Aug to 10 Oct 2011; (right) from 12 Oct to 31 Dec 2011. The winter recorders were not deployed until 10 Oct. The blue background indicates ice-free areas. No ice was present on 10 Sep or 22 Oct (mean detection date, left and right, respectively; NOAA 2012). *Corrected sum of automated call detections in all files with manual detections.

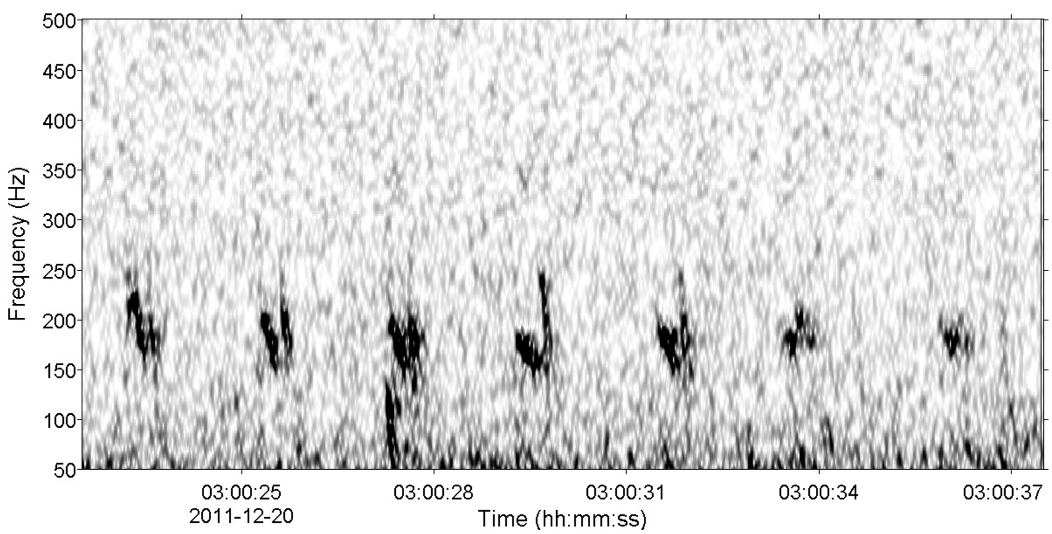


Figure 22. Spectrogram of walrus grunts recorded at Station PLN120, 20 Dec 2011 (Frequency resolution: 1 Hz; Frame size: 0.1 s; time step: 0.01 s; Reisz window).

3.4.3.3. Summer 2012 Program

Walrus detections in the summer 2012 data were initially largely restricted to the northern part of the study area (Appendix C). Walrus detections following the deployment cruise peaked at W50, BG08, PLN80, CLN90, and CLN120. These detections lasted from deployment until 15 Aug, but continued to some degree at BG08 and PLN80. Between 26 Aug and 9 Sep, detections were restricted to a small number of stations (Appendix C) with only 17% of active stations detecting walrus, compared to 44% before and 51% after that period. Detections at BG08 abruptly increased on 8 Sep, remained high until the end of September, and decreased thereafter. Walrus detections at PL05 became numerous and sustained from early September. BG08 and PL05 had the highest call counts except in August, when walrus call counts were highest at W50. WN40 and WN20 were not deployed until 10 Sep, but had among the highest number of detections until the end of the study. A negative gradient in the number of detection days as a function of distance to Hanna Shoal was observed among the Burger stations. Stations BG02, BG03, and BG08 had walrus detections on 65–91% of days, while the other four Burger stations detected walrus on 27–43% of days. For all stations southeast of the Wainwright line, detections peaked in the last week of September. Detections started on 15 Sep at CL05— the only inshore station besides PL05 to show any significant walrus acoustic activity—and lasted until recorder retrieval. Call count isopleths revealed a predominant presence of walrus on the southwest side of Hanna Shoal (W50–BG08) and near Point Lay. Walrus calls were rare at the Barrow stations (Figure 23).

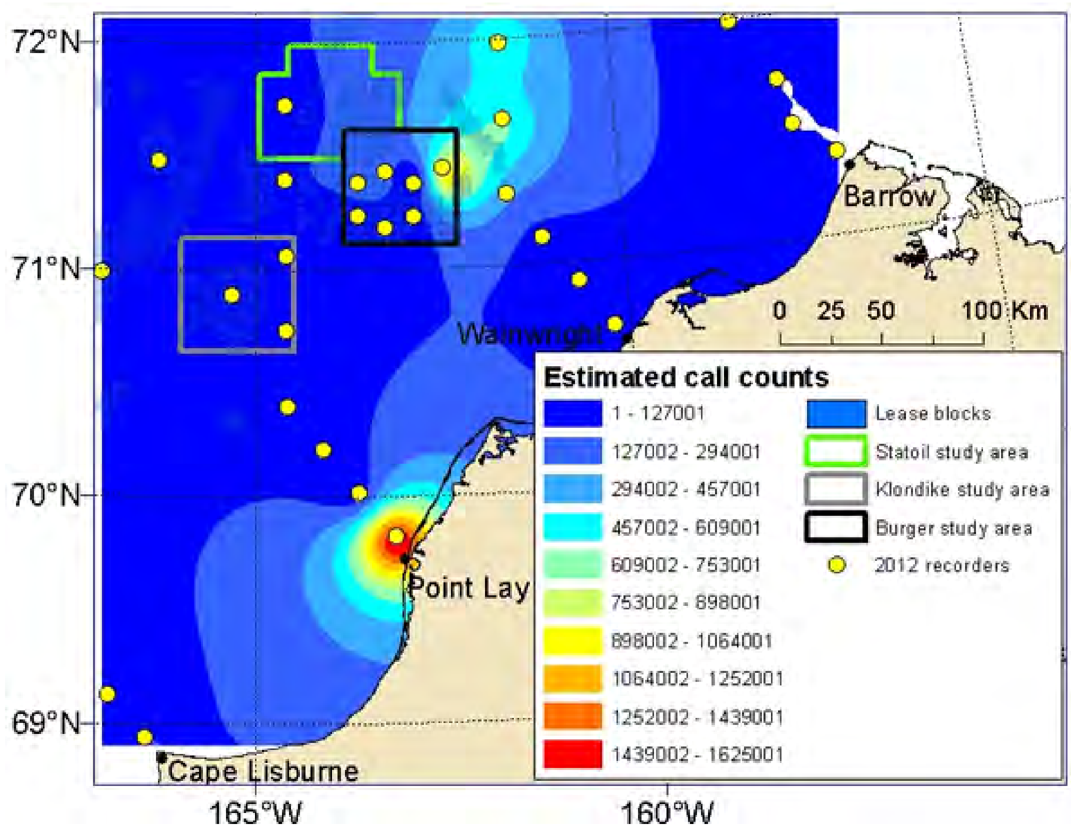


Figure 23. Interpolated walrus call counts based on the sum of automated call detections in all files with manual detections for 11 Sep to 5 Oct (period when all 30 recorders were deployed) at all summer 2012 stations in the northeastern Chukchi Sea.

Manually detected walrus calls included various grunts as well as knocks and bell calls (as described by Stirling et al. 1983, 1987, and Schusterman and Reichmuth 2008). The automated call detector targeted grunts because they are prevalent and have a longer detection range (JASCO, unpublished data; Figure 24).

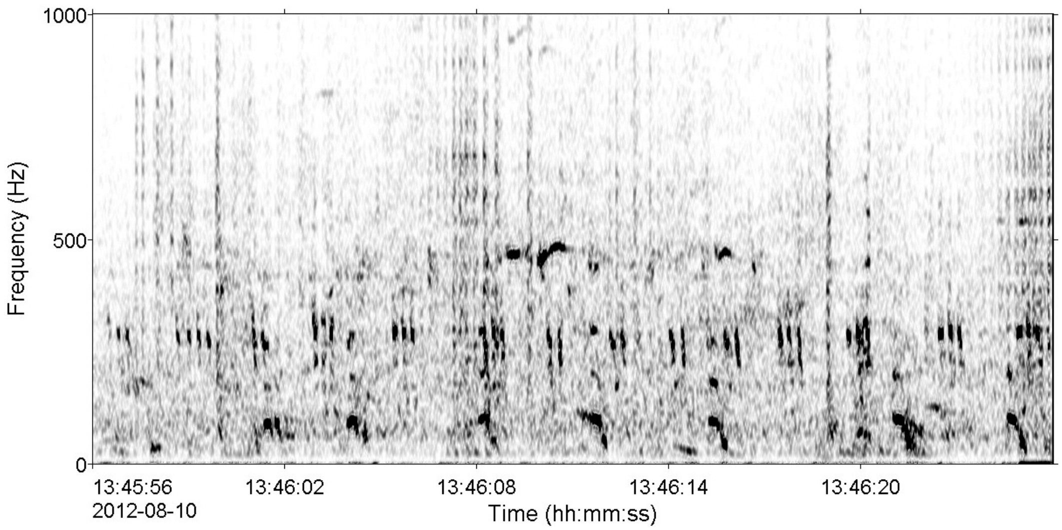


Figure 24. Spectrogram of walrus grunts, knocks, and bell sounds recorded at Station CLN120, 10 Aug 2012 (Frequency resolution: 2 Hz; Frame size: 0.1 s; time step: 0.01 s; Reisz window).

3.4.4. Beluga Whale Call Detections

3.4.4.1. Winter 2011–2012 Program

The first beluga detections occurred on 7 Oct at PLN100, PLN120, and WN60. B05 had the largest number of detection days (*n*=12). Most detections occurred between mid-October and the first week of November; three more detections occurred, with 8 Dec the last detection of the program. At the other stations, the detections were few and sporadic although a more concentrated area-wide wave of detections occurred in the second half of November. These detections were concentrated around 16–17 Nov in the northern half of the study area (e.g., WN60, W50). In the southern half of the study area (PLN40, PL50, and CL50), detections began at the same time as in the north, but were spread over a longer period. The highest call counts shifted from B05 (between 15 Oct and 7 Nov) to PL50 and CL50 (between 8 Nov and 1 Dec) (Figure 26; Appendix C).

In spring, detections started on 13 Apr at PL50 and on 15 Apr at Barrow. The Barrow detections proceeded in three distinct pulses from mid-Apr to early May, followed by a three-week gap with few to no detections. Detections resumed strongly on 20 May and continued regularly until the beginning of June when they ceased abruptly. A few sporadic detections occurred between late June and late July (Appendix C). Station B05 consistently had the highest call counts in the spring 2012 (Figure 26). Figure C.16 shows the chronological appearance of beluga calls along the Point Lay line from south to north. Detections at PLN100 started five days after PL50. Detections at WN80 occurred before those at W35 and 10 days after those at PL50. Beluga calls were detected at the three northernmost stations PLN120, WN80, and PBN40 (Figure 26).

Excluding B05 and an isolated detection at PLN100 on 12 Jun, most detections stopped by mid-May; however, in some cases, a loss of power to recorders was to blame (Table C.5).

The detected beluga calls include a variety of whistles, buzzes, chirps, and other high-frequency calls previously described for that species (Figure 27; Sjare and Smith 1986, Karlsen et al. 2002, Belikov and Bel'kovich 2006, 2008).

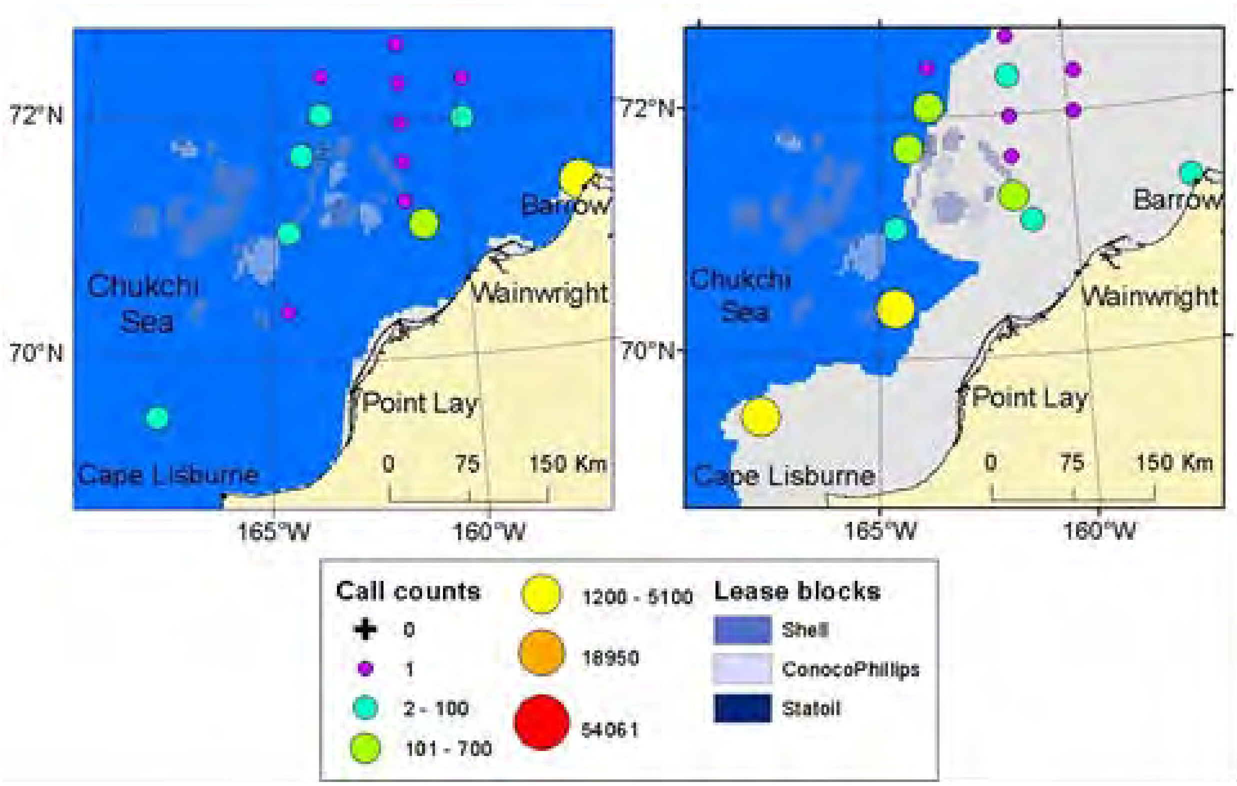


Figure 25. Beluga whale call count estimates* in the Chukchi Sea at all winter 2011–2012 recording stations. (Left) from 15 Oct to 7 Nov 2011; (right) 8 Nov–1 Dec 2011. Areas of complete ice coverage on the mean detection date are shown in gray for (left) 27 Oct 2011 and (right) 20 Nov 2011 (NOAA 2012). The blue background indicates open water. *Corrected sum of automated call detections in all files with manual detections.

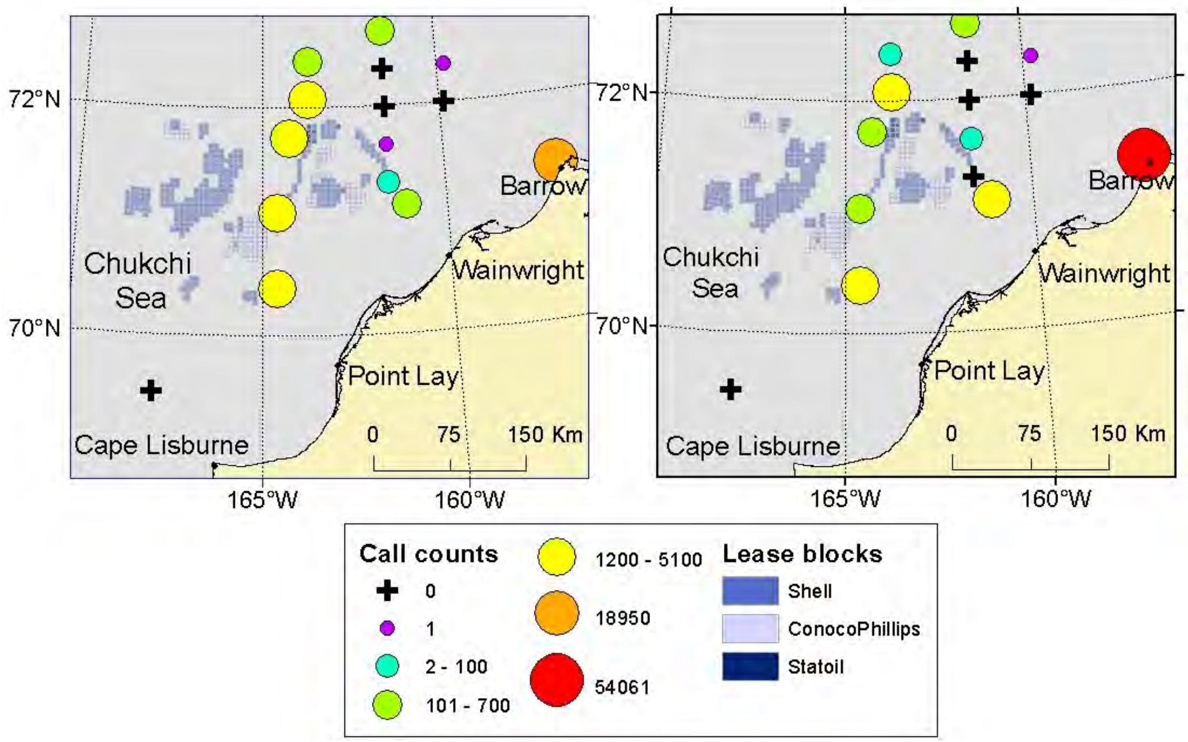


Figure 26. Beluga whale call count estimates* in the Chukchi Sea at all operational winter 2011–2012 recording stations. (Left) 13–30 Apr 2012; (right) May 2012. Areas of complete ice coverage on the mean detection date are shown in gray for (left) 22 Apr 2012 and (right) 15 May 2012 (NOAA 2012). *Corrected sum of automated call detections in all files with manual detections.

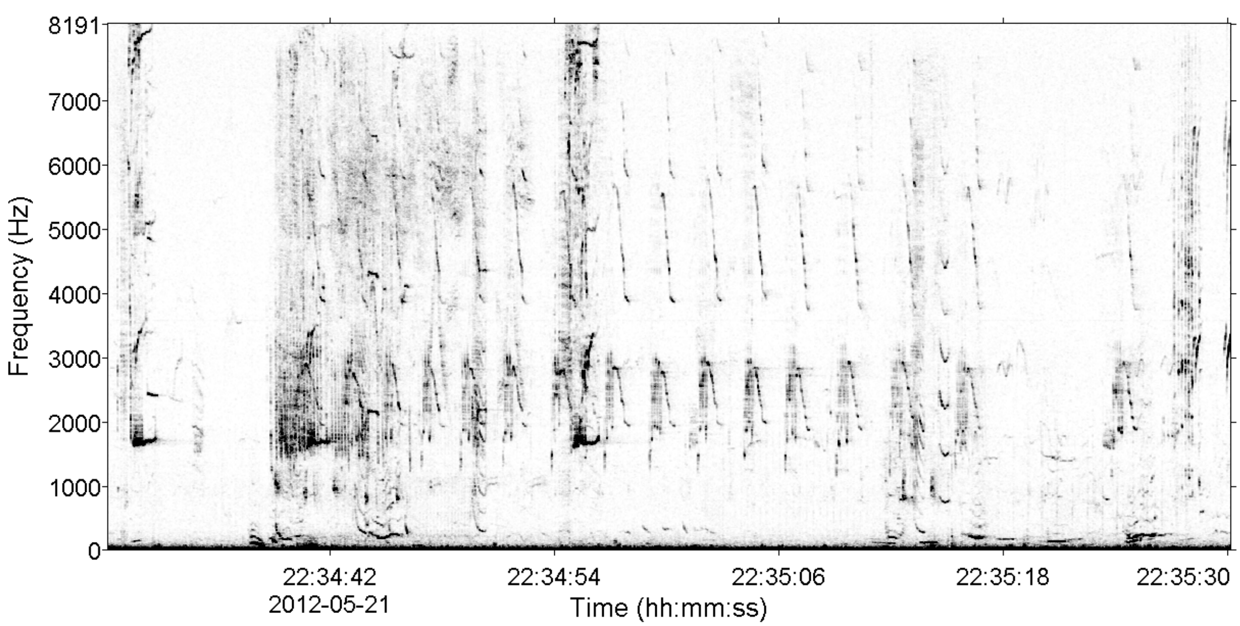


Figure 27. Spectrogram of beluga calls recorded 21 May 2012 at Station B05 (Frequency resolution: 2 Hz; Frame size: 0.128 s; time step: 0.032 s; Reisz window).

3.4.4.2. Summer 2012 Program

Few beluga calls were detected during the summer 2012. Beluga calls (Figure 29) were detected multiple times over three days between 15–20 Aug at B05. Besides these detections, all others occurred at B05, B50, and WN40 between 30 Sep and 10 Oct (Figure 28; Table 9). Belugas were detected on two different days at these three stations.

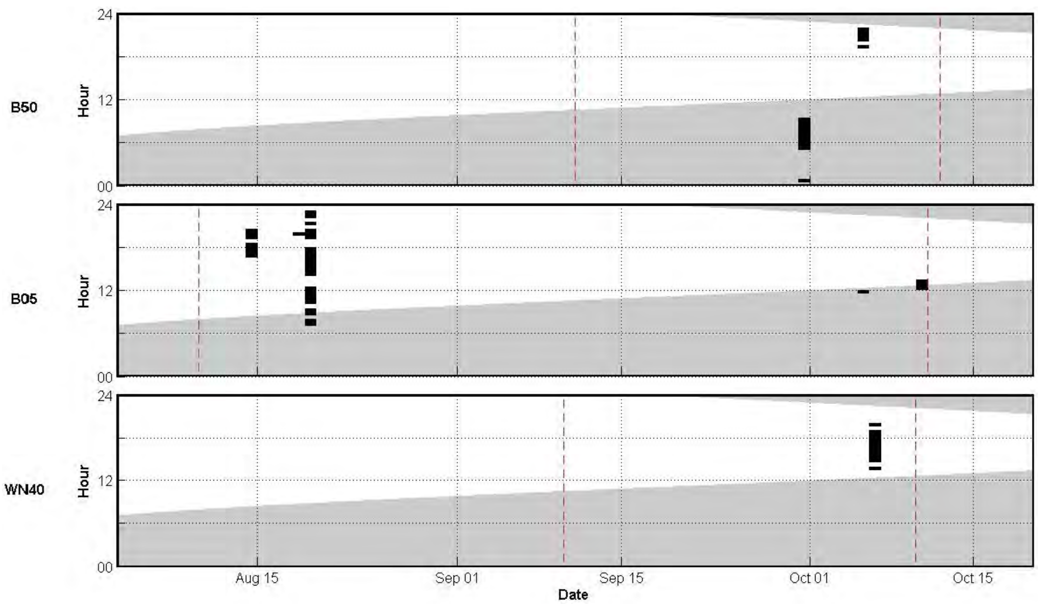


Figure 28. Summer 2012 daily beluga call detections: half-hourly occurrence of call detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2012. Each black box represent a 30-min sound file. Red dashed lines indicate recording start and end. Stations are ordered northeast (top) to southwest (bottom). Stations without call detections were omitted. Shaded areas represent hours of darkness.

Table 9. Summer 2012 beluga call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the percentage of days on which a call was detected for each recording station in the northeastern Chukchi Sea. Stations without call detections were omitted.

Station	Record Start	First Detection	Last Detection	Record End	Detection Days	% Days with Detection
B05	11-Aug	15-Aug	10-Oct	11-Oct	5	8.2
B50	11-Sep	30-Sep	06-Oct	11-Oct	2	6.7
WN40	10-Sep	06-Oct	07-Oct	10-Oct	2	6.7

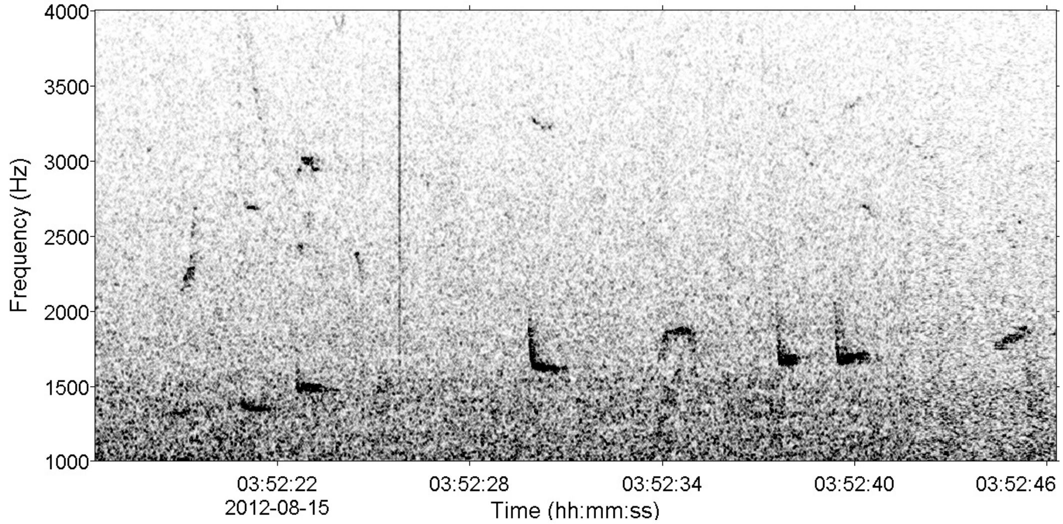


Figure 29. Beluga calls detected at Station B05 on 15 Aug 2012 (Frequency resolution: 2 Hz; Frame size: 0.1 s; time step: 0.01 s; Reisz window).

3.4.5. Bearded Seal Call Detections

3.4.5.1. Winter 2011–2012 Program

Bearded seal detections started upon deployment of the six Hanna Shoal recorders. Limited (once or twice daily) but steady detections occurred at most stations until 10 Oct. This was followed by a period of low to no detections at all stations until the last week of November, which marked the beginning of steady detections at all stations, although the amount of acoustic activity varied greatly between stations. Stations CL50, PL50 and to a lesser extent PLN40 did not have any significant increase in detections until the beginning of Jan. Detections at WN80 and PBN40 never really increased until May and April, respectively; stations WN60 and WN40 exhibited a similar pattern until their early recording end. Conversely, the northern Point Lay stations (PLN80, PLN100, and PLN120) and the Wainwright stations closest to shore (W35, W50, and WN20) showed a steady increase in bearded seal detections from late November with calls detected daily in most sound files from April until their retrieval. Except B05, no recorders lasted long enough to capture the end of the calling period. At B05 calls were not detected after 2 Jul (Figure 30; Appendix C).

Throughout the winter, the northern PLN stations repeatedly yielded the highest call counts, surpassed only by B05 in April and May (Figure 31; Appendix C), even though the high call counts at B05 may be partly due to misclassified bowhead and beluga calls in the spring. Use caution when interpreting call counts for May and June because the stop dates of several recorders varied, which led to different call count summation periods. The progressive increase in call counts from January to April is evident (Appendix C). The northern Wainwright and Peard Bay (PBN) stations consistently had the lowest call counts.

The detected calls consist primarily of upsweeping and downsweeping trills (Figure 32, Van Parijs et al. 2001).

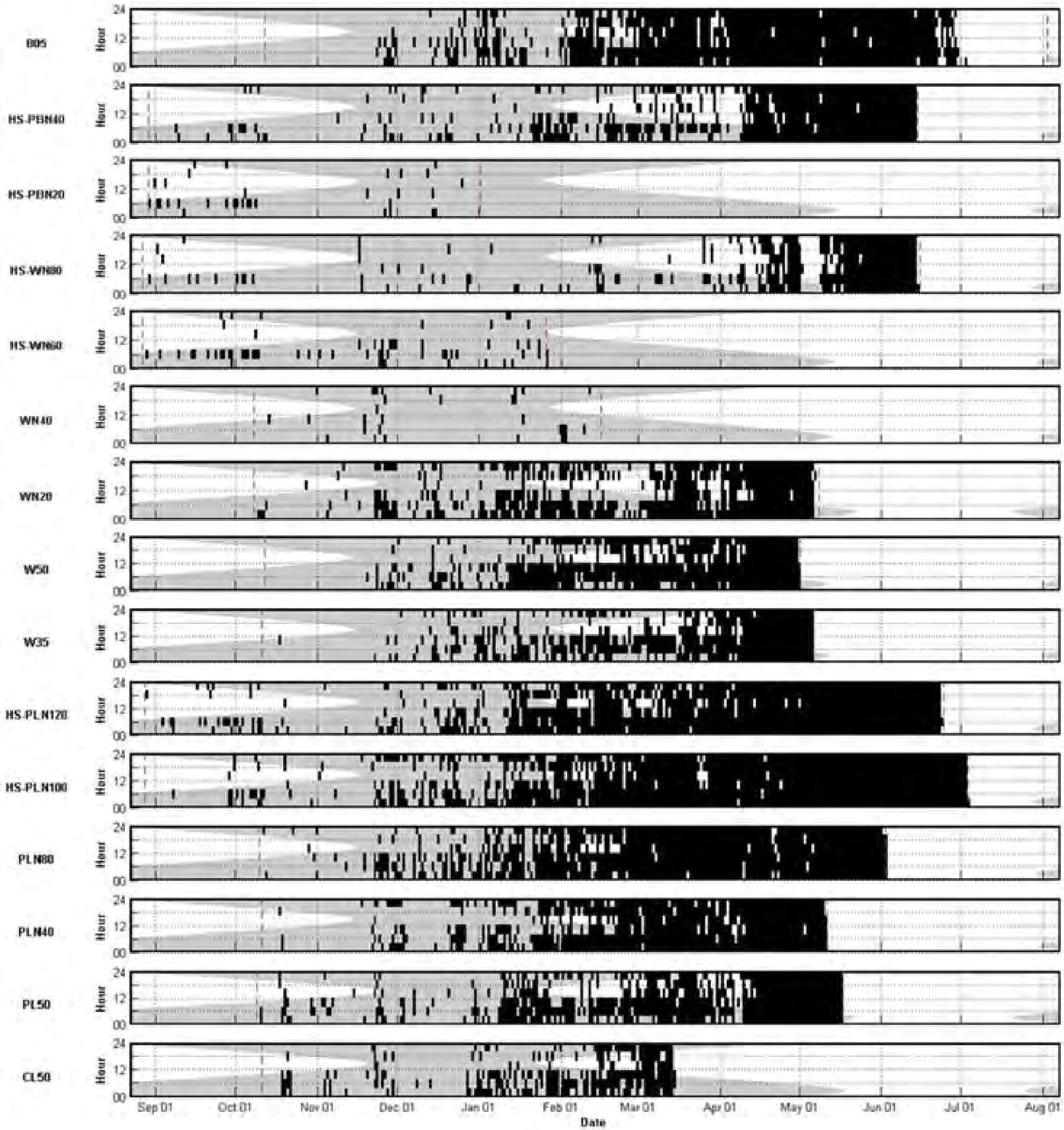


Figure 30. Winter 2011–2012 daily bearded seal call detections: Daily occurrence of call detections based on the manual analysis of 5% of the acoustic data recorded late Aug 2011 through early Aug 2012 in the northeastern Chukchi Sea for each station. Each black square represents a 4-hr period (one 30/40-minute file was recorded every four hours). Stations are ordered from (top) northeast to (bottom) southwest. The red dashed lines indicate the recording start and end dates. The shaded area shows the hours or darkness.

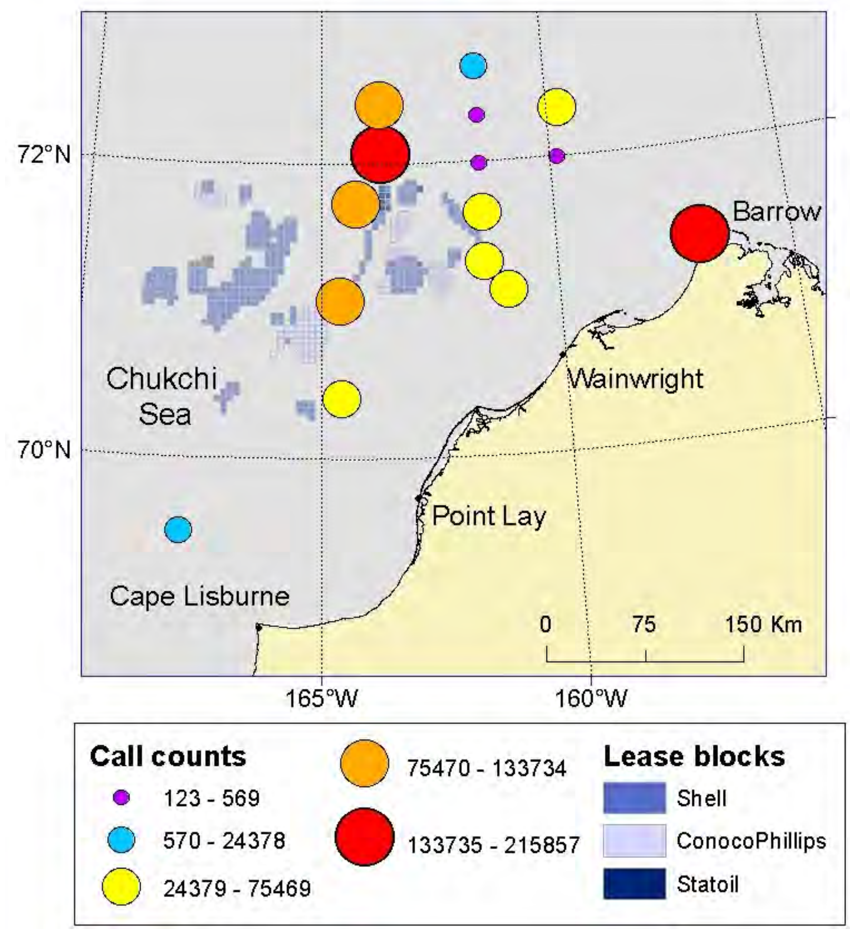


Figure 31. Bearded seal call count estimates* in the Chukchi Sea for 28 Aug 2011 through 1 Aug 2012 at all winter 2011–2012 recording stations. The gray background represents the 100% sea ice concentration that prevailed during the recording period. *Corrected sum of automated call detections in all files with manual detections.

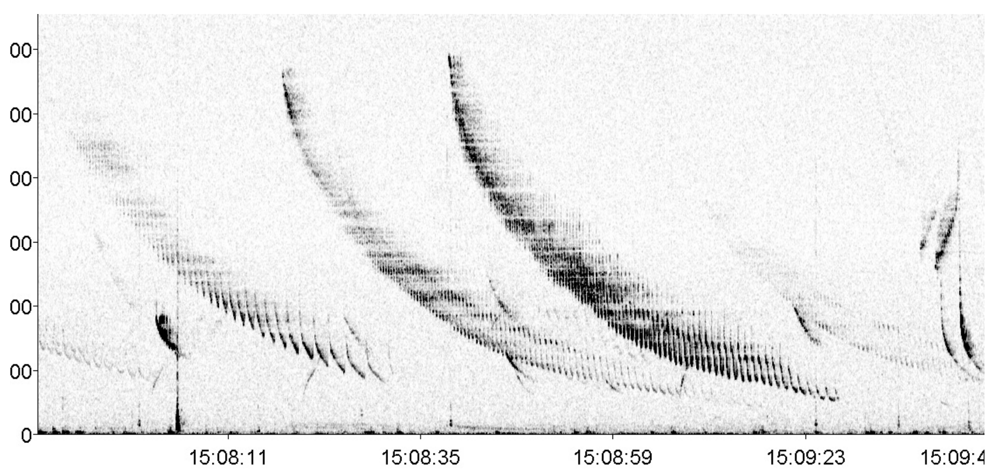


Figure 32. Spectrogram of bearded seal calls recorded 8 May 2012 at Station PLN100 (Frequency resolution: 2 Hz; Frame size: 0.128 s; time step: 0.032 s; Reisz window).

3.4.5.2. Summer 2012 Program

Bearded seals were detected at all stations except PL50 (Appendix C). Acoustic detections were fairly evenly distributed during the recording period with the exception of a few noticeable peaks at several stations. Specifically, small peaks occurred around mid-August at each of the following stations: PLN20, PLN40, KL01, and PLN60. Bearded seals were repeatedly detected between 13–23 Sep along the PL line, north of PL35. There were also periods of higher acoustic occurrence at W05–W20 and CLN90–CLN120 in September (Appendix C). These peaks, seen in the contour plots, drove the call counts up. The areas of higher acoustic activity included the coastal waters off Wainwright during the first three weeks of September (Appendix C), but were otherwise mainly located offshore and centered around the northern Cape Lisburne and Point Lay lines (Figure 33; Appendix C). The Burger study area was part of an area of low call counts located north of Icy Cape (Figure 33).

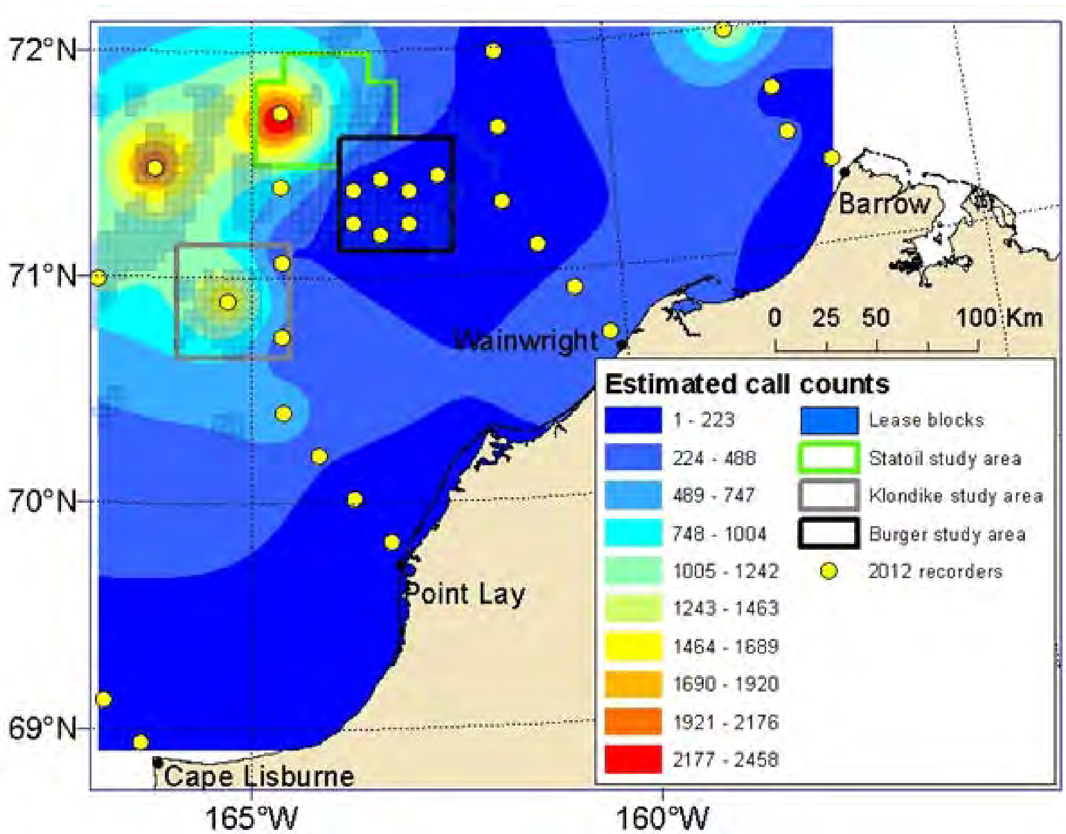


Figure 33. Interpolated bearded seal call counts based on the sum of automated call detections in all files with manual detections for 11 Sep–5 Oct (period when all 30 recorders were deployed) at all summer 2012 stations in the northeastern Chukchi Sea.

Typically, the detected bearded seal calls were produced irregularly and in small numbers. These calls were more variable (Figure 34) and different from the long, complex spiraling songs common during the spring breeding period (Ray et al. 1969, Van Parijs et al. 2001).

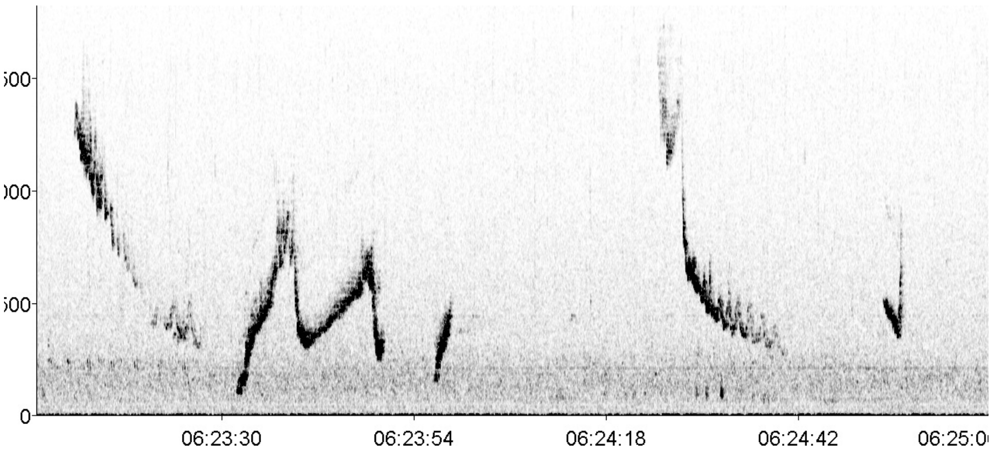


Figure 34. Spectrogram of bearded seal calls detected 19 Aug 2012 at Station PLN60 (Frequency resolution: 2 Hz; Frame size: 0.128 s; time step: 0.032 s; Reisz window).

3.4.6. Fin Whale Call Detections

3.4.6.1. Winter 2011–2012 Program

No fin whale calls were detected in the winter 2011–2012 dataset.

3.4.6.2. Summer 2012 Program

Although several low-frequency sounds are believed to be from fin whales (*Balaenoptera physalus*), there were no confirmed fin whale calls during the summer 2012 program.

3.4.7. Gray Whale Call Detections

3.4.7.1. Winter 2011–2012 Program

Gray whale calls were detected on 10 and 21 Oct 2011 at PL50 and on 6 Jun 2012 at B05.

3.4.7.2. Summer 2012 Program

Gray whale (*Eschrichtius robustus*) detections occurred between 12 Aug and 11 Oct 2012. Gray whale calls were detected at 24 stations during 1 to 33 days. The proportion of days during which gray whale calls were recorded varied greatly between stations. Station W20 recorded calls on 63.5% of days (n=33). Stations PL35, PLN20, and W05 recorded calls on 25–31% of days (n=15-16) (Appendix C). All other stations detected calls on less than 15% of days. A visual representation of the spatial trend of these detections suggest that gray whale calls were recorded most often within 20 nmi off Wainwright and to a lesser extent 35–70 nmi off Point Lay (Figure 35). Most of the detections were low-frequency moans (Figure 36), with additional contributions from pulses and bonging signals (Crane and Lashkari 1996).

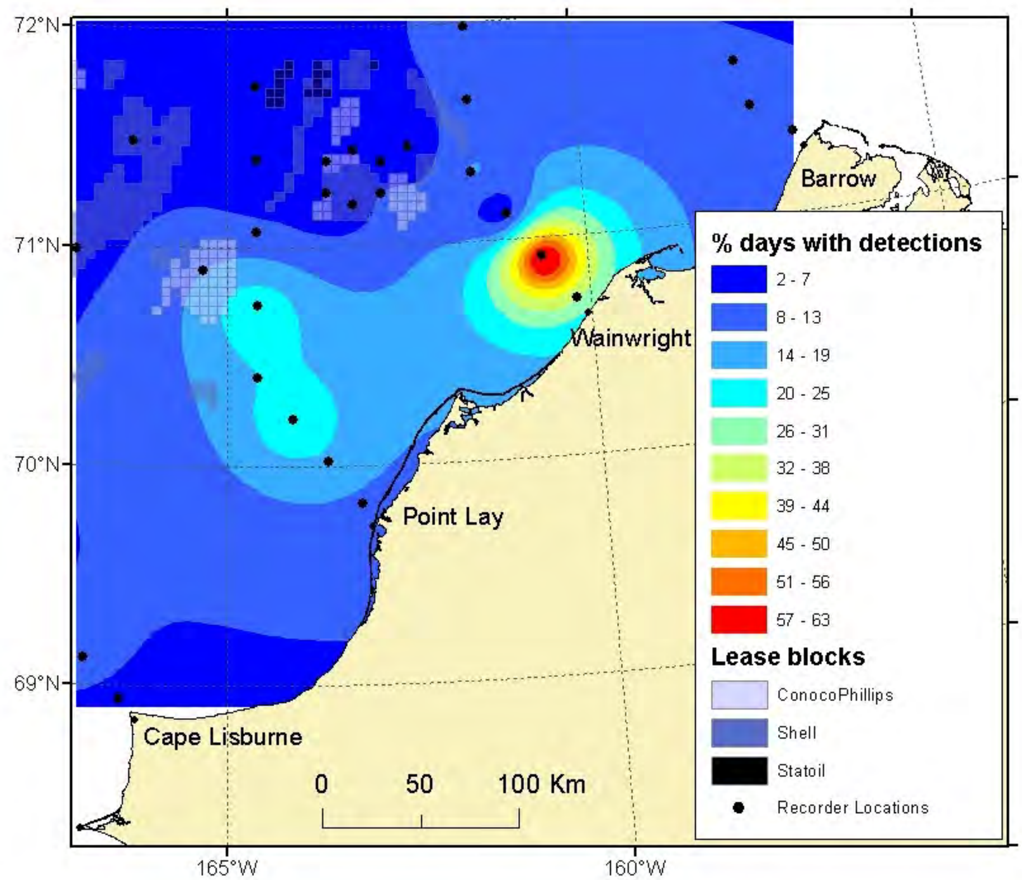


Figure 35. Interpolated contour plot of the proportion of days with gray whale detection at each station for 7 Aug to 13 Oct at all summer 2012 stations in the northeastern Chukchi Sea.

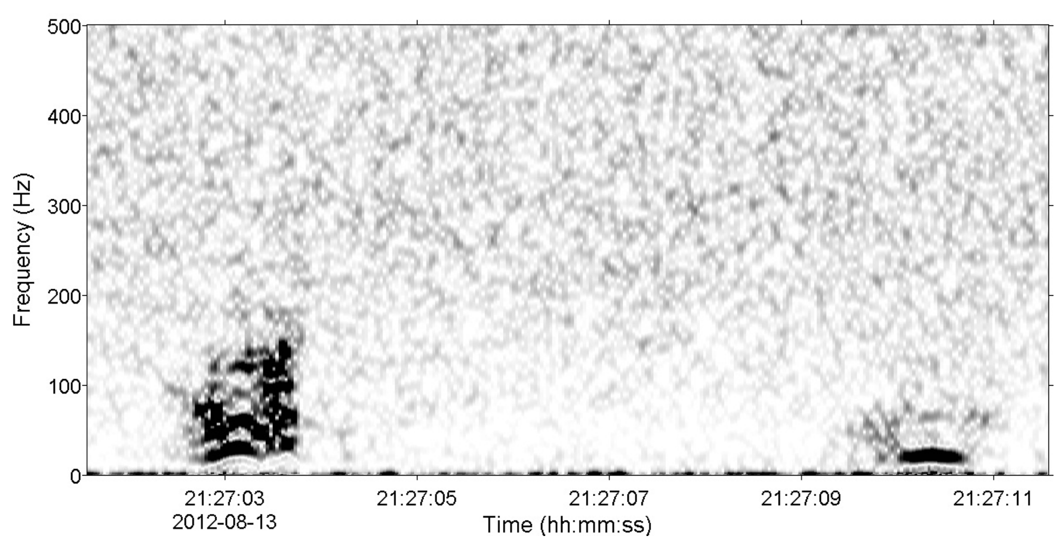


Figure 36. Gray whale moans recorded on 13 Aug 2012 at Station CLN90 (Frequency resolution: 1 Hz; Frame size: 0.128 s; time step: 0.032 s; Reisz window).

3.4.8. Humpback Whale Call Detections

3.4.8.1. Winter 2011–2012 Program

No humpback whale calls were detected in the winter 2011–2012 data.

3.4.8.2. Summer 2012 Program

Although several detected moans and scream-like sounds may have been produced by humpback whales (*Megaptera novaeangliae*), there were no confirmed detections during the summer 2012 program.

3.4.9. Killer Whale Call Detections

3.4.9.1. Winter 2011–2012 Program

No killer whale calls were detected in the winter 2011–2012 data.

3.4.9.2. Summer 2012 Program

Killer whale call detections during summer 2012 were widespread in time and space (Figure 37; Appendix C). Killer whale calls were typically recorded south of 71°N with the exception of detections in the Burger study area and off Barrow. Killer whale calls were detected at 21 stations between 18 Aug (PL35) and 10 Oct (B05). There were between one and four (KL01) detections days with a mean of two. The detected calls were mostly pulsed calls (Figure 38, Ford 1989).

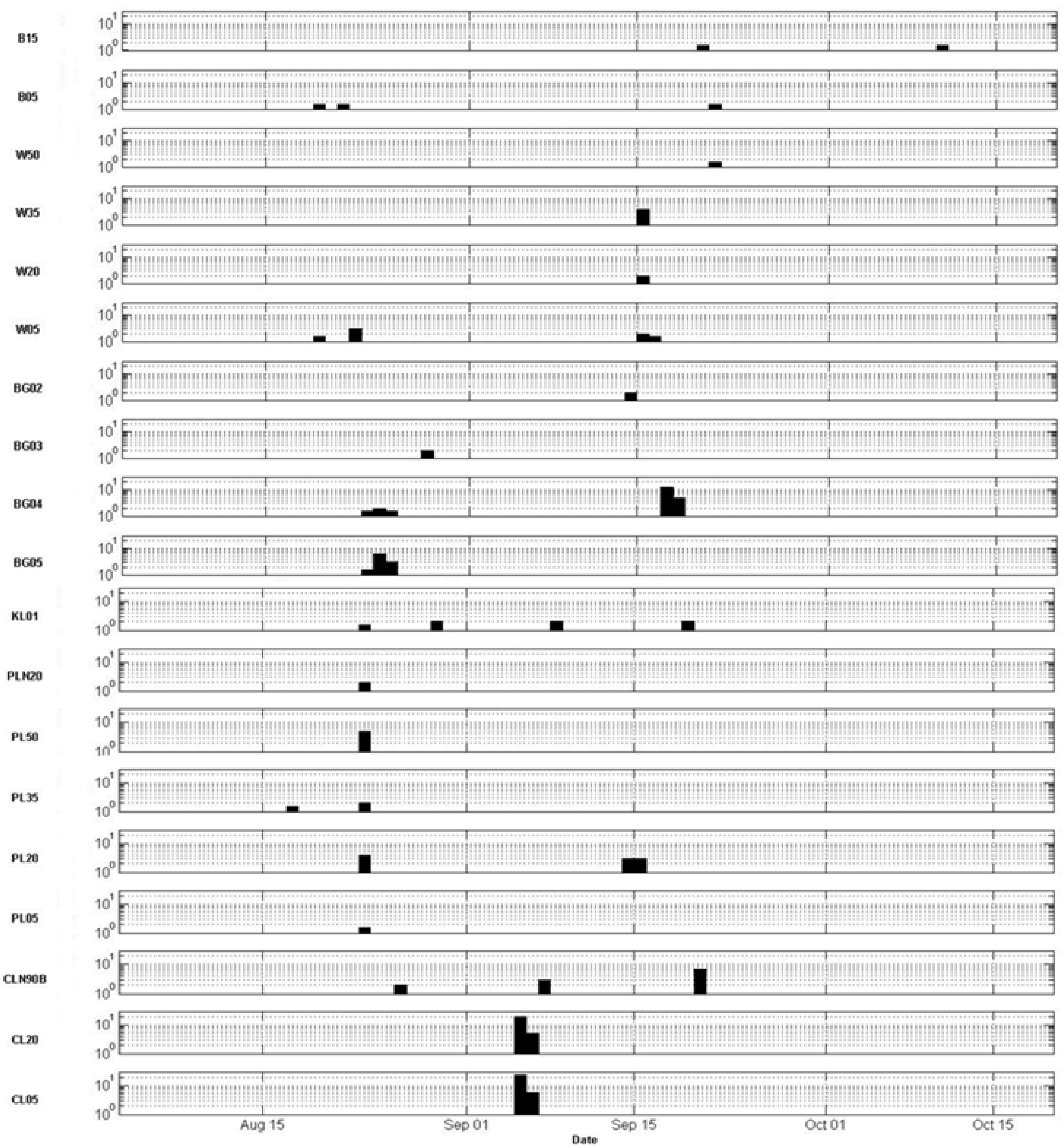


Figure 37. Summer 2012 killer whale call detections: Daily number of 30-min sound files with call detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2012. The y-axis is on a logarithmic scale. Red dashed lines indicate recording start and end. Stations are ordered from (top) northeast to (bottom) southwest. Stations without call detections were omitted. Shaded areas represent hours of darkness.

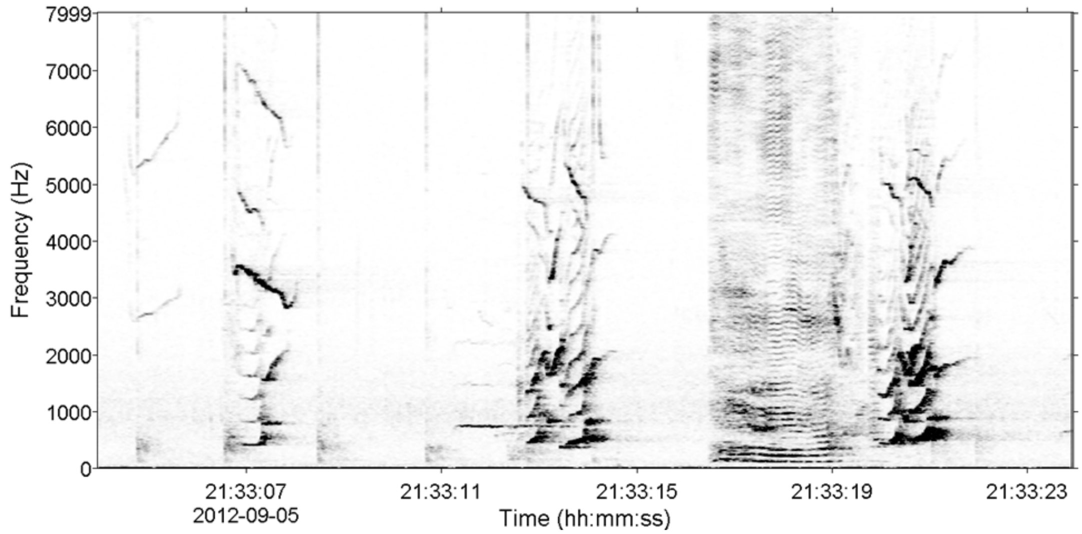


Figure 38. Killer whale call spectrogram from detection at Station CL20, 2 Sep 2011 (Frequency resolution: 1 Hz; Frame size: 0.1 s; time step: 0.01 s; Reisz window).

3.4.10. Minke Whale Call Detections

3.4.10.1. Winter 2011–2012 Program

Minke whale boing calls were detected once on 20 Oct 2011 at CL50.

3.4.10.2. Summer 2012 Program

Minke whale boing sounds (Rankin and Barlow 2005; Figure 40) were detected at five stations located off Cape Lisburne (CL20), in the Burger study area (BG05), and 20–50 nmi from Point Lay (PL20, PL35, and PL50). There were one to five detection days. Two detections occurred in late August at PL20 and PL35 and one in late September at PL50, but the majority of calls were recorded from 4–11 October 2012 (Figure 39).

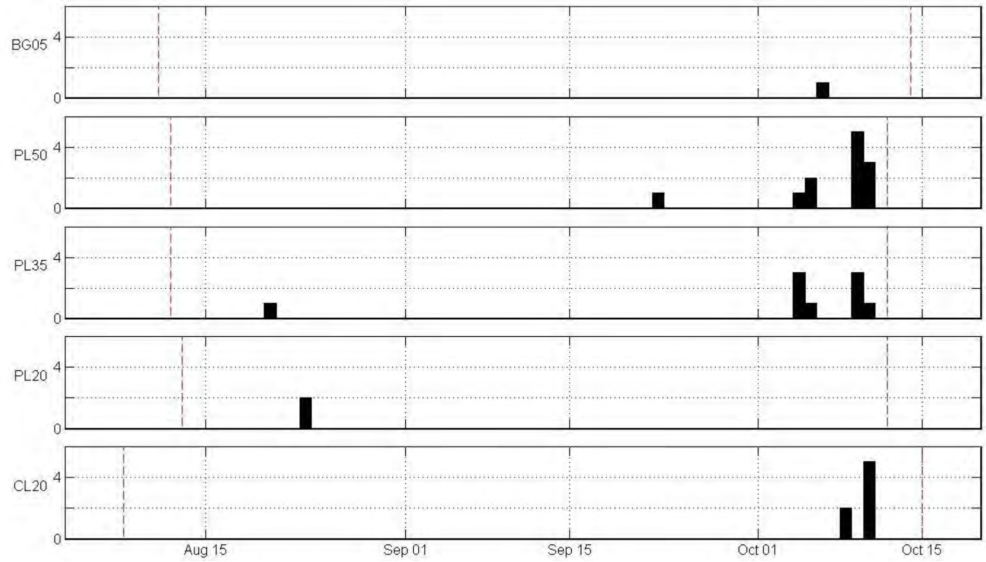


Figure 39. Summer 2012 minke whale call detections: Daily number of 30-min sound files with call detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2012. The y-axis is on a logarithmic scale. Red dashed lines indicate recording start and end. Stations are ordered from (top) northeast to (bottom) southwest. Stations without call detections were omitted. Shaded areas represent hours of darkness.

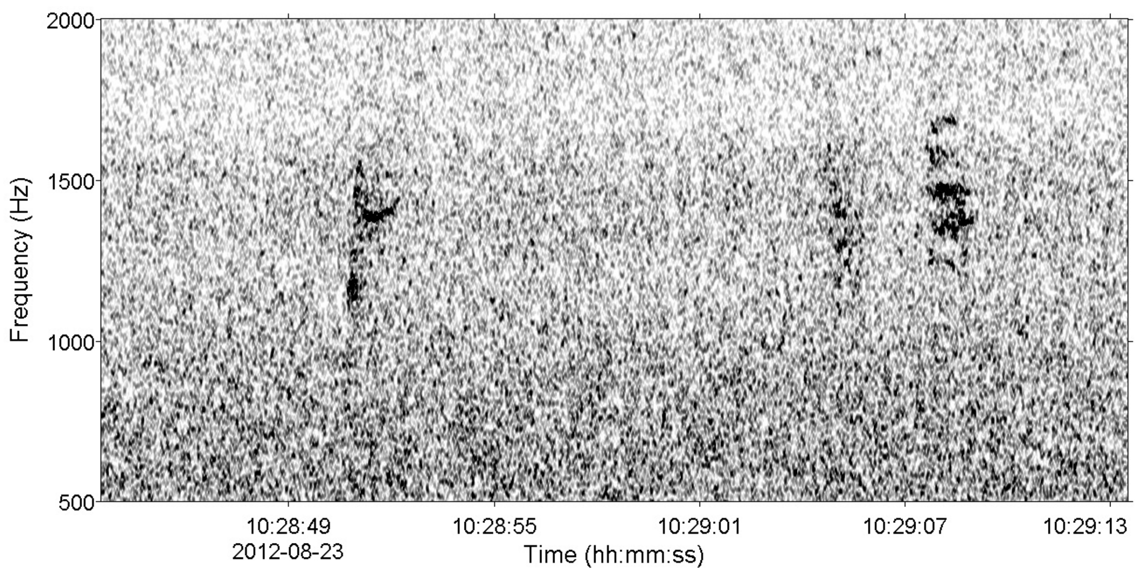


Figure 40. Minke whale boing sounds recorded 23 Aug 2012 at Station PL20 (Frequency resolution: 1 Hz; Frame size: 0.1 s; time step: 0.01 s; Reisz window).

3.4.11. Ribbon Seal Call Detections

3.4.11.1. Winter 2011–2012 Program

No ribbon seal calls were detected in the winter 2011–2012 data.

3.4.11.2. Summer 2012 Program

Ribbon seal (*Histriophoca fasciata*) calls were detected at two Burger stations and off Cape Lisburne (CLN120), Point Lay (PLN40 and PLN60), and Wainwright (WN40; Table 10). Two detections occurred in August and two in October. Two types of ribbon seal calls were detected: intense downsweeping sounds, with or without harmonic structure, corresponding to the short and medium sweeps described by Watkins and Ray (1977); and loud puffing sounds, as described by Watkins and Ray (1977) (Figure 41).

Table 10. Summer 2012 ribbon seal call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the number and proportion of days on which a call was detected for each recording station in the northeastern Chukchi Sea. Stations without call detections were omitted.

Station	Record Start	First Detection	Last Detection	Record End	Detection Days	% Days with Detection
BG05	12-Aug	13-Aug	20-Aug	13-Oct	2	3.2
BG06	12-Aug	20-Aug	20-Aug	13-Oct	1	1.6
CLN120	09-Aug	13-Aug	13-Aug	08-Oct	1	1.7
PLN40	12-Aug	20-Aug	20-Aug	13-Oct	1	1.6
PLN60	12-Aug	08-Oct	08-Oct	08-Oct	1	1.8
WN40	10-Sep	07-Oct	07-Oct	10-Oct	1	3.3

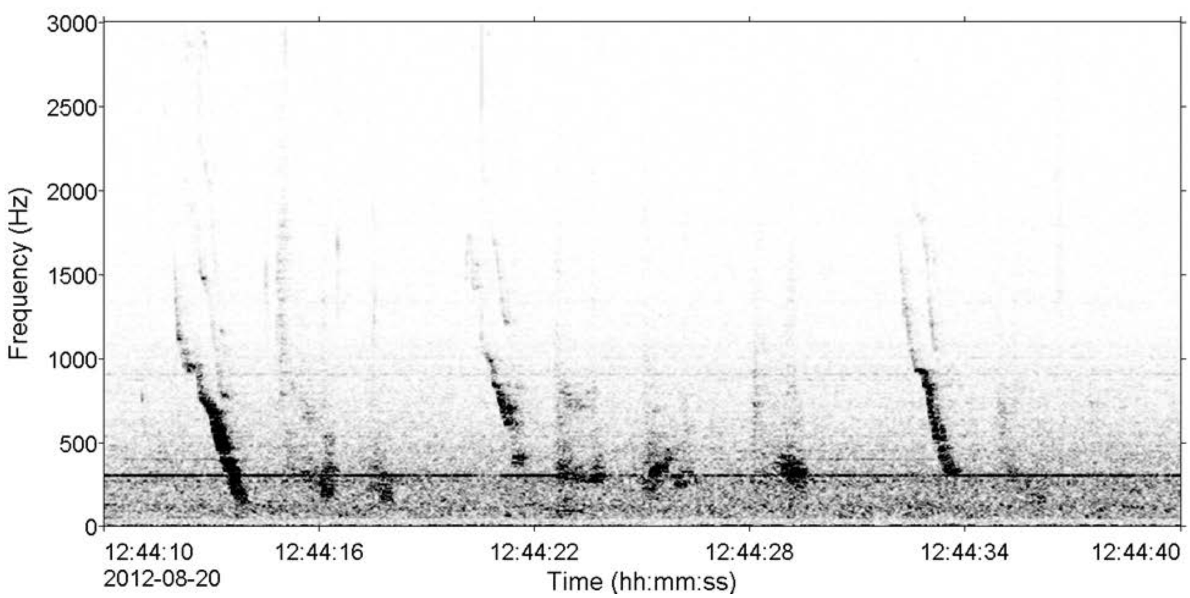


Figure 41. Spectrogram of ribbon seal calls recorded 20 Aug 2012 at Station BG06 (Frequency resolution: 2 Hz; Frame size: 0.128 s; time step: 0.032 s; Reisz window).

3.4.12. Ringed Seal Call Detections

3.4.12.1. Winter 2011–2012 Program

The first detection of ringed seal calls in the Chukchi Sea Acoustic Monitoring Programs was in winter 2009–2010. No ringed seal calls were detected in previous years' data because the call types were largely unknown, not because the seals were not in the area. The analysts targeted mainly bark and yelp calls (described by Stirling 1973; Figure 42). Ringed seals likely produce other call types, but the descriptions of those call types are inadequate to confidently detect them.

Ringed seal calls were detected between 18 Oct 2011 and 26 Jun 2012 at all stations but PLN80. Detections occurred throughout the deployment with no obvious spatial or temporal pattern. The number of detection days at each station was low, ranging from 1 to 14 with a mean of 5.5 (Figure 43, Appendix C). Due to low calling rates the detection probability for ringed seal calls using the 5% manual analysis protocol is low (22%, see Appendix A), which means that the results presented here likely under-represent the occurrence of ringed seal calls.

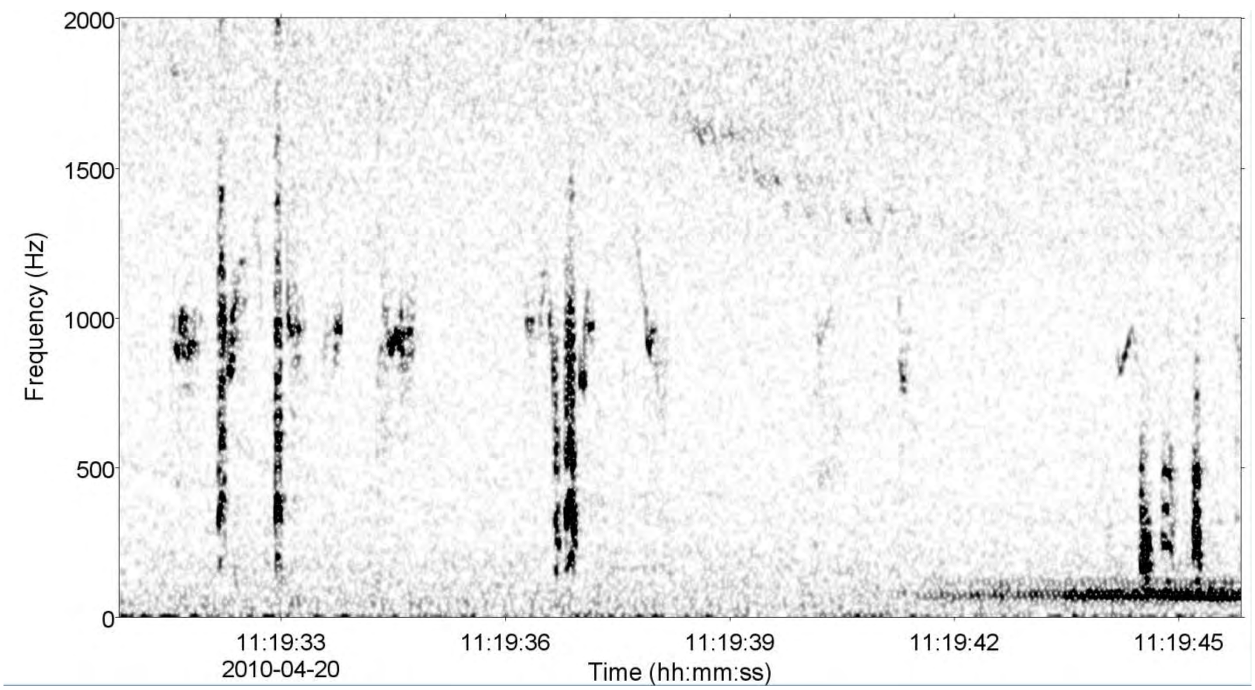


Figure 42. Spectrogram of ringed seal calls recorded 20 Apr 2010 at Station CL50 (Frequency resolution: 1 Hz; Frame size: 0.1 s; time step: 0.01 s; Hamming window).

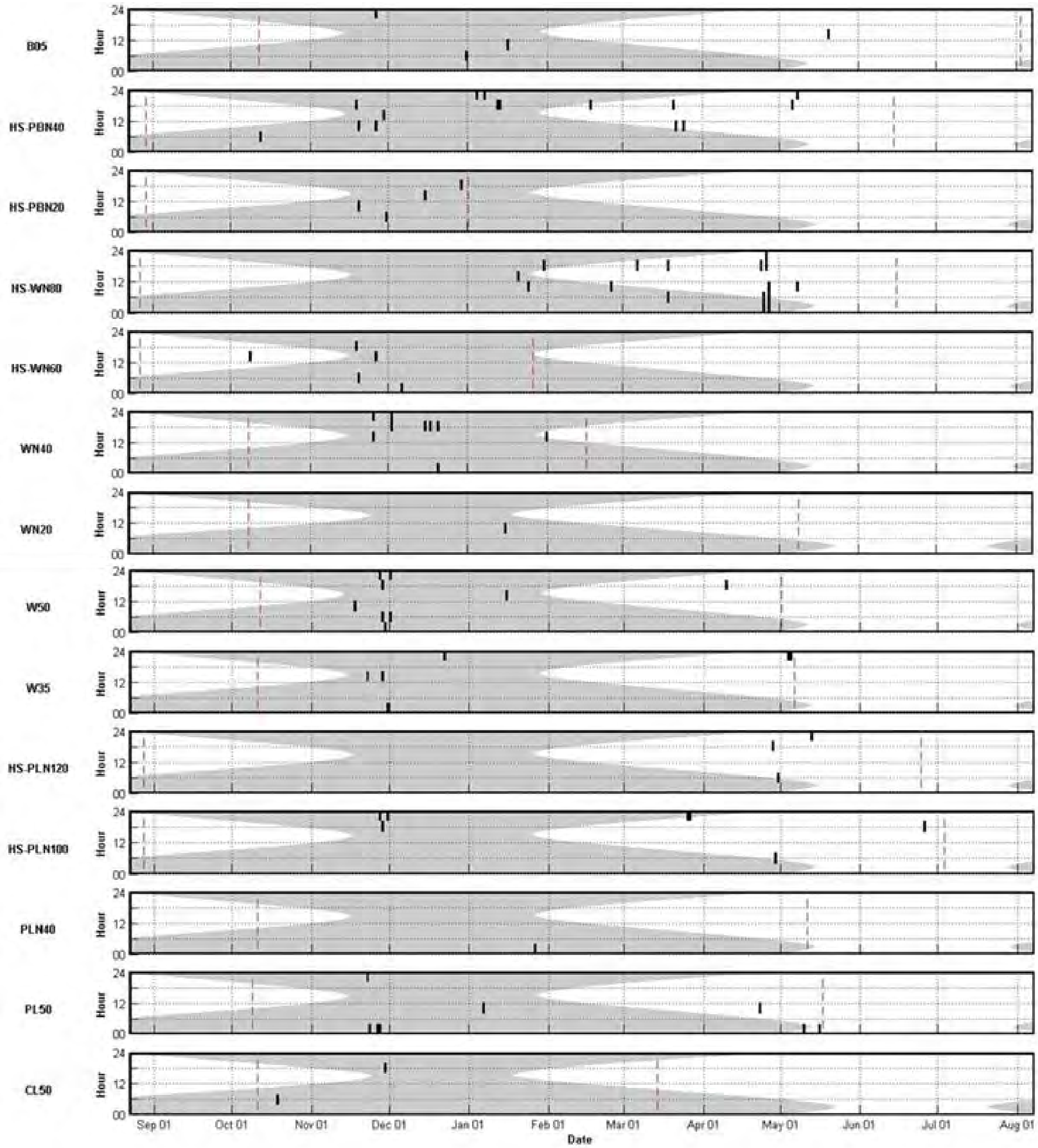


Figure 43. Winter 2011–2012 daily ringed seal call detections: Daily occurrence of call detections based on the manual analysis of 5% of the acoustic data recorded late Aug 2011 through early Aug 2012 in the northeastern Chukchi Sea for each station. Each black square represents a 4-hr period (one 30/40-minute file was recorded every four hours). Stations are ordered from (top) northeast to (bottom) southwest. The red dashed lines indicate the recording start and end dates. The shaded area shows the hours or darkness.

3.4.12.3. Summer 2012 Program

Ringed seal calls were detected at 16 stations (including four Burger stations) between 13 Aug and 11 Oct 2012 (Figure 44, Appendix C). The number of detection days at each station was low (1–5 days, mean of 2.1 days). Stations CLN120 and PLN60 had the highest number of detection days. Detection probability and calling rates were low, and these results underestimate the spatial and temporal distributions of ringed seals in the program area.

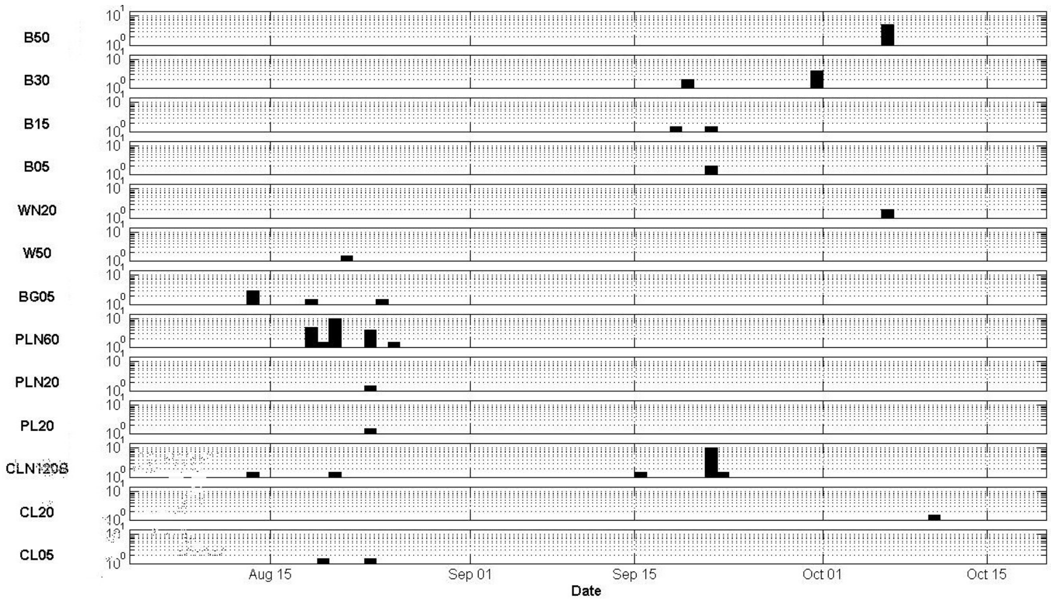


Figure 44. Summer 2012 daily ringed seal call detections: Daily number of 30-min sound files with call detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2012. The y-axis is on a logarithmic scale. Red dashed lines indicate recording start and end. Stations are ordered from northeast (top) to southwest (bottom). Stations without call detections were omitted and only one of the Burger stations is displayed. Shaded areas represent hours of darkness.

3.4.13. Spotted Seal Call Detections

No spotted seal calls were detected manually in the winter 2011–2012 or summer 2012 datasets, not because they were necessarily absent from the program area, but owing to a lack of knowledge about their calls. Spotted seals are regularly seen in the program area in summer (e.g., Funk et al. 2009). Recorders placed near known spotted seal summer haul-outs (e.g., in Kasegaluk Lagoon passes; Frost et al. 1993) could help researchers better understand spotted seal calls and assess the feasibility of acoustically surveying this species.

4. Discussion: 2007–2012 Trends

4.1. Received Ocean Noise

Ambient sound is produced by wind, waves, ice cracking events, geological seismic events, and biological sounds including those from marine mammals. Anthropogenic noise also contributes to the total underwater sound field, but is often considered separately from ambient sound. Our discussion and treatment of ambient noise includes both natural and anthropogenic sounds. The ambient sound levels at Station PLN40 throughout the summer and the winter deployments are compared from 2007 through 2012. Ambient sound levels for summer 2012 are compared across several stations.

4.1.1. Station PLN40 Multi-Year Analysis

The 2007–2012 summer programs produced similar ambient sound profiles for the Chukchi Sea. The ambient sound levels were within the expected range indicated by the Wenz curves, with local variations that were correlated with weather, mammal acoustic activity, and presence of vessel activity and seismic exploration. The 50th percentile power spectral density (PSD) levels are plotted in Figure 45 for Station PLN40 for all recordings from summer 2007 to summer 2012. Station KL11 was used for summer 2009 because it was the closest recorder to PLN40, which was not deployed in 2009. To more easily compare annual data, spectrograms for the recordings are grouped by summer and winter periods (Figures 46 and 48).

During the summer 2012 period, ambient noise levels below 1 kHz increased in mid-September (see Figure 46). This is likely attributable to increased wind speeds (see Appendix B.2.2). Distant shipping tonals occurred from mid-August to early September. Two periods of increased broadband noise occurred in mid-August and mid-September 2011. For summer 2010, the spectrogram shows seismic activity up to 200 Hz, which can also be seen as an elevation in the spectral levels (Figure 45). The summer 2008 recording period was much shorter than other recording periods, containing moderate broadband noise attributed to bowhead whales calling during migration and to the effects of early fall weather. The relatively high noise levels are also due to the recording period being later in the season, which coincides with more wind and storms. Summer 2009 was similar to summer 2008, with only a restricted period of shallow hazards seismic activity. During the summer of 2007 the PLN40 recorder was deployed until 14 Sept. Due to a very quiet period in August and the early retrieval, PLN40 reported very low summer sound levels despite an extensive seismic program in September.

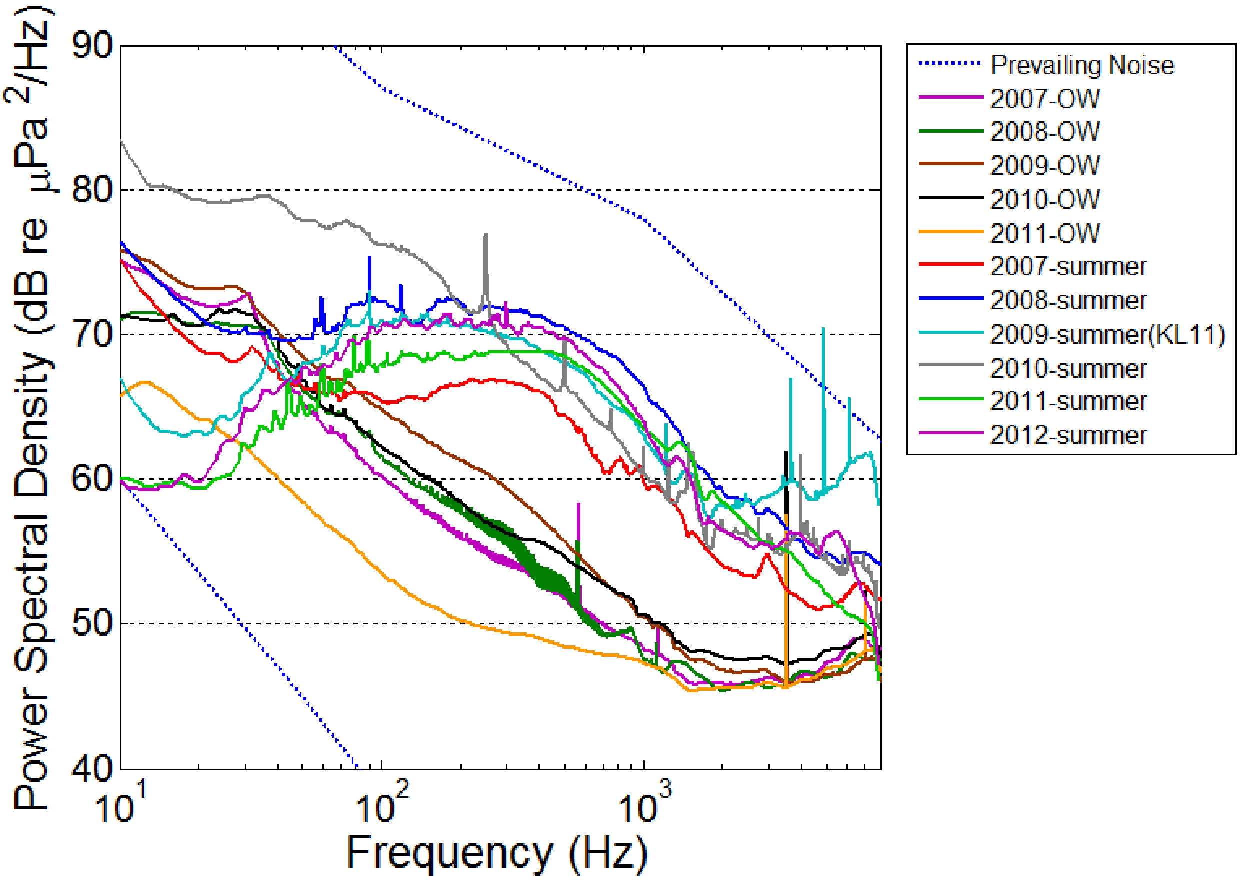


Figure 45. Percentiles of 1-min power spectral density levels at PLN40, for the monitoring periods from summer 2007 to summer 2012. KL11 was used for summer 2009 since the PLN40 data are unavailable for that period.

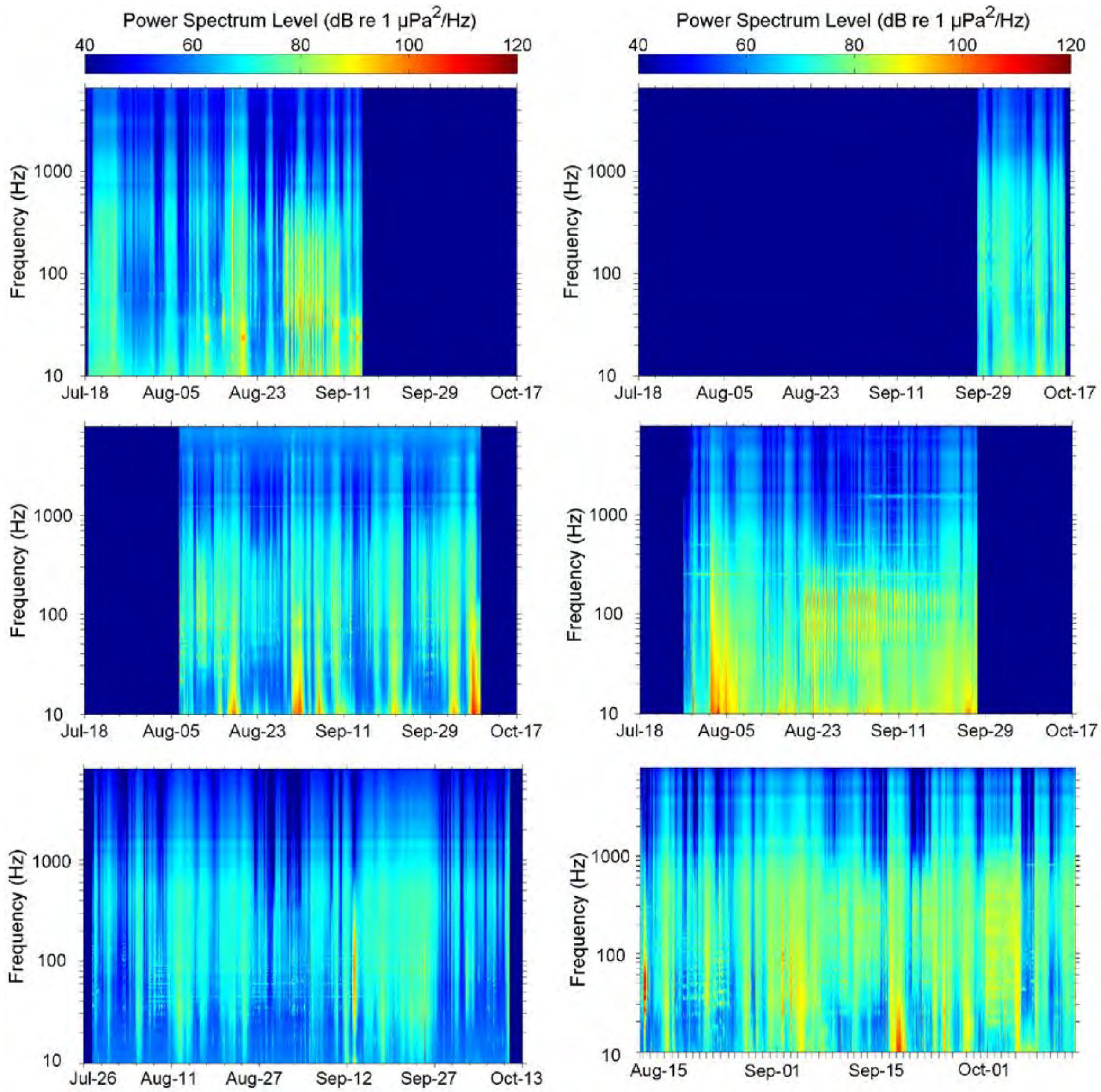


Figure 46. Spectrogram of underwater sound at Station PLN40 for the summer deployments for (top left) 2007, (top right) 2008, (middle left) 2009, (middle right) 2010, (bottom left) 2011 and (bottom right) 2012. Station KL11 was used for summer 2009 since the PLN40 data are unavailable for that period.

The percentiles (Figure 45) and spectrograms (Figure 46) both indicate that the spectral density sound levels are higher at the low frequencies than in the higher frequencies. When integrated over decade-bands to find the in-band SPLs the results show that the total sound levels from 10–100 Hz are generally the lowest compared to the 100–1000 and 1000–8000 Hz bands (Table 11). In fact, the sound levels in the 100–1000 Hz band are generally the highest, which indicates that wind generated surface noise is the dominant noise source in the Chukchi during summer months.

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

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

The cumulative and probability distribution functions of the decade–band SPLs for 2009–2012 show very good agreement, with the exception of 2009 in the 1000–8000 Hz band, and 2010 in the 10–100 Hz band (Figure 47). The 2009 result at high frequency is due to an elevated high-frequency noise floor in the AMAR G2 recorders used during that year compared to later generations. The 2010 low frequency result shows the effect of the Statoil 3-D seismic survey at PLN40.

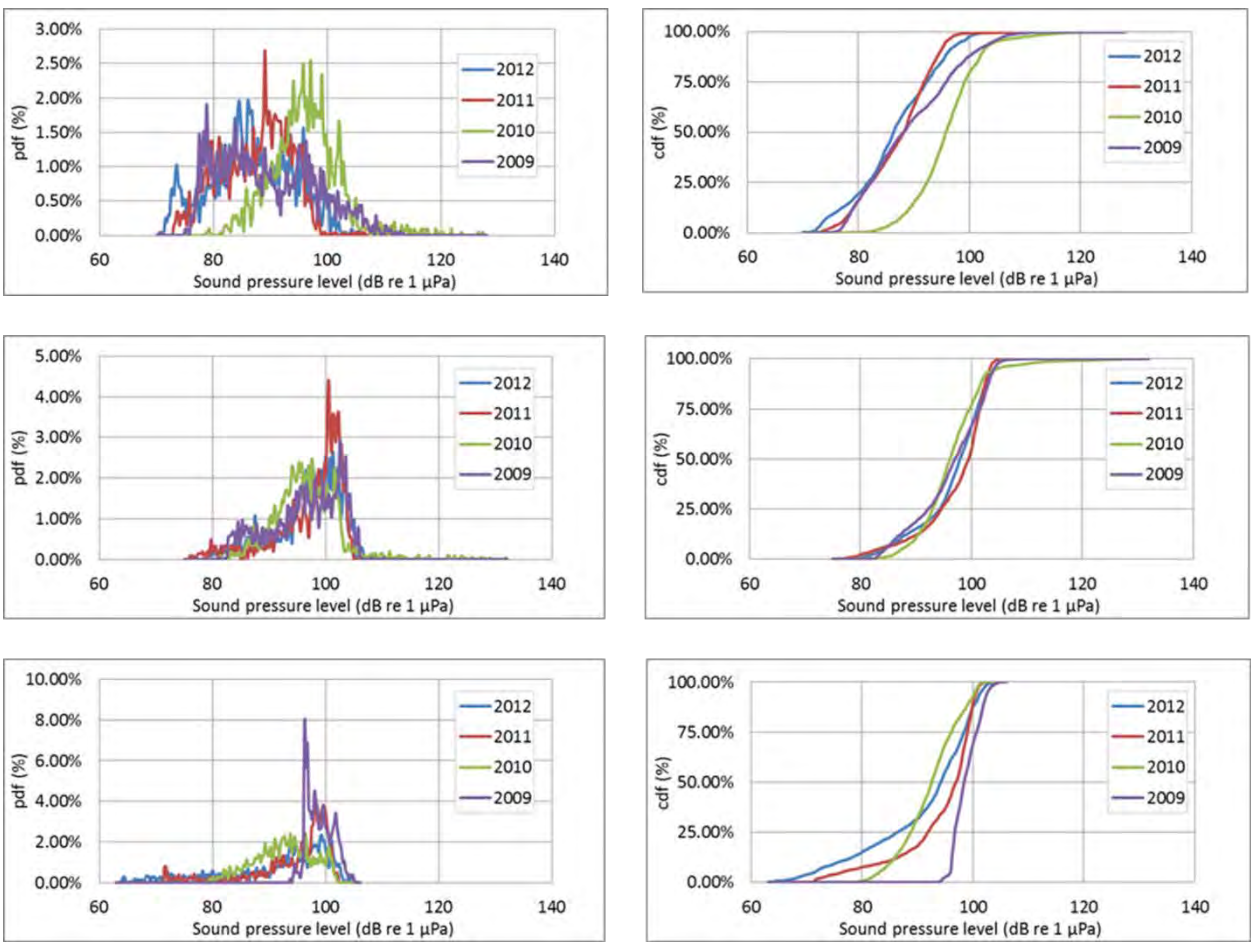


Figure 47. (Left) Histograms of SPL distributions and (right) cumulative distribution function (CDF) for summer 2009, 2010, 2011, and 2012, station PLN40. (Top) 10 Hz to 100 Hz, (middle) 100 Hz to 1 kHz, and (bottom) 1 kHz to 10 kHz.

Ambient noise levels of winter periods from 2007 to 2010 are similar, showing a linear decrease from 40 Hz to 2 kHz. The winter 2011 recording period was much quieter than the other recording periods (Figure 45, Figure 48). The loudest periods of all five correspond with ice formation and break up. The relatively high levels below 100 Hz are attributed to wind noise propagating through the ice.

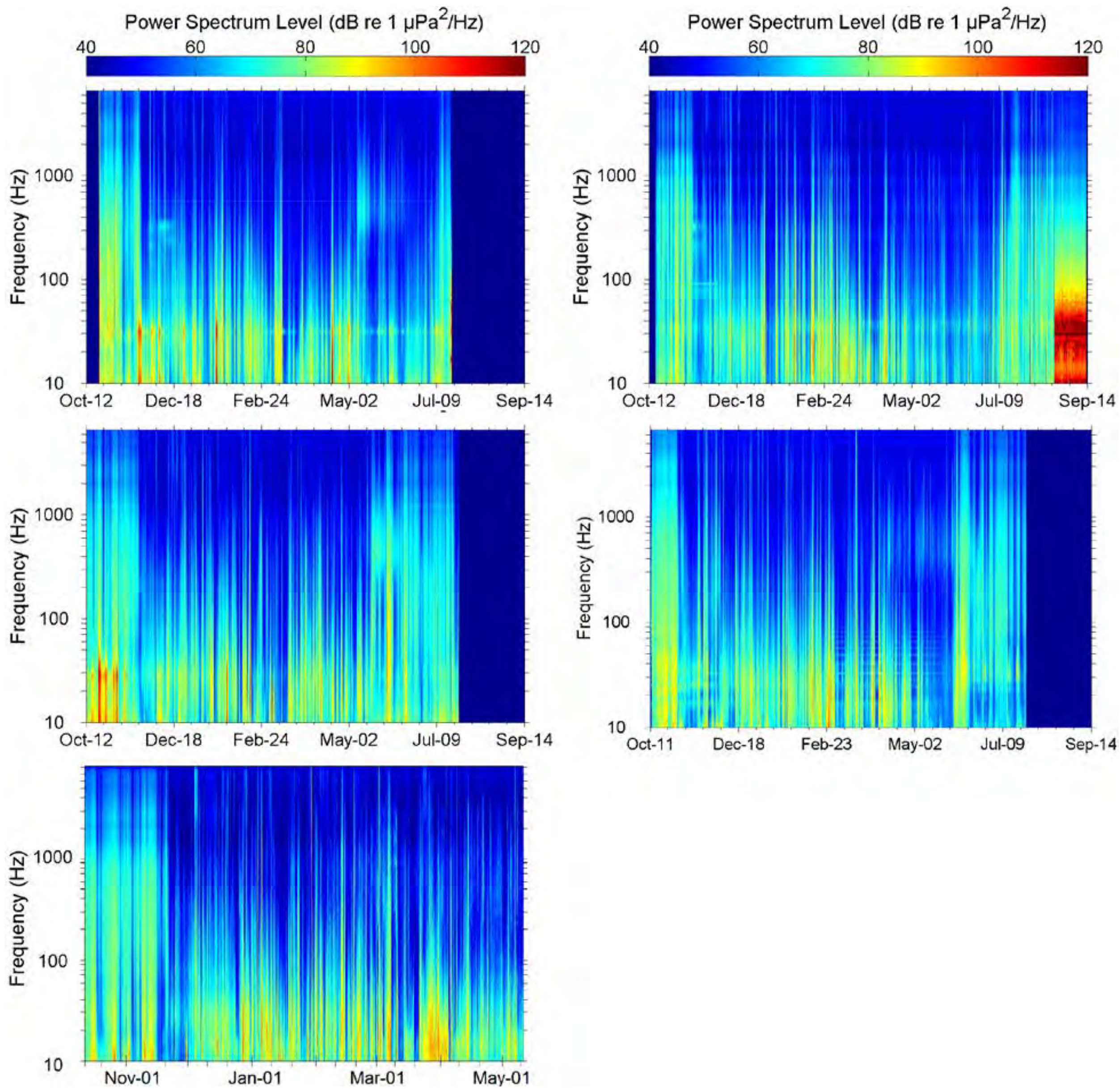


Figure 48. Spectrogram of underwater sound at Station PLN40 for the winter programs for (top left) 2007-2008, (top right) 2008-2009, (middle left) 2009-2010, (middle right) 2010–2011 and (bottom) 2011-2012.

4.1.3. Summer 2012 Program

The 50th percentile power spectral density levels are plotted for stations along a roughly east-west line from the summer 2012 program (Figure 49); the corresponding spectrograms for the recorders are shown in Figure 50. Low frequency sound levels at WN20 were elevated up-to 12 dB due to the proximity to the Shell drilling program at Burger.

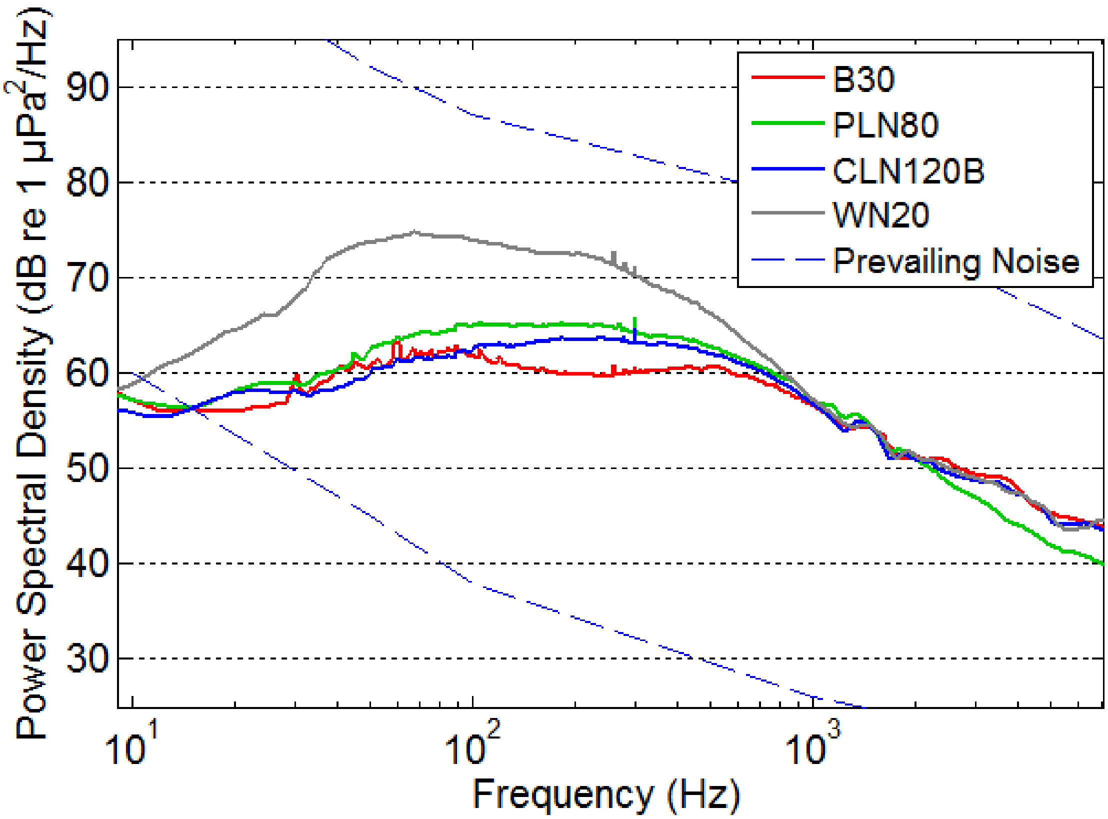


Figure 49. Percentile 1-min power spectral density levels at stations along a roughly east-west line across the Chukchi Sea for summer 2012.

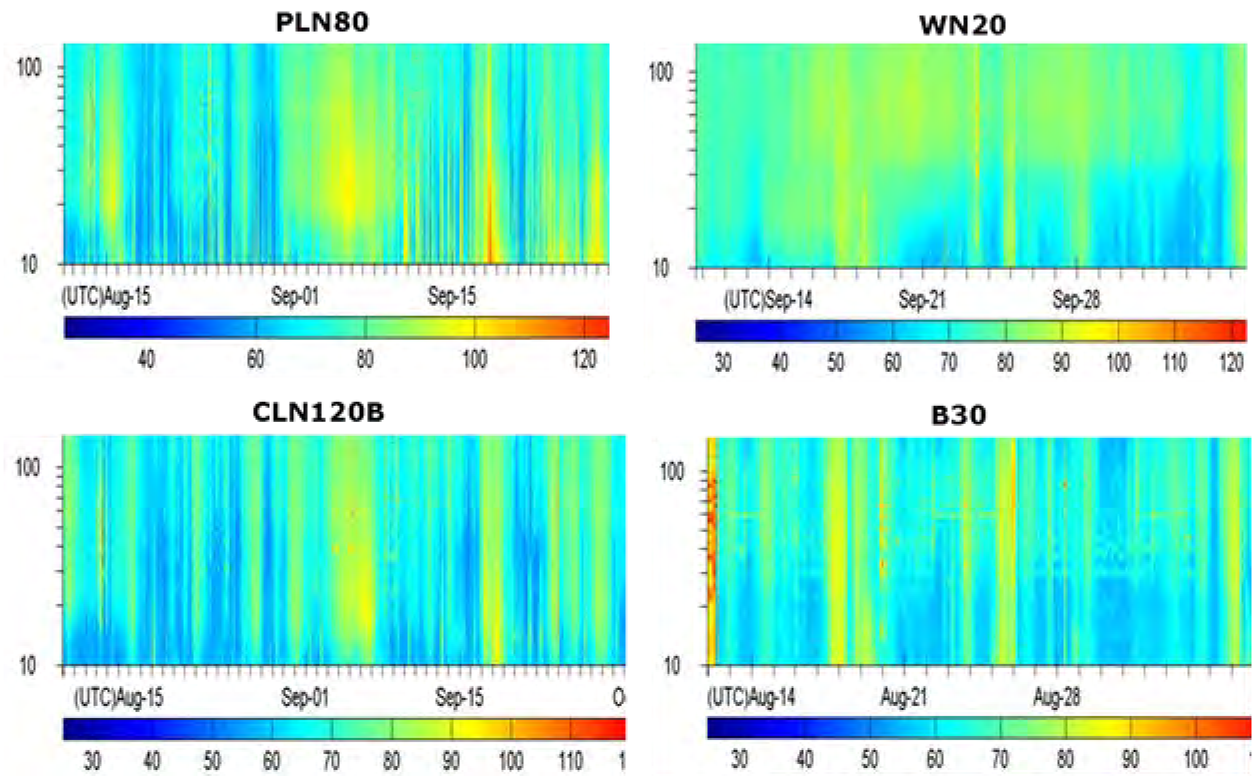


Figure 50. Spectrogram of underwater sound at (top left) PLN80, (top right) WN20, (bottom left) CLN120B, and (bottom right) B30 for the summer 2012 program.

The daily cumulative sound exposure level helps us visualize the total sound energy received at each recorder in the course of one day. In the summer of 2012, anthropogenic, geophonic, and biologic sources all created cSEL peaks in different parts of the Chukchi (Figure 51).

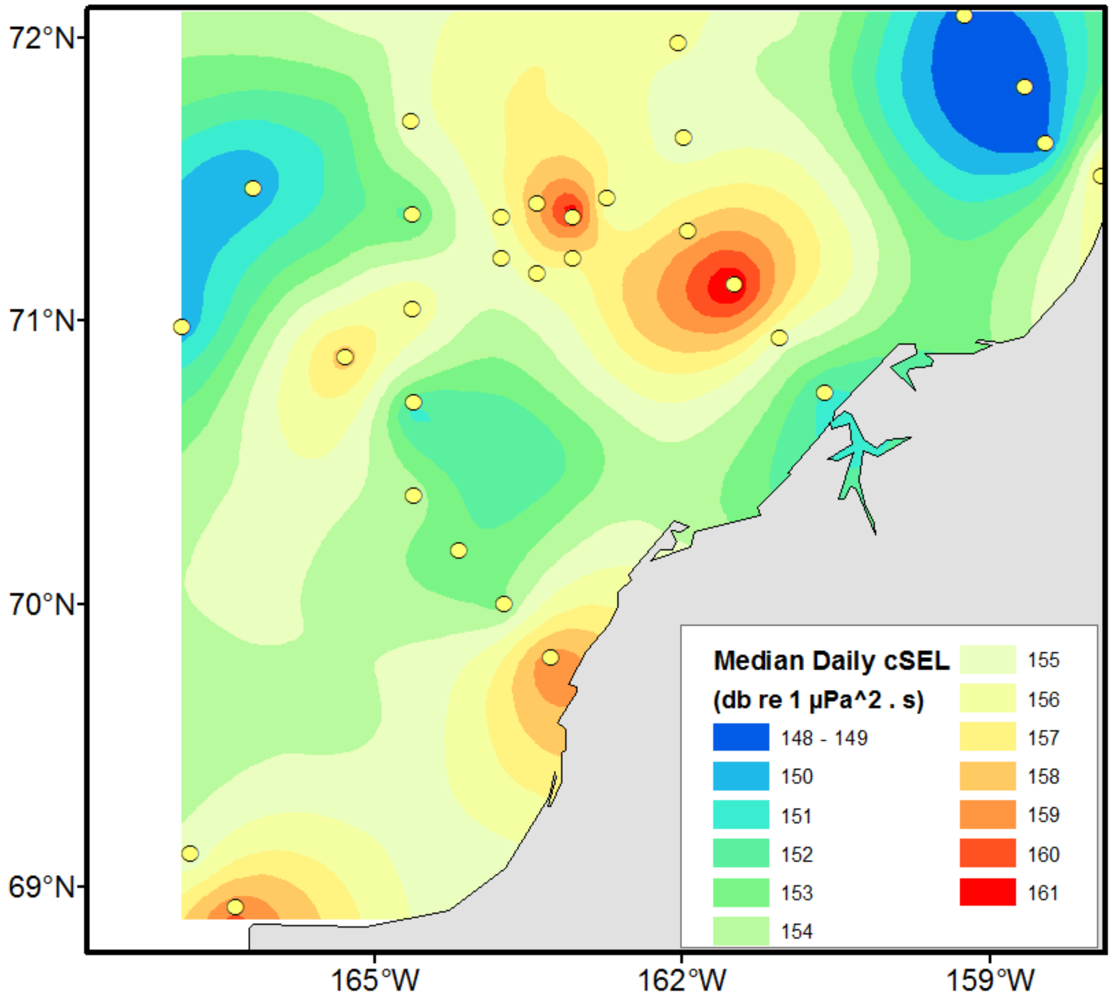


Figure 51. Median daily cumulative sound exposure levels, summer 2012, kriging interpolated. Increased sound levels at CL05 are due to high sound levels coming from the Bering Sea to the south, as well as flow and sediment movement noise (geophonic source). High levels at PL05 are due to walrus (biologic source). High levels in the middle of the Chukchi are due to the drilling program at Burger and the vessel standby area near W35 (anthropogenic source). Each of these levels is 160 dB re 1 µPa^2·s ±2 dB.

4.2. Marine Mammal Call Detections

Because recorders have been deployed at the same or similar locations each year since 2007, we are able to, with some limitations, compare data collected over the years. This report does not discuss the 2008 summer dataset, which was restricted to five recorders late in the season (26 Sep to 16 Oct 2008). The summer 2007 (first deployment) and winter 2007–2008 data were not analyzed using the standardized protocol first applied to the winter 2008–2009 data; therefore, the results from these two datasets are not directly comparable to later datasets. The Burger and Klondike cluster arrays were first deployed in summer 2009. In summer 2010, a third cluster array was added at the Statoil lease area. In summer 2011, these arrays were removed, but a recorder was retained at each former location to continue monitoring the three lease areas. The number of recorders in the winter program increased from five in 2007–2008 to fifteen in 2011–2012.

4.2.1. Bowhead Whale Call Detections

4.2.1.1. Winter Acoustic Monitoring Programs

The winter 2011–2012 program added six recorders on the western, northern, and eastern sides of Hanna Shoal. Previous years' programs (mainly summer and to a lesser extent winter), have revealed that the fall migration is centered between 71° N and 72° N, with detections declining on either side of this corridor. The Hanna Shoal data have confirmed the decreasing acoustic occurrence of bowhead north of that corridor while showing that some bowheads migrate near 73° N, on the north side of Hanna Shoal.

The heading of the 2012 fall migration appeared to be due west across the northeastern Chukchi Sea until 15 Nov as bowheads presumably headed to a known fall feeding aggregation along the northern Chukotka coast (Quakenbush et al. 2010). The line connecting the highest call count locations between 15 Nov and 16 Dec was oriented on SSW heading i.e., more or less parallel to the coast and to the advancing ice edge. This heading would lead bowheads toward the Bering Strait, suggesting that some individuals may linger in the northeastern Chukchi Sea to forage late in the fall and do not visit the Chukotka feeding grounds. In both cases, it is likely bowhead whales would migrate through the lease area as previously observed by Quakenbush et al. (2010, 2012).

The last winter detection was on 15 Dec 2012, earlier than in the 2007–2008 and 2010–2011 winter data (17 Jan), but the same as in 2009. The first spring detections of bowheads near Barrow occurred two weeks later than the last two years, which may be due to an increase in the amount of ice. Although the Arctic experienced a new record low for sea ice extent in summer 2012, sea ice remained in the northeastern Chukchi Sea much later than in previous years, making it likely that the concentration of spring sea ice in the Chukchi Sea were higher in 2012 than in 2011. In most cases, in previous years, stations that are more than 50 nmi offshore had their first spring detections in late May or June. The lack of detections at the offshore stations in spring 2012 can be partly attributed to recordings that stopped earlier than anticipated at some of these stations, but is, nevertheless, consistent with previous years' findings that bowhead acoustic occurrence decreases with increasing distance from shore in the spring.

4.2.1.2. Summer Acoustic Monitoring Programs

Bowheads were first detected in 2012 during a short period in mid-August, mainly at CLN120 although detections occurred widely in the central part of the study area for two days. This echoes the 2011 results; bowheads were detected between late July and early Aug in the central part of the study area. The duration of this detection period suggested that bowheads were foraging. In 2009 and 2010 only 1–2 sporadic detections occurred in that same period, which were tentatively linked to known movements of tagged individuals between the Beaufort Sea and Russia. The possible increase in mid-summer occurrence of bowhead whales in the Chukchi Sea should be monitored because their distribution includes Burger, which is an active lease site.

Detections throughout Sep were characterized by an apparent aggregation of bowhead whales in Peard Bay as inferred from the high call counts recorded inshore off Wainwright and Barrow, compared to the rest of the study area (Figure C.5). This finding is consistent with previous reports of bowhead sightings in this area in summer (Moore 1992). Lower call counts at BG04 and BG05 from late Sep to mid-Oct are visible in the call count contour plots (Figure C.6).

Numerous vessels supporting Shell's drilling operations were in stand-by southeast of the Burger lease area for much of the summer. Acoustic masking was investigated as a possible explanation for the lower call counts at BG04 and BG05. Preliminary results suggest that masking due to higher sound levels is not the reason for the lower number of detections at BG04 and BG05. A generalized linear model (GLM) was used to investigate covariates that could influence the number of detections observed at the Burger stations.

The variables included in the model were SPL (the average SPL summed over the seven 1/3-octave bands centered between 100 and 400 Hz), vessel detection flag (flag for each minute of data a vessel tone was detected), and station. Of those covariates, SPL was ranked as the most influential factor in the number of call count estimates. This is confirmed by a trend showing a reduction in the number of detections with increasing SPL at all stations investigated. However, when investigating the variance in the number of call counts between the stations, there is still a significant difference even after accounting for SPL. In other words, at the same SPL there are significantly fewer call counts at BG04 and BG05; therefore, SPL alone does not account for the difference observed. An upcoming publication will contain detailed results. A Shell-sponsored aerial survey also sighted more bowhead whales northwest of the drill site (C. Reiser, pers. comm.), which coincides with the acoustic detection patterns. These detections, therefore, appear to represent the true distribution of bowheads during the fall migration.

Although masking does not explain the lower call counts at BG04 and BG05, the variability between the northern and southern Burger stations is consistent with the expected migration path. In previous years, the Burger study area was regularly near the center of the migration corridor with some variability to the south and north, and Klondike has repeatedly been on the migration corridor's southern edge, which was again the case in 2012 (Figure 52). The call count contour plots (Figure C.5–Figure C.6) and the results of the masking analysis suggest the migration corridor was along the northern edge of the Burger study area; most bowheads migrated north of 71° N except near Wainwright, which is similar to observations from previous years (Figure 52).

Call densities (Figure 53) paint a similar picture of bowhead whale distribution to the call counts recorded at each station (Figure 52). Call densities are highest off Barrow and Wainwright, presumably because migrating bowheads are most concentrated as they enter the Chukchi Sea after passing Barrow. They fan out more broadly as they move away from Barrow, leading to lower animal and call densities. The highest call densities since 2009 were recorded in 2012, 35 to 50 nmi from Wainwright, which was largely due to an intense detection period in this area in September combined with high noise levels associated with the presence of vessels involved in Shell's drilling operations. High noise levels decrease the detection range and area of bowhead calls thereby increasing the call density for a given call count. The very low call densities in 2011 corresponded to the low call counts that we attributed to a delayed fall migration in the study area.

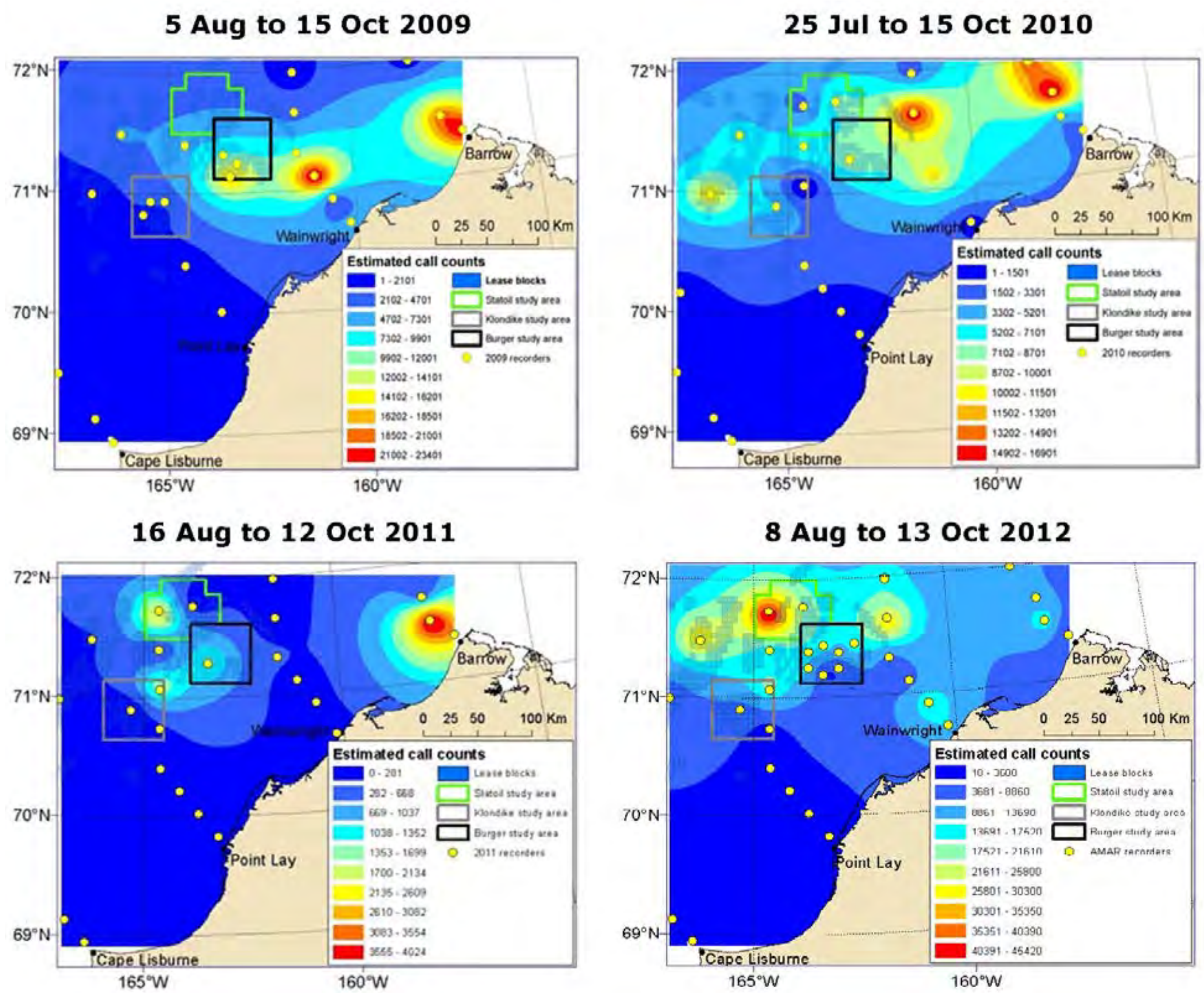


Figure 52. Summer bowhead whale call counts: Radial basis-interpolated call counts based on the sum of automated call detections in all files with manual detections at all summer recording stations in the northeastern Chukchi Sea.

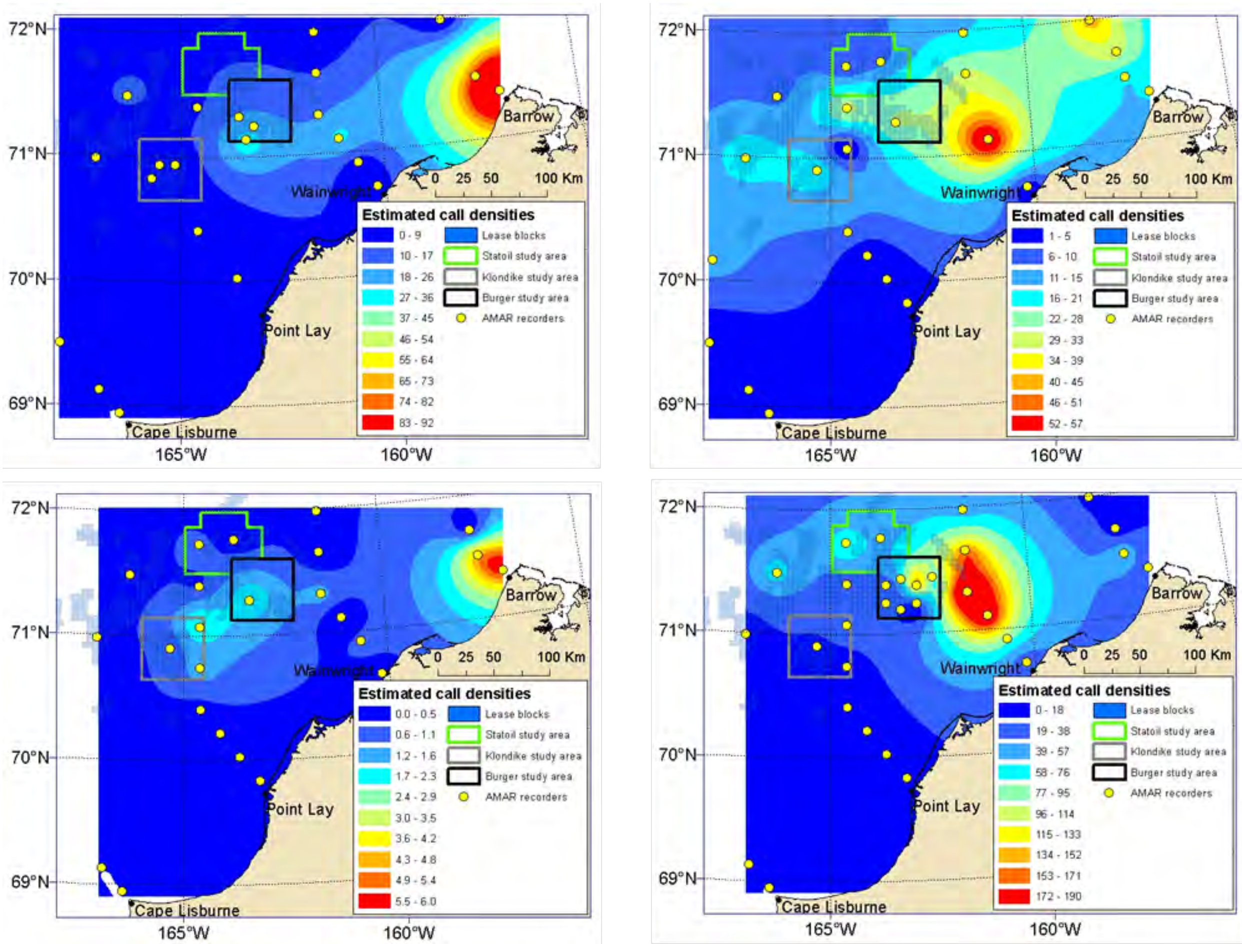


Figure 53. Summer bowhead whale call densities in 2009, 2010, 2011, and 2012 (clockwise from top left): Radial basis-interpolated call densities based on the sum of automated call detections in all files with manual detections at all summer recording stations in the northeastern Chukchi Sea.

4.2.2. Walrus Call Detections

4.2.2.1. Winter Acoustic Monitoring Programs

The 2011 winter program introduced recorders on the eastern, northern, and western sides of Hanna Shoal, which had not yet been acoustically surveyed. These recorders revealed the consistent presence of walrus from late August to early October, with a peak on the north-central part of the Shoal (WN60). Detections during the remainder of the fall at the winter recorders were similar to those from the two previous years: Except at WN20, which was not part of previous winter programs, there were few detections and most were concentrated in a three-day peak, which perhaps indicated an area-wide, southerly movement of walrus. Detections at WN20 were similar to those collected by the summer 2011 recorder retrieved on 8 Oct, confirming this location as a walrus hotspot in the northeastern Chukchi Sea (Delarue et al. 2012).

The limited spring 2012 detections preclude any accurate comparisons with previous years.

4.2.2.2. Summer Acoustic Monitoring Programs

The walrus summer detections offer a model of multi-year consistency (Figure 54). Detections were highest south of Hanna Shoal and just off Point Lay, similar to those observed in previous years. Walrus detections off Point Lay started in the third week of August, but did not become continuous until the beginning of September. Interestingly, sea ice was still present on or near Hanna Shoal until at least the middle of September. However, very high call counts at PL05 from early September indicate that some walrus were possibly hauling out on land as witnessed in 2010 and 2011. Although call counts were similar at BG08 and PL05 during the first three weeks of September, they increased to twice that amount at PL05 in the last three weeks of recording.

The extent of walrus' spatial distribution was highest in late September/early October (50–76% of active stations with detections; Appendix C), possibly due to walrus dispersing following the total disappearance of sea ice at Hanna Shoal and migrating back to the northern Chukotka coast where they typically aggregate in the fall. The above-average number of detection days at CL05 indicates that many walrus follow the coast between Point Lay and Cape Lisburne as they leave the study area.

Of all the Burger stations, BG08, the station closest to Hanna Shoal, consistently had the highest call counts. Excluding BG08, BG02, and BG07, the northernmost BG stations, had the highest call counts, a pattern similar to the bowhead detections. Surprisingly, BG03, located between BG08 and BG02, had the lowest call counts throughout the study. The strong gradient in call counts between stations (up to two orders of magnitude), particularly at the eastern edge of Burger, could be due to differences in ambient noise levels yielding different levels of call masking. However, because the Burger lease area marked the western edge of walrus distribution around Hanna Shoal over all recorded years (Figure 54), habitat preferences are at least partly responsible for the observed biased spatial distribution in the Burger lease area.

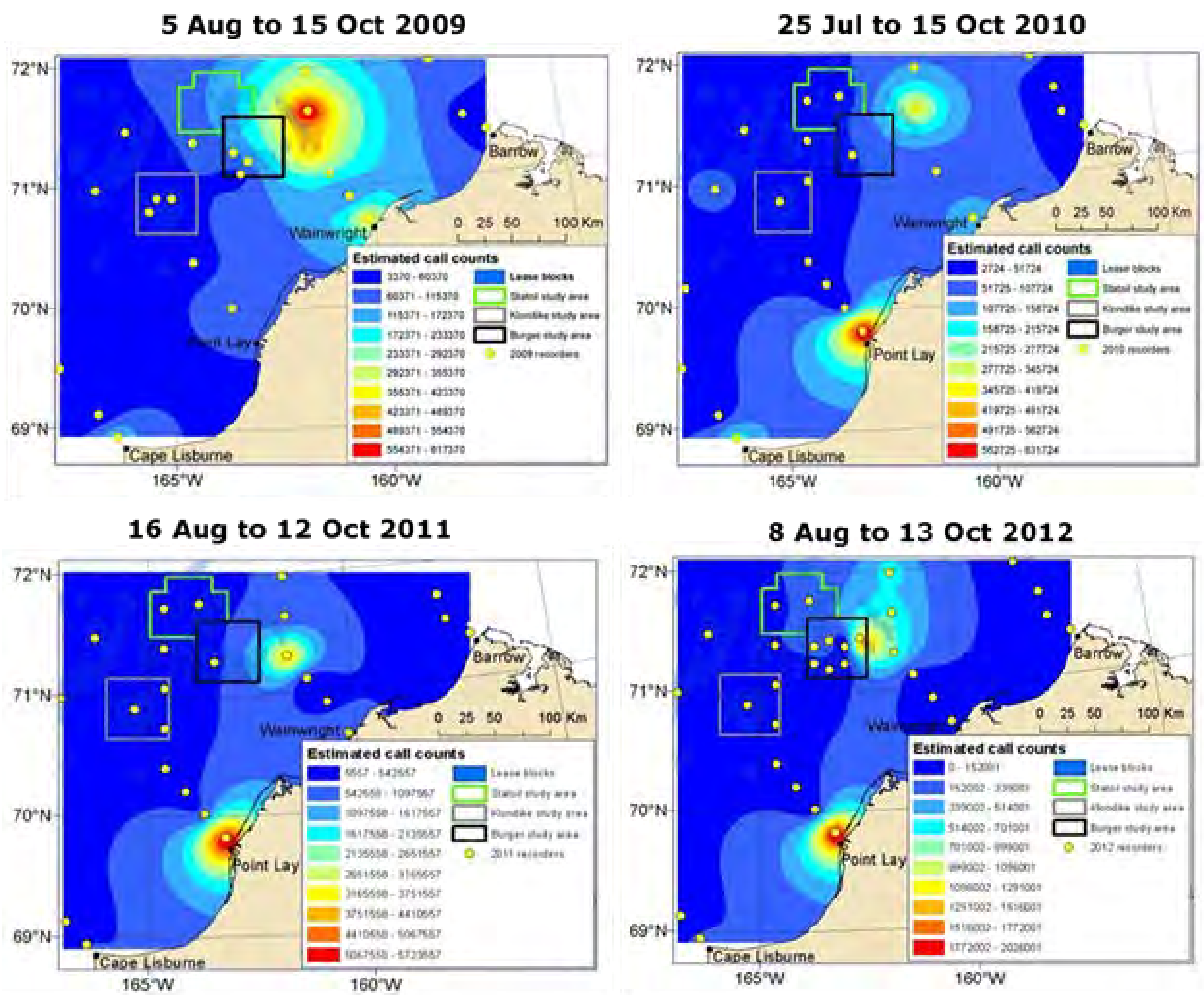


Figure 54. Summer walrus call counts: Radial basis-interpolated call counts based on the sum of automated call detections in all files with manual detections at all summer recording stations in the northeastern Chukchi Sea.

4.2.3. Beluga Whale Call Detections

4.2.3.1. Winter Acoustic Monitoring Programs

The winter 2011–2012 detections confirmed the detection trend observed in previous years in the main part of the study area. B05 usually has the most consistent and predictable detections. As whales migrate across the Chukchi Sea, detections at the other stations become more sporadic. The slight increase in the number of detection days with decreasing distance to shore suggests that a larger proportion of the migrating population may follow the coast, thereby being undetectable.

One of the reasons for deploying recorders on the north side of Hanna Shoal was to capture the eastern Beaufort Sea beluga fall migration. These animals have been shown to migrate through the northern Chukchi Sea, along the shelf break, in September (Richard et al. 2001). The complete absence of beluga detections in that month strongly suggests that the Hanna Shoal recorders were not in the migration corridor of eastern Beaufort Sea belugas. Recorders attempting to intercept the fall migration of that stock would have to be deployed in the deep waters of the Chukchi basin.

Observed spring detection patterns were comparable to those from previous years. Belugas can be detected early in the migration far offshore in almost 100% sea ice concentration. Despite incomplete coverage of the main migration period at several stations, the negative gradient in the number of detection days as a function of distance to shore, which was demonstrated in previous years, was again apparent in spring 2012.

4.2.3.2. Summer Acoustic Monitoring Programs

The 2012 summer data confirm the limited occurrence of belugas in the northeastern Chukchi Sea in summer. Over the last years, detections have always been concentrated in/near Barrow canyon in August as eastern Chukchi Sea belugas forage locally or head north in the northern Chukchi and Beaufort Seas (Suydam et al. 2005, Delarue et al. 2011*b*). Sporadic detections usually occur in late September and early October as part of the fall migration. These detection patterns are consistent with results from a satellite-telemetry study (Suydam et al. 2005) and sightings obtained as part of the Chukchi Joint Acoustic Monitoring Program (Ireland et al. 2009). The high detection probability in three files analyzed for this purpose suggests that these results are representative of the occurrence of belugas in summer months (Appendix A.8).

4.2.4. Killer Whale Call Detections

Killer whales were acoustically detected in the 2009, 2010, and 2011 summer datasets; they were first recorded in 2007 (Delarue et al. 2010a). Killer whales were detected predominantly off Cape Lisburne and Point Lay in all years with a few detections off Wainwright. In 2012, there was no clear spatial distribution pattern and detections extended up to B05. Further analysis of the 2007 data revealed that mammal-eating killer whales, called transients, were the source of the detected calls (Delarue et al. 2010a), the latter being consistent with observations of killer whale predation on marine mammals in the Chukchi Sea (George and Suydam 1998). Unique calls, detected in multiple years including 2012, indicate that the same pods or individuals belonging to the same community return to the northeastern Chukchi Sea each year.

4.2.5. Fin Whale Call Detections

Fin whale acoustic detections in the 2009, 2010, and 2011 summer datasets have confirmed their presence in the Chukchi Sea. These whales were first recorded in 2007 (Delarue et al. 2013). In all years, fin whales were only detected at the offshore Cape Lisburne stations, except at Station PL50. The number of detections decreased sharply between 2007 and 2009 with detections remaining rare thereafter, indicating that fin whales are occasional visitors the northeastern Chukchi Sea.

4.2.6. Gray Whale Call Detections

A large increase in gray whale detections was noted in 2011 owing to a new call type included in the repertoire used to identify gray whales and improvements to recorders that made this call type easier to detect. The 2012 detections were consistent with those in 2011. The main feature of gray whale detections, i.e., their concentration off Wainwright, coincides with the latest information on gray whale distribution based on aerial surveys (Clarke and Ferguson 2010). The mean detection probability for five files analyzed for this purpose was 0.42. Excluding a file containing continuous series of knocking sounds (which occur rarely in the data; Delarue, pers. observation), the mean DP fell at 0.27. This suggests that the current 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 chosen analysis protocol while the occurrence (i.e., number of detection days) of gray whale at each station is underestimated.

4.2.7. Bearded Seal Call Detections

4.2.7.1. Winter Acoustic Monitoring Programs

There were no obvious changes in bearded seal acoustic occurrence in winter 2011–2012 compared to previous years. The overall detection pattern for 2012 suggests that most bearded seals in the northeastern Chukchi Sea were concentrated to the north of the study area, near stations PLN80 and PLN100. Detections were typically lower on either side of these two stations.

The typical temporal distribution of detections consists of a steady increase in calling rates from October, peaking in May and June, which coincides with the mating season. Call detections usually stop abruptly in late June–early July, with very sporadic, or no detections thereafter. Bearded seals are the most common acoustically-detected marine mammal species in the winter programs.

4.2.7.2. Summer Acoustic Monitoring Programs

The typical detection pattern in the summer data consists of a few sporadic detections in late July and August and a steady increase in detections in September peaking in October. The summer 2012 detections are consistent with the results from previous years. Bearded seal calls were most commonly detected in the northern and northwestern sections of the study areas. The coastal waters off Wainwright offered one counter-example to this offshore preference of bearded seals, although it was restricted to three weeks in September. A similar distribution pattern was observed in 2009 (Figure 55). The steady increase in calling rate from September to May makes it difficult to compare estimated call counts between months. Fewer detections in July and August are attributed to behavior, not necessarily fewer animals. The lower call counts on the eastern side of Burger as well as W35 and W50 appear to coincide with the standby locations of the vessels supporting Shell's drilling operations, and could therefore be due to call masking.

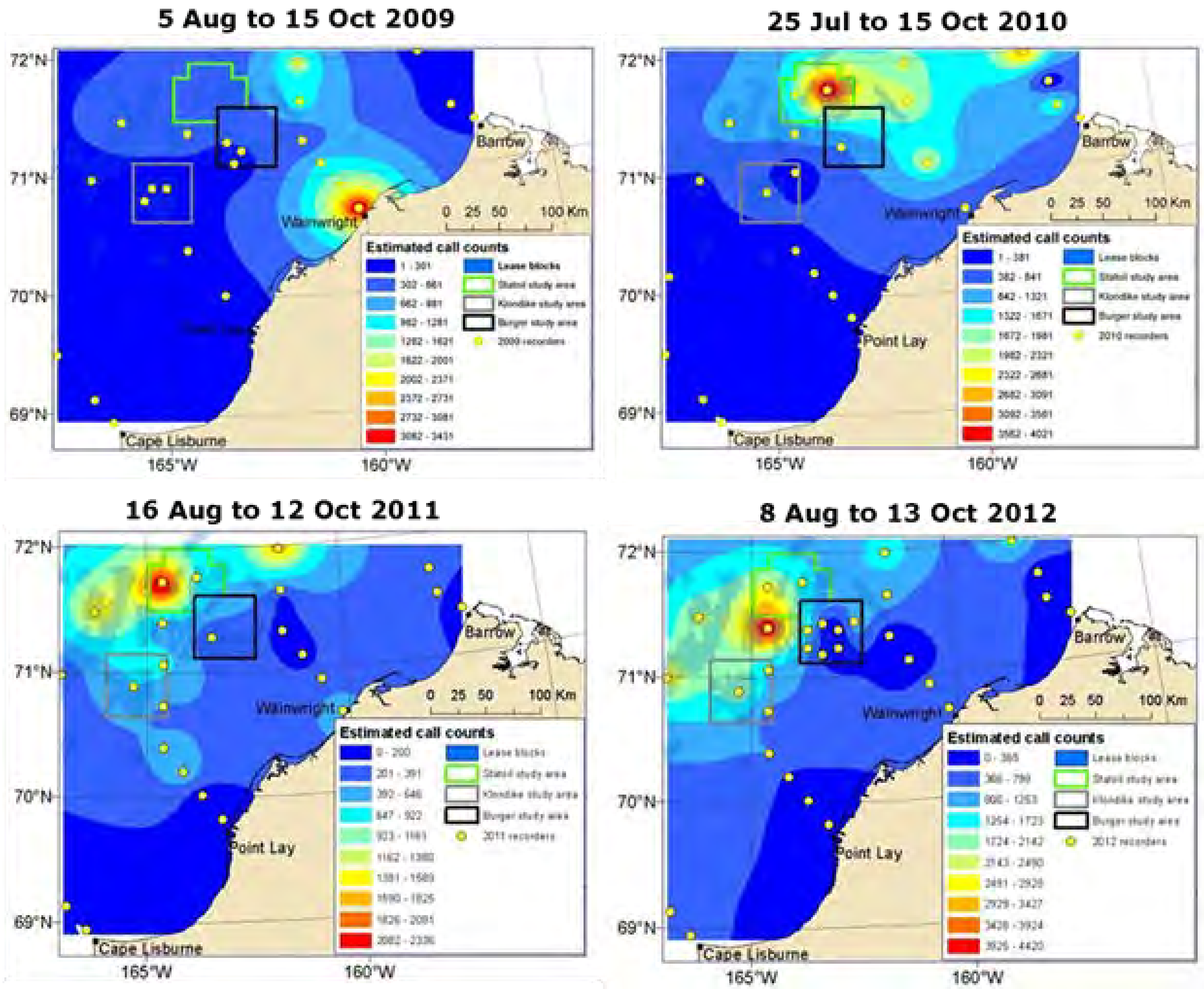


Figure 55. Summer bearded seal call counts: Radial basis-interpolated call counts based on the sum of automated call detections in all files with manual detections at all summer recording stations in the northeastern Chukchi Sea.

5. Conclusion

5.1. Winter 2011–2012 Program

The winter 2011–2012 Joint Acoustic Monitoring Program provided information about ambient noise levels and biological sounds including marine mammal vocalizations[3] in the northeastern Chukchi Sea from August 2011 to 2012.

Key results and conclusions:

- Ambient sound levels were influenced by weather (wind speed), ice presence, and marine mammal vocalizations. The ambient sound spectral levels were within the ranges of the Wenz curves (see Figure 7).
- The winter recordings revealed regular marine mammal presence throughout the winter. Bearded seal sounds were a major contributor to ambient noise in spring, and were detected from October until early July. Bowhead whale calls were predominant from mid-October until 1 Dec 2011.
- The last fall detections of bowheads, belugas, and walrus occurred earlier than the average last detection date observed from the four previous winter programs. The first detection also occurred later than the average first detection date, though in the case of walrus this may be confounded by recordings stopping earlier at stations where they are usually detected first.
- Fall distribution of bowhead and beluga whales was consistent with previous years. Although this may be effort-related, there were fewer spring bowhead detections at stations beyond 50 nmi from shore than in other years. In contrast, beluga whales were detected broadly in the spring. This confirms that although many individuals migrate through the lead system forming along the coast, others travel far offshore and through the lease areas on their way to the Beaufort Sea.
- Walrus acoustic presence in the fall was strong on the Hanna Shoal recorders until mid-October and limited throughout the study area after that. There were few walrus detections in the spring due to a strong decrease in the number of active recorders during their normal period of occurrence.
- Ringed seal calls were detected throughout the deployment with no obvious spatio-temporal trends. As in previous years, the analysis protocol combined with low calling rates presumably results in an underestimation of their occurrence.

[3] 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.

5.2. Summer 2012 Program

The summer 2012 Joint Acoustic Monitoring Program in the northeastern Chukchi Sea provided marine mammal and seismic airgun acoustic detection results, and compared them with results from previous years' Acoustic Monitoring Programs.

Key findings:

- Median ambient sound levels in the Chukchi Sea varied considerably between 2010 and 2012 at frequencies below 100 Hz, reaching differences of up to 20 dB. The large differences are attributed to the presence of 3-D seismic surveys in 2007, 2008, and 2010.
- A wave of bowhead detections occurred in mid-August in the central and western part of the study area. A similar event was observed in 2011. Bowhead detections in the first half of September were most common off Wainwright. Detections off Barrow peaked in the second half of September before spreading west with the onset of the migration across the Chukchi Sea. Bowhead call counts were typically lower in the Burger study area. Preliminary results suggest masking due to higher background noise was not the reason for significantly lower call counts at BG04 and BG05.
- Acoustic masking analysis reveals that at the same SPL, call counts were significantly lower at BG04 and BG05 compared to the other Burger stations; therefore, SPL alone does not account for the difference in the number of call counts. The call contour plots and the masking results suggest that the whales migrated along the northern edge of the Burger study area. With the exception of two isolated detections at PL20 and PL35, there were no detections south of a line running along 70.71° N between Stations W05 and PLN20, indicating that most bowheads migrated north of 71°, as observed in previous years.
- Walrus were the most commonly detected species in the Chukchi Sea in summer. The highest call counts were recorded on the south and southwest sides of Hanna Shoal and at Station PL05. There were marked differences in the number of detection days between the seven Burger stations. This may be explained by masking effects, habitat preferences, or both.
- Beluga calls were detected for a few days in August off Barrow. Most detections occurred in October at B05, B50, and WN40. Overall, detections were rare, as in other years.
- Minke whales were detected acoustically twice in August, once in September and multiple times in October 2012. Most detections occurred within 50 nmi from Point Lay.
- Killer whale detections were widespread in time and space but remained rare overall during the summer 2012.
- Gray whale detections appear largely concentrated with 20 nmi off Wainwright and to a lesser extent between 35–70 nmi from Point Lay. These results are similar to those from 2011.
- Bearded seal acoustic detections were widespread but more concentrated off Wainwright in September and in the northern and northwestern sections of the study area.
- Ribbon seal calls were detected during two days in August and in October. Ringed seal calls were more common and more widely detected even though the current results likely still

underestimate their occurrence. Passive acoustic monitoring may be an appropriate survey tool for ringed seals only if calls can be efficiently automatically detected or if a larger proportion of data can be manually reviewed.

- Species that may benefit from changing conditions in the Arctic (see for instance Moore and Huntington 2008), particularly fin, minke and humpback whales, only occur at low levels and have not been detected often enough to assess any annual trends in occurrence since the beginning of the program.

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Abbreviations & Glossary

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

mi	mile
min	minute
NASA	National Aeronautics and Space Administration (US)
nmi	nautical mile (1 nmi = 1.852 km = 1.15 mi)
NSIDC	National Snow and Ice Data Center
P	precision
P_n	noise power
P_s	signal power
PL*XX*	regional array recorder Station, *XX* nmi from Point Lay
PLN*XX*	regional array recorder Station, *XX* nmi north of Station PL50
pt(s)	point(s)
R	recall
rms	root-mean-square
ROC	receiver operating characteristic
SEL	sound exposure level (dB re 1 $\mu Pa^2 \cdot s$)
Shell	Shell Exploration and Production Company
SNR	signal-to-noise ratio
SO01	the Statoil lease recorder Station
SPL	sound pressure level (dB re 1 μPa)
Statoil	Statoil USA Exploration and Production Inc.
STFT	short-time Fourier transform
TB	terabyte (1TB = 10244 bytes)
Ti	duration index
TP	true positive
TPR	true-positive rate
TN	true negative
USCRN	United States Climate Reference Network
UTC	Coordinated Universal Time
W*XX*	regional recorder Station *XX* nmi from Wainwright
WN*XX*	regional recorder Station *XX* nmi north of Station W50

Literature Cited

Abbot, T.A., V.E. Premus, and P.A. Abbot. 2010. A real-time method for autonomous passive acoustic detection classification of humpback whales. *Journal of the Acoustical Society of America.* 12:2894–2903.

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

Austin, M. E. 2012. *Modelling three-dimensional sound propagation in wedge environments*. PhD Dissertation, University of Victoria, Victoria, BC.

Balanda, K. and H. MacGillivray. 1988. Kurtosis: a critical review. *The American Statistician.* 42:111–119.

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

Belikov, R.A. and V.M. Bel'kovich. 2008. Communicative pulsed signals of beluga whales in the reproductive gathering off Solovetskii Island in the White Sea. *Acoustical Physics.* 54:115–123.

[BRP] Bioacoustics Research Program. 2010. *Passive Acoustic Monitoring of Marine Mammals in the Chukchi Sea 9 September–14 October 2008*. Final Report. 31 March 2010. Technical Report 10-04 by Cornell Lab of Ornithology, prepared for ConocoPhillips Alaska, Inc., 49 pp.

Blackwell S.B., T.L. McDonald, K.H. Kim, L.A.M Aerts., J.W. Richardson, et al. 2012. Directionality of bowhead whale calls measured with multiple sensors. *Marine Mammal Science*. 28, p 200–212.

Breiman, L. 2001. Random Forests. *Machine Learning.* 45:5–32.

Breiman, L., J. Friedman, R. Olshen, and C. Stone. 1984. *Classification and Regression Trees*. Wadsworth International Group, Belmont, CA.

Burns, J.J. 1981. Bearded seal, *Erignathus barbatus* (Erxleben, 1777). In: Handbook of Marine Mammals (Ed. By S.R. Ridgway & R.J. Harrison), pp. 145-170. London: Academic Press.

[CSESP] Chukchi Sea Environmental Studies Program www.chukchiscience.com

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

Clark, C.W., W.T. Ellison, and K. Beeman. 1986. *An Acoustic Study of Bowhead Whales, Balaena mysticetus, off Point Barrow, Alaska During the 1984 Spring Migration*. A Report to the North Slope Borough, Department of Wildlife Management. Marine Acoustics. 145 pp.

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

Cleator, H.J., I. Stirling, and T.G. Smith. 1989. Underwater vocalizations of the bearded seal (*Erignathus barbatus*). *Canadian Journal of Zoology.* 67, 1900-1910.

Cleator, H.J. and I. Stirling. 1990. Winter distribution of bearded seals (*Erignathus barbatus*) in the Penny Strait Area, Northwest Territories, as determined by underwater vocalizations. *Canadian Journal of Fisheries and Aquatic Sciences.* 47, 1071-1109.

Cleator, H.J. 1996. The status of the bearded seal, *Erignathus barbatus* in Canada. *Canadian Field Naturalist.* 110, 501-510.

Clemins, P.J. and M.T. Johnson. 2006. Generalized perceptual linear prediction features for animal vocalization analysis. *Journal of the Acoustical Society of America.* 120:527–534.

Clemins, P.J., M.T. Johnson, K.M. Leong, and A. Savage. 2005. Automatic classification and speaker identification of African elephant *Loxodonta africana* vocalizations. *Journal of the Acoustical Society of America.* 117: 956–963.

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

Cummings, W.C. and D.V. Holliday. 1985. Passive acoustic location of bowhead whales in a population census off Point Barrow, Alaska. *Journal of the Acoustical Society of America.* 78: 1163-1169.

Cummings, W. C. and D.V. Holliday. 1987. Sounds and source levels from bowhead whales off Pt. Barrow, Alaska. *Journal of the Acoustical Society of America.* 82: 814-821.

Davis, J. and M. Goadrich. 2006. The relationship between precision-recall and ROC curves. *Proc. 23rd Intl. Conf. Machine Learning (ICML)*, Pittsburgh, PA.

Delarue, J., M. Laurinolli, and B. Martin. 2009. Bowhead whale (*Balaena mysticetus*) songs in the Chukchi Sea between October 2007 and May 2008. *Journal of the Acoustical Society of America.* 126:3319–3328.

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

Delarue, J., B. Martin, X. Mouy, J. MacDonnell, D. Hannay, N.E. Chorney, and J. Vallarta. 2010*b*. Northeastern Chukchi Sea Joint Acoustic Monitoring Program 2008–2009. Technical report for ConocoPhillips Company, Shell Exploration & Production Company, and Statoil USA E&P, Inc. by JASCO Applied Sciences.

Delarue, J., B. Martin, X. Mouy, J. MacDonnell, D. Hannay, N.E. Chorney, and J. Vallarta. 2011*a*. Northeastern Chukchi Sea Joint Acoustic Monitoring Program 2009–2010. Technical report for ConocoPhillips Company, Shell Exploration & Production Company, and Statoil USA E&P, Inc. by JASCO Applied Sciences.

Delarue, J., M. Laurinolli, and B. Martin. 2011*b*. Acoustic detections of beluga whales in the northeastern Chukchi Sea, July 2007 to July 2008. *Arctic.* 64(1): 15–24.

Delarue, J., J. MacDonnell, B. Martin, X. Mouy, D. Hannay, N.E. Chorney, and J. Vallarta. 2012. Northeastern Chukchi Sea Joint Acoustic Monitoring Program 2010–2011. JASCO Applied Sciences Document 00301, Version 1.0. Technical report for ConocoPhillips Company, Shell Exploration & Production Company, and Statoil USA E&P, Inc. by JASCO Applied Sciences. Available at https://www.chukchiscience.com/DesktopModules/Bring2mind/DMX/Download.aspx?EntryId=72&PortalId=5&DownloadMethod=attachment

Delarue, J., B. Martin, D. Hannay, and C.L. Berchok. 2013. Acoustic occurrence and affiliation of fin whales detected in the northeastern Chukchi Sea, July to October 2007–2010. *Arctic.* 66 (2): 159-172.

Diachok, O.I. 1976. Effects of sea-ice ridges on sound propagation in the Arctic Ocean. *Journal of the Acoustical Society of America.* 59(5): 11.

Ding Hui, Bo Qian, Yanping Li, Zhenmin Tang. 2006. A method combining lpc-based cepstrum and harmonic product spectrum for pitch detection. IIH-MSP. *Intl. Conf. Intelligent Information Hiding and Multimedia Signal Processing (IIH-MSP'06)*. pp 537–540.

Dunlop, R.A., M.J. Noad, D.H. Cato, and D. Stokes. 2007. The social vocalization repertoire of east Australian migrating humpback whales (*Megaptera novaeangliae*). *Journal of the Acoustical Society of America.* 122: 2893–2905.

[ESA] Endangered Species Act of 1973 as Amended. 2002. United States Pub. L. No. 93–205, 87 Stat. 884, 16 U.S.C. 1531 (Dec 28, 1973) as amended by Pub. L. No. 107–136 (Jan 24, 2002).

Erbe, C. 2002. *Hearing abilities of baleen whales*. DRDC Atlantic Report CR2002-065. Defence Research & Development Canada—Atlantic. http://pubs.drdc.gc.ca/PDFS/unc09/p519661.pdf.

Erbe, C. 2009. Underwater noise from pile driving in Moreton Bay, Qld. *Acoustics Australia.* 37(3): 87-92.

Erbe, C. and D.M. Farmer. 2000. Zones of impact around icebreakers affecting beluga whales in the Beaufort Sea. *Journal of the Acoustical Society of America.* 108(3): 1332–1340.

Erbe, C. and J. King. 2008. Automatic detection of marine mammals using information entropy. *Journal of the Acoustical Society of America.* 124: 2833.

Ford, J.K.B. 1989. Acoustic Behavior of Resident Killer Whales (*Orcinus Orca*) off Vancouver Island, British-Columbia. *Canadian Journal of Zoology*. 67(3):727–745.

Fristrup, K.M. and W.A. Watkins. 1993. *Marine Animal Sound Classification*. Technical Report WHOI-94-13, Woods Hole Oceanographic Institution, Woods Hole, MA. 32 p.

Frost, K.J., L.F. Lowry, and G. Carroll. 1993. Beluga whale and spotted seal use of a coastal lagoon system in the northeastern Chukchi Sea. *Arctic*. 46(1): 7–16.

Funk, D.W., D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.). 2009. *Joint Monitoring Program in the Chukchi and Beaufort Seas, Open Water Seasons 2006–2008*. LGL Alaska Rep. P1050-1. Report from LGL Alaska Research Associates Inc., LGL Ltd., JASCO Research Ltd., and Greeneridge Sciences Inc. for Shell Offshore Inc., ConocoPhillips Alaska Inc., Nat. Mar. Fish. Serv., and US Fish and Wildlife Service. 488 p.

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

Gillespie, D. 2004. Detection and classification of right whale calls using an “edge” detector operating on a smoothed spectrogram. *Canadian Acoustics*. 32: 39–47.

Greene, C.R., Jr. 1997. Physical acoustics measurements. (3) In: Richardson, W.J. (ed.). Northstar Marine Mammal Monitoring Program, 1996: Marine Mammal and Acoustical Monitoring of a Seismic Program in the Alaskan Beaufort Sea. LGL Report 2121-2. Report from LGL Ltd. and Greeneridge Sciences Inc. for BP Exploration (Alaska) Inc. and the National Marine Fisheries Service (US).

Greene, C.R. and B.M. Buck. 1979. Influence of atmospheric pressure gradient on under-ice ambient noise. *Journal of the Acoustical Society of America.* 66(S1): S25.

Hannay, D. 2005. *Acoustic Model Validation*. Technical report prepared for Sakhalin Energy.

Hannay, D., B. Martin, M. Laurinolli, and J. Delarue. 2009. Chukchi Sea Acoustic Monitoring Program. *In*: Funk, D.W., D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.). 2009. *Joint Monitoring Program in the Chukchi and Beaufort Seas, Open Water Seasons 2006–2008*. LGL Alaska Report P1050-1. Report from LGL Alaska Research Associates Inc., LGL Ltd., Greeneridge Sciences Inc., and JASCO Research Ltd., for Shell Offshore Inc., and other industry contributors, and National Marine Fisheries Service, US Fish and Wildlife Service. 288 p.

Ireland, D.S., W.R. Koski, T.A. Thomas, J. Beland, C.M. Reiser, D.W. Funk, and A.M. Macrander. 2009. *Updated Distribution and Relative Abundance of Cetaceans in the Eastern Chukchi Sea 2006–8*. Paper No. SC/61/BRG4 presented to the IWC Scientific Committee. 14 p.

Karlsen, J.D., A. Bisther, C. Lydersen, T. Haug, and K.M. Kovacs. 2002. Summer vocalisations of adult male white whales (*Delphinapterus leucas*) in Svalbard, Norway. *Polar Biology* 25: 808–817.

Kogan, J.A., and D. Margoliash. 1998. Automated recognition of bird song elements from continuous recordings using dynamic time warping and hidden Markov models: A comparative study. *Journal of the Acoustical Society of America.* 103: 2185–2196.

Kovacs, K.M., C. Lydersen, I. Gjertz. 1996. Birth-site characteristics and prenatal moulting in bearded seals (*Erignathus barbatus*). *Journal of Mammalogy.* 77: 1085-1091.

Krafft, B.A., C. Lydersen, K.M. Kovacs, I. Gjertz, and T. Haug. 2000. Diving behaviour of lactating bearded seals (*Erignathus barbatus*) in the Svalbard area. *Canadian Journal of Zoology.* 78: 1408–1418.

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

Ma, B.B. and J.A. Nystuen. 2005. Passive acoustic detection and measurement of rainfall at sea. *Journal of Atmospheric and Oceanic Technology.* 22(8):24.

MacDonnell, J. and B. Martin. 2011. Estimating bowhead whale communications space using measured and modeled data. *Journal of the Acoustical Society of America.* 129: 2574.

Martin, B., D. Hannay, M. Laurinolli, C. Whitt, X. Mouy, and R. Bohan. 2009. Chukchi Sea acoustic monitoring program. (Chapter 5) In: Ireland, D.S., D.W. Funk, R. Rodrigues, and W.R. Koski (eds.). *Joint Monitoring Program in the Chukchi and Beaufort Seas, open water seasons, 2006–2007*. LGL Alaska Report P971-2. Report from LGL Alaska Research Associates Inc., LGL Ltd., JASCO Research Ltd., and Greeneridge Sciences Inc. for Shell Offshore Inc., ConocoPhillips Alaska Inc., National Marine Fisheries Service (US), and US Fish and Wildlife Service. 485 p. http://www-static.shell.com/static/usa/downloads/alaska/2007_jmp_final_comprehensive_report.pdf

Martin, B., D. Hannay, C. Whitt, X. Mouy, and R. Bohan. 2010. Chukchi Sea acoustic monitoring program. (Chapter 5) In: Funk, D.W., D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.). *Joint Monitoring Program in the Chukchi and Beaufort seas, open water seasons, 2006–2008*. LGL Alaska Report P1050-2. Report from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research, Ltd., for Shell Offshore, Inc. and other industry contributors, the National Marine Fisheries Service (US), and the US Fish and Wildlife Service. 506 p plus appendices. http://s02.static-shell.com/content/dam/shell/static/usa/downloads/alaska/report-2006-2008jmpcomprehensivereportdraftfinal.pdf.

McLaren, I.A. 1958. Some aspects of growth and reproduction of the bearded seal, *Erignathus barbatus* (Erxleben). *Journal of Fisheries Research Board of Canada.* 15: 219-227.

Mellinger, D. 2004. A comparison of methods for detecting right whale calls. *Canadian Acoustics*. 32(2): 55-65.

Mellinger, D.K. 2001. Ishmael 1.0 User's Guide. NOAA. Technical Memorandum OAR PMEL-120, available from NOAA/PMEL/OERD, 2115 SE OSU Drive, Newport, OR, 97365-5258. http://www.pmel.noaa.gov/pubs/PDF/mell2434/mell2434.pdf

Mellinger, D.K. and J.W. Bradbury. 2007. Acoustic measurement of marine mammal sounds in noisy environments. *Proc. Intl. Conf. Underwater Acoustic Measurements: Technologies and Results*, Heraklion, Greece, pp. 273–280.

Mellinger, D.K. and C.W. Clark. 1997. Methods for automatic detection of mysticete sounds. *Marine and Freshwater Behaviour and Physiology*. 29: 163–181.

Mellinger, D.K. and C.W. Clark. 2006. MobySound: A reference archive for studying automatic recognition of marine mammal sounds. *Applied Acoustics* 67:1226–1242. Mellinger, D.K. and C.W. Clark. 2000. Recognizing transient low frequency whale sounds by spectrogram correlation. *Journal of the Acoustical Society of America.* 107: 3518–3529.

Mellinger, D. K., S. W. Martin, R. P. Morrissey, L. Thomas, and J.J. Yosco. 2011. A method for detecting whistles, moans, and other frequency contour sounds. *Journal of the Acoustical Society of America.* 129: 4055-4061.

Mellinger, D.K., K.M. Stafford, S.E. Moore, R.P. Dziak, and H. Matsumoto. 2007. An overview of fixed passive acoustic observation methods for cetaceans. *Oceanography* 20(4):36–45.

Miller, E.H. 1985. Airborne acoustic communication in the walrus *Odobenus rosmarus*. *National Geographic Research.* 1: 124–145.

Moore, S. E. 1992. Summer records of bowhead whales in the northeastern Chukchi Sea. *Arctic.* 45(4): 398-400.

Moore, S.E. and E.I. Barrowclough. 1984. Incidental sighting of a ribbon seal (*Phoca fasciata*) in the western Beaufort Sea. *Arctic.* 37(3): 290–290.

Moore, S. E. and H. Huntington. 2008. Arctic marine mammals and climate change: impacts and resilience. *Ecological Applications*. 18(2): S157–S165

Mouy, X., M. Bahoura, and Y. Simard. 2009. Automatic recognition of fin and blue whale calls for real-time monitoring in the St. Lawrence. *Journal of the Acoustical Society of America.* 126:2918–2928.

Mouy, X., D. Leary, B. Martin, and M. Laurinolli. 2008. A comparison of methods for the automatic classification of marine mammal vocalizations in the Arctic. *New Trends for Environmental Monitoring Using Passive Systems, 2008 (Conf. Proc.)*. Institute of Electrical and Electronics Engineers.

[NCDC] National Climatic Data Center. 2012. *U.S. Climate Reference Network, Station 1007 AK Barrow 4 ENE*. National Oceanic and Atmospheric Administration, U.S. Department of Commerce. http://www.ncdc.noaa.gov/crn/

[NRC] National Research Council. 2003. *Ocean Noise and Marine Mammal*s. National Research Council (US), Ocean Studies Board, Committee on Potential Impacts of Ambient Noise in the Ocean on Marine Mammals. National Academies Press, Washington, DC. 192 p.

NOAA/NESDIS/OSDPD/SSD. 2012. *IMS Daily Northern Hemisphere Snow and Ice Analysis at 4 km and 24 km Resolution*. Boulder, CO: National Snow and Ice Data Center. http://nsidc.org/data/G02156.html

Nosal, E.M. 2008. Flood-fill algorithms used for passive acoustic detection and tracking. *Proc. IEEE Workshop and Exhibition on New Trends for Environmental Monitoring using Passive Systems*, Hyeres, France.

Oswald, J., J. Barlow, and T. Norris. 2003. Acoustic identification of nine delphinid species in the eastern tropical Pacific Ocean. *Marine Mammal Science.* 19: 20–037.

Oswald, J.N., S. Rankin, J. Barlow, and M.O. Lammers. 2007. A tool for real-time acoustic species identification of delphinid whistles. *Journal of the Acoustical Society of America.* 122: 587–595.

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

Quakenbush, L.T., J. Citta, J.C. George, R.J. Small, M.P. Heide-Jørgensen, H. Brower, L. Harwood, B. Adams, L. Brower, G. Tagarook, C. Pokiak, and J. Pokiak. 2012. Seasonal movements of the Bering-Chukchi-Beaufort stock of bowhead whales: 2006–2011 satellite telemetry results. Paper SC/64/BRG1 presented to the Scientific Committee of the International Whaling Commission. Available at http://www.adfg.alaska.gov/static/home/about/management/wildlifemanagement/marinemammals/pdfs/BRG_Bowhead_Sat_tag_Quakenbush_et_al_2012.pdf

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

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

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

Risch, D., Clark, C.W., Corkeron, P.J., Elepfandt, A., Kovacs, K.M., Lydersen, C., Stirling, I., Van Parijs, S.M. 2007. Vocalizations of male bearded seals, *Erignathus barbatus*: classification and geographical variation. *Animal Behaviour.* 73: 747-762.

Ross, D. 1976. *Mechanics of Underwater Noise*. Pergamon Press, New York. 375 p.

Roth, E.H. 2012. Underwater ambient noise on the Chukchi Sea continental slope from 2006-2009. *Journal of the Acoustical Society of America*. 13(1): 7.

Scrimger, P. and R.M. Heitmeyer. 1991. Acoustic source-level measurements for a variety of merchant ships. *Journal of the Acoustical Society of America.* 89(2): 691-699.

Sjare, B.L. and T.G. Smith. 1986. The vocal repertoire of white whales, *Delphinapterus leucas*, summering in Cunningham Inlet, Northwest Territories. *Canadian Journal of Zoology.* 64: 407–415.

Stafford, K.M. 1995. *Characterization of Blue Whale Calls from the Northeast Pacific and Development of a Matched Filter to Locate Blue Whales on U.S. Navy SOSUS (SOund SUrveillance System) arrays*. M.Sc. Thesis, Oregon State University, Corvallis, OR.

Stirling, I. 1973. Vocalization in the ringed seal (*Phoca hispida*). *J. Fisheries Research Board of Canada.* 30: 1592–1594.

Stirling, I., W. Calvert, and H. Cleator. 1983. Underwater vocalizations as a tool for studying the distribution and relative abundance of wintering pinnipeds in the high arctic. *Arctic.* 36: 262–274.

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

Struzinski, W. A. and E.D. Lowe. 1984. A performance comparison of four noise background normalization schemes proposed for signal detection systems. *Journal of the Acoustical Society of America.* 76: 1738–1742.

Suydam, R.S., L.F. Lowry, and K.J. Frost. 2005. Distribution and movements of beluga whales from the 469 eastern Chukchi Sea stock during summer and early autumn. OCS Study MMS 2005-035. Available at: http://www.mms.gov/alaska/reports/2005rpts/2005_035.pdf

Thompson, P.O., W.C. Cummings, and S.J. Ha. 1986. Sounds, source levels, and associated behavior of humpback whales, Southeast Alaska. *Journal of the Acoustical Society of America.* 80: 735–740.

[USFWS] U.S. Fish & Wildlife Service. 2012. *Environmental Conservation Online System: Listed Animals*. U.S. Department of the Interior. http://ecos.fws.gov/tess_public/pub/listedAnimals.jsp (accessed 28 Feb 2012).

Urick, R.J. 1983. *Principles of Underwater Sound*. 3rd edition. McGraw Hill, New York. 423 p.

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

Van Parijs, S., C. Lydersen, and K. Kovacs. 2003. Vocalizations and movements suggest alternative mating tactics in male bearded seals. *Animal Behaviour.* 65: 273-283.

Van Parijs, S., C. Lydersen, and K.M. Kovacs. 2004. Effects of ice cover on the behavioural patterns of aquatic-mating male bearded seals. *Animal Behaviour.* 68: 89-96.

Watkins, W.A. and G.C. Ray. 1977. Underwater sounds from ribbon seal, *Phoca* (*Histriophoca*) *fasciata*. *Fishery Bulletin.* 75: 450–453.

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

Notes on Spectrogram Processing

This report contains many grayscale and color spectrograms representing the spectral evolution with time of sounds recorded during the acoustics programs in the northeastern Chukchi Sea. The horizontal axis of these figures is time and the vertical axis is frequency, so that the plot provides a visualization of time-varying frequency content of the acoustic data. The spectrograms were processed to exploit the visual contrast of the signal of interest for purposes of the discussion, and therefore the displayed traces do not provide a direct measure of the received SPL.

The caption of each spectrogram describes how the spectrogram was created, including:

FFT Size

Number of points (pts) in each fast Fourier transform (FFT). The acoustic data have a sample rate of 16,384 Hz (samples per second), so a 4096 pt FFT has 4 Hz resolution, and a 16,384 pt FFT has 1 Hz resolution.

Real Samples

Number of actual data points in each FFT. Often less than the FFT size. The actual data points are zero-padded out to the FFT size, which allows display of the spectral content at a high frequency-resolution while maintaining sufficient time resolution for short-duration events. Since many signals of interest are short duration transients, fewer real data points were used in the FFT window to more clearly show the rapid time evolution.

Overlap

Number of data points overlapped from one FFT to the next. Generally half the number of real samples, but may be more for finer time resolution.

Window

Type of windowing function applied to the data before FFT to reduce spectral leakage.

Normalization

Most spectrograms in this report are normalized for improved display. Normalization optimizes contrast in each region of the plot so that both weak and intense signals are similarly visible. As a result, the displayed grayscales or colors no longer represent the sound spectral pressure level as they would without normalization. The normalization scheme applied here is:

For each frequency bin, compute the average level over the entire file.

For each time step, compute a moving average of the results from Step 1, with a frequency bandwidth of 200 Hz.

Normalize each time-frequency bin by the average of Step 1, and the value from Step 2 that is 300 Hz above the current frequency.

Appendix A. Automated Detection and Classification of Marine Mammal Vocalizations

A.1. Introduction

This appendix describes the methods developed by JASCO Applied Sciences Ltd. for automated detection of beluga whistles, bowhead moans, bowhead songs, and walrus grunts within the data collected during the winter 2011−2012 and summer 2012 Chukchi Sea Joint Acoustic Monitoring Programs (AMPs). The algorithms JASCO developed and their performance are described.

Methods to automatically detect and classify marine mammal vocalizations[4] in digital acoustic recordings have been developed over several decades. The variability of the target vocalizations influences the performance of detection algorithms. Some species, such as fin and blue whales, produce highly stereotyped vocalizations, which are easier to detect automatically than are more variable sounds. For these stereotyped vocalizations, template-matching methods such as matched filter (Stafford 1995) and correlation of spectrograms (Mellinger and Clark 1997, 2000, Mouy et al. 2009) are generally effective (Mellinger et al. 2007). Other species produce more variable and complex tonal sounds that are more difficult to detect and classify. Such vocalizations generally require band-limited energy summation for detection, followed by statistical classification techniques to identify species (Fristrup and Watkins 1993, Oswald et al. 2003). Several classification methods have been investigated for belugas (Clemins and Johnson 2006, Mouy et al. 2008), dolphins (Oswald et al. 2007), humpback whales (Abbot et al. 2010), elephants (Clemins et al. 2005), and birds (Kogan and Margoliash 1998).

Acoustical surroundings also influence how well detection algorithms perform. Noise generated by anthropogenic activities such a shipping and seismic exploration, or by weather such as wind, rain, and waves, may be mistaken as biological. Increased ambient noise reduces the signal-to-noise ratio of vocalizations, making them harder to detect and classify. The sound propagation characteristics of the study area can alter the spectral and temporal structure of received vocalizations, which can interfere with detection and classification algorithms that have worked well in a different propagation environment. The presence of other marine animals vocalizing in the frequency band of interest also greatly increases the risk of misclassification. The influences of these factors generally also vary with time. Consequently, methods shown to be successful for a specific location, season, and species may not be successful under different circumstances.

The Chukchi Sea AMP recordings contain vocalizations produced by several species of marine mammals, including bowhead (*Balaena mysticetus*), beluga (*Delphinapterus leucas*), gray (*Eschrichtius robustus*), fin (*Balaenoptera physalus*), and killer (*Orcinus orca*) whales, walrus (*Odobenus rosmarus*), and various ice seals. Vocalizations produced by several of these species

[4] 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.

share frequency bands and can occur in the same period of the year. For instance, certain vocalizations produced by bowheads and walrus have similar durations and frequency ranges. While an experienced human analyst can usually distinguish between those vocalizations, creating computer algorithms to do the same is not simple.

Multiple sources contribute to ambient noise in the eastern Chukchi Sea. In winter, ice noise is highly problematic for automated detection algorithms—ice cracking sounds can be emitted at surprisingly regular intervals, which resemble walrus knocks. Ice squeaking sounds are often in the frequency range of beluga vocalizations. Detection algorithms, therefore, must be well adapted to the variable and overlapping vocalizations of the species that frequent the eastern Chukchi Sea as well as robust against the surrounding noise background. Because many terabytes of data are collected during the Chukchi Sea AMPs, the automated analysis methods must also be computationally efficient, with computing times taking no less than five times real time (per processor).

A.2. Bowhead and Beluga Call Detection and Classification

The bowhead acoustic repertoire includes low-frequency moans (< 1 kHz) produced in summer and higher frequency, more complex songs produced in fall and early winter (Delarue et al. 2009). Belugas produce tonal whistles in the 1–8 kHz frequency band (Karlsen et al. 2002).

Because these three sound types are produced in different frequency bands, three unique detectors and classifiers were created for:

- Bowhead winter and fall songs
- Bowhead summer moans
- Beluga whistles

To optimize performance on the call type of interest, each detector has unique spectrogram settings. The output of each detector was run through its associated classifier.

The detection/classification process consists of the following steps:

1. Creating the normalized spectrogram.
2. Extracting the time-frequency contours using the tonal detector developed by Mellinger et al. 2011.
3. Extracting 46 features from each contour to create binary random forest models.
4. Classifying the contours as either “target species” (bowhead or beluga) or “other” with the random forest models.
5. Post-processing of bowhead moans and songs to combine parts of single calls that were detected separately.

Once random forest models were created for bowhead moans, bowhead songs, and beluga whistles, they were tested on the test datasets described in Section A.5. The detection/classification process is described in detail in the following sections.

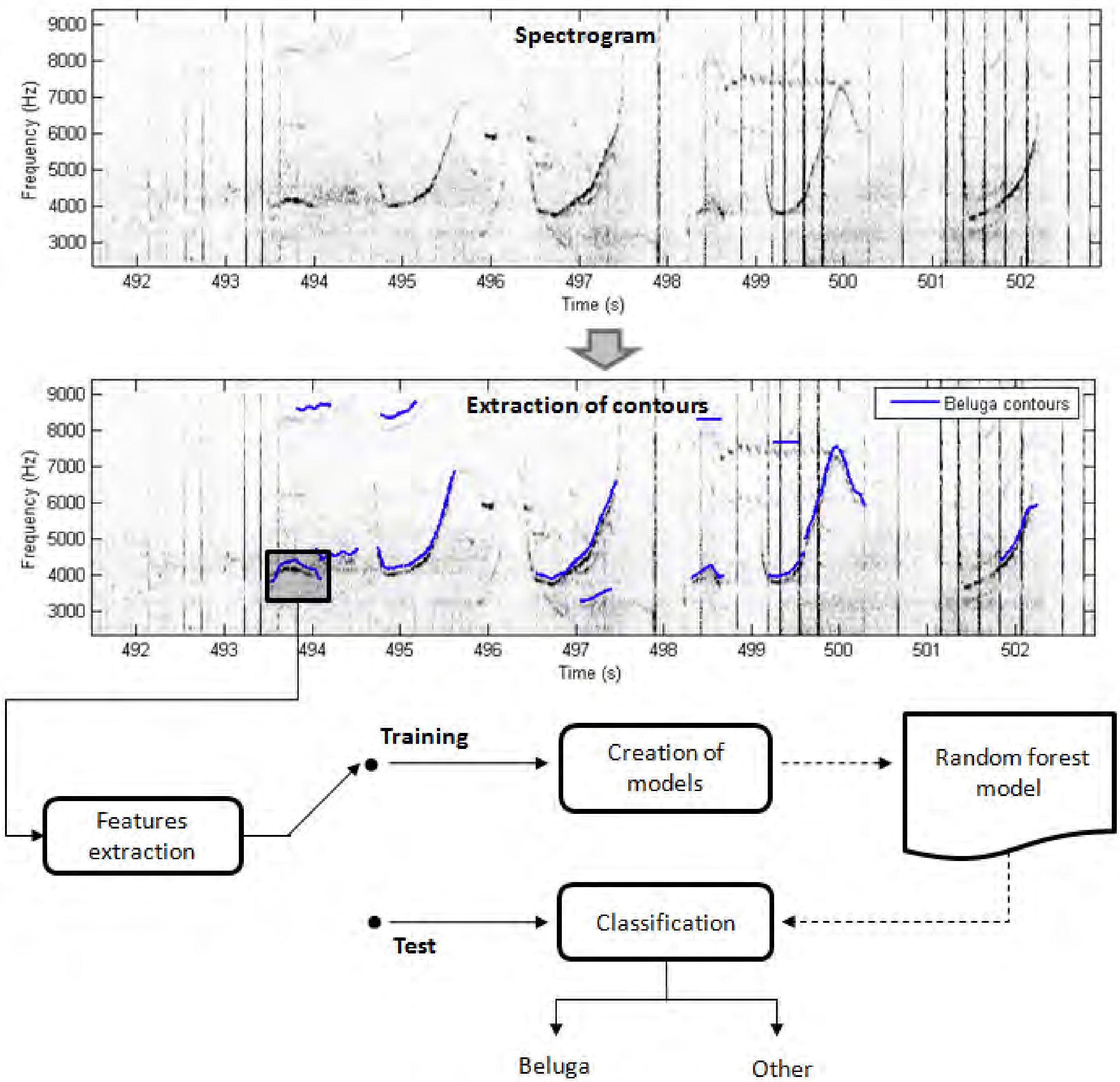

Figure A.1. Steps in the detection/classification process.

A.2.1. Step 1: Spectrogram Processing

The first step of the detection process was the calculation of the spectrogram. Spectrogram resolutions differed for each species to ensure accurate time-frequency representation of the calls (Table A.1). To attenuate long spectral rays in the spectrogram due to vessel noise and to enhance weaker transient biological sounds, the spectrogram was normalized in each frequency band (i.e., each row of the spectrogram) with a split-window normalizer. The size of the window and the notch of the normalizer are indicated in Table A.1. For the processing of beluga whistles, the spectrogram was smoothed by convolving it with a 2-D Gaussian kernel (Gillespie 2004). Gaussian smoothing was not used for analyzing bowhead calls because it did not improve the performance of the contour extraction.

Table A.1. Spectrogram parameters for each call type.

	Bowhead winter songs	Bowhead summer moans	Beluga whistles
Analysis frame size (samples)	4096	4096	1024
Overlap between frames (samples)	3500	3500	896
FFT size (samples)	16,384	16,384	1024
Window function	Hanning	Hanning	Blackman
Normalizer window size (s)	1.5	1.5	0.7
Normalizer notch size (s)	0.4	0.4	0.1
Gaussian kernel size (bins)	n/a	n/a	3×3

A.2.2. Step 2: Contour Extraction

Vectors representing the time-evolution of the fundamental frequency of marine mammal calls (referred to as “contours”) were extracted from the spectrograms with the MATLAB version of a tonal detector developed by Mellinger et al. 2011. This tonal detector is implemented in the latest version of the widely-used Ishmael acoustic analysis software (Mellinger 2001). The algorithm works as follows, based on user-defined parameters (chosen empirically, Table A.2):

1. Candidate frequency peaks were identified for each time slice of the spectrogram in the frequency band [f_0, f_1]. Peaks of height h (dB) above the noise threshold (defined as the percentile P_{bg} of the spectrum values) that are the highest point in their neighborhood (n Hz wide) were selected.
2. Successive peaks differing in frequency by less than f_d were connected.
3. To accurately follow simultaneous calls, the location of the next candidate peak was estimated by fitting a line to the most recent k seconds of the contour and looking for spectral peaks where the line continues.
4. Candidate contours must persist for a minimum duration d.

Figure A.1 shows an example of contours extracted from a recording containing beluga whistles.

Table A.2. Contour extraction parameters for each call type.

Symbol	Description	Bowhead winter songs	Bowhead summer moans	Beluga whistles
P_{bg}	Percentile for estimating background noise	50	50	50
h	Height above that estimate (dB)	2	2	1.2
n	Neighborhood width (Hz)	50	50	250
f_d	Frequency difference from one step to the next (Hz)	25	25	300
d	Minimum duration (s)	0.5	0.5	0.3
k	Duration for estimating next spectral peak location (s)	0.2	0.2	0.2
f_0	Minimum frequency (Hz)	1000	50	50
f_1	Maximum frequency (Hz)	1000	50	8000

A.2.3. Step 3: Feature Extraction

Using custom MATLAB software, 46 features were measured from each extracted time-frequency contour. These features describe the frequency content, duration, and shape of the contour (slopes, number of inflection points, etc., Table A.3).

Table A.3 The 46 features measured from each time-frequency contour.

Feature	Definition
Beginning sweep	Slope at the beginning of the call (1=positive, −1=negative, 0=flat)
Beginning up	Binary variable: 1=beginning slope is positive, 0=beginning slope is negative
Beginning down	Binary variable: 1=beginning slope is negative, 0=beginning slope is positive
End sweep	Slope at the end of the call (1=positive, −1=negative, 0=flat)
End up	Binary variable: 1=ending slope is positive, 0=ending slope is negative
End down	Binary variable: 1=ending slope is negative, 0=ending slope is positive
Duration	Call duration (s)
Beginning frequency	Frequency at start of call (Hz)
End frequency	Frequency at end of call (Hz)
Minimum frequency, f_{min}	Minimum frequency (Hz)
Maximum frequency, f_{max}	Maximum frequency (Hz)
Frequency range	$f_{max}–f_{min}$ (Hz)
Mean frequency	Mean of frequency values (Hz)
Median frequency	Median of frequency values (Hz)
Standard deviation frequency	Standard deviation frequency values (Hz)
Frequency spread	Difference between the 75th and 25th percentiles of the frequency
Quarter frequency	Frequency at one-quarter of the duration (Hz)
Half frequency	Frequency at one-half of the duration (Hz)
Three-quarter frequency	Frequency at three-quarters of the duration (Hz)
Center frequency, f_c	$(f_{max}–f_{min})/2 + f_{min}$
Relative bandwidth	$(f_{max}–f_{min})/f_c$
Maxmin	f_{max}/f_{min}
Begend	Beginning frequency/end frequency
Steps	Number of steps (≥ 10% increase or decrease in frequency over two contour pts)
Inflection points	Number of inflection points (changes from positive to negative slope or *vice versa*)
Max delta	Maximum time between inflection points
Min delta	Minimum time between inflection points
Maxmin delta	Max delta/Min delta
Mean delta	Mean time between inflection points
Standard deviation delta	Standard deviation of the time between inflection points
Median delta	Median of the time between inflection points
Mean slope	Overall mean slope
Mean positive	Mean positive slope
Mean negative	Mean negative slope
Mean absolute	Mean absolute value of the slope

Feature	Definition
Ratio posneg	Mean positive slope/Mean negative slope
Percent up	Percentage of the call having positive slope
Percent down	Percentage of the call having negative slope
Percent flat	Percentage of the call having zero slope
Up-down	Number of inflection points going from positive to negative slope
Up-flat	Number of times the slope changes from positive to zero
Flat-down	Number of times the slope changes from zero to negative
Step-up	Number of steps with increasing frequency
Step-down	Number of steps with decreasing frequency
Step-duration	Number of steps/Duration
Inflection-duration	Number of inflection points/Duration

A.2.4. Step 4: Classification

A random forest classifier was created for each call type (bowhead winter songs, bowhead summer moans, and beluga whistles). A random forest is a collection of decision trees that grow using binary partitioning of the data based on the value of one of the 46 features (see Table A.3) at each branch, or node. Randomness is injected into the tree-growing process by choosing the feature to use as the splitter based on a random subsample of the features at each node (Breiman 2001). Each of these random forests was a binary classifier, so contours were classified as "target species" (i.e., bowhead or beluga whale) or "other".

The number of decision trees to include in each random forest was determined by empirical trials on datasets of calls extracted from annotated recordings. Recordings made during previous year's AMPs were used to train and optimize the random forests: winter 2008–2009 program data for the bowhead winter song and beluga whistle detectors, and summer 2009 program data for the bowhead summer moan detector. Contours were detected and extracted based on parameters specific to bowhead or beluga sounds (Table A.2).

Sample sizes for each trial dataset are given in Table A.4. First, these datasets were randomly sampled so each class ("target species" and "other") had equal sample sizes. Sampling was performed so that the proportion of species and call-types within species in the "other" class reflected those in the full dataset. Next, a random forest analysis was run on the sampled data. The sampling and random forest analysis were each repeated 100 times. The output for each random forest analysis included out-of-bag (OOB) error estimates for forests of 1–800 trees. To calculate OOB errors, each tree was grown using about two-thirds of the trial data. The remaining third of the trial data was used as the OOB test data, which was used to evaluate the performance of the tree. The OOB error estimates were averaged over 100 runs (Figure A.2). The number of decision trees to include in the random forest was when the OOB error approached its asymptote, because after this point adding more trees did not result in significantly better classifications. Based on these analyses, all three random forests had 300 decision trees.

Table A.4. Sample size of the trial datasets used to train and optimize the random forest classifiers for each call type.

Class	Winter 2008–2009 beluga whistles	Winter 2008–2009 bowhead songs	Summer 2009 bowhead moans
Beluga	1295	24	0
Bowhead	2837	3989	754
Bearded seal	20,331	17,887	269
Non-biological noise	9443	6491	536
Ribbon seal	530	0	0
Unknown	864	1148	1177
Walrus	483	199	625
Killer whale	0	0	13

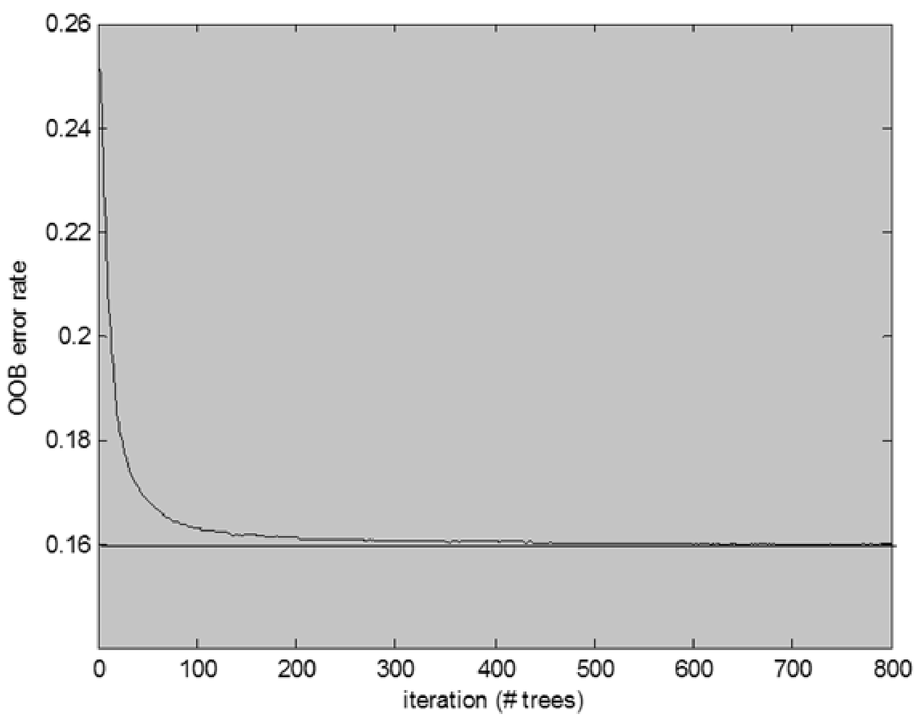

Figure A.2. Out-of-bag (OOB) error rates averaged over 100 random forest runs (example of the beluga whistle classifier).

Another output of the random forest analysis is the Gini importance index (Breiman et al. 1984), which measures how strongly each feature contributes to the random forest model predictions. The optimal subset of features included in each random forest was based on this importance index. Feature importance was averaged over all 100 runs, which were described above (Figure A.3). The three random forests included the features most important to the model predictions (Table A.5).

Table A.5. Features included in bowhead moan, bowhead song, and beluga whistle random forests, listed in order of importance to the model.

Bowhead moan	Bowhead song	Beluga whistle
Minimum frequency	Maximum frequency	Mean frequency
Median frequency	Center frequency	End frequency
Mean frequency	Beginning frequency	Median frequency
Three-quarter frequency	Mean frequency	Three-quarter frequency
End frequency	End frequency	Center frequency
Half frequency	Mean slope	Half frequency
Quarter frequency	Median frequency	Maximum frequency
Beginning frequency	Quarter frequency	Quarter frequency
Duration	Three-quarter frequency	Minimum frequency
Center frequency	Half frequency	Beginning frequency
Mean negative slope	Mean absolute slope	

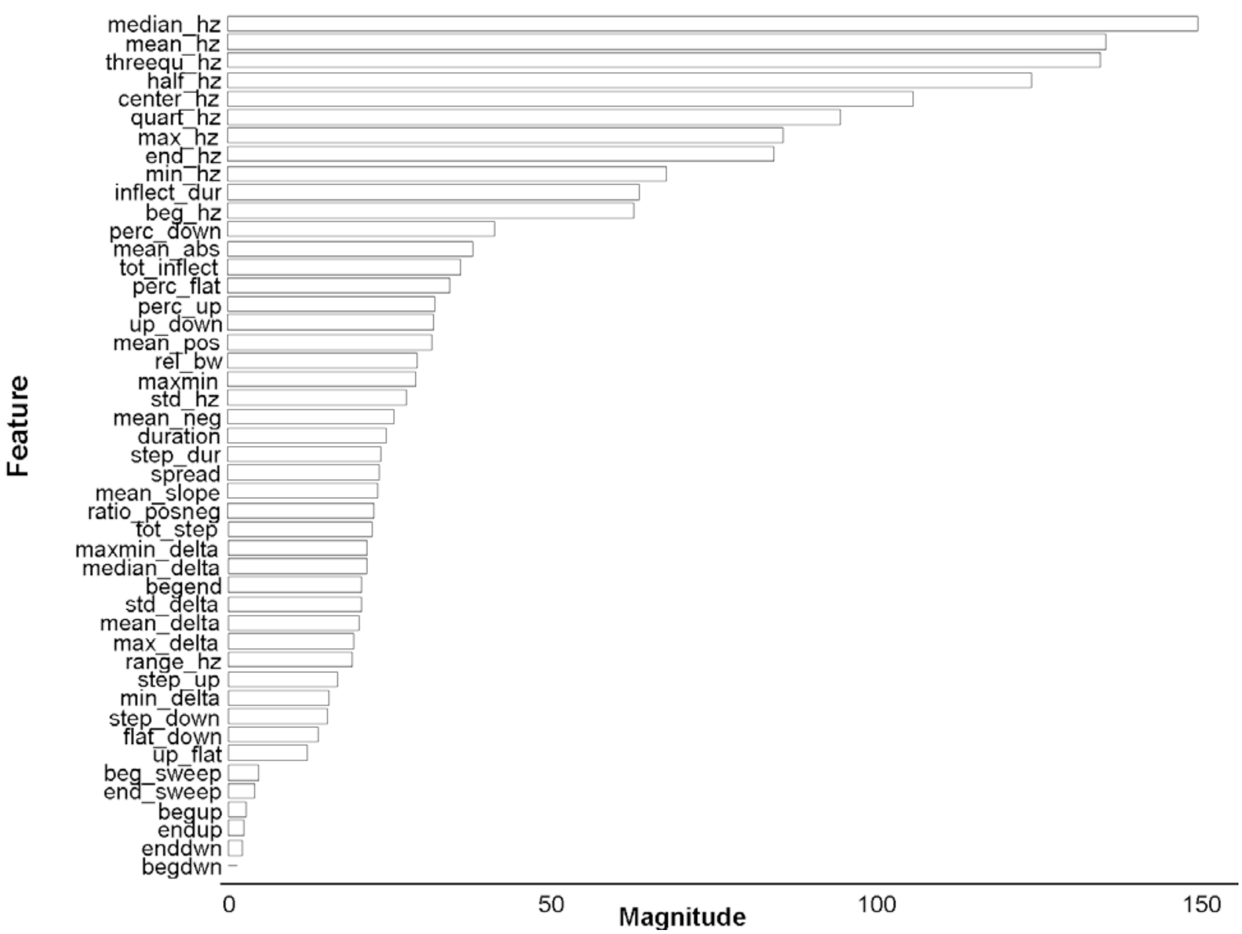

Figure A.3. Gini importance indices; averaged over 100 random forest runs.

A.2.5. Step 5: Post-Processing

Bowhead calls recorded in the winter program generally consisted of several harmonics, which the automated detector considered separate calls, thus overestimating the number of calls in the recordings. To avoid this, all bowhead detections that overlapped in time were merged to form a single detection. Also, only detections occurring below 300 Hz were considered. No post-processing was performed on beluga detections.

A.3. Walrus Grunt Detection and Classification

The algorithm first calculated the spectrogram and normalized it for each frequency band. An energy detector in the frequency band 50−600 Hz detected events in the spectrogram. For each detection, a set of features representing salient characteristics of the spectrogram were extracted in the frequency band 50–600 Hz. Extracted features were presented to a four-class random forest classifier to determine the class of the sound detected (i.e., “walrus grunt” , “seismic”, “bowhead”, or “other”). During the training phase, features of known sounds (i.e., manual annotations) were extracted to create the random forest model. Figure A.4 illustrates the detection process.

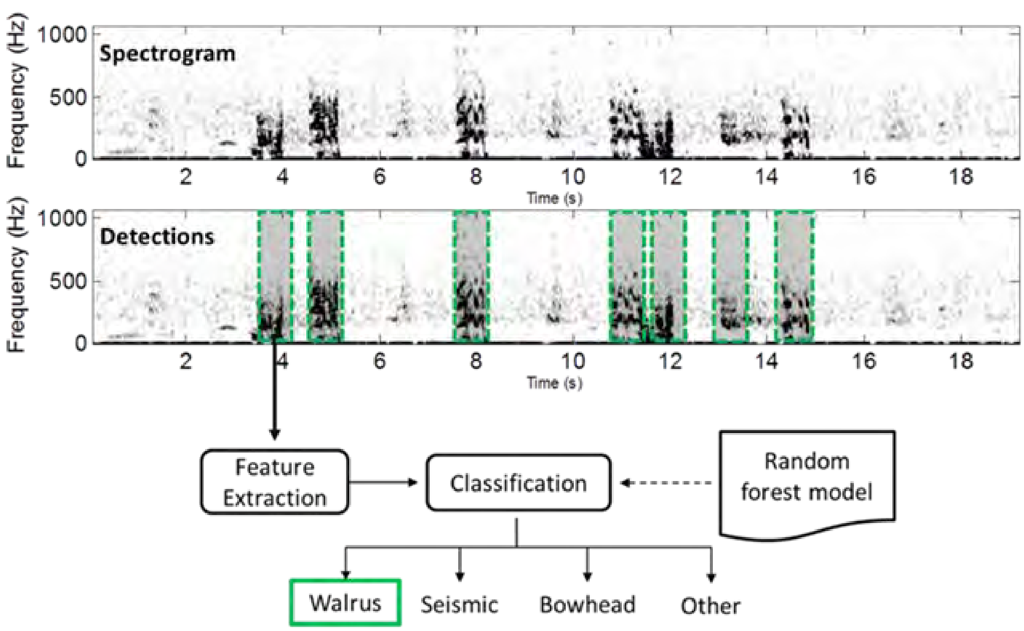

Figure A.4. Steps of the walrus grunt detector.

A.3.1. Step 1: Spectrogram Processing

The spectrogram resolution was chosen to ensure accurate time-frequency representation of the walrus grunts (Table A.6). The spectrogram was normalized by the averaged spectrum calculated over every 80 s of the recording.

Table A.6. Spectrogram parameters used in the walrus grunt detector.

Spectrogram parameters	Walrus Grunts
Analysis frame size (samples)	1024
Overlap between frames (samples)	896
FFT size (sample)	2048
Window function	Blackman

A.3.2. Step 2: Events detection

First, energy values in the normalized spectrogram below an empirically defined threshold of 2 were set to 0. Second, a detection function was created by calculating the mean of the amplitude in the normalized spectrogram every 25 ms (3 spectrogram bins) on a 50 ms long window (6 spectrogram bins) in the 50–600 Hz frequency band. Finally, a detection threshold T was chosen empirically and sections of the detection function exceeding this threshold were considered acoustic events (T = 0.15). Only detections longer than 100 ms were kept and classified.

A.3.3. Step 3: Feature Extraction

Each detection was represented by 20 features, several which were calculated following Fristrup and Watkins (1993) and Mellinger and Bradbury (2007), using the spectrogram, frequency envelope, and amplitude envelope of the signal (Figure A.5a, b, and c, respectively). The frequency envelope is the sum of the spectrogram amplitudes for each frequency. The maximum of the frequency envelope was normalized to 1. The amplitude envelope is the sum of the spectrogram amplitude values for each time step.

These are the measured features:

- *Median frequency*, f_{med} (*F1*): Based on the frequency envelope. The cumulative sum of the spectrum was calculated by moving from low to high frequencies. The median frequency is the frequency at which the cumulative energy reaches 50% of the total energy (green dashed line in Figure A.5b).
- *Spectral inter-quartile range* (*F2*): Calculated by defining the 25th percentile of the energy on each side of the median frequency (dashed blue lines in Figure A.5b). Each quartile was defined as frequency for which the cumulative energy calculated from the median frequency equaled 25% of the total energy. The spectral inter-quartile range is the difference between the higher (f_{Q3}) and lower quartiles (f_{Q1}).
- *Spectral asymmetry* (*F3*): Skewness of the spectral envelope calculated as $(f_{Q1} + f_{Q3} – 2f_{med})/(f_{Q1} + f_{Q3})$.
- *Spectral concentration* (*F4*): Calculated by ranking amplitude values of the spectral envelope from largest to smallest. The cumulative sum of ranked amplitude values was computed beginning with larger values until 50% of the total energy was reached. The lowest frequency index included in the additive set was considered the minimum; the highest index was the

maximum, with their difference providing the spectral concentration (red box in Figure A.5b).

- *Maximum frequency peak* (*F5*): Frequency of the highest amplitude peak in the spectral envelope (red dot in Figure A.5b).
- *Maximum frequency peak width* (*F6*): Width (Hz) of the maximum frequency peak measured at the point where amplitude values on each side of the peak reached the 75th percentile of all the spectral envelope amplitude values (red vertical line in Figure A.5b).
- *Second frequency peak* (*F7*): Frequency of the second highest peak in the spectral envelope.
- *Comparison of the maximum and second frequency peaks* (*F8, F9*): Amplitude ratio and frequency difference between the maximum and second frequency peaks.
- *Variance and kurtosis of frequency envelope* (*F10, F11*): These describe the distribution of the amplitude in the spectral envelope (Balanda and MacGillivray 1988).
- *Frequency modulation index* (*F12*): Calculated as follows:
  - o First, the maximum frequency of the maximum amplitude peak was extracted for each time slice of the spectrogram. Frequency values of the selected peaks were stored in the vector F_{max}, and their associated energy values in the vector E_{max}. Only peaks with an amplitude value exceeding the median amplitude of the spectrogram were considered (white dots in Figure A.5a).
  - o Second, the weighted maximum frequency offset vector O was defined as $O = (F_{max} – X_{med}) \cdot E_{max}/max(E_{max})$, where X_{med} is a scalar representing the median frequency of the vector F_{max}. The frequency modulation index was defined as the standard deviation of the vector O.
- *Asymmetry of the maximum frequencies* (*F13*): The skewness of the vector O defined above.
- *Duration* (*F14*): Number of spectrogram frames with a maximum amplitude value above the 90th percentile of the amplitude values of the spectrogram. The resultant number of frames was then multiplied by the spectrogram time resolution to give the duration in seconds.
- *Amplitude modulation index* (*F15*): The 90th percentile of the first derivative of the amplitude envelope. See Figure A.5d for an example of the derivative of the amplitude envelope.
- *Signal-to-noise ratio* (*F16*): Ratio of the 100th percentile and 25th percentile of the amplitude values of the spectrogram.
- *Overall spectral entropy* (*F17*): The Shannon entropy (Erbe and King 2008) calculated for each time slice of the spectrogram in the frequency band 50–600 Hz (Figure A.5e). The overall spectral entropy is the 10th percentile of these values.
- *Kurtosis of the spectral entropy* (*F18*): Kurtosis of the Shannon entropy values calculated on each time slice of the spectrogram.
- *Minimum of the spectral entropy* (*F19*): Minimum of the Shannon entropy values calculated on each time slice of the spectrogram.

- *Overall harmonicity* (*F20*): Harmonicity was calculated for each time slice of the spectrogram by calculating the Shannon entropy of the Harmonic Product Spectrum (e.g., Figure A.5f; see Ding et al. 2006). Low harmonicity means the frequency content of the analyzed signal is harmonic. The overall harmonicity is the 10th percentile of all the harmonicity values.

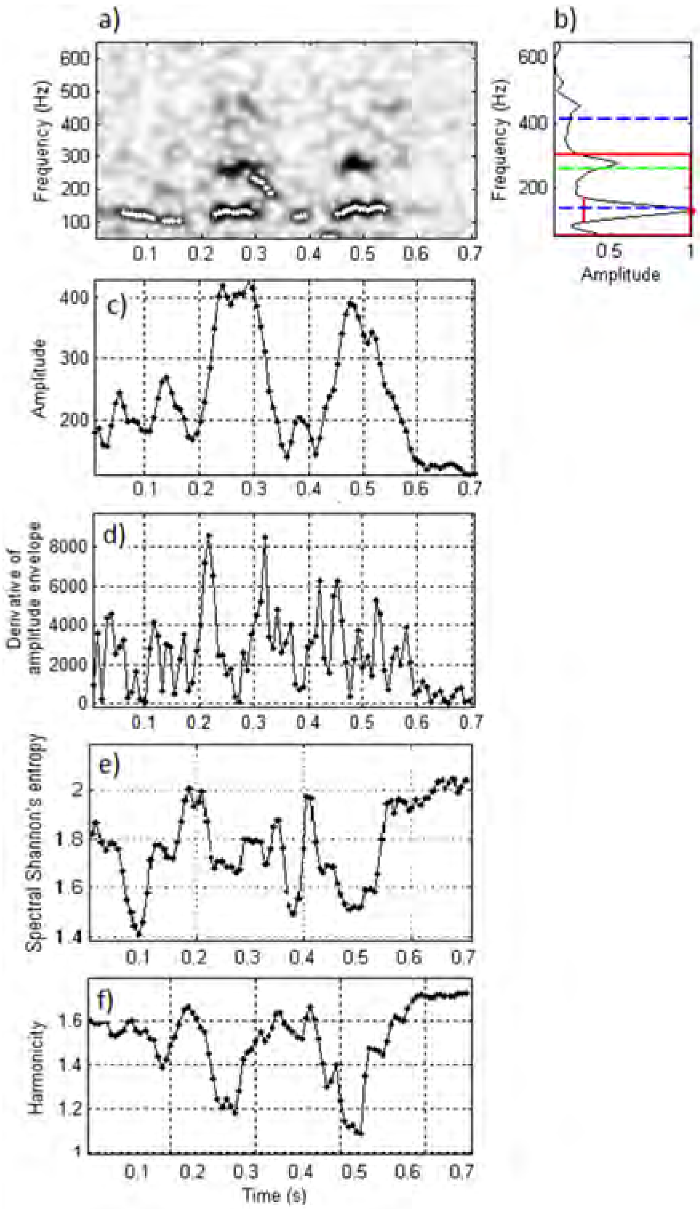

Figure A.5. Extraction of features used in the walrus grunt classifier: (a) Spectrogram of the analyzed frame; (b) frequency envelope (black line), with the median frequency (green line), the upper and lower quartiles (blue lines), the maximum frequency peak (red dot), and the spectral concentration (red box); (c) amplitude envelope; (d) first derivative of the amplitude envelope; (e) spectral entropy; and (f) harmonicity index.

A.3.4. Step 4: Classification

Classification was performed using a random forest classifier (Breiman 2001), which was trained using all manual annotations in recordings from the summer 2010 AMP. The random forest was defined with these four classes: “walrus grunt”, “seismic”, “bowhead”, and “other”. Training the classifier, optimizing the number of decision trees in the forest, and selecting the most relevant features based on the Gini index, were performed using the same process described for bowhead and beluga whale call detection (Section A.2). The optimal number of decision trees was 600. Because feature importance did not decrease abruptly, all 20 features were used for classification.

A.4. Bearded Seal Call Detection

The automated detection and classification of bearded seal calls is performed in four steps:

1. Calculation and binarization of the spectrogram
2. Definition of time-frequency objects
3. Extraction of features
4. Classification

A.4.1. Step 1: Spectrogram Processing

The first step of the detection process was calculating the spectrogram. Table A.7 lists the spectrogram parameters. To attenuate long spectral rays in the spectrogram due to vessel noise, and to enhance weaker transient biological sounds, the spectrogram was normalized in each frequency band (i.e., each row of the spectrogram) with a median normalizer. Table A.7 lists the size of the window used by the normalizer. The normalized spectrogram was binarized by setting all the time-frequency bins that exceed a normalized amplitude of 4 (no unit) to 1 and the other bins to 0.

Table A.7. Spectrogram parameters used in the bearded seal call detector.

	Bearded seal calls
Analysis frame size (samples)	4096
Overlap between frames (samples)	3072
FFT size (sample)	4096
Window function	Reisz
Normalizer window size (s)	120
Binarization threshold (no unit)	4

A.4.3. Step 2: Definition of Time-Frequency Objects

The second step of the detection process consisted of defining time-frequency objects (or events) by associating contiguous bins in the binary spectrogram. The algorithm implemented is a variation of the flood-fill algorithm (Nosal 2008). Every spectrogram bin that equals 1 and is separated by less than three bins in both time and frequency are connected. Figure A.6 illustrates the search area used to connect spectrogram bins. The bin connection process moves from oldest data to newest and from lowest frequency to highest. Each group of connected bins is referred to as a time-frequency object. A spectrogram bin can only belong to one time-frequency object.

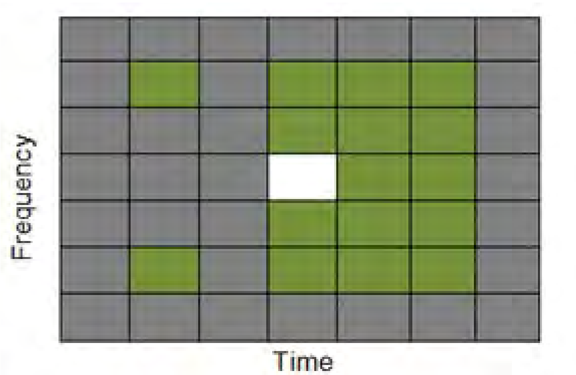

Figure A.6. Illustration of the search area used to connect spectrogram bins. The white square represents a bin of the binary spectrogram equaling 1; the green squares represent the potential bins to which it could be connected. The algorithm advances from left to right so gray cells left of the test cell need not be checked; however, checking the far left cells may join broken contours.

Because time-frequency objects are sensitive to noise generated by small pleasure craft or fishing vessels near recorders—they can generate many time-frequency objects that may be mistaken for marine life calls—to reduce false detections a vessel detector is incorporated into the time-frequency event definition process. Vessel noise is considered detected when at least five frequencies have detected contours for 5 s. Files with at least two vessel detections are not processed further.

A.4.4. Step 3: Feature extraction

The third step consists of representing each of the time-frequency objects extracted in the previous step by a set of features. Features of the time-frequency objects were defined by:

- Start time (date)
- Duration (s)
- Minimum frequency (Hz)
- Maximum frequency (Hz)
- Bandwidth (Hz)

A.4.5. Step 4: Classification

- o The final step consisted of classifying the time-frequency objects by comparing their features against a dictionary that defines the features of the vocalizations present in the Chukchi Sea based on the literature and on analysts' observations. In the present study, only bearded seal calls were represented in the dictionary (Table A.8). The classification process can handle vocalizations made of several time-frequency objects, such as vocalizations with harmonics ("Multi-Frequency-Components") and vocalizations made of a succession of time-frequency objects such as seal trills and groups of beluga, dolphin, or beaked whale whistles ("Multi-Time-Components").

Vocalizations in the dictionary are defined by the following features:

- Minimum frequency
- Maximum frequency
- Minimum duration: at least one spectrogram time slice.
- Maximum duration
- Minimum bandwidth
- Maximum bandwidth
- Multi-Frequency-Component (Boolean): for call types where contours should be grouped in frequency, with some time overlap before applying the frequency, duration, and bandwidth constraints. Each contour that is added to the multi-component contour has the following constraints applied:
    - o minComponentDuration: minimum duration for a contour to be added to the multi-component contour.
    - o minComponentBW: minimum bandwidth for a contour to be added to the multi-component contour.
    - o Minimum and maximum frequencies: as per the global definition.
- Multi-Time-Component (Boolean): for call types where contours should be grouped in time before applying the frequency, duration, and bandwidth constraints. Each contour that is added to the multi-time-component contour has the following constraints applied:
    - o minTimeComponentDuration: minimum duration for a contour to be added to the multi-time-component contour.
    - o minTimeComponentBW: minimum bandwidth for a contour to be added to the multi-time-component contour.
    - o Minimum and maximum frequencies: as per the global definition.

Table A.8. Definitions for the time-frequency features of bearded seal calls in the Chukchi Sea in the summer and in the winter.

	Call Type	Min/Max frequency (Hz)	Min/Max duration (s)	Min/Max bandwidth (Hz)	Min/Max sweep rate	Multi-Frequency-component settings	Multi-time-component settings
Winter calls	Full Trill	250/5000	5/60	500/–	−100/−10	Min BW=30 Max BW=200 Min Dur=0.5 Max Dur=5 MaxFreqShift=100	0
	Trill end	250/1200	10/60	100/–	−50/−5	Min BW=20 Max BW=100 Min Dur=0.5 Max Dur=8 MaxFreqShift=100	0
Summer calls	Downsweep	200/1500	0.6/10	38/–	−200/−20	N/A	0
	Upsweep	200/1500	0.6/4.5	100/–	50/250	N/A	0

- Figure A.7 shows a block diagram of the several stages of the classification algorithm. The algorithm consists of two loops. The outer loop iterates through all the time-frequency objects. For each time-frequency object that has not yet been classified, the object's features are compared to each call in the dictionary. If the call is a multi-frequency-component or multi-time-component type, the list of time-frequency objects is searched for unsorted objects that meet the multi-components settings (see Table A.8).
- The total time-frequency object duration, minimum and maximum frequencies, and frequency bandwidth are compared to the call's definitions in the dictionary. If the object's features fall within the call type's bounds, then the bandwidth (BW_i) and duration (T_i) indices are computed:

$$BW_i = \frac{BW_{object}}{BW_{dictionary}} \quad T_i = \frac{T_{object}}{T_{dictionary}}$$

If either of these indices exceeds the empirically chosen threshold of 1.5 times the current best index, then the current best-match call type is updated. The 1.5 threshold for updating the best-match call type means the algorithm prefers call types that are defined earlier. Therefore, if, for a particular recording, killer whales are more likely to occur than humpbacks, the killer whale call definitions should occur first in the mammalContours.xml definition file.

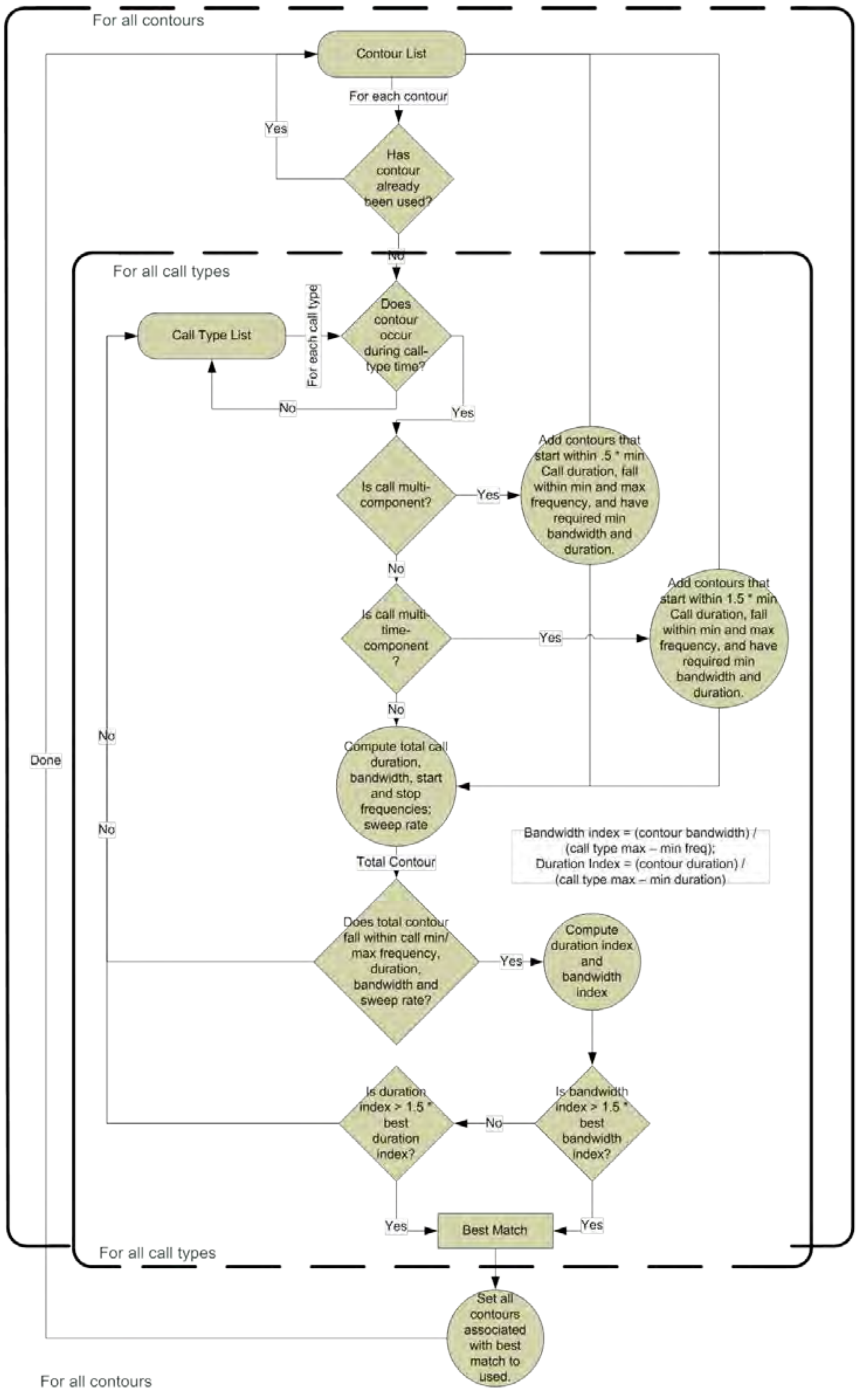

Figure A.7. Block diagram of the classification algorithm.

The classification algorithm also implements a time-based filter. Because the classification algorithm is intended to count calls of species expected to be in an area, it is reasonable to limit the algorithm to those species. For instance, bowhead calls won't be detected before 1 Sep or after 1 Jan in the Chukchi Sea. Manual analysis is used to detect extra-limital species and unusual detections as a function of time. Figure A.8 shows an example of detection and classification of bearded seal calls.

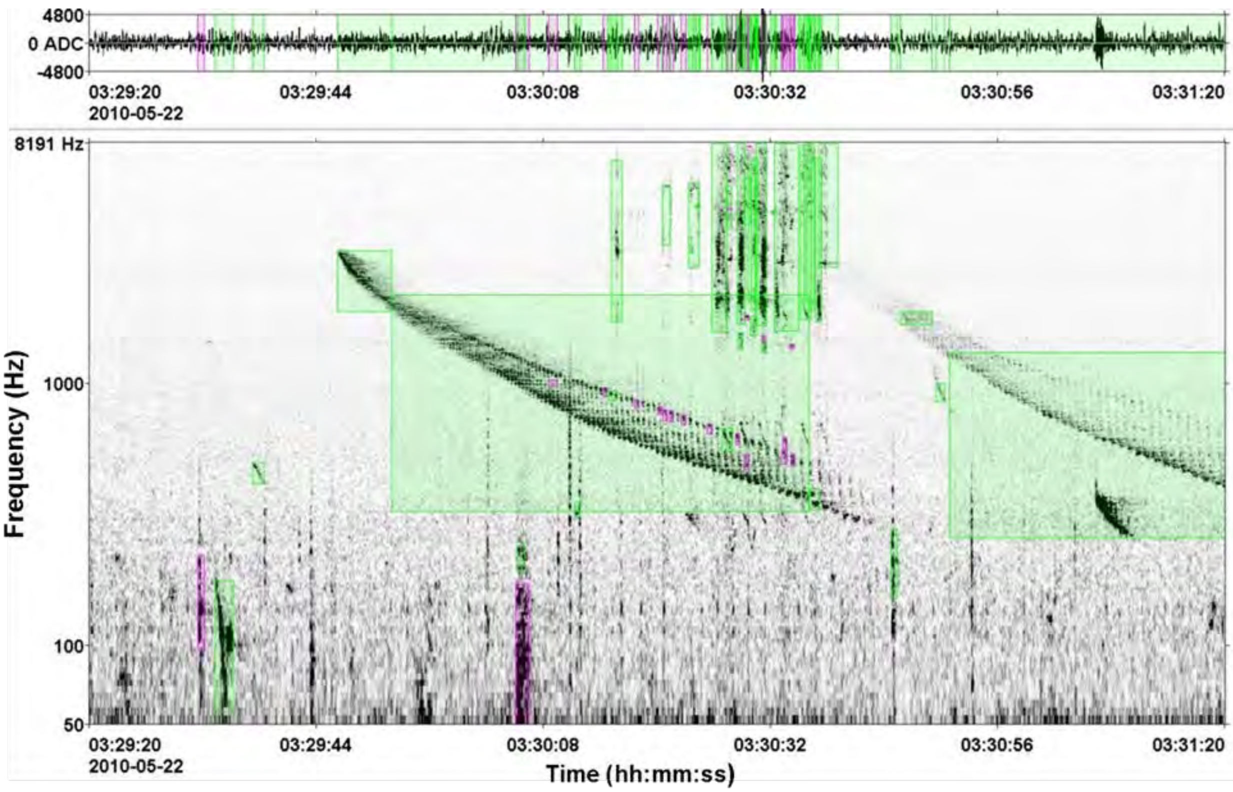

Figure A.8. (Top) Pressure in digital units and (bottom) spectrogram of bearded seal trills (500–200 Hz; downsweeps in center) detected using the multi-time-component contour type. Beluga and bowhead calls are also visible in this figure (16 kHz sample rate, 4096 pt STFT, 1024 pt advance).

A.5. Performance Evaluation

A.5.1. Test Datasets

The automated detectors/classifiers must be verified with a test dataset that represents the spatio-temporal variations of the marine mammal calls and background noise in the entire dataset. Since the acoustic environment in the eastern Chukchi Sea differs between winter and summer, a unique test dataset was used to test the detection/classification algorithms for each season. For the winter 2011–2011 AMP data, marine mammal calls were fully manually-annotated in the first 2 min of each day for recordings from Stations B05 (until 28 Feb 2011), W50 (until 31 Mar 2011), PLN40 (until 10 Apr 2011), PLN80 (until 26 May 2011), and CL50 (until 31 Oct 2010). This yielded a test dataset of 804 2 min fully-annotated samples. For the summer 2010 AMP data, marine mammal calls were fully manually annotated in the first 1.5 min after midnight of each day for Stations W50 (until 11 Aug 2011), W20 (until 15 Aug 2011), PL35, PLN20, PLN60, and PLN80. This yielded a test dataset of 623 1.5 min fully-annotated samples.

A.5.2. Performance Metrics

The decisions made by detectors/classifiers can be represented as a confusion matrix. The confusion matrix consists of four categories: true positives (*TP*), false positives (*FP*), true negatives (*TN*), and false negatives (*FN*). Table A.9 depicts the confusion matrix, where E is the signal event we want to detect/classify and $\overline{E}$ is a non-event that we want to ignore (i.e., noise). The definition of $\overline{E}$ varies depending on the detector/classifier.

Table A.9. Confusion matrix.

		True Result	
		E	$\overline{E}$
Detection/ classification result	E	*TP*	*FP*
	$\overline{E}$	*FN*	*TN*

A true positive (*TP*) corresponds to a signal of interest being correctly classified as such. A false negative (*FN*) is a signal of interest being classified as noise (i.e., missed). A false positive (*FP*) is a noise classified as a signal of interest (i.e., a false alarm). A true negative (*TN*) is a noise correctly classified as such.

The numbers of *TP*s, *FP*s, and *FN*s were calculated for each detector and test dataset by comparing the manual annotations of marine mammal calls (considered true results, i.e., ground truth) with the automated detections/classifications. Numbers of *FP*s, *TP*s, and *FN*s were calculated on all dataset samples containing annotations of the target call type. If a manually-annotated call was automatically detected/classified, then the detection was considered a *TP*, if undetected, it was a *FN*. Each automated detection occurring in the sample that did not correspond to a manually-annotated call was considered a *FP*.

A.5.3. Precision and Recall

To assess the performance of the detectors/classifiers, precision (*P*) and recall (*R*) metrics were calculated based on the numbers (*N*) of *TP*s, *FP*s, and *FN*s:

$$P = \frac{N_{TP}}{N_{TP} + N_{FP}} \quad R = \frac{N_{TP}}{N_{TP} + N_{FN}} \tag{1}$$

P measures exactness, and *R* completeness. For instance, a *P* of 0.9 for beluga means that 90% of the detections classified as beluga were in fact beluga calls, but says nothing about whether all beluga vocalizations in the dataset were identified. An *R* of 0.8 for beluga means that 80% of all beluga calls in the dataset were classified, but says nothing about how many beluga classifications were wrong. Thus, a perfect detector/classifier would have $P = R = 1$. Neither *P* nor *R* alone can describe the performance of a detector/classifier on a given dataset; both metrics are required.

The advantages of the *P-R* metric over the True-Positive Rate (TPR) and False-Positive Rate (FPR) generally used in Receiver Operating Characteristic (ROC) curves include:

- The *P-R* metric is more adapted to skewed datasets.
- An algorithm dominates in ROC space only if it dominates in *P-R* space (Davis and Goadrich 2006).
- Most significantly, not taking into account N_{TN}. A subjective criterion is necessary to define the length of time that counts as one *TN* value over a continuous recording that contains no targeted vocalizations, whereas N_{TN} does not need to be calculated for the *P-R* metric, so *P-R* values are better suited to analyzing these time-continuous data.

A.5.4. Signal-to-Noise Ratio

The signal-to-noise ratio (SNR) is the ratio of signal power (P_s) to noise power corrupting the signal (P_n). The SNR compares the level of the desired signal to the level of the background noise; the greater this ratio, the less obtrusive the background noise. SNR is defined in decibels as:

$$\mathrm{SNR} = 10\log_{10}\left(\frac{P_s}{P_n}\right) \tag{2}$$

The signal power of a call in a spectrogram is the average power of the call within the frequency range of the vocalization; the noise power is the average power before and after the call within the same frequency band (Mellinger 2004, Mellinger and Clark 2006). The duration of the noise signal measured before and after the call equals the duration of the call (Figure A.9). This calculation was performed on the original spectrogram without noise reduction. To quantify detector performance for various SNRs, N_{FN} and N_{TP} were calculated for SNR intervals of < 0 dB, 0–5 dB, 5–10 dB, and ≥ 10 dB. *P* values are influenced by the background noise and not by the SNR of the calls. Therefore, *P* values per SNR intervals were not calculated.

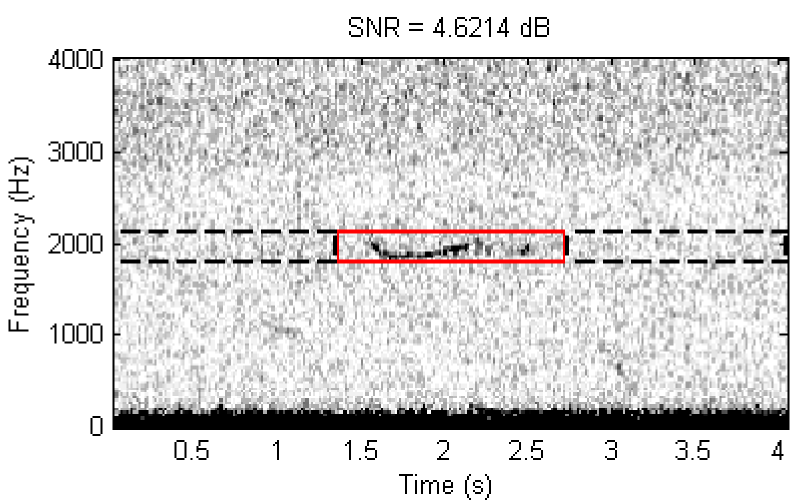

Figure A.9. Calculation of the signal-to-noise ratio (SNR). The power of the call (P_s) is calculated in the red box; the power of the noise (P_n) is calculated in the black boxes on either side of the call.

A.6. Call Count Estimation

Because the detectors/classifiers have false alarms and missed calls, they are imperfect and, as such, the number of automated detections does not exactly equal the actual number of calls present in the recordings. A better estimate can be achieved using P and R. These values characterize the relationship between the detector/classifier and the dataset. Therefore, these values are specific to, and depend on, both the detector/classifier and the dataset. If the subset of data used to characterize P and R is representative of the entire dataset, P and R can be used to extrapolate the total number of vocalizations from the number of detected vocalizations. The total number of detections (N_{det}) found by the detector/classifier is the sum of the number of true and false positives:

$$N_{\text{det}} = N_{TP} + N_{FP} \tag{3}$$

From the definition of P (Equation 1), N_{TP} can be defined as:

$$N_{TP} = P \cdot (N_{TP} + N_{FP}) = P \cdot N_{\text{det}} \tag{4}$$

The total number of vocalizations in the data (N_{voc}) is the sum of those correctly identified (TP) and those that were missed (FN):

$$N_{voc} = N_{TP} + N_{FN} \tag{5}$$

Therefore, R becomes:

$$R = \frac{N_{TP}}{N_{TP} + N_{FN}} = \frac{N_{TP}}{N_{voc}} \tag{6}$$

Combining Equations 4 and 6 yields the total number of vocalizations in terms of P, R, and the number of detections:

$$N_{voc} = \frac{N_{TP}}{R} = \frac{P \cdot N_{\text{det}}}{R} \tag{7}$$

All call-count estimation plots in the main report (bubble-plots) were produced using Equation 7.

A.7. Detector/Classifier Performance

The performance of each automated detector/classifier is provided for test datasets of both the winter 2011–2012 and summer 2012 AMPs. The test datasets consist of all fully manually-annotated data samples for each AMP. For each detector/classifier and AMP season dataset, the precision (P) and recall (R) of the detector/classifier on the entire test dataset are given. The SNR distribution of the test dataset over four SNR intervals and the R values calculated for each SNR interval are shown in Figure A.10.

A.7.1. Bowhead Winter Songs

The bowhead winter song detector/classifier was tested against the fully manually-annotated recordings of the winter 2011–2012 AMP. The test dataset had 4162 manually-annotated bowhead songs (Figure A.10, left). The performance of the bowhead song detector/classifier on the test dataset yielded $P = 0.66$ and $R = 0.34$. As expected, the detector/classifier was able to detect more calls at higher SNRs (Figure A.10, right). The highest R value was 0.71, obtained for calls with SNR > 10 dB.

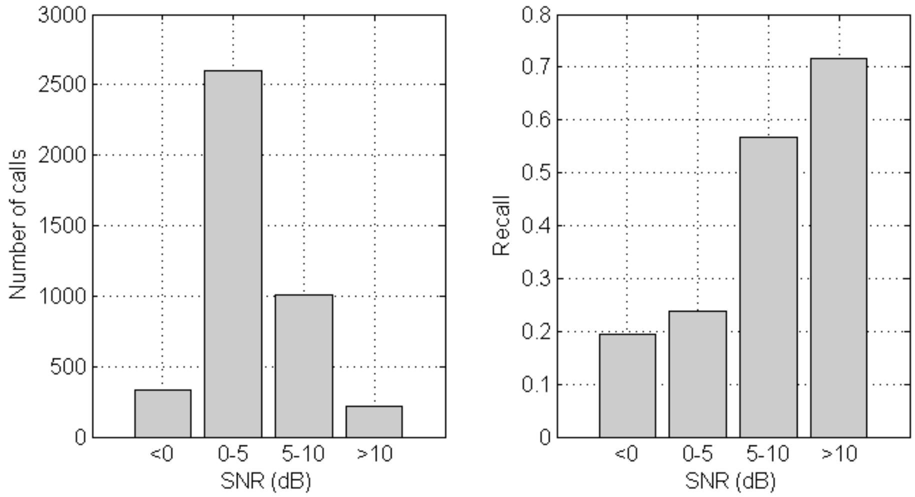

Figure A.10. Performance of the bowhead winter song detector/classifier on the winter 2011–2012 test dataset. (Left) Signal-to-noise ratio (SNR) distribution of calls in the test dataset. (Right) Recall of the detector/classifier per call SNR interval.

A.7.2. Bowhead Summer Moans

The bowhead summer moan detector/classifier was tested against fully-annotated recordings collected during the summer 2012 AMP. The test dataset had 724 manually-annotated bowhead moans (Figure A.11, left). The performance of the bowhead moan detector/classifier on the test dataset yielded $P = 0.73$ and $R = 0.44$. As expected, R increased with increasing SNR (Figure A.11, right).

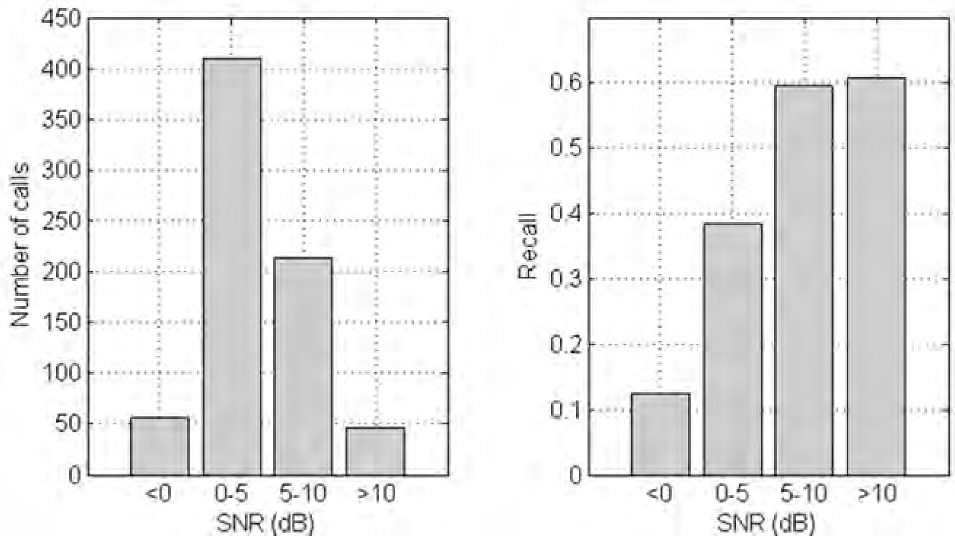

Figure A.11. Performance of the bowhead summer moan detector/classifier on the summer 2012 test dataset. (Left) Signal-to-noise ratio (SNR) distribution of calls in the test dataset. (Right) Recall of the detector/classifier per call SNR interval.

A.7.3. Beluga Whistles

The beluga whistle detector/classifier was only used to analyze the winter 2011–2012 AMP data because very few beluga whistles occurred in the summer 2012 AMP data. The test dataset had 836 manually-annotated beluga whistles (Figure A.11, left). Most annotated whistles had a SNR between 0 and 5 dB. The beluga whistle detector/classifier had $P = 0.42$ and $R = 0.40$. The highest R was 0.78, obtained for whistles with SNR > 10 dB (Figure A.11, right).

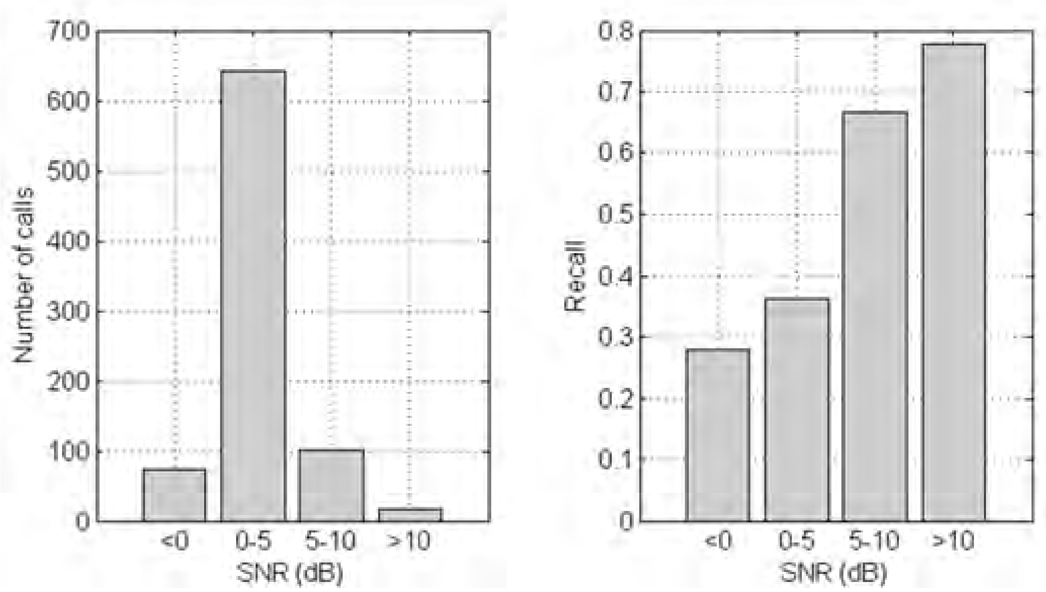

Figure A.12. Performance of the beluga whistle detector/classifier on the winter 2011–2012 test dataset. (Left) Signal-to-noise ratio (SNR) distribution of calls in the test dataset. (Right) Recall of the detector/classifier per call SNR interval.

A.7.4. Walrus Grunts

Walrus grunts were recorded in both winter and summer. Therefore, the performance of the walrus grunt detector/classifier was calculated independently for the summer 2012 and for the winter 2011–2012 datasets (i.e., one set of *P* and *R* values for each datasets).

Winter 2011–2012 Program

The winter 2011–2012 AMP test dataset had 3872 manually annotated bearded seal calls (Figure A.13, left). The bearded seal call detector/classifier had *P* = 0.62 and *R* = 0.1 for the winter 2011–2012 AMP test dataset. *R* for calls with a SNR > 10 dB is lower than that for calls with a SNR of 5–10 dB due to the misrepresentation of that SNR interval in the winter 2011–2012 AMP test dataset (only 57 walrus grunts annotated with a SNR > 10 dB, (Figure A.13, right).

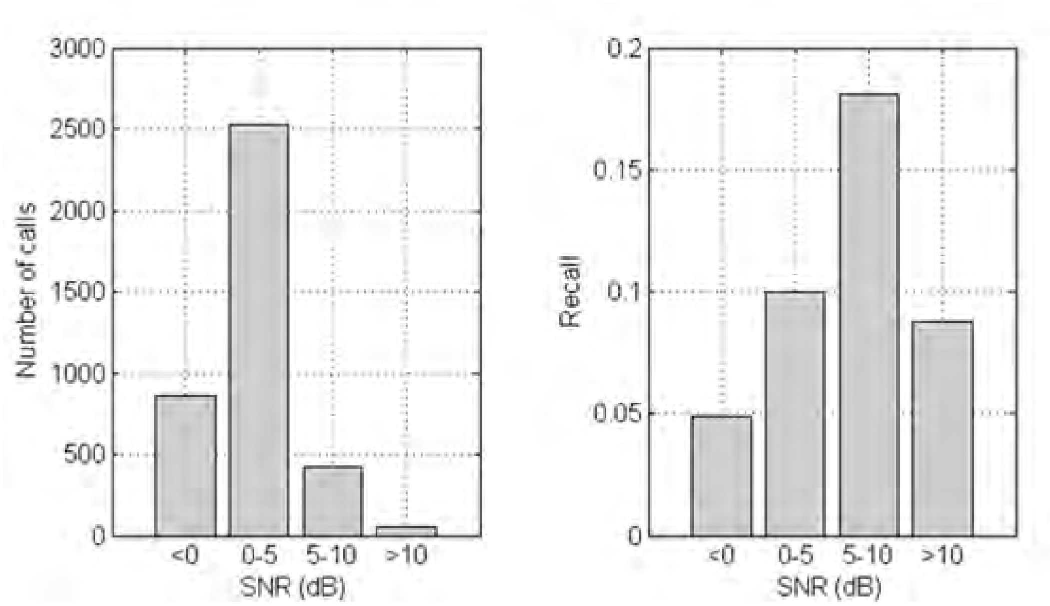

Figure A.13. Performance of the walrus grunt detector/classifier on the winter 2011–2012 test datasets. (Left) Signal-to-noise ratio (SNR) distribution of calls in the combined test datasets. (Right) Recall of the detector per call SNR interval.

Summer 2012 Program

The walrus grunt detector/classifier was tested against fully-annotated recordings collected during the summer 2012 AMP. The test dataset had a total of 3715 manually-annotated walrus grunt (Figure A.14, left). The performance of the bowhead moan detector/classifier on the test dataset yielded *P* = 0.43 and *R* = 0.19. *R* increased gradually with increasing SNR (Figure A.14, right). The highest *R* was 0.62 and was obtained for whistles with SNR > 10 dB.

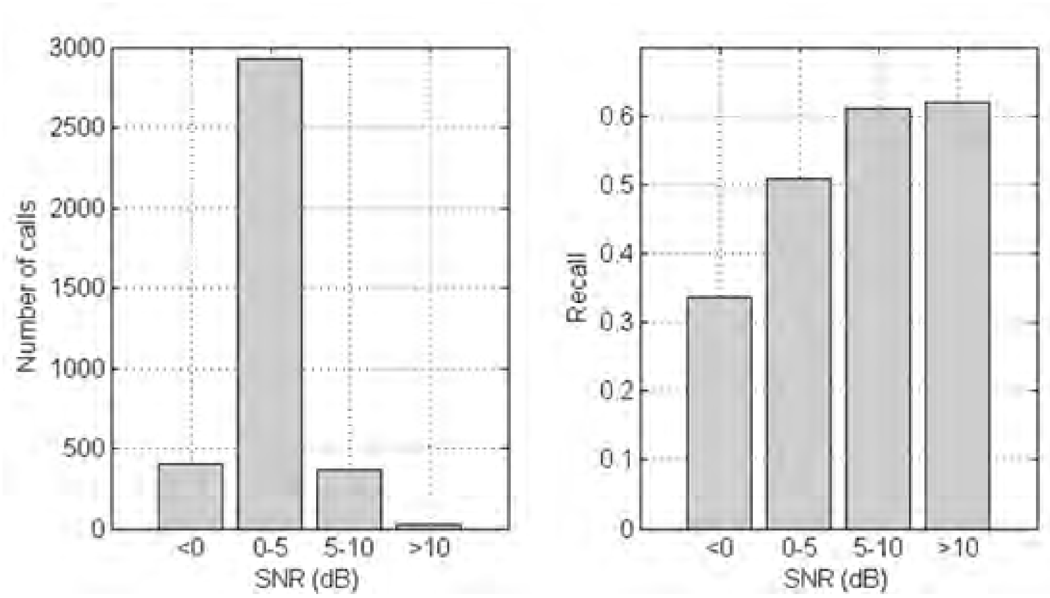

Figure A.14. Performance of the walrus grunt detector/classifier on the summer 2012 test datasets. (Left) Signal-to-noise ratio (SNR) distribution of calls in the combined test datasets. (Right) Recall of the detector per call SNR interval.

A.7.5. Bearded Seal Calls

Bearded seal calls were detected and classified in both winter 2011–2012 and summer 2012, with a greater vocal presence in the winter. The performance of the bearded seal call detector/classifier was evaluated separately for each AMP season.

Winter 2011–2012 Program

The winter 2011–2012 AMP test dataset had 6233 manually-annotated bearded seal calls (Figure A.15, left). P and R were calculated on many more calls for the winter test dataset than for the summer (6233 vs. 69, respectively) due to high vocal presence of bearded seals in winter. The bearded seal call detector/classifier had $P = 0.62$ and $R = 0.45$ for the winter 2011–2012 AMP test dataset. R for calls with a SNR < 0 dB is higher than that for calls with a SNR of 0–5 dB due to bias in the estimation of SNR for concurrent bearded seal calls (Figure A.15, right).

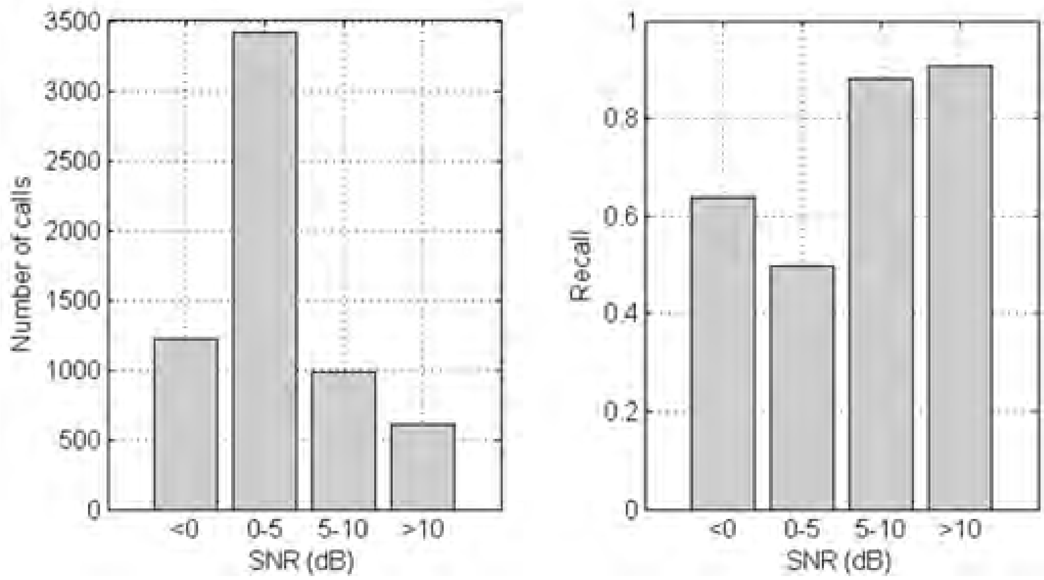

Figure A.15. Performance of the bearded seal detector/classifier on the winter 2011–2012 test dataset. (Left) Signal-to-noise ratio (SNR) distribution of calls in the test dataset. (Right) Recall of the detector/classifier per call SNR interval.

Summer 2012 Program

The summer 2012 AMP test dataset had 69 manually-annotated bearded seal calls (Figure A.16, left). The detector/classifier had $P = 0.74$ and $R = 0.25$ for the summer 2012 AMP test dataset. R increased gradually with increasing SNR (Figure A.16, right)

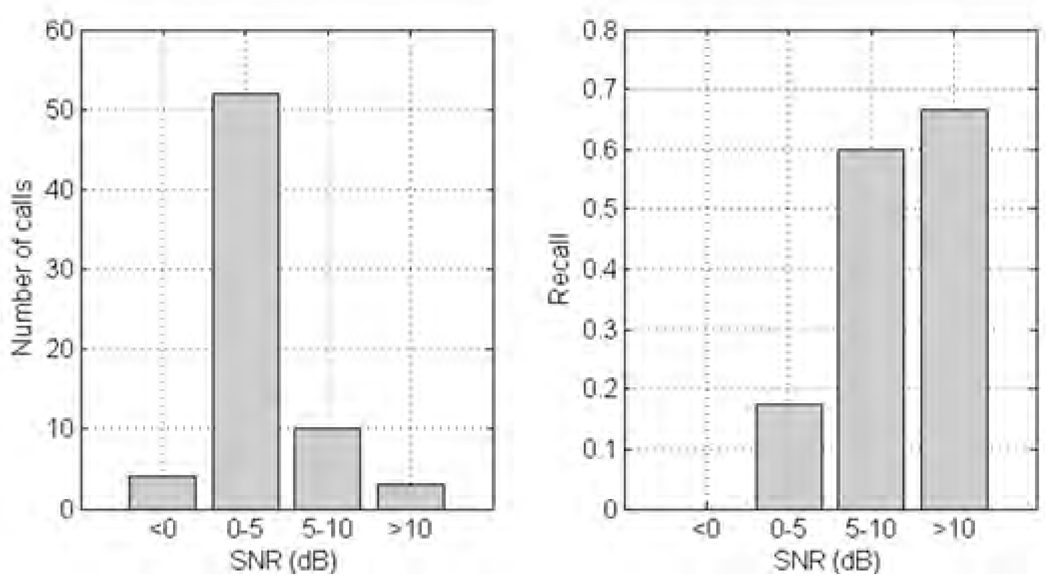

Figure A.16. Performance of the bearded seal detector/classifier on the summer 2012 test dataset. (Left) Signal-to-noise ratio (SNR) distribution of calls in the test dataset. (Right) Recall of the detector/classifier per call SNR interval.

A.7.6. Summary

Table A.10. Precision (*P*) and recall (*R*) for all SNRs of each detector/classifier.

Detector	*P*	*R*
Bowhead winter songs	0.66	0.34
Bowhead summer moans	0.73	0.44
Beluga whistles, winter	0.42	0.40
Walrus grunts, summer	0.43	0.19
Walrus grunts, winter	0.62	0.1
Bearded seal, summer	0.74	0.25
Bearded seal, winter	0.45	0.62

A.8. Probability of Detection by Manual Analysis

To determine whether manually reviewing only 5% of the data provided an accurate estimate of the acoustic occurrence of marine mammal calls, analysts randomly selected, then fully-annotated more than 43 h of acoustic data containing a representative sample of the commonly detected species, specifically bowhead, beluga and gray whales, bearded and ringed seals, and walrus. Selected files were distributed across stations and over the whole recording period. For each file, an algorithm written for this purpose then chose a random start time and manually searched the next *n*% of the file (corresponding to the analysis sample) for manual annotations. *n* was varied from 1 to 100% in increments of one. This random sample selection was iterated 2000 times per file for each sample size. A detection probability (DP) was obtained for each file and sample size by dividing the number of samples containing at least one annotation in the random sample by 2000. The comparison of detection probabilities across the sampling period provided an overview of seasonal and inter-specific variations.

A.8.1. Manual Analysis Detection Probability: Winter 2011–2012 and Summer 2012 Programs

Samples of data of 5% of each acoustic data file were manually analyzed to determine the presence of calls from each species in the winter and summer datasets. The goal of this analysis was to assess and validate the protocol of manual examination of a fraction of the datasets. The 5% manual analysis protocol is compared to hypothetical 1%, 2%, and 10% manual analysis protocols (Table A.11, Table A.12).

The estimated DP for selected files that contain bowhead, beluga and gray whale, ringed and bearded seal and walrus (Table A.11, Table A.12) calls indicate that the performance of the manual analysis protocol[5] varies with species and season.

Bowhead calls had a mean DP of 0.82 during the winter deployment (range: 0.33 to 1). DPs increased in late Oct, were highest in Nov, Dec, Apr, and May when bowheads produce long, elaborate songs (Delarue et al. 2009) as they migrate through the Chukchi Sea, and then decreased in late spring. The mean DP in summer 2012 was 0.55, which indicated lower calling rates in summer months. The high DP detected in the file recorded at the end of the summer program, on 10 Oct, corresponded to the annual increase in vocal activity during fall associated with the onset of singing (Table A.12).

Bearded seal calls had a mean DP of 0.62 (range 0.09 to 1) during the winter deployment. DP was close or equal to 1 from November to early July, with one exception at CL50 in February. The mean DP (0.4) during the summer 2012 deployment persisted into fall, although some peaks in calling activity are possible, as indicated on 11 Oct at CL05 (Table A.11, Table A.12).

Beluga whales' DP was variable (mean: 0.56; range: 0.14 to 1) during the winter deployment. The highest DPs were recorded during the spring migration. The three summer 2012 files analyzed each had DP close or equal to 1 (Table A.11, Table A.12).

Ringed seals' DP was relatively constant throughout the year and consistently low, averaging 0.14 (Table A.11). Although not included in this analysis, summer data follow the same pattern (see Delarue et al. 2011*a*). This suggests the current analysis protocol underestimates the presence of ringed seal calls in the data (Table A.11, Table A.12).

Walrus calls typically have a high DP due to high calling rates, with a few exceptions. The mean DP was 0.71 and 0.87 in the winter and summer data, respectively (Table A.11, Table A.12).

Gray whale DP averaged 0.42 in the summer data (range: 0.13–1). A strong variability in DP, and therefore calling rate, was observed (Table A.12).

[5] i.e., The probability that a randomly selected 2 min/90 s [winter/summer] sample will contain calls of a given species if calls are present within its 40 min/30 min [winter/summer] source file.

Table A.11. Manual analysis detection probabilities (DPs) of bowheads, belugas, ringed seals, bearded seals, and walrus for files recorded at several stations during the winter 2011–2012 program when 1%, 2%, 5%, and 10% of the data was manually reviewed. Results for each species are ordered chronologically. The 5% DP column is highlighted because this percentage of data was analyzed in the present study.

Species	Station	Date and Time	DP (1%)	DP (2%)	DP (5%)	DP (10%)
Bearded seal	WN60	15 Sep 2011	0.06	0.10	0.21	0.34
	PLN40	17 Oct 2011	0.04	0.05	0.12	0.24
	WN20	16 Nov 2011	0.02	0.05	0.09	0.14
	PLN100	15 Dec 2011	0.61	0.74	0.94	1.00
	PL50	15 Jan 2012	1.00	1.00	1.00	1.00
	CL50	17 Feb 2012	0.12	0.16	0.24	0.27
	B05	19 Mar 2012	0.76	0.92	0.99	1.00
	W35	17 Apr 2012	1.00	1.00	1.00	1.00
	PLN100	3 Jul 2012	1.00	1.00	1.00	1.00
Beluga whale	WN60	7 Oct 2011	0.22	0.37	0.59	0.87
	W35	19 Oct 2011	0.06	0.13	0.30	0.40
	PLN80	7 Nov 2011	0.16	0.27	0.51	0.73
	CL50	23 Nov 2011	0.17	0.28	0.49	0.67
	B05	8 Dec 2011	0.03	0.06	0.14	0.24
	B05	15 Apr 2012	0.11	0.18	0.41	0.65
	PLN40	1 May 2012	0.07	0.12	0.24	0.37
	PL50	16 May 2012	0.94	0.99	1.00	1.00
	B05	1 Jun 2012	0.86	0.98	1.00	1.00
	B05	3 Jul 2012	0.20	0.31	0.49	0.65
	B05	30 Jul 2012	0.58	0.76	0.98	1.00
Bowhead whale	WN80	27 Aug 2011	0.18	0.27	0.47	0.58
	PLN100	9 Oct 2011	0.20	0.35	0.67	0.81
	PLN40	25 Oct 2011	0.58	0.74	0.92	1.00
	W50	4 Nov 2011	1.00	1.00	1.00	1.00
	PL50	17 Nov 2011	1.00	1.00	1.00	1.00
	CL50	15 Dec 2011	1.00	1.00	1.00	1.00
	B05	15 Apr 2012	0.84	0.95	1.00	1.00
	W35	30 Apr 2012	0.40	0.59	0.81	0.93
	PL50	17 May 2012	0.36	0.61	0.90	1.00
	B05	23 May 2012	0.77	0.90	0.98	1.00
	PBN40	10 Jun 2012	0.10	0.18	0.33	0.50
	B05	22 Jul 2012	0.24	0.40	0.75	0.96
Ringed seal	WN60	8 Oct 2011	0.07	0.12	0.25	0.51
	W35	22 Nov 2011	0.12	0.18	0.40	0.55
	PBN20	15 Dec 2011	0.01	0.03	0.05	0.06

Species	Station	Date and Time	DP (1%)	DP (2%)	DP (5%)	DP (10%)
Ringed seal (cont.)	W50	15 Jan 2012	0.03	0.07	0.15	0.31
	PBN40	18 Feb 2012	0.01	0.01	0.01	0.01
	WN80	18 Mar 2012	0.01	0.03	0.09	0.16
	PL50	22 Apr 2012	0.04	0.08	0.11	0.17
	PLN120	13 May 2012	0.02	0.03	0.08	0.09
Walrus	WN80	28 Aug 2011	0.51	0.68	0.90	1.00
	PN120	16 Sep 2011	0.15	0.24	0.36	0.49
	WN20	15 Oct 2011	0.72	0.84	0.98	1.00
	WN40	1 Nov 2011	0.05	0.09	0.15	0.27
	PLN80	3 Dec 2011	0.73	0.85	0.98	1.00
	PLN100	24 Jun 2012	0.77	0.90	1.00	1.00
	B05	26 Jul 2012	0.29	0.39	0.59	0.77

Table A.12. Manual analysis detection probabilities (DPs) of bowheads, belugas, ringed seals, bearded seals, and walrus for files recorded at several stations during the summer 2012 program when 1%, 2%, 5%, and 10% of the data was manually reviewed. Results for each species are ordered chronologically. The 5% DP column is highlighted because this percentage of data was analyzed in the present study.

Species	Station	Date	DP (1%)	DP (2%)	DP (5%)	DP (10%)
Bearded seal	CLN90	13 Aug 2012	0.23	0.34	0.56	0.74
	W35	25 Aug 2012	0.01	0.02	0.02	0.02
	B05	10 Sep 2012	0.03	0.04	0.03	0.03
	PLN80	29 Sep 2012	0.11	0.21	0.40	0.61
	CL05	11 Oct 2012	0.34	0.66	1.00	1.00
Beluga whale	B05	15 Aug 2012	0.38	0.69	0.97	1.00
	B50	30 Sep 2012	1.00	1.00	1.00	1.00
	WN40	7 Oct 2012	0.37	0.63	0.96	1.00
Bowhead whale	CLN120	13 Aug 2012	0.13	0.22	0.45	0.67
	W20	9 Sep 2012	0.15	0.26	0.58	0.87
	B30	20 Sep 2012	0.16	0.30	0.54	0.80
	PLN60	30 Sep 2012	0.05	0.08	0.19	0.26
	BG07	10 Oct 2012	0.44	0.69	0.98	1.00
Gray whale	PL50	13 Aug 2012	1.00	1.00	1.00	1.00
	PLN40	26 Aug 2012	0.05	0.11	0.25	0.45
	W50	7 Sep 2012	0.03	0.05	0.13	0.23
	W20	20 Sep 2012	0.17	0.28	0.57	0.77
	PL35	9 Oct 2012	0.03	0.06	0.15	0.28
Walrus	CLN120	10 Aug 2012	1.00	1.00	1.00	1.00
	PLN40	25 Aug 2012	0.10	0.19	0.36	0.61
	PL50	10 Sep 2012	1.00	1.00	1.00	1.00
	WN40	25 Sep 2012	1.00	1.00	1.00	1.00
	BG08	10 Oct 2012	0.34	0.64	0.98	1.00

Figure A.17 suggests that a substantial increase in the length of the analysis sample would be required to reach 50% DP for ringed seals. Bowhead, bearded seal, and walrus DPs with a 5% analysis sample are all above 60% and would not benefit significantly from an increase in sample size. Simply doubling the sample size would raise the DP near or above 70% for all species except ringed seals.

For the summer data, a doubling of the sample size would raise the detection probability of gray whales and bearded seals near 50%, and that of bowheads to just above 70% (Figure A.18).

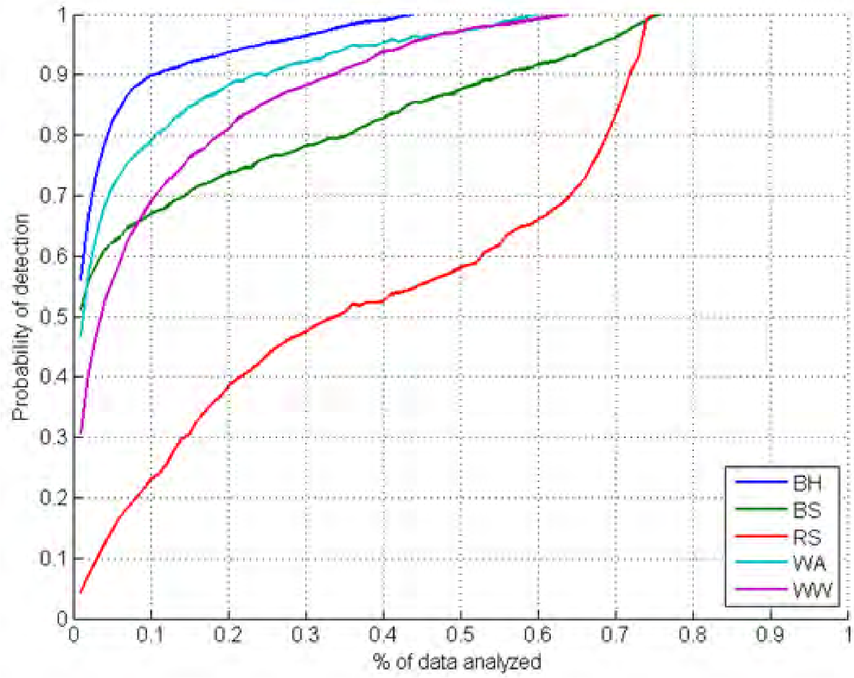

Figure A.17. Detection probability for bowhead and beluga whales, ringed and bearded seals, and walrus as a function of the percent data manually analyzed for a sample of files recorded during the winter 2011-2012 in the northeastern Chukchi Sea.

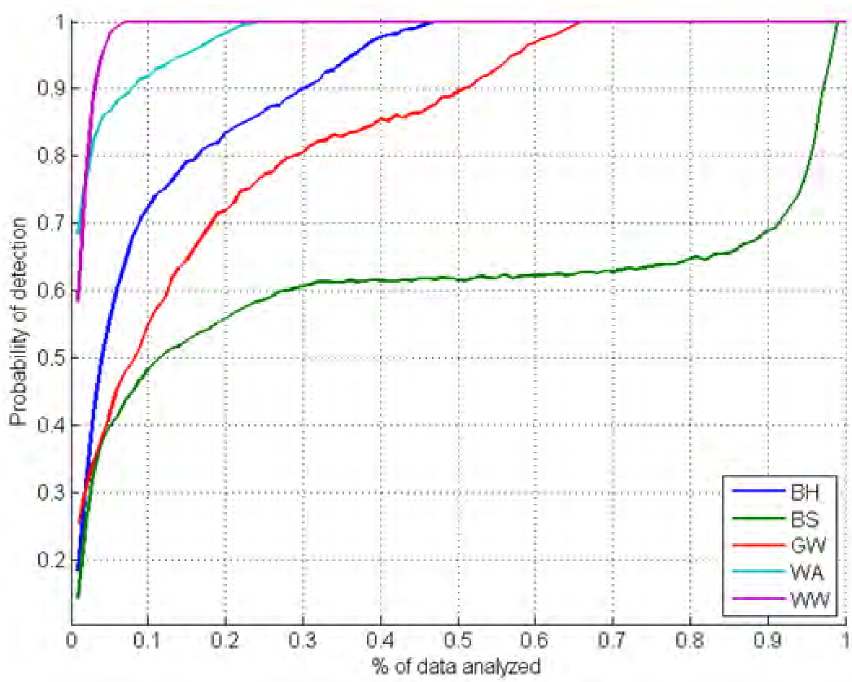

Figure A.18. Detection probability for bowhead, gray, and beluga whales, bearded seals, and walrus as a function of the percent data manually analyzed for a sample of files recorded during the summer 2012 in the northeastern Chukchi Sea.

Appendix B. Ambient Noise Results

B.1. Analysis Methods

Ambient noise levels at all winter and summer recording stations were examined to document baseline underwater sound conditions in the Chukchi Sea.

Ambient noise levels at each recording station are presented as:

- Statistical distribution of sound pressure levels in each 1/3-octave-band over the monitoring period. The boxes of the statistical distributions indicate the first (25%), second (50%), and third (75%) quartiles. The whiskers indicate the maximum and minimum range of the data. The red line indicates the root-mean-square (rms) in each 1/3-octave.
- Spectral level percentiles: Histograms of each frequency bin per 1 min of data. The 5th, 25th, 50th, 75th, and 95th percentiles are plotted. The 95th percentile curve is the frequency-dependent level exceeded by 5% of the 1 min averages. Equivalently, 95% of the 1 min spectral levels are below the 95th percentile curve.
- Broadband and approximate-decade-band sound pressure levels (SPLs) over time for the following frequency bands: 10 Hz to 8 kHz, 10–100 Hz, 100 Hz to 1 kHz, and 1–8 kHz.
- Spectrograms: Ambient noise at each station was analyzed by Hamming-windowed fast Fourier transforms (FFTs), with 1 Hz resolution and 50% window overlap. The 120 FFTs performed with these settings are averaged to yield 1 min average spectra.
- Daily cumulative sound exposure levels (cSELs) computed for the total received sound energy, the detected seismic survey energy, the detected shipping energy, and the ambient estimated periods when there were no anthropogenic detections within 2 hours. The cSEL is the linear sum of the 1-minute sound exposure levels (SELs). For ambient and shipping, the 1-minute cSELs are the linear 1-minute squared rms levels multiplied by the duration, 60 s. For seismic survey pulses, the 1-minute SEL is the linear sum of the per-pulse SELs.
- Cumulative distribution functions (CDF) for the total received sound energy, the detected seismic survey energy, the detected shipping energy, and the ambient estimated periods.
- Power spectral density against frequency for the 5th and the 50th (median) of the total received sound energy, the detected seismic survey energy, the detected shipping energy, and the ambient estimated periods.

The 50th percentile (median of 1 min spectral averages) can be compared to the well-known Wenz ambient noise curves (see Figure 7). The Wenz curves show ranges of variability of ambient spectral levels as a function of frequency of measurements off the US Pacific coast over a range of weather, vessel traffic, and geologic conditions. The Wenz curve levels are generalized and are used for approximate comparisons only.

The 1-minute averaged, 1 Hz spectral density levels are summed over the 1/3-octave and decade-bands to obtain 1-minute averaged broadband levels (dB re 1 μPa). These values are available on request. Table B.1 lists the 1/3-octave-band frequencies, Table B.2 the decade-band frequencies. Weather and ice coverage conditions throughout the deployment periods are also provided.

Table B.1. Third-octave-band frequencies (Hz).

Band	Lower frequency	Nominal center frequency	Upper frequency
1	8.9	10	11.2
2	11.6	13	14.6
3	14.3	16	17.9
4	17.8	20	22.4
5	22.3	25	28.0
6	28.5	32	35.9
7	35.6	40	44.9
8	45.0	51	57.2
9	57.0	64	71.8
10	72.0	81	90.9
11	90.9	102	114.4
12	114.1	128	143.7
13	143.4	161	180.7
14	180.8	203	227.9
15	228.0	256	287.4
16	287.7	323	362.6
17	362.7	406	455.7
18	456.1	512	574.7
19	574.6	645	723.9
20	724.2	813	912.6
21	912.3	1024	1149
22	1150	1290	1447
23	1448	1625	1824
24	1824	2048	2297
25	2298	2580	2896
26	2896	3251	3649
27	3649	4096	4597
28	4598	5161	5793
29	5793	6502	7298
30	7298	8192	9195
31	9195	10,321	11,585
32	11,585	13,004	14,597

Table B.2. Decade-band frequencies (Hz).

Decade-band	Lower frequency	Nominal center frequency	Upper frequency
2	10	50	100
3	100	500	1000
4	1000	5000	10,000

B.2. Weather and Ice Conditions

B.2.1. Winter 2011–2012 Program

During the winter program, air temperature varied from −44 to 1.3 °C, with a mean of −20.2 °C. Reported wind speeds were as high as 15.6 m/s and averaged 2.7 m/s (

Figure B.1). Ice coverage increased in November, and by 1 Dec the entire program area was almost 100% covered with ice (Figure B.2). Initial ice break-up started by 1 Jun, along the shore between Cape Lisburne and Wainwright, and progressed offshore by 1 Jul (Figure B.3). The program area was ice-free south of 70° N by the start of August.

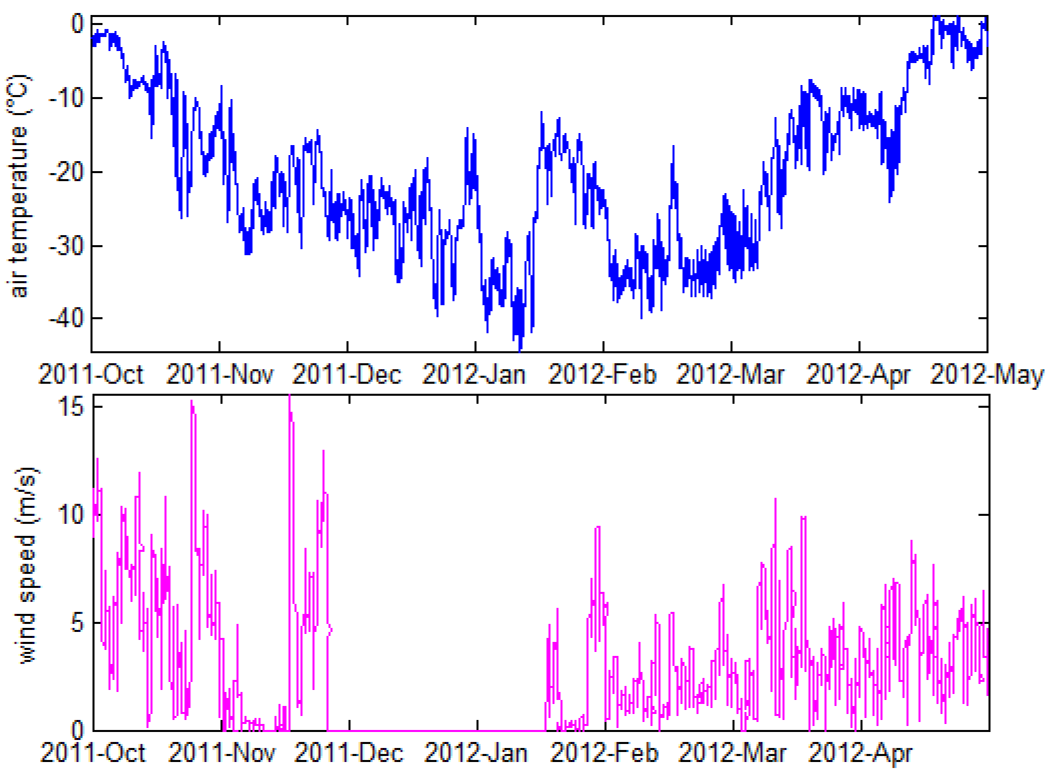

Figure B.1. (Top) Air temperature and (bottom) wind speed from the Barrow station, 15 Oct 2011 to 31 May 2012 (71.32° N, 156.61° W; NCDC 2012).

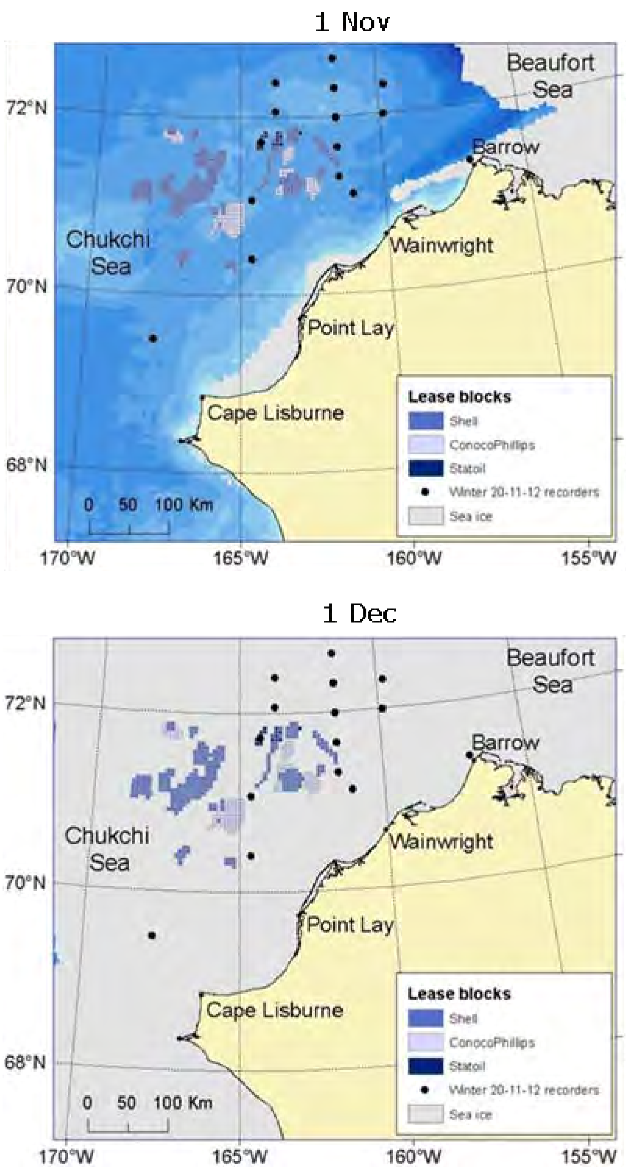

Figure B.2. Sea ice coverage (ice vs. open water) in the Chukchi and Beaufort Seas. (Top left) 1 Nov, (top right) 15 Nov, (bottom left) 1 Dec, and (bottom right) 15 Dec 2011 (NOAA 2012). The winter 2011-2012 recording stations are shown for reference.

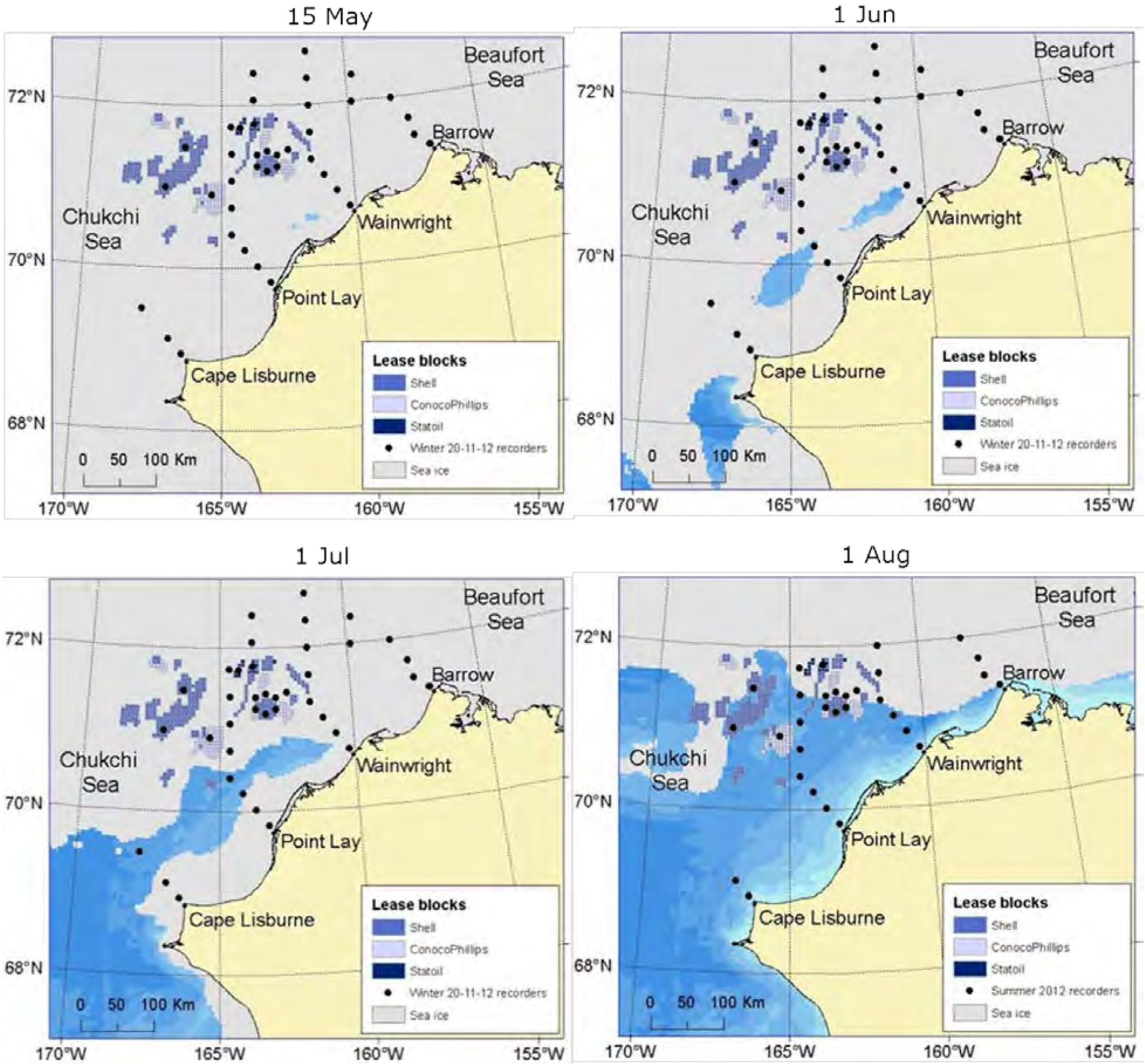

Figure B.3. Sea ice coverage (ice vs. open water) in the Chukchi and Beaufort Seas. (Top left) 15 May, (top right) 1 Jun, (bottom left) 1 Jul, and (bottom right) 1 Aug 2012 (NOAA 2012). The winter 2011–2012 recording stations are shown for reference.

B.2.2. Summer 2012 Program

During the summer program, air temperature varied from −6.9 to 19 °C, with a mean of 3.6 °C. Reported wind speeds were as high as 11.3 m/s and averaged 4.3 m/s (Figure B.4). Northern areas had high ice coverage early in the deployment, and the program area was ice free by the end of the 2012 summer deployment (Figure B.5).

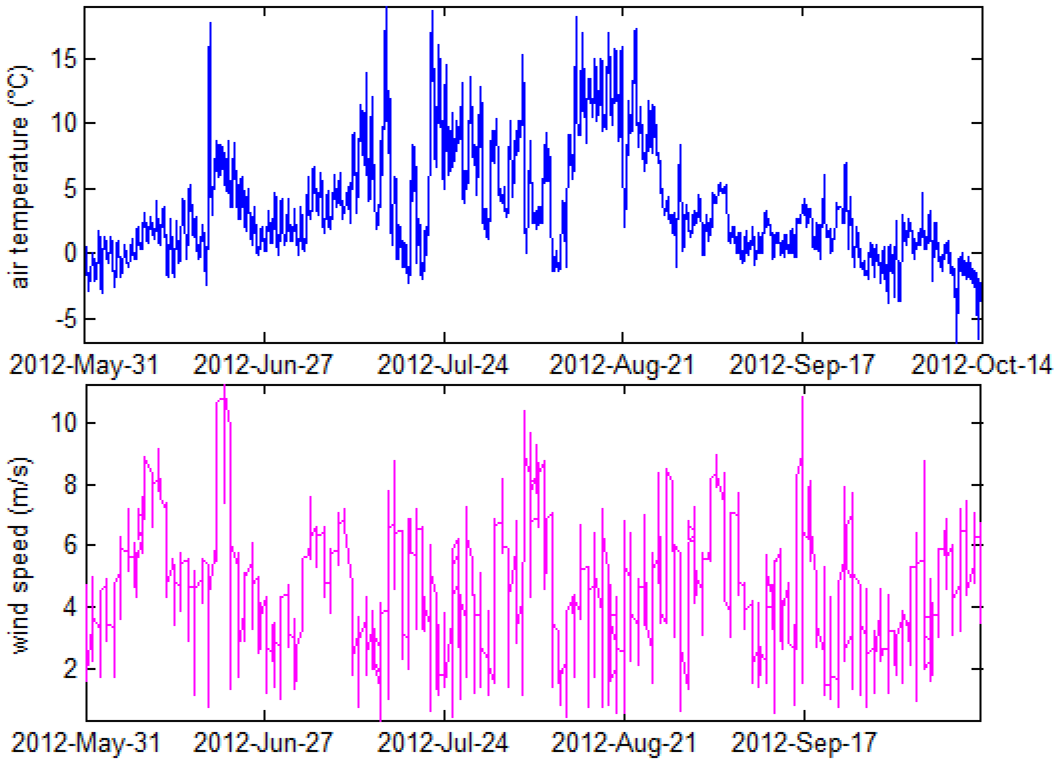

Figure B.4. (Top) Air temperature and (bottom) wind speed from the Barrow station 31 May to 14 Oct 2012 (71.32° N, 156.61° W; NCDC 2012).

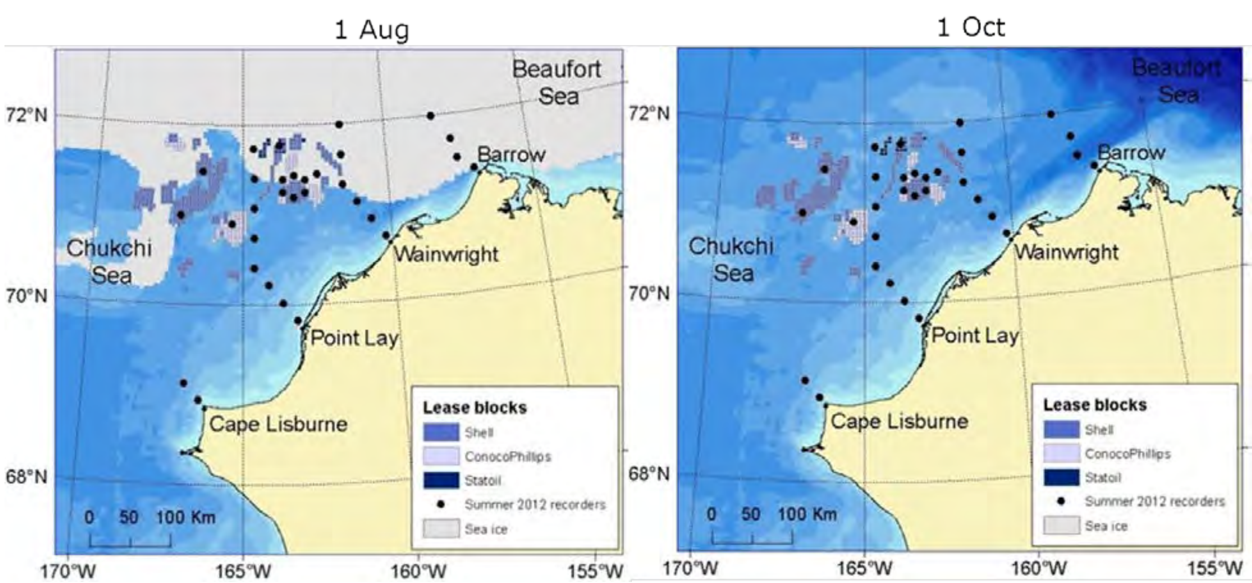

Figure B.5. Sea ice coverage (ice vs. open water) in the Chukchi and Beaufort Seas relative to the summer 2012 recording stations. (Left) 1 Aug and (right) 1 Oct 2012 (NOAA 2012).

B.3. Winter 2011–2012 Program

B.3.1. One-Third-Octave-Band Sound Pressure and Power Spectral Density Levels

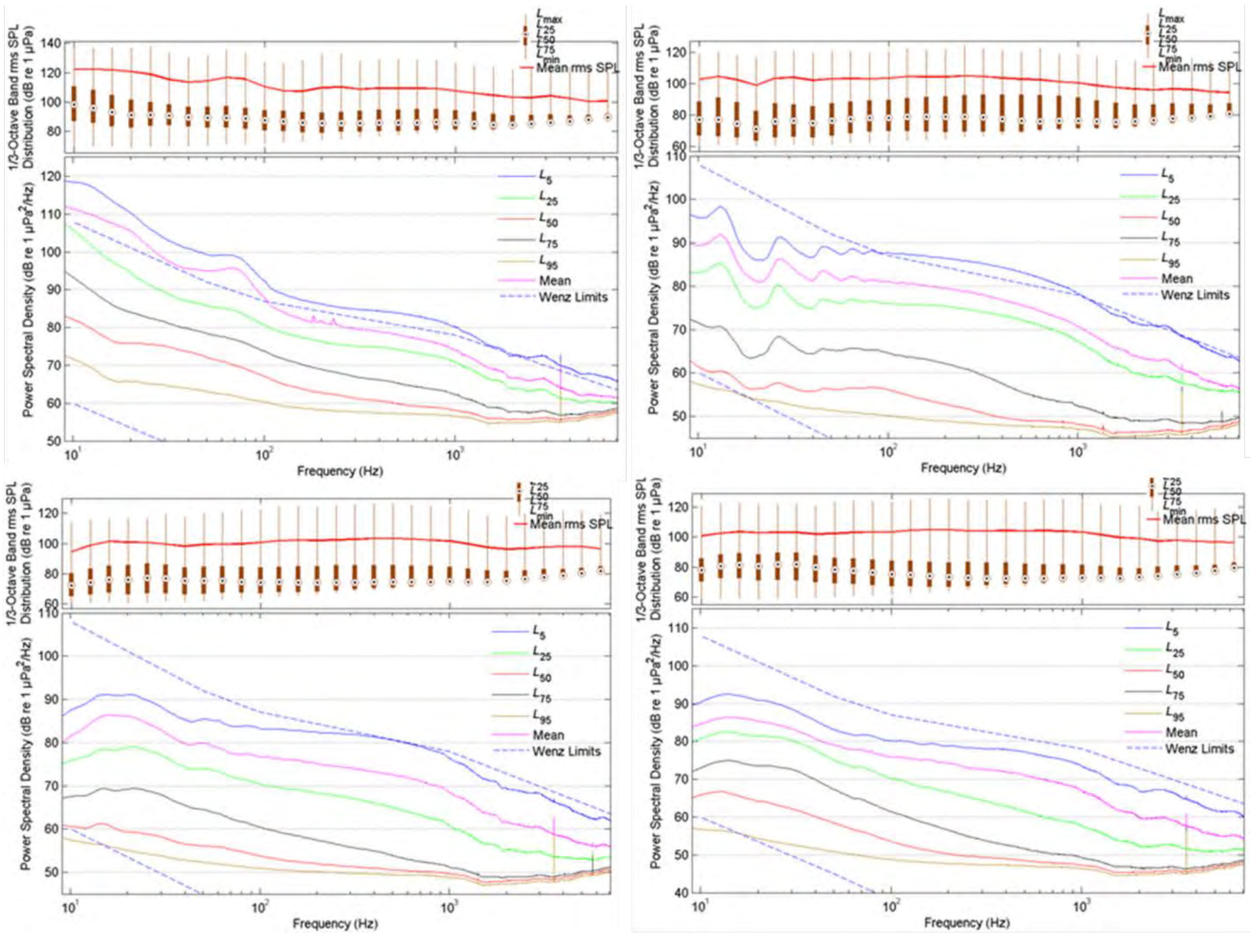

Figure B.6. 1/3-octave-band sound pressure levels and percentile 1-min power spectral density levels for winter 2011–2012 stations. (Top left) B05 from October 2011 to August 2012, (top right) CL50 from October 2011 to March 2012, (bottom left) PL50 from October 2011 to May 2012, and (bottom right) PLN40 from October 2011 to May 2012.

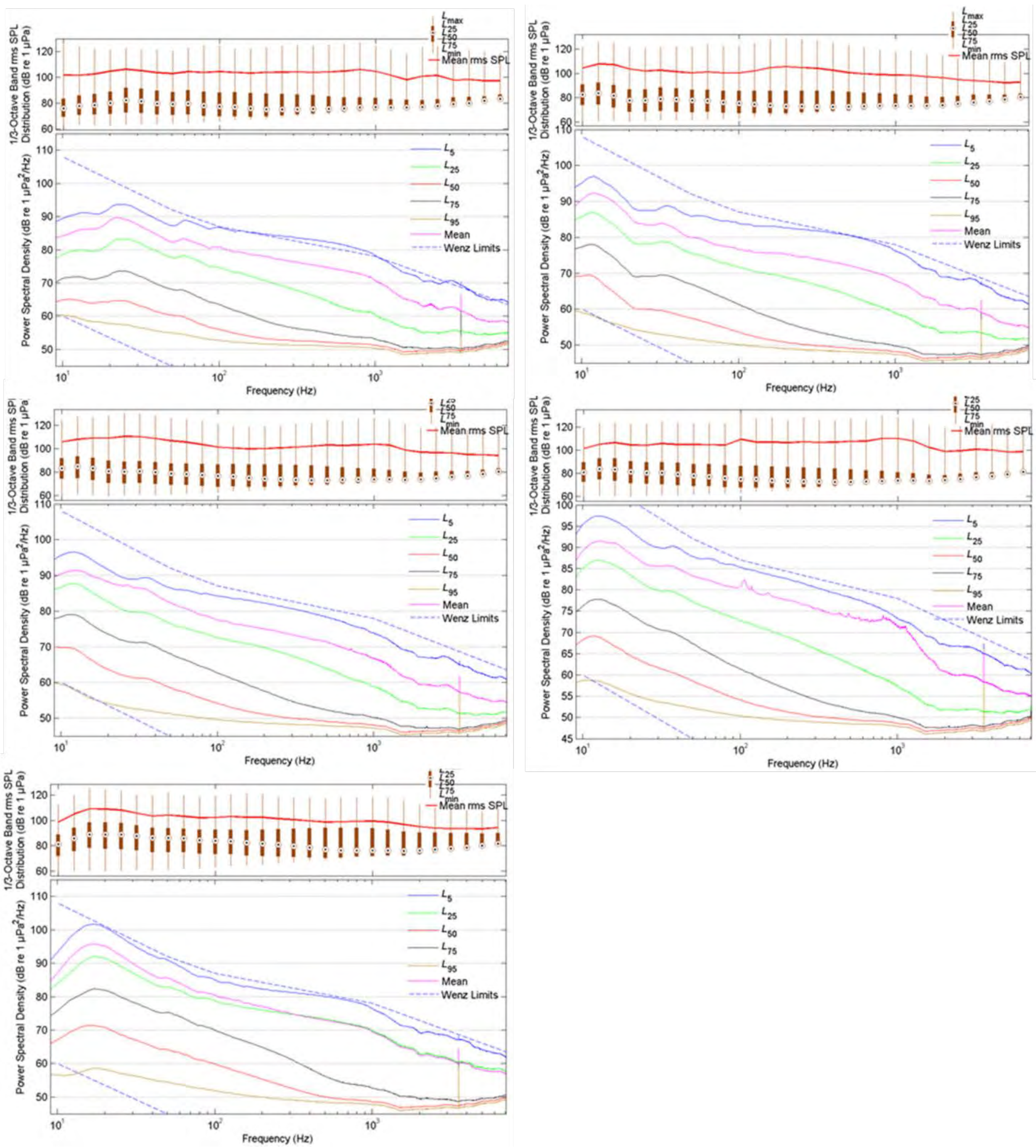

Figure B.7. 1/3-octave-band sound pressure levels and percentile 1-min power spectral density levels for winter 2011–2012 stations. (Top left) PLN80 from October 2011 to June 2012, (top right) W35 from October 2011 to May 2012, (middle left) W50 from October 2011 to April 2012, (middle right) WN20 from October 2011 to May 2012, and (bottom left) WN40 from October 2011 to February 2012.

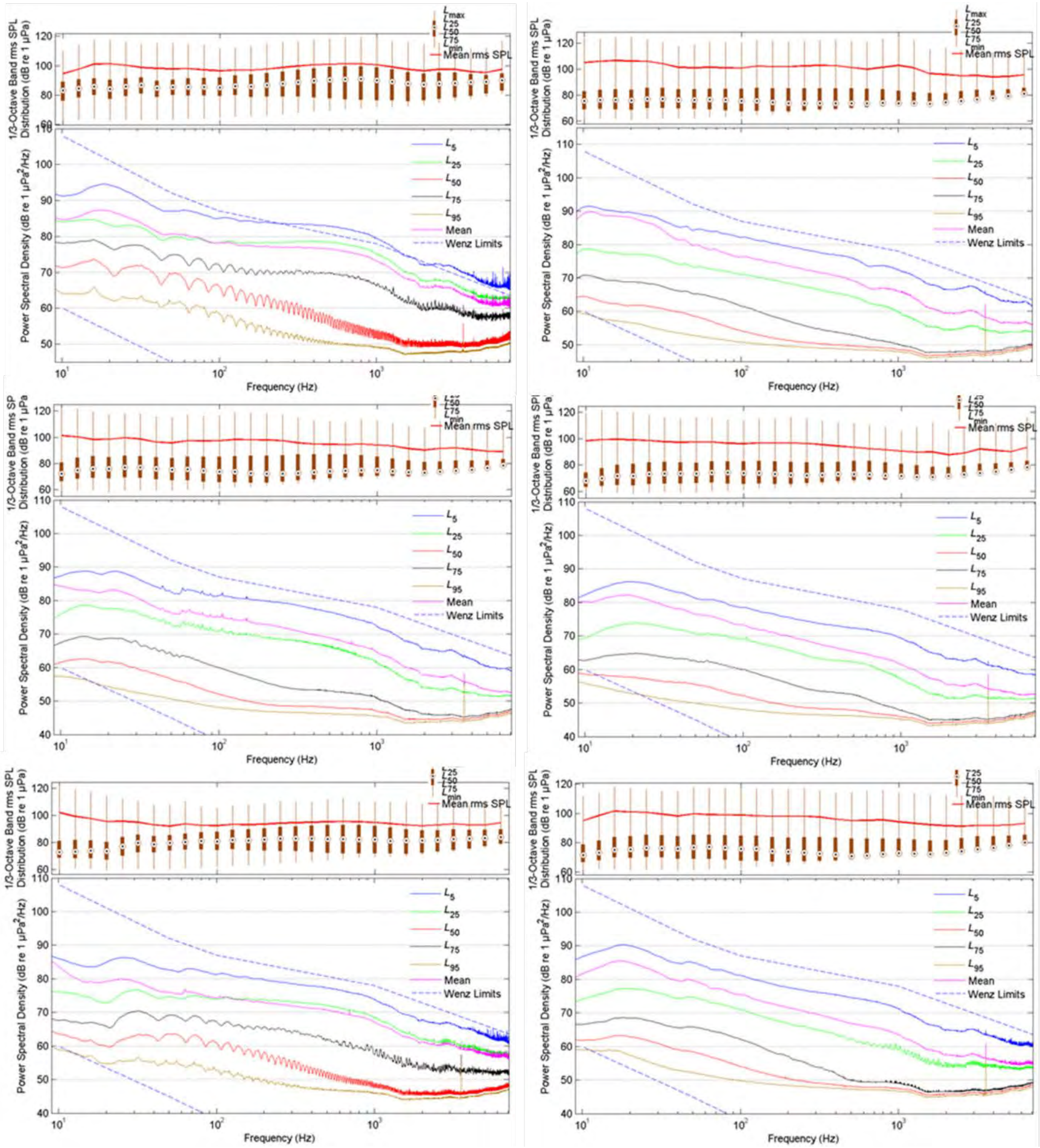

Figure B.8. 1/3-octave-band sound pressure levels and percentile 1-min power spectral density levels for winter 2012 stations. (Top left) PBN20 from September to December 2011, (top right) PBN40 September 2011 to June 2012, (middle left) PLN100 from September 2011 to July 2012, (middle right) PLN120 from September 2011 to June 2012, (bottom left) WN60 from September 2011 to January 2012, and (bottom right) WN80 from September 2011 to June 2012.

B.3.2. Broadband and Decade-Band Sound Pressure Levels and Spectrograms

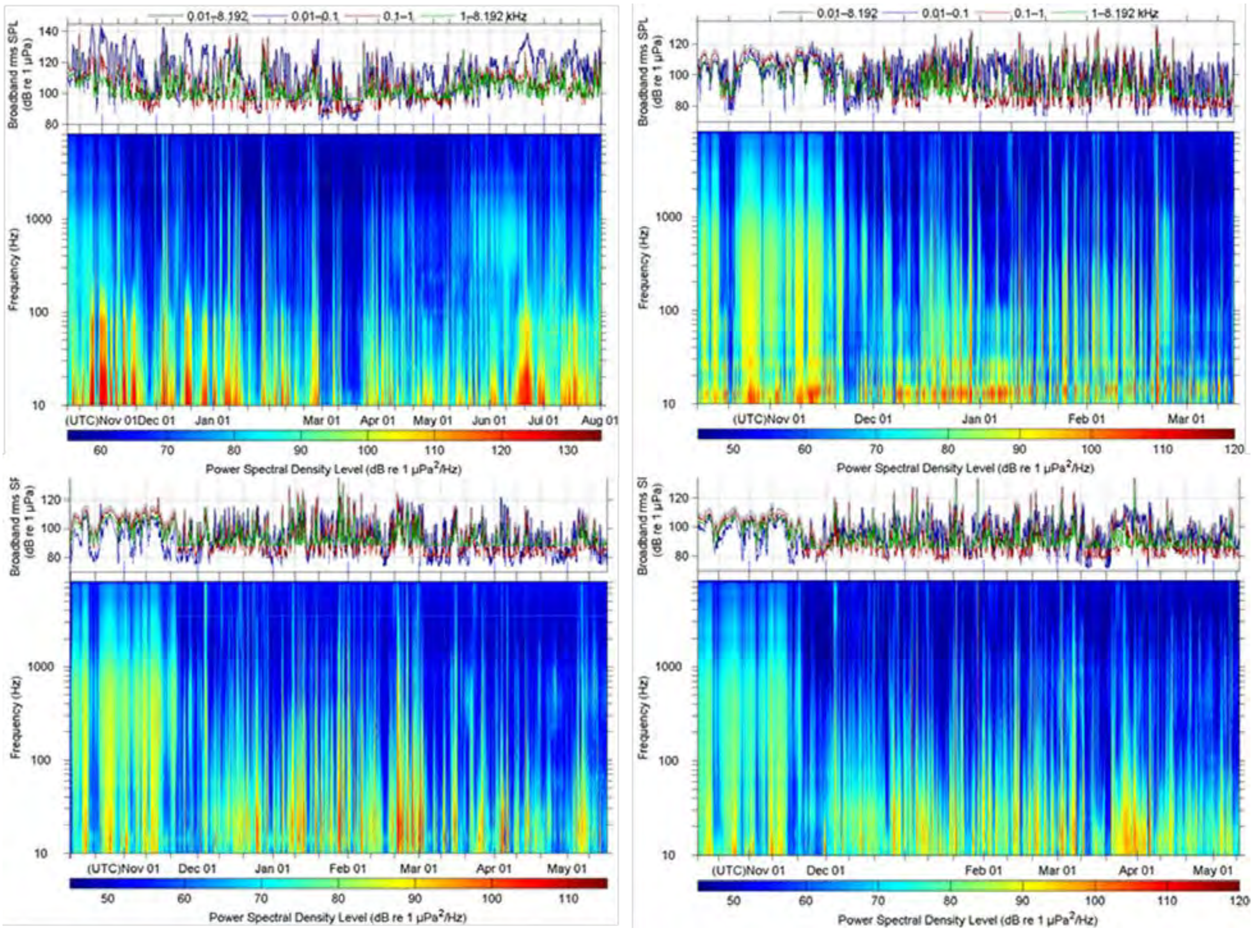

Figure B.9. Broadband and decade-band sound pressure levels (SPLs) and spectrograms for winter 2011–2012 stations. (Top left) B05 from October 2011 to August 2012, (top right) CL50 from October 2011 to March 2012, (bottom left) PL50 from October 2011 to May 2012, and (bottom right) PLN40 from October 2011 to May 2012.

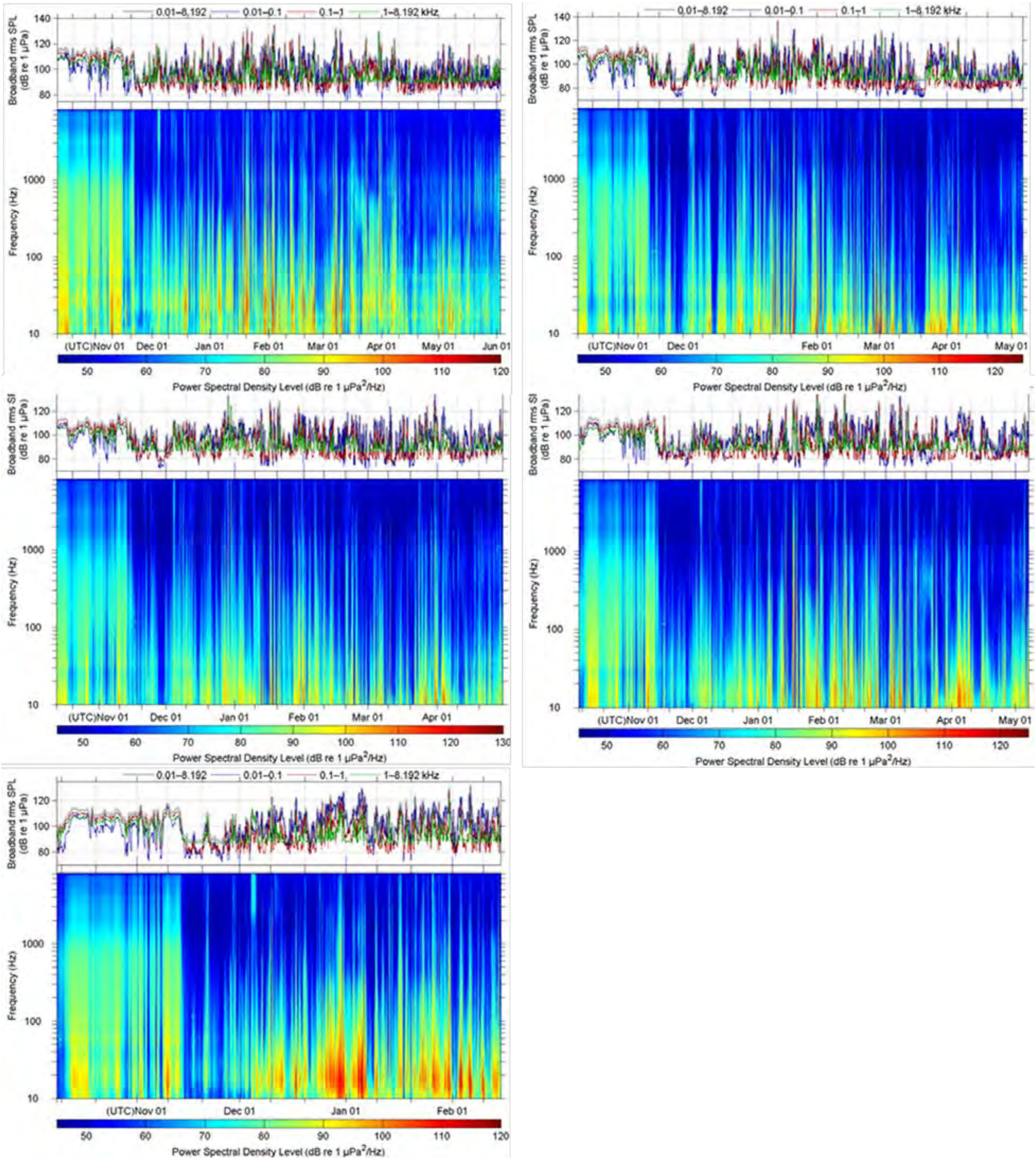

Figure B.10. Broadband and decade-band sound pressure levels (SPLs) and spectrograms for winter 2011–2012 stations. (Top left) PLN80 from October 2011 to June 2012, (top right) W35 from October 2011 to May 2012, (middle left) W50 from October 2011 to April 2012, (middle right) WN20 from October 2011 to May 2012, and (bottom left) WN40 from October 2011 to February 2012.

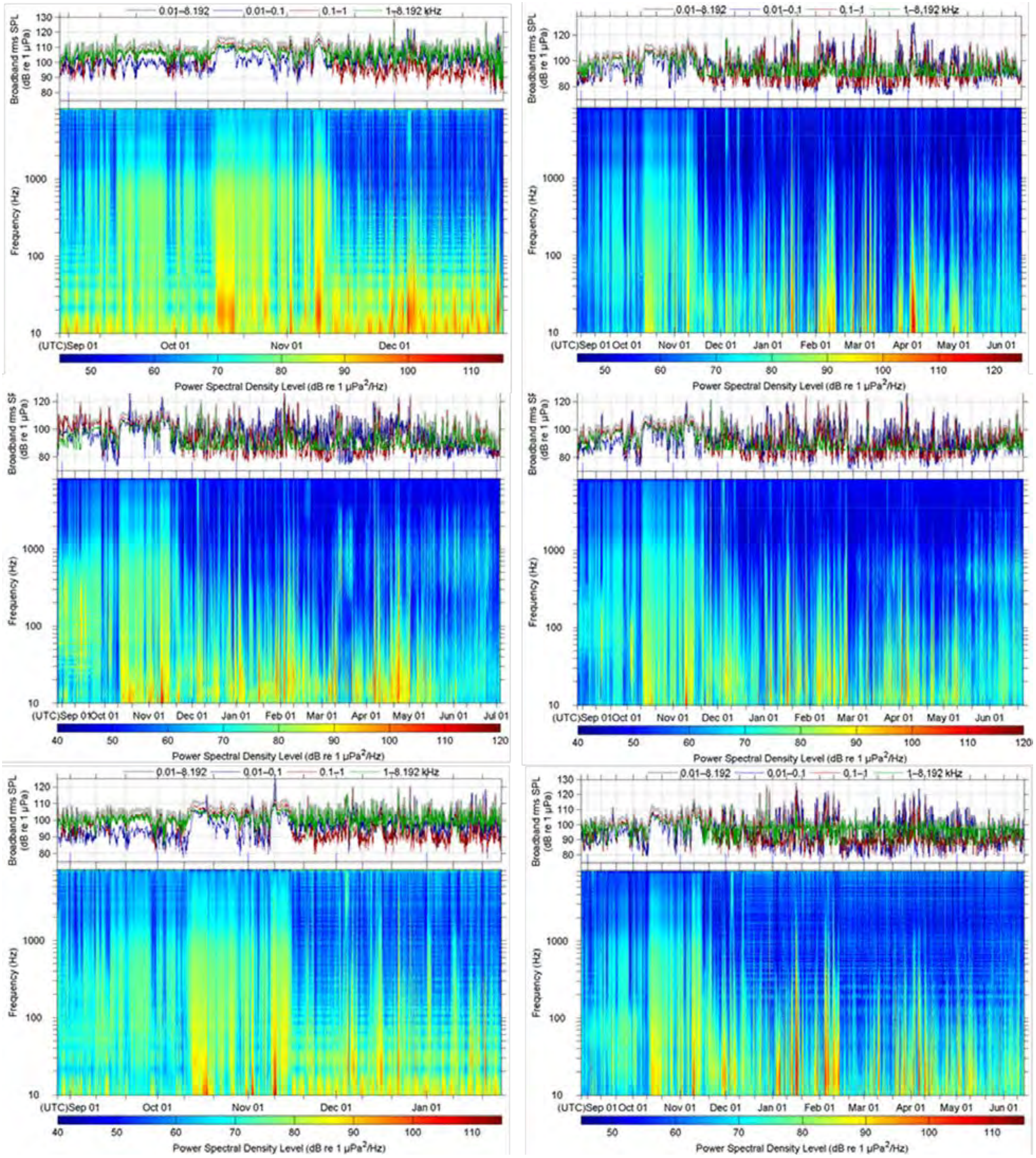

Figure B.11. Broadband and decade-band sound pressure levels (SPLs) and spectrograms for winter 2012 stations. (Top left) PBN20 from September to December 2011, (top right) PBN40 September 2011 to June 2012, (middle left) PLN100 from September 2011 to July 2012, (middle right) PLN120 from September 2011 to June 2012, (bottom left) WN60 from September 2011 to January 2012, and (bottom right) WN80 from September 2011 to June 2012.

B.3.3. Daily Cumulative Sound Exposure Level, Cumulative Distribution Function and Power Spectral Density

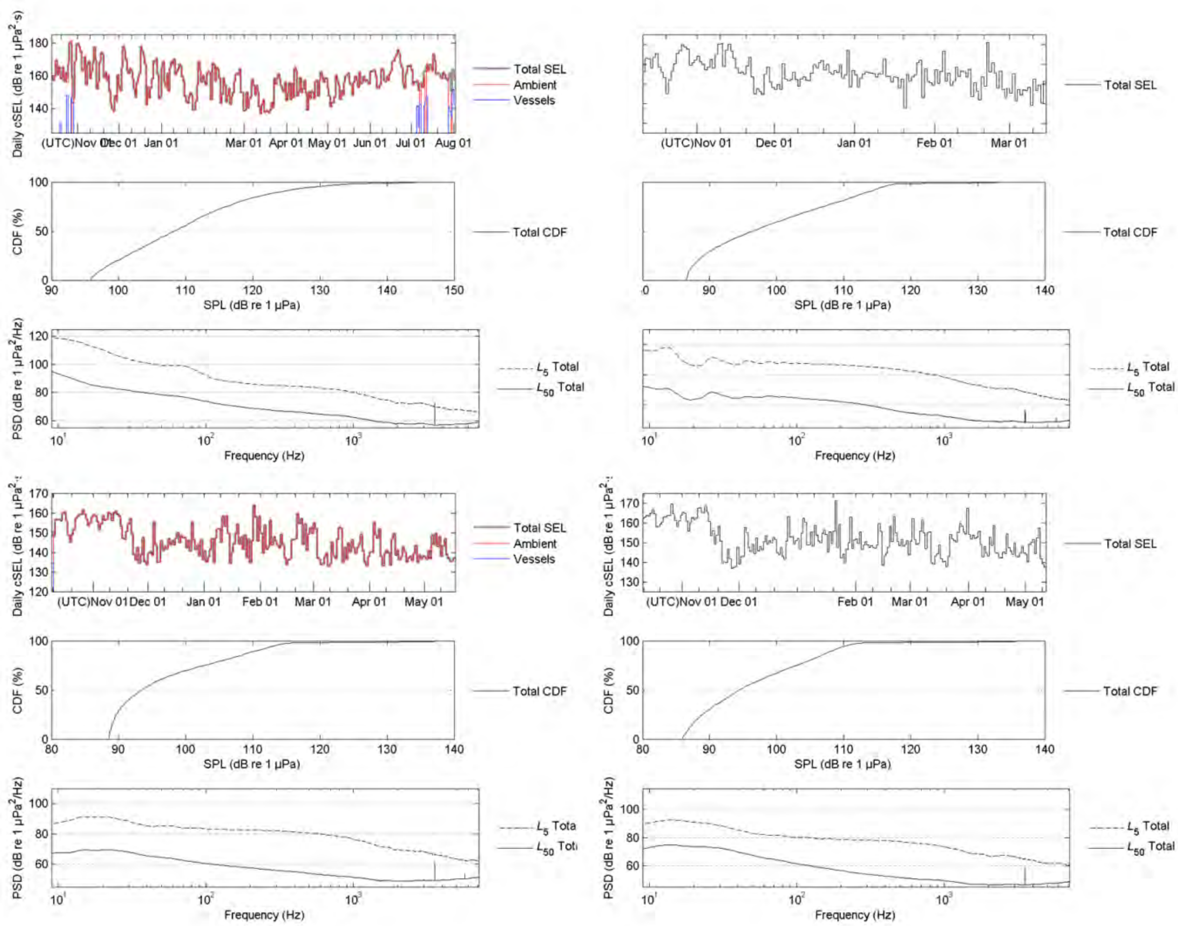

Figure B.12. Daily cumulative sound exposure levels (cSEL), cumulative distribution function (CDF), and power spectral density (PSD) for winter 2011–2012 stations. (Top left) B05 from October 2011 to August 2012, (top right) CL50 from October 2011 to March 2012, (bottom left) PL50 from October 2011 to May 2012, and (bottom right) PLN40 from October 2011 to May 2012.

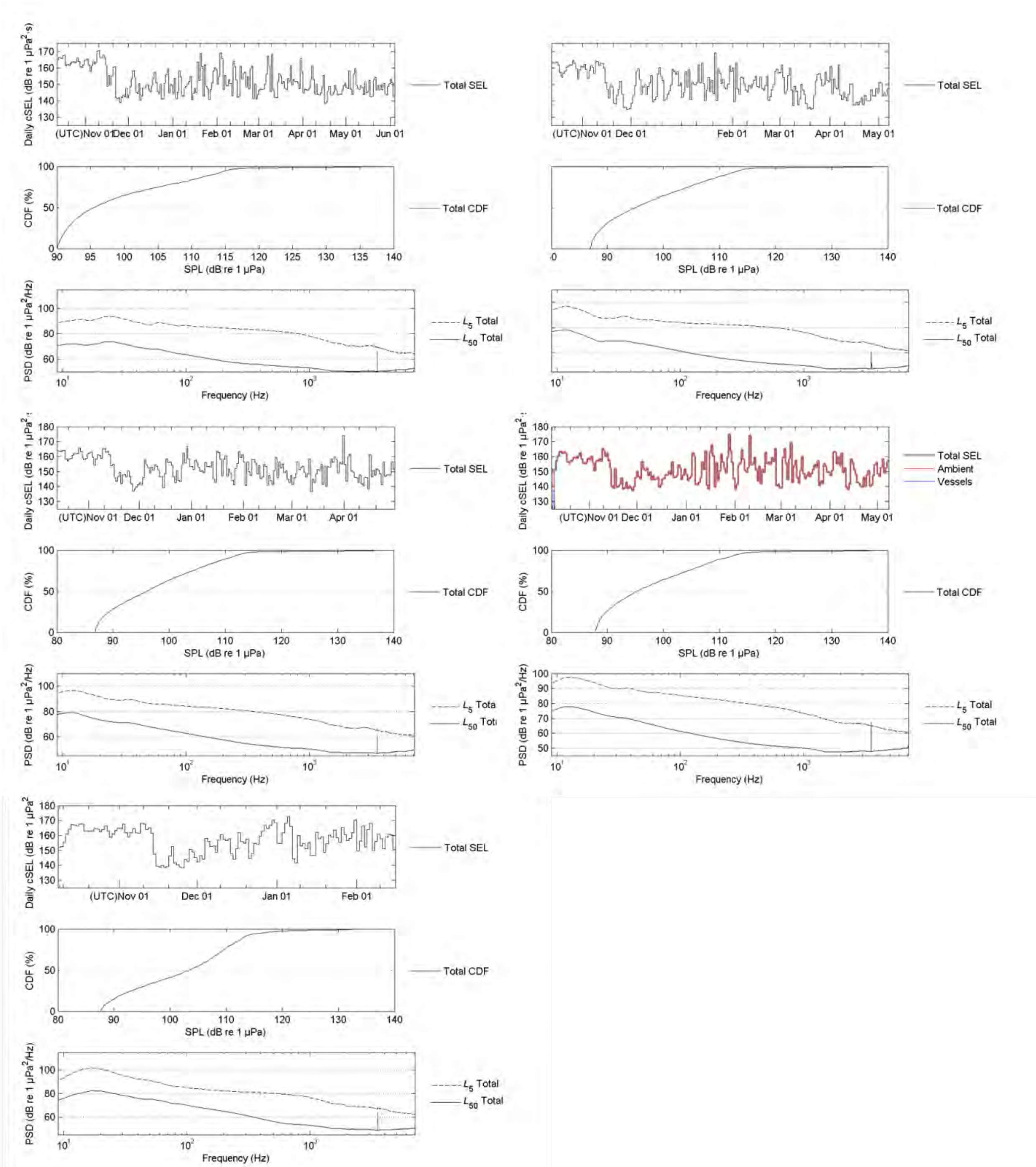

Figure B.13. Daily cumulative sound exposure levels (cSEL), cumulative distribution function (CDF), and power spectral density (PSD) for winter 2011–2012 stations. (Top left) PLN80 from October 2011 to June 2012, (top right) W35 from October 2011 to May 2012, (middle left) W50 from October 2011 to April 2012, (middle right) WN20 from October 2011 to May 2012, and (bottom left) WN40 from October 2011 to February 2012.

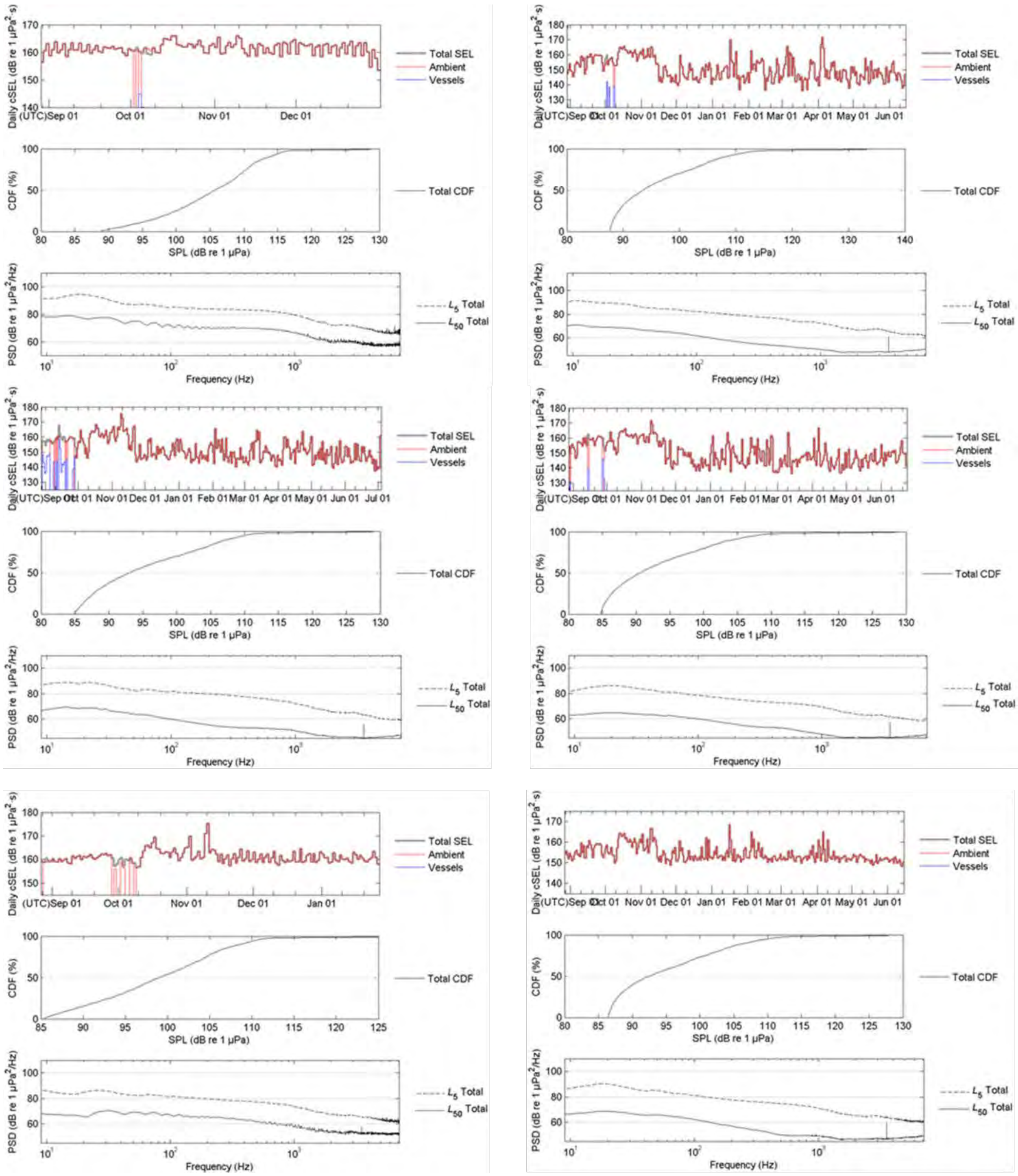

Figure B.14. Daily cumulative sound exposure levels (cSEL), cumulative distribution function (CDF), and power spectral density (PSD) for winter 2012 stations. (Top left) PBN20 from September to December 2011, (top right) PBN40 from September 2011 to June 2012, (middle left) PLN100 from September 2011 to July 2012, (middle right) PLN120 from September 2011 to June 2012, (bottom left) WN60 from September 2011 to January 2012, and (bottom right) WN80 from September 2011 to June 2012.

B.4. Summer 2012 Program

B.4.1. One-Third-Octave-Band Sound Pressure and Power Spectral Density Levels

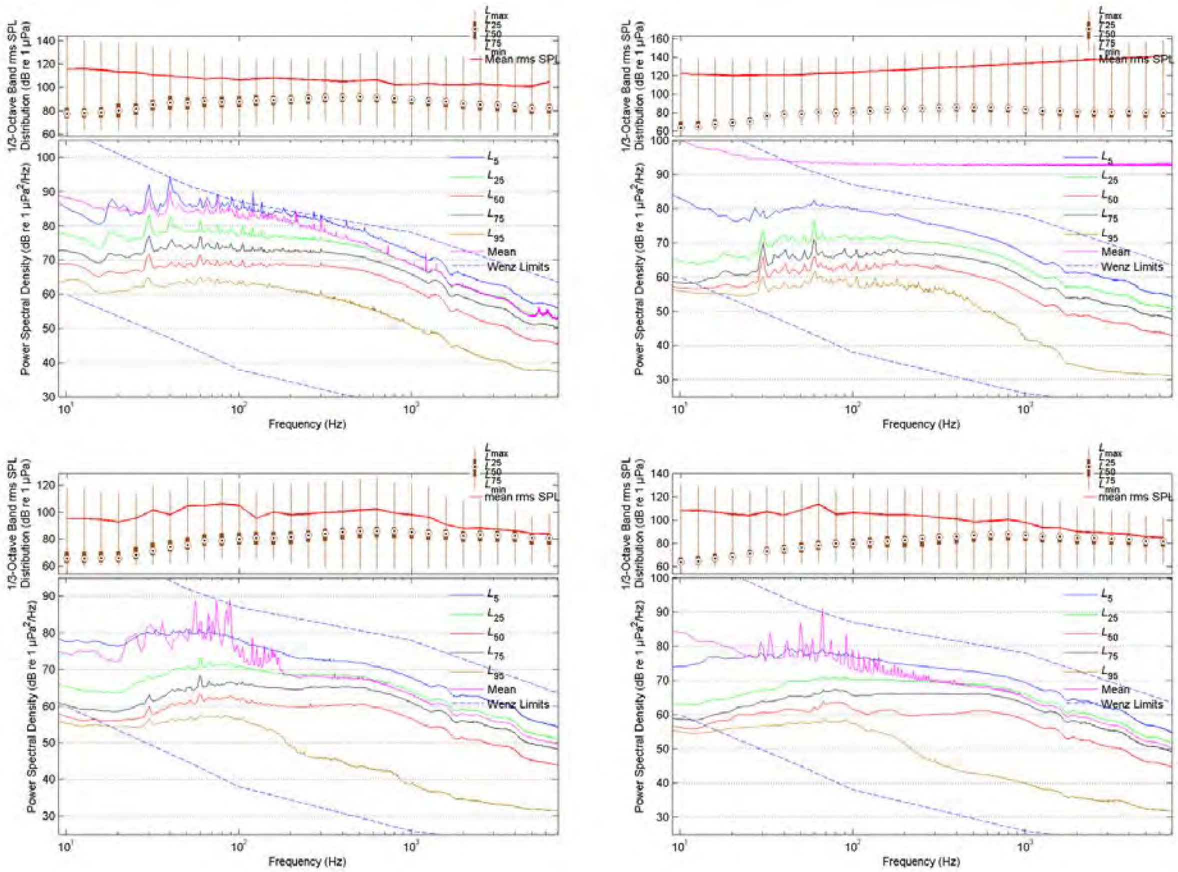

Figure B.15. 1/3-octave-band sound pressure levels and percentile 1-min power spectral density levels for summer 2012 stations. (Top left) B05 from August to October, (top right) B15 September to October, (bottom left) B30 from August to September, and (bottom right) B50 from September to October.

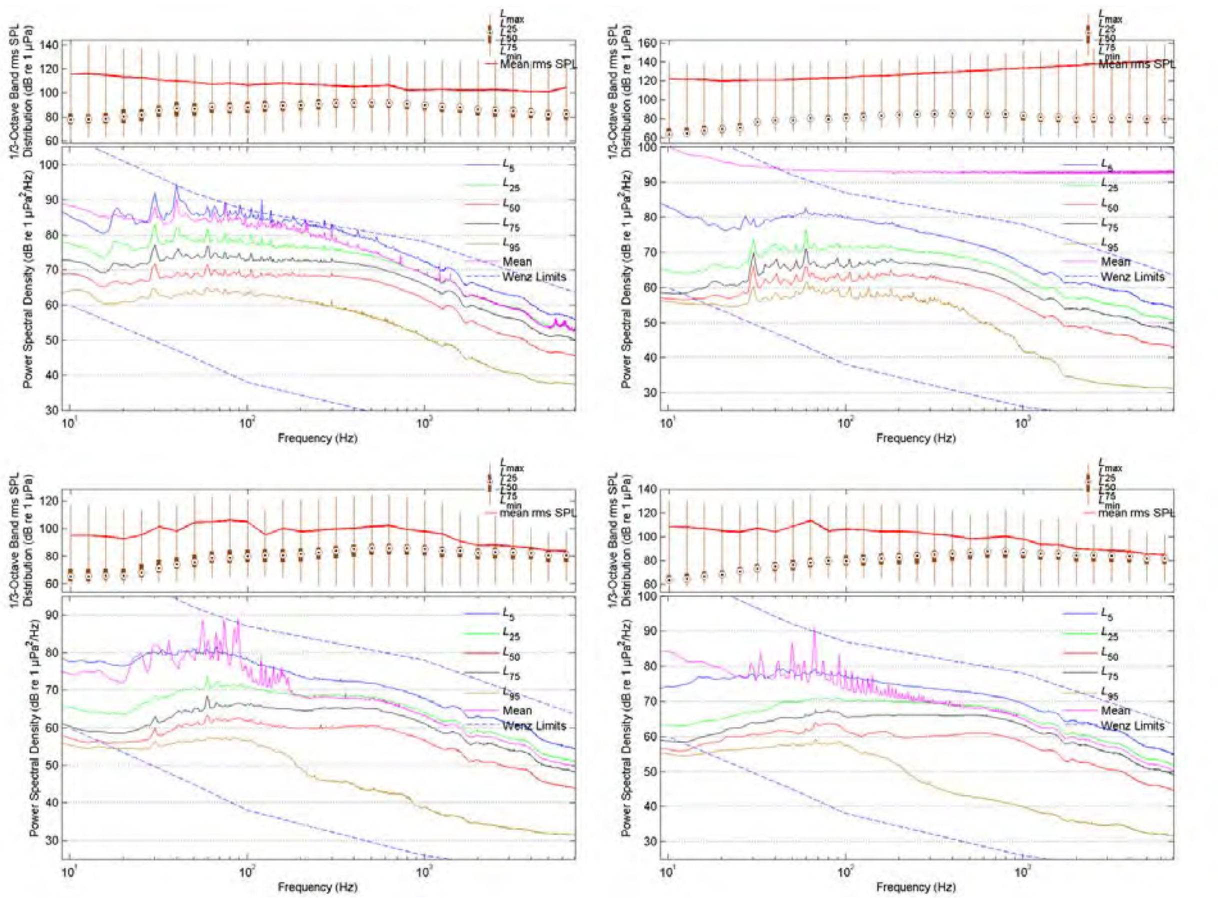

Figure B.16. 1/3-octave-band sound pressure levels and percentile 1-min power spectral density levels for summer 2012 stations—August to October 2012. (Top left) CL05, (top right) CL20, (bottom left) CLN90B, and (bottom right) CLN120B.

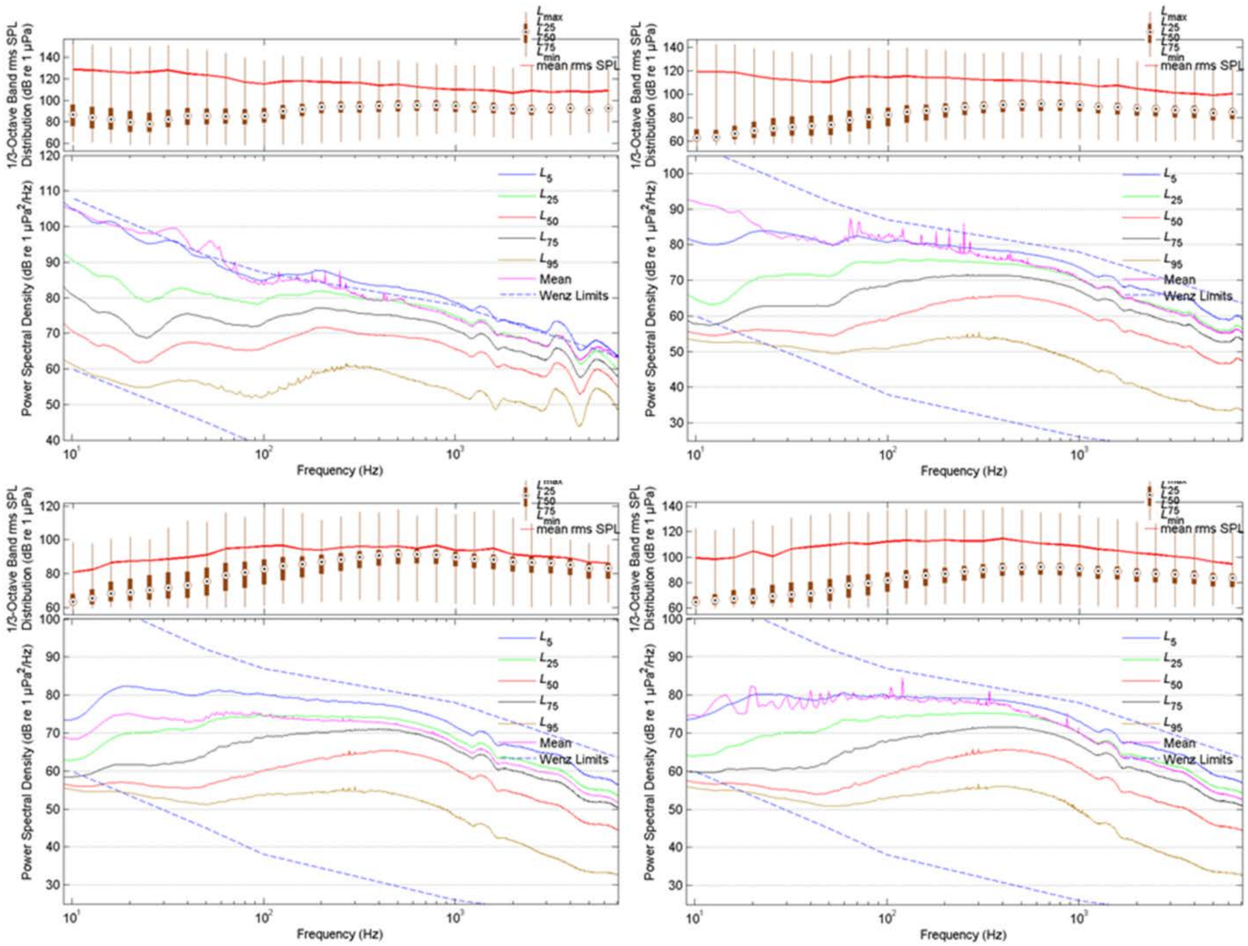

Figure B.17. 1/3-octave-band sound pressure levels and percentile 1-min power spectral density levels for summer 2012 stations—August to October 2012. (Top left) PL05, (top right) PL20, (bottom left) PL35, and (bottom right) PL50.

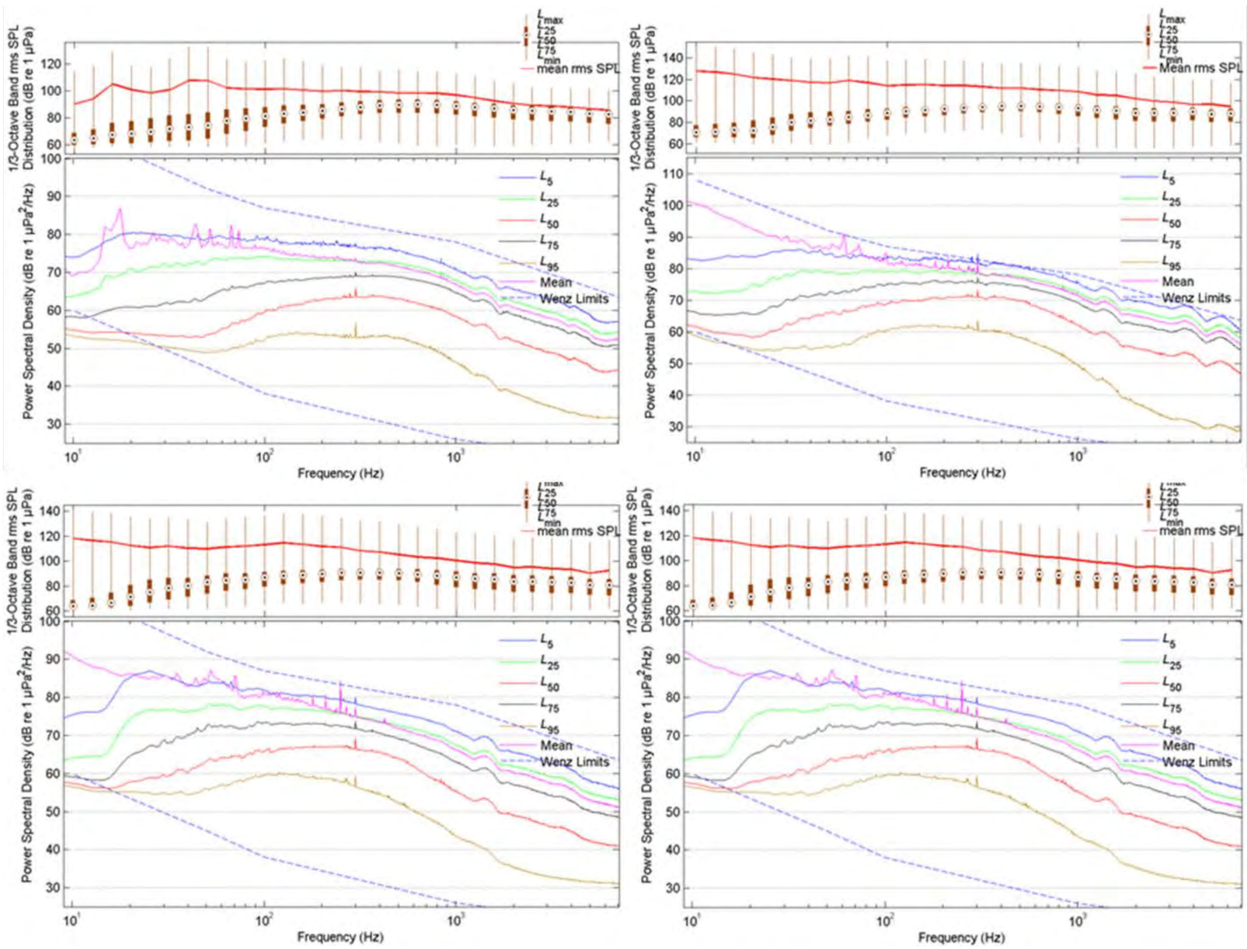

Figure B.18. 1/3-octave-band sound pressure levels and percentile 1-min power spectral density levels for summer 2012 stations—August to October 2012. (Top left) PLN20, (top right) PLN40, (bottom left) PLN60, and (bottom right) PLN80.

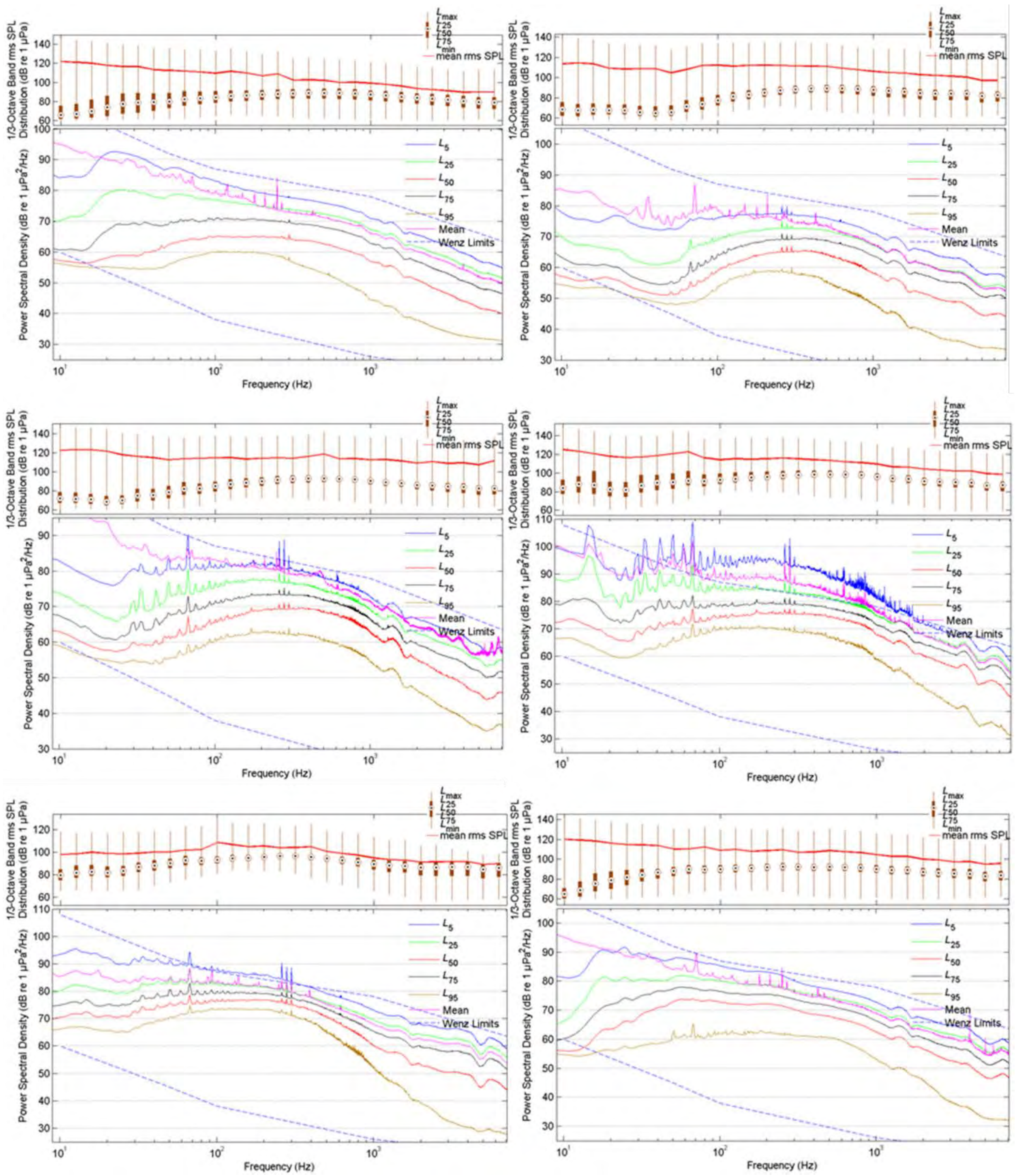

Figure B.19. 1/3-octave-band sound pressure levels and percentile 1-min power spectral density levels for summer 2012 stations—August to October 2012. (Top left) W05, (top right) W20, (middle left) W35, (middle right) W50. From September to October: (Bottom left) WN20 and (bottom right) WN40.

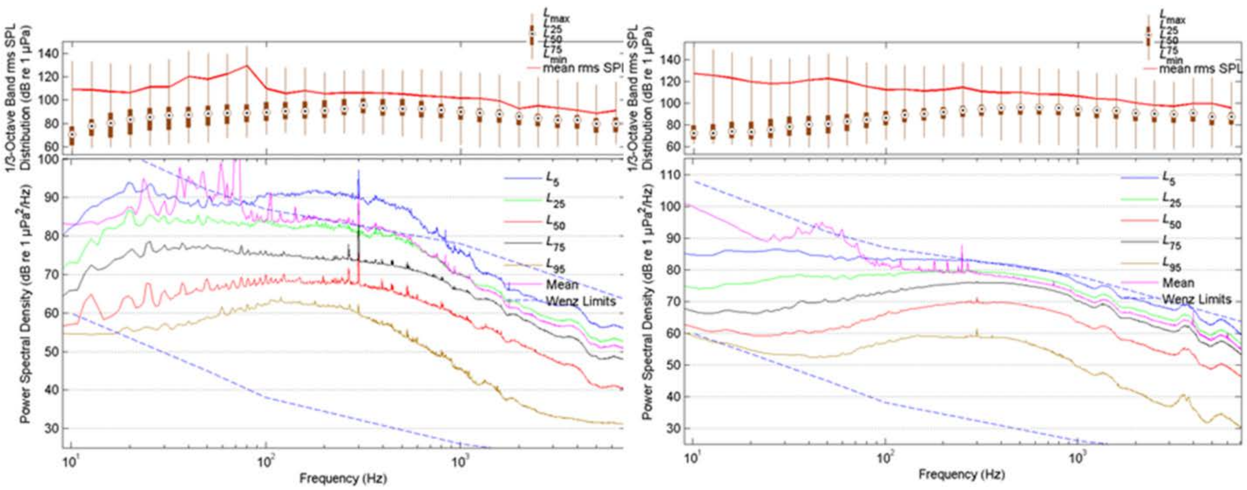

Figure B.20. 1/3-octave-band sound pressure levels and percentile 1-min power spectral density levels for summer 2012 stations—August to October 2012. (Left) BG02 and (right) KL01.

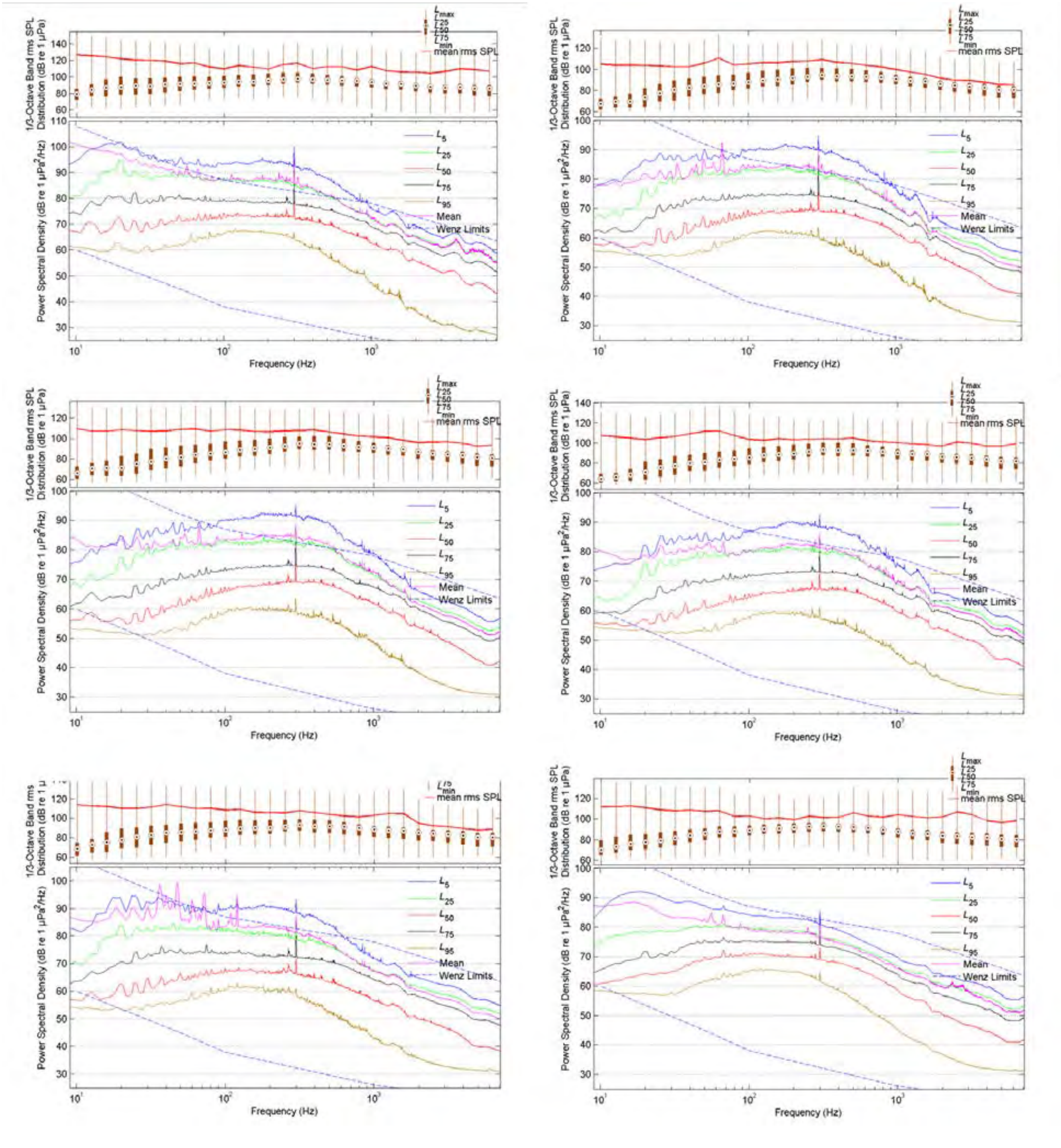

Figure B.21. 1/3-octave-band sound pressure levels and percentile 1-min power spectral density levels for summer 2012 stations—August to October 2012. (Top left) BG03, (top right) BG04, (middle left) BG05, (middle right) BG06, (bottom left) BG07, and (bottom right) BG08.

B.4.2. Broadband and Decade-Band Sound Pressure Levels and Spectrograms

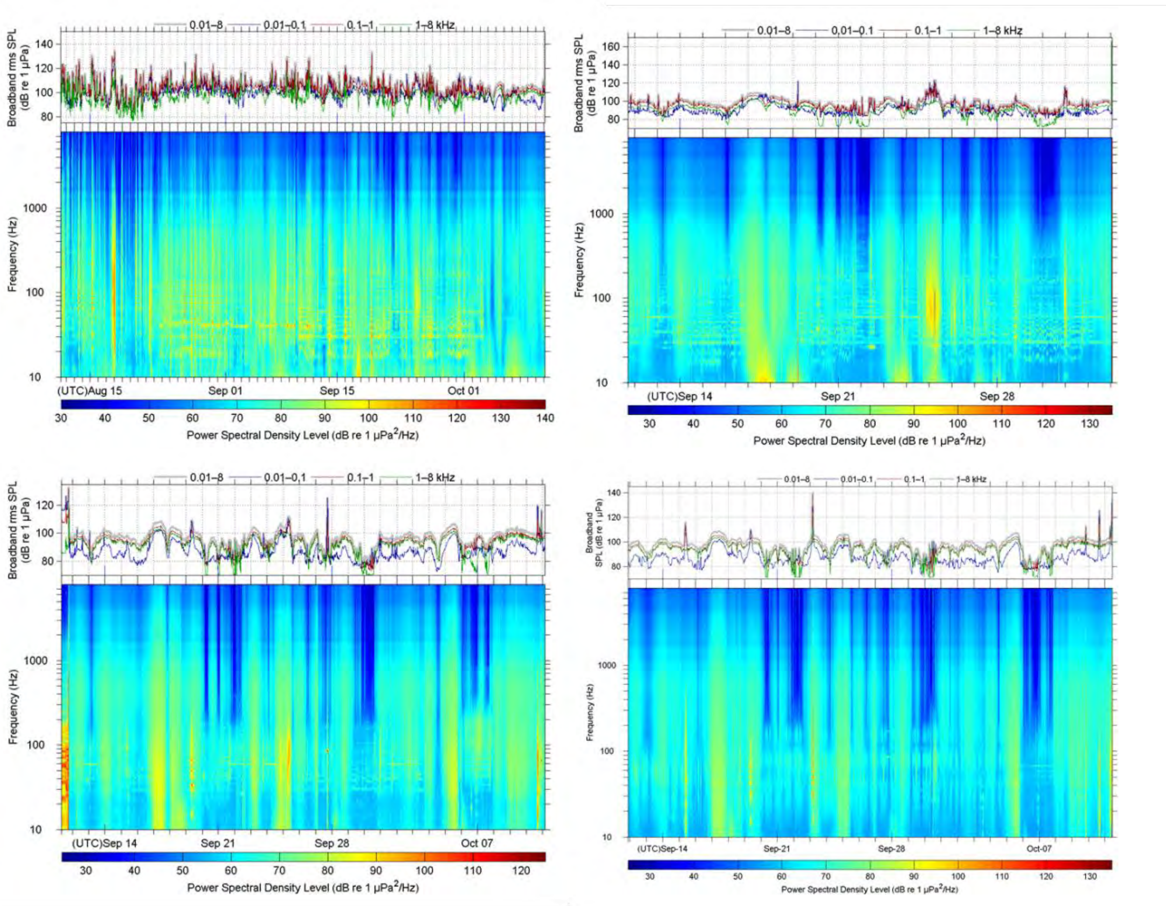

Figure B.22. Broadband and decade-band sound pressure levels (SPLs) and spectrograms for summer 2012 stations. (Top left) B05 from August to October, (top right) B15 from September to October, (bottom left) B30 from August to September, and (bottom right) B50 from September to October.

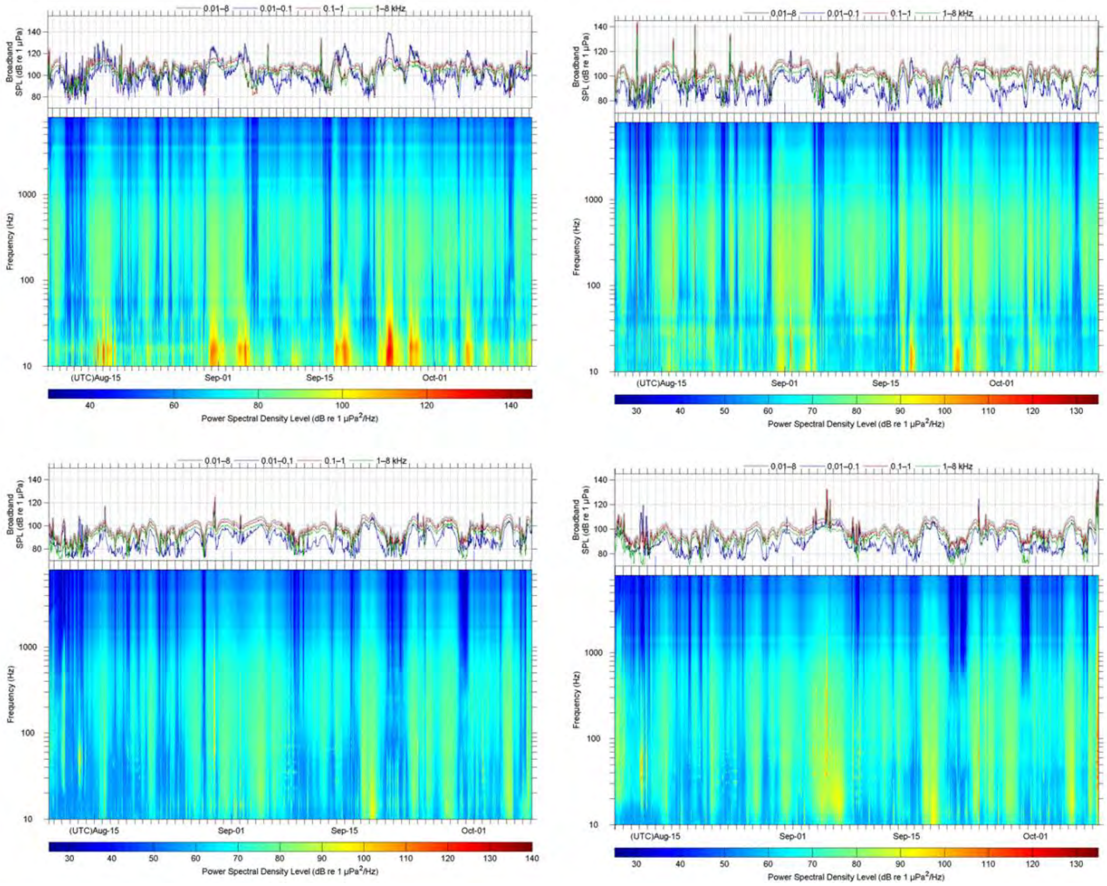

Figure B.23. Broadband and decade-band sound pressure levels (SPLs) and spectrograms for summer 2012 stations—August to October 2012. (Top left) CL05, (top right) CL20, (bottom left) CLN90B, and (bottom right) CLN120B.

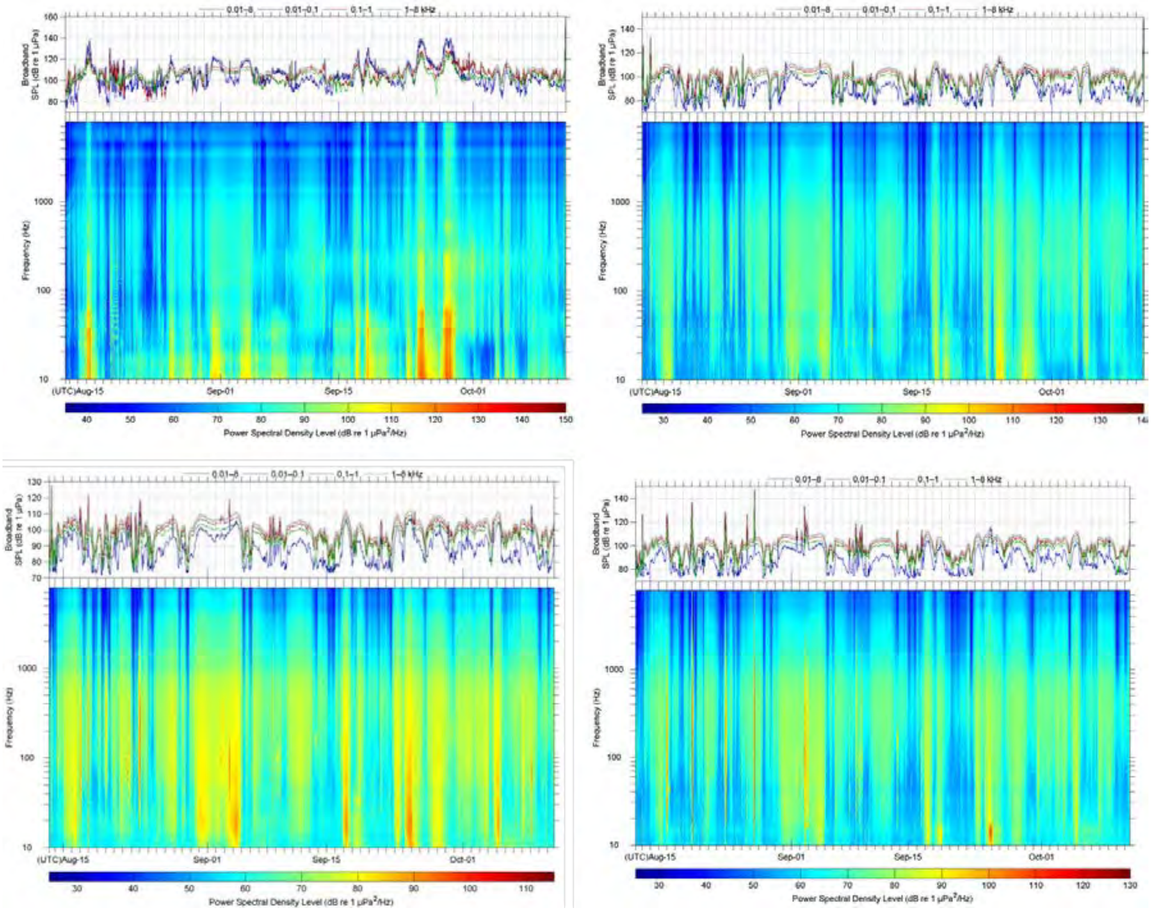

Figure B.24. Broadband and decade-band sound pressure levels (SPLs) and spectrograms for summer 2012 stations—August to October 2012. (Top left) PL05, (top right) PL20, (bottom left) PL35, and (bottom right) PL50.

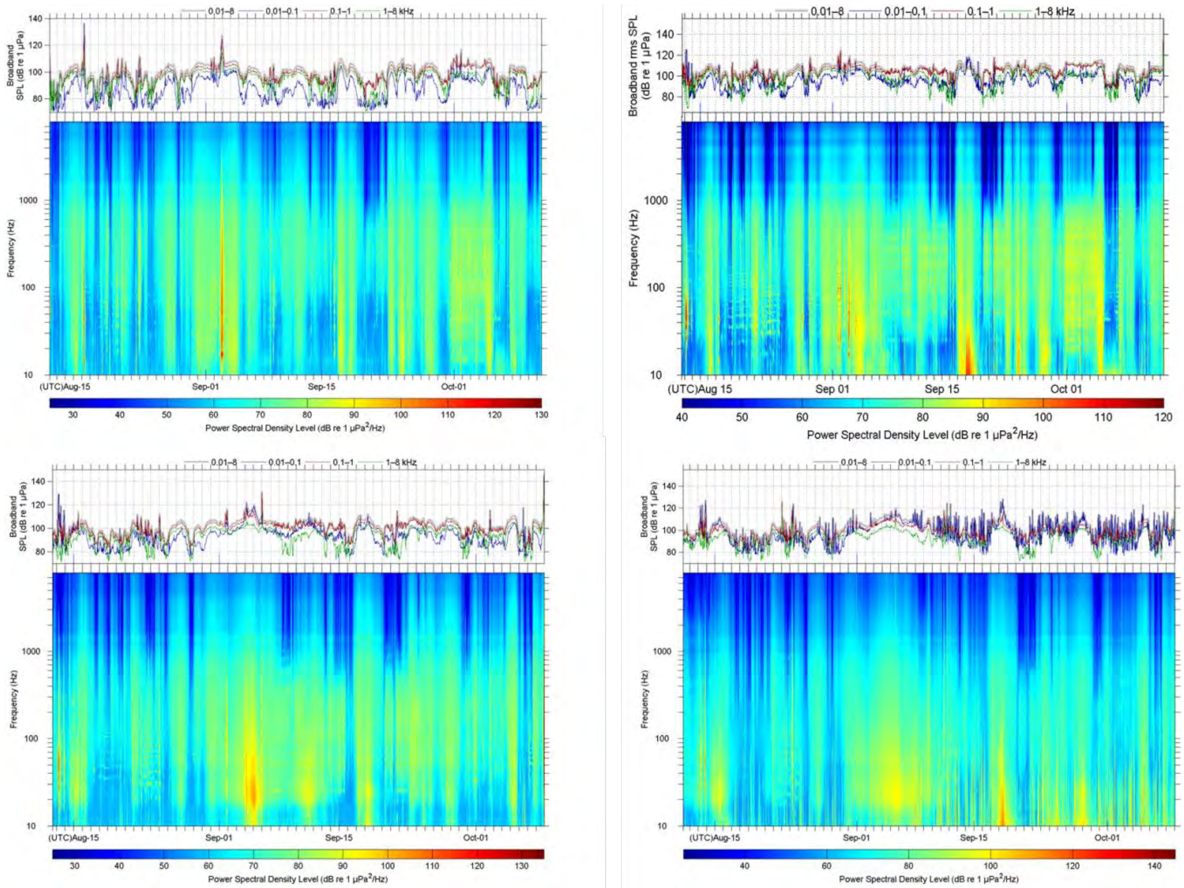

Figure B.25. Broadband and decade-band sound pressure levels (SPLs) and spectrograms for summer 2012 stations—August to October 2012. (Top left) PLN20, (top right) PLN40, (bottom left) PLN60, and (bottom right) PLN80.

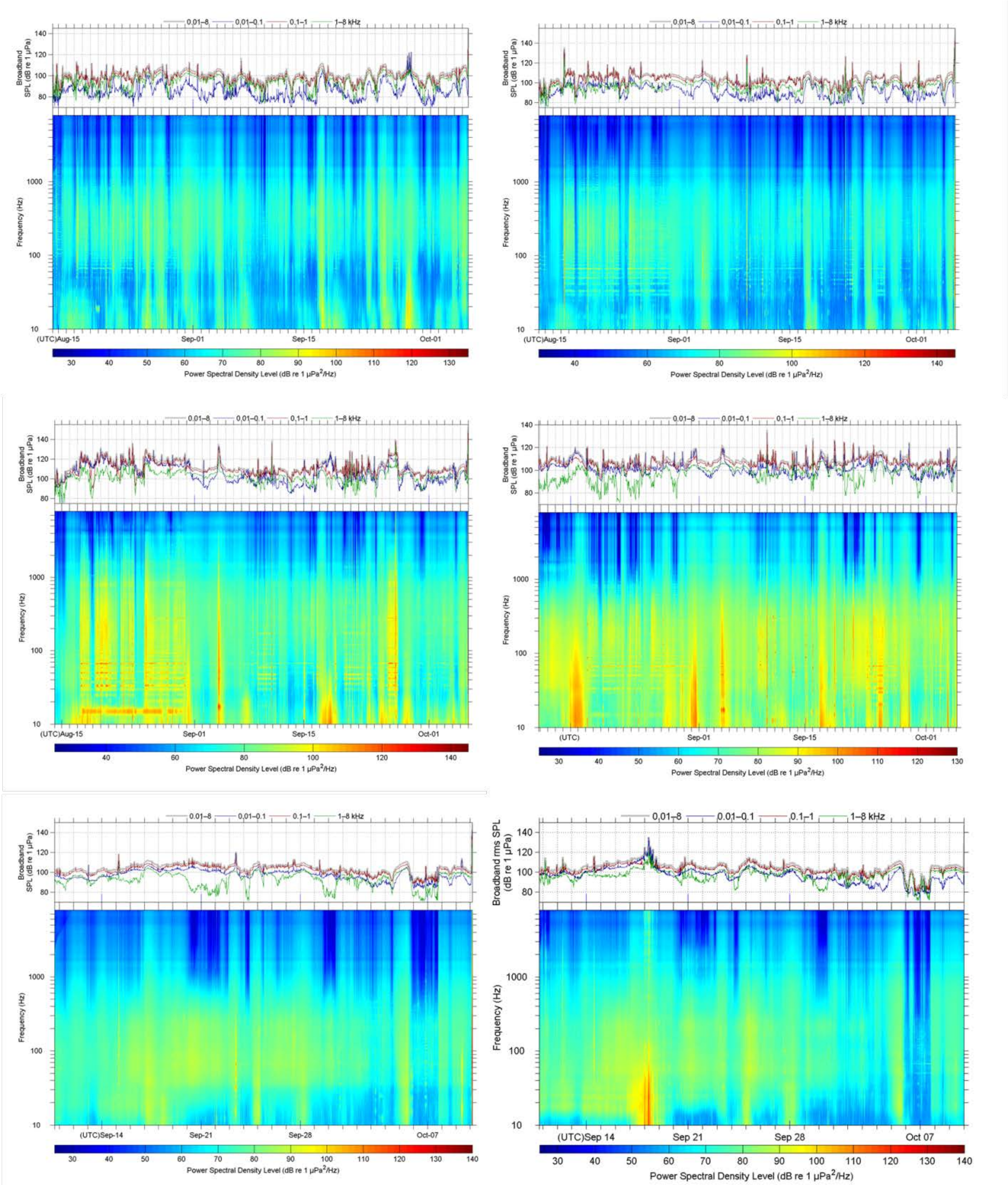

Figure B.26. Broadband and decade-band sound pressure levels (SPLs) and spectrograms for summer 2012 stations. From August to October: (Top left) W05, (top right) W20, (middle left) W35, (middle right) W50. From September to October: (bottom left) WN20 and (bottom right) WN40.

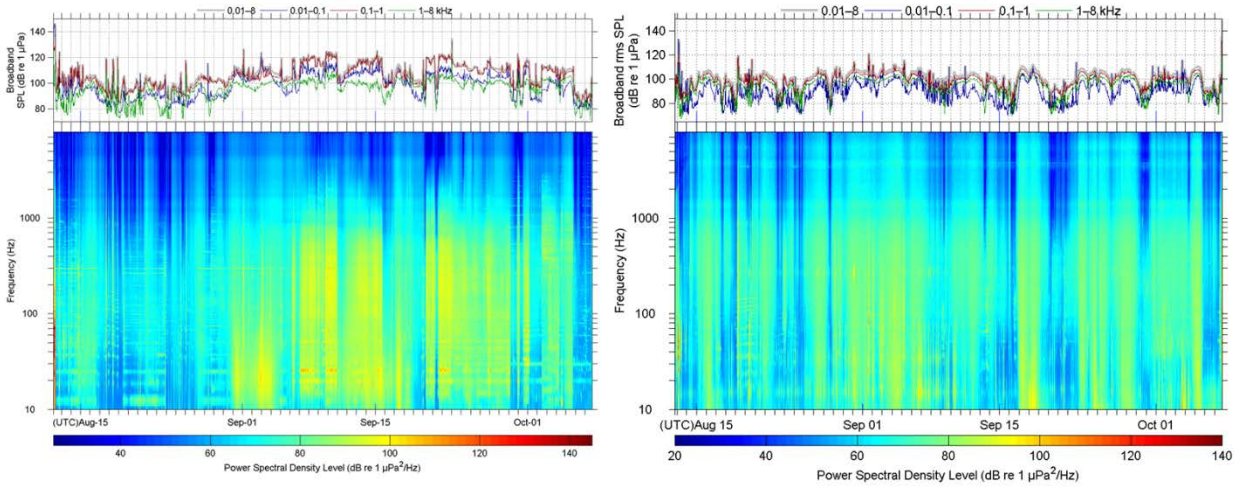

Figure B.27. Broadband and decade-band sound pressure levels (SPLs) and spectrograms for summer 2012 stations—August to October 2012. (Left) BG02 and (right) KL01.

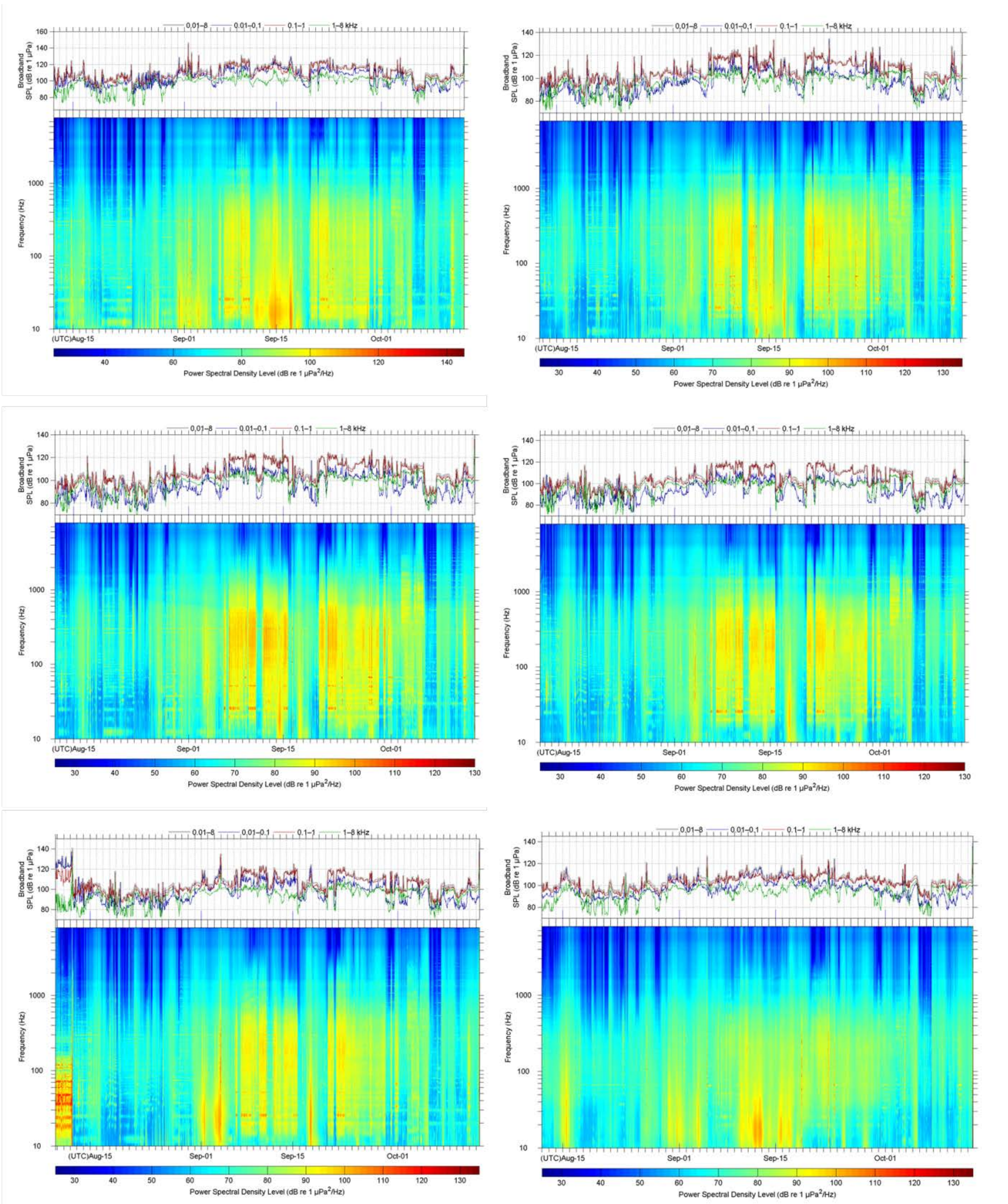

Figure B.28. Broadband and decade-band sound pressure levels (SPLs) and spectrograms for summer 2012 stations—August to October 2012. (Top left) BG03, (top right) BG04, (middle left) BG05, (middle right) BG06, (bottom left) BG07, and (bottom right) BG08.

B.4.3. Daily Cumulative Sound Exposure Level, Cumulative Distribution Function and Power Spectral Density

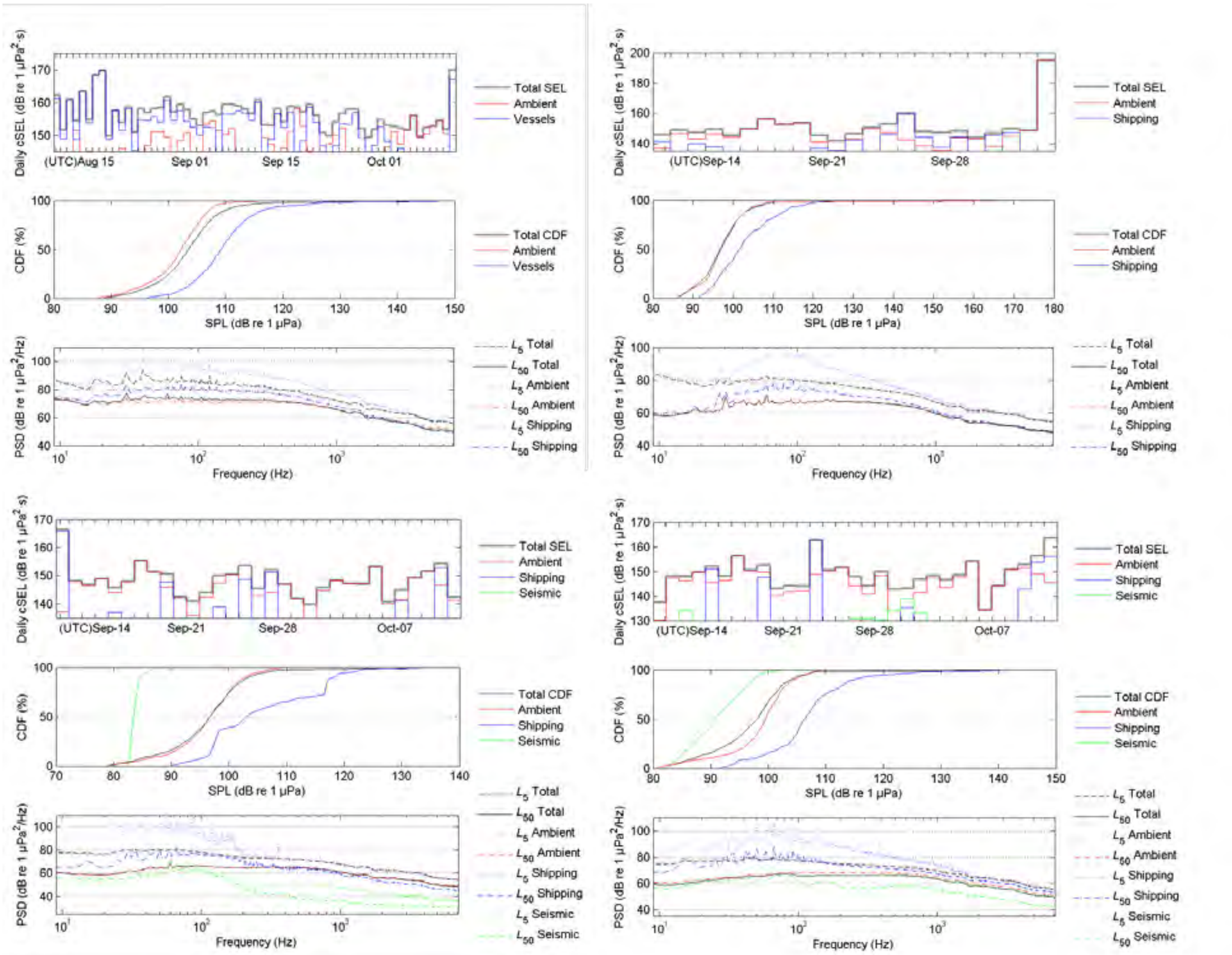

Figure B.29. Daily cumulative sound exposure levels (cSEL), cumulative distribution function (CDF), and power spectral density (PSD) for summer 2012 stations. (Top left) B05 from August to October, (top right) B15 September to October, (bottom left) B30 from August to September, and (bottom right) B50 from September to October.

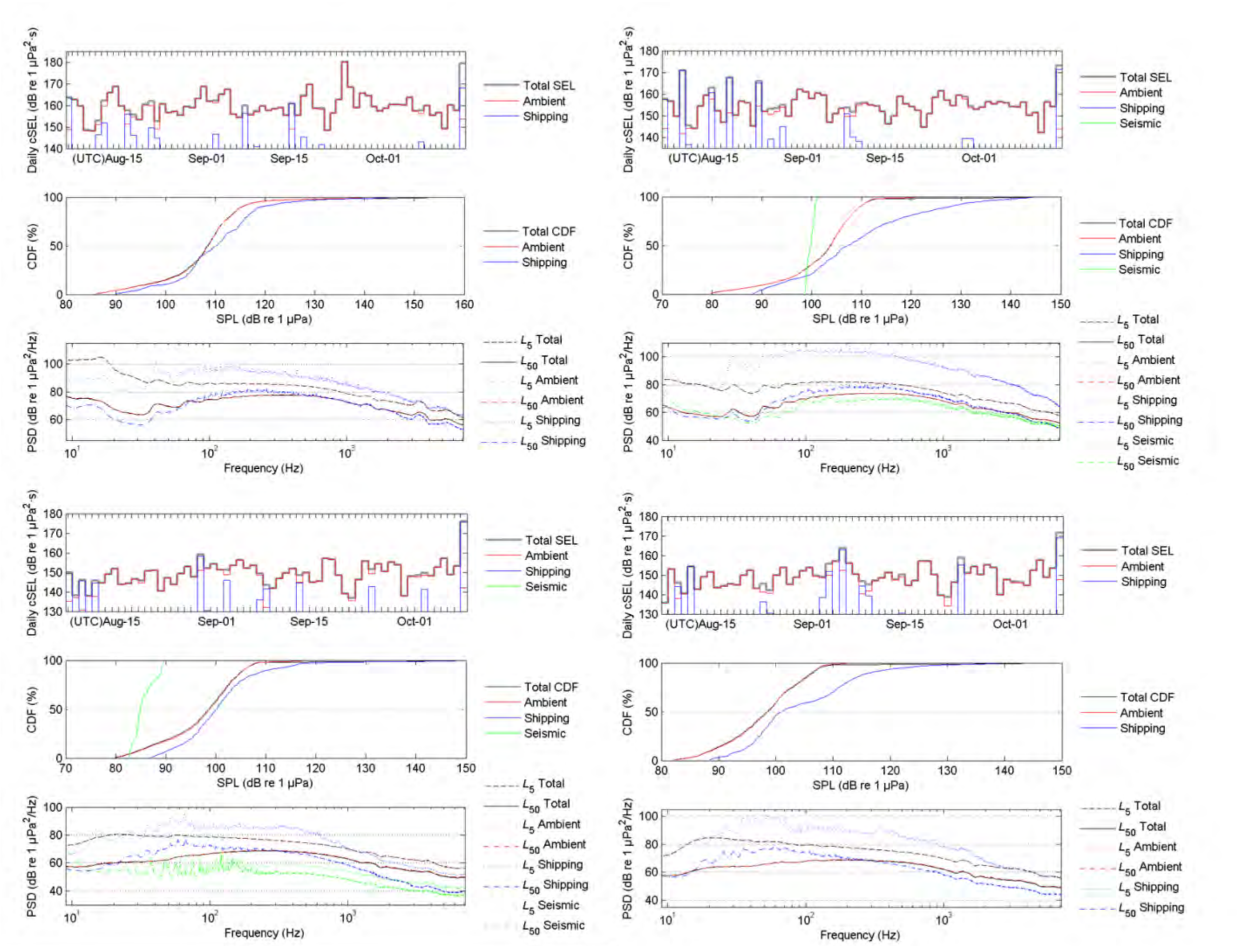

Figure B.30. Daily cumulative sound exposure levels (cSEL), cumulative distribution function (CDF), and power spectral density (PSD) for summer 2012 stations—August to October 2012. (Top left) CL05, (top right) CL20, (bottom left) CLN90B, and (bottom right) CLN120B.

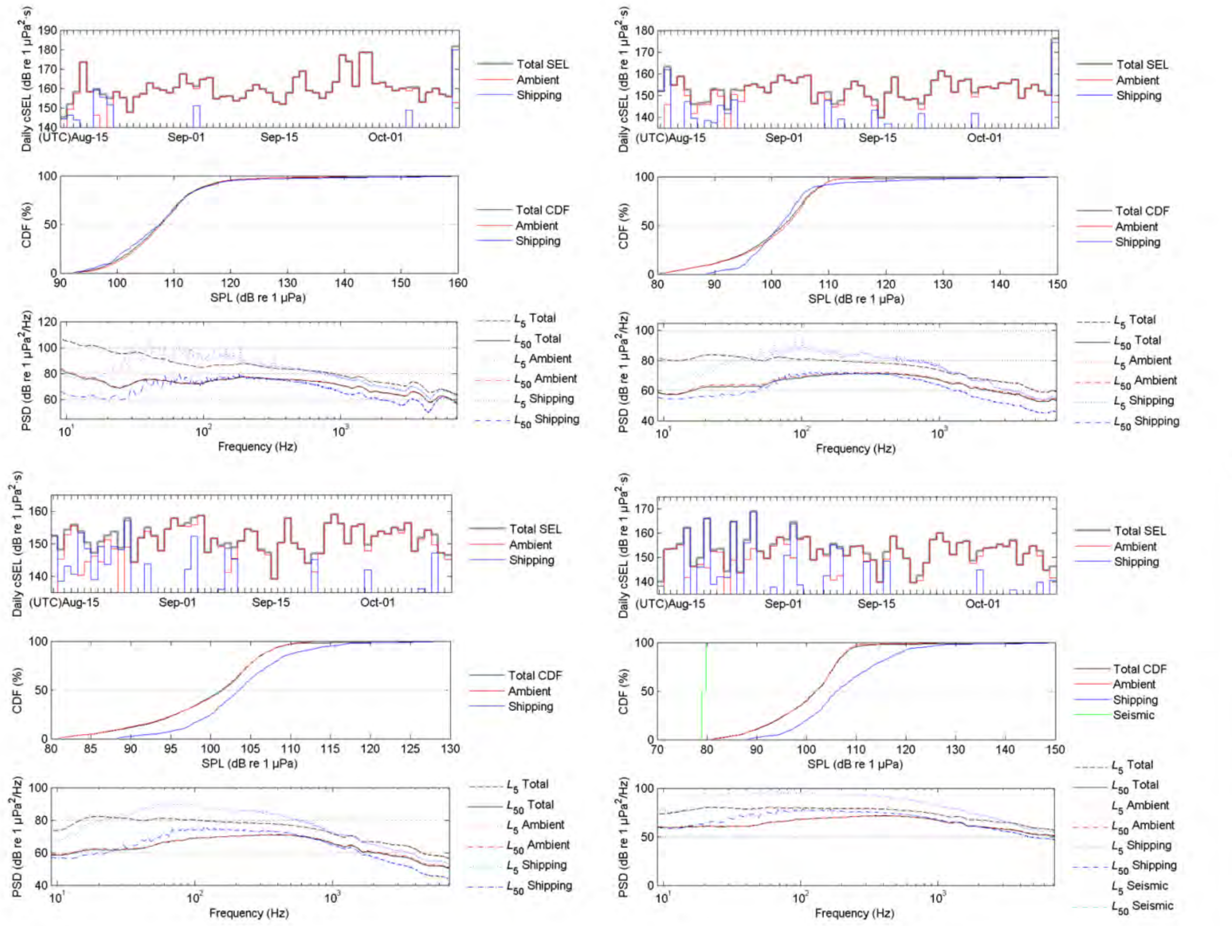

Figure B.31. Daily cumulative sound exposure levels (cSEL), cumulative distribution function (CDF), and power spectral density (PSD) for summer 2012 stations—August to October 2012. (Top left) PL05, (top right) PL20, (bottom left) PL35, and (bottom right) PL50.

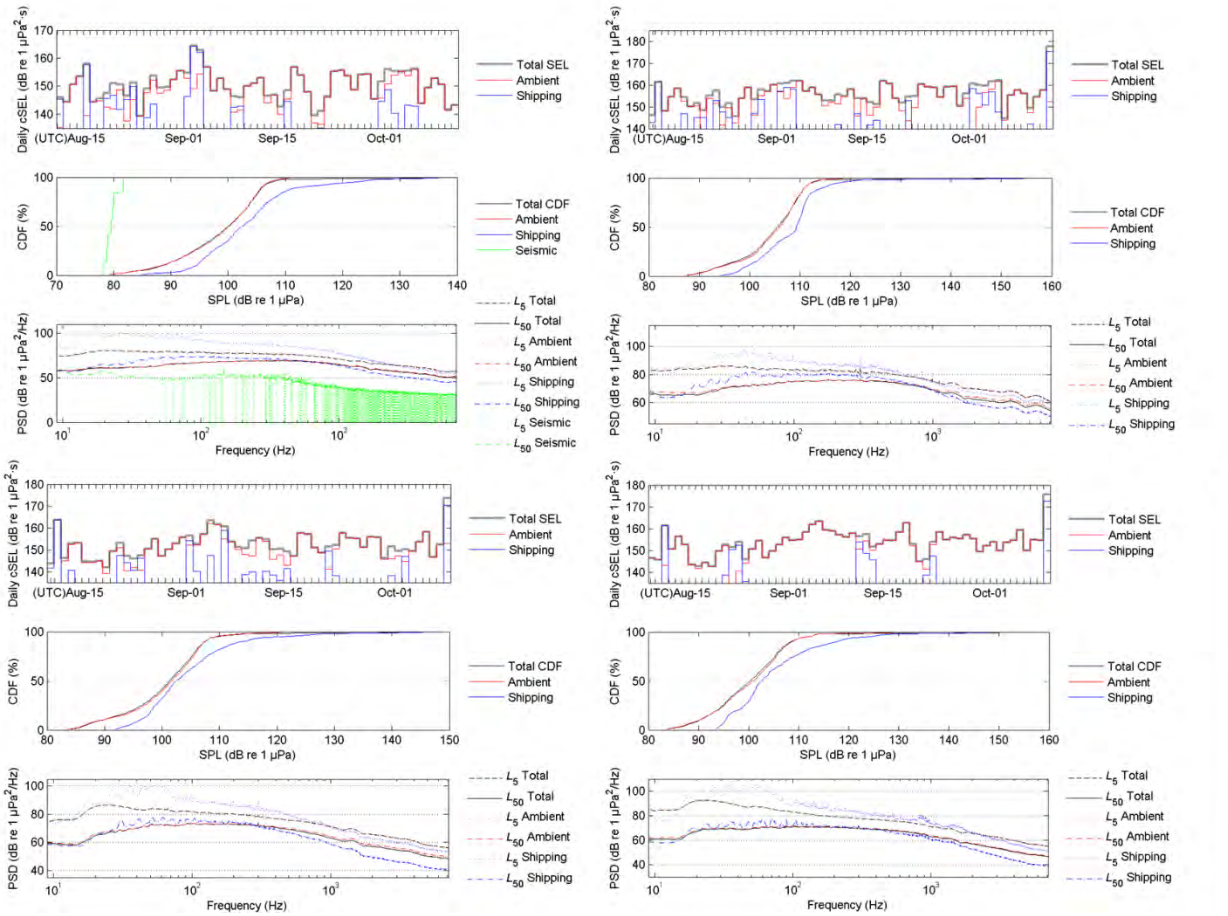

Figure B.32. Daily cumulative sound exposure levels (cSEL), cumulative distribution function (CDF), and power spectral density (PSD) for summer 2012 stations—August to October 2012. (Top left) PLN20, (top right) PLN40, (bottom left) PLN60, and (bottom right) PLN80.

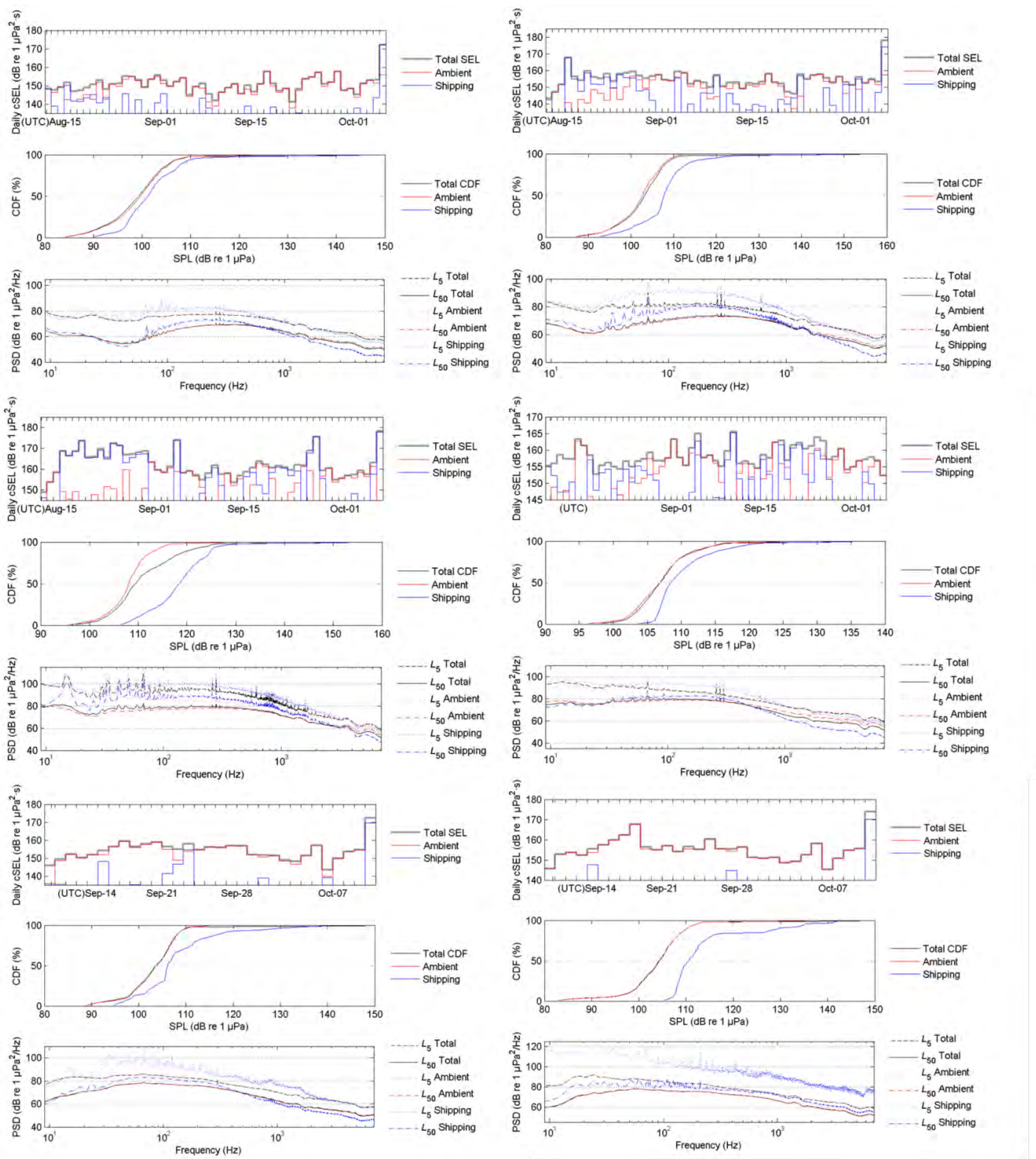

Figure B.33. Daily cumulative sound exposure levels (cSEL), cumulative distribution function (CDF), and power spectral density (PSD) for summer 2012 stations. From August to October: (Top left) W05, (top right) W20, (middle left) W35, (middle right) W50. From September to October: (Bottom left) WN20 and (bottom right) WN40.

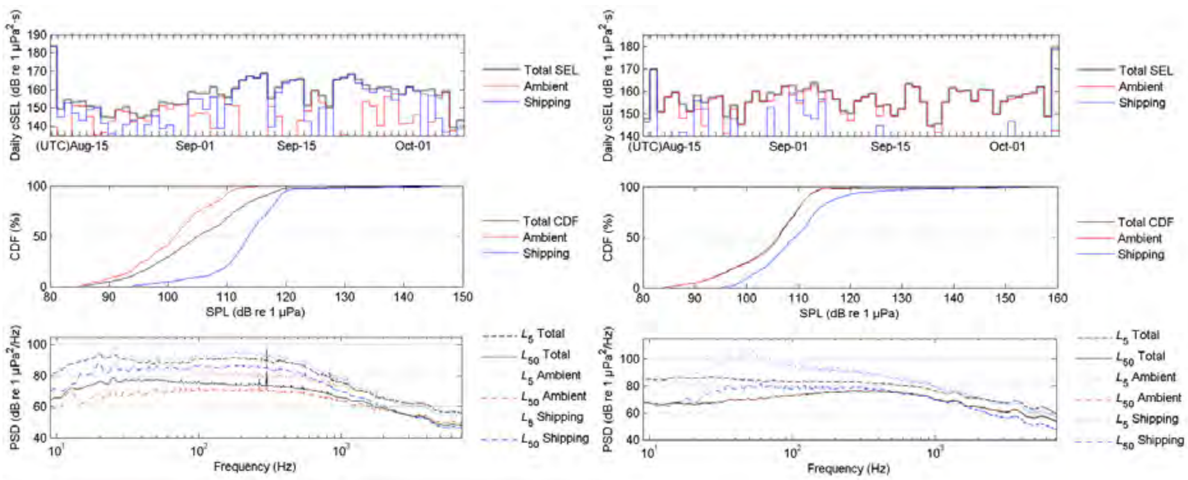

Figure B.34. Daily cumulative sound exposure levels (cSEL), cumulative distribution function (CDF), and power spectral density (PSD) for summer 2012 stations—August to October 2012. (Left) BG02 and (right) KL01.

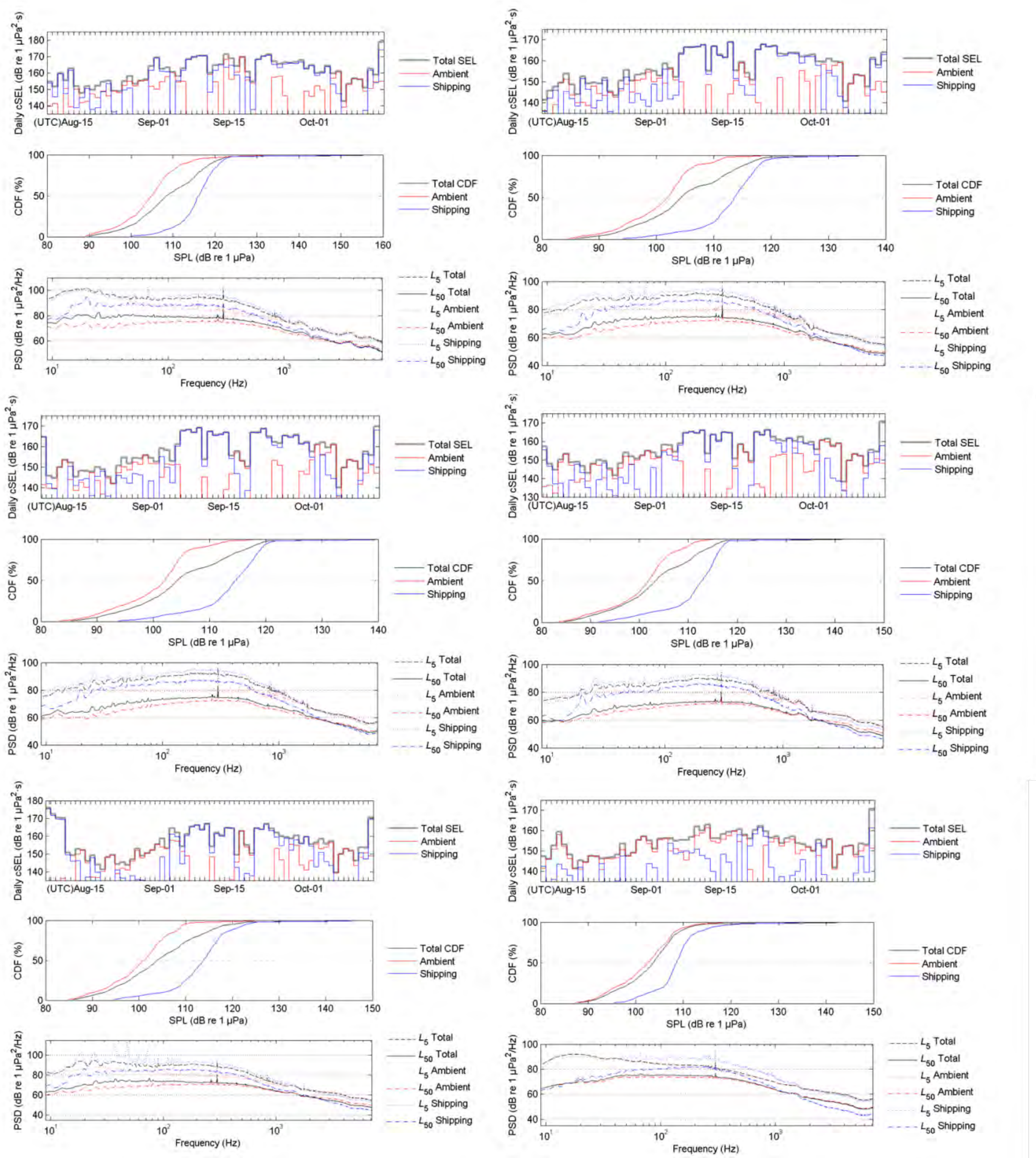

Figure B.35. Daily cumulative sound exposure levels (cSEL), cumulative distribution function (CDF), and power spectral density (PSD) for summer 2012 stations—August to October 2012. (Top left) BG03, (top right) BG04, (middle left) BG05, (middle right) BG06, bottom (left) BG07, and (bottom right) BG08.

Appendix C. Marine Mammal Detection Results

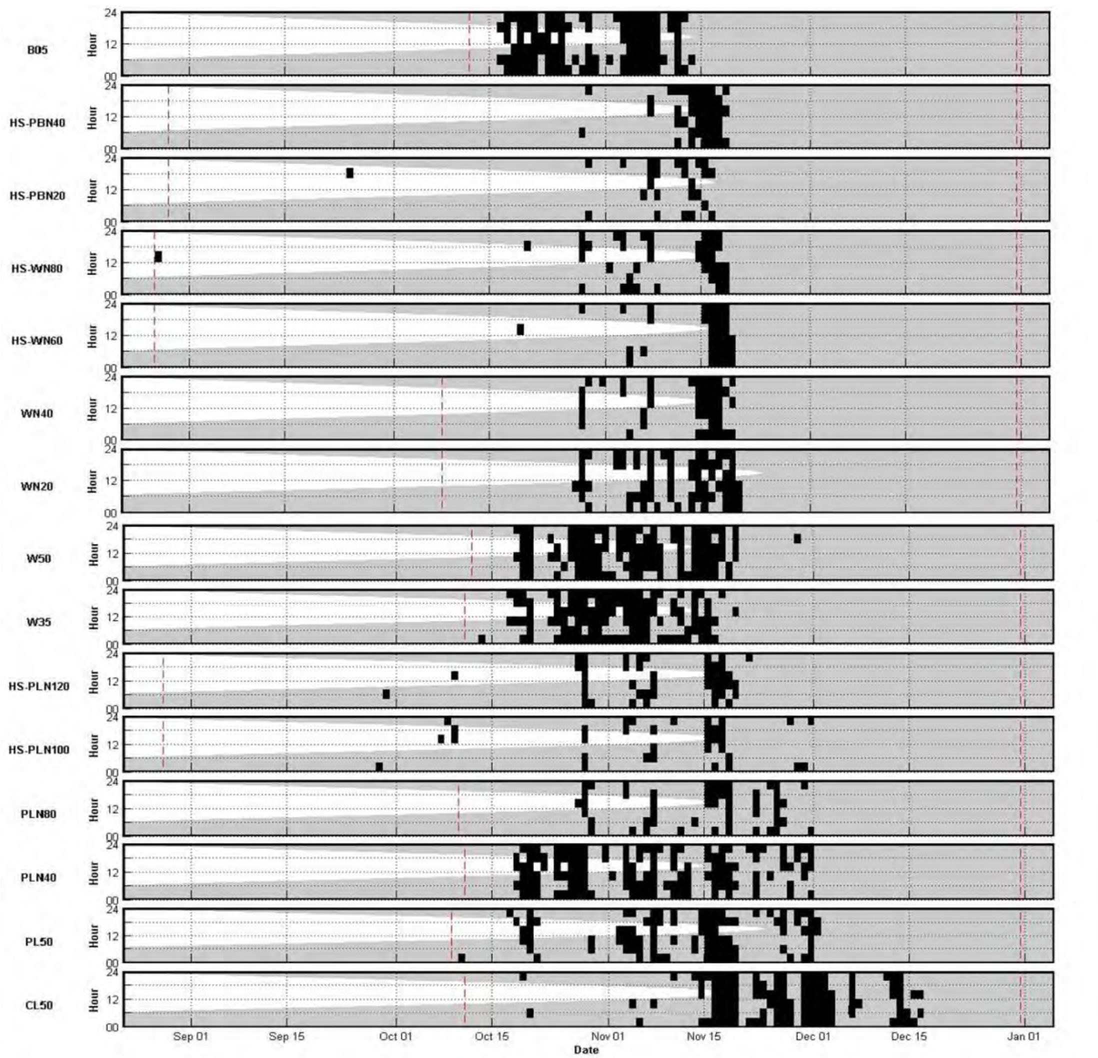

Figure C.1. Fall 2011 daily bowhead call detections: Daily occurrence of call detections based on the manual analysis of 5% of the acoustic data recorded mid-October 2011 through late December 2012 in the northeastern Chukchi Sea for each station. Each black square represents a 4-hr period (one 30/40-minute file was recorded every four hours).Stations are ordered from northeast (top) to southwest (bottom). The leftmost red dashed lines are the recording start, and the rightmost, the end of the result compilation period (31 Dec 2011). The shaded area shows the hours of darkness.

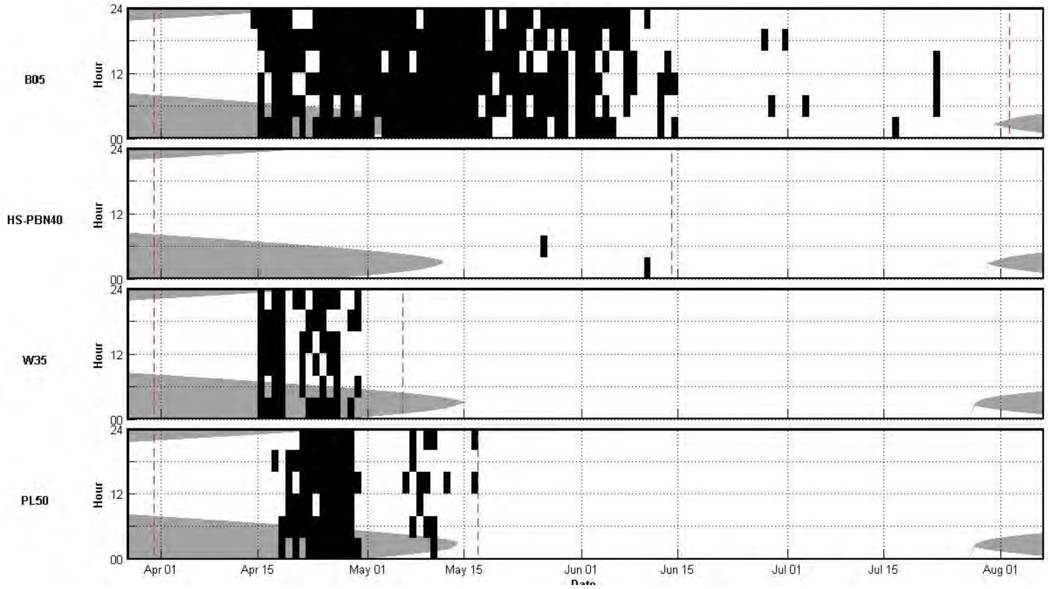

Figure C.2. Spring 2012 daily bowhead call detections: Daily occurrence of call detections based on the manual analysis of 5% of the acoustic data recorded 1 Apr through 1 Aug 2012 in the northeastern Chukchi Sea. Each black square represents a 4-hr period (one 30/40-minute file was recorded every four hours).Stations are ordered from northeast (top) to southwest (bottom).The leftmost red dashed lines are the start of the spring compilation period, and the rightmost, the recording end date. The shaded area shows the hours or darkness. Stations without call detections were omitted.

Table C.1. Winter 2011–2012 bowhead 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 recording station in the northeastern Chukchi Sea. The recorders operated for 30–40 min of every 4 h.

Station	Record start	Fall 2011			Spring 2012			Record end
		First detection	Last detection	Detection days	First detection	Last detection	Detection days	
B05	13 Oct	16 Oct	13 Nov	26	14 Apr	22 Jul	64	01 Aug
PBN40	29 Aug	28 Oct	19 Nov	13	26 May	10 Jun	2	14 Jun
PBN20	29 Aug	25 Sep	17 Nov	14	–	–	–	31 Dec
WN80	27 Aug	27 Aug	18 Nov	16	–	–	–	14 Jun
WN60	27 Aug	19 Oct	19 Nov	9	–	–	–	26 Jan
WN40	08 Oct	28 Oct	20 Nov	15	–	–	–	15 Feb
WN20	08 Oct	27 Oct	20 Nov	20	–	–	–	07 May
W50	12 Oct	18 Oct	29 Nov	32	–	–	–	30 Apr
W35	12 Oct	13 Oct	19 Nov	33	15 Apr	30 Apr	15	06 May
PLN120	28 Aug	29 Sep	22 Nov	14	–	–	–	23 Jun
PLN100	28 Aug	28 Sep	01 Dec	19	–	–	–	03 Jul
PLN80	11 Oct	27 Oct	30 Nov	21	–	–	–	03 Jun
PLN40	11 Oct	18 Oct	01 Dec	36	–	–	–	10 May
PL50	09 Oct	10 Oct	02 Dec	32	18 Apr	17 May	21	17 May
CL50	11 Oct	20 Oct	16 Dec	31	–	–	–	14 Mar

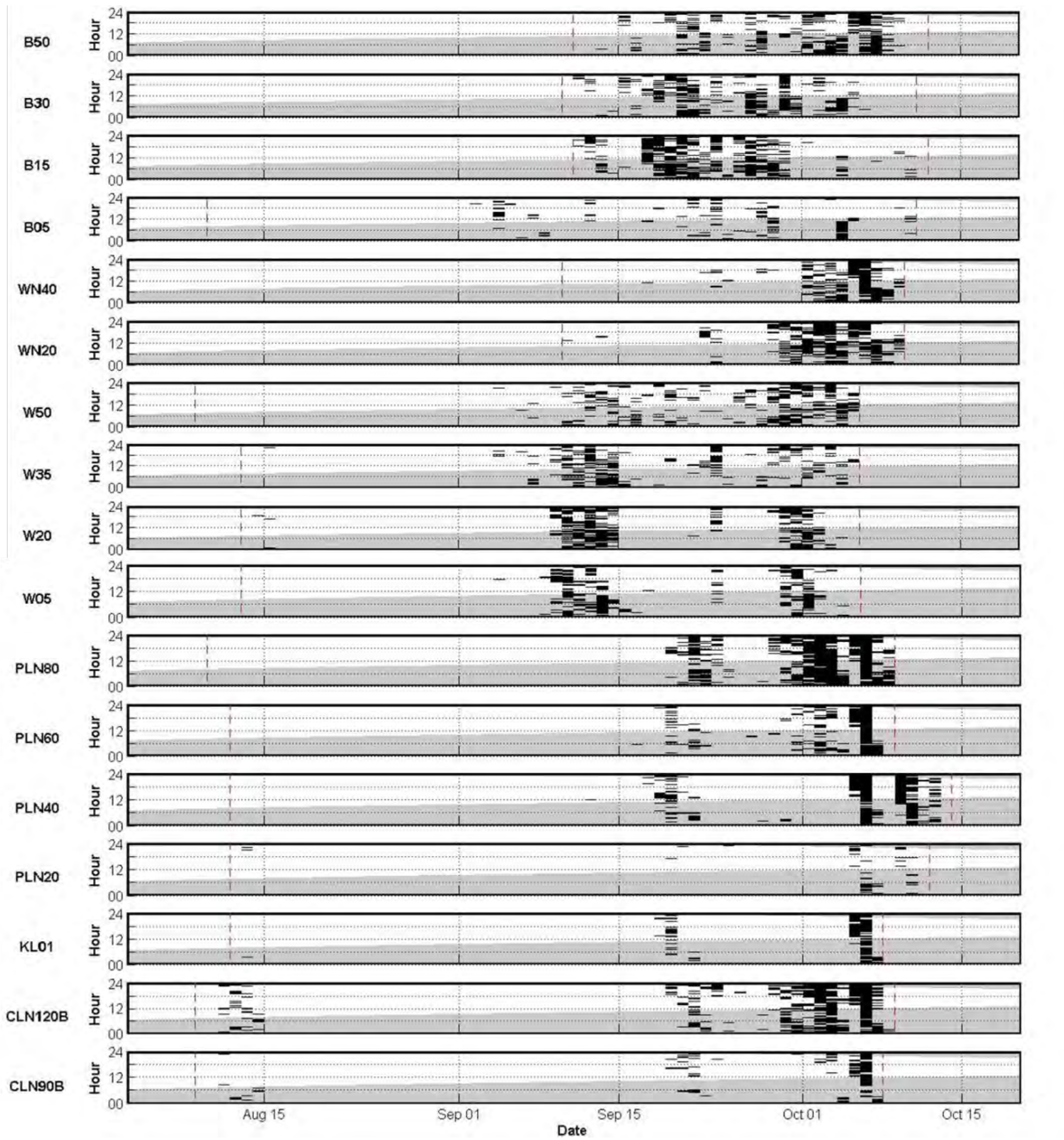

Figure C.3. Summer 2012 daily bowhead call detections in the northeastern Chukchi Sea: Daily and half-hourly occurrence of call detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2012. Each black square represents a 30-min period. Red dashed lines indicate recording start and end. Stations are ordered from northeast (top) to southwest (bottom). Stations without call detections as well as PL35 and PL20, which only had 1 and 2 detection days, respectively, were omitted. Shaded areas represent hours of darkness.

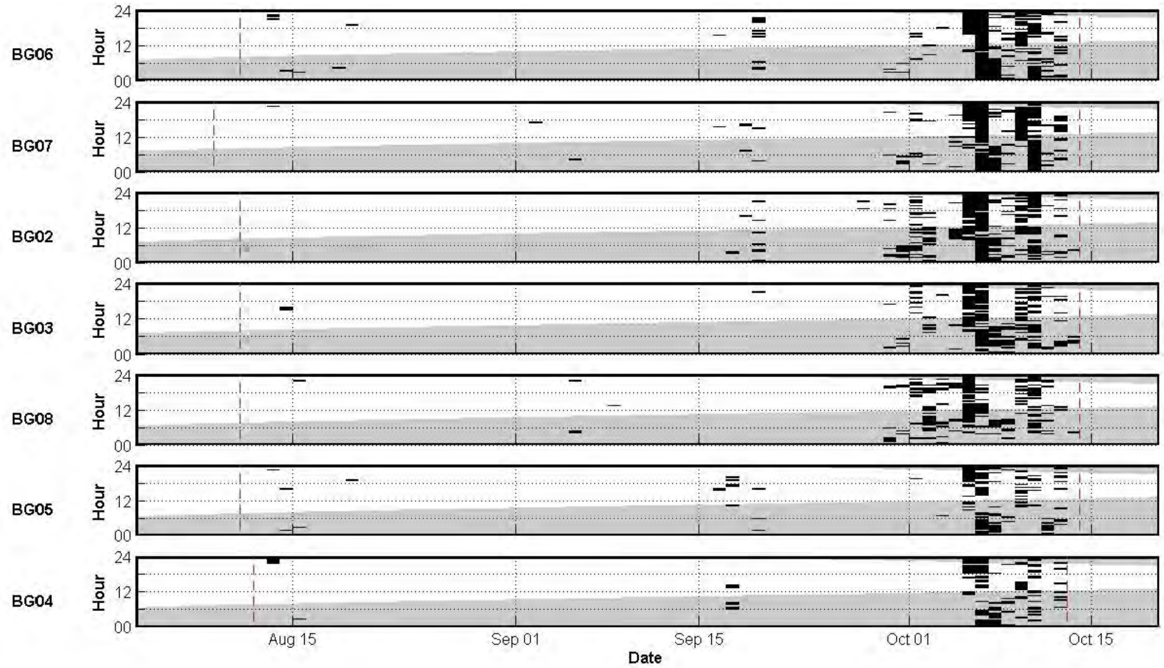

Figure C.4. Summer 2012 daily bowhead call detections in the Burger study area: Daily and half-hourly occurrence of call detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2012. Each black square represents a 30-min period. Red dashed lines indicate recording start and end. Shaded areas represent hours of darkness.

Table C.2. Summer 2012 bowhead call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the percentage of days on which a call was detected for each recording station in the northeastern Chukchi Sea. Stations without call detections were omitted.

Station	Record start	First detection	Last detection	Record end	Detection days	% Days with detection
B05	11 Aug	03 Sep	10 Oct	11 Oct	23	37.7
B15	11 Sep	12 Sep	10 Oct	11 Oct	23	76.7
B30	11 Sep	12 Sep	06 Oct	11 Oct	24	80.0
B50	11 Sep	13 Sep	10 Oct	11 Oct	22	73.3
BG02	12 Aug	17 Sep	13 Oct	13 Oct	20	35.7
BG03	12 Aug	14 Aug	13 Oct	13 Oct	16	25.8
BG04	12 Aug	14 Aug	13 Oct	13 Oct	12	19.4
BG05	12 Aug	14 Aug	13 Oct	13 Oct	18	29.0
BG06	12 Aug	14 Aug	13 Oct	13 Oct	21	33.9
BG07	09 Aug	14 Aug	13 Oct	13 Oct	21	32.3
BG08	12 Aug	16 Aug	13 Oct	13 Oct	20	32.3
CLN120B	09 Aug	11 Aug	08 Oct	08 Oct	22	36.7
CLN90B	09 Aug	11 Aug	07 Oct	08 Oct	14	23.3
KL01	12 Aug	13 Aug	07 Oct	07 Oct	8	14.3
PL20	13 Aug	14 Aug	15 Sep	11 Oct	2	3.4
PL35	13 Aug	15 Sep	15 Sep	11 Oct	1	1.7
PLN20	13 Aug	14 Aug	11 Oct	11 Oct	10	16.9
PLN40	12 Aug	13 Aug	13 Oct	13 Oct	16	25.8
PLN60	12 Aug	16 Sep	07 Oct	08 Oct	16	28.1
PLN80	11 Aug	13 Sep	09 Oct	09 Oct	20	33.9
W05	14 Aug	05 Sep	04 Oct	05 Oct	20	38.5
W20	14 Aug	15 Aug	04 Oct	05 Oct	18	34.6
W35	14 Aug	16 Aug	05 Oct	06 Oct	27	50.9
W50	10 Aug	02 Sep	06 Oct	05 Oct	30	53.6
WN20	10 Sep	10 Sep	09 Oct	10 Oct	17	56.7
WN40	10 Sep	12 Sep	09 Oct	10 Oct	15	50.0

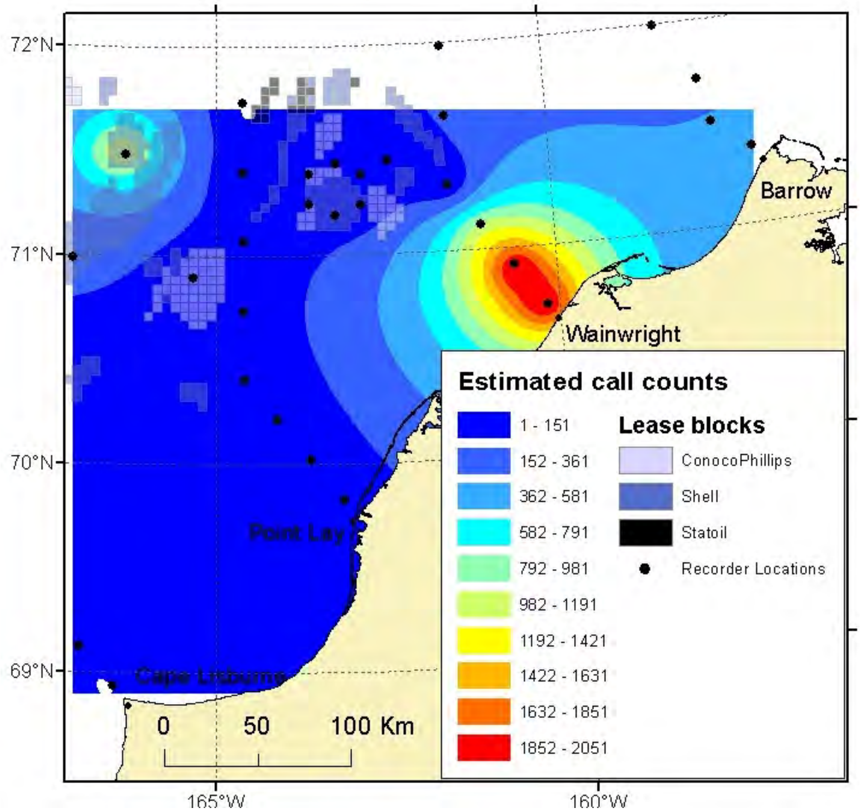

Figure C.5. Interpolated bowhead whale call counts based on the sum of automated call detections in all files with manual detections from 7 Aug to 10 Sep at all operational summer 2012 stations in the northeastern Chukchi Sea.

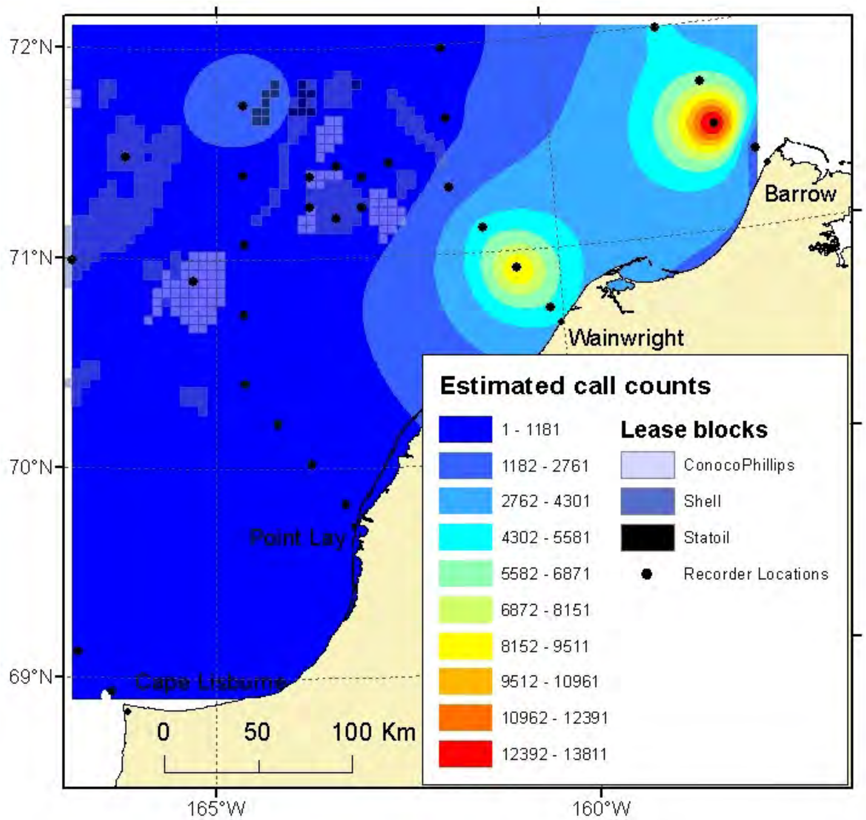

Figure C.6. Interpolated bowhead whale call counts based on the sum of automated call detections in all files with manual detections for 11–27 Sep at all summer 2012 recording stations in the northeastern Chukchi Sea.

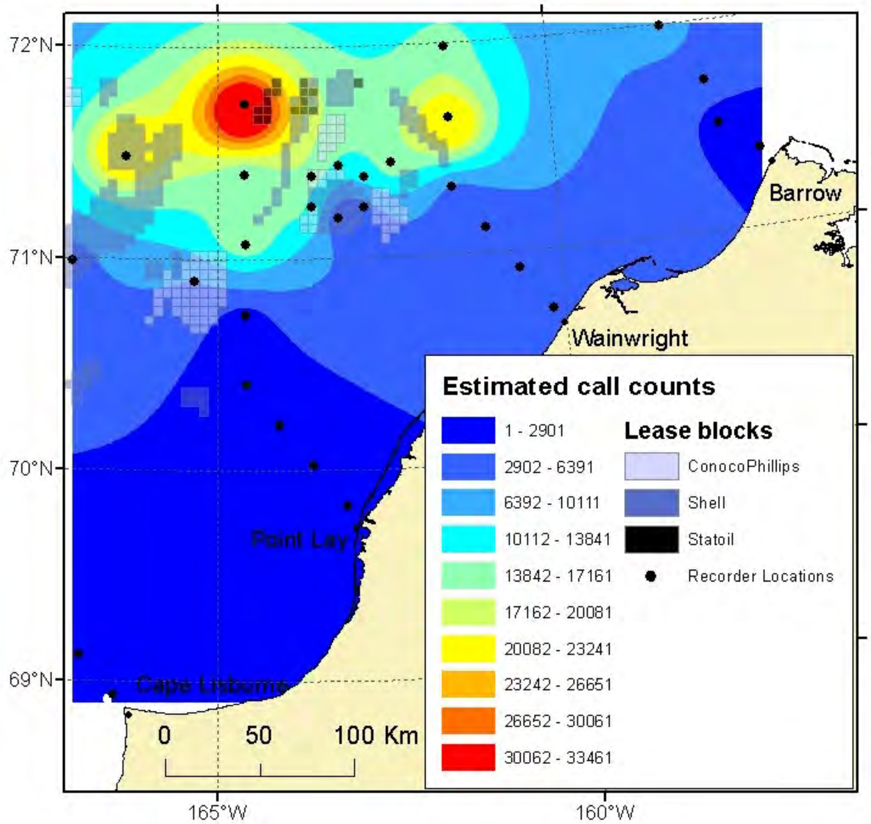

Figure C.7. Interpolated bowhead whale call counts based on the sum of automated call detections in all files with manual detections for 28 Sep to 13 Oct at all summer 2012 recording stations in the northeastern Chukchi Sea.

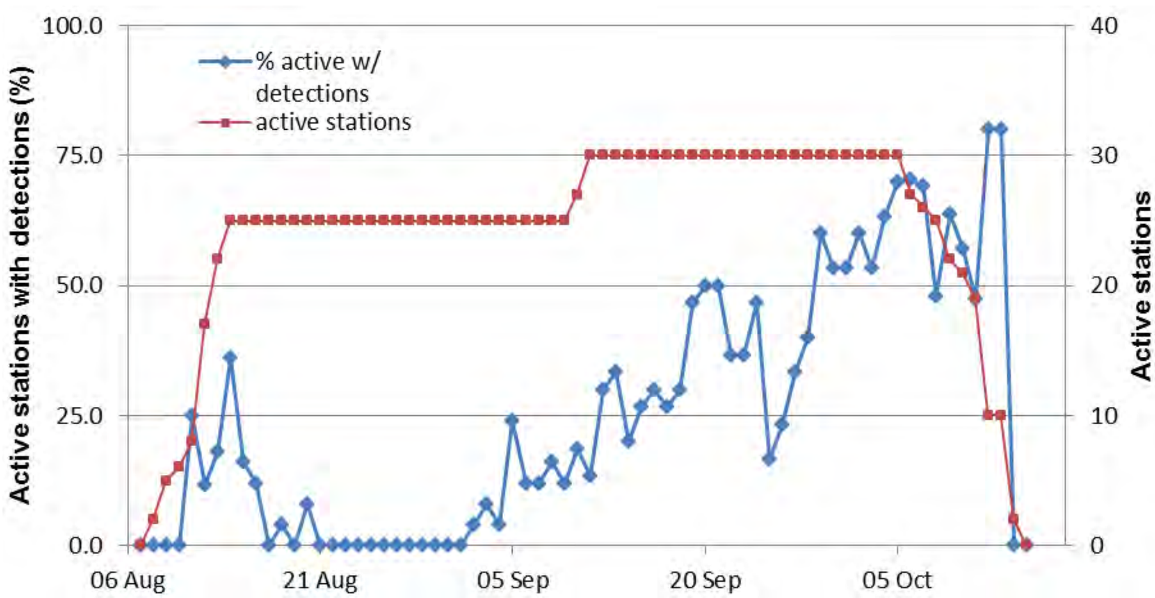

Figure C.8. Daily number of active stations and the proportion of active stations at which bowhead whale calls were recorded from 5 Aug to 13 Oct 2012 in the northeastern Chukchi Sea.

Table C.3. Winter 2011–2012 walrus 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 recording station in the northeastern Chukchi Sea. The recorders operated for 30–40 min of every 4 h.

Station	Record start	Fall 2011			Spring 2012			Record end
		First detection	Last detection	Detection days	First detection	Last detection	Detection days	
B05	13 Oct	–	–	–	22 Jul	27 Jul	6	01 Aug
PBN40	29 Aug	29 Aug	08 Oct	27	–	–	–	14 Jun
PBN20	29 Aug	29 Aug	07 Oct	27	–	–	–	31 Dec
WN80	27 Aug	27 Aug	09 Oct	29	–	–	–	14 Jun
WN60	27 Aug	27 Aug	08 Oct	35	–	–	–	26 Jan
WN40	08 Oct	29 Oct	01 Nov	2	–	–	–	15 Feb
WN20	08 Oct	08 Oct	23 Nov	22	–	–	–	07 May
W50	12 Oct	17 Oct	20 Oct	3	–	–	–	30 Apr
W35	12 Oct	18 Oct	23 Oct	3	–	–	–	06 May
PLN120	28 Aug	29 Aug	20 Dec	33	–	–	–	23 Jun
PLN100	28 Aug	28 Aug	28 Nov	21	24 Jun	02 Jul	3	03 Jul
PLN80	11 Oct	30 Nov	03 Dec	3	–	–	–	03 Jun
PLN40	11 Oct	17 Oct	26 Nov	7	–	–	–	10 May
PL50	09 Oct	10 Oct	18 Nov	8	–	–	–	17 May
CL50	11 Oct	17 Oct	04 Nov	5	–	–	–	14 Mar

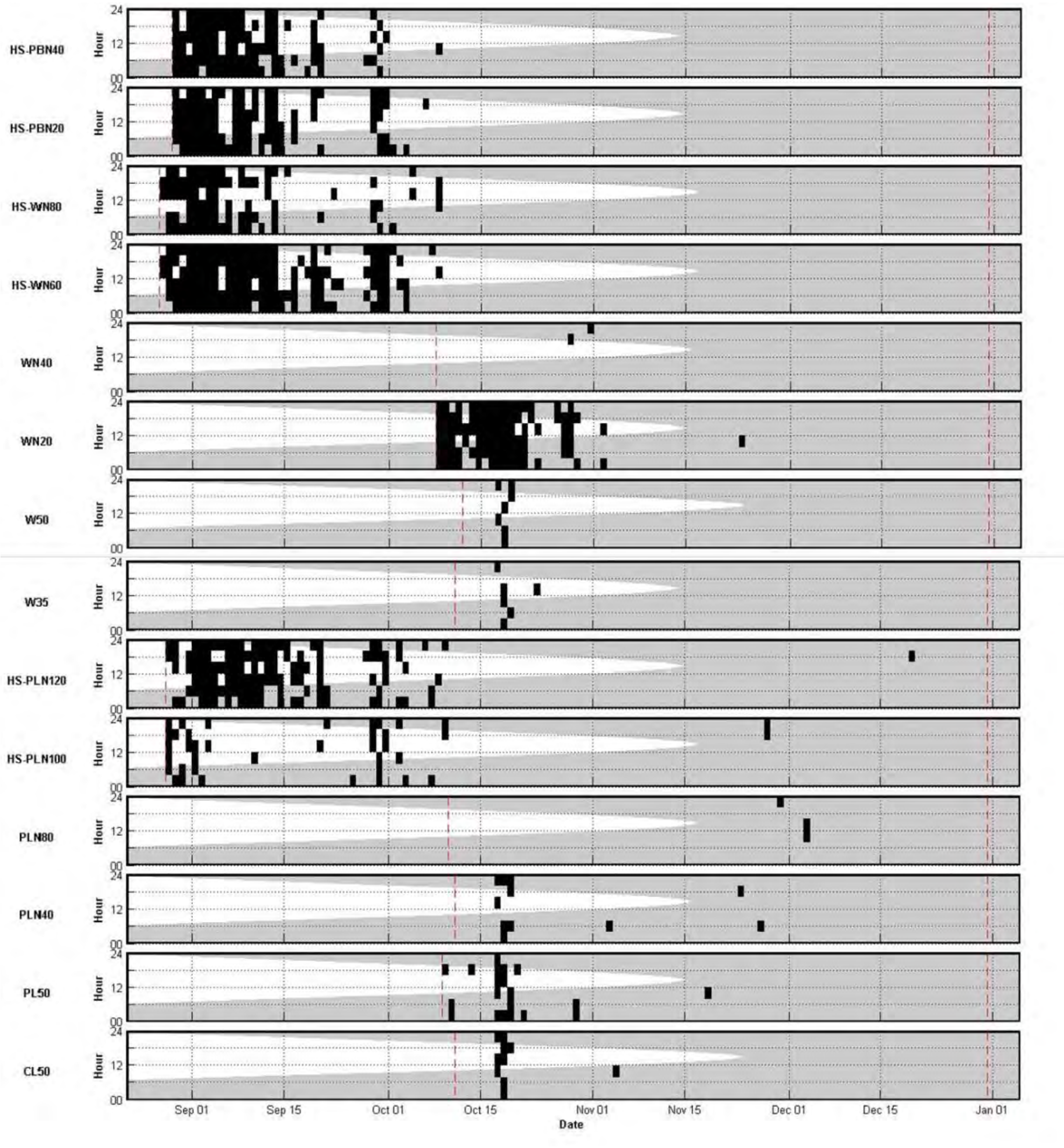

Figure C.9. Fall 2011 daily walrus call detections: Daily occurrence of call detections based on the manual analysis of 5% of the acoustic data recorded mid-October 2011 through late December 2012 in the northeastern Chukchi Sea for each station. Each black square represents a 4-hr period (one 30/40-minute file was recorded every four hours).Stations are ordered from northeast (top) to southwest (bottom). The leftmost red dashed lines are the recording start, and the rightmost, the end of the result compilation period (31 Dec 2011).

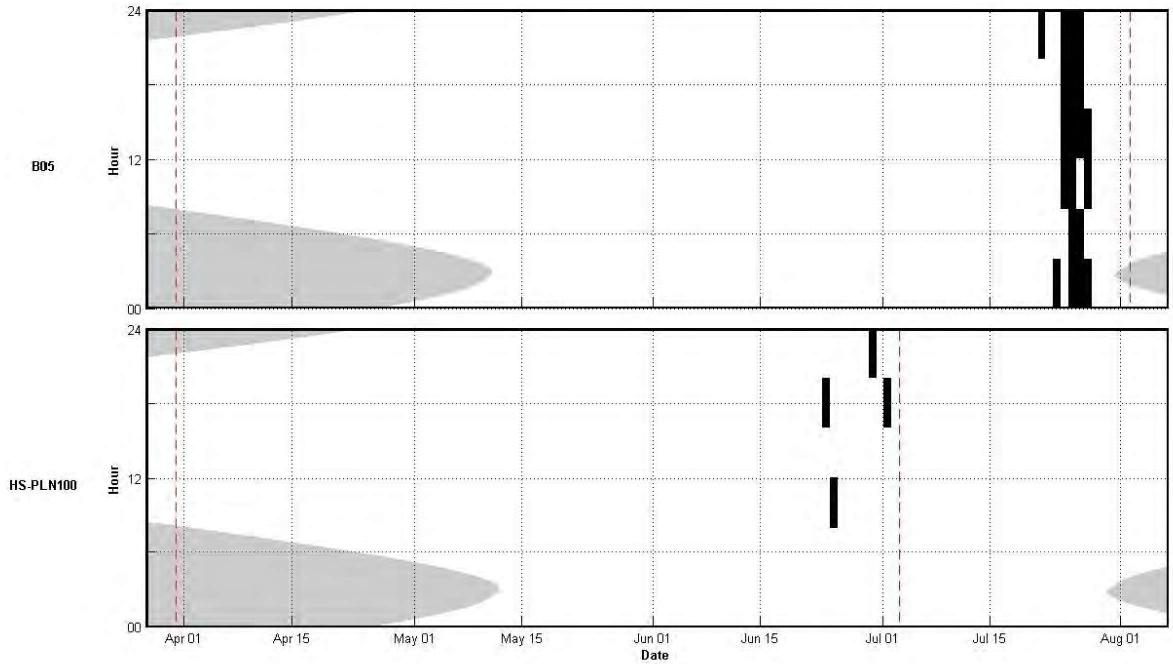

Figure C.10. Spring 2012 daily walrus call detections: Daily occurrence of call detections based on the manual analysis of 5% of the acoustic data recorded mid-October 2011 through late December 2012 in the northeastern Chukchi Sea for each station. Each black square represents a 4-hr period (one 30/40-minute file was recorded every four hours).Stations are ordered from northeast (top) to southwest (bottom). The leftmost red dashed lines are the recording start, and the rightmost, the end of the result compilation period (31 Dec 2011).

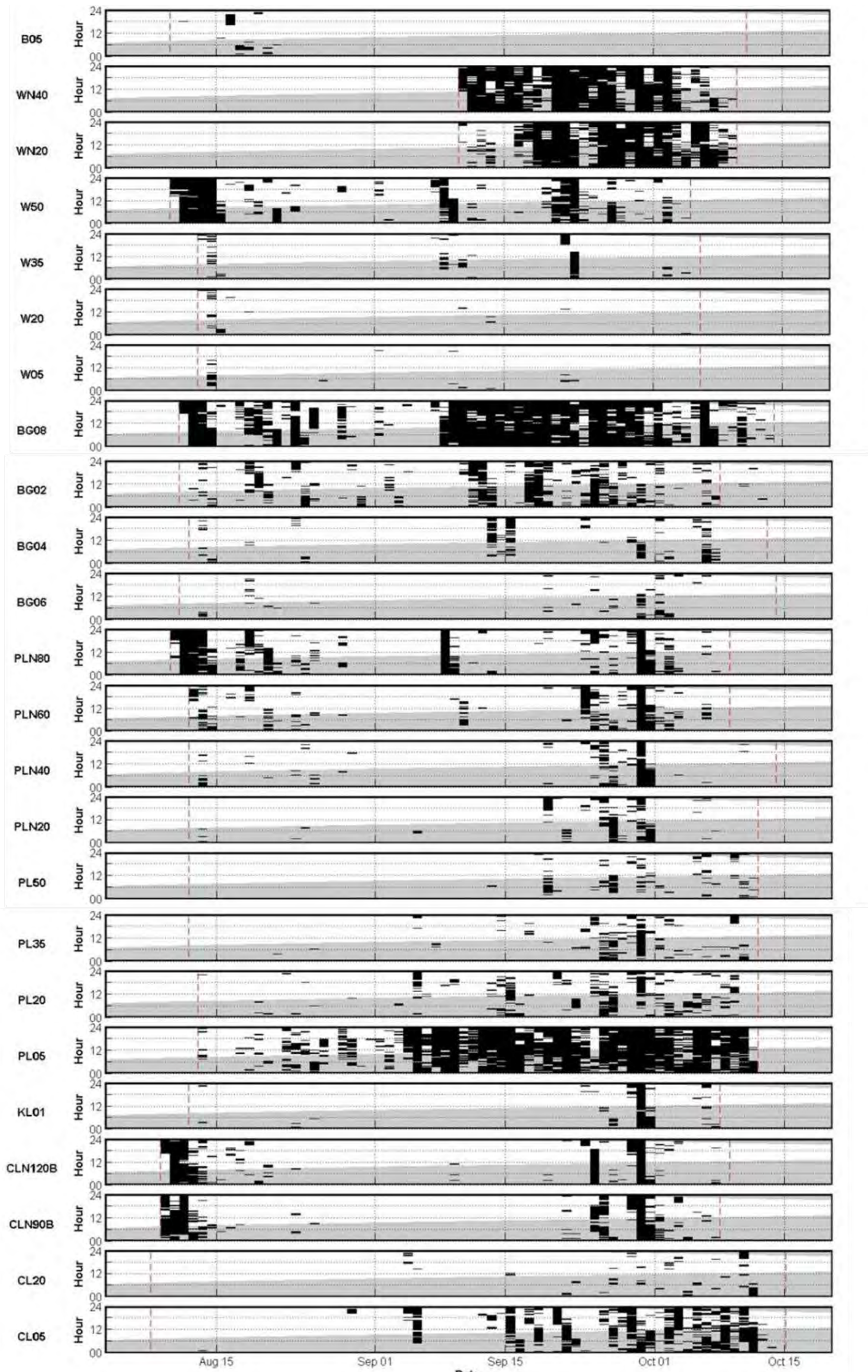

Figure C.11. Summer 2012 daily walrus call detections: Daily and half-hourly occurrence of call detections based on the manual analysis of 5% of the continuous acoustic data recorded late July through mid-October 2012 in the northeastern Chukchi Sea. Each black square represents a 30-min period. Stations with two detection days or less were omitted; only four of seven Burger stations are shown. Red dashed lines indicate recording start and end. The shaded areas represent the hours of darkness.

Table C.4. Summer 2012 walrus call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the percentage of days on which a call was detected for each recording station in the northeastern Chukchi Sea. Stations without call detections were omitted.

Station	Record start	First detection	Last detection	Record end	Detection days	% Days with detection
B05	11 Aug	12 Aug	21 Aug	11 Oct	6	9.8
B50	11 Sep	22 Sep	03 Oct	11 Oct	2	6.7
BG02	12 Aug	12 Aug	12 Oct	13 Oct	42	75.0
BG03	12 Aug	14 Aug	12 Oct	13 Oct	40	64.5
BG04	12 Aug	12 Aug	07 Oct	13 Oct	17	27.4
BG05	12 Aug	12 Aug	07 Oct	13 Oct	20	32.3
BG06	12 Aug	13 Aug	07 Oct	13 Oct	20	32.3
BG07	09 Aug	14 Aug	08 Oct	13 Oct	28	43.1
BG08	12 Aug	12 Aug	13 Oct	13 Oct	57	91.9
CL05	08 Aug	13 Aug	13 Oct	14 Oct	34	50.7
CL20	08 Aug	05 Sep	11 Oct	14 Oct	16	23.9
CLN120B	09 Aug	10 Aug	08 Oct	08 Oct	28	46.7
CLN90B	09 Aug	09 Aug	07 Oct	08 Oct	26	43.3
KL01	12 Aug	13 Aug	07 Oct	07 Oct	14	25.0
PL05	13 Aug	13 Aug	11 Oct	11 Oct	56	94.9
PL20	13 Aug	14 Aug	10 Oct	11 Oct	33	55.9
PL35	13 Aug	21 Aug	11 Oct	11 Oct	30	50.8
PL50	13 Aug	13 Sep	11 Oct	11 Oct	16	27.1
PLN20	13 Aug	13 Aug	07 Oct	11 Oct	17	28.8
PLN40	12 Aug	13 Aug	11 Oct	13 Oct	20	32.3
PLN60	12 Aug	12 Aug	06 Oct	08 Oct	29	50.9
PLN80	11 Aug	10 Aug	07 Oct	09 Oct	39	66.1
W05	14 Aug	14 Aug	22 Sep	05 Oct	8	15.4
W20	14 Aug	14 Aug	04 Oct	05 Oct	8	15.4
W35	14 Aug	14 Aug	04 Oct	06 Oct	9	17.0
W50	10 Aug	10 Aug	04 Oct	05 Oct	36	64.3
WN20	10 Sep	10 Sep	10 Oct	10 Oct	29	96.7
WN40	10 Sep	10 Sep	09 Oct	10 Oct	30	100.0

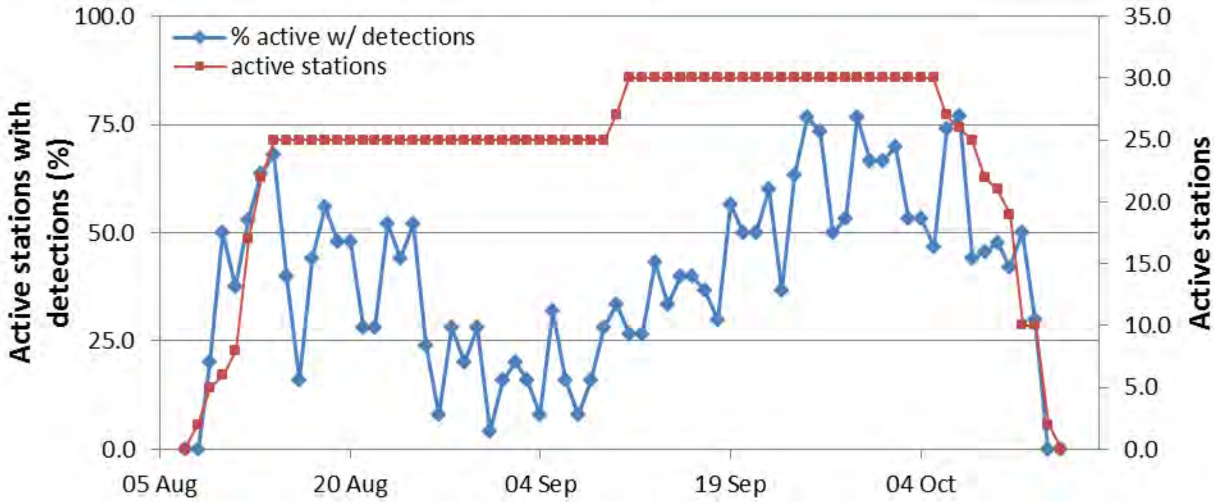

Figure C.12. Daily number of active stations and proportion of active station with walrus detections from 5 Aug to 13 Oct 2012 in the northeastern Chukchi Sea.

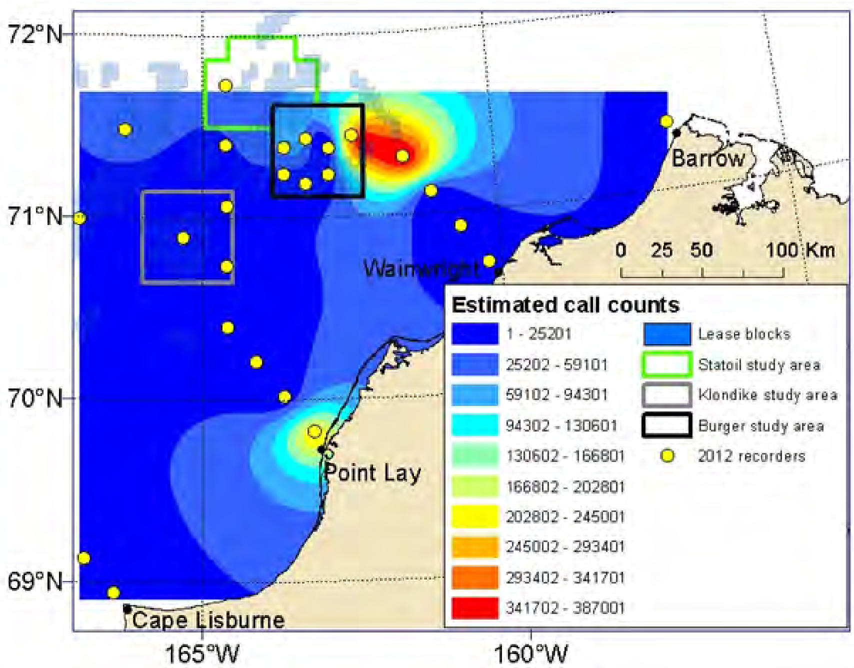

Figure C.13. Interpolated walrus call counts based on the sum of automated call detections in all files with manual detections from 7 Aug to 10 Sep at all operational summer 2012 recording stations in the northeastern Chukchi Sea.

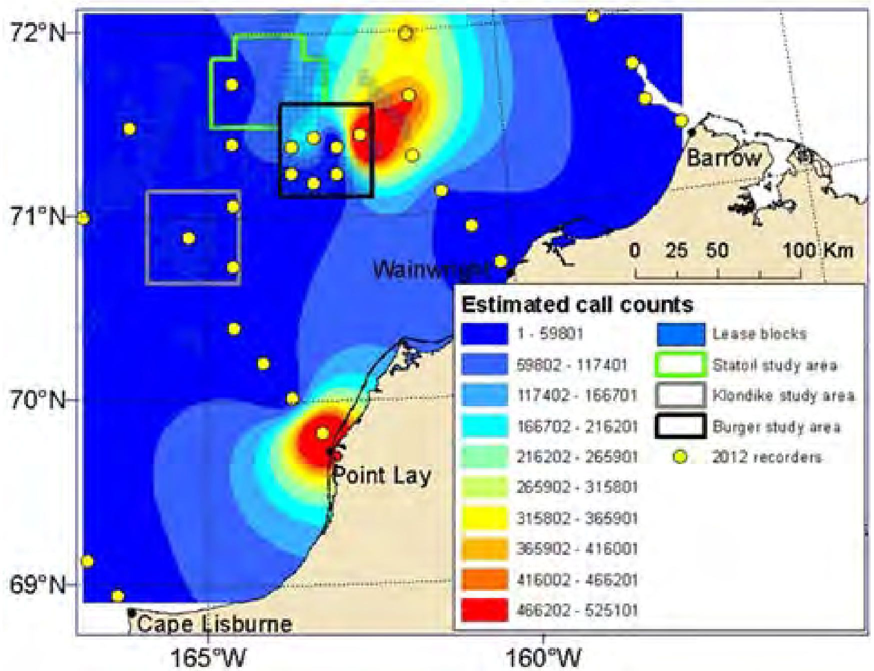

Figure C.14. Interpolated walrus call counts based on the sum of automated call detections in all files with manual detections from 11–27 Sep at all summer 2012 recording stations in the northeastern Chukchi Sea.

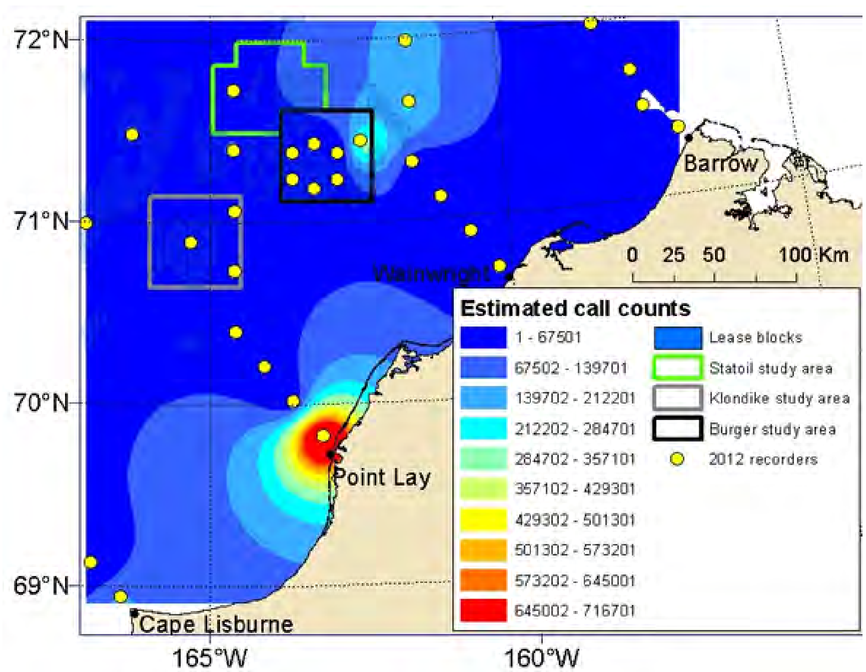

Figure C.15. Interpolated walrus call counts based on the sum of automated call detections in all files with manual detections from 28 Sep to 13 Oct at all summer 2012 recording stations in the northeastern Chukchi Sea.

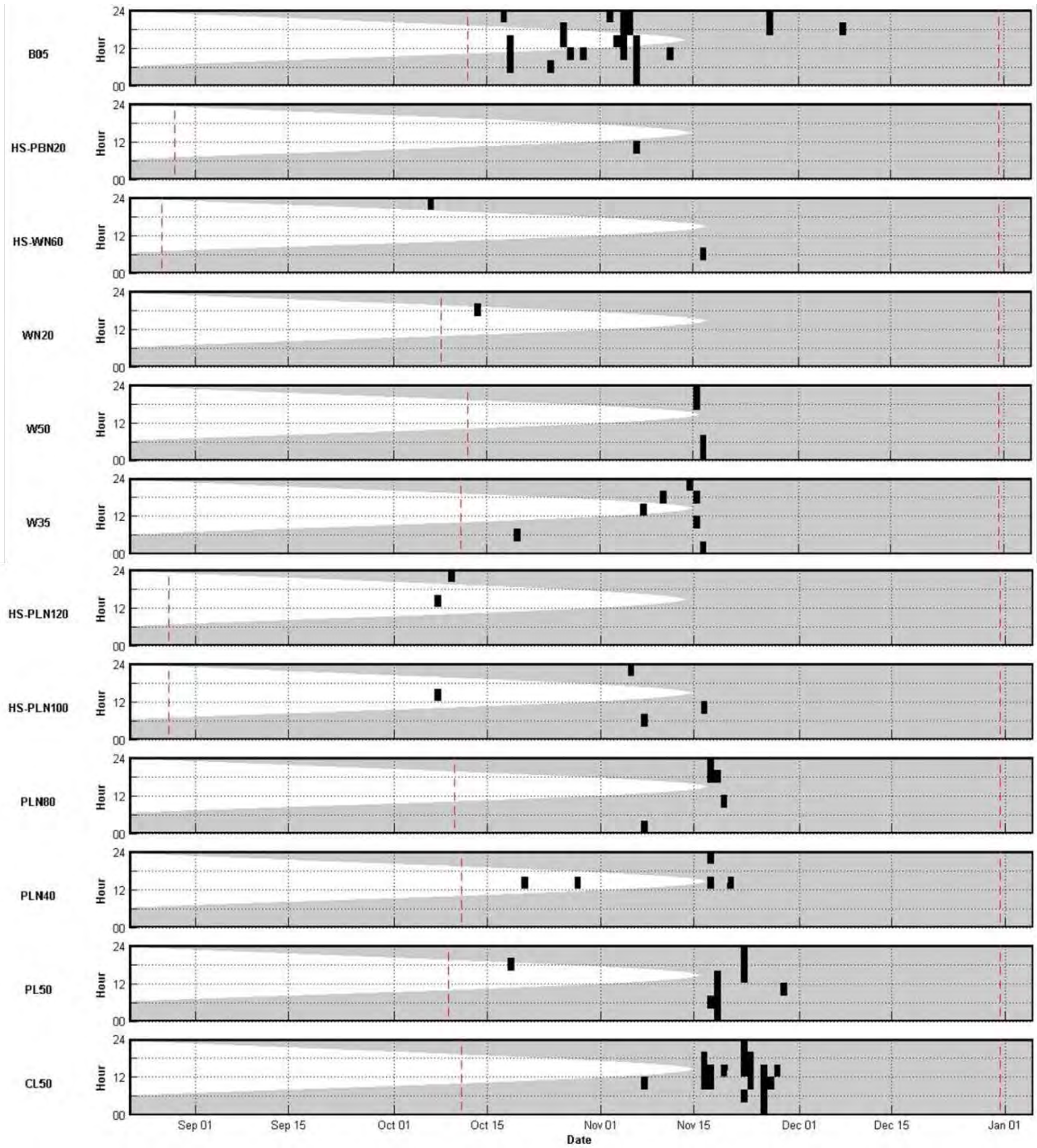

Figure C.16. Fall 2011 daily beluga call detections: Daily occurrence of call detections based on the manual analysis of 5% of the acoustic data recorded mid-October 2011 through late December 2012 in the northeastern Chukchi Sea for each station. Each black square represents a 4-hr period (one 30/40-minute file was recorded every four hours).Stations are ordered from northeast (top) to southwest (bottom). The leftmost red dashed lines are the recording start, and the rightmost, the end of the result compilation period (31 Dec 2011).

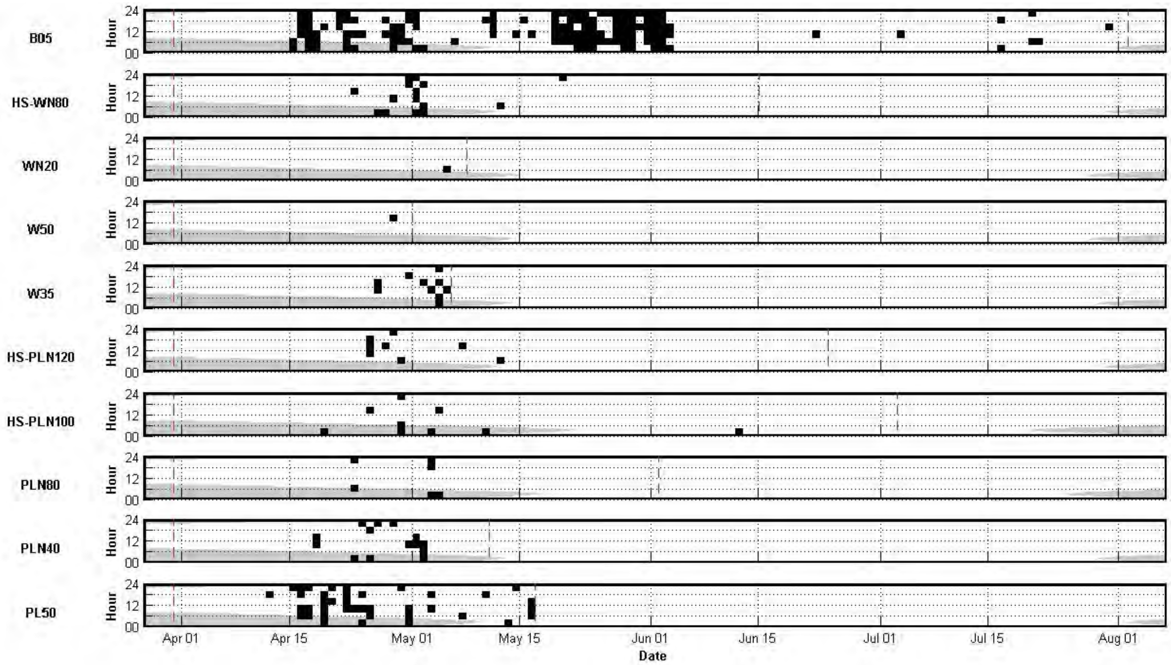

Figure C.17. Spring 2012 daily beluga call detections: Daily occurrence of call detections based on the manual analysis of 5% of the acoustic data recorded mid-October 2011 through late December 2012 in the northeastern Chukchi Sea for each station. Each black square represents a 4-hr period (one 30/40-minute file was recorded every four hours).Stations are ordered from northeast (top) to southwest (bottom). The leftmost red dashed lines are the recording start, and the rightmost, the end of the result compilation period (31 Dec 2011).

Table C.5. Winter 2011–2012 beluga 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 recording station in the northeastern Chukchi Sea. The recorders operated for 30–40 min of every 4 h.

Station	Record start	Fall 2011			Spring 2012			Record end
		First detection	Last detection	Detection days	First detection	Last detection	Detection days	
B05	13 Oct	18 Oct	08 Dec	12	15 Apr	30 Jul	43	01 Aug
PBN40	29 Aug	–	–	–	–	–	–	14 Jun
PBN20	29 Aug	06 Nov	06 Nov	1	–	–	–	31 Dec
WN80	27 Aug	–	–	–	23 Apr	21 May	9	14 Jun
WN60	27 Aug	07 Oct	16 Nov	2	–	–	–	26 Jan
WN40	08 Oct	–	–	–	–	–	–	15 Feb
WN20	08 Oct	14 Oct	14 Oct	1	05 May	05 May	1	07 May
W50	12 Oct	16 Nov	16 Nov	1	28 Apr	28 Apr	1	30 Apr
W35	12 Oct	19 Oct	16 Nov	5	26 Apr	05 May	6	06 May
PLN120	28 Aug	07 Oct	10 Oct	2	25 Apr	12 May	6	23 Jun
PLN100	28 Aug	07 Oct	16 Nov	4	19 Apr	12 Jun	8	03 Jul
PLN80	11 Oct	07 Nov	19 Nov	3	23 Apr	04 May	4	03 Jun
PLN40	11 Oct	20 Oct	20 Nov	5	18 Apr	02 May	9	10 May
PL50	09 Oct	19 Oct	28 Nov	6	13 Apr	16 May	19	17 May
CL50	11 Oct	07 Nov	27 Nov	10	–	–	–	14 Mar

Table C.6. Winter 2011–2012 bearded seal 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 recording station in the northeastern Chukchi Sea. The recorders operated for 30–40 min of every 4 h.

Station	Record start	First detection	Last detection	Record end	Detection days
B05	13 Oct	23 Nov	02 Jul	01 Aug	191
PBN40	29 Aug	08 Sep	14 Jun	14 Jun	179
PBN20	29 Aug	29 Aug	25 Dec	31 Dec	30
WN80	27 Aug	29 Aug	14 Jun	14 Jun	112
WN60	27 Aug	28 Aug	26 Jan	26 Jan	53
WN40	08 Oct	13 Oct	12 Feb	15 Feb	22
WN20	08 Oct	09 Oct	07 May	07 May	162
W50	12 Oct	19 Nov	30 Apr	30 Apr	145
W35	12 Oct	17 Oct	06 May	06 May	145
PLN120	28 Aug	28 Aug	23 Jun	23 Jun	224
PLN100	28 Aug	07 Sep	03 Jul	03 Jul	235
PLN80	11 Oct	01 Oct	03 Jun	03 Jun	196
PLN40	11 Oct	17 Oct	10 May	10 May	153
PL50	09 Oct	10 Oct	17 May	17 May	160
CL50	11 Oct	18 Oct	14 Mar	14 Mar	91

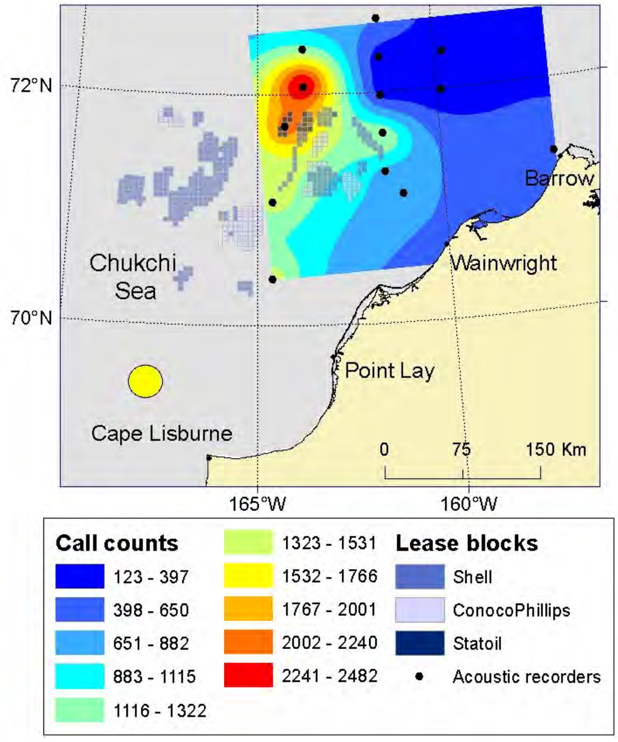

Figure C.18. Bearded seal call count estimates* in the Chukchi Sea for 15 Oct to 31 Dec 2011 at all winter 2011–2012 recording stations. Areas of complete ice coverage data are shown in gray for 6 Dec 2011, the mean detection date (NOAA 2012). The yellow bubble follows the legend's color scale and indicate the call count at station CL50. *Corrected sum of automated call detections in all files with manual detections.

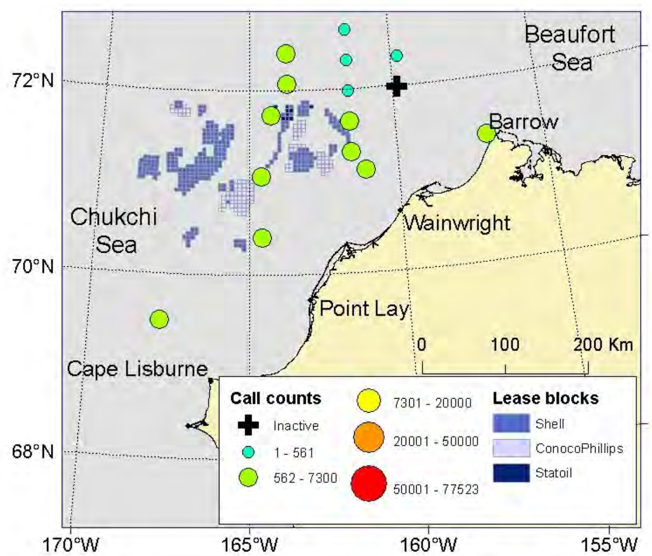

Figure C.19. Bearded seal call count estimates* in the Chukchi Sea for January 2012 at all winter 2011–2012 recording stations. Areas of complete ice coverage are shown in gray for 15 Jan 2012, the mean detection date (NOAA 2012). *Corrected sum of automated call detections in all files with manual detections.

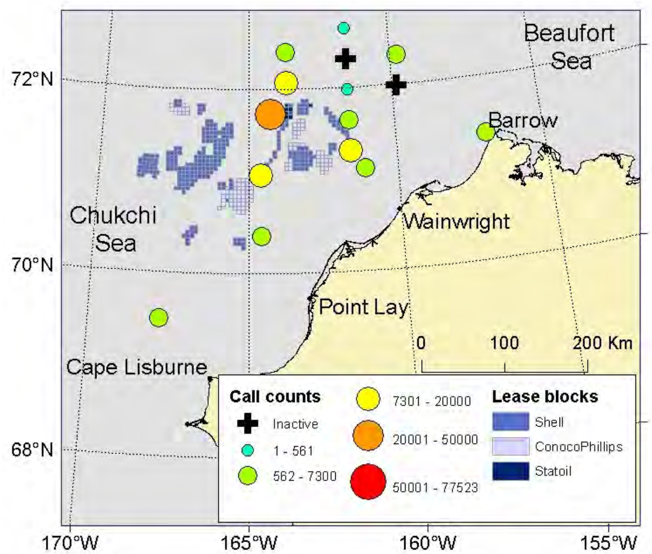

Figure C.20. Bearded seal call count estimates* in the Chukchi Sea for February 2012 at all winter 2011–2012 recording stations. Areas of complete ice coverage are shown in gray for 15 Feb 2012, the mean detection date (NOAA 2012). *Corrected sum of automated call detections in all files with manual detections.

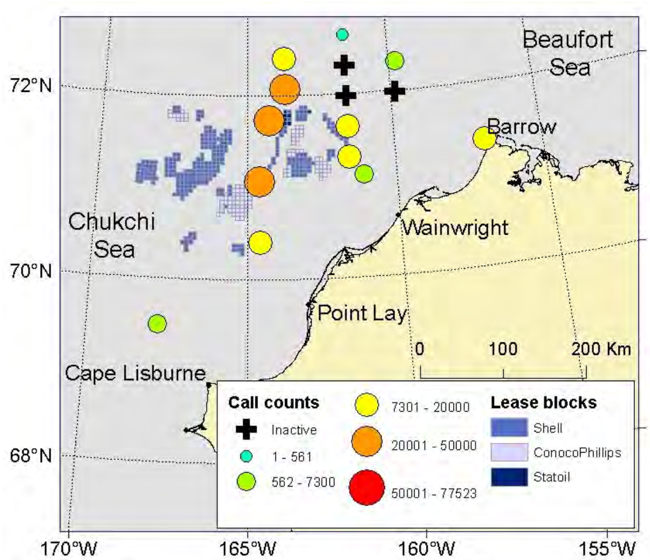

Figure C.21. Bearded seal call count estimates* in the Chukchi Sea for March 2012 at all winter 2011-2012 recording stations. Areas of complete ice coverage are shown in gray for 15 Mar 2012, the mean detection date (NOAA 2012). *Corrected sum of automated call detections in all files with manual detections.

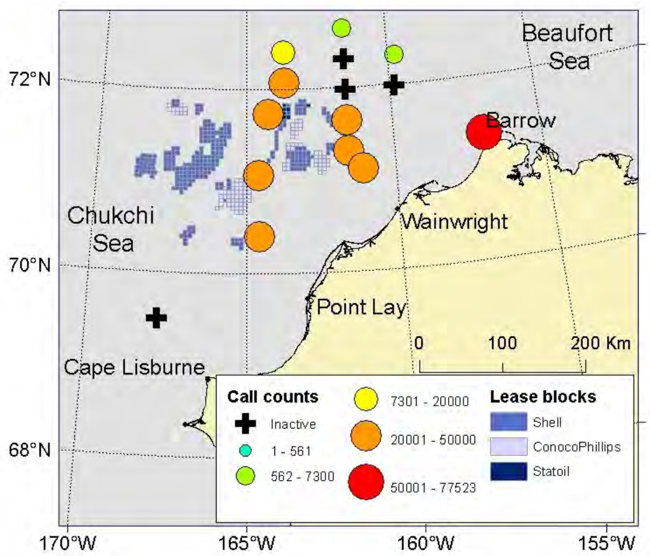

Figure C.22. Bearded seal call count estimates* in the Chukchi Sea for April 2012 at all winter 2011-2012 recording stations. Areas of complete ice coverage are shown in gray for 15 Apr 2012, the mean detection date (NOAA 2012). *Corrected sum of automated call detections in all files with manual detections.

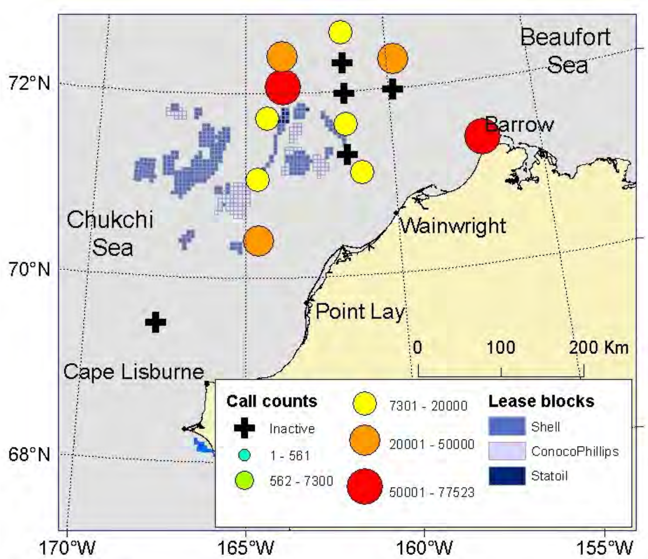

Figure C.23. Bearded seal call count estimates* in the Chukchi Sea for May 2012 at all winter 2011-2012 recording stations. Areas of complete ice coverage are shown in gray for 15 May 2012, the mean detection date (NOAA 2012). *Corrected sum of automated call detections in all files with manual detections.

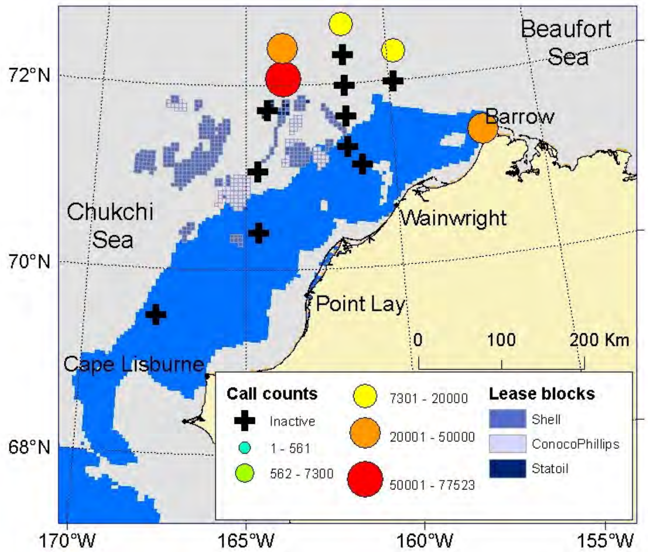

Figure C.24. Bearded seal call count estimates* in the Chukchi Sea for June 2012 at all winter 2011–2012 recording stations. Areas of complete ice coverage are shown in gray for 15 Jun 2012 (mean detection date; NOAA 2012). The blue background and gray background indicate open water and sea ice, respectively. *Corrected sum of automated call detections in all files with manual detections.

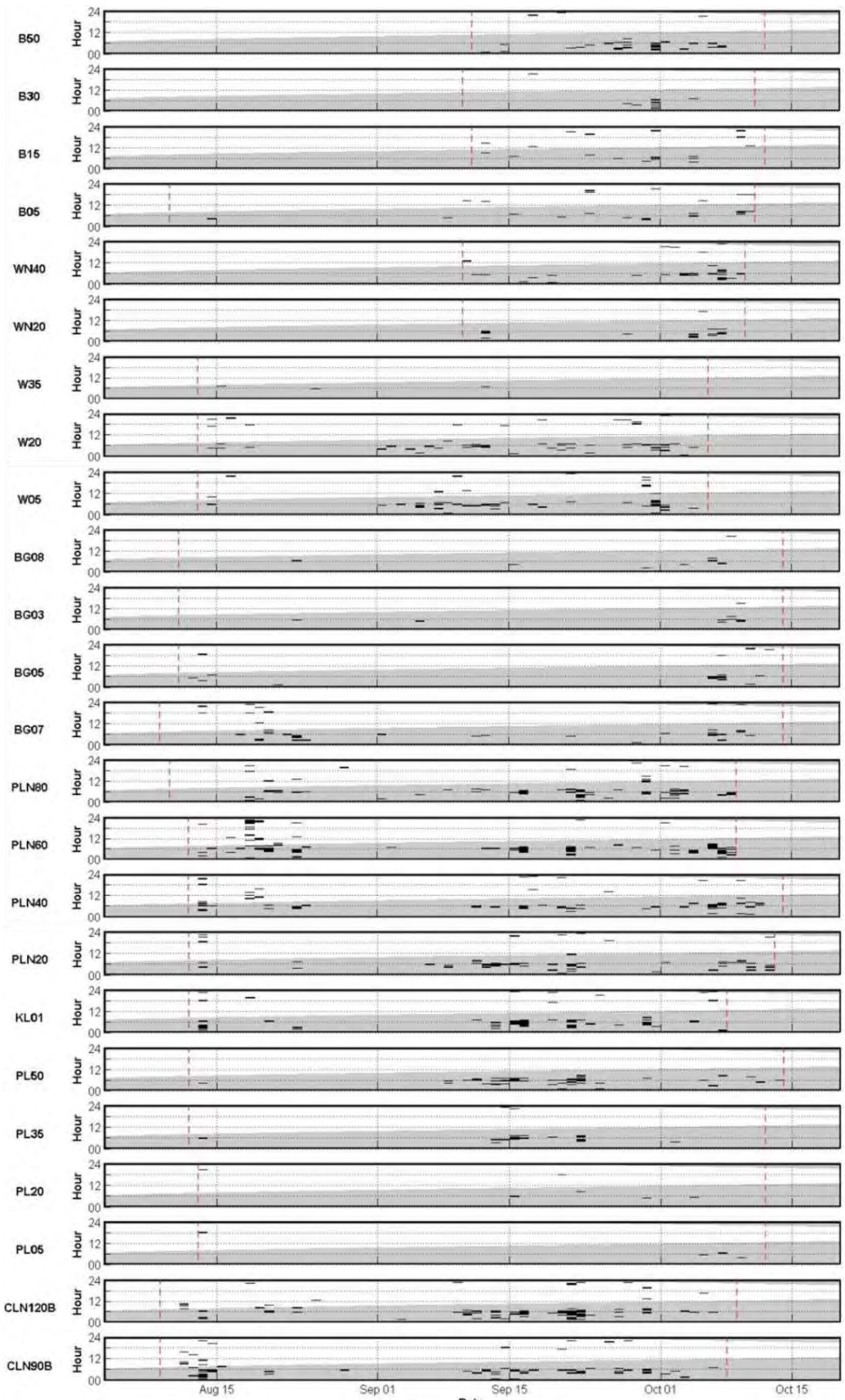

Figure C.25. Summer 2012 daily bearded seal call detections: Daily and half-hourly occurrence of call detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2012 in the northeastern Chukchi Sea. Each black square represents a 30-min period. Stations with three detection days (*n* = 2) or less were omitted; only four of seven Burger stations are plotted. Red dashed lines indicate recording start and end. The shaded areas represent hours of darkness.

Table C.7. Summer 2012 bearded seal call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the percentage of days on which a call was detected for each recording station in the northeastern Chukchi Sea. Stations without call detections were omitted.

Station	Record start	First detection	Last detection	Record end	Detection days	% Days with detection
B05	11 Aug	14 Aug	11 Oct	11 Oct	16	26.2
B15	11 Sep	12 Sep	10 Oct	11 Oct	12	40.0
B30	11 Sep	18 Sep	04 Oct	11 Oct	6	20.0
B50	11 Sep	12 Sep	07 Oct	11 Oct	15	50.0
BG02	12 Aug	19 Aug	12 Oct	13 Oct	13	23.2
BG03	12 Aug	23 Aug	09 Oct	13 Oct	5	8.1
BG04	12 Aug	14 Aug	11 Oct	13 Oct	6	9.7
BG05	12 Aug	12 Aug	13 Oct	13 Oct	10	16.1
BG06	12 Aug	14 Aug	10 Oct	13 Oct	10	16.1
BG07	09 Aug	14 Aug	10 Oct	13 Oct	20	30.8
BG08	12 Aug	23 Aug	09 Oct	13 Oct	7	11.3
CL05	08 Aug	16 Sep	11 Oct	14 Oct	3	4.5
CL20	08 Aug	22 Sep	11 Oct	14 Oct	2	3.0
CLN120B	09 Aug	11 Aug	06 Oct	08 Oct	27	45.0
CLN90B	09 Aug	10 Aug	06 Oct	08 Oct	28	46.7
KL01	12 Aug	13 Aug	07 Oct	07 Oct	21	37.5
PL05	13 Aug	14 Aug	09 Oct	11 Oct	5	8.5
PL20	13 Aug	14 Aug	08 Oct	11 Oct	7	11.9
PL35	13 Aug	13 Aug	02 Oct	11 Oct	8	13.6
PL50	13 Aug	13 Aug	13 Oct	11 Oct	21	35.6
PLN20	13 Aug	13 Aug	13 Oct	11 Oct	26	44.1
PLN40	12 Aug	13 Aug	11 Oct	13 Oct	26	41.9
PLN60	12 Aug	13 Aug	08 Oct	08 Oct	28	49.1
PLN80	11 Aug	18 Aug	08 Oct	09 Oct	27	45.8
W05	14 Aug	14 Aug	04 Oct	05 Oct	22	42.3
W20	14 Aug	14 Aug	04 Oct	05 Oct	29	55.8
W35	14 Aug	14 Aug	23 Sep	06 Oct	6	11.3
WN20	10 Sep	12 Sep	07 Oct	10 Oct	5	16.7
WN40	10 Sep	10 Sep	09 Oct	10 Oct	15	50.0

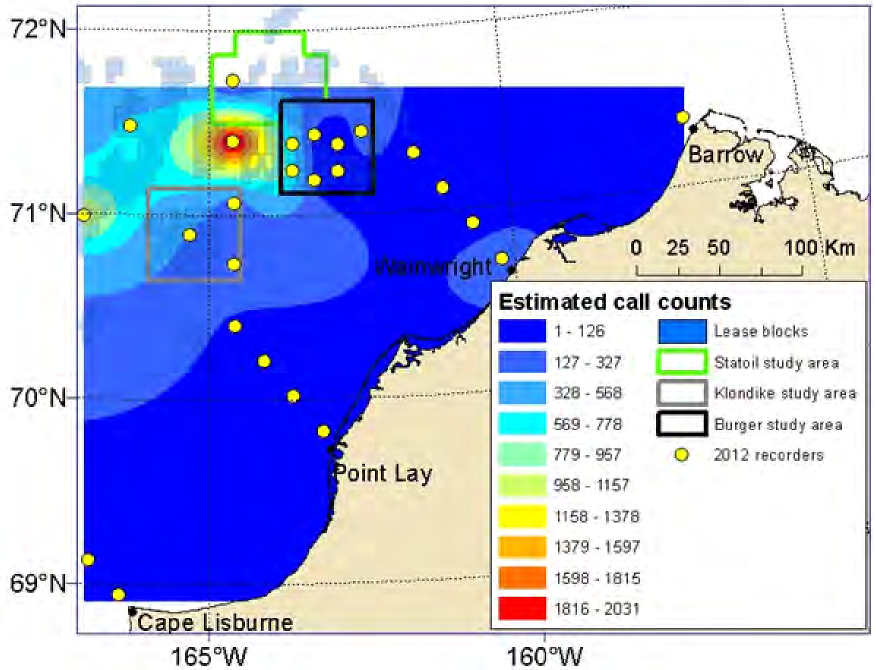

Figure C.26. Interpolated bearded seal call counts based on the sum of automated call detections in all files with manual detections from 7 Aug to 10 Sep at all operational summer 2012 recording stations in the northeastern Chukchi Sea.

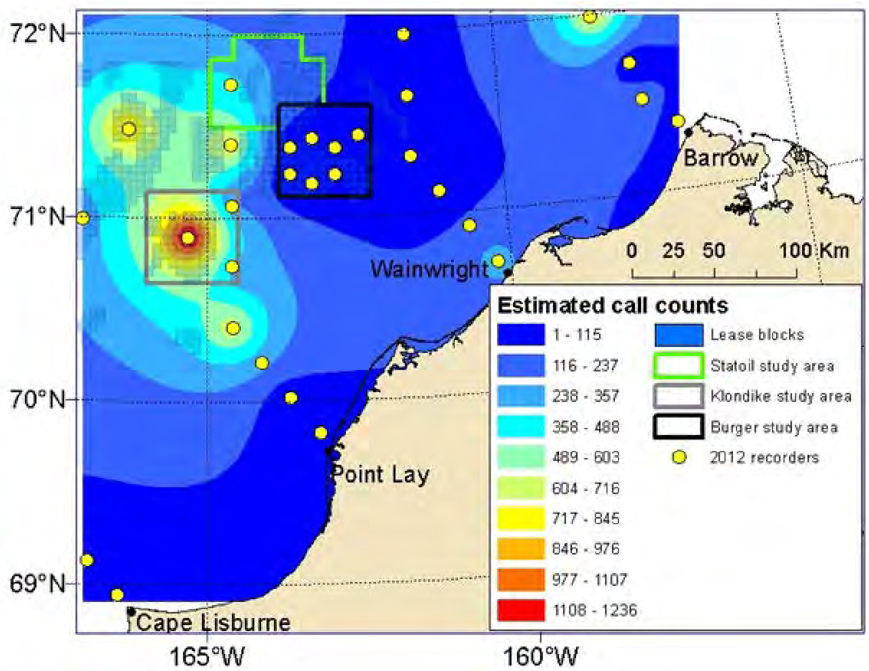

Figure C.27. Interpolated bearded seal call counts based on the sum of automated call detections in all files with manual detections from 11–27 Sep at all summer 2012 recording stations in the northeastern Chukchi Sea.

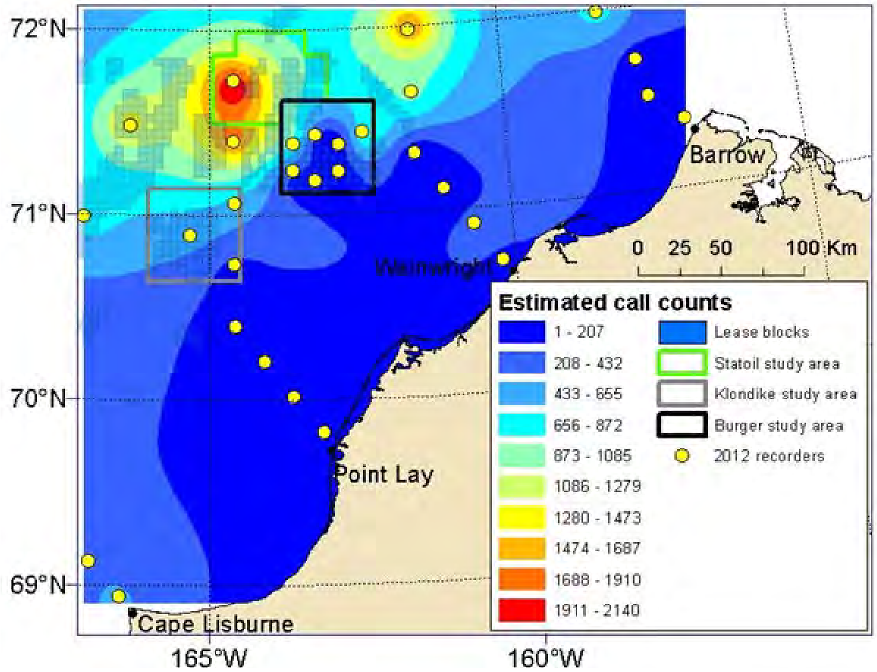

Figure C.28. Interpolated bearded seal call counts based on the sum of automated call detections in all files with manual detections from 28 Sep to 13 Oct at all summer 2011 recording stations in the northeastern Chukchi Sea.

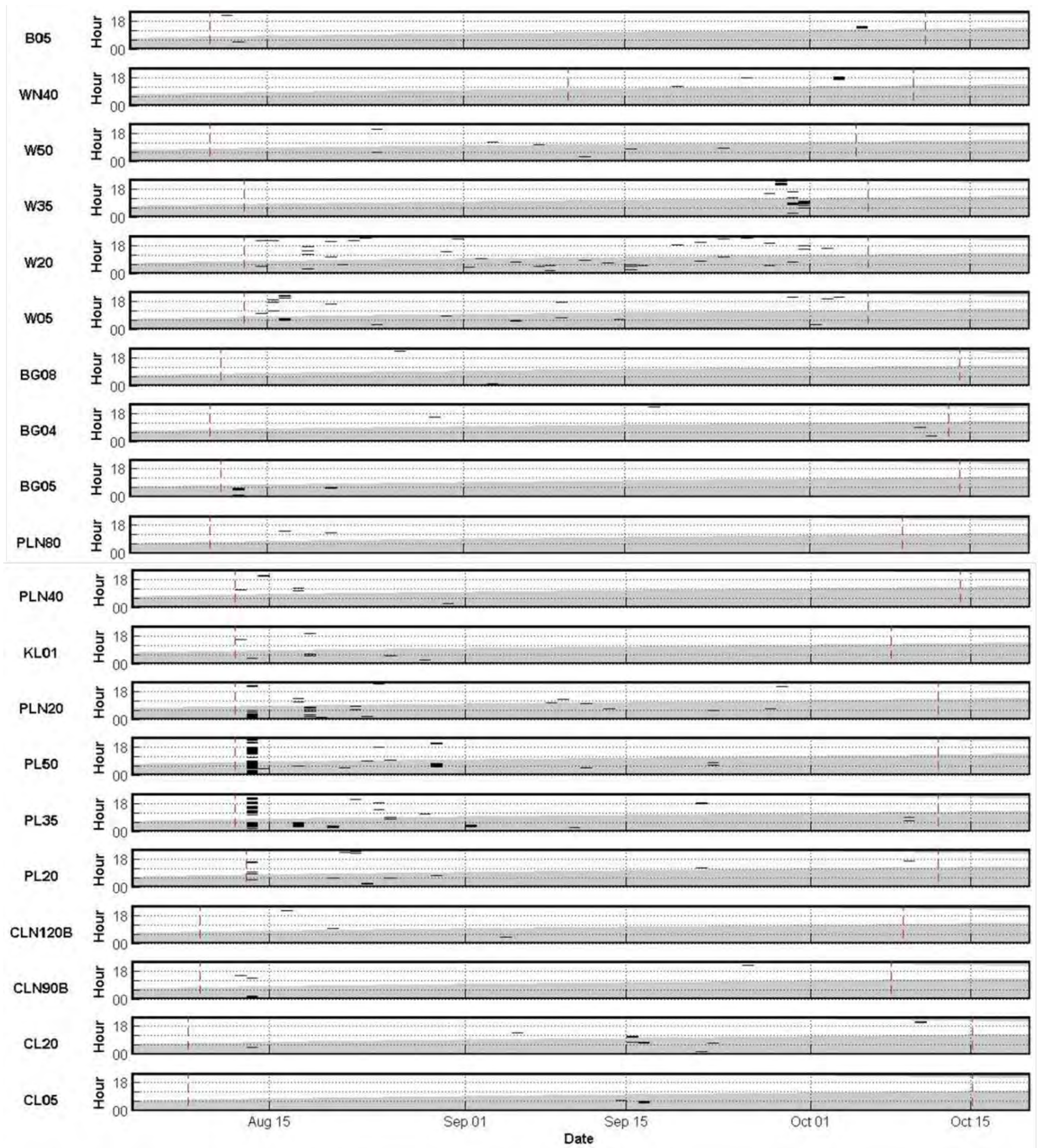

Figure C.29. Summer 2012 daily gray whale call detections: Daily and half-hourly occurrence of call detections based on the manual analysis of 5% of the acoustic data recorded late July through mid-October 2012 in the northeastern Chukchi Sea. Each black square represents a 30-min period. Stations with one detection day or less were omitted. Red dashed lines indicate recording start and end.

Table C.8. Summer 2012 gray whale call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the percentage of days on which a call was detected for each recording station in the northeastern Chukchi Sea. Stations without call detections were omitted.

Station	Record start	First detection	Last detection	Record end	Detection days	% Days with detection
B05	11 Aug	12 Aug	05 Oct	11 Oct	6	9.8
BG02	12 Aug	30 Aug	30 Aug	13 Oct	1	1.8
BG04	12 Aug	12 Aug	11 Oct	13 Oct	5	8.1
BG05	12 Aug	12 Aug	20 Aug	13 Oct	2	3.2
BG06	12 Aug	18 Aug	18 Aug	13 Oct	1	1.6
BG07	09 Aug	02 Sep	02 Sep	13 Oct	1	1.5
BG08	12 Aug	27 Aug	03 Sep	13 Oct	2	3.2
CL05	08 Aug	14 Sep	16 Sep	14 Oct	2	3.0
CL20	08 Aug	13 Aug	11 Oct	14 Oct	7	10.4
CLN120B	09 Aug	17 Aug	04 Sep	08 Oct	3	5.0
CLN90B	09 Aug	12 Aug	26 Sep	08 Oct	3	5.0
KL01	12 Aug	12 Aug	28 Aug	07 Oct	7	12.5
PL20	13 Aug	13 Aug	10 Oct	11 Oct	10	16.9
PL35	13 Aug	13 Aug	09 Oct	11 Oct	15	25.4
PL50	13 Aug	13 Aug	02 Oct	11 Oct	11	18.6
PLN20	13 Aug	13 Aug	29 Sep	11 Oct	15	25.4
PLN40	12 Aug	12 Aug	30 Aug	13 Oct	5	8.1
PLN60	12 Aug	12 Aug	12 Aug	08 Oct	1	1.8
PLN80	11 Aug	16 Aug	20 Aug	09 Oct	2	3.4
W05	14 Aug	14 Aug	04 Oct	05 Oct	16	30.8
W20	14 Aug	14 Aug	02 Oct	05 Oct	33	63.5
W35	14 Aug	27 Sep	30 Sep	06 Oct	3	5.7
W50	10 Aug	24 Aug	23 Sep	05 Oct	7	12.5
WN40	10 Sep	19 Sep	04 Oct	10 Oct	3	10.0

Table C.9. Summer 2012 killer whale call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the percentage of days on which a call was detected for each recording station in the northeastern Chukchi Sea. Stations without call detections were omitted.

Station	Record start	First detection	Last detection	Record end	Detection days	% Days with detection
B05	11 Aug	20 Aug	22 Sep	11 Oct	3	4.9
B15	11 Sep	20 Sep	10 Oct	11 Oct	2	6.7
BG02	12 Aug	14 Sep	14 Sep	13 Oct	1	1.8
BG03	12 Aug	29 Aug	29 Aug	13 Oct	1	1.6
BG04	12 Aug	24 Aug	18 Sep	13 Oct	3	4.8
BG05	12 Aug	24 Aug	26 Aug	13 Oct	3	4.8
BG06	12 Aug	24 Aug	26 Aug	13 Oct	3	4.8
BG07	09 Aug	25 Aug	29 Aug	13 Oct	2	3.1
CL05	08 Aug	05 Sep	06 Sep	14 Oct	2	3.0
CL20	08 Aug	05 Sep	06 Sep	14 Oct	2	3.0
CLN90B	09 Aug	27 Aug	20 Sep	08 Oct	3	5.0
KL01	12 Aug	23 Aug	20 Sep	07 Oct	4	7.1
PL05	13 Aug	23 Aug	23 Aug	11 Oct	1	1.7
PL20	13 Aug	23 Aug	15 Sep	11 Oct	2	3.4
PL35	13 Aug	18 Aug	23 Aug	11 Oct	2	3.4
PL50	13 Aug	23 Aug	23 Aug	11 Oct	1	1.7
PLN20	13 Aug	23 Aug	24 Aug	11 Oct	2	3.4
W05	14 Aug	19 Aug	16 Sep	05 Oct	3	5.8
W20	14 Aug	15 Sep	15 Sep	05 Oct	1	1.9
W35	14 Aug	15 Sep	15 Sep	06 Oct	1	1.9
W50	10 Aug	21 Sep	21 Sep	05 Oct	1	1.8

Table C.10. Summer 2012 minke whale call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the percentage of days on which a call was detected for each recording station in the northeastern Chukchi Sea. Stations without call detections were omitted.

Station	Record start	First detection	Last detection	Record end	Detection days	% Days with detection
BG05	12-Aug	06-Oct	06-Oct	13-Oct	1	1.6
CL20	08-Aug	09-Oct	11-Oct	14-Oct	2	3.0
PL20	13-Aug	23-Aug	23-Aug	11-Oct	1	1.7
PL35	13-Aug	20-Aug	11-Oct	11-Oct	5	8.5
PL50	13-Aug	22-Sep	11-Oct	11-Oct	5	8.5

Table C.11. Winter 2011–2012 ringed seal 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 recording station in the northeastern Chukchi Sea. The recorders operated for 30–40 min of every 4 h.

Station	Record start	First detection	Last detection	Record end	Detection days
B05	13 Oct	27 Nov	19 May	01 Aug	4
PBN40	29 Aug	12 Oct	08 May	14 Jun	13
PBN20	29 Aug	19 Nov	30 Dec	31 Dec	4
WN80	27 Aug	20 Jan	07 May	14 Jun	10
WN60	27 Aug	08 Oct	06 Dec	26 Jan	4
WN40	08 Oct	25 Nov	31 Jan	15 Feb	8
WN20	08 Oct	15 Jan	15 Jan	07 May	1
W50	12 Oct	17 Nov	10 Apr	30 Apr	7
W35	12 Oct	22 Nov	05 May	06 May	6
PLN120	28 Aug	28 Apr	13 May	23 Jun	3
PLN100	28 Aug	28 Nov	26 Jun	03 Jul	7
PLN80	11 Oct	–	–	03 Jun	–
PLN40	11 Oct	26 Jan	26 Jan	10 May	1
PL50	09 Oct	23 Nov	15 May	17 May	7
CL50	11 Oct	18 Oct	30 Nov	14 Mar	2

Table C.12 Summer 2012 ringed seal call detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the percentage of days on which a call was detected for each recording station in the northeastern Chukchi Sea. Stations without call detections were omitted.

Station	Record start	First detection	Last detection	Record end	Detection days	% Days with detection
B05	11 Aug	22 Sep	22 Sep	11 Oct	1	1.6
B15	11 Sep	19 Sep	22 Sep	11 Oct	2	6.7
B30	11 Sep	20 Sep	30 Sep	11 Oct	2	6.7
B50	11 Sep	06 Oct	07 Oct	11 Oct	2	6.7
BG03	12 Aug	24 Aug	25 Aug	13 Oct	2	3.2
BG04	12 Aug	22 Aug	24 Aug	13 Oct	2	3.2
BG05	12 Aug	14 Aug	24 Aug	13 Oct	3	4.8
BG06	12 Aug	14 Aug	24 Aug	13 Oct	3	4.8
CL05	08 Aug	19 Aug	23 Aug	14 Oct	2	3.0
CL20	08 Aug	11 Oct	11 Oct	14 Oct	1	1.5
CLN120B	09 Aug	13 Aug	22 Sep	08 Oct	5	8.3
PL20	13 Aug	23 Aug	23 Aug	11 Oct	1	1.7
PLN20	13 Aug	23 Aug	23 Aug	11 Oct	1	1.7
PLN60	12 Aug	19 Aug	25 Aug	08 Oct	4	7.0
W50	10 Aug	21 Aug	21 Aug	05 Oct	1	1.8
WN20	10 Sep	06 Oct	07 Oct	10 Oct	2	6.7

Appendix D. Bearded Seals

D.1. Introduction

The Chukchi Sea Environmental Studies Program (CSESP; www.chukchiscience.com), sponsored by Statoil, ConocoPhillips, and Shell, includes passive acoustic monitoring that has operated almost continuously since summer 2006. Bearded seal is a highly vocal ice seal that is widely distributed in the Arctic. Due to the implementation of the CSESP, and monitoring during seismic acquisition in 2007, scientific knowledge regarding their movements and behavior has increased. By using autonomous long-term acoustic recordings, researchers have been able to investigate the acoustic behavior and seasonal occurrence of marine mammals in areas, and in periods where ship-based or on ice studies were not previously possible.

This appendix describes the seasonal and diel/daily variations of male bearded seal (*Erignathus barbatus*) vocalizations based on recordings obtained in these Acoustic Monitoring Programs: winter 2007–2008, winter 2008–2009, and summers 2009, 2010, and 2011.

D.2. Methods

D.2.1. Data Acquisition

Acoustic data acquisition for the winters 2007–2008 and 2008–2009 had been described in a previous report (Martin et al. 2010). Acoustic data acquisition for the summers 2009, 2010, and 2011 had also been described in previous reports (Delarue et al. 2010, 2011, 2012).

D.2.2. Manual Data Analysis

For the bearded seal project, one trained analyst, with more than two years' experience, manually analyzed data from the winter 2007–2008 and 2008–2009 programs by visually examining spectrograms and listening to audio playbacks. See the previous reports (Delarue et al. 2010, 2011, 2012) for more information about the manual analysis of the summer 2009, 2010, and 2011 programs.

The objectives of this manual analysis were to:

- Detect and classify bearded seal calls within a subset of the data to evaluate the geographic distribution of male bearded seals in the Chukchi Sea.
- Determine the seasonal variation in the occurrence of male bearded seal vocalizations over two consecutive years.
- Estimate the influence of the diel/daily cycle on the vocal activity of male bearded seals before (early January to mid-March) and during (mid-March to late June) the mating period.
- Evaluate the proportion of each call type before and during the mating period in male bearded seals.

- Using a different approach, estimate the influence of the diel/daily cycle on the vocal activity of male bearded seals after the mating period (early July to mid-October).

For the first two objectives, three percent per winter season (winter 2007–2008 and 2008–2009) data from all regional array recorders (winter 2007–2008: $n = 5$, winter 2008–2009: $n = 7$; see Figure D.1) were analyzed manually. The winter acoustic data were acquired on a duty-cycle, recording for 48 min (winter 2007–2008) or 40 min (winter 2008–2009) every 4 h, yielding 6 files per day. In Svalbard and in Canada, male vocalizations exhibited a clear temporal pattern in relation to the diel/daily cycle, with a peak around 04:00 (Cleator et al. 1989, Van Parijs et al. 2001). To determine the presence and the vocal activity of male bearded seals, this analysis targeted files starting between 02:00 and 06:00 (Alaska Standard Time, AST) on every third day. The first 20 min of each selected 48 or 40 min data file was manually analyzed by visually examining spectrograms and listening to audio playbacks. The analyst annotated all bearded seal calls.

For the third and fourth objectives, 2.5% per winter season (winter 2007–2008 and 2008–2009) data from all regional array recorders were analyzed manually. The analysis targeted the first 10 min of all 48 or 40 min data files that were recorded every tenth day. The analyst annotated all bearded seal calls.

For the last objective, 5% of the summer (2009, 2010, and 2011) data from selected regional array recorders (summer 2009: $n = 8$, summer 2010: $n = 10$, summer 2011: $n = 9$; see Figure D.2) were analyzed manually. The summer acoustic data were acquired continuously and stored in 30-minute long files yielding 48 files per day. The first 90 s of each 30 min file per station each day were sampled for manual analysis (See Delarue et al. 2010, 2011, or 2012 for more information). Analysts annotated a single bearded seal call for each sample.

This manual analysis used call types modified from Risch et al. 2007. Table D.1 describes the call types; Figure D.3 illustrates them. Vocalizations from Alaska (AL) were divided into three basic call categories by visually inspecting the sound spectrogram: trill (T), moan (M), and ascent (A). Moans can be distinguished from other bearded seal vocalizations because they have little to no frequency modulation and less frequency change from the call start to its end. However, when received levels of calls were low, distinction between moans, the AL6 trill and the AL5 trill, was often difficult. For this reason, we set frequency of 120 Hz as the cutoff between moans and AL6 trills, and a frequency of 240 Hz as the cutoff between AL6 trills and AL5 trills.

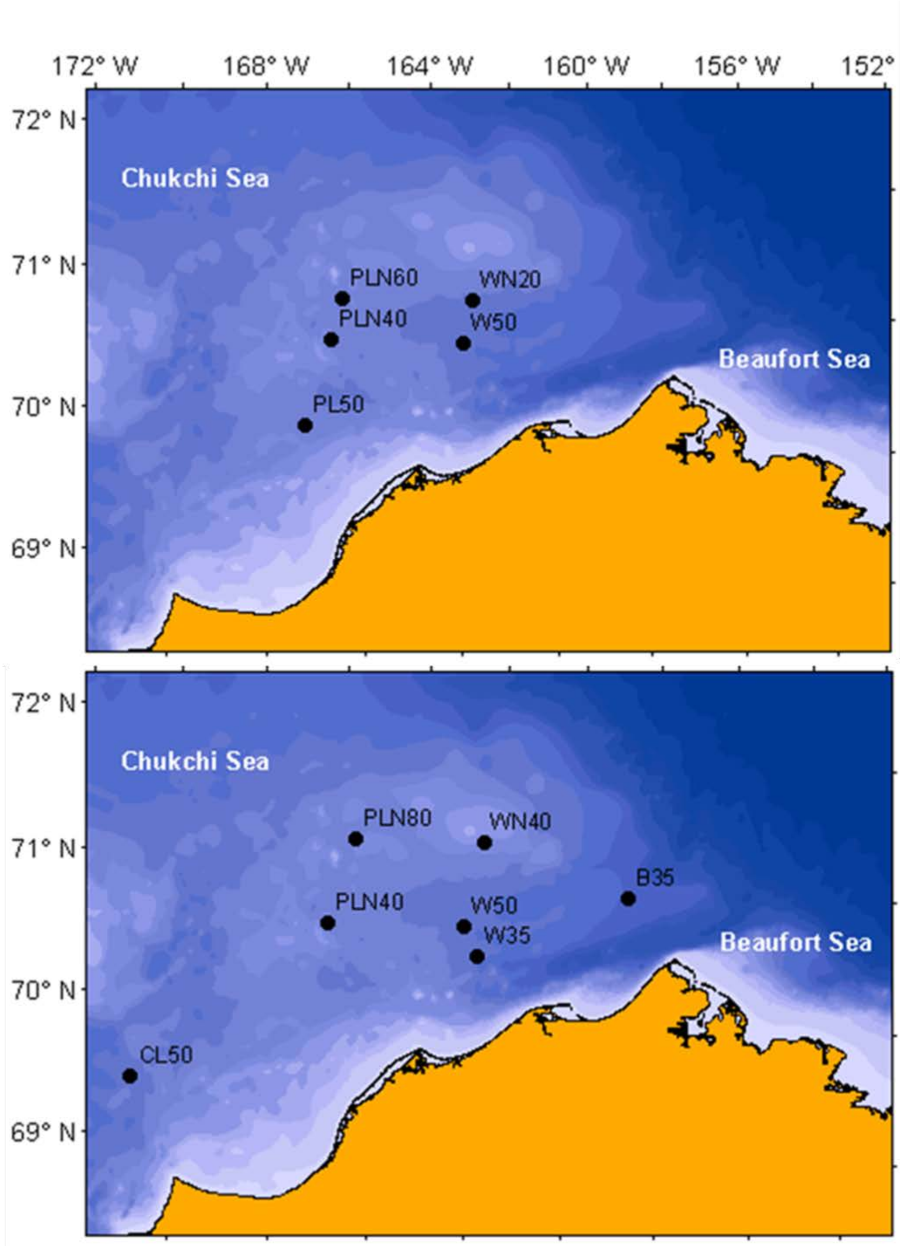

Figure D.1. Overwinter deployment locations used in this study. (Top) 2007–2008, and (bottom) 2008–2009. Shades of blue represent the bathymetry.

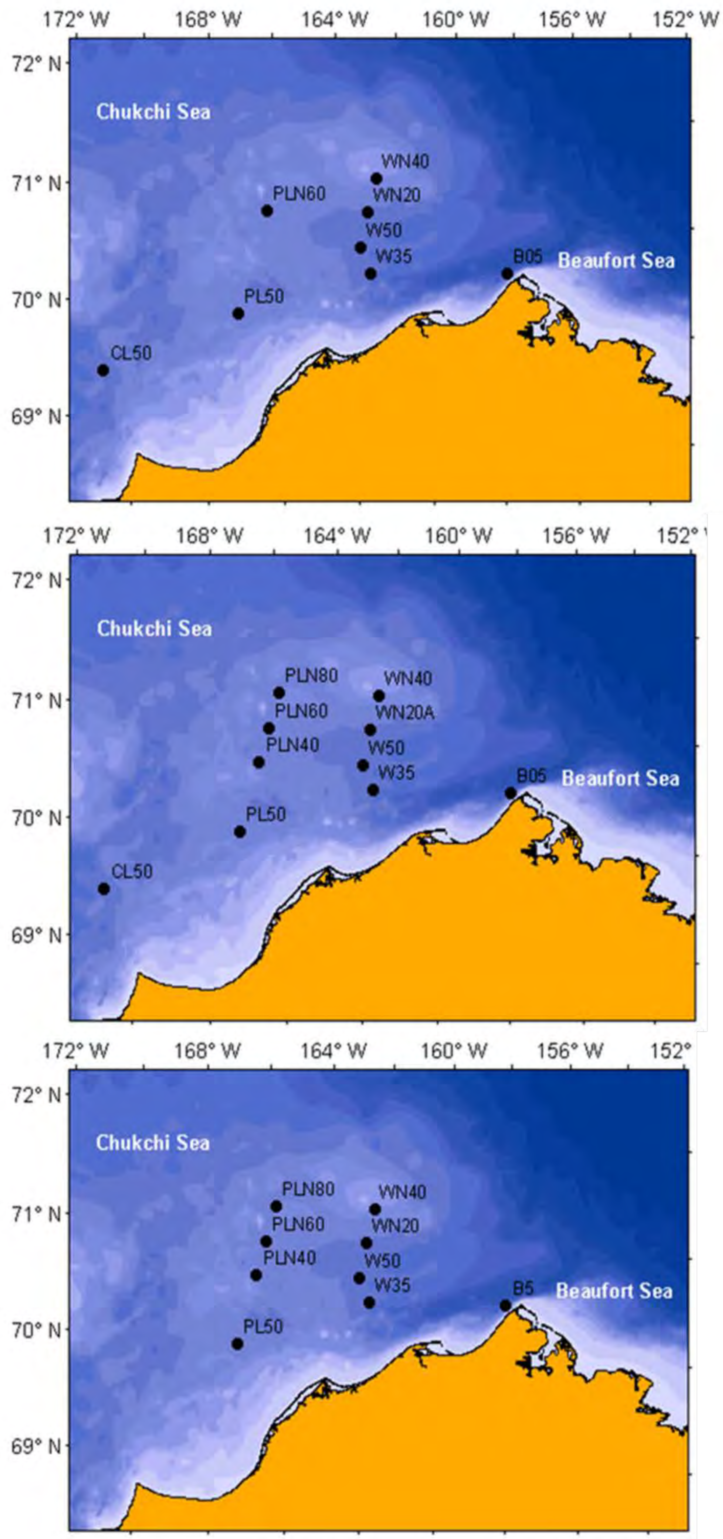

Figure D.2. Open water season deployment locations used in this study: (Top) 2009, (middle) 2010, and (bottom) 2011. Shades of blue represent the bathymetry.

Table D.1. Call types for bearded seals annotated during manual analysis of the winter 2007–2008 and winter 2008–2009 datasets (call types modified from Risch et al. 2007). Abbreviations: AL=Alaska, T=trill, M= moan, A=ascent.

Call Type	Description
AL1(T)	Trill with ascent and plume
AL1i(T)	Trill with ascent
AL2(T)	Downsweeping trill longer than 13 s
Al3(M)	Moan (frequency modulation under 120 Hz)
AL4(T)	Trill containing both down- and upsweeping segments
AL5(T)	Downsweeping trill shorter than 13 s and with a frequency range above 240 Hz
AL6(T)	Downsweeping trill shorter than 13 s and with a frequency range between 120 and 240 Hz
AL7(A)	Upsweeping trill (Ascent)
Other	Bearded seal call outside the above categories

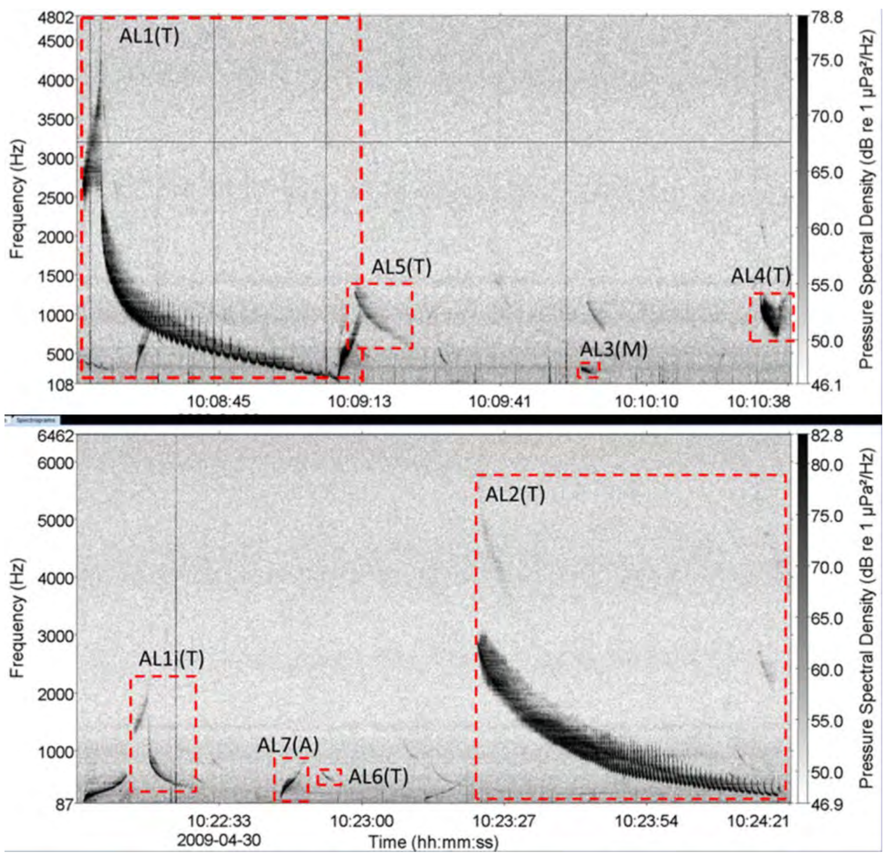

Figure D.3. Bearded seal calls representing the major call types found in the Chukchi dataset (call types modified from Risch et al. 2007). (Top) AL1(T), AL5(T), AL3(M), and AL4(T). (Bottom) AL1i(T), AL7(A), AL6(T), and AL2(T).

D.3. Results

Bearded seal calls were detected at all winter 2007–2008 and 2008–2009 stations (Figure D.1). Using only the overwinter data (October–July), bearded seal detections increased progressively from December to early March, peaked between mid-March and June (mating period), and were essentially absent in July. Bearded seal detections were relatively uniformly distributed throughout the program area during the 2008 mating period. During the 2009 mating period, bearded seal detections varied between stations, for example there were lower annotated call counts at PLN40. The maximum number of male bearded seal calls varied between years with fewer calls in 2008–2009 than in 2007–2008. The decreased male vocalization rate suggests either a decrease in calling rates of individual seals, a decrease in the number of displaying males, or a combination of these two factors. The number of calls increased when ice concentration was near 100%. In spring 2008, at stations PL50 and PLN40, and to a lesser extent at W50, a temporary decrease in ice cover was associated with an increase in call counts during the peak of the mating season. Call counts decreased toward the end of the season, regardless of ice cover.

In 2008 and in 2009, frequency of occurrence of bearded seal calls showed a clear diel/daily cycle both before (early January to mid-March) and during (mid-March to late June) the mating period at all stations, even though the strength of this pattern varied between stations (Figure D.5). Generally, males vocalized more from 20:00 (AST) onwards with a peak in the number of calls around 04:00.

Figure D.6 illustrates the proportion of each male bearded seal call type before and during the mating period at each station in 2008 and in 2009. The most common bearded seal vocalizations detected both before and during the mating period, were trills—notably AL5(T) and AL6(T)—followed by moans AL3(M), and then ascents AL7(A). During the mating period, AL1(T) and AL2(T) counts increased, whereas AL3(M) counts decreased.

After the mating period, call detections resumed progressively with a notable increase in the second half of September. The occurrence of bearded seal calls varied on a diel/daily cycle; they were higher during periods of night at all summer 2009 (Figure D.7), 2010 (Figure D.8), and 2011 (Figure D.9) stations.

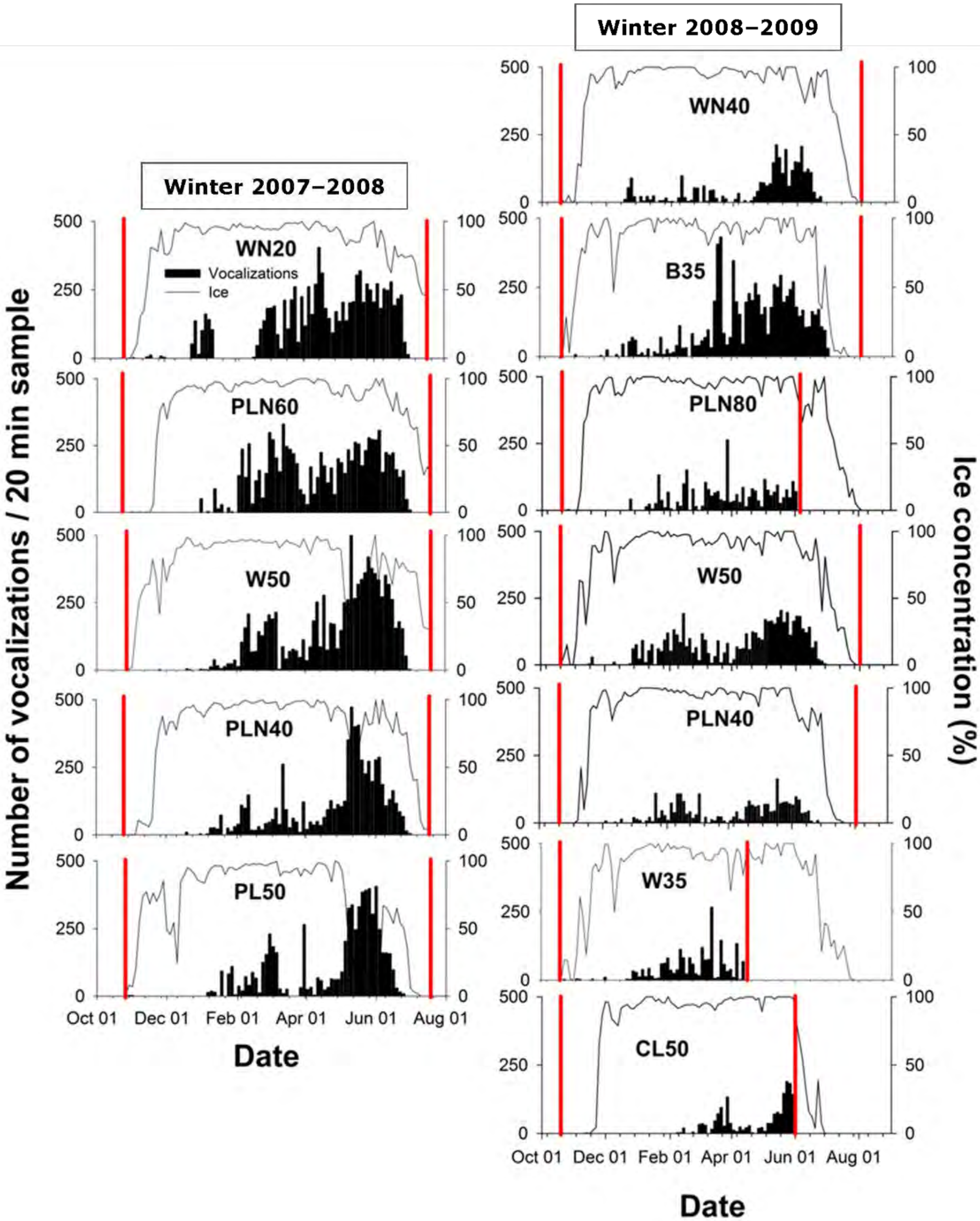

Figure D.4. Seasonal variation in the total number of male bearded seal calls per analysis sample. Samples were 20 min long and recorded every third day between 02:00 and 06:00 AST. Red lines indicate recording start and end.

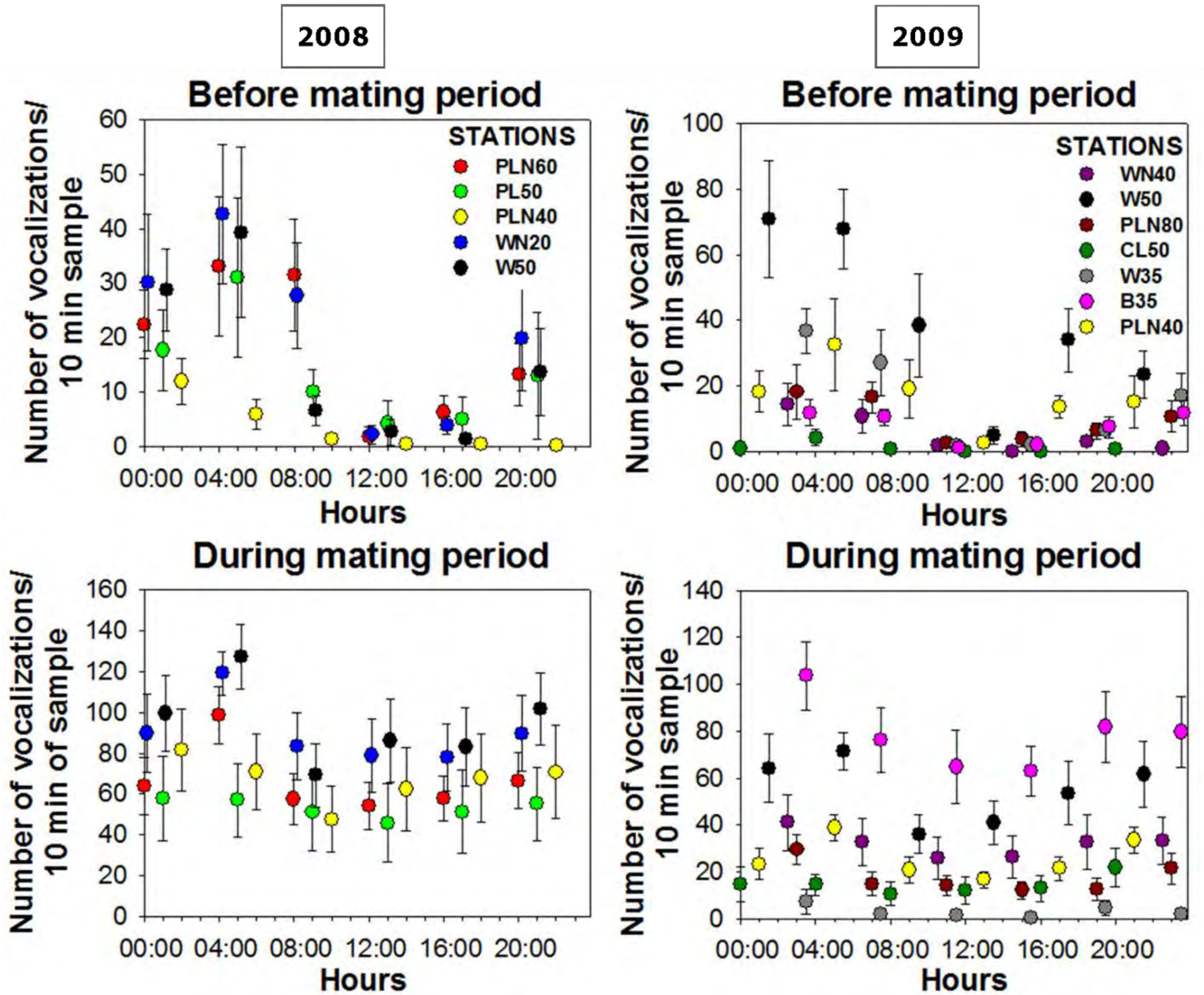

Figure D.5. Diel/daily cycle of the average number of male bearded seal calls per 10-minute recording sample (every ten days) before (early January to mid-March) and during (mid-March to late June) the mating period. Left column is 2008, right column is 2009. Time is in AST. Results are expressed as mean ± standard error.

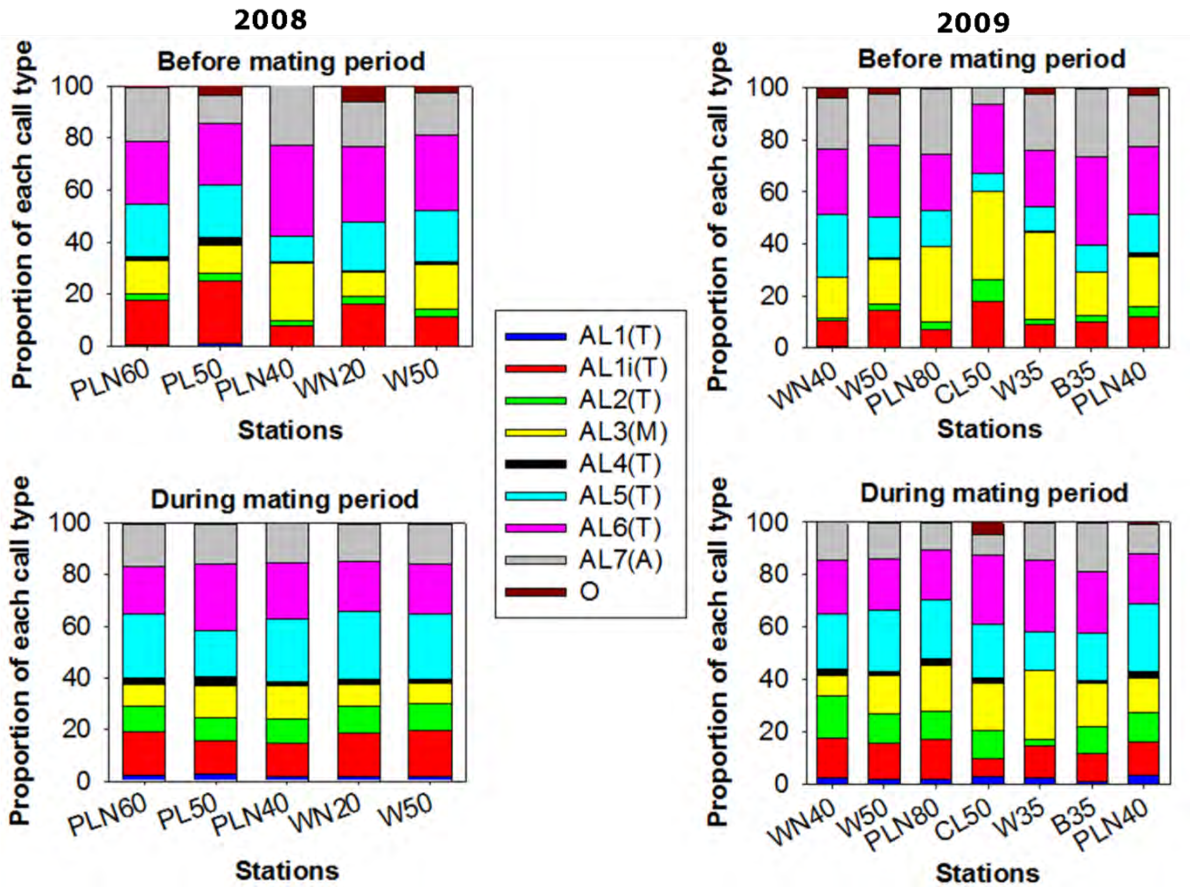

Figure D.6. Proportion of each call type before (January to mid-March) and during (mid-March to late June) the mating period in the 10-minute recording sample (every ten days). Left column is 2008, right column is 2009.

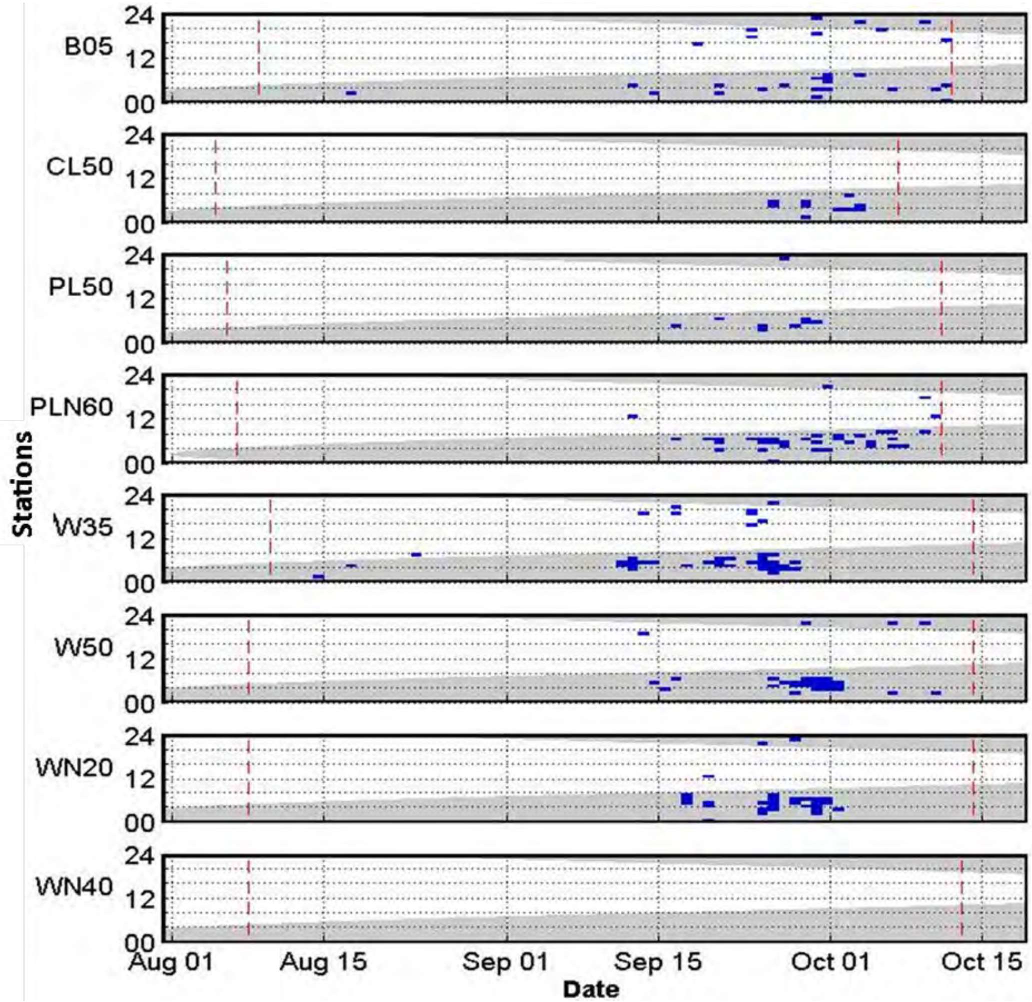

Figure D.7. Diel/daily cycle after the mating period in 2009 summer datasets. Gray areas represent darkness period. Red dashed lines indicate recording start and end.

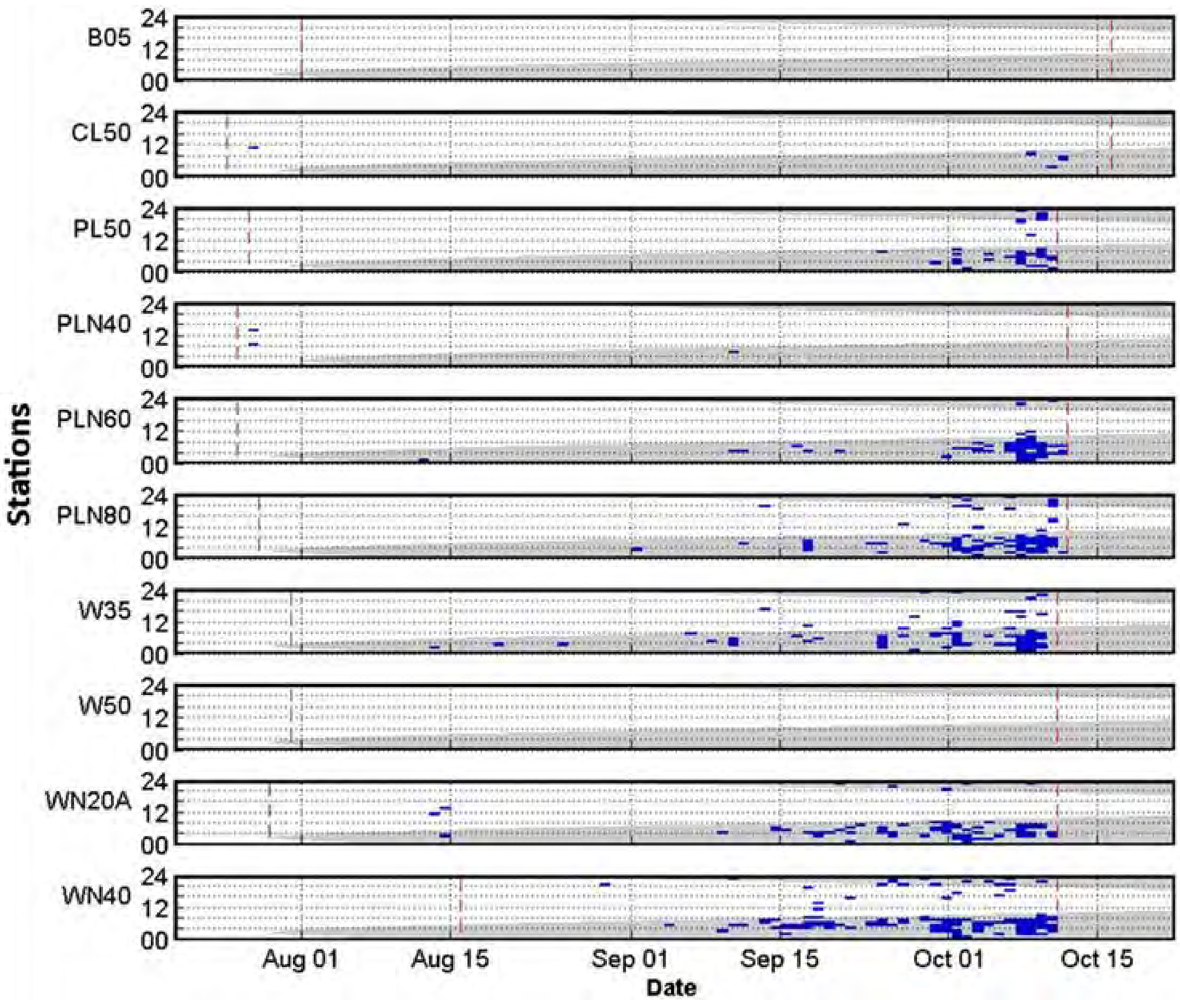

Figure D.8. Diel/daily cycle after the mating period in 2010 summer datasets. Gray areas represent darkness period. Red dashed lines indicate recording start and end.

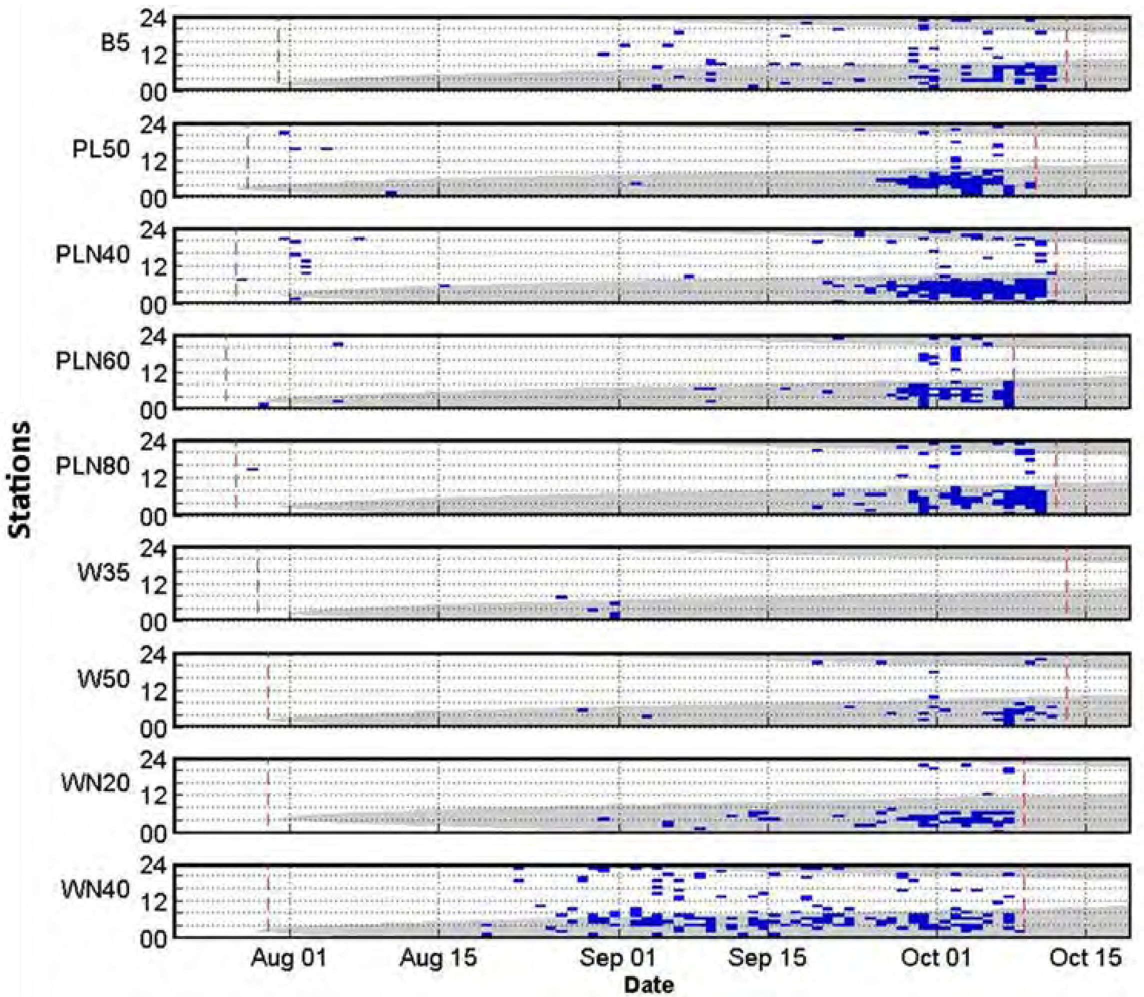

Figure D.9. Diel/daily cycle after the mating period in 2011 summer datasets. Gray areas represent darkness period. Red dashed lines indicate recording start and end.

D.4. Discussion

D.4.1. Bearded seal project

Bearded seals were present at all winter 2007–2008 and 2008–2009 stations. A similar seasonal pattern was observed for both years, but call counts were lower in 2008–2009. A peak in calling occurred in the spring (between May and June), coinciding with the mating period (Van Parijs et al. 2001). In May 2008, a temporary decrease in ice cover at PL50, PLN40, and W50 resulted in more males displaying and/or increased calling rates. The number of calls declined in late June at all stations regardless of ice cover.

Van Parijs et al. (2004) had reported a similar effect of ice cover on the behavioral patterns of male bearded seals. In Svalbard, bearded seal vocalizations occur over a 90-day period starting in early April and continuing until mid-July. No calls were heard at any other time of the year (Van Parijs et al. 2001). However, this observation is partly effort-related due to recordings made only on the 20th of each month between 14:00 h and 18:00 h for 20 minutes.

Our summer results suggest an increase in the number of calls throughout September and October, whereas the winter results show barely any calls before January. This finding, however, is effort-related because we analyzed 5% of summer data and only 2.5% of the winter data, giving us better opportunity to detect calls in the summer dataset. Previous reports where the winter data have been analyzed using 5% approach demonstrated that detected bearded seal calls started in October increasing progressively thereafter (e.g., Delarue et al. 2011*a*; 2012).

In the northeastern Chukchi Sea, few vocalizations were detected in summer (July to August). Counts of vocalizations increased when the ice concentration become established near 100% (December to early March); vocalizing was most intense during a 100-day period between mid-March and late June. A long mating period reflects this species' long pupping period. Bearded seals give birth on the ice between March and May (Burns 1981) and pups are not weaned until they are around 18–24 days old (Kovacs et al. 1996). Mating takes place toward the end of lactation, with males likely in breeding condition from April to July (Burns 1981, Cleator and Stirling, 1990, Cleator 1996) with a peak in male potency occurring before June (McLaren 1958). During the breeding period, Male bearded seals advertise their breeding condition by producing long underwater trills (e.g., Cleator et al. 1989, Van Parijs et al. 2001). Our results suggest that during mating period, Arctic male bearded seals produce long trills (notably AL2(T) and trills with ascent/plume [AL1(T)] to advertise their breeding condition. Those types of vocalizations probably also serve to display fitness (Cleator et al. 1989) and/or to maintain aquatic territories (e.g., Burns 1981, Van Parijs et al. 2001). Van Parijs et al. (2003) suggested that trill duration may serve as a useful indicator of male quality—condition and reproductive success—in bearded seals. Our results from the Chukchi Sea study suggest that male bearded seal vocalizations, notably AL1(T) and AL2(T), may be used as a crude indicator of the length of the mating period.

Analysis of daily cycles before, during, and after the mating period revealed that vocalizations varied in frequency and occurrence. Male vocalizations increase after 20:00 h (AST) and peak around 04:00 h. In Svalbard (Van Parijs et al. 2001) and in Canada (Cleator et al. 1989), male vocalizations also exhibited a 24-hour pattern during the mating period, with a similar increase in male vocalizations in the afternoon and in the late night/early morning hours. Female bearded seals spend little time on the ice with their pups beyond nursing. Most the time they attend to the pups from the water next to the floe on which the pup rests. Krafft et al. (2000) reported that in Svalbard, females spent the greatest proportion of their time in the water during the night from 21:00 h to 09:00 h (Central European Time). Therefore, the increase in male vocalizations during the mating period coincides with the period when most females are in the water (Van Parijs et al. 2001).

Based on our study, it seems unlikely that female activity patterns, before and after the mating period, affects male vocalizing nighttime pattern. Moreover, during the mating period, males vocalized more at night than in the day, a pattern that continued throughout summer (after the mating period) when there were no real periods of darkness at night (midnight sun) and throughout winter (before the mating period) when there were no real periods of daylight (polar night). Those observations suggest that the circadian rhythm of vocalizing activity in male bearded seals is not guided by the darkness period.

Appendix E. Estimating the Detection Range of Bowhead Moans

This appendix describes how the detection range of bowhead moans was calculated for each recorder of the summer 2012 Program.

E.1. Methods

The received sound level (*RL*) of a bowhead moan at a recorder is defined by the following equation (Urick 1983):

$$RL = SL - TL \quad (1)$$

where *SL* is the source level of the bowhead moan, and *TL* is the transmission loss between the whale and the hydrophone. The detection range of a bowhead moan was assumed to be the distance from the recorder for which the received level of the bowhead call equaled or exceeded the noise level at the recorder (*NL*):

$$NL = RL. \quad (2)$$

Cummings and Holliday (1987), and Clark et al. (1986) estimated that source levels of simple moans range from ~128 to 178 dB re 1 µPa at 1 m. In 2011 MacDonnell et al. estimated that bowhead moans recorded near the Burger lease area had source levels of 140.2 ± 4.1 dB re 1 µPa at 1 m (mean ± standard deviation), with minimum and maximum levels of 129.7 and 164.4 dB respectively (Figure E.1). These latter values were used for estimating the bowhead detection range at each recorder Equation 1.

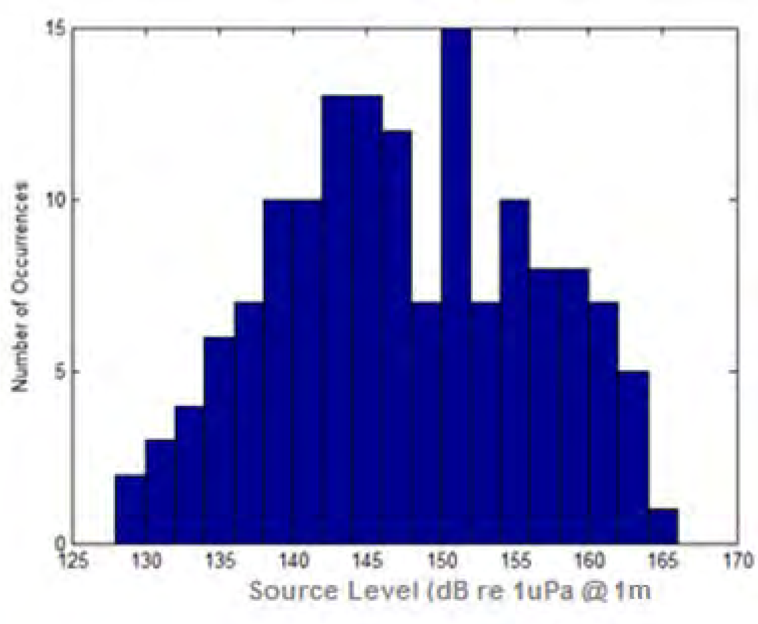

Figure E.1. Distribution of source levels reported by MacDonnell et al. (2011).

Transmission loss values used for estimating the bowhead detection range came from a previous study by MacDonnell et al. (2011) at the Burger lease area. In that study, transmission loss was calculated between 89 and 447 Hz using JASCO's Marine Operations Noise Model (Hannay 2005, Austin 2012). This frequency range comes from using the seven 1/3-octave-bands centered between 100 and 400 Hz. Figure E.2 shows a transmission loss map calculated by MacDonnell et al. (2011) at BG01 (summer 2009).

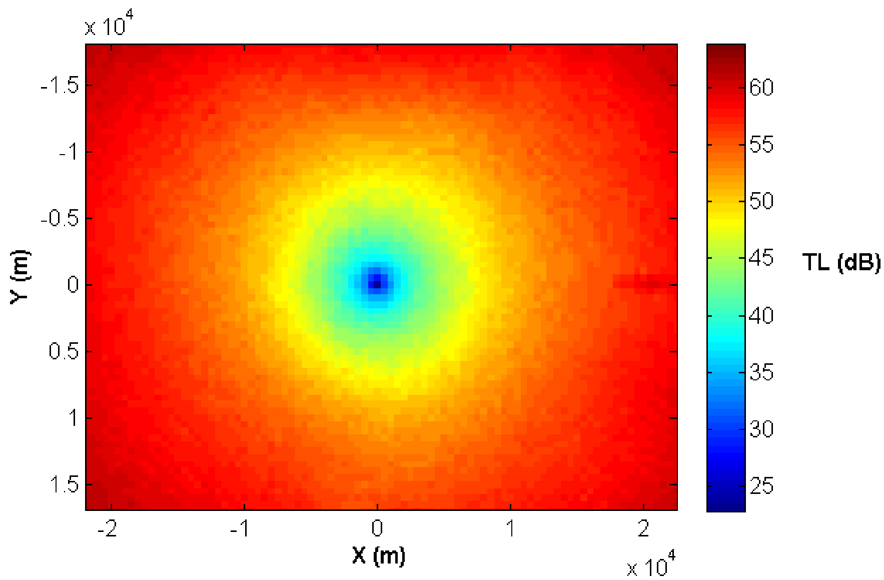

Figure E.2. Map of the transmission loss values calculated by MacDonnell et al. (2011) at station BG01 (summer 2009).

The water depth in the eastern Chukchi Sea is nearly constant. Consequently, the transmission loss is nearly the same for all azimuths (Figure E.2). To simplify the calculation of the detection range, the transmission loss values from MacDonnell et al. (2011) were represented by one equation:

$$TL(R) = A \log_{10}(R) + \alpha R \quad (3)$$

where, R is the distance from hydrophone to whale, A is the spreading coefficient and α is the attenuation coefficient (Urick 1983). The coefficients A and α were defined by fitting (in the least square sense) Equation to the average transmission loss taken in four different azimuths from the recorder (i.e., 0°, 90°, 180°, and 270°). Figure E.3 (left) shows the transmission loss curve from MacDonnell et al. 2011 at the location BG01 in four different azimuths.
Figure E.3 (right) shows the average transmission loss curve with its simplified transmission loss function.

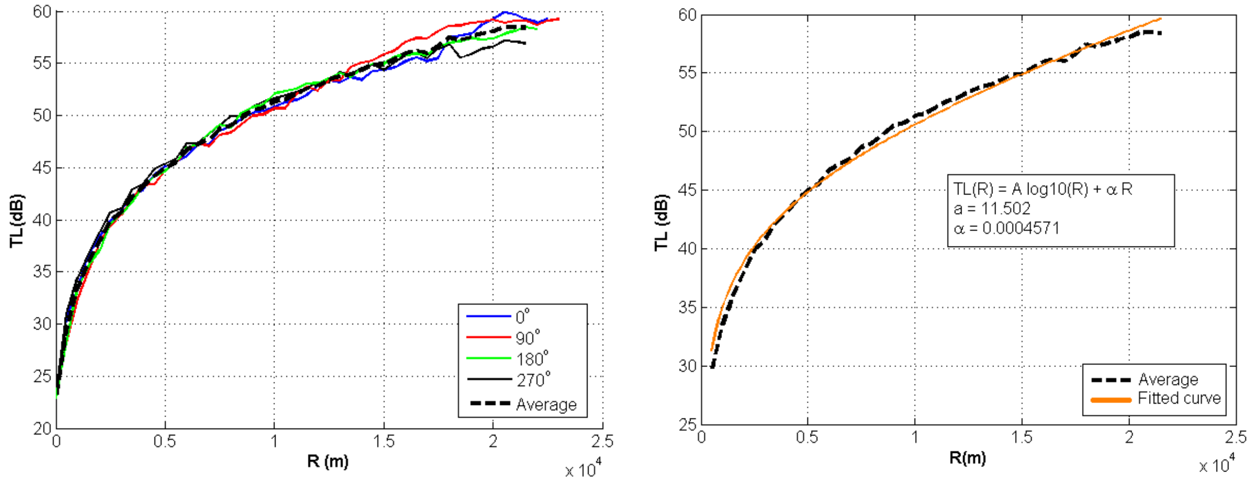

Figure E.3. Transmission loss modeled by MacDonnell et al. 2011 at location BG01. (Left) Transmission loss curves in four different azimuths. (Right) Average transmission loss and its simplified transmission loss function.

Coefficients A and α were calculated for each location modeled by MacDonnell et al. (2011) and then averaged to obtain a single set of coefficients for the whole area. Final coefficients used for the detection range analysis were $A = 11.29$ and $\alpha = 0.00057$.

Noise levels used for estimating the bowhead detection range were calculated for every minute of recording by summing the 1/3-octave-band levels between 89 and 447 Hz.

The detection range was calculated at each recorder and for each minute of recording. The probability of detecting a bowhead moan at a given range was the number of 1-minute recordings with a detection range equal to or greater than the given range divided by the number of 1-minute recordings. Detection ranges were calculated independently for each recorder.

A Monte Carlo method accounted for the measured variability in source levels. Detection ranges were re-calculated 50 times by randomly choosing 50 normally distributed source level values, with the means and standard deviations defined by MacDonnell et al. (2011; Figure E.1), Consequently, a distribution of probability is associated with each range.

E.2. Results

Figure E.4 shows the extent of the median probability of detection at each monitoring location. Figure E.5 through Figure E.34 show the detection probability of bowhead moans at each monitoring location.

Recorders off Barrow had the largest detection ranges. Locations B15, B30, and B50 had a detection range of 8.6 km, 7.5 km, and 7.7 km for 80% of the monitoring period, respectively. Locations W35, W50, and BG03 had the smallest detection ranges, measuring 580 m, 1800 m and 500 m, reached 80 % of the time, respectively.

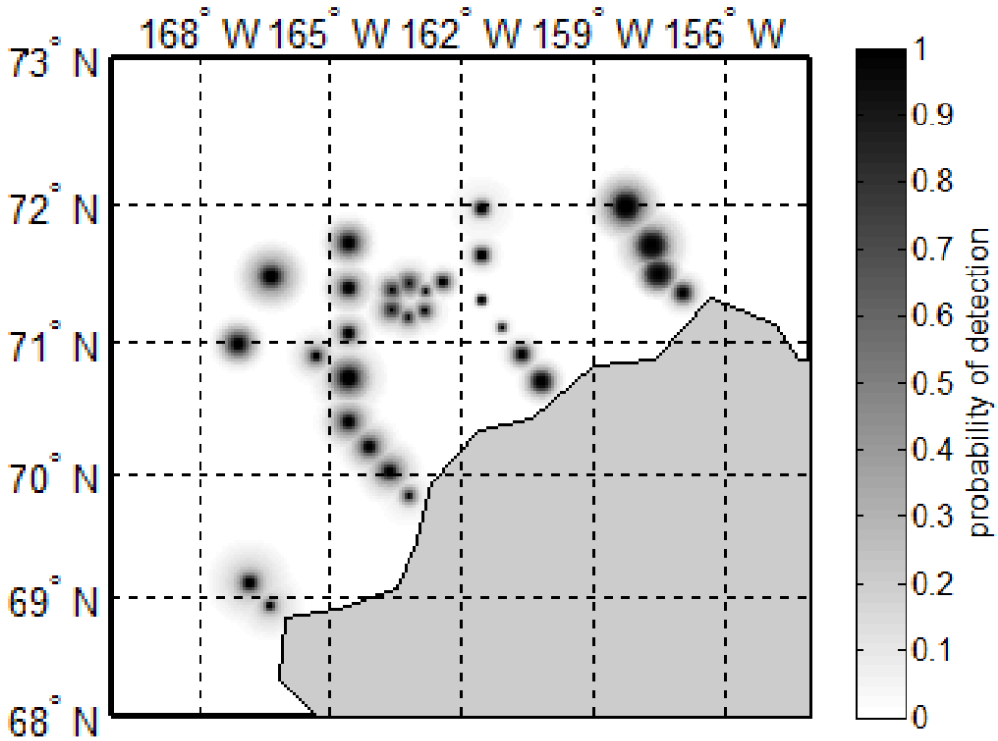

Figure E.4. Extent of the median detection probability ranges at each monitoring location.

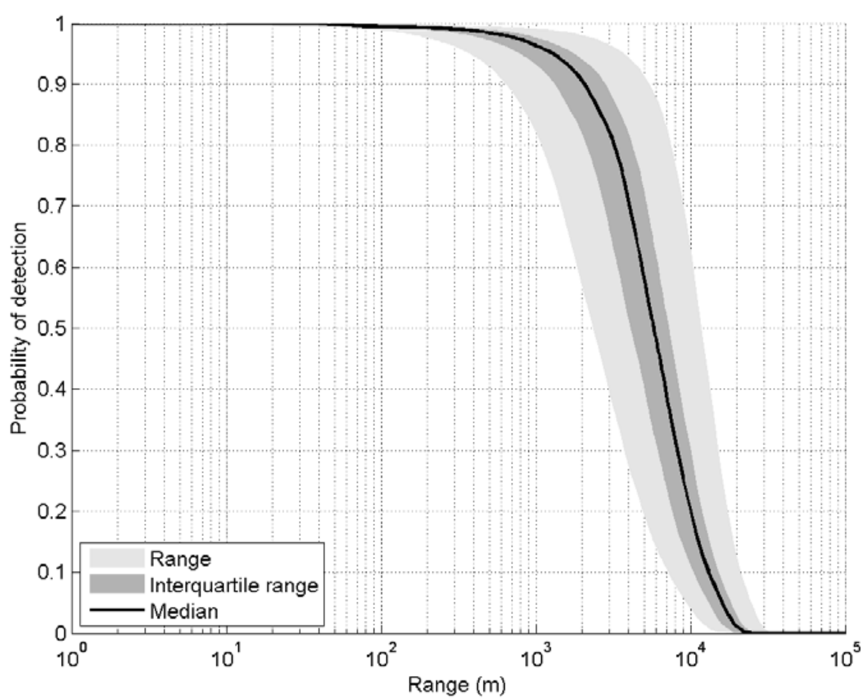

Figure E.5. Detection probability of bowhead moans at monitoring Station B05. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

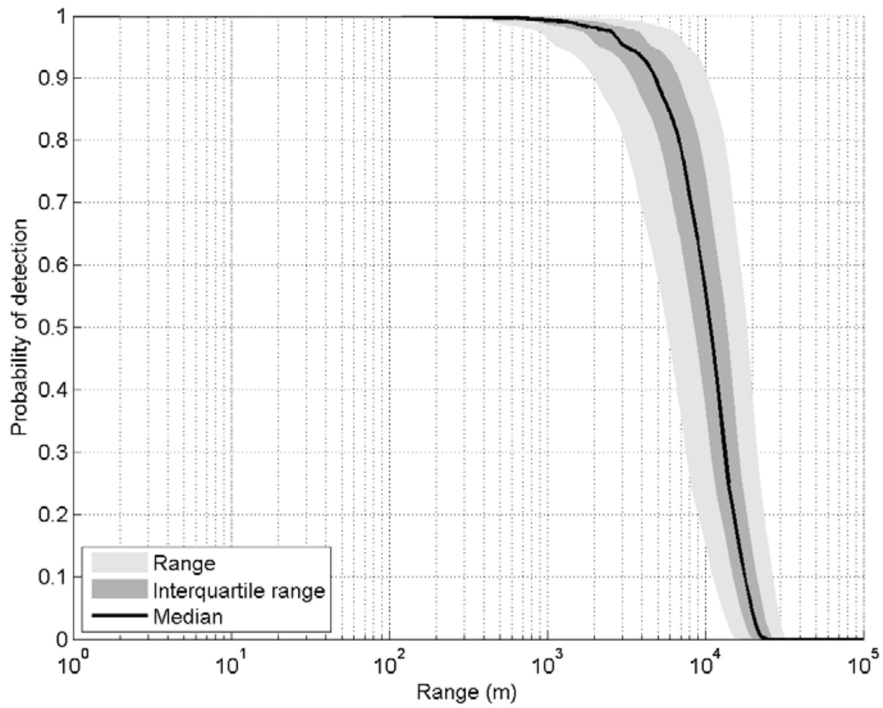

Figure E.6. Detection probability of bowhead moans at monitoring Station B15. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

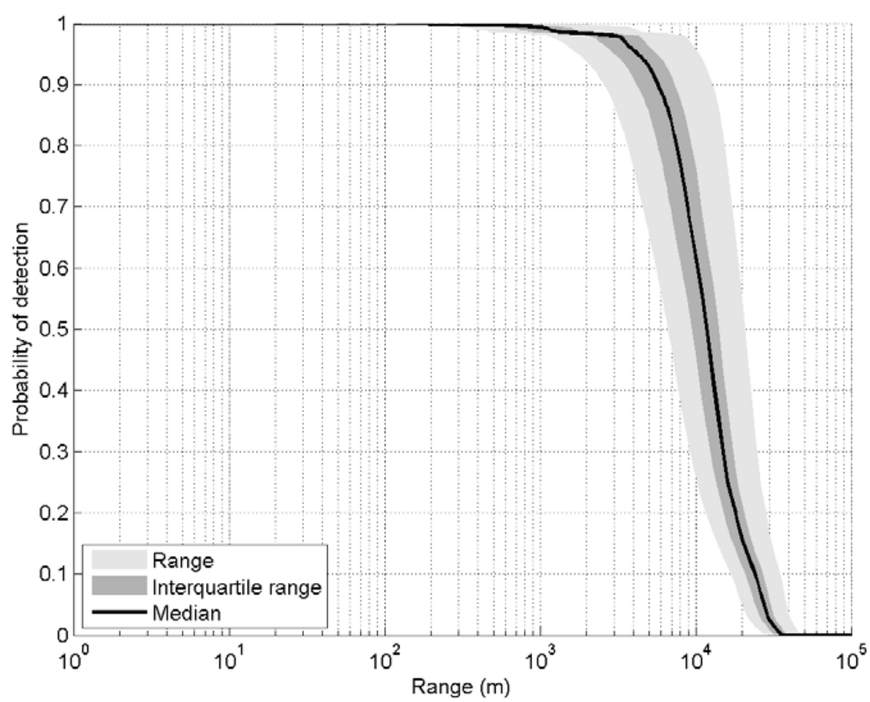

Figure E.7.Detection probability of bowhead moans at monitoring Station B30. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

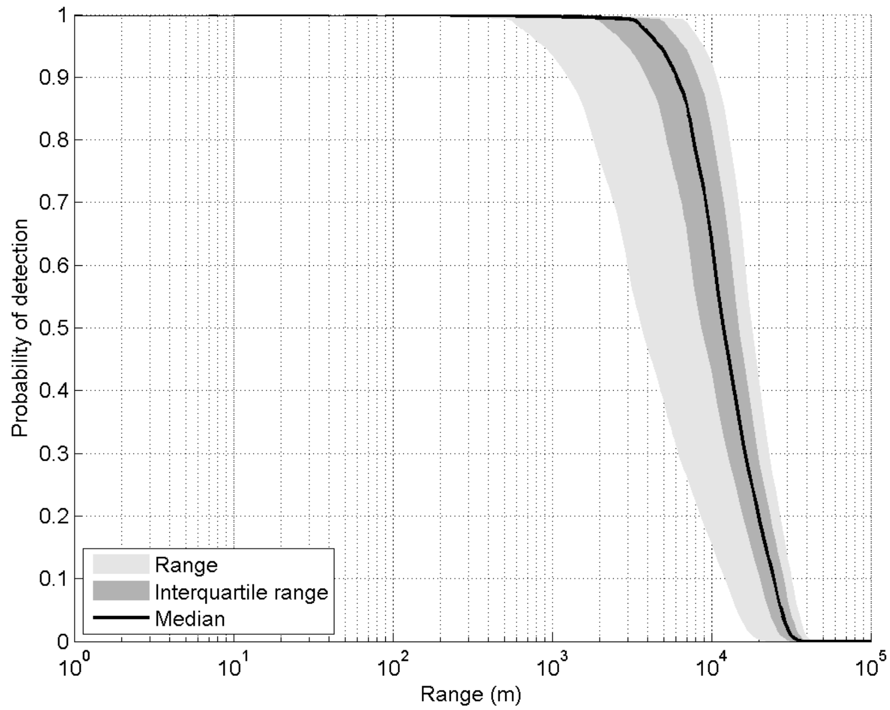

Figure E.8. Detection probability of bowhead moans at monitoring Station B50. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

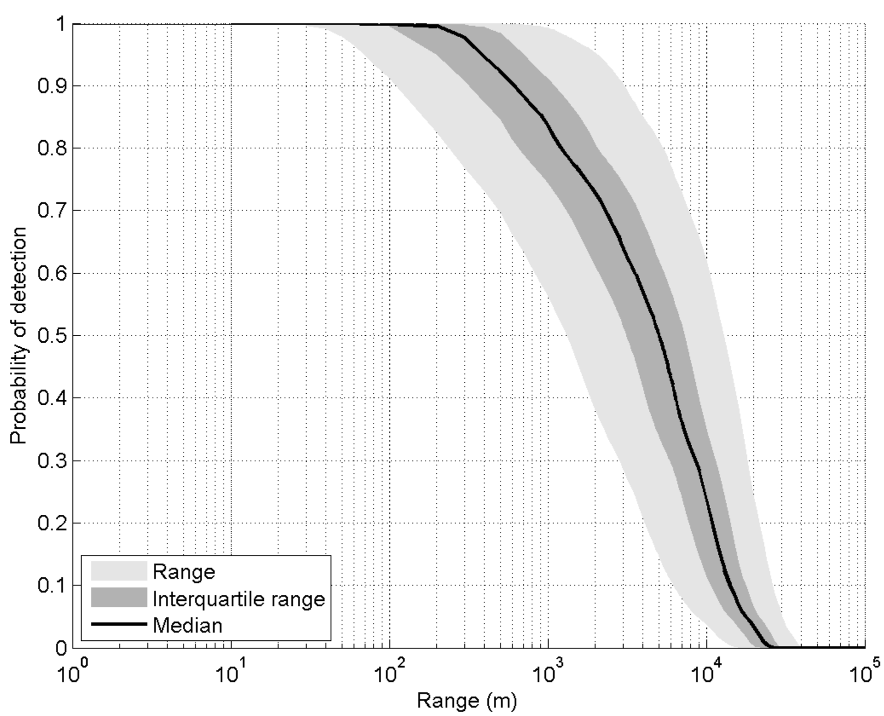

Figure E.9. Detection probability of bowhead moans at monitoring Station BG02. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

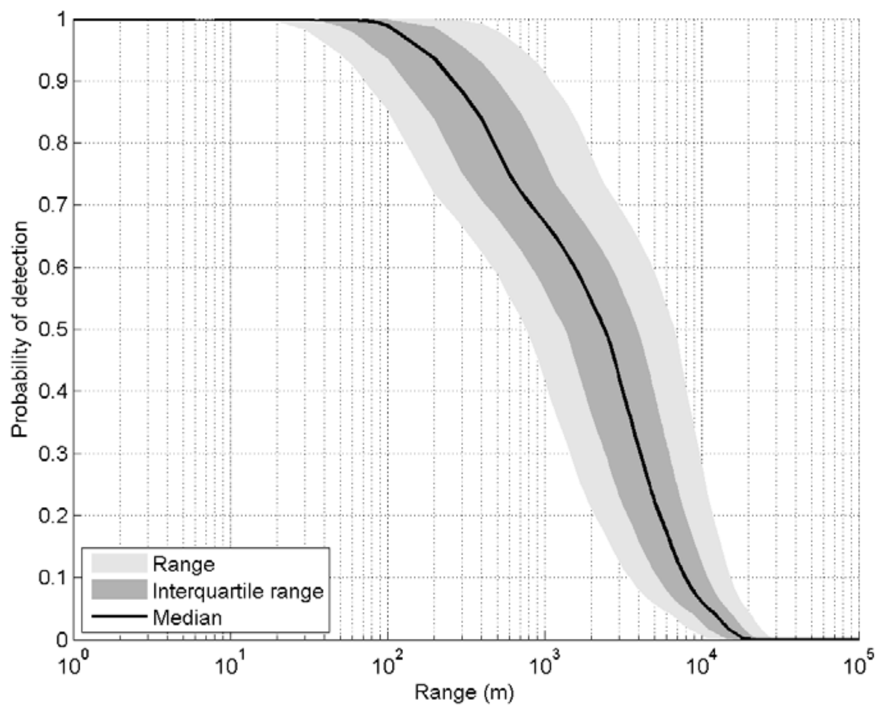

Figure E.10. Detection probability of bowhead moans at monitoring Station BG03. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

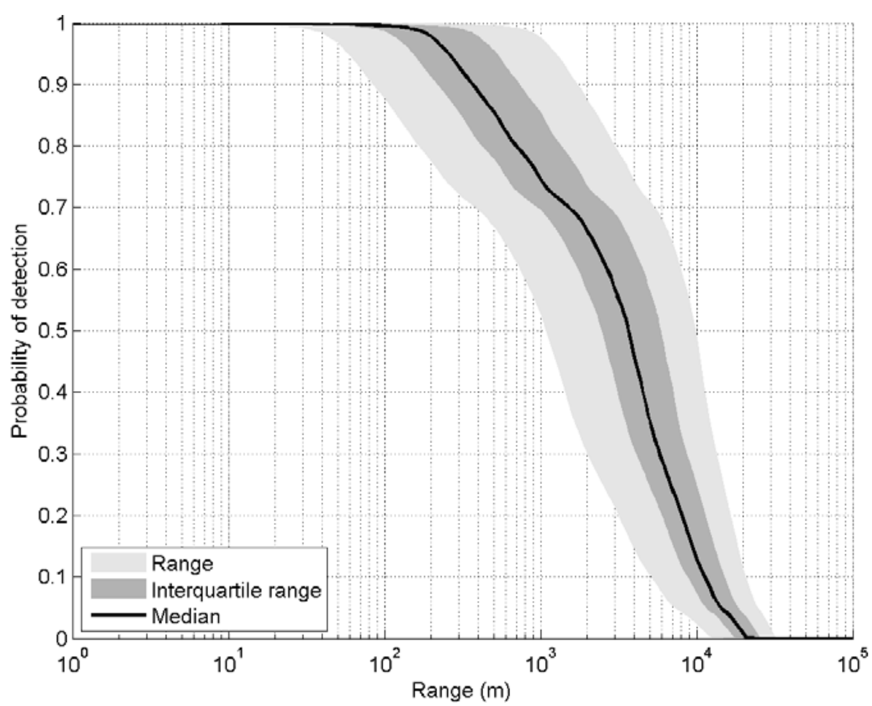

Figure E.11. Detection probability of bowhead moans at monitoring Station BG04. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

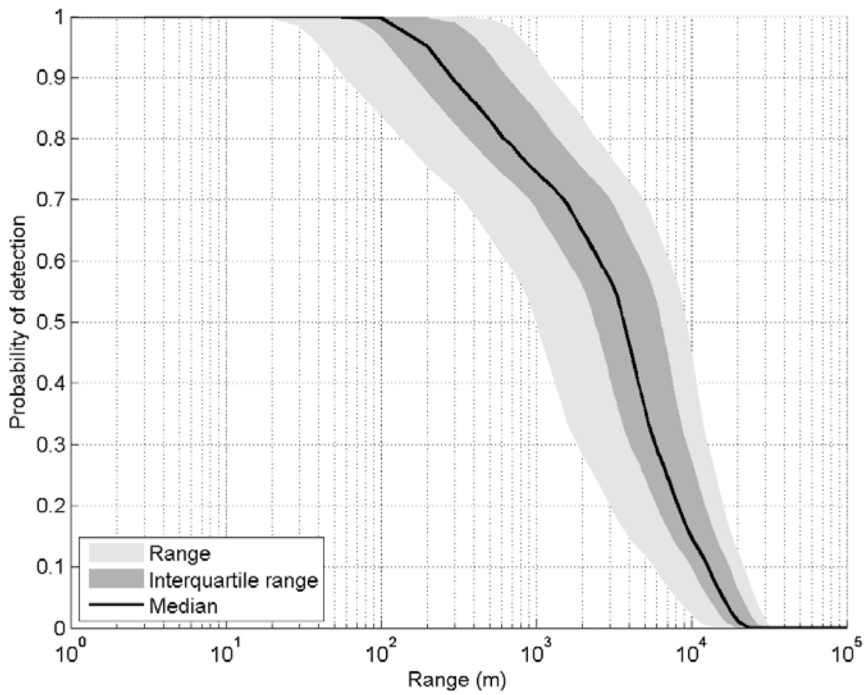

Figure E.12. Detection probability of bowhead moans at monitoring Station BG05. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

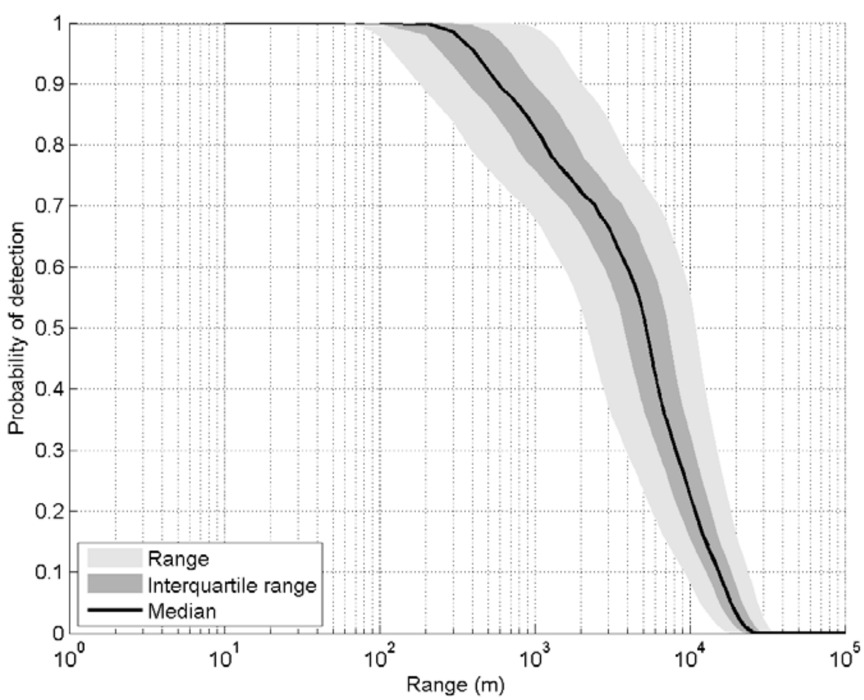

Figure E.13. Detection probability of bowhead moans at monitoring Station BG06. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

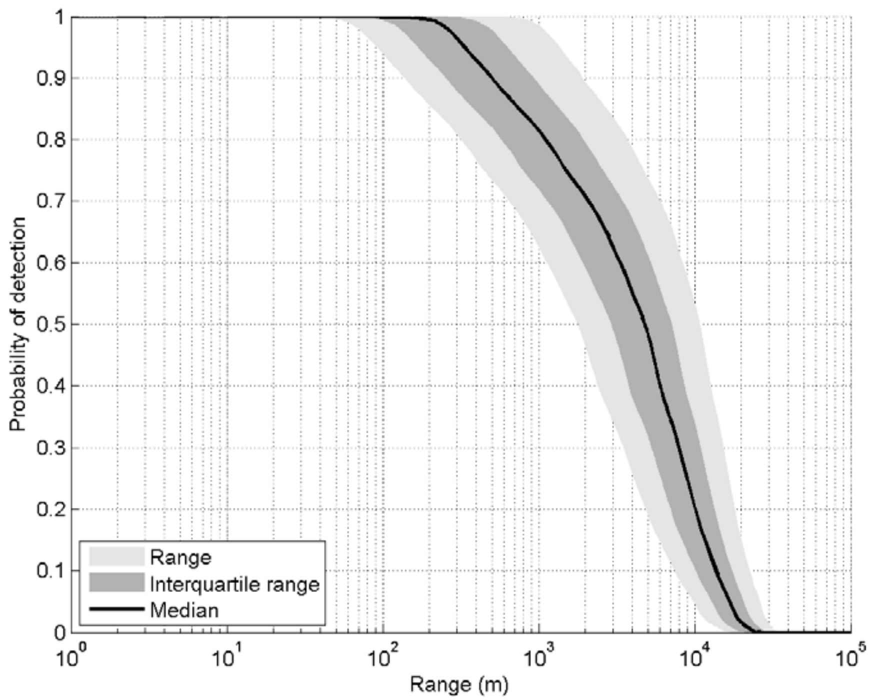

Figure E.14. Detection probability of bowhead moans at monitoring Station BG07. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

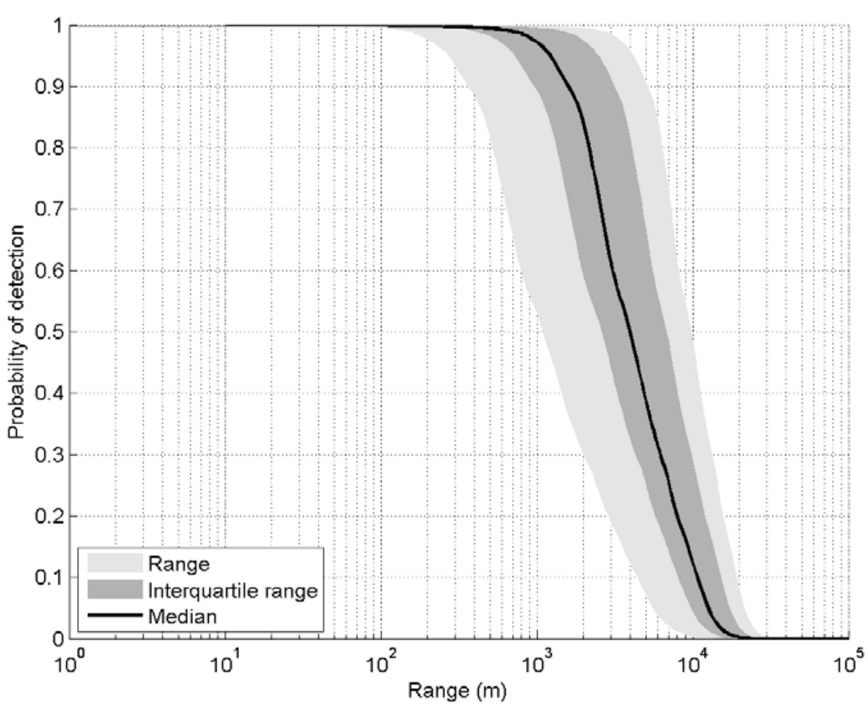

Figure E.15. Detection probability of bowhead moans at monitoring Station BG08. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

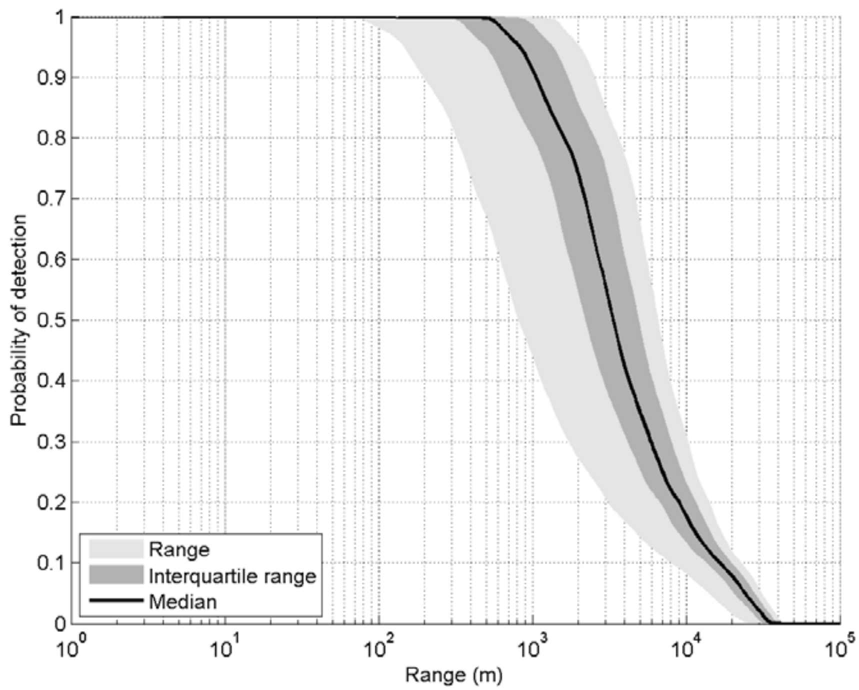

Figure E.16. Detection probability of bowhead moans at monitoring Station CL05. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

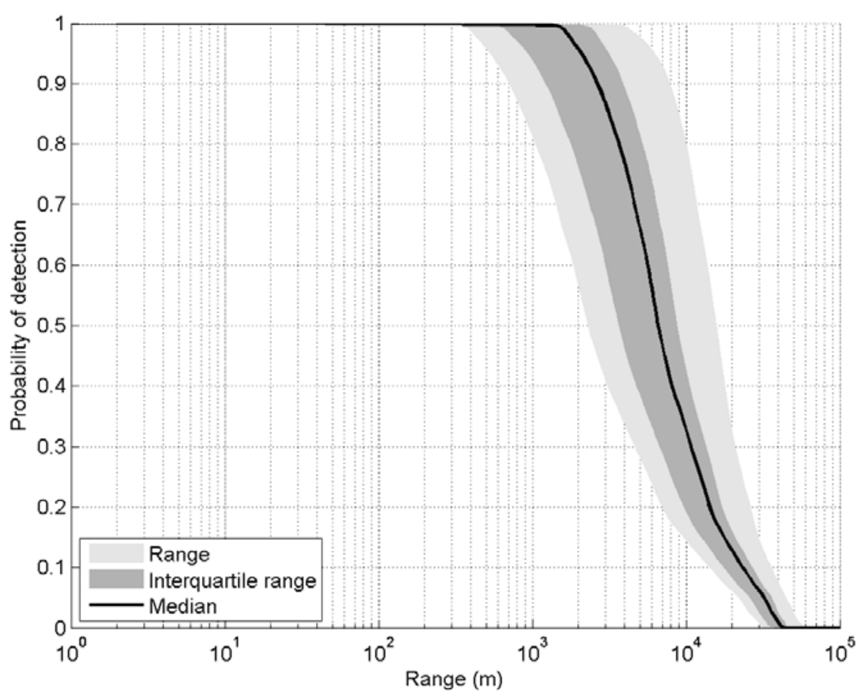

Figure E.17. Detection probability of bowhead moans at monitoring Station CL20. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

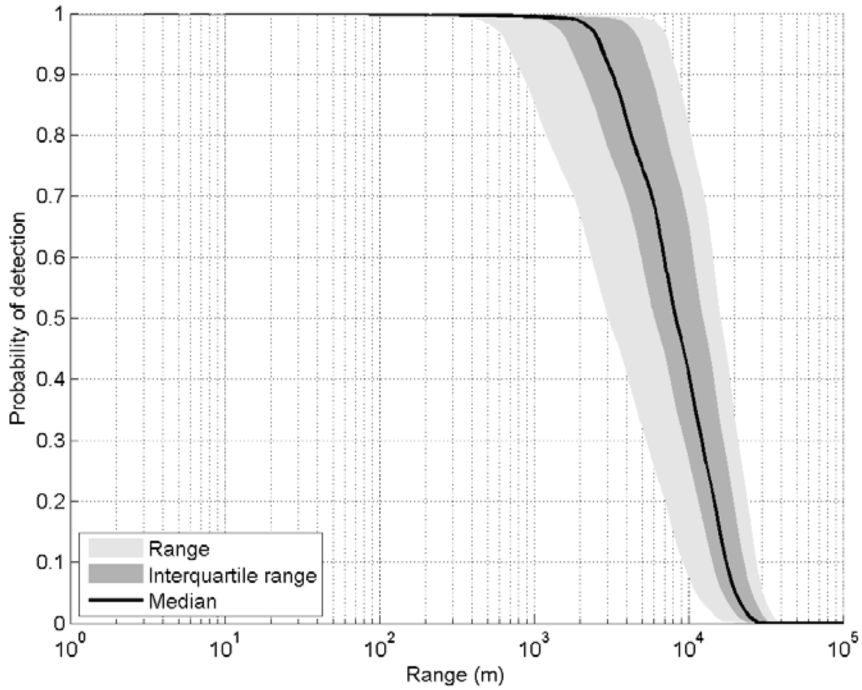

Figure E.18. Detection probability of bowhead moans at monitoring Station CLN120B. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

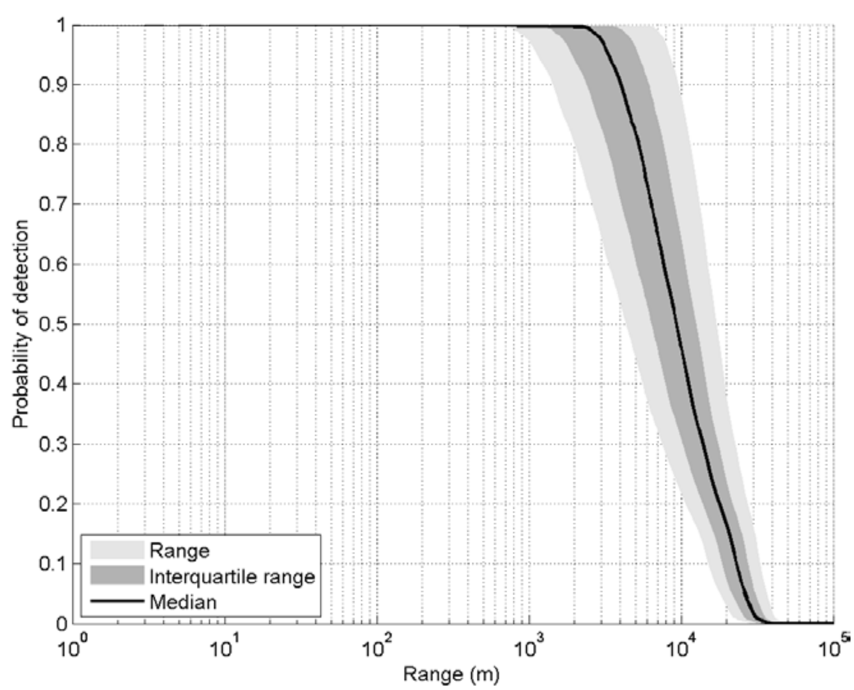

Figure E.19. Detection probability of bowhead moans at monitoring Station CLN90B. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

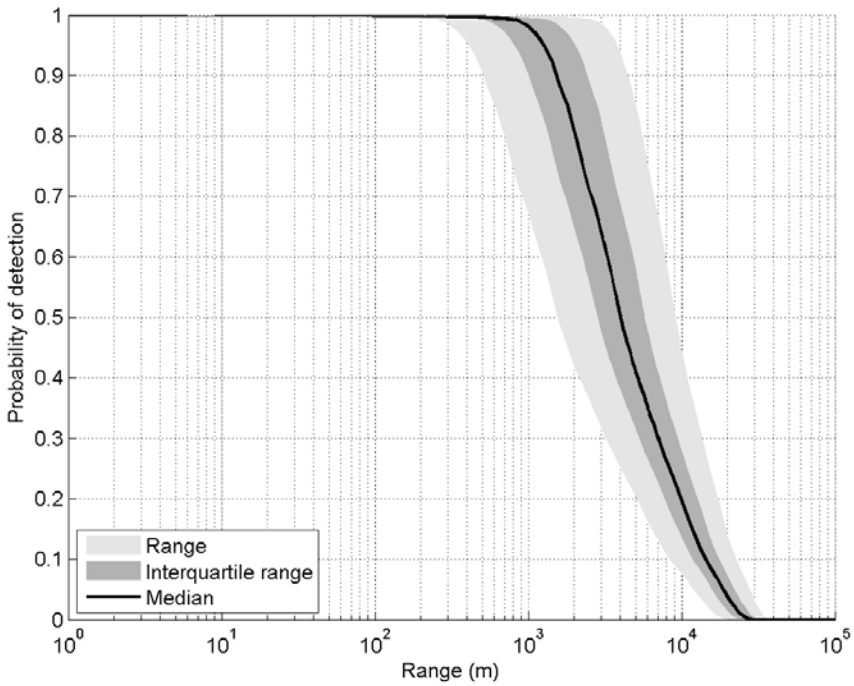

Figure E.20. Detection probability of bowhead moans at monitoring Station KL01. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

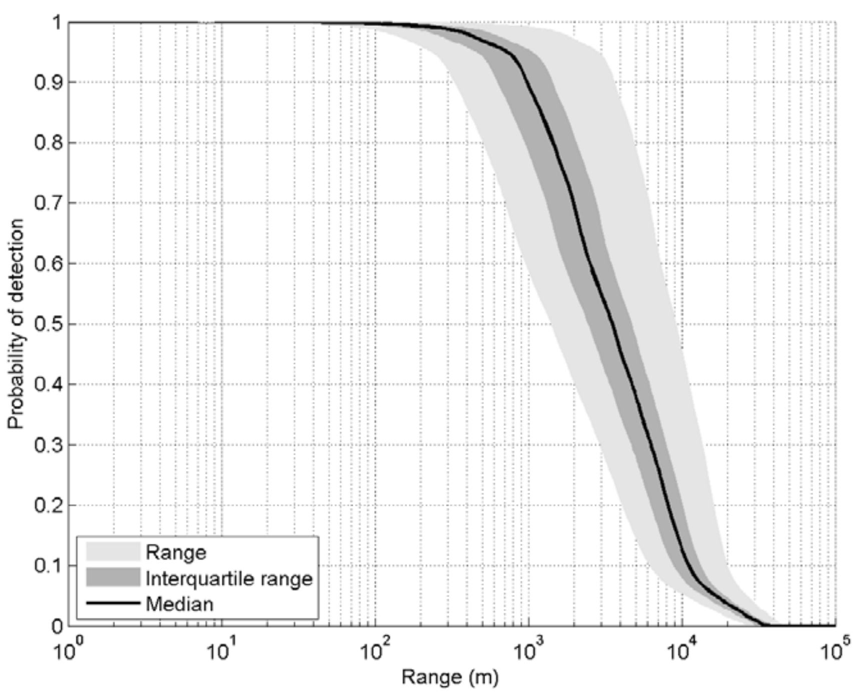

Figure E.21. Detection probability of bowhead moans at monitoring Station PL05. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

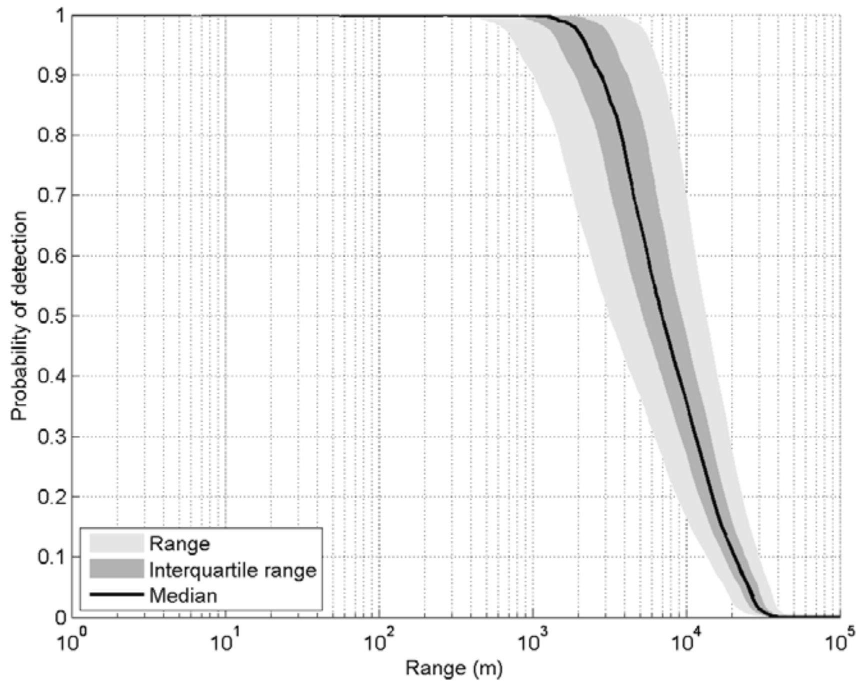

Figure E.22. Detection probability of bowhead moans at monitoring Station PL20. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

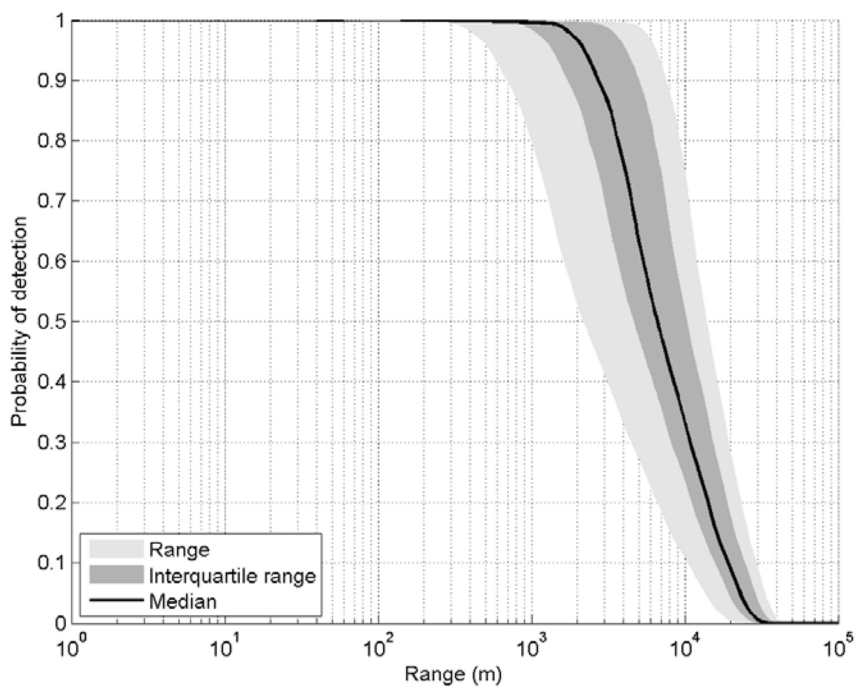

Figure E.23. Detection probability of bowhead moans at monitoring Station PL35. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

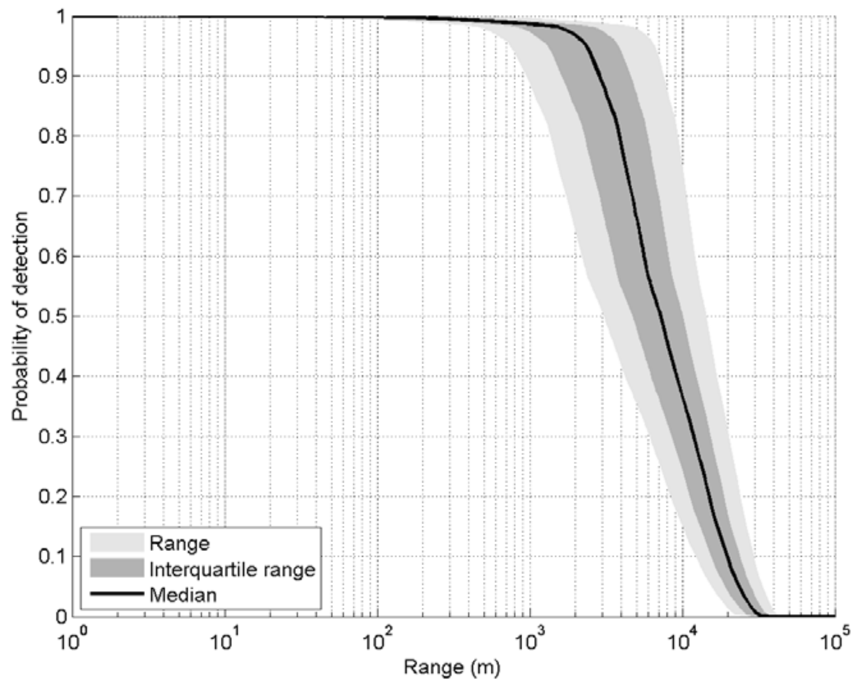

Figure E.24. Detection probability of bowhead moans at monitoring Station PL50. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

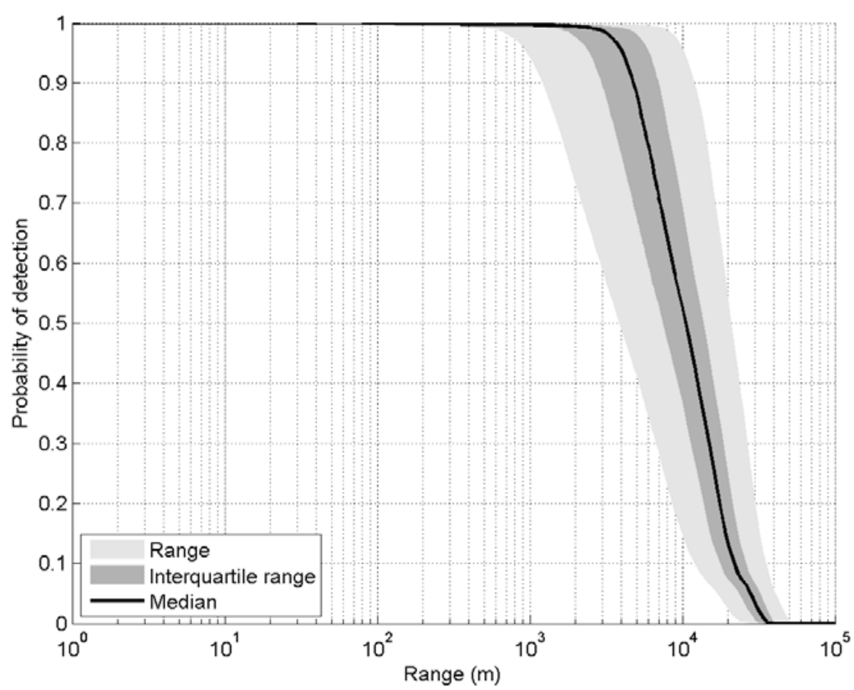

Figure E.25. Detection probability of bowhead moans at monitoring Station PLN20. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

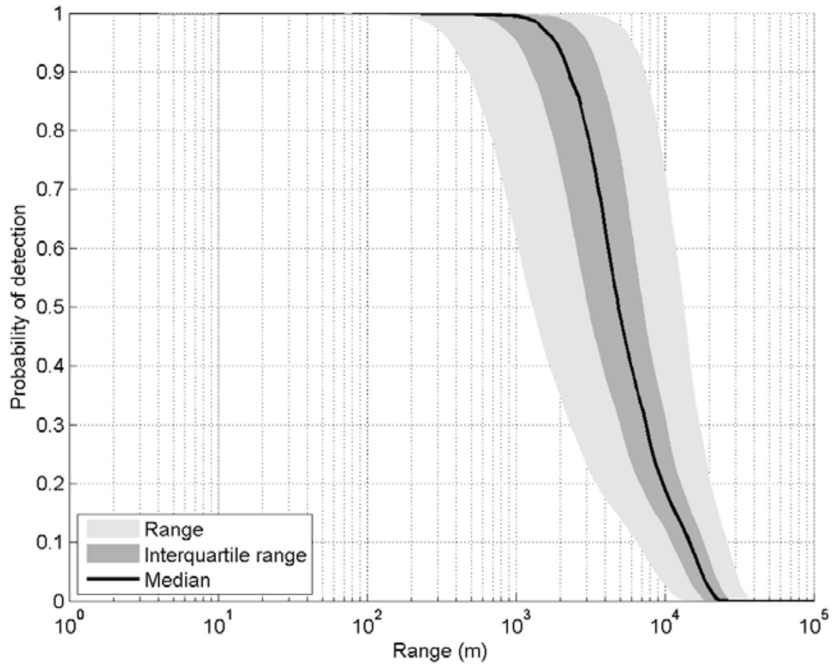

Figure E.26. Detection probability of bowhead moans at monitoring Station PLN40. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

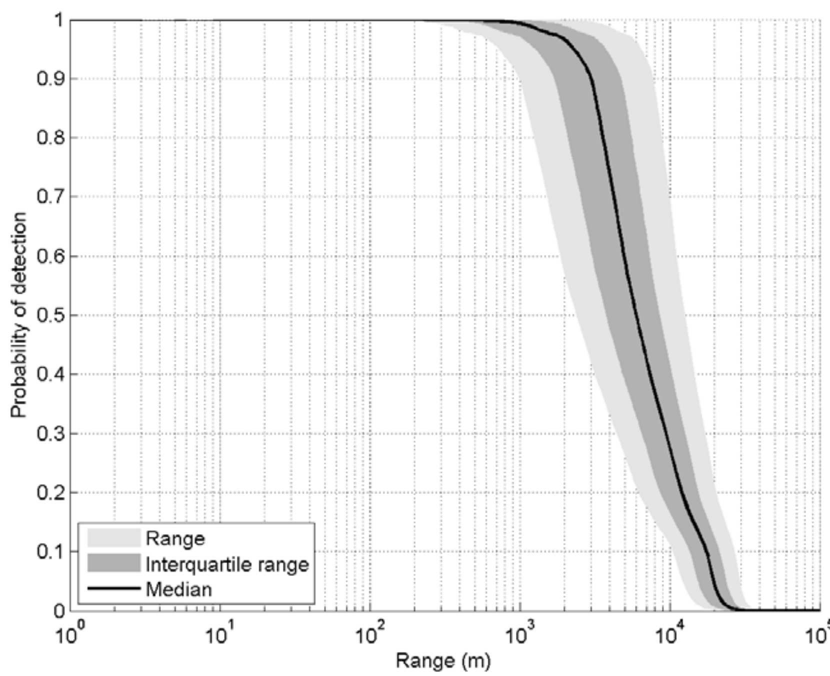

Figure E.27. Detection probability of bowhead moans at monitoring Station PLN60. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

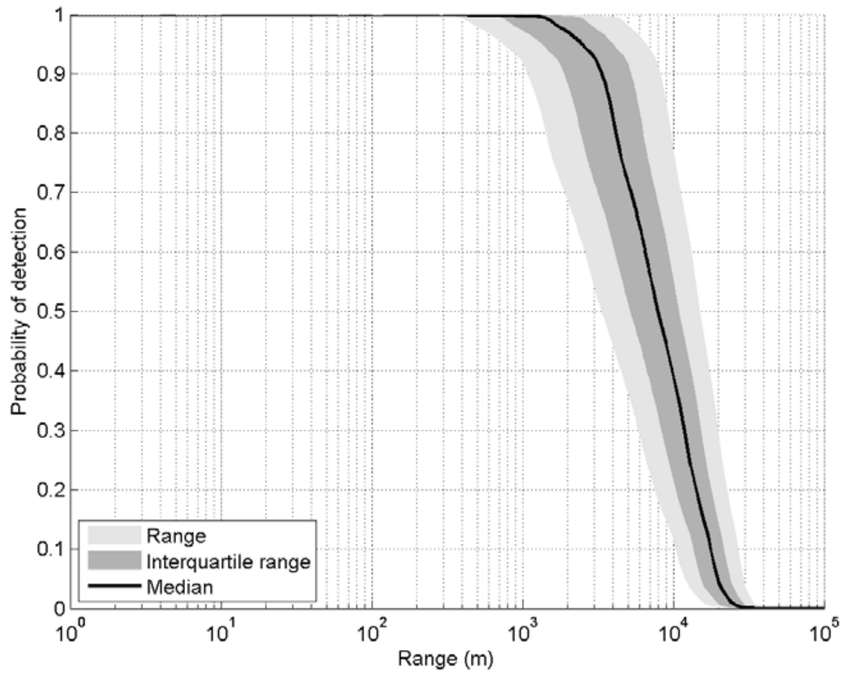

Figure E.28. Detection probability of bowhead moans at monitoring Station PLN80. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

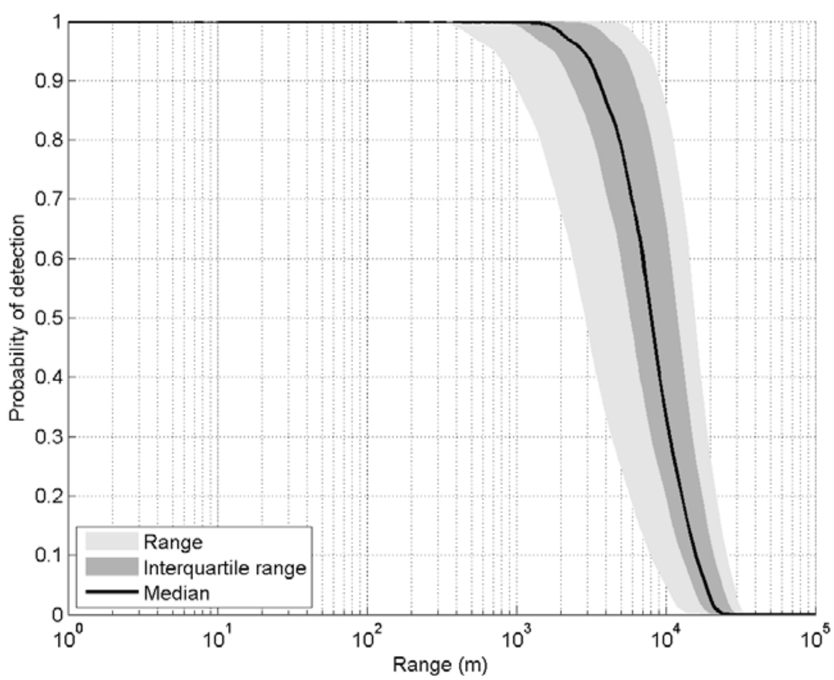

Figure E.29.Detection probability of bowhead moans at monitoring Station W05. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

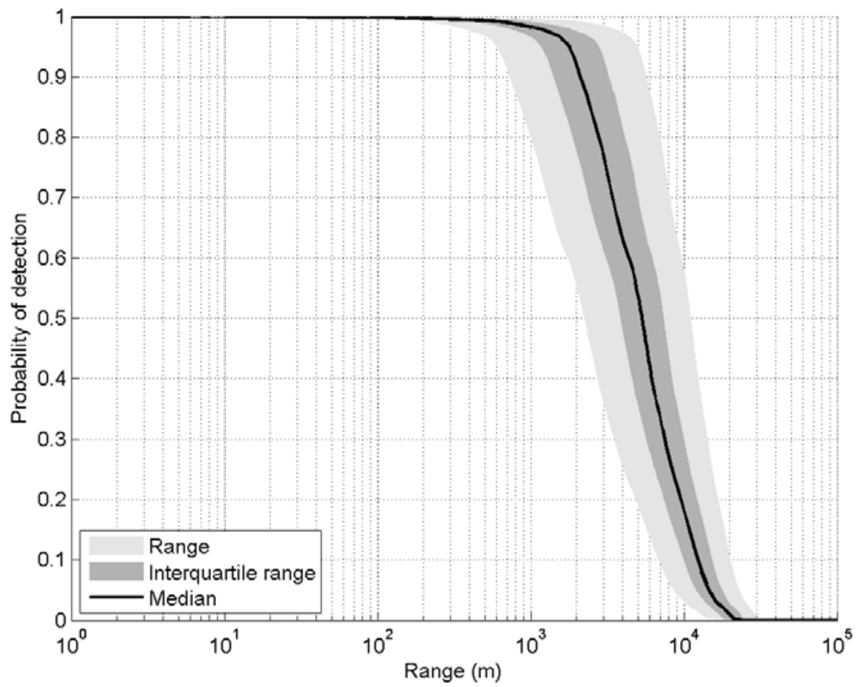

Figure E.30. Detection probability of bowhead moans at monitoring Station W20. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

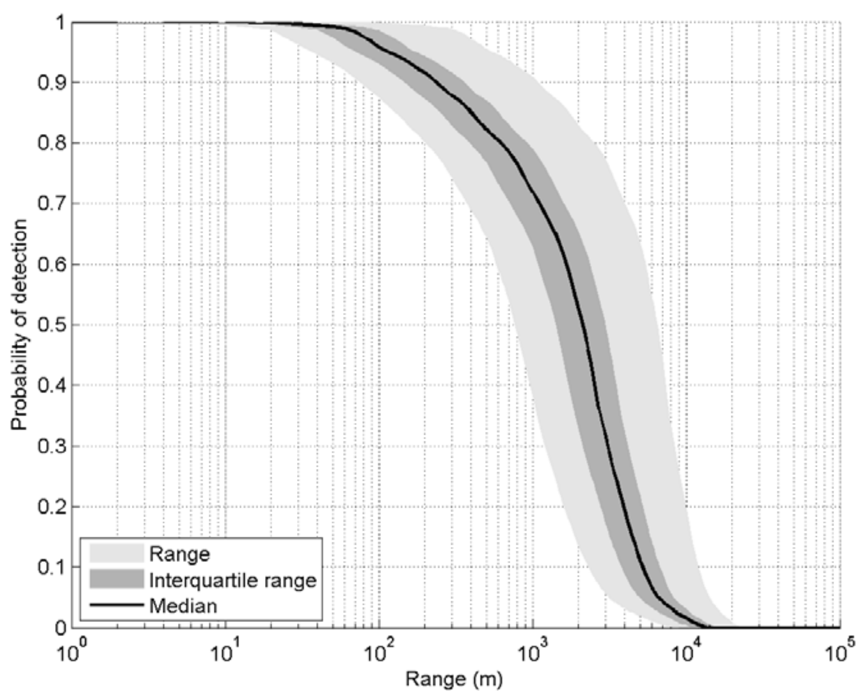

Figure E.31. Detection probability of bowhead moans at monitoring Station W35. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

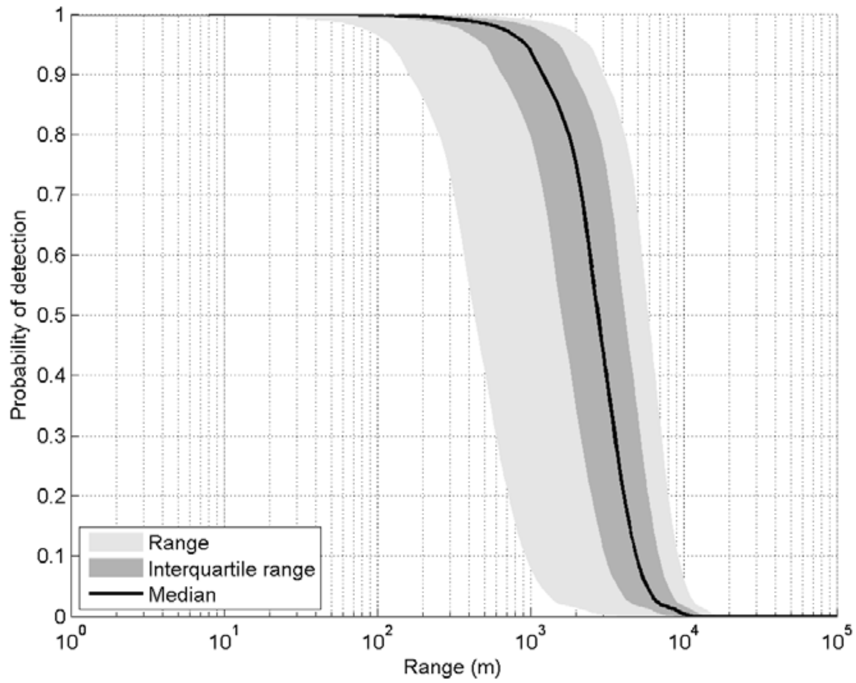

Figure E.32. Detection probability of bowhead moans at monitoring Station W50. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

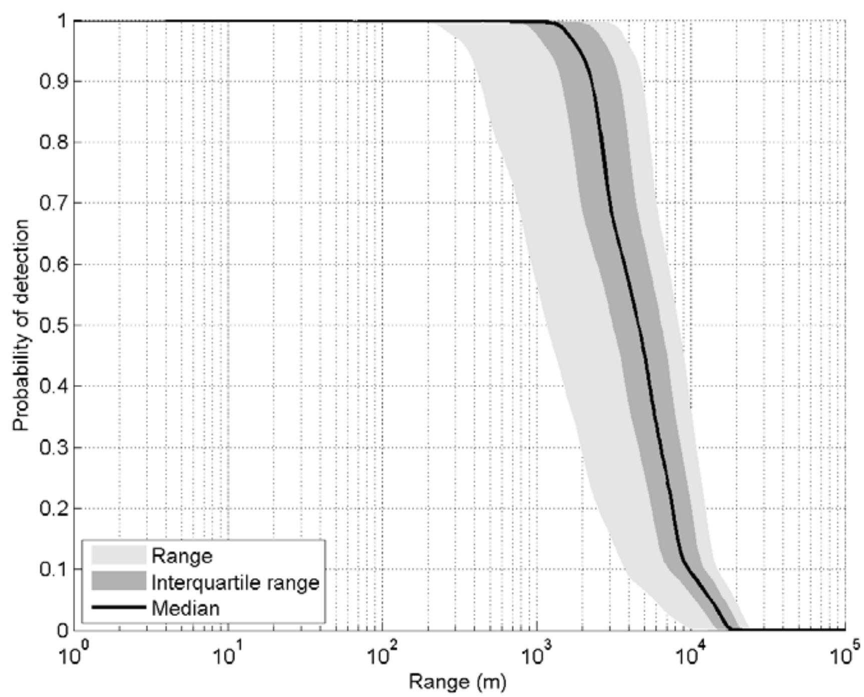

Figure E.33. Detection probability of bowhead moans at monitoring Station WN20. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

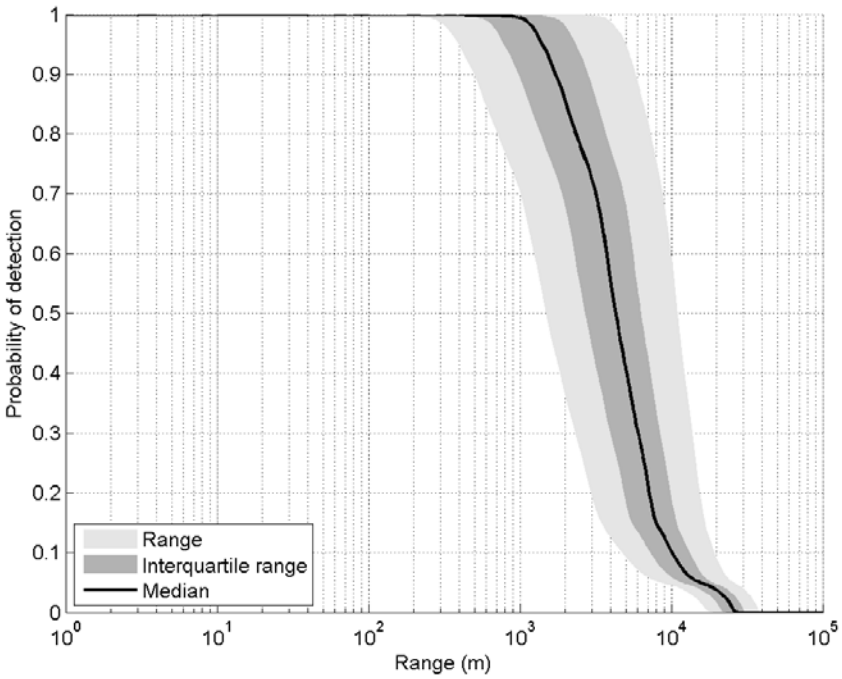

Figure E.34.Detection probability of bowhead moans at monitoring Station WN40. The solid black line represents the median probability of detection. The light gray areas represent the probability range (from percentile 5 to 95), and the dark gray areas the probability interquartile range (from percentile 25 to 75).

E.3. Discussion

The maximum detection ranges calculated in this study are consistent with maximum detection ranges reported in the literature. Cummings and Holliday (1985) and Clark et al. (1986) detected bowhead moans off Barrow up to 20 km from a hydrophone although most of the bowhead moans they localized were less than 10 km away. Figure E.5 and Figure E.6 show similar results with a maximum detection range near Barrow close to 20 km.

Smallest detection ranges were obtained at locations W35, W50, and BG03, which corresponded to the area where most of the Shell drilling support vessels were standing by. Consequently, bowhead moans at these locations were more likely to be masked by the more intense vessel traffic noise.

Blackwell et al. (2012) reported that bowhead moans are directional with sounds being stronger in front of the animal than behind. Equation 1 did not explicitly consider this; however, the distribution of source levels used (Figure E.1) were obtained from bowheads at different angles, which accounts for the directivity of the bowhead moans.

The transmission loss used in this study was calculated in the middle of the water column. This was not optimal since bowheads vocalize at different depths through the water column and that transmission loss also varies with depth. Although because the eastern Chukchi Sea is very shallow (~50 m), the variation of received levels due to the variations of source depth is not likely to greatly affect the detection range results.