NORTHEASTERN CHUKCHI SEA
JOINT ACOUSTIC MONITORING PROGRAM 2010–2011

Prepared for

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Anchorage, Alaska

Shell Exploration & Production Company
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Cover photos: JASCO Autonomous Multichannel Acoustic Recorder (Julien Delarue); bearded seal (U.S. Fish and Wildlife Service); bowhead whale (Department of Fisheries and Oceans Canada); Pacific walrus (Eric Lumsden).

Contents

1. Introduction

The Chukchi Sea 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 by documenting baseline ambient noise conditions, characterizing sounds produced by oil and gas exploration activities, and examining the distribution of marine mammals based on acoustic detections of their vocalizations[1].

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. Acoustic monitoring programs were run by the Bioacoustics Research Program in the Cornell Lab of Ornithology (BRP 2010) in the summers of 2006 and 2008. Since summer 2007, JASCO has conducted consecutive summer and winter programs.

The bowhead whale (*Balaena mysticetus*) migration patterns near the Alaskan coast are known well by local bowhead whalers, but migration patterns in offshore areas—the focus of oil and gas exploration—are poorly understood. One goal of the acoustic monitoring programs is to provide information about the locations of vocalizing bowheads further offshore.

Knowledge of walrus (*Odobenus rosmarus*) habitat use in the northeastern Chukchi Sea is sparse, but the 2007 (Martin et al. 2009), 2008 (Hannay et al. 2009), 2009 (Delarue et al. 2010b), and 2010 (Delarue et al. 2011) programs provided new information. The 2007 program addressed walrus presence and timing, while the 2010 program highlighted possible calling behavior modifications in the presence of seismic survey sounds.

The acoustic monitoring programs use recording systems deployed on the seabed for extended periods over large areas of the northeastern Chukchi Sea. 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*)
- walrus (*Odobenus rosmarus*)
- bearded seal (*Erignathus barbatus*)
- ribbon seal (*Histriophoca fasciata*)

The winter 2009–2010 and summer 2010 programs detected the following species for the first time:

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

- ringed seal (*Pusa hispida*)
- minke whale (*Balaenoptera acutorostrata*)
- humpback whale (*Megaptera novaeangliae*)

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:
  - Bowheads are present later into the winter than previously thought.
  - 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.
  - Provided information about bearded seal presence and vocalizations in winter and spring.
- Summer programs:
  - Focus on marine mammals present during the ice-free season, a time of increased human activity.
  - Established this area is important to walrus in summer.
  - Have consistently demonstrated the relatively limited acoustic occurrence of bowheads and belugas in Jul and Aug, but their return in late Sep and Oct with the onset of the fall migration.
  - Indicated vocalizing bowheads preferred a fall migration corridor approximately along 71° N.

This report provides the results from the winter 2010–2011 and summer 2011 acoustic monitoring programs. The winter data were acquired with eight Autonomous Underwater Recorders for Acoustic Listening, Model 2 (AURALs, by Multi-Electronique Ltd.) recorders deployed offshore of Cape Lisburne, Point Lay, Wainwright, and Barrow from mid-Oct 2010 through early Aug 2011. The summer data were acquired with 25 Autonomous Multichannel Acoustic Recorders (AMARs, by JASCO) deployed from late Jul through mid-Oct 2011 throughout the northeastern Chukchi Sea. The recorders were positioned in a regional array and were deployed along four lines extending offshore from Cape Lisburne, Point Lay, Wainwright, and Barrow. Three single recorders were deployed respectively near the Klondike, Burger, and Statoil lease areas.

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

1.1. Acoustic Monitoring Program History

The first Joint Acoustic Monitoring Program was run by the Cornell Lab of Ornithology's Bioacoustics Research Program in summer 2006. Since Jul 2007, JASCO has conducted consecutive summer and winter programs using AMARs and AURALs, respectively, sampling at 16 kHz.

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 Cape Lisburne, Point Lay, Wainwright, and Barrow. These lines were augmented with clusters of recorders near sponsor company lease blocks and historic well sites as follows:

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

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

The winter acoustic monitoring programs consisted of five to eight recorders deployed throughout the program area from 2007 to 2010. A 2011 winter program is underway; eight recorders will be retrieved in summer 2012. The 2010–2011 winter program used eight recorders on a 17% duty cycle. The 2008–2009 winter program used seven recorders on 17% duty cycle. The 2007–2008 winter program used five recorders on a 20% duty cycle.

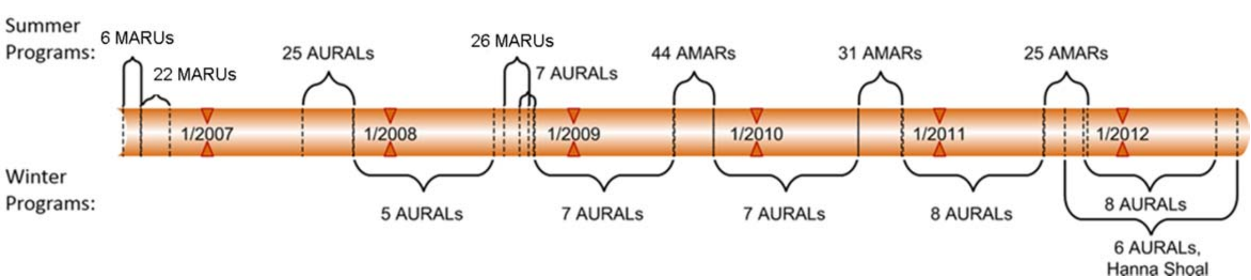

Figure 1. Timeline of Chukchi Sea acoustic monitoring programs, 2006 to 2012. JASCO conducted all but three of the programs; the Bioacoustics Research Program, Cornell Lab of Ornithology ran the remaining three programs (BRP 2010).

2. Methods

2.1. Data Acquisition

The winter 2010–2011 acoustic monitoring program deployed AURALs at eight regional stations. The summer 2011 acoustic monitoring program deployed AMARs at 22 regional stations and three lease area stations.

2.1.1. Winter 2010–2011 Program

Wind speed and air temperature data were acquired from the Barrow station of the US Climate Reference Network (USCRN Barrow in Figure 2; National Climatic Data Center 2011). Ice concentration data were obtained from the Advance Microwave Scanning Radiometer–Earth Observing System (AMSR-E) dataset, distributed by the National Snow and Ice Data Center (Cavalieri et al. 2004).

Acoustic data for the winter 2010–2011 program were acquired with eight Autonomous Underwater Recorders for Acoustic Listening, Model 2 (AURALs, by Multi-Electronique Ltd.). The AURALs incorporate a single omnidirectional hydrophone and are 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 (-164 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 57 dB re 1 µPa, and the usable bandwidth is 10–7700 Hz. The recorders were set to operate for 40 min of every 4 h, actively recording 1/6 of the time (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 mounted in a frame on the seabed. A secondary 15 lb anchor weight, attached by a sinking ground line to the main anchor weight, was deployed about 100 m away. For retrieval, a grapple hook was dragged across the ground line and the apparatus, including anchor weights, was hauled onboard. All recorders were successfully retrieved, leaving no material on the seafloor. The eight recorders were deployed 10 through 16 Oct 2010 (Figure 2) and retrieved 26 Jul through 6 Aug 2011. Table 1 lists geographic coordinates, deployment dates, and recording durations of each recorder. All recorders operated until retrieved, except the W35 recorder, which recorded for only four days.

Table 1. Recorder locations (Figure 2) and recording periods for the winter 2010–2011 acoustic monitoring program in the northeastern Chukchi Sea. The AURALs operated on a 1/6 duty cycle (recording 40 min of every 4 h) from deployment to retrieval, except where noted.

Station	Latitude (°N)	Longitude (°W)	Deployment	Retrieval	Recording days
B05	71.36400	156.93478	16 Oct 10	06 Aug 11	294
WN40	71.97470	161.53628	10 Oct 10	31 Jul 11	294
W50	71.31112	161.53328	10 Oct 10	30 Jul 11	293
W35	71.10275	161.04825	10 Oct 10	30 Jul 11	4*
PLN80	71.72382	164.24037	11 Oct 10	28 Jul 11	290
PLN40	71.06703	164.58947	11 Oct 10	27 Jul 11	289
PL50	70.40288	164.59333	11 Oct 10	28 Jul 11	290
CL50	69.49688	167.77957	15 Oct 10	26 Jul 11	284

* Recording stopped 13 Oct 2010.

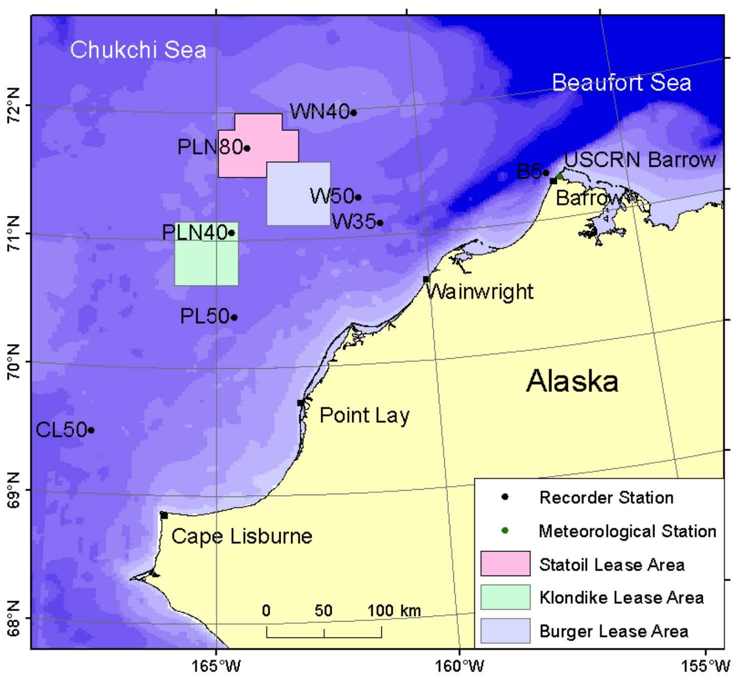

Figure 2. Recorder stations for winter 2010–2011 of the Joint Acoustic Monitoring Program in the northeastern Chukchi Sea. Shades of blue represent water depth. The recorder at Station W35 operated for only four days after deployment.

2.1.2. Summer 2011 Program

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; Figure 4). Ice concentration data were obtained from the Advance Microwave Scanning Radiometer–Earth Observing System (AMSR-E) dataset, distributed by the National Snow and Ice Data Center (Cavalieri et al. 2004).

Acoustic data for the summer 2011 program were acquired with 25 JASCO Autonomous Multichannel Acoustic Recorders (AMARs). The AMARs incorporate a single omnidirectional hydrophone and are 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-M15B or GTI-M8E hydrophone (−160 or −164 dB re 1 V/µPa nominal sensitivity, respectively) and set for a gain of 0 dB. The spectral density of the electronic background noise of the AMARs in this configuration is approximately 34 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, so they were set to record continuously for the full deployment period.

Each AMAR was deployed with a float collar (Figure 3) and fastened by 1.5 m of rope to a 120 lb steel anchor weight so it would float about 1 m above the seafloor. A secondary 15 lb anchor weight, attached by a sinking ground line to the main anchor weight, was deployed about 100 m away. For retrieval, a grapple hook was dragged across the ground line and the apparatus, including anchor weights, was hauled onboard. All recorders were successfully retrieved, leaving no material behind.

Figure 3. An AMAR being deployed from the M/V *Westward Wind* in summer 2009 in the northeastern Chukchi Sea.

Recorder deployments for the summer 2011 program consisted of a regional array of 22 recorders deployed as shown in Figure 4. 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 2010 summer regional programs. These lines extend perpendicularly from the coastline for 50 nautical miles (nmi) then continue northward to about 120 nmi offshore (Figure 4). As in 2009 and 2010, the northernmost Cape Lisburne stations, CLN90B and CLN120B, were shifted east of the line to the Shell lease areas.

Table 2 shows locations and times of the deployments and retrievals for the regional array and lease site recorders. All recorders were deployed between 26 Jul and 1 Aug 2011 and retrieved between 7 and 13 Oct 2011. Most recorders operated as expected; however, the recorder at B50 did not acquire data, and the recorders at Stations W35, WN20, and PL20 had bad memory modules that prevented them from acquiring a full dataset. Seven recorders stopped before retrieval but only two stopped prior to 27 Sep.

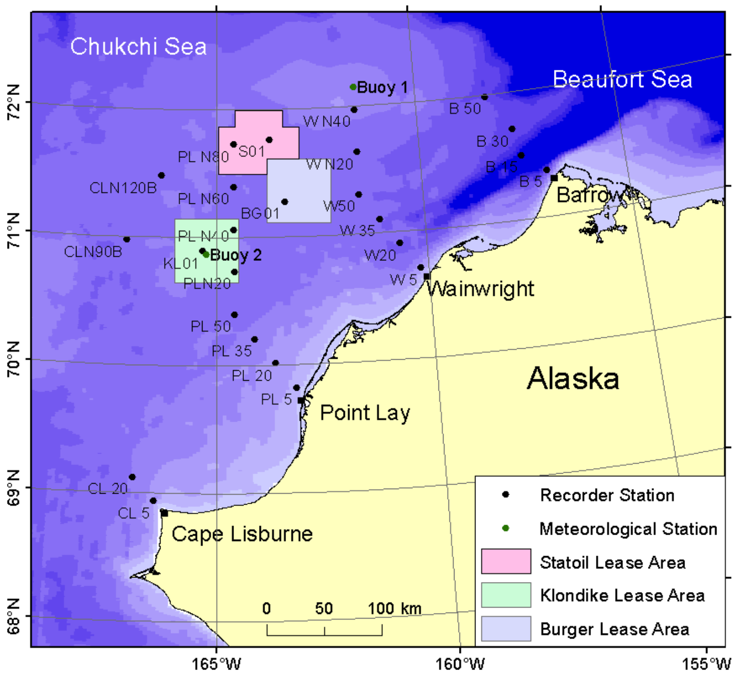

Figure 4. Recorder stations for summer 2011 of the Joint Acoustic Monitoring Program in the northeastern Chukchi Sea. Shades of blue represent water depth.

Table 2. Recorder locations (Figure 4) and recording durations for the summer 2011 acoustic monitoring program in the Chukchi Sea. The AMARs recorded continuously from deployment to retrieval, except where noted. Stations are listed by line east-to-west, and north-to-south within the lines.

Station	Latitude (°N)	Longitude (°W)	Deployment (UTC)	Retrieval (UTC)	Recording days
B50	71.98862	-158.23632	01 Aug 11	11 Oct 11	0 [a]
B30	71.71232	-157.64617	01 Aug 11	12 Oct 11	72
B15	71.50443	-157.50185	01 Aug 11	12 Oct 11	72
B05	71.35957	-156.92075	31 Jul 11	13 Oct 11	74
WN40	71.97443	-161.54047	31 Jul 11	08 Oct 11	69
WN20	71.64268	-161.53632	31 Jul 11	08 Oct 11	43 [b]
W50	71.31063	-161.53620	30 Jul 11	12 Oct 11	74
W35	71.11055	-161.07548	30 Jul 11	13 Oct 11	21 [c]
W20	70.91137	-160.62492	30 Jul 11	07 Oct 11	69
W05	70.64072	-160.16957	29 Jul 11	07 Oct 11	70
S01	71.76490	-163.70252	28 Jul 11	08 Oct 11	72
BG01	71.27763	-163.34868	27 Jul 11	09 Oct 11	74
PLN80	71.73145	-164.58770	28 Jul 11	12 Oct 11	76
PLN60	71.39932	-164.58867	27 Jul 11	08 Oct 11	73
PLN40	71.06722	-164.58740	27 Jul 11	11 Oct 11	76
PLN20	70.73723	-164.58325	28 Jul 11	09 Oct 11	73
PL50	70.40298	-164.58825	28 Jul 11	09 Oct 11	73
PL35	70.21115	-164.11773	29 Jul 11	09 Oct 11	72
PL20	70.01890	-163.65402	29 Jul 11	09 Oct 11	60 [d]
PL05	69.82388	-163.20195	29 Jul 11	09 Oct 11	72
KL01	70.89767	-165.32578	27 Jul 11	08 Oct 11	73
CLN120B	71.48522	-166.34248	27 Jul 11	08 Oct 11	73
CLN90B	70.97900	-167.13877	26 Jul 11	08 Oct 11	74
CL20	69.12777	-166.83548	26 Jul 11	10 Oct 11	76
CL05	68.94137	-166.37432	26 Jul 11	10 Oct 11	76

[a] No data were recorded.
[b] Bad data module; no data recorded before 26 Aug.
[c] Bad data modules; data before 10 Aug are unusable; no data recorded after 31 Aug.
[d] Bad data module; data before 10 Aug are unusable.

2.2. Data Analysis Overview

Researchers detected and classified marine mammal vocalizations[2] both manually and with JASCO's automated acoustic analysis software suite. Three species of key interest—bowhead whale, beluga whale, and walrus—were more thoroughly analyzed than other species with

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

manual and automated approaches because of their conservation status and their importance to the Alaska North Slope communities (Appendix C). Automated techniques were used to detect bearded seal calls. Calls of other seal species were only manually catalogued from part of the dataset. Marine mammal vocalization rates can vary among individuals and over time, and may depend on age or sex. Thus, numbers of calls per species do not necessarily represent their relative abundances.

Manual analysis, as described in Appendix A, was performed on a fraction of the data to establish the acoustic occurrence of marine mammal species, and to characterize call types to use to evaluate the performance of the automated detection and classification methods. The automated detection and classification computer programs 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.

2.3. Manual Data Analysis

Six trained analysts manually analyzed data by visually examining spectrograms and reviewing audio playbacks. Two analysts had more than two years' experience; two others had one year's experience classifying Arctic marine mammal vocalizations in previous Chukchi Sea program datasets. The other two analysts had experience identifying marine mammal sounds, but limited experience with Arctic species calls. The lead analyst trained the latter two analysts with a standard set of vocalizations from all species of interest from the previous year's Chukchi Sea acoustic dataset.

The objectives of the manual analysis were to:

1. Quantitatively assess automated detector performance by manually detecting and classifying marine mammal calls within a subset of the data using precision and recall methods (described in Appendix A).
2. Review a fraction of the data over the recording period to assess where and when target species are acoustically present in the Chukchi Sea to identify periods and stations with significant or unexpected detections.
3. Identify non-target and extra-limital species—species such as killer whales and fin whales, that are observed less frequently in the Chukchi Sea—to help us understand their present habitat use and changes in habitat use over time, which could indicate environmental changes. Manual analysis is especially important in this context because there are no automated classifiers for these species.

2.3.1. Manual Analysis Protocol

Five percent of the winter 2010–2011 data from all eight regional array recorders were analyzed manually. The winter acoustic data were acquired on a duty-cycle, recording for 40 min of every 4 h, yielding six files per day. The middle 2 min sample of each 40 min data file was manually analyzed by visually examining spectrograms and 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 the first sample of selected days for five of the eight stations (CL50, B05, PLN40, PLN80, and W50). Automated detector performance was evaluated with these fully-annotated samples (Appendix A).

Five percent of the summer 2011 data from all 24 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. For 12 of the 24 recorders, analysts annotated all identified marine mammal vocalizations in the first sample of each day, starting between midnight and 12:30 a.m., for eight stations or on selected days for four stations, totaling seven samples each day. This corresponds to analyzing 2% (1/48) of the 90-second samples at a high level of detail and 98% (47/48) of the samples at a moderate level of detail for these 10 stations. This protocol generated enough fully-annotated samples to evaluate the performance of the automated detectors. For the other 12 stations, analysts annotated one call per species per sample for all 48 samples of each day.

If we weren't sure about a species' call within a sample, we examined the sample source file to find more easily identifiable calls. We used JASCO's custom software tool, SpectroPlotter, to provide standardized annotations and to help analysts consistently manually analyze data. Calls were identified by species and call type (Table 3). For bowhead whales, analysts annotated individual sounds, but did not distinguish or characterize songs (see Delarue et al. 2009a).

Table 3. Call types by species annotated during manual analysis of the winter 2010–2011 and summer 2011 datasets. Abbreviations: AM, amplitude-modulated; FM, frequency-modulated; HF, high-frequency; and 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	Knocks	Broadband impulsive sounds typically occurring in long series.
	Bells	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.
	Grunts	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.
	Tones	LF tonal calls, typically flat or downsweeping. Usually around 100–200 Hz. Similar to bowhead moans but shorter (< 0.5 s).
	Overlap	Overlapping calls produced by several animals concurrently.
	Other	Walrus calls outside the above categories.
Beluga whale	Low whistles	FM calls without harmonics below 2500 Hz.
	High whistles	FM calls without harmonics above 2500 Hz.
	Buzzes	Broadband buzzing sounds.
	Chirps	Very short, HF sound. Reminiscent of small-bird chirps.
	Clicks	Broadband clicks, presumably echolocation related.
	Overlap	Overlapping calls produced by several animals concurrently.
	Other	Beluga calls outside the above categories.

Table continues on following page.

Table 3 (cont'd.). Call types by species annotated during manual analysis of the winter 2010–2011 and summer 2011 datasets. Abbreviations: AM, amplitude-modulated; FM, frequency-modulated; HF, high-frequency; and LF, low-frequency.

Species	Call Type	Description
Bearded seal	Long trills	Downsweeping trills longer than 6 s.
	Short trills	Downsweeping trills shorter than 6 s.
	Upsweeping trills	All upsweeping trills.
	Constant trills	Flat trills.
	Complex trills	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.
	Clicks	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	Grunts/snorts, wops	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 calls	Characterized by harmonic structure. Fundamental frequency usually around 800–1000 Hz. Expect repetitions of stereotyped calls within files.
	Whistles	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.
	Other	Minke whale calls that do not match the above categories.
Ribbon seal	Medium downsweeps	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	Barks	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 can be expected to be logged here.
	Grunts	Any grunt-like calls not likely produced by walrus.

2.3.2. Analysis Validation

The lead analyst helped other analysts classify calls that were difficult to attribute to a known call type, by reviewing a random subset of annotations from all analysts to ensure the calls were correctly identified and, if they weren't, 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 analysts flagged notable or suspicious annotations for review.

2.3.3. 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 within 24 hours, analysts randomly sampled, then fully-annotated more than 30 h of calls of the commonly detected species. Analysts then chose a random start time within the file and manually searched the next 5% of the file for detections. This random sample selection was iterated 2000 times. A detection probability was obtained for each file 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. Sample sizes equaled 1%, 2%, 5%, and 10% of the entire file.

2.4. Automated Data Analysis

A specialized computing platform, operating at about 800 times greater than real-time recording, analyzed ambient noise, seismic survey sounds, vessel noise, and calls of marine mammal species of interest. Appendix C outlines the automated analysis stages. Beluga, bowhead, and walrus calls were detected and classified with algorithms coded in MATLAB and executed separately on the computing platform.

An overview of ambient, seismic and vessel noise analysis, and bowhead, beluga, walrus, and bearded seal call detection and classification is provided in Appendix A.

2.4.1. Seismic Survey Event Detection

Detection of seismic surveys occurs in the frequency domain. A Reisz window was applied to the data before the fast Fourier transform (FFT; Oppenheim and Schafer 1999) that converts the data to the frequency domain. The Reisz window, with its flatter time-domain shape, provided better performance for short event identifications than other window types. Through experience, JASCO found that an FFT with a 4 Hz resolution and 50% advance is best for seismic detection.

The spectrogram values in each 120 s time window were normalized by dividing by the median value over frequency for the time window. Normalized time-frequency bins that exceed a threshold of "4" are copied into the detected data space. The detected bins are then collapsed over the frequency band of 30–500 Hz, which creates an event time series that finds evenly spaced events. Seismic survey events were identified based on the periodicity of the impulsive events.

Once a sequence of events was identified, to trigger the detection, the following conditions were applied:

1. The pulse time separation was between 3.5 and 20 s (empirical bounds for shallow hazards and 3-D seismic surveys, respectively).
2. The sequence contained at least 8 pulses (in a 240 s window).
3. Only one pulse in three could be missing from the sequence.

Detected pulses were then analyzed to calculate their root-mean-square (rms) SPL using a 5–95% cumulative energy time window for the pulse duration. Per-shot sound exposure levels (SELs) were also computed.

2.4.2. Marine Mammal Vocalization Detection

Automated detection of marine mammal vocalizations, except bowhead, beluga, and walrus, was performed using a specialized software system described in Appendix A. The software outlined vocalization energy in the time-frequency domain.

The adjacent time-frequency bins above a detection threshold were joined to create contours using a contour-following algorithm similar to that employed by Nosal 2008. The contours were then sorted to classify the probable type of call. The effectiveness of the call sorter was evaluated by comparing the precision and recall of the sorter against the ground truth results obtained from manual analysis of selected data sets.

2.4.3. Ambient Noise and Time Series Analyses

The frequency domain ambient analysis provides 1 Hz resolution spectral density values for each minute of recording. These values directly compare to the Wenz curves (Appendix B.1) which represent typical sound levels in the ocean. The ambient analysis also provides 1/3-octave band and decade-band sound pressure levels for each minute of data.

The Time Series processing tool chain performs time domain ambient analysis. This tool finds peak amplitudes, peak-to-peak amplitudes and rms amplitudes of the time series for each minute of data.

2.4.4. Vessel Noise Detection

The vessel detector was designed to locate narrow tonal peaks characteristic of vessel motors, pumps, and gearing. The tonal detector calculates spectra using a 2 s FFT with a Hamming window and 25% advance. The spectra were limited to 0–2000 Hz, and concatenated to create a 120-second detection workspace. A split-window normalizer was applied to each time slice, which accentuates frequency tonals and suppresses wide bandwidth transient events. The time-frequency bins that exceed the detection threshold were passed to the same contour follower and sorter used to detect mammals. Contours that fit the description below are output as vessel detections to an XML file.

The contour sorter looked for vessel tonals in which:

- Multiple frequency components were:

- At least 5 s long.
- At most 20 Hz in bandwidth.

- The sum of all components at least 10 s long.
- The bandwidth of all components at least 40 Hz wide.

2.4.5. Bowhead and Beluga Call Detection

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 vs. "other", beluga vs. "other").

Random forest classifiers were trained with the manually annotated calls. See Appendix A for a description of the detection and classification process.

Detectable bowhead calls 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. 2009a), 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. 2009a). Figure 5 shows an example of output from the bowhead detector/classifier.

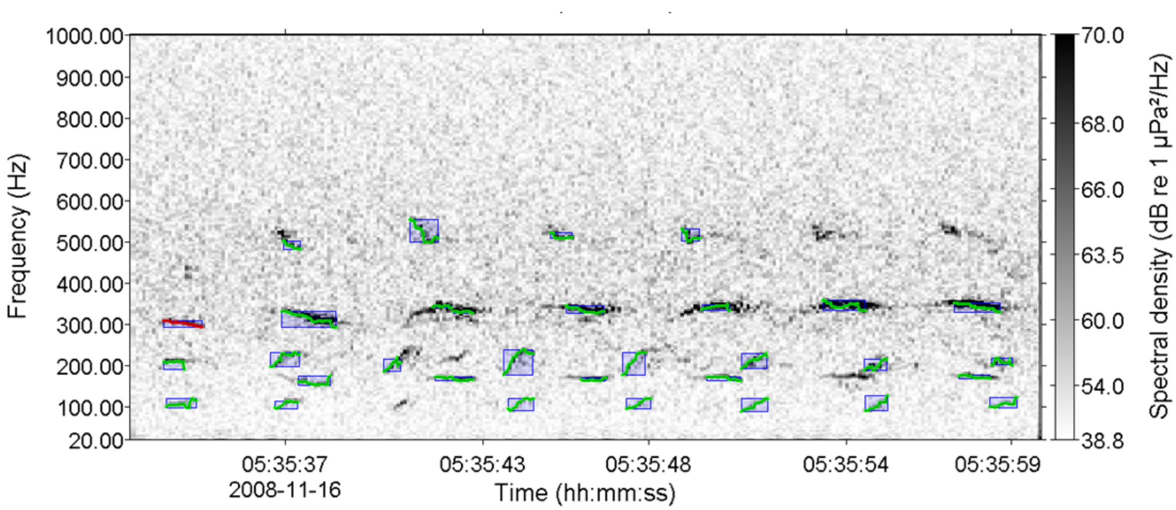

Figure 5. (Top) Pressure time series and (bottom) spectrogram of automated detections and classifications of bowhead vocalizations. The first step of the process identifies time-frequency contours that represent candidate vocalizations (blue boxes). The second step classified contours into two categories, "bowhead" (green contours) and "other" (red contours), with a random forest classifier. Some misclassifications can occur; the red contour on the left side of the spectrogram is related to the bowhead calls, but was incorrectly identified as "other".

2.4.6. Walrus Grunt Detection

The walrus grunt detector/classifier is based on time-frequency representation of the acoustic signal. The spectrogram was 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. Bearded Seal Call Detection

The automated detection and classification of bearded seal vocalizations was performed in three steps:

1. The spectrogram was calculated and binarized. Adjacent bins of the binary spectrogram were grouped together to create time-frequency "objects".
2. Each object was represented by a set of features including the maximum and minimum frequency and duration.
3. Each object was classified based on a set of empirically defined rules.

Appendix A has a detailed description of the detection and classification process.

2.4.8. 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. Marine mammal calls in the winter 2010-2011 dataset were fully-annotated for the first two minutes of each day for recordings from Stations W50, PLN40, PLN80, B05, and CL50, to provide a set of 804 two-minute fully-annotated samples. Marine mammal calls in the 2011 summer dataset were fully manually annotated for Stations PL35, PLN20, PLN60, PLN80, W20, and W50, to provide a set of 6231 five-minute fully-annotated samples.

The performance of the detectors for each species were measured by calculating the precision index (P), which measures ability to correctly identify the species, and recall index (R), which measures completeness. P and R values were calculated separately for vocalizations with signal-to-noise ratios of < 0 dB, 0-5 dB, 5-10 dB, and > 10 dB (Appendix A). Table 4 summarizes the performance of the detectors used for each species for all detected vocalizations, with the majority of signal-to-noise ratios being 0-5 dB. P and R values can be used to correct the automated detection and classification results to values that would be obtained by manual analysts.

Table 4. Performance of the automated detectors/classifiers (precision, *P* and recall, *R*) applied to the winter 2010–2011 and summer 2011 datasets.

Species	Winter 2010–2011			Summer 2011		
	R (%)	*P* (%)	Detector/classifier	*R* (%)	*P* (%)	Detector/classifier
Bowhead	36.1	74.4	Tonal detector + Random forest classifier	74.3	86.9	Tonal detector + Random forest classifier
Walrus	35.1	40.0	Grunt detector	35.1	40.0	Grunt detector
Beluga	30.0	70.0	Tonal detector + Random forest classifier	–	–	n/a
Bearded seal	35.4	82.2	Contour follower/sorter	85.4	39.0	Contour follower/sorter

3. Results

3.1. Weather and Ice Conditions

All figures that illustrate ice concentration data appear in Appendix C.

3.1.1. Winter 2010–2011 Program

Air temperature and wind speed from the Barrow station of the US Climate Reference Network are shown in Figure 6 (National Climatic Data Center 2011). During the winter program, air temperature varied from −43 to 15 °C, with a mean of −10.8 °C. Reported wind speeds were as high as 17.8 m/s and averaged 3.7 m/s.

Ice concentration data for the 1st and 15th of Nov and December 2010 (Cavalieri et al. 2004) show that ice coverage increased in Nov; by 15 Dec the entire program area was more than 90% covered with ice. Initial ice break-up started at the end of May, along the shore between Cape Lisburne and Barrow, and progressed offshore and to the north (Appendix C.2). The program area was ice-free by the start of Aug except for extreme northern areas.

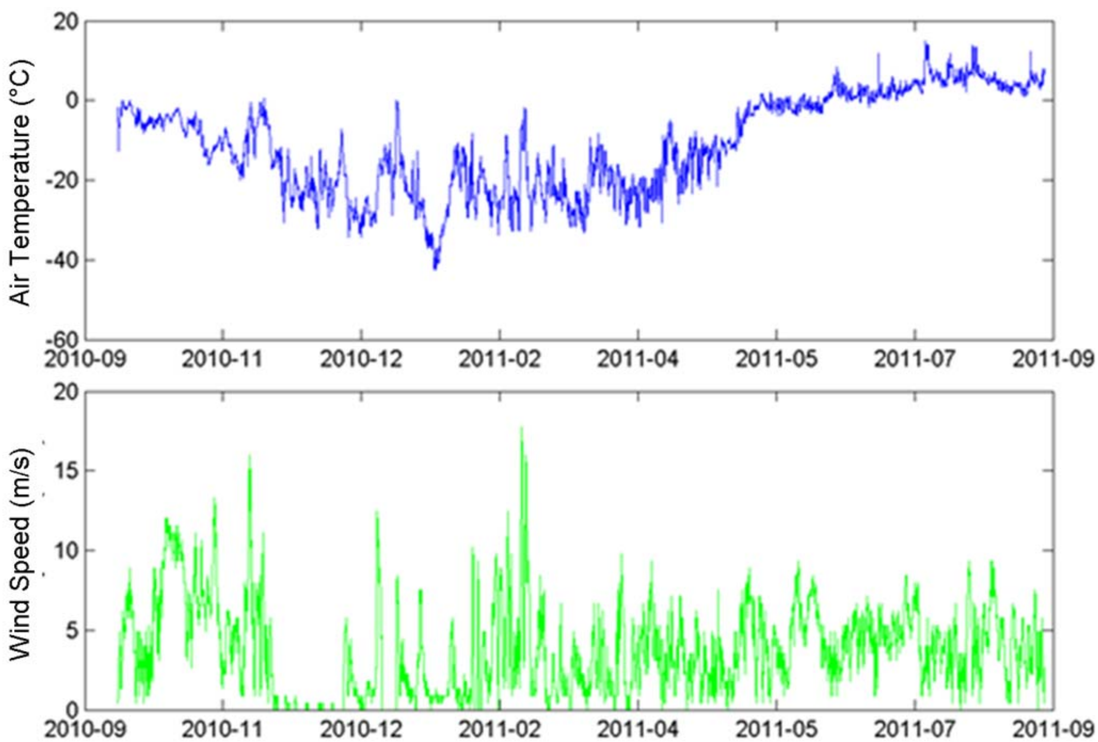

Figure 6. (Top) Air temperature and (bottom) wind speed at the Barrow station of the US Climate Reference Network, 1 Oct 2010 to 31 Aug 2011 (National Climatic Data Center 2011).

3.1.2. Summer 2011 Program

Water temperature and wind speed for Aug through Oct 2011 measured by the Shell meteorological buoys are shown in Figures 7 and 8, and are summarized in Table 5. See Appendix C for ice concentrations at the start and end of summer. Except for a few northern areas early in the deployment, the program area was ice-free through the 2011 summer deployment.

Table 5. Global statistics of Chukchi Sea water temperature and wind speed from 1 Aug through 8 Oct 2011, as measured by the Shell meteorological buoys. Buoy 1 did not record data 8 through 14 Sep.

Buoy	Latitude	Longitude	Water temperature (°C)			Wind speed (m/s)	
			Min	Mean	Max	Mean	Max
1	71.15° N	161.52° N	2.9	4.85	6.4	5.9	11.9
2	70.87° N	165.24° N	3.8	6.51	8.5	7.0	14.0

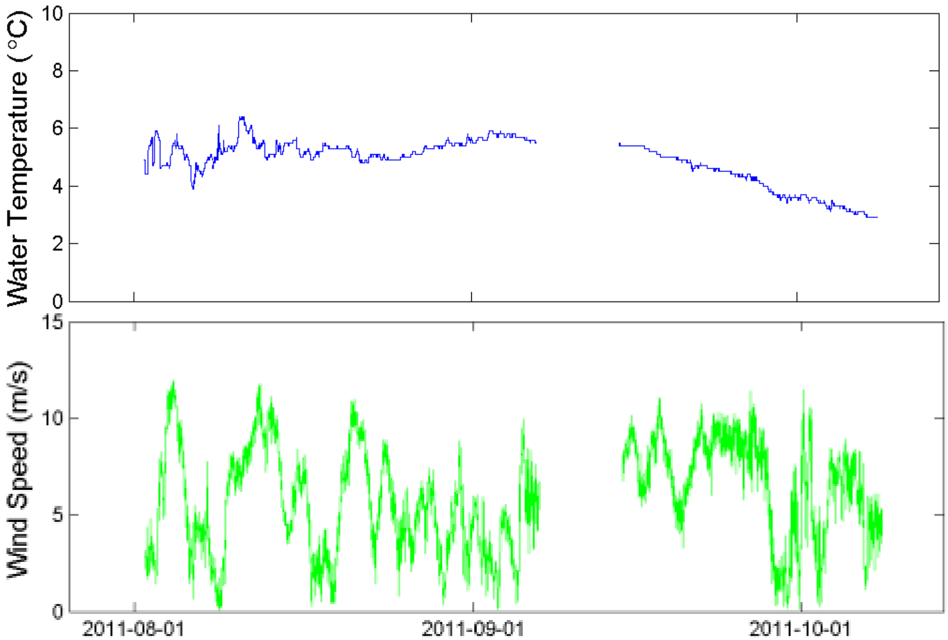

Figure 7. (Top) Water temperature and (bottom) wind speed for Shell meteorological Buoy 1, Aug through Oct 2011. Data were not recorded 8–14 Sep.

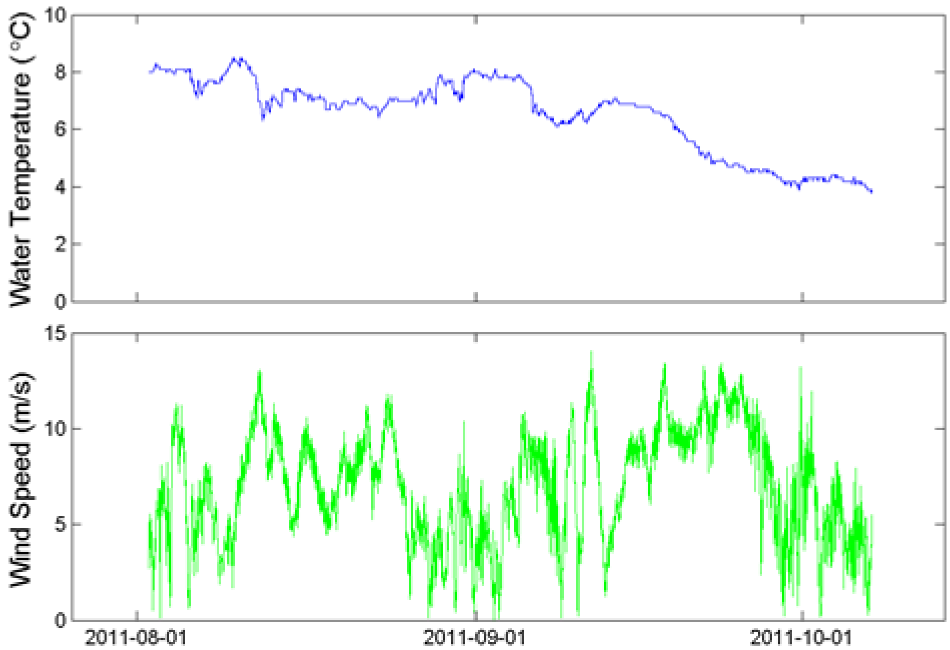

Figure 8. (Top) Water temperature and (bottom) wind speed for Shell meteorological Buoy 2, Aug through Oct 2011.

3.2. Ambient Noise

The ambient noise from PLN40, a representative recording station,) illustrates the ambient sound conditions during the program. See Appendix B for ambient noise results for all other stations.

3.2.1. Winter 2010–2011 Program

The percentile spectral levels of ambient noise for winter Station PLN40 (Oct 2010 to Aug 2011) are shown in Figure 9. Generally, the spectral levels decrease almost linearly with increasing frequency from 10 Hz to 2 kHz, then level off at higher frequencies. Electronic background noise at 8 Hz is present with harmonics. There's an electronic noise spike at 3.5 kHz with a harmonic at 7 kHz. The 50th percentile can be compared to the Wenz curves (Appendix B.1): the dashed lines in the percentile plots indicate the limits of prevailing noise from the Wenz curves.

Figure 10 shows decade-band sound pressure levels (SPLs) while Figure 11 shows a spectrogram for winter Station PLN40. The higher broadband sound levels present from the start of recording in Oct to early Nov and from early Jun to the end of recording in Aug coincided with ice-free periods (Appendix C.2); wind (Figure 6) and wave action increased the sound levels over this period. Bowhead vocalizations contributed to sound levels in the 10–1000 Hz band during both ice-free periods and bearded seal vocalizations contributed in the same band from late May to the end of recording in early Aug (Figures 22 and 75).

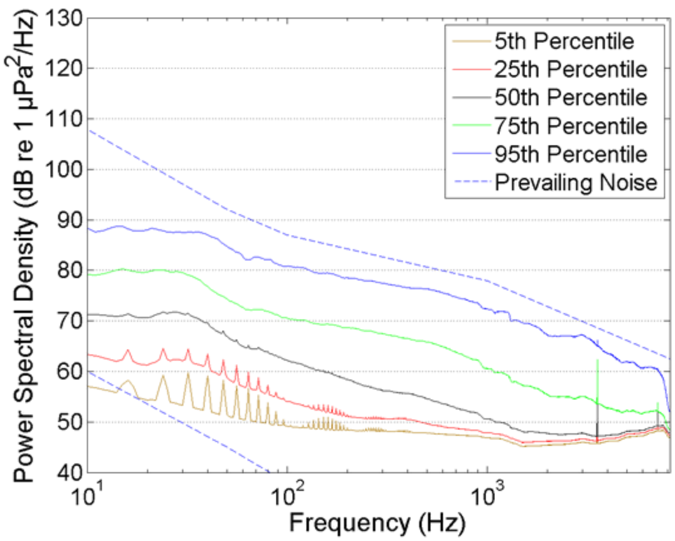

Figure 9. Percentile 1 min power spectral density levels for winter Station PLN40, 11 Oct 2010 to 27 Jul 2011. The lower percentile results are affected by the AURALs' electronic background noise. The dashed lines represent the limits of prevailing noise from the Wenz curves (Appendix B.1).

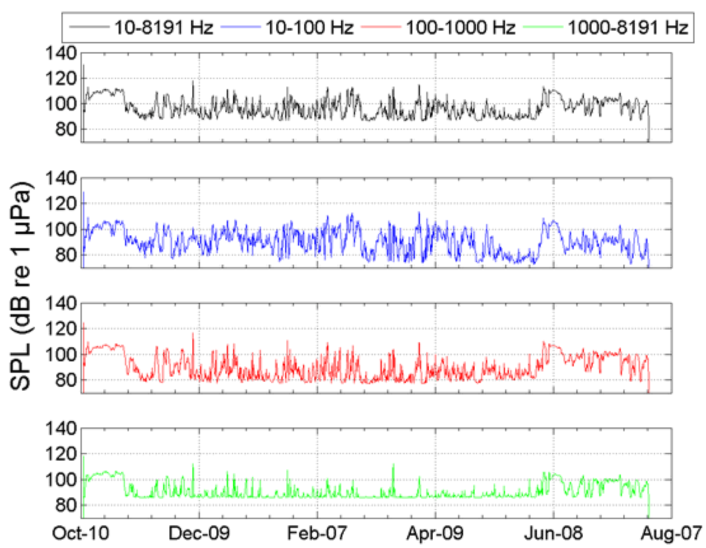

Figure 10. Broadband (top) and decade-band sound pressure levels (SPLs) for winter Station PLN40, Oct 2010 to Aug 2011.

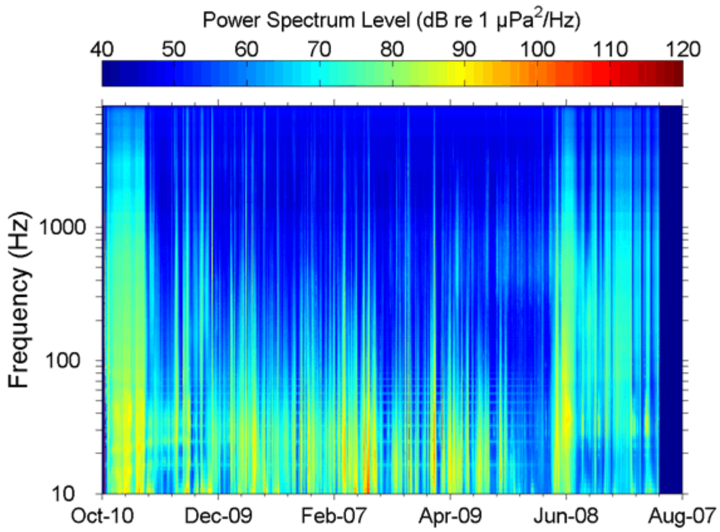

Figure 11. Spectrogram of underwater sound at winter Station PLN40, Oct 2010 to Aug 2011.

3.2.2. Summer 2011 Program

Figure 12 shows the percentile spectral levels of ambient noise for summer Station PLN40 (Jul to Oct 2011). Generally, the spectral levels decrease almost linearly with increasing frequency from 500 Hz to 3 kHz, which is a common characteristic of ambient noise spectra. The electronic background noise of the AMARs is negligible so sound levels below 500 Hz reflect the true ambient noise conditions. Some data collected by AURALs showed tonal noise above background levels for lower percentiles (Figure 9). Figures 13 and 14 show the broadband and decade-band SPLs and spectrogram, respectively for summer Station PLN40. The elevated sound levels in the spectrogram below 1 kHz in mid-Aug and mid-Sep are attributed to wind and wave-break noise and partially to water movement against the hydrophone (Figure 7, Figure 8). Wind speed is generally associated with higher sound levels in shallow water (Greene and Buck 1979). Tonal noise is present from early Aug to mid-Sep; this is associated with a loud vessel operating near the Statoil lease area.

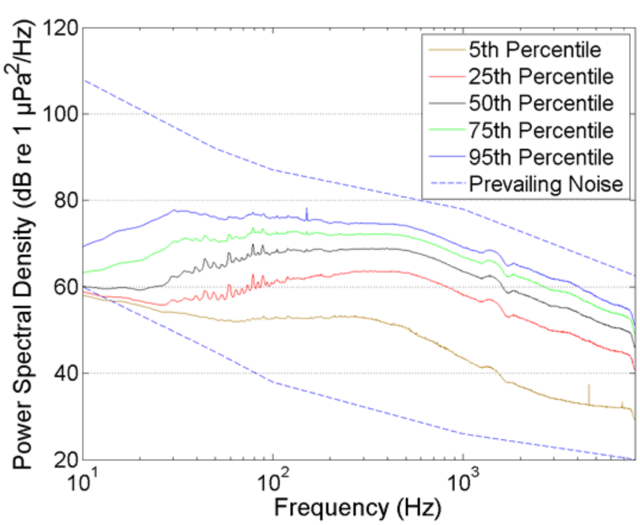

Figure 12. Percentile 1 min power spectral density levels for summer Station PLN40, 26 Jul through 13 Oct 2011. The dashed lines are the limits of prevailing noise from the Wenz curves (Appendix B.1).

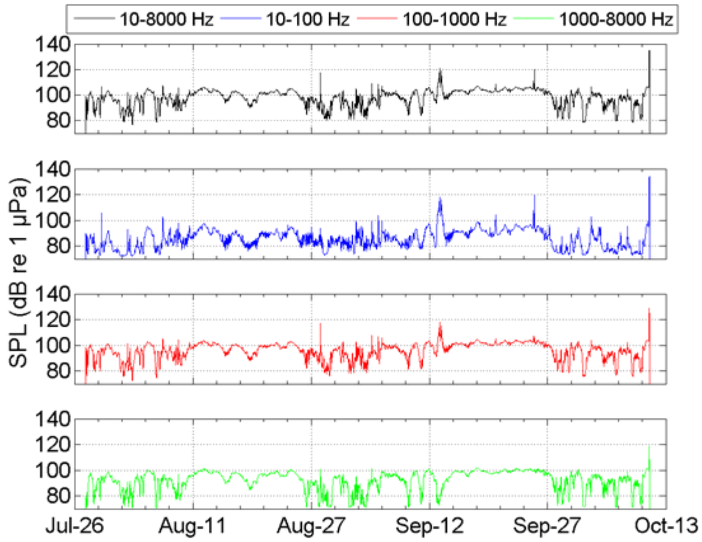

Figure 13. Broadband and decade-band sound pressure levels (SPLs) for summer Station PLN40, Jul to Oct 2011.

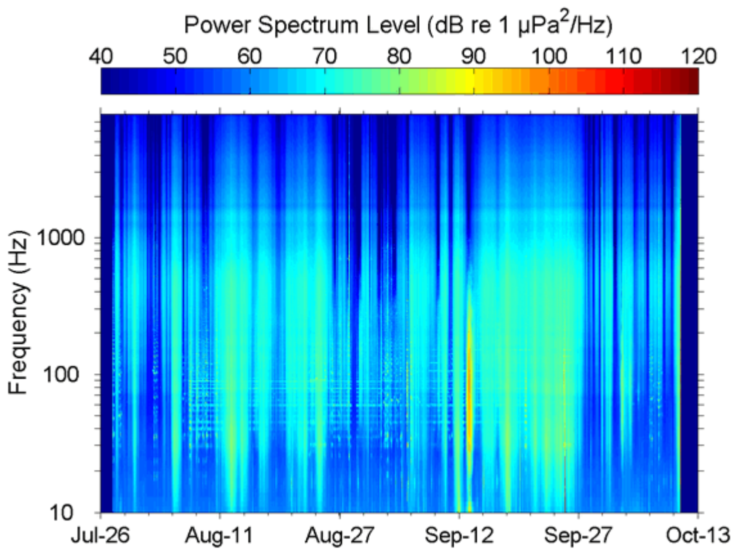

Figure 14. Spectrogram of underwater sound for summer Station PLN40, Jul to Oct 2011.

The ambient noise throughout the program area was computed by inverse-distance interpolation for a period of low ambient noise on 6 Aug 2011 (Figure 15), with rms SPLs between 81.9 and 102.2 dB re 1 µPa, and for a period of high ambient noise on 12 Sep 2011 (Figure 16), with rms SPLs between 97.2 and 114.8 dB re 1 µPa. Inverse-distance interpolation weights measurements from nearby recorders based on the inverse of the distances of the recorders from the site.

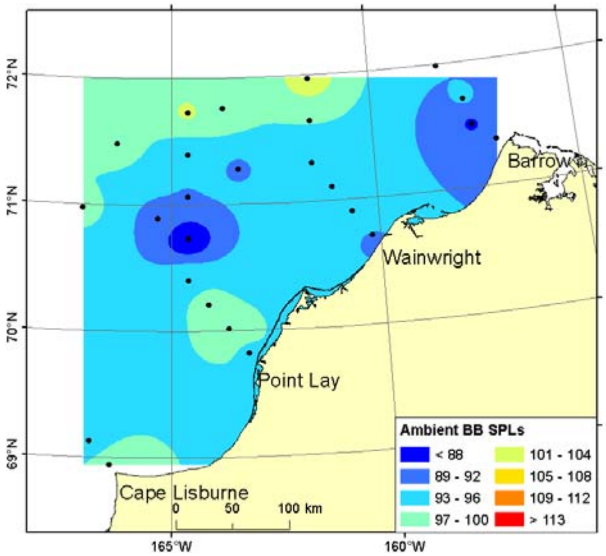

Figure 15. Broadband rms sound pressure levels (interpolated by inverse distance weighting) of ambient noise during a period of low ambient noise at 00:00, 6 Aug 2011. The SPLs are between 81.9 and 102 dB re 1 µPa.

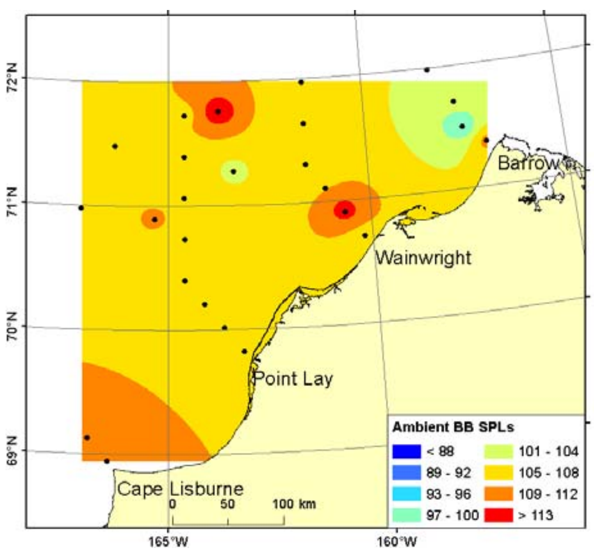

Figure 16. Broadband rms sound pressure levels (interpolated by inverse distance weighting) of ambient noise during a period of high ambient noise at 00:00, 12 Sep 2011. The SPLs are between 97.2 and 115 dB re 1 µPa.

3.3. Seismic Survey Event Detections

3.3.1. Winter 2010–2011 Program

No seismic survey events were detected manually or automatically in the winter program data, which spanned early Oct 2010 through Jul 2011.

3.3.2. Summer 2011 Program

3.3.2.1. Statoil Shallow Hazards Program

Most seismic source events detected were from the Statoil shallow hazards survey program performed from the M/V *Duke*, 8 Aug through 20 Sep 2011. That survey employed a 40 in^3 airgun array at a nominal shot interval of 10 s as well as a single 10 in^3 airgun. Seismic shots of unknown origin were detected on Station CLN120B on 13 Sep and on Stations CLN120B, PLN80, and S01 on 4 Oct. Seismic source detections above 110 dB re 1 µPa were recorded at BG01, PLN60, and PLN80. Seismic shots were detected up to 150 km from source position. Figure 17 shows a sample of strong seismic pulse detections. See Section 3.6 *Seismic Survey Sounds and Marine Mammals*, p 101.

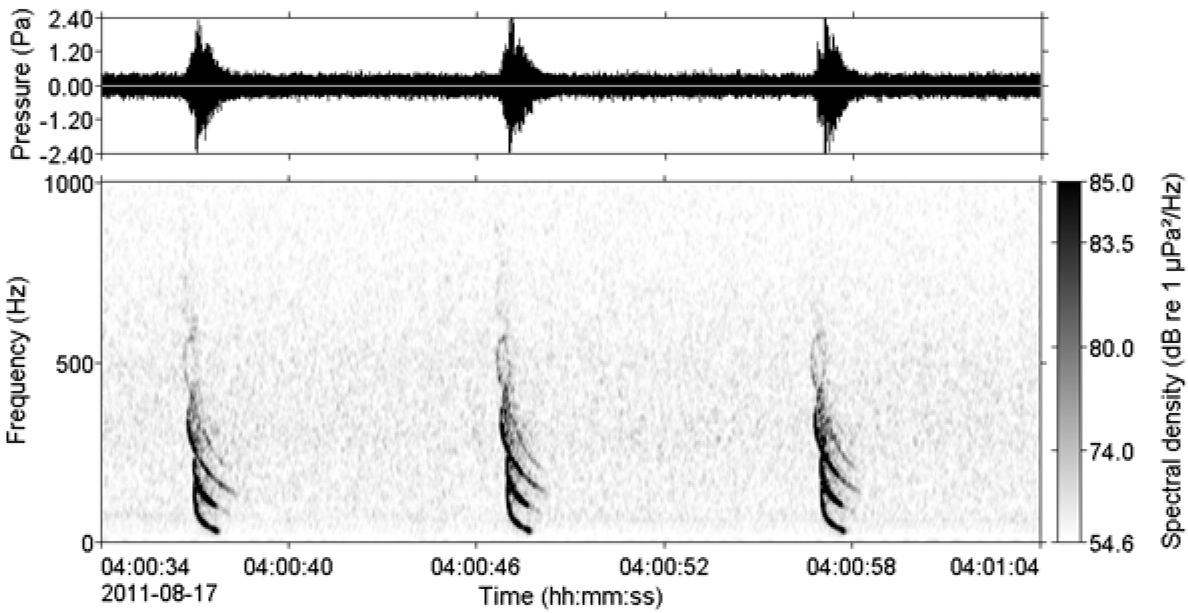

Figure 17. (Top) Pressure signature and (bottom) spectrogram of seismic airgun shots from the M/V *Duke* 40 in^3 airgun array, 17 Aug 2011 at summer Station PLN80 (16 384 pt FFT, 1600 pts real data, 80 pt advance).

3.3.2.2. Evaluating the Seismic Footprint

The ensonification from the *Duke* airgun array was determined by:

1. Computing the received 90% rms SPLs of one half-hour of data (00:00–00:30 27 Aug 2011) at each recording station.
2. Creating a geo-referenced grid and inserting the measured SPLs at each recorder location.
3. Inserting the measured source level of 217 dB re 1 µPa @ 1 m (Warner et al. 2011) for the *Duke* airgun array at its known position at 00:15 27 Aug 2011.
4. Inserting four grid points around the source that represent the 160 dB re 1 µPa 90% rms SPL threshold as derived from the program's sound source verification measurements (Warner et al. 2011).
5. Interpolating (kriging) between these data points to obtain a seismic footprint.

Figure 18 shows the results of this analysis for the full 40 in^3 array on 27 Aug 2011, which indicates the 90% rms SPL of the airgun array was at or above 120 dB re 1 µPa out to approximately 30 km in all directions. The figure also shows a decrease in received 90% rms SPL at CLN120B (west of the source). This is because the seabed slopes upward from the source location (near Station PLN80) toward CLN120B, which attenuates the sound.

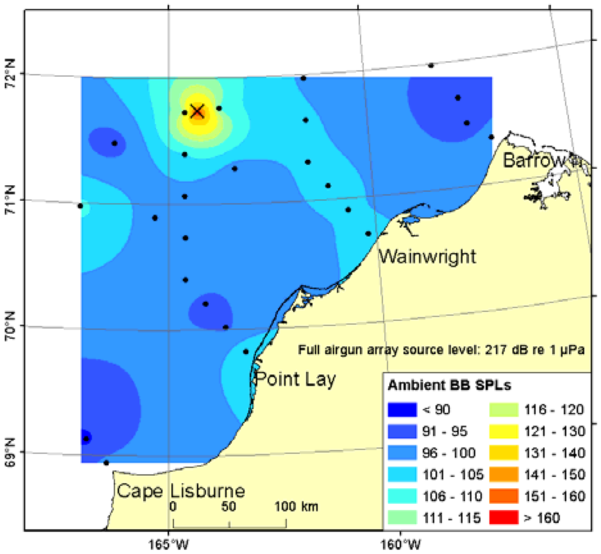

Figure 18. Measured and kriging-interpolated sound pressure levels (90% rms SPL where seismic pulses were detected and rms otherwise) during operation of the M/V *Duke* 40 in^3 airgun array (at location X) at 00:00 on 27 Aug 2011.

3.4. Vessel Noise Detections, Summer 2011 Program

Vessel noise was detected from the program ships M/V *Westward Wind* and M/V *Norseman II*, the Statoil seismic survey vessel M/V *Duke*, and the Statoil coring vessel *Synergy*. Greater vessel activity was detected near Barrow but the sources of those detections are unknown.

The automated vessel detector (described in Section 2.4.4, p15) detects steady tones produced by transiting vessels. The spectrogram in Figure 19 shows tones, which appear as horizontal lines, of a transiting vessel near BG01. Figure 20 shows a sample of detected tonal counts across a line of recorders near the top of the regional array. Regularly occurring vessel detections between 8 Aug and 25 Sep 2011 at Stations PLN80 and S01 are attributed to the program vessels and the Statoil seismic survey vessel M/V *Duke*. The *Duke* was also detected to a lesser extent on CLN120B. Increased Sep detections of vessel tones are attributed to the coring vessel M/V *Synergy* at the Statoil lease area.

Figure 21 shows the number of vessel tones detected at each station (with inverse-distance interpolation between stations) over the summer 2011 program. The vessel detections were nearly constant from 7 Aug through 26 Sep near the Statoil lease area and these were associated with the *Duke* shallow hazards seismic survey and the *Synergy* coring operations.

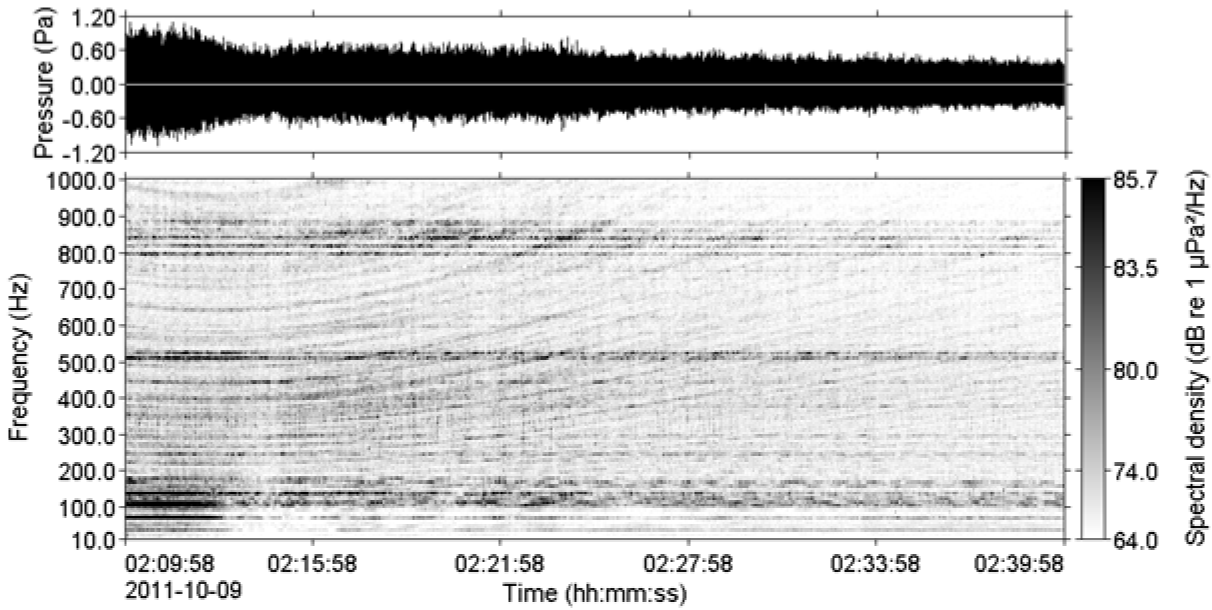

Figure 19. (Top) Pressure signature and (bottom) spectrogram of tonal vessel noise from a vessel, 9 Oct 2011 at summer 2011 Station BG01 (8192 pt FFT, 4000 pts real data, 4000 pts advance, Reisz window). Upward curves are due to the Lloyd mirror effect as the vessel passed the recorder. Narrowband tones are also present.

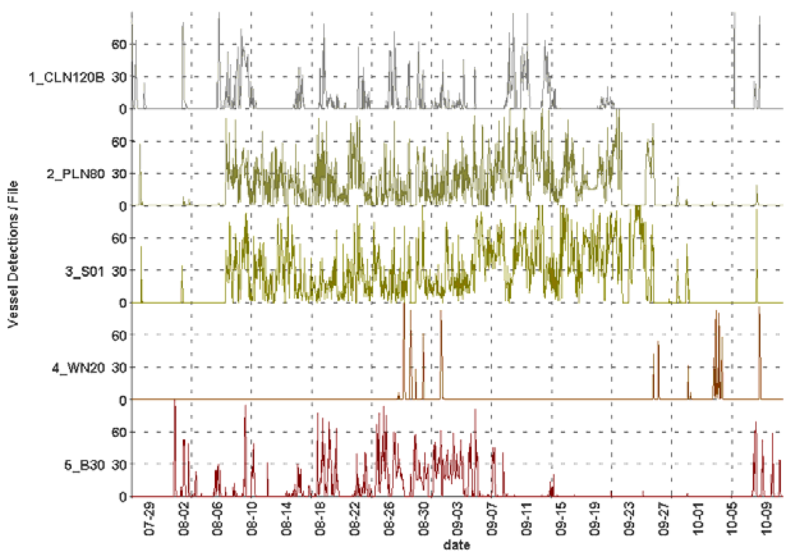

Figure 20. Number of vessel tones detected per half-hour at five summer 2011 stations, 28 Jul through 10 Oct 2011.

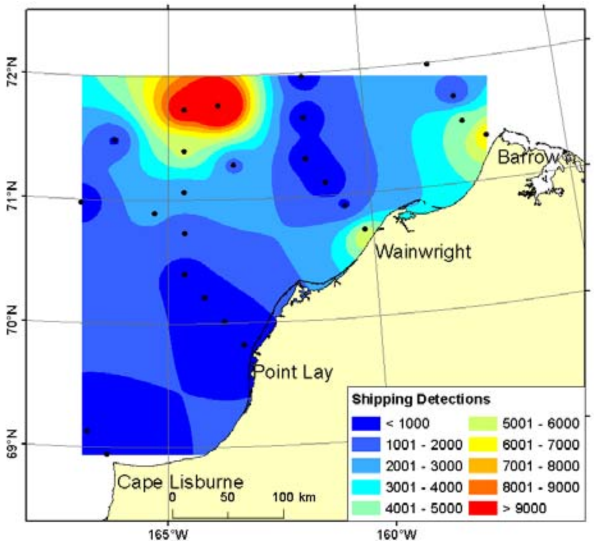

Figure 21. Total detections of vessel noise (interpolated by inverse distance weighting) throughout the Chukchi Sea, 26 Jul through 13 Oct 2011. The peak value is 16,203 at Station S01.

3.5. Marine Mammal Vocalization Detections

The vocalization detections in the winter and summer datasets are presented by species; the order of prevalence was bowhead whale, walrus, beluga whale, and bearded seal. Calls from these species were detected by manual analysis and using the automated detector/classifiers. Vocalizations by other whale and seal species were detected only by manual analysis; these detections are presented alphabetically by each species' common name.

Marine mammal acoustic occurrence at each station is presented as the daily number of 40 min/30 min sound files (winter/summer, respectively) with manual detections for each species. If a station did not have at least one detection of a species, it was omitted from the plots (Table 9, Table 10).

Gray whale acoustic occurrence is presented differently because a call type (low-frequency moan, see Section 3.5.8.2, p 88) was only confirmed as a gray whale halfway through the manual analysis, with the first part of the analysis classifying many of these calls as "possible gray whale calls". Time constraints limited reviewing these early annotations to one annotation per station per day. Therefore, the acoustic occurrence plots for gray whales show only the daily presence or absence of a call detection for each station.

Species-specific call count estimates are presented as the number of automated detections as an index of abundance, over various periods. Automated detectors were not available for gray whales so the analysis used the number of detection days. These results are shown as either bubble plots (winter data: bowheads, walrus, belugas, and bearded seals; summer data: belugas) or interpolated contour plots (summer data: bowheads, gray whales, walrus, and bearded seals) (Table 6).

Counter plots were produced using an inverse-distance interpolation method. 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* values to account for the detectors' false alarms and missed calls (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.

Table 6. Periods over which the numbers of acoustic detections (or the number detection days, in the case of gray whales) were summed for each species, for which bubble or interpolated contour plots were created.

Species	Fall 2010	Spring 2011	Summer 2011
Bowhead whale	Every 2 weeks [b]	Every 2 weeks [b]	Every 2 weeks [c]
Walrus	– [d]	Every 2 weeks [b]	Every 2 weeks [c]
Beluga whale	Every 2 weeks [b]	Every 2 weeks [b]	Monthly [b]
Bearded seal	Monthly [b]	Monthly [b]	Every 2 weeks [c]
Gray whale	– [a]	– [a]	All season [c]

[a] Not detected in this period.
[b] Bubble plot.
[c] Interpolated contour plot.

3.5.1. Manual Analysis Detection Probability: Winter 2009–2010 and Summer 2010 Programs

As discussed in Section 2.3 p 10, 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. This section presents the results of estimating the probability that the manual analysis protocol will detect each species, as a function of season for the winter 2009–2010 and summer 2010 datasets (Delarue et al. 2011).

The goal of this analysis was to assess and validate the protocol of manual examination of a fraction of the datasets. Detection probabilities (DPs) are also used to indicate calling rate. The 5% manual analysis protocol is compared to hypothetical 1%, 2%, and 10% manual analysis protocols (Table 7, Table 8).

The estimated detection probabilities for selected files that contain bowhead, beluga, ringed seal, bearded seal (Table 7), and walrus (Table 8) calls indicate that the performance of the manual analysis protocol[3] varies with species and season.

Bowhead calls had a high DP from late Oct 2009 until Jun 2010 (> 61%), due to high calling rates associated with singing. In summer 2010 (Jul and Aug), bowhead calls had a low DP (< 30%), likely because bowheads are largely absent from the Chukchi Sea. From late Sep until early Nov, bowhead DP increased following an increase in calling rate when these animals migrated through the Chukchi Sea (Table 7).

Bearded seal calls had a high DP from late Oct 2009 until late Jun/early Jul 2010, at which time the seals abruptly stopped vocalizing. In summer 2010 and early fall, DPs were typically low, with a few exceptions (Table 7).

[3] 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.

Beluga whale calls had a high DP during the fall 2009 and spring 2010 migrations, which was expected as these are the periods of highest beluga occurrence in the northeastern Chukchi Sea (Delarue et al. 2011). Alternatively, beluga calls had a low DP in Aug 2010 (Table 7).

Ringed seal call DP was relatively constant throughout the year and consistently low, averaging 22% (Table 7). Reviewing 10% of the recordings would raise the mean DP to only 35.7%. This suggests the current analysis protocol underestimates the presence of ringed seal calls in the data.

Walrus calls had a high DP in fall, spring, and early summer (Table 8). After the start of the Statoil seismic survey, the DP was negatively correlated with the 30 min mean rms SPL ($p < 0.029$), which suggests calling rate and/or detectability decreases with increasing airgun pulse SPL. Walrus are thus less likely to be detected during seismic surveys. Summer 2010 files with faint or no airgun sounds generally had high DPs.

Table 7. Manual analysis detection probabilities (DPs) of bowheads, belugas, ringed seals, and bearded seals for files recorded at several stations during the winter 2009–2010 and summer 2010 programs when manually reviewing 1%, 2%, 5%, and 10% of the data (Delarue et al. 2011). 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%)
Bowhead whale	B05	21 Oct 09 03:00	27.4	39.8	61.1	85.4
	CL50	12 Dec 09 00:00	86.6	95.3	98.8	100.0
	PL50	13 Apr 10 11:00	19.7	33.3	61.1	86.9
	B05	10 May 10 03:00	99.4	100.0	100.0	100.0
	W35	19 Jun 10 19:00	40.3	58.2	92.1	98.9
	PLN40	11 Jul 10 15:00	6.3	11.6	22.2	36.2
	CLN120B	28 Jul 10 16:36	7.5	15.9	22.3	26.1
	B50	18 Aug 10 07:29	7.8	13.0	28.1	38.5
	WN40	08 Sep 10 01:29	1.9	4.2	8.9	15.4
	B30	15 Sep 10 20:43	9.0	13.7	26.3	38.1
	CLN90	24 Sep 10 04:36	8.5	16.5	37.1	62.0
	W35	01 Oct 10 00:12	32.9	51.5	82.5	98.8
	PL50	08 Oct 10 08:31	46.8	66.3	90.5	98.5
Bearded seal	W50	27 Oct 09 11:00	20.5	33.6	67.4	94.6
	B05	24 Nov 09 16:00	62.5	84.5	98.2	100.0
	PLN80	08 Jan 10 20:00	25.4	41.4	69.2	87.0
	CL50	15 Feb 10 16:00	74.4	87.6	100.0	100.0
	WN40	27 Mar 10 07:00	25.6	44.2	65.1	74.0
	W35	05 May 10 03:00	100.0	100.0	100.0	100.0
	PLN40	18 Jun 10 23:00	100.0	100.0	100.0	100.0
	PL20	28 Jul 10 21:26	5.6	9.4	16.1	28.3
	W05	16 Aug 10 14:36	5.6	8.8	11.1	15.2
	PLN60	10 Sep 10 12:43	1.8	3.4	5.1	4.3
	B50	20 Sep 10 13:44	47.5	70.3	96.0	100.0
	S01	01 Oct 10 14:57	11.8	21.0	42.4	65.1
	CL50	11 Oct 10 15:11	1.0	1.7	4.6	9.0
Beluga whale	B05	27 Oct 09 03:00	100.0	100.0	100.0	100.0
	CL50	22 Nov 09 16:00	15.0	26.7	40.9	68.2
	PLN40	10 Apr 10 19:00	100.0	100.0	100.0	100.0
	W35	03 May 10 03:00	100.0	100.0	100.0	100.0
	WN40	10 Jun 10 23:00	32.5	46.9	64.5	82.4
	B05	11 Jul 10 11:00	78.7	92.6	100.0	100.0
	W05	05 Aug 10 05:51	5.5	10.5	22.2	31.8
	B05	31 Aug 10 21:01	4.4	7.2	14.0	22.9
	B05	08 Oct 10 12:01	34.1	52.7	81.2	93.9
Ringed seal	WN40	17 Nov 09 16:00	2.5	5.6	11.8	23.5
	PLN80	22 Dec 09 16:00	2.8	4.3	11.1	23.4
	W35	14 Jan 10 08:00	7.3	14.7	30.1	45.8
	PLN40	10 Feb 10 04:00	3.6	5.4	9.5	15.2
	B05	14 Mar 10 11:00	15.1	23.7	48.3	65.6
	CL50	20 Apr 10 11:00	8.0	12.2	25.1	44.8
	PL50	07 May 10 03:00	9.9	11.0	19.0	31.6

Table 8. Manual analysis detection probability (DP) of walrus for files recorded at stations during the winter 2009–2010 and summer 2010 programs when manually reviewing 1%, 2%, 5%, and 10% of the data. When airgun pulses were detected, the 30 min mean airgun pulse rms SPL is provided (Delarue et al. 2011). Results for each species are sorted chronologically.

Station	Date and time	DP (1%)	DP (2%)	DP (5%)	DP (10%)	Airgun 30 min mean rms SPL (dB re 1 µPa)
CL50	16 Dec 09 16:00	76.8	89.8	99.7	100.0	n/a
PLN40	22 Jan 10 08:00	71.0	92.1	100.0	100.0	n/a
CL50	18 Jun 10 03:00	94.7	99.3	100.0	100.0	n/a
W35	10 Jul 10 03:00	96.9	99.7	100.0	100.0	n/a
CLN90	27 Jul 10 06:06	60.4	77.0	94.5	98.7	n/a
WN40	05 Aug 10 19:00	97.2	100.0	100.0	100.0	n/a
WN20	11 Aug 10 10:24	86.6	97.2	100.0	100.0	n/a
CL05	23 Aug 10 14:29	100.0	100.0	100.0	100.0	n/a
BG01	24 Aug 10 07:55	4.7	9.1	16.4	22.7	137.9
S01	28 Aug 10 03:27	10.7	11.9	10.7	11.9	151.4
S01	28 Aug 10 03:57	9.1	12.2	18.3	23.7	155.3
PLN80	28 Aug 10 14:21	5.3	7.5	13.0	21.1	137.8
S01	30 Aug 10 04:57	3.8	6.5	9.9	15.0	145.8
BG01	02 Sep 10 02:04	11.1	20.4	44.6	67.8	129.6
PL20	05 Sep 10 00:26	73.8	87.1	99.3	100.0	99.5
PLN80	07 Sep 10 13:21	4.1	5.6	11.3	24.4	147.8
PLN60	09 Sep 10 06:43	40.1	50.9	69.5	80.8	132
BG01	09 Sep 10 14:34	31.7	54.9	85.5	100.0	130
PLN80	11 Sep 10 14:36	19.8	29.1	44.3	59.3	130.7
B50	19 Sep 10 01:14	28.0	40.2	57.3	71.1	111.5
BG01	19 Sep 10 07:34	18.4	32.4	54.0	80.3	129.7
BG01	02 Oct 10 02:34	56.2	70.8	92.1	100.0	n/a
S01	11 Oct 10 03:57	31.1	40.1	56.7	73.6	n/a

3.5.2. Summary of Manual Call Detections

Nearly 13,000 sounds in the winter 2010–2011 data and over 33,000 sounds in the summer 2011 data were annotated manually; 12,257 sounds (Table 9) in the winter 2010–2011 data and 28,196 sounds (Table 10) in the summer 2011 data were classified as marine mammal calls. From the winter program, Station PLN80 had the most marine mammal call detections, the majority (72% of annotations) of which were bearded seal calls followed by bowhead whales at 18%. Station WN40 had the fewest marine mammal call detections.

In the summer 2011 program data, walrus calls accounted for 87% of the manual annotations; bearded seal accounted for 6.6%, bowhead calls for 3.7%, while contributions of other species were negligible. Stations W50 and PL05 had the most manual annotations, largely due to the high numbers of walrus calls. Station KL01 (within the Klondike lease area) had the fewest annotations, in contrast with BG01 (within the Burger lease area) which ranked fourth.

Table 9. Winter 2010–2011 Call Detections: Marine mammal annotations resulting from the manual analysis of 5% of the data from each recording station.

Station	Bowhead	Walrus	Beluga	Bearded seal	Ringed seal	**All mammals**	Unknown
B05	244	3	233	1056	3	**1539**	24
WN40	69	215	27	843	17	**1171**	49
W50	162	119	33	1270	12	**1596**	54
PLN80	426	158	47	2148	1	**2780**	93
PLN40	333	93	19	1229	9	**1683**	58
PL50	594	82	47	1271	1	**1995**	170
CL50	374	52	70	995	2	**1493**	246
Total	**2202**	**722**	**476**	**8812**	**45**	**12,257**	**694**

Table 10. Summer 2011 Call Detections: Marine mammal annotations resulting from the manual analysis of 5% of the data from each recording station. Spotted seal sounds were not detected due to a lack of knowledge about their calls (Section 3.5.14, p 101).

Station	Bowhead	Walrus	Beluga	Bearded seal	Fin whale	Gray whale	Humpback	Killer whale	Minke whale	Ribbon seal	Ringed seal	All mammals	Unknown
B30	64	578		76		3					13	**734**	257
B15	232	327	74	113		8					12	**766**	312
B05	157	78	83	91		47					3	**459**	388
WN40	6	1885	16	207		13	6					**2133**	115
WN20	2	1808		65		2						**1877**	71
W50	11	3292		36		6						**3345**	141
W35		613		6		16						**635**	83
W20	18	1233	36	115		56						**1458**	371
W05	7	1575	28	133		54					1	**1798**	451
S01	7	411		106		1						**525**	234
BG01	100	1826	2	63		3		2			1	**1997**	265
PLN80	77	513	2	133		1		1			3	**730**	322
PLN60	45	355		92		3	3		1			**499**	272
PLN40	102	456	10	174		24		1	1	1		**769**	233
KL01	42	160		75		1		6	2			**286**	86
PLN20	97	776	2	104		15		3	2		8	**1007**	360
PL50	29	503		88	1	13	1	1			8	**644**	164
PL35	24	1382		68		15		2			2	**1493**	460
PL20		1634		23		9						**1666**	195
PL05		3187		9		3						**3199**	154
CLN120B	20	327		86	2	7		5				**447**	49
CLN90B	19	264	29	49		3		1		2	4	**371**	141
CL20		439		2		2		1	2		1	**447**	105
CL05		905				3		3				**911**	23
Total	**1059**	**24,527**	**282**	**1914**	**3**	**308**	**10**	**26**	**8**	**3**	**56**	**28,196**	**5252**

3.5.3. Bowhead Whale Call Detections

3.5.3.1. Winter 2010–2011 Program

The winter 2010–2011 program began in mid-Oct 2010 and captured much of the fall southward migration of bowhead whales (*Balaena mysticetus*) through the Chukchi Sea toward the Bering Sea. In the 2009–2010 program, the first part of the migration began in late Sep 2010 (Delarue et al. 2011).

Bowhead calls were detected at all stations in fall 2010 (Figure 22). Bowhead calls were detected from the deployment (10–16 Oct) at all stations except at PL50 and CL50, where detections started on 26 Oct and 10 Nov, respectively (Table 11). This finding suggests these two stations were outside the main migration corridor during the first part of the migration; this is consistent with the summer 2010 program results which showed they were outside or at the edge of the migration corridor from late Sep to mid-Oct (Figure 147 in Delarue et al. 2011). The advance of the ice edge from the north (Figures 23 to 26) likely forced late migrants to the south, closer to Stations PL50 and CL50, which increased detections at these stations later in Nov and Dec. These two stations also recorded bowhead whales later than the other stations, until 22 Dec and 17 Jan, respectively (Table 11). The latest detection of the fall migration over all winter programs to date (2007–2010) occurred at CL50 on 17 Jan.

As observed during the summer 2010 program for the first part of the fall migration (see Delarue et al. 2011), the winter 2010–2011 detections of the fall migration occurred in waves. This was most apparent at the Point Lay stations (Figure 22). The last, strongest, wave was detected at all stations except B05. The number of detection days increased with increasing distance from Barrow, a finding consistent with the westward progress of the fall migration. Call counts were highest at Station PLN80 until mid-Nov (Figure 23, Figure 24). Subsequent call count maxima all occurred at CL50 (25 to 28). The increase in observed call counts over the detection period is likely related to increases in song production rather than increases in the number of vocalizing individuals. Because songs are repeated, they create high call rates thereby triggering more automated detections than did the comparatively more spaced sequences of moans recorded earlier in the fall.

Calls were detected in 99–100% ice concentration on multiple occasions (e.g., Figures 26 to 28). A field of slightly lower ice concentration near Station CL50 (Figure 28) may explain the Jan detections, which occurred after a 10-day break in detections.

Except at Station B05, the spring 2011 northward migration in the program area produced few detections (Figure 22, Table 11). Station PL50 was the only station to record more than a few bowhead calls during the core migration period (1 Apr to 15 Jun). There were no detections from Stations WN40, W50, and PLN80 during that period; Stations CL50 and PLN40 had one detection each. This indicates most bowheads migrated within 90 km of shore in 2011. This finding differed from the winter 2010 program results in which bowheads were detected throughout the spring migration at most stations (Delarue et al. 2011).

Spring detections at Stations PLN40 and PLN80 occurred mostly from mid-Jul onward. Detections at PL50 started on 1 Apr and continued until the end of the recording. Previous winter acoustic monitoring programs have shown the core of the migration typically ends mid-Jun, with a few late migrants detected no later than mid-Jul (Delarue et al. 2011). Persistent detections at Station PLN40 suggest bowheads may have also foraged in the area in summer 2011.

The detections on Station B05 are consistent with those of previous years. Bowhead calls were first detected on 29 Mar (the first 2011 spring detection; Table 11, Figure 22). The early detections were sporadic until 2 Apr and became frequent on 10 Apr. The data reveal three waves of migrants (Figure 22). The detections decreased approximately 24 May but continued almost daily until 14 Jun. Only three isolated detections occurred between then and 27 Jun. The early detections occurred in close to complete ice coverage conditions (Figures 29 to 31). The Jul detections occurred in ice-free water and were concentrated in and around the lease areas (Figure 35).

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 (Ljungblad et al. 1982, Clark and Johnson 1984). In fall, these calls became increasingly organized into stereotyped sequences, called songs, as the migration progressed (Figure 36; Delarue et al. 2009*a*). From mid-Nov, detections at all stations consisted exclusively of songs. The early spring detections were usually songs. These songs were typically less stereotyped than those occurring in late Nov and Dec, and had an increasingly disorganized structure. By Jun, most detections consisted of non-stereotyped moans and/or complex call sequences. Calling rates decreased after Jun (Table 7).

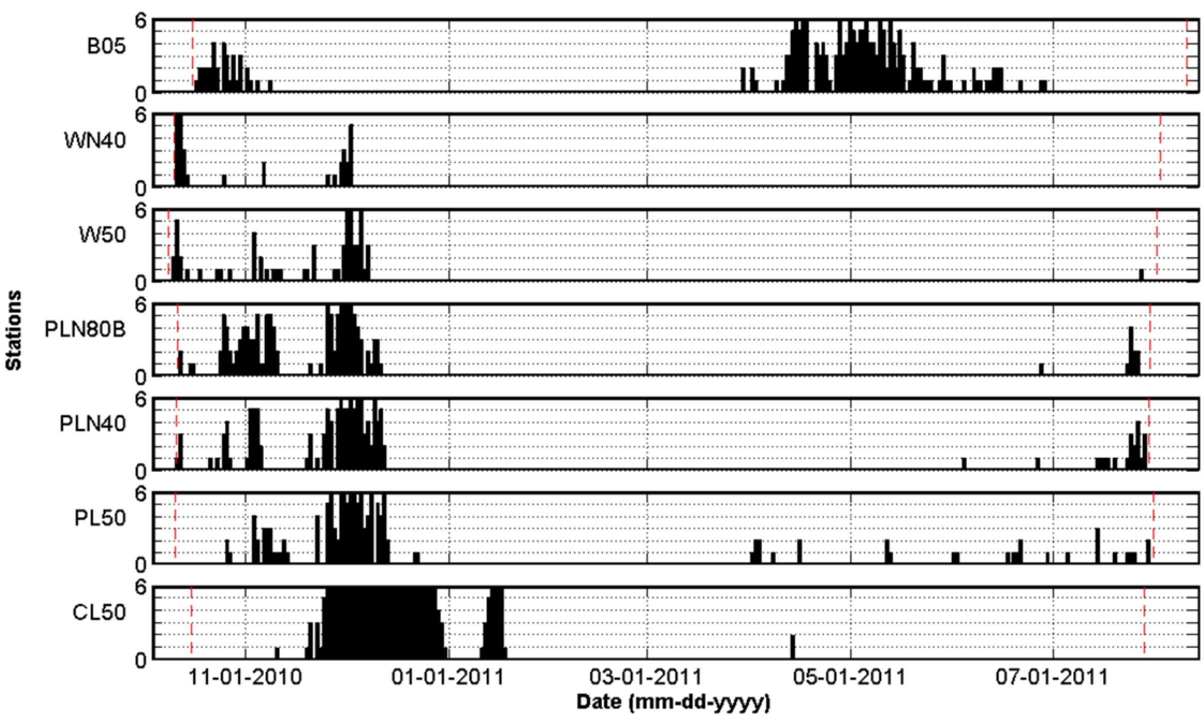

Figure 22. Winter 2010–2011 Daily Bowhead Call Detections: Daily number of sound files (six 40-min files recorded per day) with call detections based on the manual analysis of 5% of the acoustic data recorded mid-Oct 2010 through early Aug 2011 in the northeastern Chukchi Sea for each station. Red dashed lines indicate when the recording started and ended.

Table 11. Winter 2010–2011 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 40 min of every 4 h.

Bowhead Whale								
Station	Record start	Fall-Winter 2010–2011			Spring 2011			Record end
		First detection	Last detection	Detection days	First detection	Last detection	Detection days	
B05	16 Oct	17 Oct	08 Nov	17	29 Mar	27 Jun	61	06 Aug
WN40	10 Oct	11 Oct	02 Dec	12	–	–	0	31 Jul
W50	10 Oct	10 Oct	07 Dec	27	26 Jul	26 Jul	1	30 Jul
PLN80	11 Oct	12 Oct	11 Dec	39	26 Jun	25 Jul	5	28 Jul
PLN40	11 Oct	11 Oct	12 Dec	33	03 Jun	27 Jul	13	27 Jul
PL50	11 Oct	26 Oct	22 Dec	35	01 Apr	28 Jul	21	28 Jul
CL50	15 Oct	10 Nov	17 Jan	50	13 Apr	13 Apr	1	26 Jul

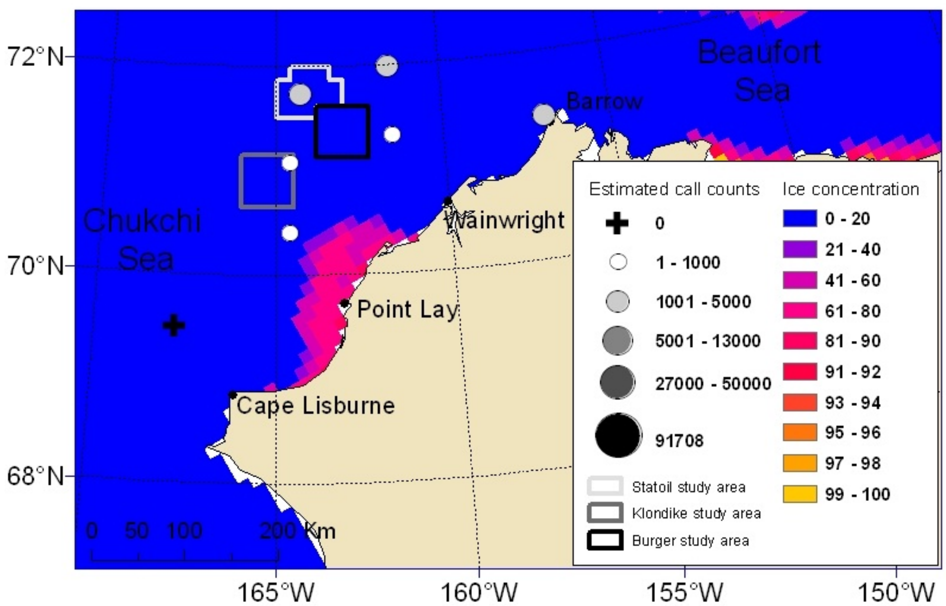

Figure 23. Bowhead whale call count estimates, 12–31 Oct 2010: Corrected sum of automated call detections in all files with manual detections on winter 2010–2011 stations in the Chukchi Sea. Ice concentration data are for 22 Oct 2010 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

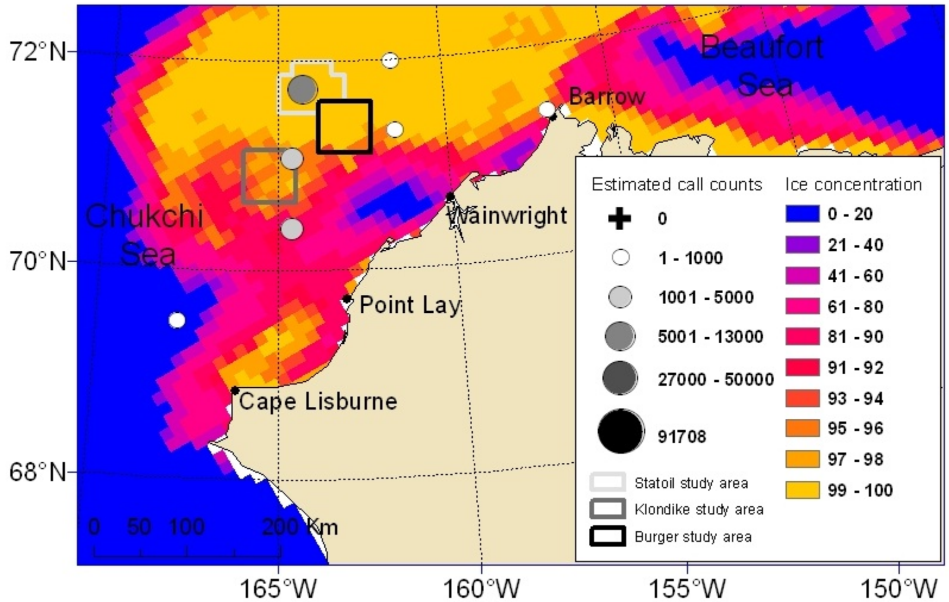

Figure 24. Bowhead whale call count estimates, 1–15 Nov 2010: Corrected sum of automated call detections in all files with manual detections on winter 2010–2011 stations in the Chukchi Sea. Ice concentration data are for 7 Nov 2010 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

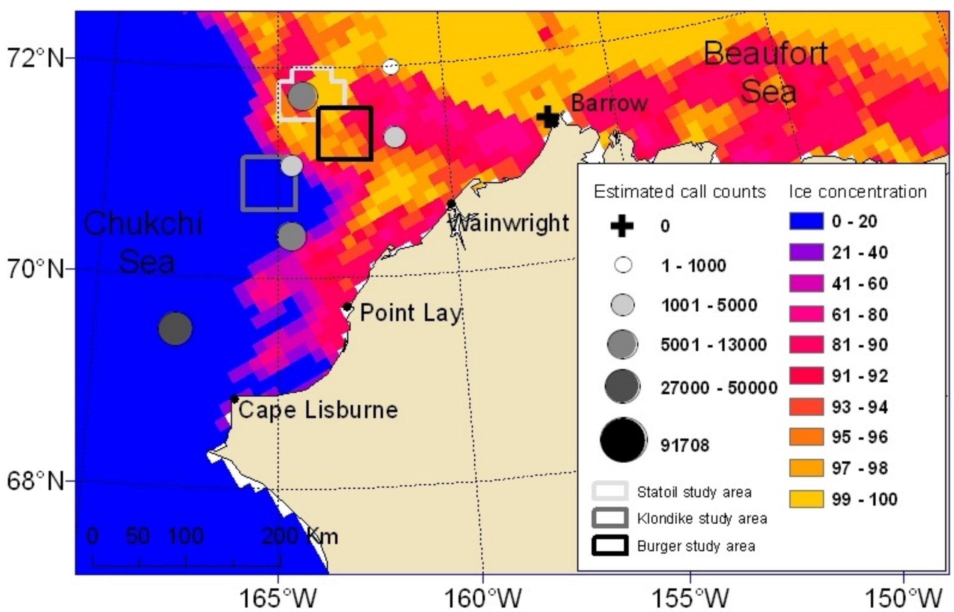

Figure 25. Bowhead whale call count estimates, 16–30 Nov 2010: Corrected sum of automated call detections in all files with manual detections on winter 2010–2011 stations in the Chukchi Sea. Ice concentration data are for 22 Nov 2010 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

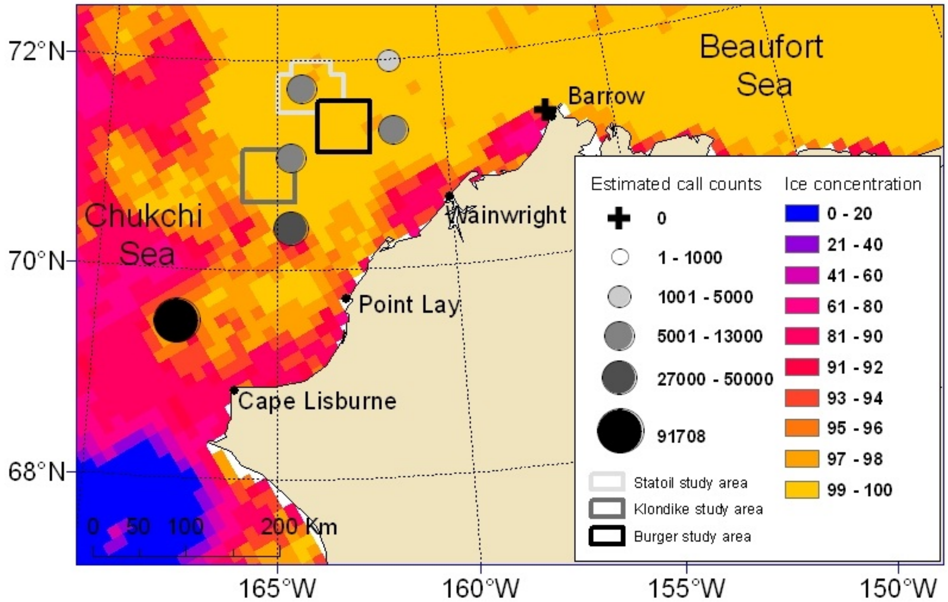

Figure 26. Bowhead whale call count estimates, 1–15 Dec 2010: Corrected sum of automated call detections in all files with manual detections on winter 2010–2011 stations in the Chukchi Sea. Ice concentration data are for 7 Dec 2010 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

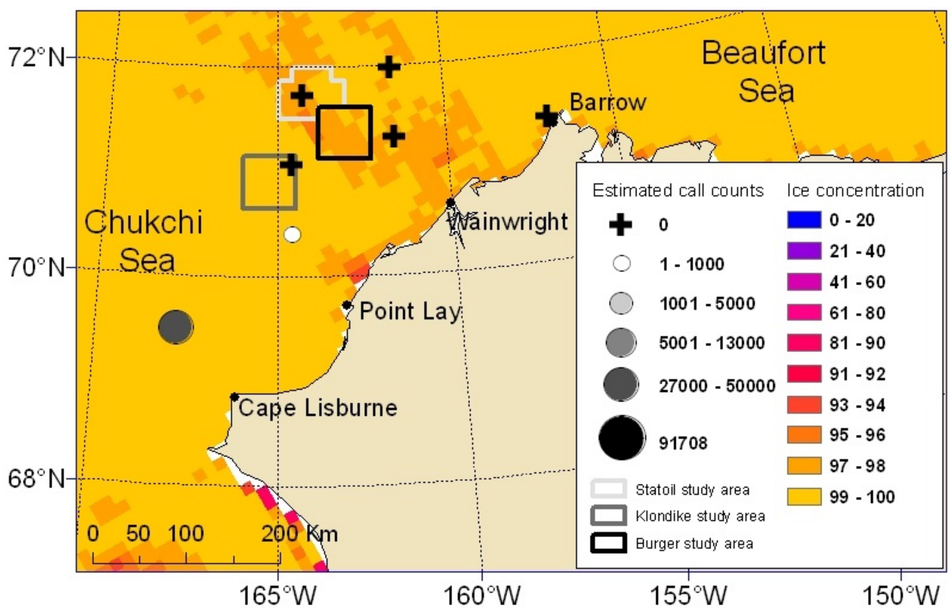

Figure 27. Bowhead whale call count estimates, 16–31 Dec 2010: Corrected sum of automated call detections in all files with manual detections on winter 2010–2011 stations in the Chukchi Sea. Ice concentration data are for 22 Dec 2010 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

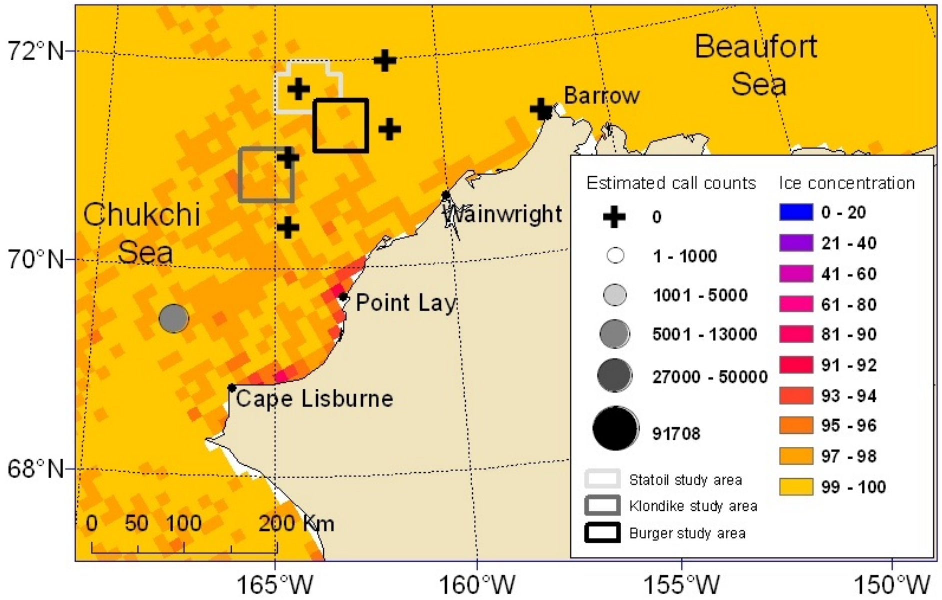

Figure 28. Bowhead whale call count estimates, 10–17 Jan 2011: Corrected sum of automated call detections in all files with manual detections on winter 2010–2011 stations in the Chukchi Sea. Ice concentration data are for 15 Jan 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

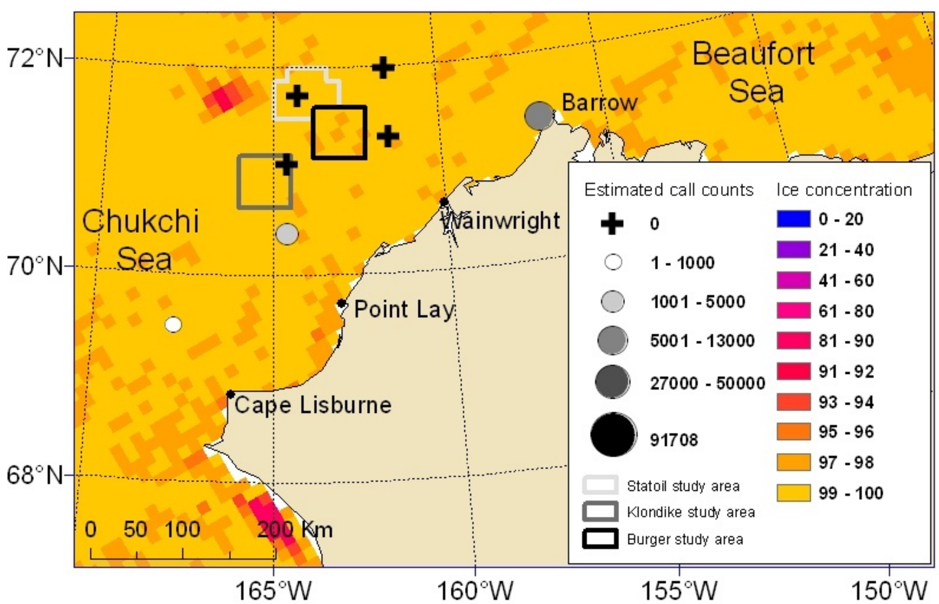

Figure 29. Bowhead whale call count estimates, 29 Mar through 15 Apr 2011: Corrected sum of automated call detections in all files with manual detections on winter 2010–2011 stations in the Chukchi Sea. Ice concentration data are for 7 Apr 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

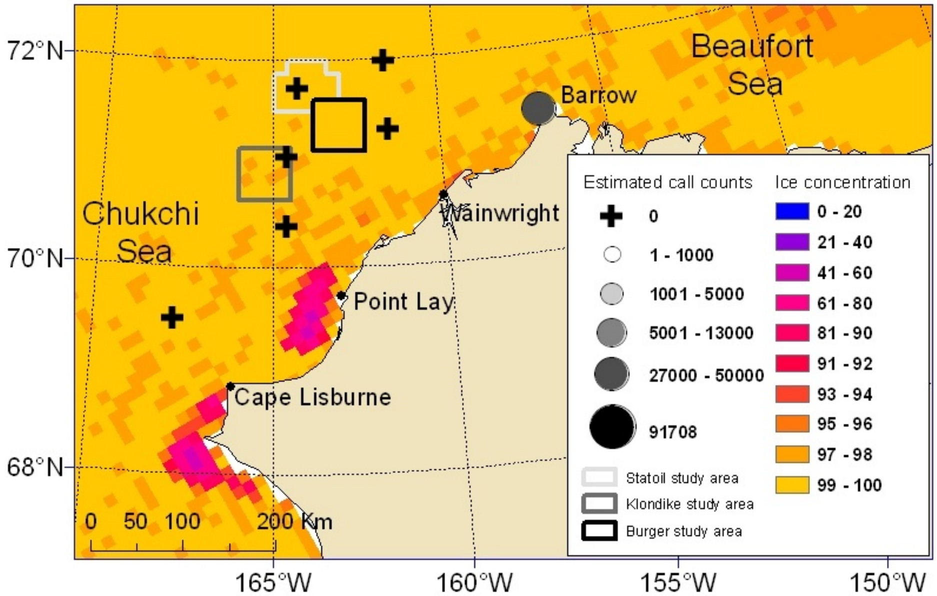

Figure 30. Bowhead whale call count estimates, 16–30 Apr 2011: Corrected sum of automated call detections in all files with manual detections on winter 2010–2011 stations in the Chukchi Sea. Ice concentration data are for 22 Apr 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

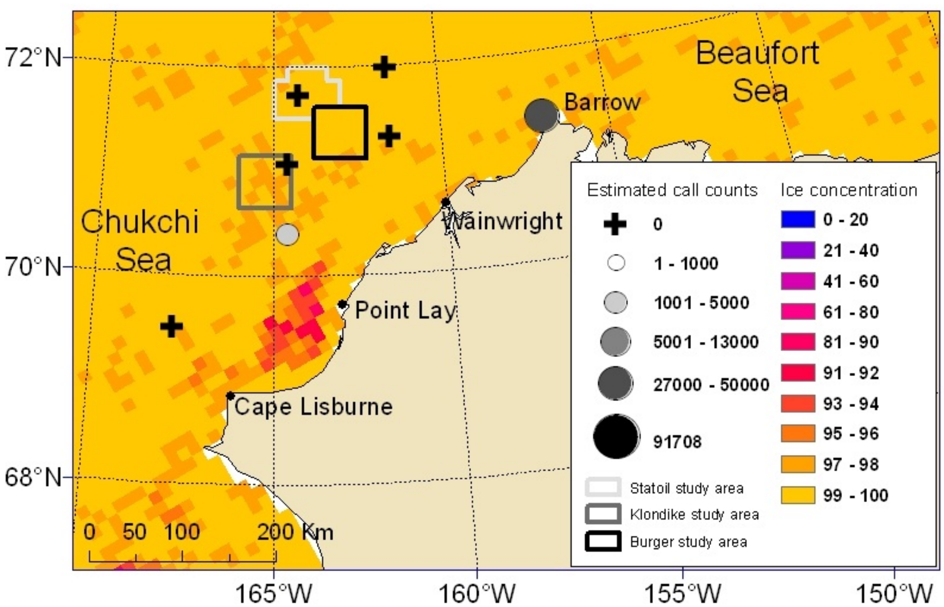

Figure 31. Bowhead whale call count estimates, 1–15 May 2011: Corrected sum of automated call detections in all files with manual detections on winter 2010–2011 stations in the Chukchi Sea. Ice concentration data are for 7 May 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

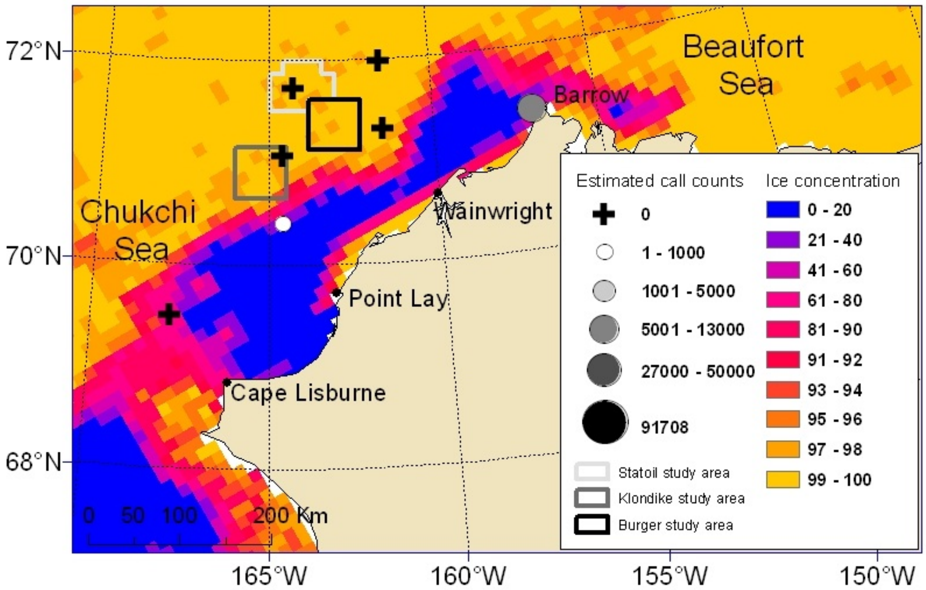

Figure 32. Bowhead whale call count estimates 16–31 May 2011: Corrected sum of automated call detections in all files with manual detections on winter 2010–2011 stations in the Chukchi Sea. Ice concentration data are for 22 May 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

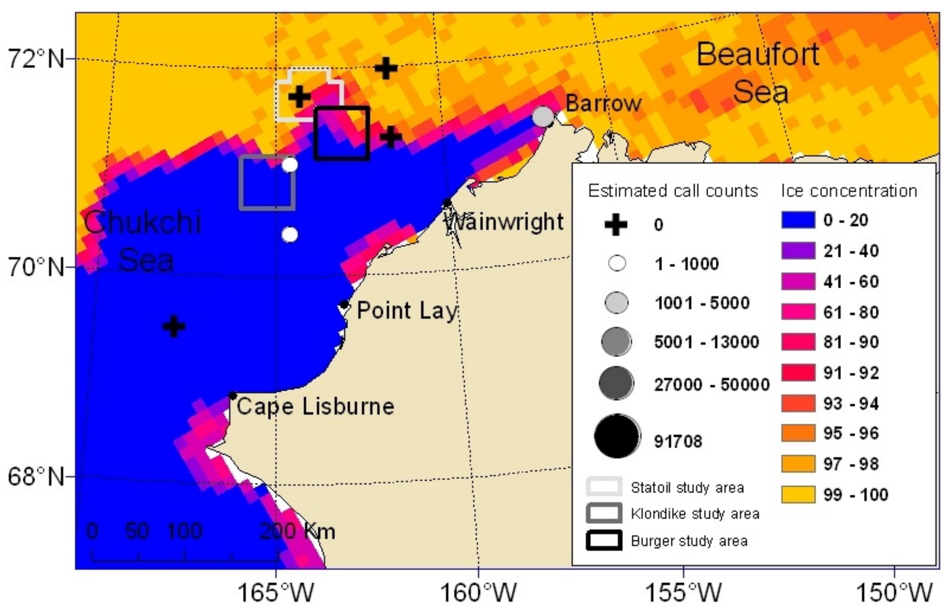

Figure 33. Bowhead whale call count estimates, 1–15 Jun 2011: Corrected sum of automated call detections in all files with manual detections on winter 2010–2011 stations in the Chukchi Sea. Ice concentration data are for 7 Jun 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

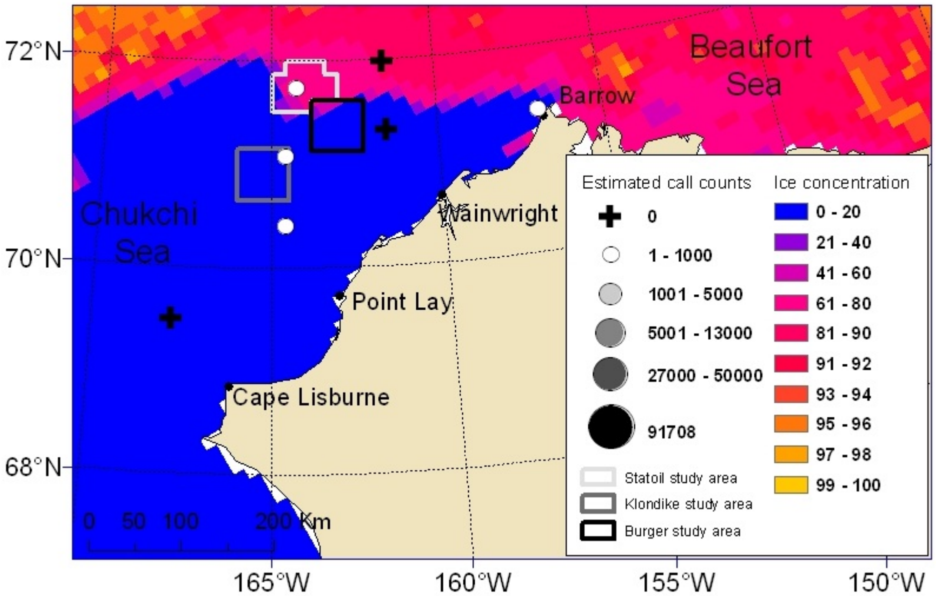

Figure 34. Bowhead whale call count estimates, 16–30 Jun 2011: Corrected sum of automated call detections in all files with manual detections on winter 2010–2011 stations in the Chukchi Sea. Ice concentration data are for 22 Jun 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

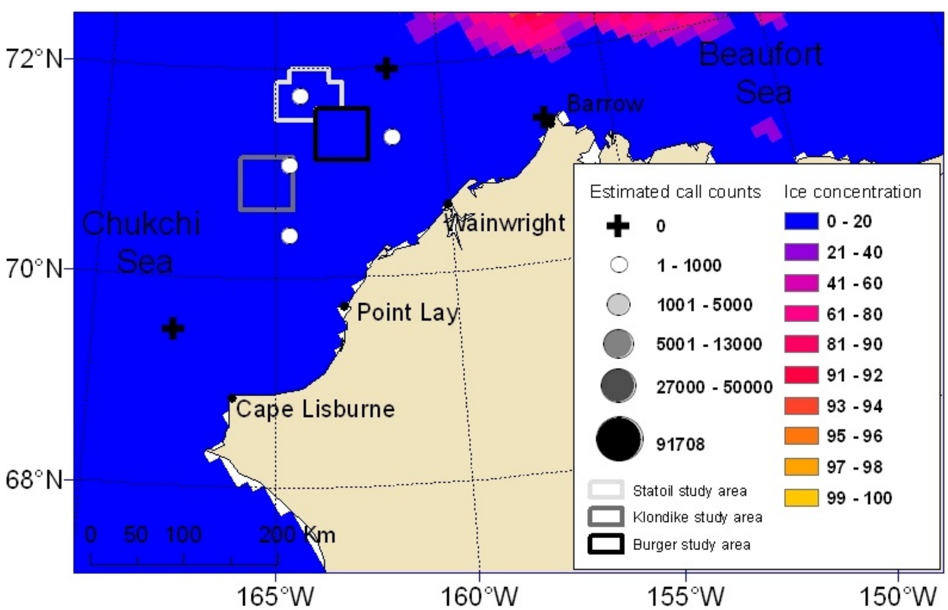

Figure 35. Bowhead whale call count estimates, Jul 2011: Corrected sum of automated call detections in all files with manual detections on winter 2010–2011 stations in the Chukchi Sea. Ice concentration data are for 15 Jul 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

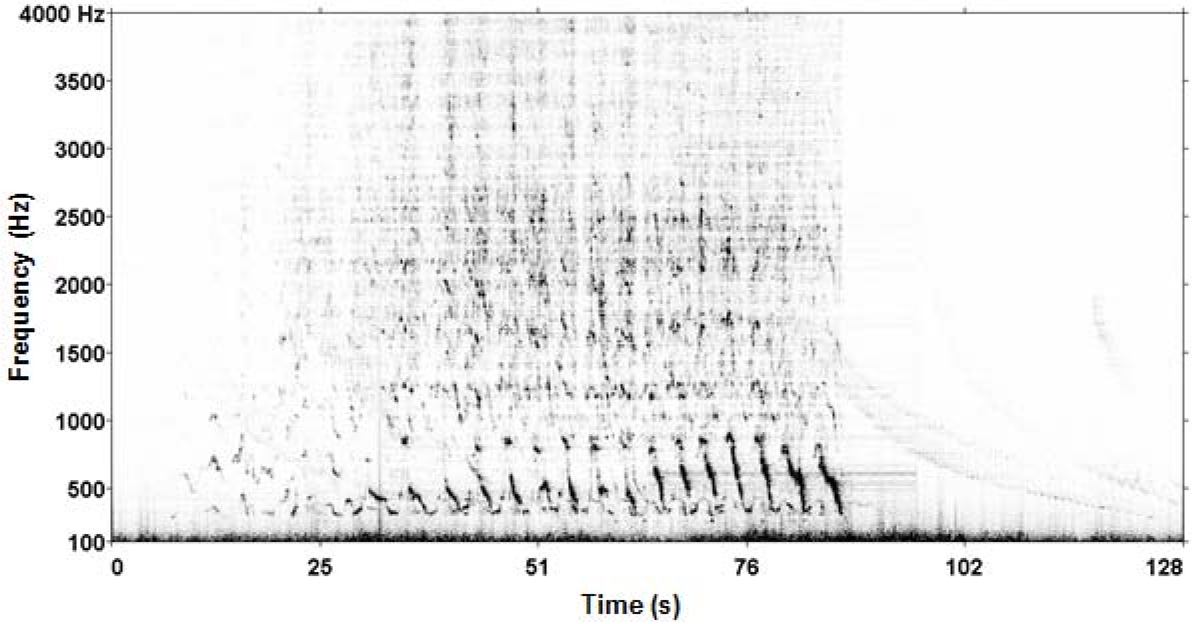

Figure 36. Spectrogram of a complex bowhead song recorded at winter 2009–2010 Station B05, 1 Apr 2010 (4096 pt FFT, 8192 real data pts, 1024 pt overlap, Hamming window; Delarue et al. 2011).

3.5.3.2. Summer 2011 Program

Bowhead vocalizations were manually detected in the summer 2011 dataset at all analyzed stations except PL05, PL20, CL05, CL20, and W35 (Figure 37, Table 12). The distribution of bowhead call detections in the first part of the summer 2011 dataset was unexpected. Between 27 Jul and 9 Aug, bowhead calls were detected at 17 stations with an average of 5 detection days per station (range: 1–12 detection days). These detections started on 27 Jul and were most abundant within, or north-northeast of, an area bounded by Stations PLN20, PLN60, and BG01 (Figure 38) as well as at CLN90 and CLN120. Around 1 Aug, they then appeared farther south-southwest at stations KL01, PL50, and PL35. Detections at stations north and east of PLN20 stopped 1–4 days prior to the end of detections west or south of PLN20. This suggests the detected bowheads left the program area heading west-northwest. This is consistent with the movements of a satellite-tracked bowhead moving from Barrow to the northern Chukotkan coast in late Jul–early Aug 2010 (J. Citta, pers. comm.); some bowheads also headed northeast via Barrow.

Four detections occurred in the second half of Aug, at Stations B15 and B30 (Figure 39). These may represent offshore feeding whales (see Moore et al. 2010) or early migrants heading from Barrow toward Wrangel Island. The 2009 results of a bowhead satellite tracking program (Quakenbush et al. 2010) showed a higher probability of occurrence in an area northwest from Barrow in the fall, which supports the latter hypothesis.

Between 5 and 18 Sep, bowhead calls were consistently detected at all three Barrow stations, with a peak between 6 and 12 Sep (Figure 37). There were no other detections in the program area during that period (Figure 40). A few whales appear to have crossed the northeastern Chukchi Sea around 24 Sep, based on detections moving from Barrow on 22–23 Sep, to Wainwright and PL50 on 24 Sep, and to PLN40 and CLN90 on 25 and 26 Sep, respectively (Figure 37, Figure 41).

A more sustained movement of bowheads throughout the program area started around 28 Sep and lasted until the end of the recording period (around 10 Oct). Bowhead calls were first detected at the Barrow stations, but were nearly absent off Wainwright (Figure 37, Figure 42). They were commonly detected at the PLN stations as well as Station BG01 and to a lesser extent at the two CLN stations. Figure 42 suggests the migration corridor was between 71° N and 72° N, with few individuals following the coast past Barrow. This affirms the 2009 and 2010 observations (Delarue et al. 2011). Again, the Klondike lease area was at the southern edge of the migration corridor while the Burger and Statoil lease areas were at its core. The summer 2011 call counts were lower than those of 2010, which suggests that although the migration timing was comparable to that of previous program years—late Sep to early Oct—either fewer individuals transited through the northeastern Chukchi Sea or most bowheads summering in the Beaufort Sea migrated in early Oct, after we retrieved the summer recorders. A delayed migration was also observed in fall 2007, a year that, like 2011, had record-low ice conditions.

The detected calls consisted mostly of simple moans (Figure 43) although we detected a higher proportion of complex calls near the end of the recording period. See Section 3.6 *Seismic Survey Sounds and Marine Mammals*, p 101.

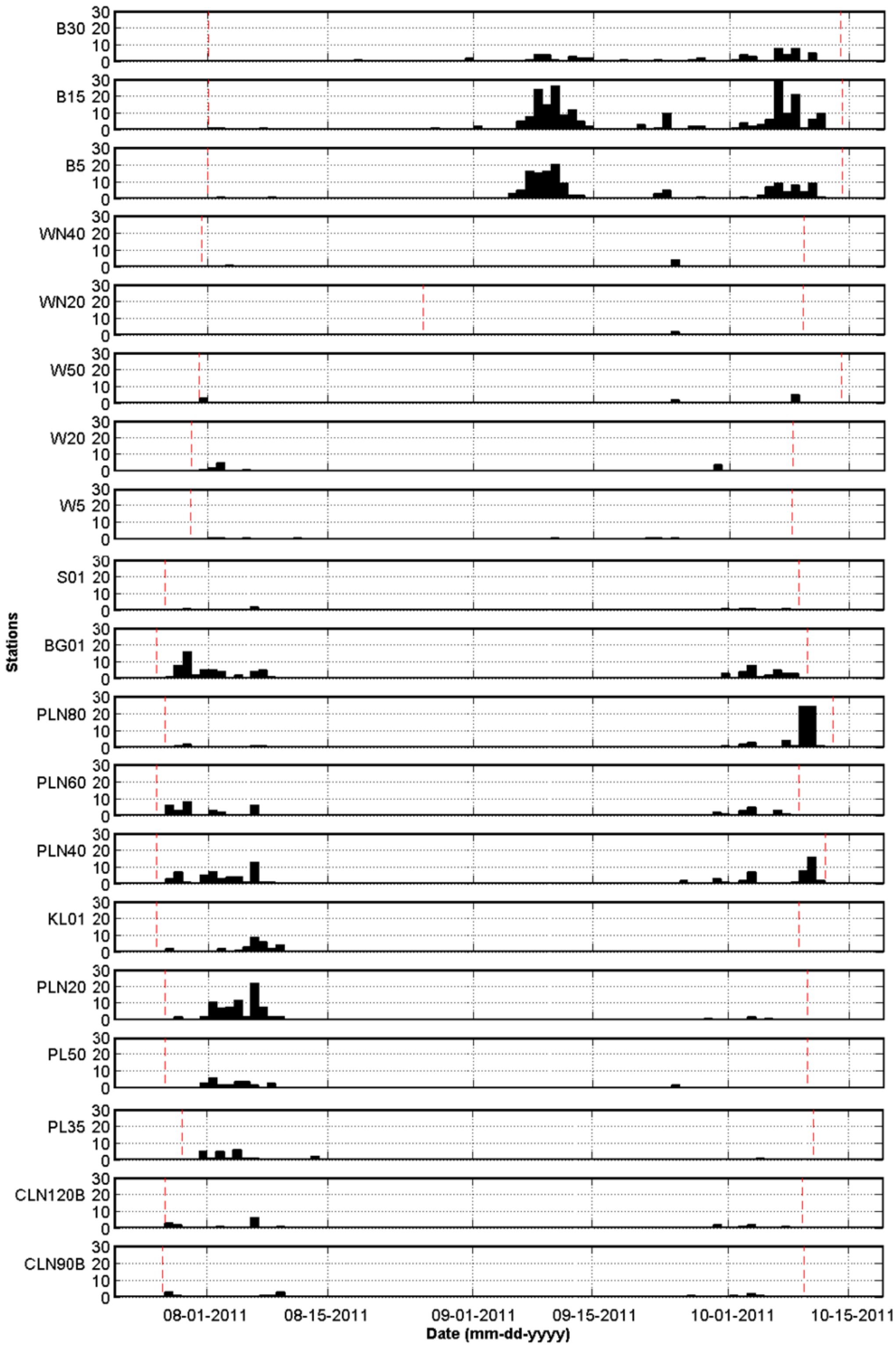

Figure 37. Summer 2011 Daily Bowhead Call Detections: Daily number of sound files (six 40-min files recorded per day) with call detections based on the manual analysis of 5% of the acoustic data recorded late Jul through mid-Oct 2011 in the northeastern Chukchi Sea for each station. Red dashed lines indicate recording start and end. Stations without call detections were omitted.

Table 12. Summer 2011 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 for each recording station in the northeastern Chukchi Sea. Stations without call detections were omitted.

Bowhead Whale					
Station	Record start	First detection	Last detection	Record end	Detection days
B30	01 Aug	18 Aug	10 Oct	12 Oct	20
B15	01 Aug	01 Aug	11 Oct	12 Oct	30
B05	31 Jul	02 Aug	11 Oct	13 Oct	23
WN40	31 Jul	03 Aug	24 Sep	08 Oct	2
WN20	26 Aug	24 Sep	24 Sep	08 Oct	1
W50	30 Jul	31 Jul	8 Oct	12 Oct	3
W20	30 Jul	31 Jul	29 Sep	07 Oct	5
W05	29 Jul	01 Aug	24 Sep	07 Oct	6
S01	28 Jul	29 Jul	7 Oct	08 Oct	6
BG01	27 Jul	27 Jul	8 Oct	09 Oct	19
PLN80	28 Jul	28 Jul	11 Oct	12 Oct	12
PLN60	27 Jul	27 Jul	7 Oct	08 Oct	12
PLN40	27 Jul	27 Jul	11 Oct	11 Oct	21
KL01	27 Jul	27 Jul	9 Aug	08 Oct	8
PLN20	28 Jul	28 Jul	5 Oct	09 Oct	14
PL50	28 Jul	31 Jul	24 Sep	09 Oct	9
PL35	29 Jul	31 Jul	4 Oct	09 Oct	9
CLN120B	27 Jul	27 Jul	7 Oct	08 Oct	9
CLN90	26 Jul	27 Jul	4 Oct	08 Oct	9

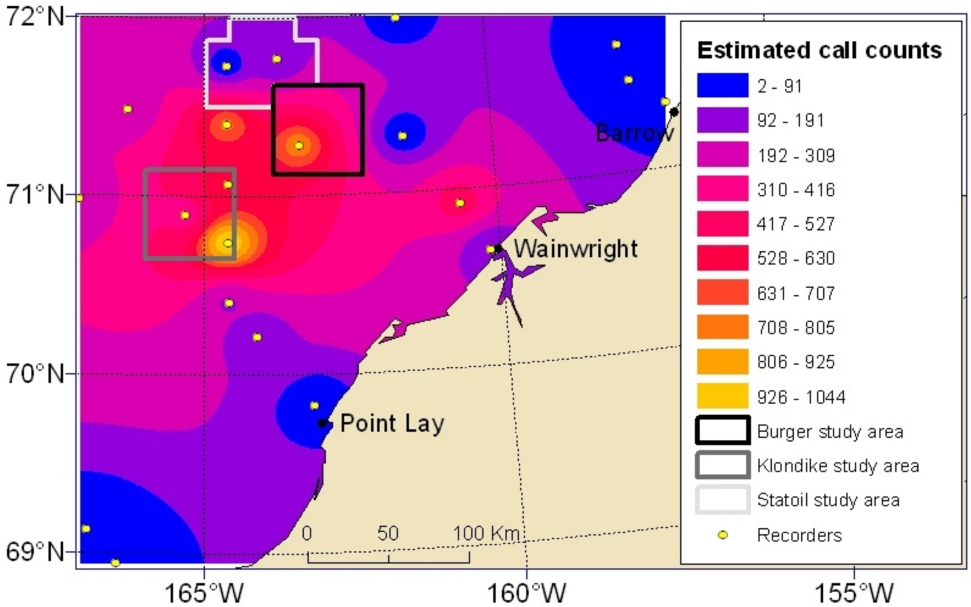

Figure 38. Interpolated bowhead whale call count contour plot based on the sum of automated call detections in all files with manual detections for 27 Jul through 15 Aug at all summer 2011 recording stations in the northeastern Chukchi Sea. Only the results of operational recorders are shown.

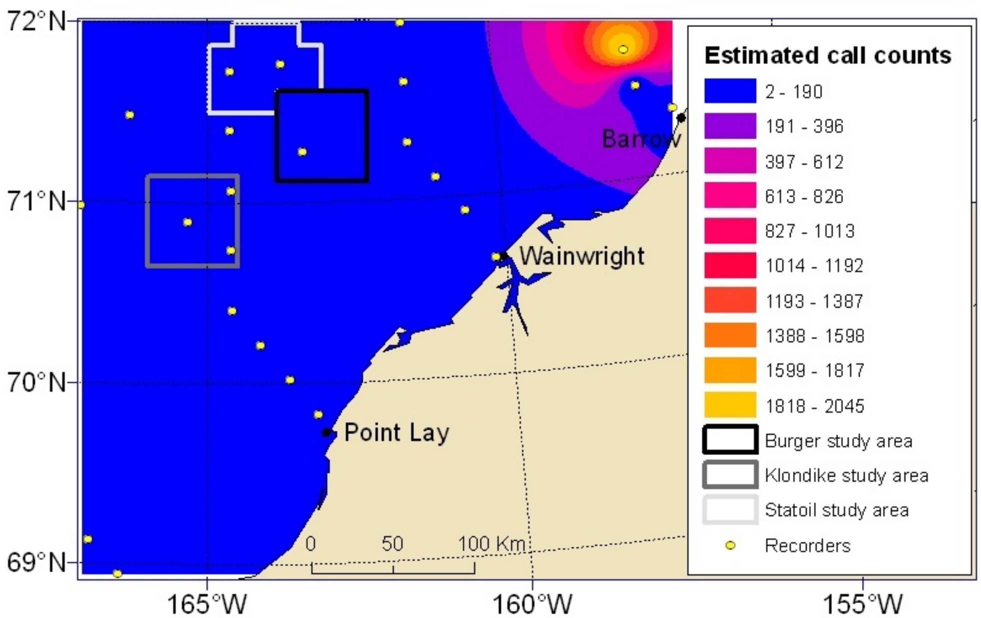

Figure 39. Interpolated bowhead whale call count contour plot based on the sum of automated call detections in all files with manual detections for 16–31 Aug at all summer 2011 recording stations in the northeastern Chukchi Sea.

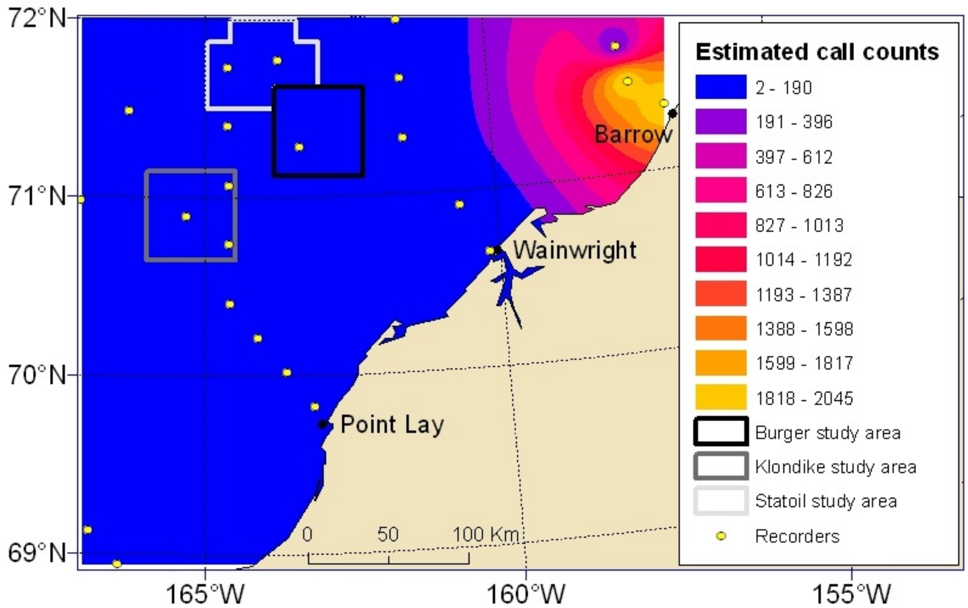

Figure 40. Interpolated bowhead whale call count contour plot based on the sum of automated call detections in all files with manual detections for 1–15 Sep at all summer 2011 recording stations in the northeastern Chukchi Sea. Only the results of operational recorders are shown.

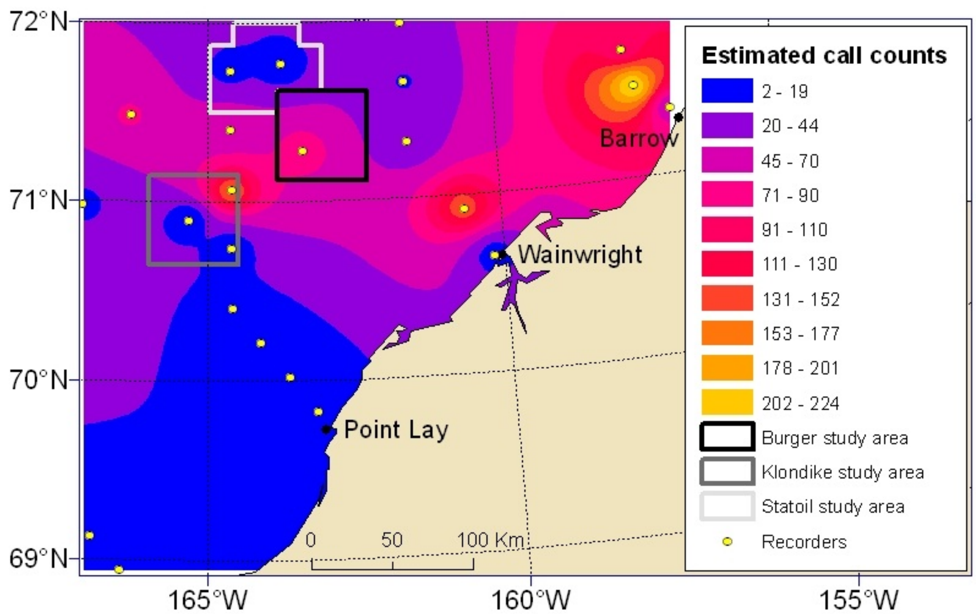

Figure 41. Interpolated bowhead whale call count contour plot based on the sum of automated call detections in all files with manual detections for 16–30 Sep at all summer 2011 recording stations in the northeastern Chukchi Sea. Only the results of operational recorders are shown.

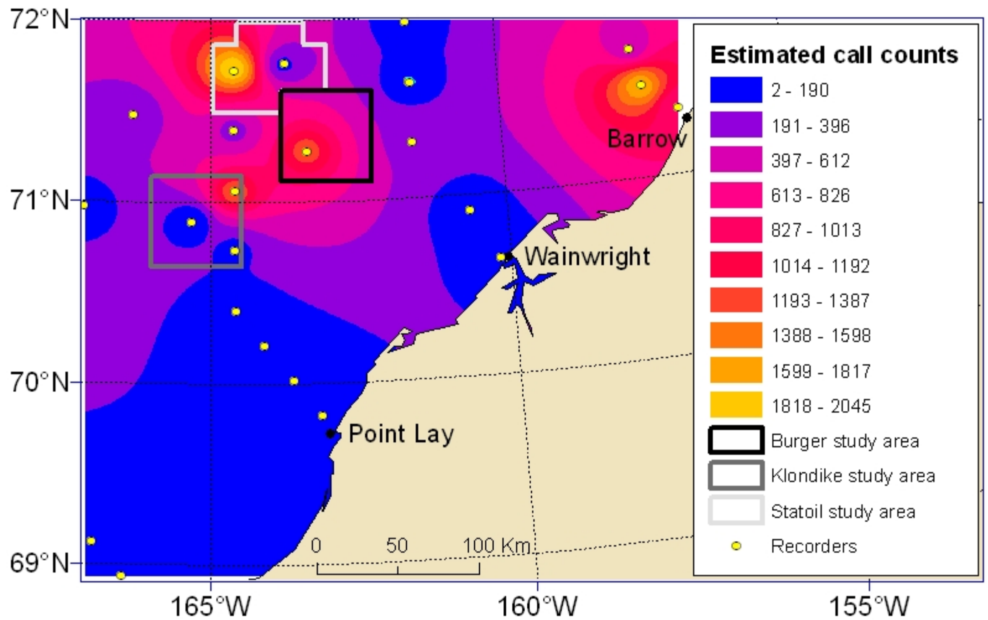

Figure 42. Interpolated bowhead whale call count contour plot based on the sum of automated call detections in all files with manual detections for 1–12 Oct at all summer 2011 recording stations in the northeastern Chukchi Sea. Only the results of operational recorders are shown.

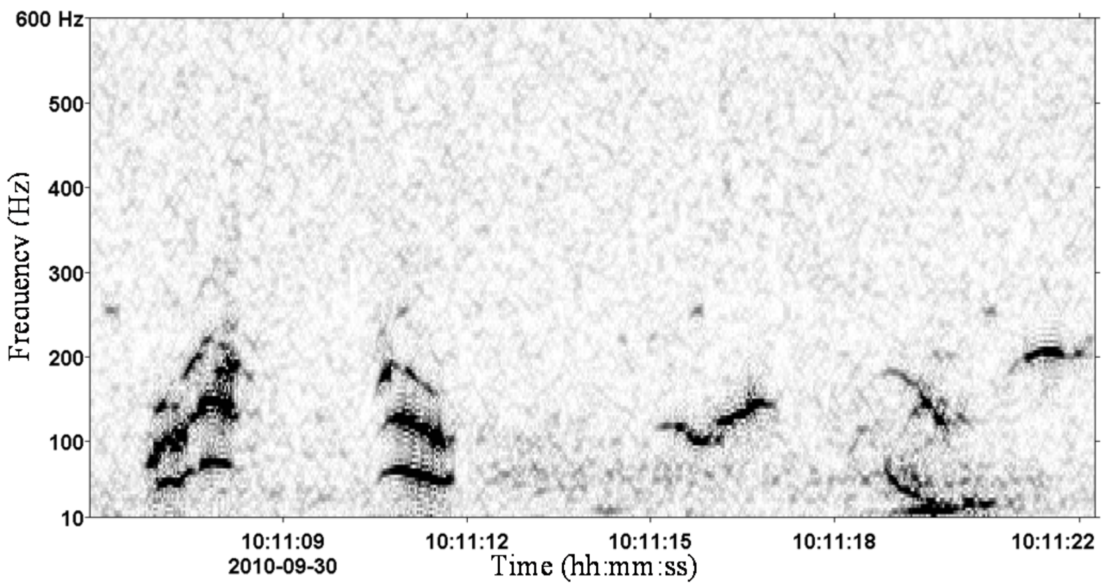

Figure 43. Spectrogram of bowhead moans at summer 2010 Station B50, 30 Sep 2010 (2048 pt FFT, 4096 real pts, 1024 pt advance, Hamming window; Delarue et al. 2011).

3.5.4. Walrus Call Detections

3.5.4.1. Winter 2010–2011 Program

Walrus (*Odobenus rosmarus*) calls were detected at Station PLN80 on 20 Nov 2010, at WN40 on 14 Dec, and at PLN40 on 27 Dec and 27 Feb 2011 (Figure 44, Table 13). These detections indicate some individuals remained in the northeastern Chukchi Sea later than most of the population, which typically leaves the area by mid-Oct. If walrus were detected in Dec or later, it was at PLN40.

In spring 2011, walrus calls were recorded at all stations, although there were fewer at Station B05. The first detections occurred 14 May at Station PLN40, earlier than in any other program year. Most of the detections followed the similar pattern observed in previous years (Delarue et al. 2011). On 29 May, walrus were first detected at Station CL50, which was a few days earlier than when they typically arrive (the first week of Jun; Delarue et al. 2011), after which they progressed northeast (Figures 44 to 48). Detections started at Station WN40 about a month later, on 26 Jun. Because the main detection period lasted 3–4 weeks, we believe walrus were mainly transiting at Station CL50 and to a lesser extent at Stations PL50 and PLN40. In contrast, once walrus reached Stations PLN80, W50, and, in particular, WN40, they were detected daily until the end of the program. Their progression northeast followed the retreat of sea ice (Figures 45 to 48); however, they remained in the Hanna Shoal area (near Stations WN40 and W50) in the second half of Jul when the ice edge was farther north, confirming this is a key foraging area for walrus in the northeastern Chukchi Sea.

The high call counts in the second half of Jun indicate this was the peak of the walrus northward migration into the program area. The highest call counts were recorded at Stations WN40 and W50 in the second half of Jul, presumably because of increasing walrus density in this favored feeding area following the disappearance of sea ice in the rest of the program area, and because sea ice usually stays longer at Hanna Shoal.

Most detected walrus calls consisted of a variety of grunt-like sounds; knocks and bell sounds were detected intermittently (Figure 49; Stirling et al. 1983, 1987, Schusterman and Reichmuth 2008). All late (winter) detections consisted of knock sequences, produced by males (Stirling et al. 1987).

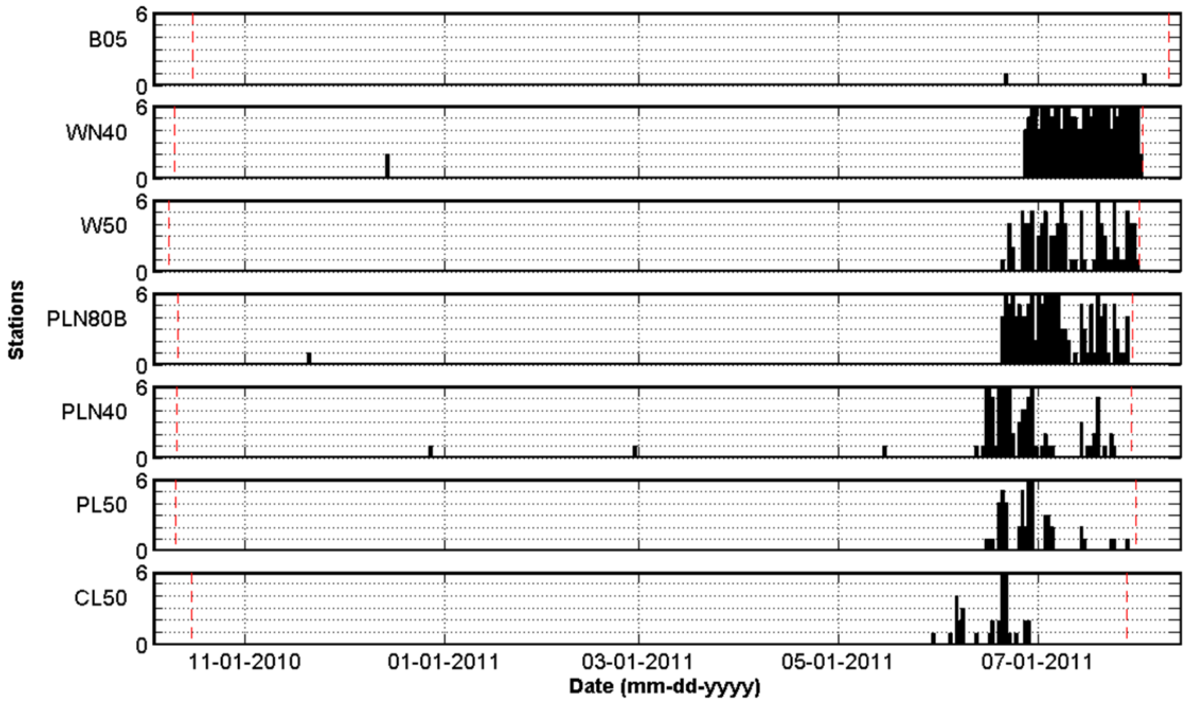

Figure 44. Winter 2010–2011 Daily Walrus Call Detections: Daily number of sound files (six 40-min files recorded per day) with call detections based on the manual analysis of 5% of the acoustic data recorded mid-Oct 2010 through early Aug 2011 in the northeastern Chukchi Sea for each station. Red dashed lines indicate when the recording started and ended.

Table 13. Winter 2010–2011 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 40 min of every 4 h.

Station	Record start	Fall–Winter 2010–2011			Spring 2011			Record end
		First detection	Last detection	Detection days	First detection	Last detection	Detection days	
B05	16 Oct	–	–	0	20 Jun	01 Aug	2	06 Aug
WN40	10 Oct	14 Dec	14 Dec	1	26 Jun	31 Jul	36	31 Jul
W50	10 Oct	–	–	0	19 Jun	30 Jul	3	30 Jul
PLN80	11 Oct	20 Nov	20 Nov	1	19 Jun	27 Jul	36	28 Jul
PLN40	11 Oct	27 Dec	27 Feb	2	14 May	23 Jul	30	27 Jul
PL50	11 Oct	–	–	0	14 Jun	27 Jul	19	28 Jul
CL50	15 Oct	–	–	0	29 May	27 Jun	15	26 Jul

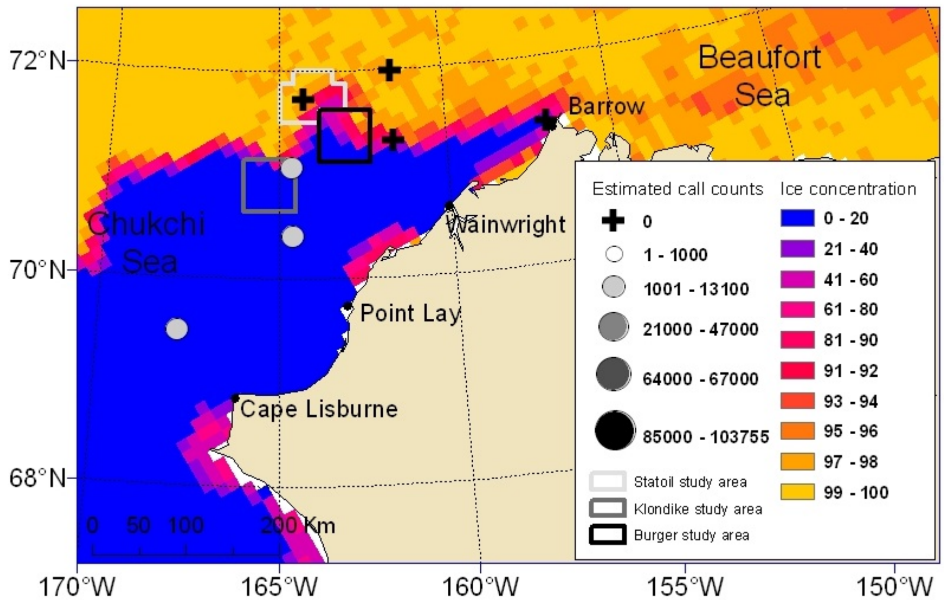

Figure 45. Walrus call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for 1–15 Jun 2011 at the seven operational winter 2010–2011 recording stations. Ice concentration data are from 7 Jun 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

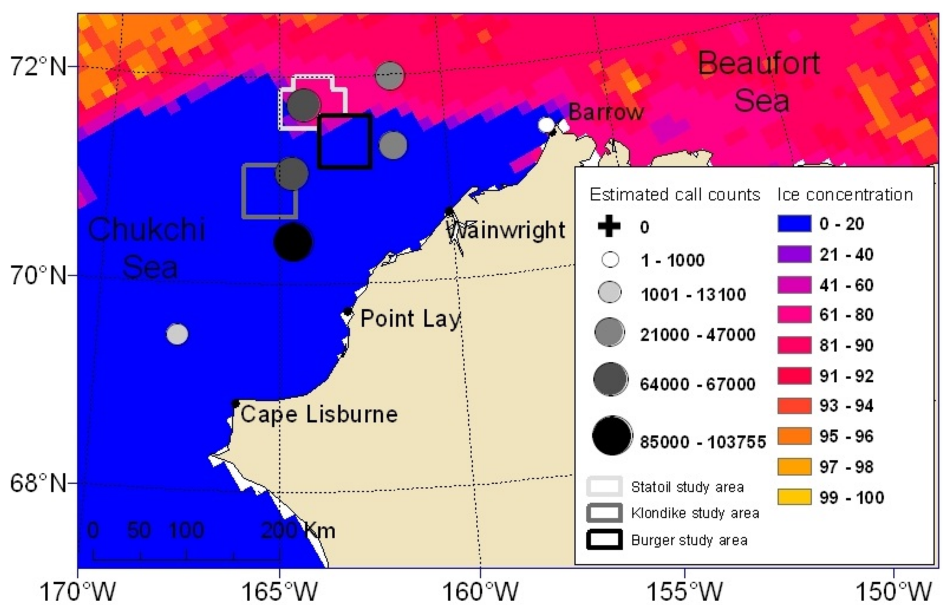

Figure 46. Walrus call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for 16–30 Jun 2011 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 22 Jun 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

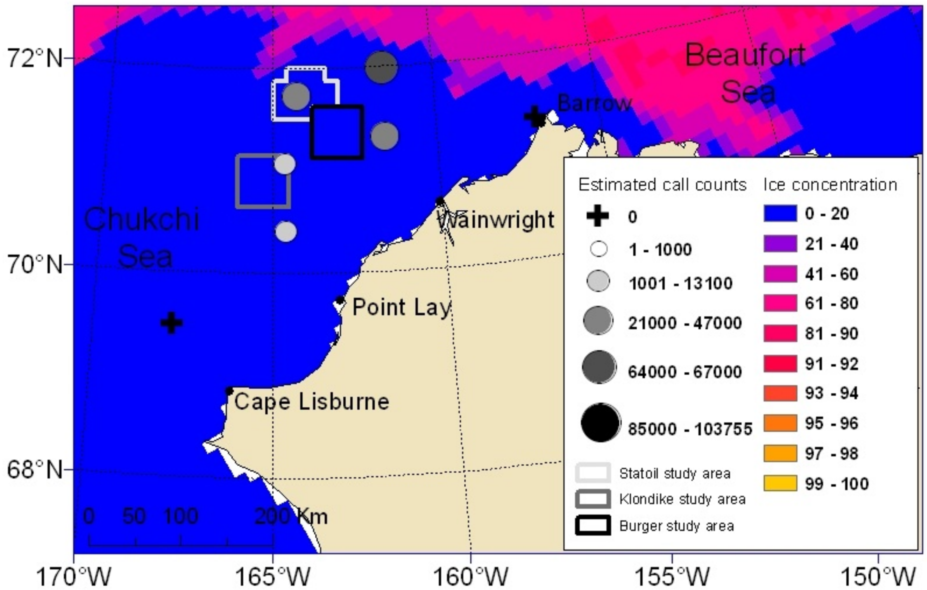

Figure 47. Walrus call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for 1–15 Jul 2011 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 7 Jul 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

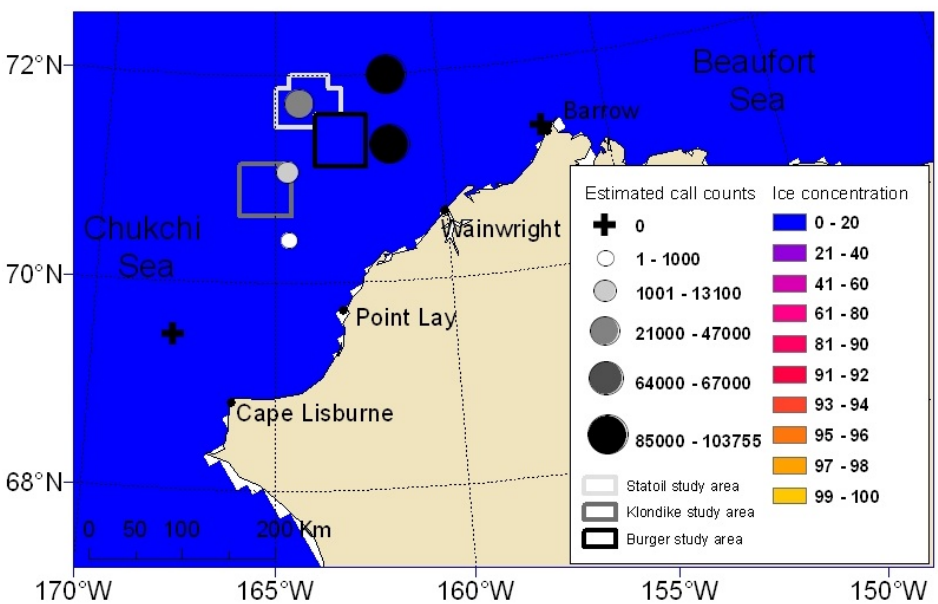

Figure 48. Walrus call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for 16–31 Jul 2011 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 22 Jul 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

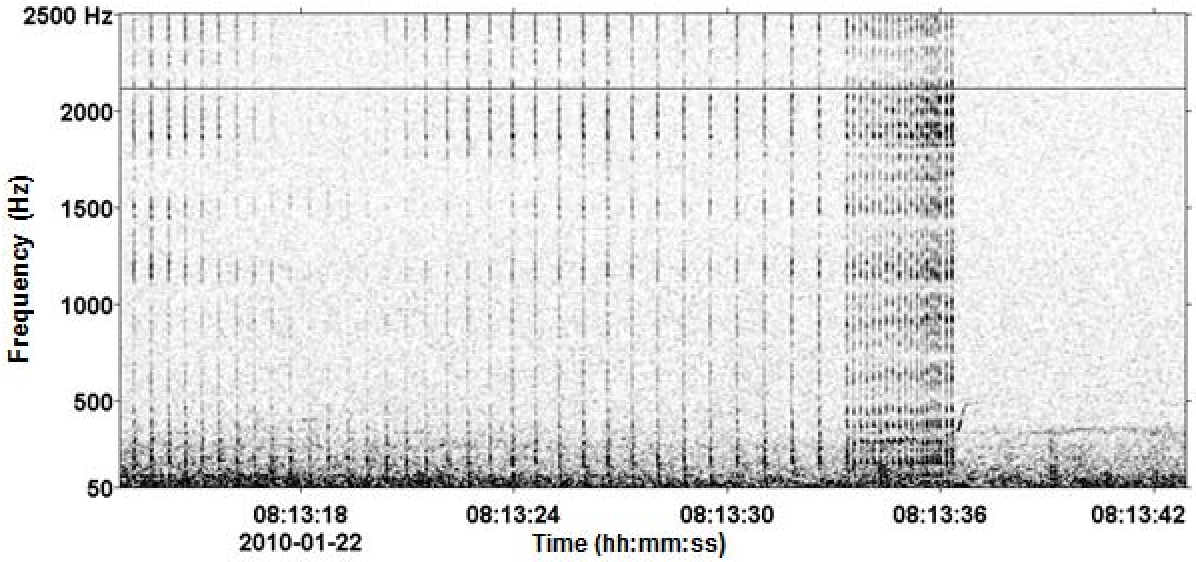

Figure 49. Spectrogram of walrus knocks and bell sounds recorded at winter 2009–2010 Station PLN40, 22 Jan 2010 (2048 pt FFT, 2048 real pts, 512 pt advance, Hamming window; Delarue et al. 2011).

3.5.4.2. Summer 2011 Program

Walrus calls were detected acoustically at all summer 2011 stations throughout the program (late Jul through early Oct). The first walrus call detection was 26 Jul at Station CL20; the last detections were at Stations B30 and W50 on 11 Oct. Excluding Stations W35 and WN20, which had shorter recording periods, the recording stations had an average of 47.7 walrus call detection days (Table 14). W50 and PL05 had the most detection days (n = 73). Station BG01, in the Burger lease area, recorded walrus on 65 days; KL01 (Klondike lease area) and S01 (Statoil lease area) recorded walrus on 32 and 40 days, respectively.

The daily number of stations at which walrus calls were detected (Figure 50) varied throughout the season, with an average of 14.3 stations per day. Two sustained peaks were observed, one from 23 Aug to 5 Sep and another from 28 Sep to 8 Oct, with walrus detected at about 20 stations on several consecutive days. In contrast, there was an area-wide drop in detections between 15 and 19 Sep. About six stations per day recorded walrus calls during that period.

The number of walrus calls detected at each station varied depending on location and time (Figures 52 to 56). Stations in the southern Hanna Shoal area (Stations W50, WN20, and WN40) and near Point Lay (Station PL05) consistently had the highest call counts. Because of high walrus densities near Point Lay, PL05 had the highest call counts throughout the summer (Figures 52 to 56). In 2011 and in previous summer programs, the walrus preferred southern Hanna Shoal as a feeding ground (see Delarue et al. 2011). The distribution of walrus was broadest from the end of Jul to the end of Aug (Figure 52, Figure 53), presumably because remnant ice in the area, at least until early Aug, allowed walrus to forage more broadly. When no ice remained on which they could haul out, walrus returned to shore to rest.

Walrus may have foraged only in the most productive areas, which would have decreased their distribution and possibly explain the narrower corridor between Hanna Shoal and the main haul-out near Point Lay starting in early Sep (Figures 53 and 54). From mid-Sep until the end of the recording period, call counts decreased, indicating the onset of the southward migration out of the northeastern Chukchi Sea. The decrease in call counts at stations near Hanna Shoal and the simultaneous increase near Point Lay from the second half of Sep through the first half of Oct (Figure 55, Figure 56) further indicate southward migration of walrus, mainly along the coast between Point Lay and Cape Lisburne. The relatively high call counts at Station CL05 compared with the other Cape Lisburne stations throughout the summer not only suggest that this area acts as the exit point from the northeastern Chukchi Sea, but also that there may be a walrus haul-out in the vicinity.

The manually detected walrus calls included various grunts, knocks, and bell calls (as described by Stirling et al. 1983, 1987, and Schusterman and Reichmuth 2008). The automated call detector targeted grunts because of their prevalence and longer detection range (JASCO, unpublished data; Figure 57).

See Section 3.6 *Seismic Survey Sounds and Marine Mammals*, p 101.

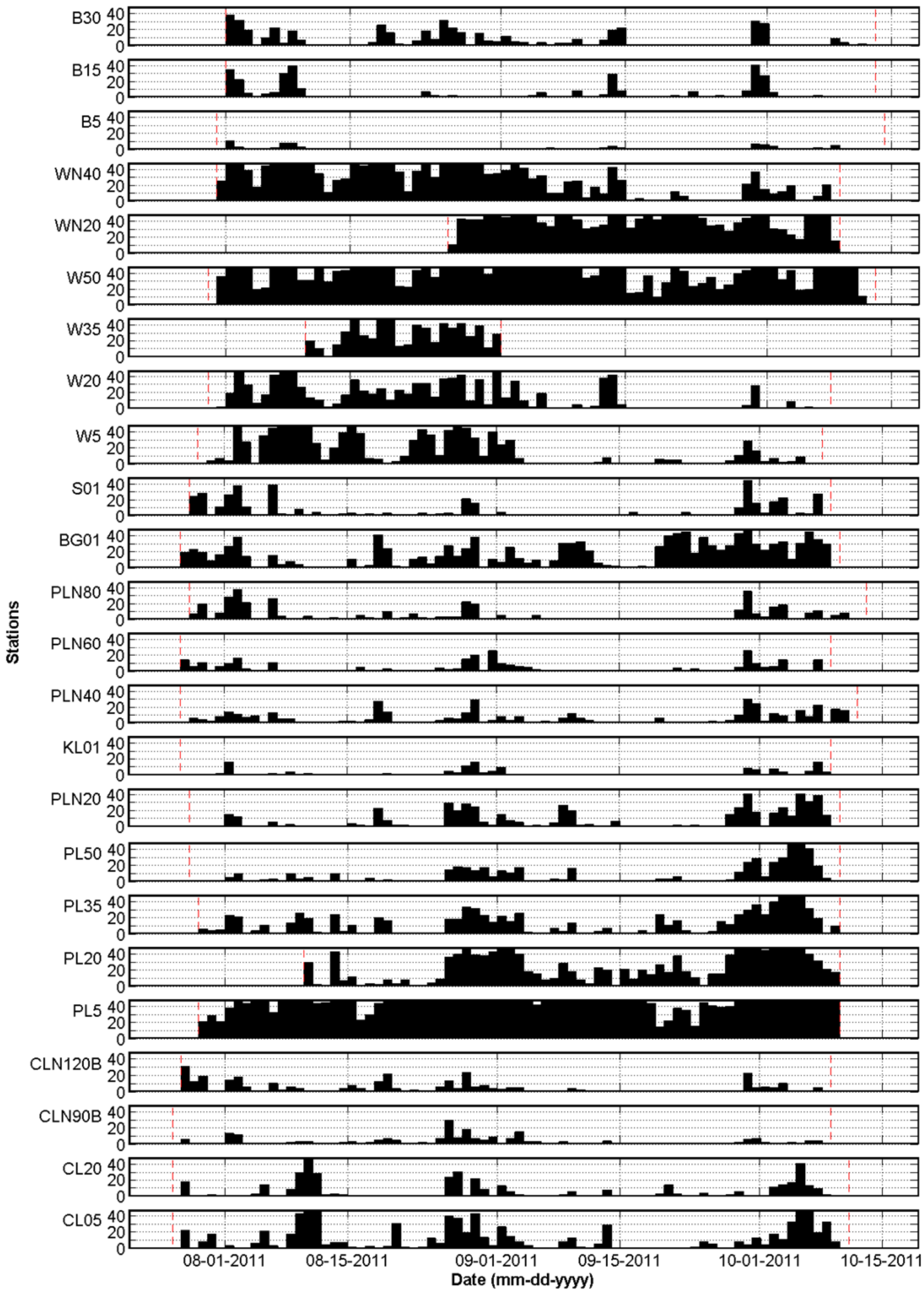

Figure 50. Summer 2011 Daily Walrus Call Detections: Daily number of sound files (six 40-min files recorded per day) with call detections based on the manual analysis of 5% of the acoustic data recorded late Jul through mid-Oct 2011 in the northeastern Chukchi Sea for each station. Red dashed lines indicate recording start and end. Stations without call detections were omitted.

Table 14. Summer 2011 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 for each recording station in the northeastern Chukchi Sea. Stations without call detections were omitted.

Walrus					
Station	Record Start	First detection	Last detection	Record end	Detection days
B30	01 Aug	01 Aug	11 Oct	12 Oct	40
B15	01 Aug	01 Aug	08 Oct	12 Oct	33
B05	31 Jul	01 Aug	10 Oct	13 Oct	24
WN40	31 Jul	31 Jul	07 Oct	08 Oct	60
WN20	26 Aug	26 Aug	08 Oct	08 Oct	44
W50	30 Jul	31 Jul	11 Oct	12 Oct	73
W35	30 Jul	10 Aug	31 Aug	13 Oct	21
W20	30 Jul	31 Jul	05 Oct	07 Oct	50
W05	29 Jul	30 Jul	05 Oct	07 Oct	51
S01	28 Jul	28 Jul	07 Oct	08 Oct	40
BG01	27 Jul	27 Jul	08 Oct	09 Oct	65
PLN80	28 Jul	28 Jul	10 Oct	12 Oct	45
PLN60	27 Jul	27 Jul	07 Oct	08 Oct	36
PLN40	27 Jul	27 Jul	10 Oct	11 Oct	51
KL01	27 Jul	29 Jul	08 Oct	08 Oct	32
PLN20	28 Jul	01 Aug	08 Oct	09 Oct	45
PL50	28 Jul	29 Jul	09 Oct	09 Oct	41
PL35	29 Jul	29 Jul	09 Oct	09 Oct	52
PL20	29 Jul	29 Jul	09 Oct	09 Oct	59
PL05	29 Jul	29 Jul	09 Oct	09 Oct	73
CLN120B	27 Jul	27 Jul	07 Oct	08 Oct	42
CLN90	26 Jul	27 Jul	08 Oct	08 Oct	38
CL20	26 Jul	26 Jul	08 Oct	10 Oct	43
CL05	26 Jul	27 Jul	10 Oct	10 Oct	56

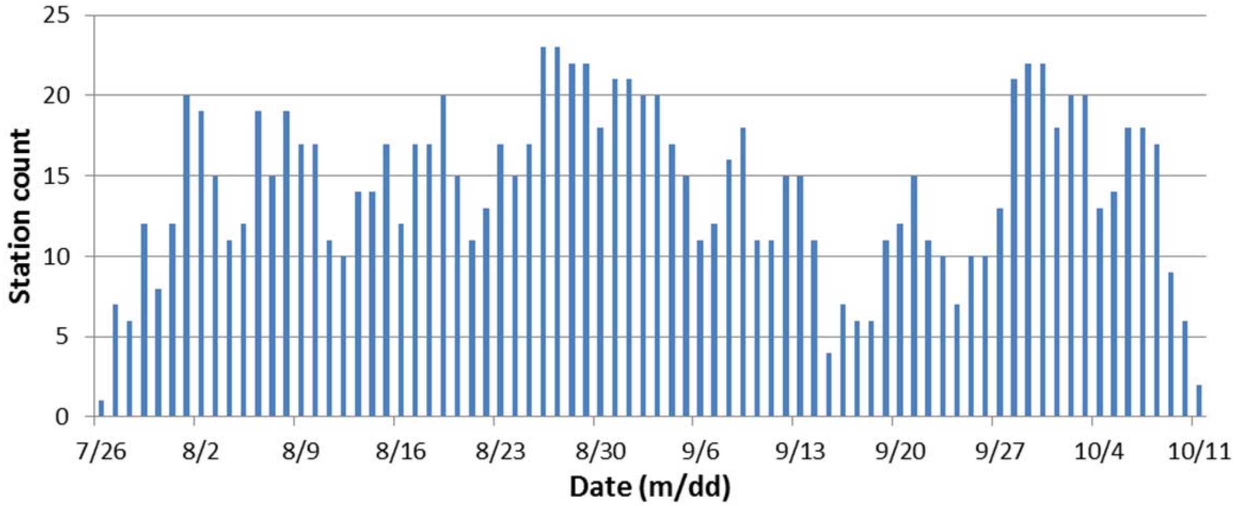

Figure 51. Daily number of summer stations with walrus acoustic detections for 26 Jul through 11 Oct 2011 in the northeastern Chukchi Sea.

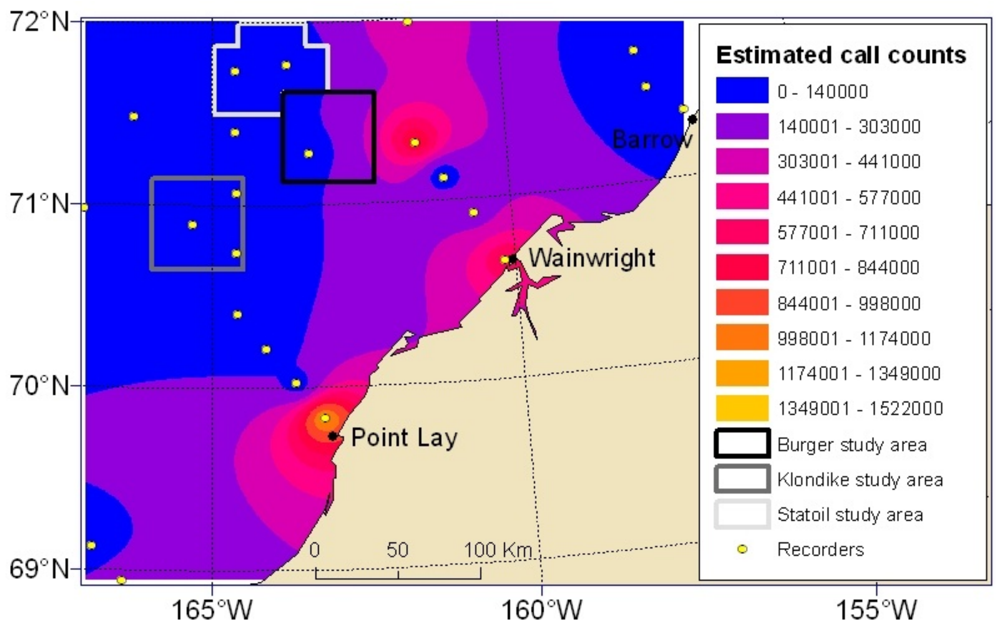

Figure 52. Interpolated walrus call counts based on the sum of automated call detections in all files with manual detections for 27 Jul through 15 Aug at all summer 2011 recording stations in the northeastern Chukchi Sea.

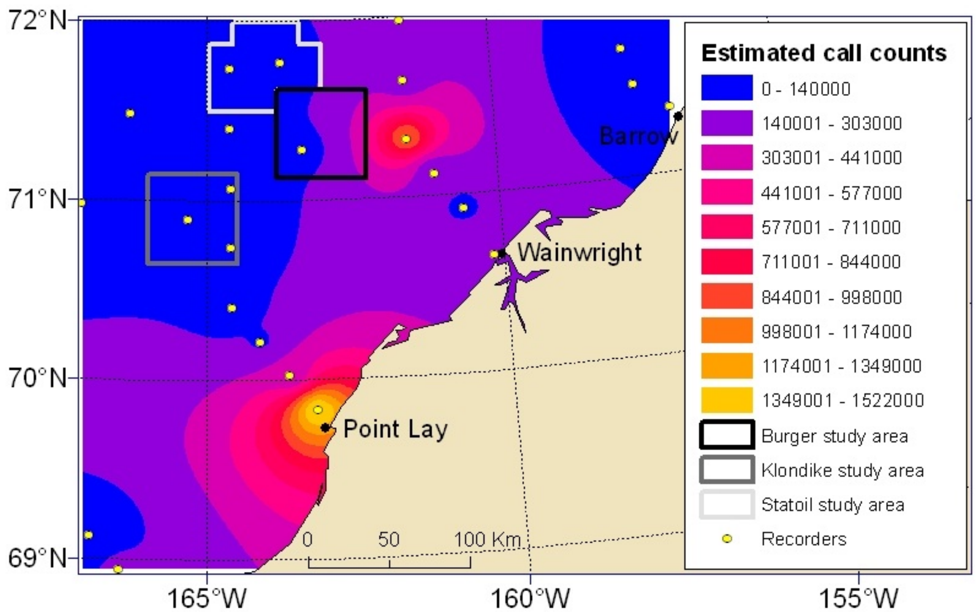

Figure 53. Interpolated walrus call counts based on the sum of automated call detections in all files with manual detections for 16–31 Aug at all summer 2011 recording stations in the northeastern Chukchi Sea.

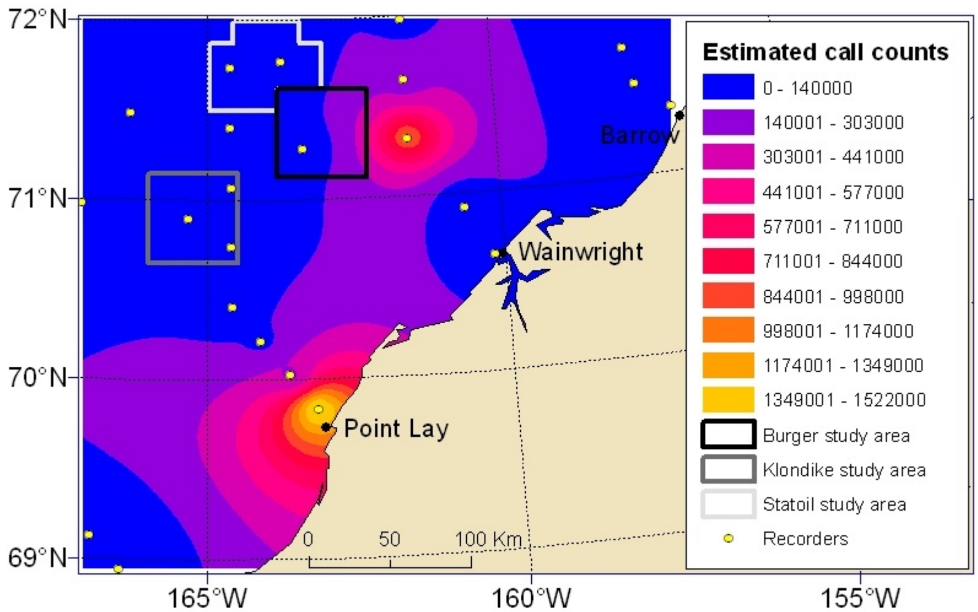

Figure 54. Interpolated walrus call counts based on the sum of automated call detections in all files with manual detections for 1–15 Sep at all summer 2011 recording stations in the northeastern Chukchi Sea.

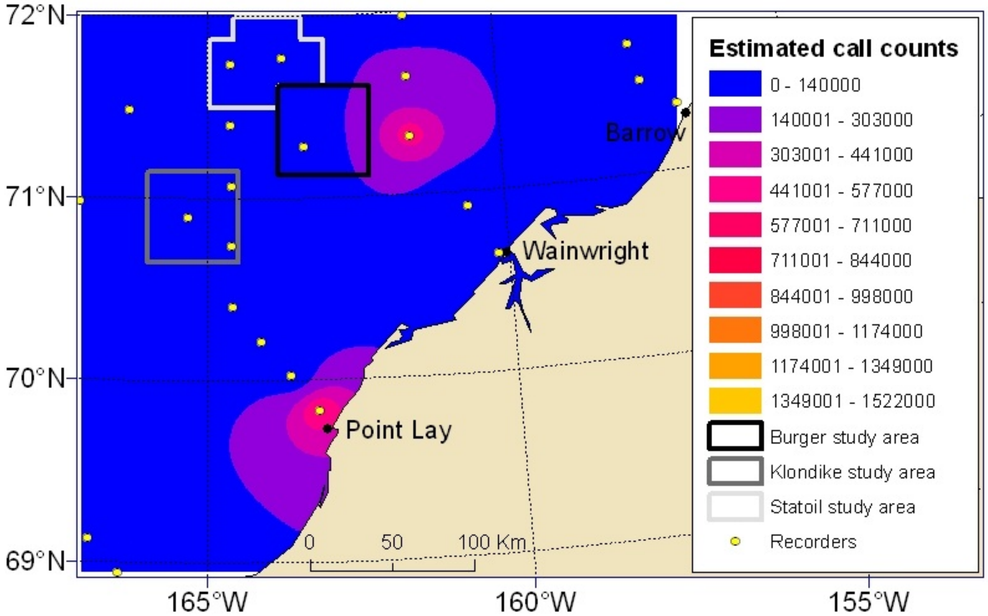

Figure 55. Interpolated walrus call counts based on the sum of automated call detections in all files with manual detections for 16–30 Sep at all summer 2011 recording stations in the northeastern Chukchi Sea.

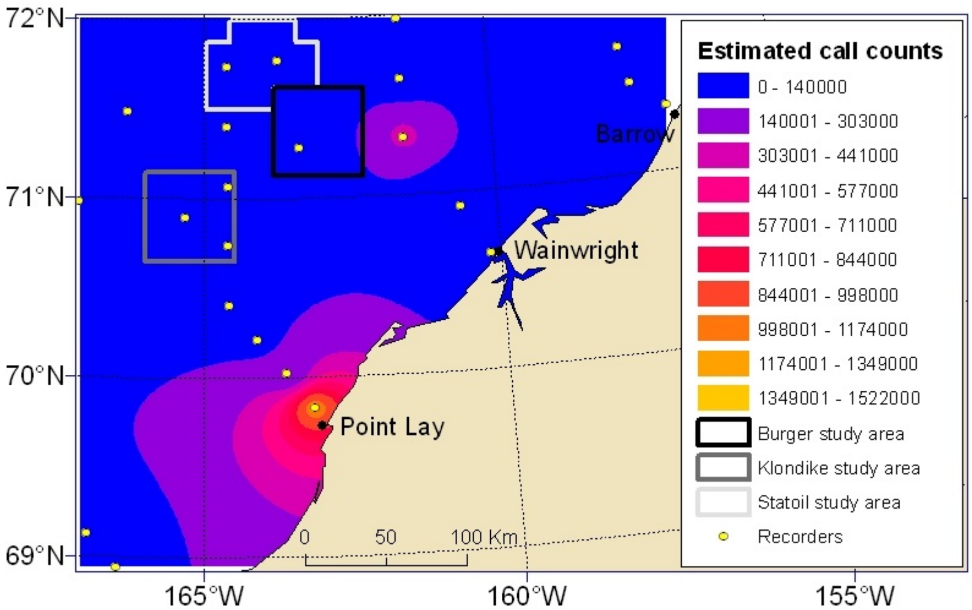

Figure 56. Interpolated walrus call counts based on the sum of automated call detections in all files with manual detections for 1–12 Oct at all summer 2011 recording stations in the northeastern Chukchi Sea. Most recorders were retrieved between 8 and 12 Oct.

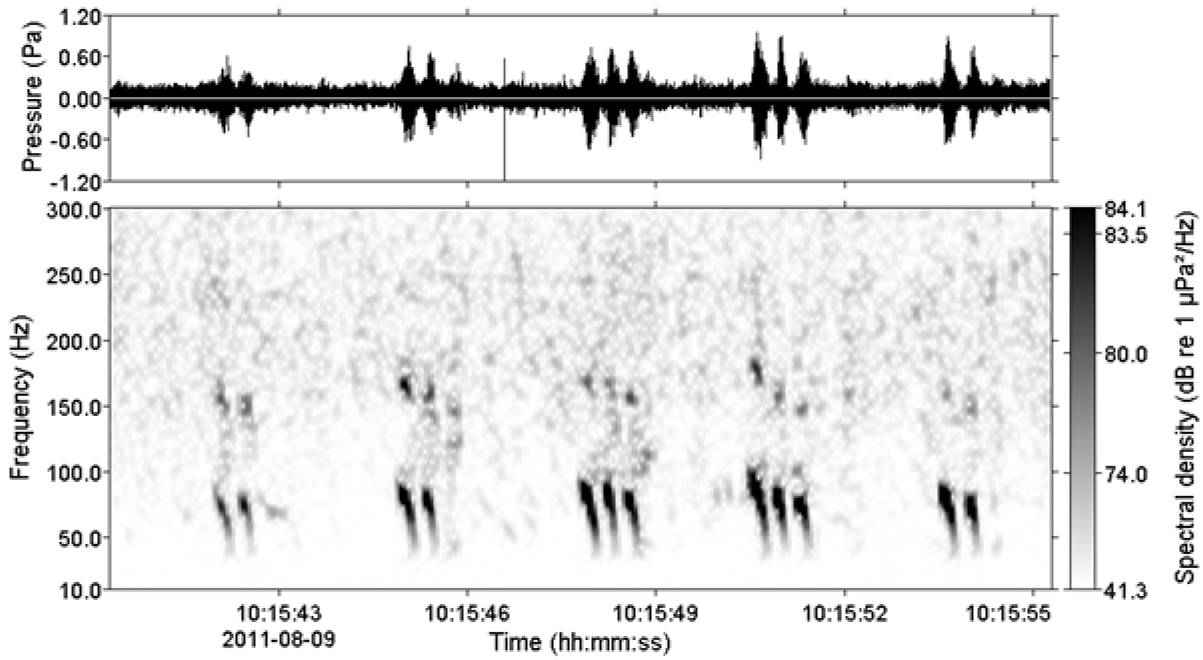

Figure 57. (Top) Pressure signature and (bottom) spectrogram of walrus grunts recorded at summer 2011 Station PL05, 9 Aug 2011 (8192 pt FFT, 3200 pts real data, 80 pt advance, Reisz window).

3.5.5. Beluga Whale Call Detections

3.5.5.1. Winter 2010–2011 Program

Beluga (*Delphinapterus leucas*) calls were detected at all stations in fall and winter 2010–2011. Detections started on 12 Oct 2010 at WN40 and ended on 2 Dec at CL50 except for one detection, which occurred on 20 Jan 2011 at PL50 (Figure 58, Table 15). Richard et al. (2001) have shown some eastern Beaufort Sea belugas migrate west from the Beaufort Sea toward Wrangel Island along and north of the Beaufort/Chukchi shelf edge, thus remaining out of the instrumented area. Because these tagged individuals migrated north of Barrow in late Aug and early Sep, the timing of these detections suggests the detected belugas belonged to the eastern Chukchi Sea stock (Suydam et al. 2005, Delarue et al. 2011).

Except for an early WN40 detection, most Oct detections occurred at B05. Detections at B05 ended on 15 Nov, about the same time they started occurring regularly at the Point Lay and Cape Lisburne stations. This contrasts with detections from the 2010 fall migration when many detections occurred at B05 and few occurred elsewhere in the program area, possibly indicating that eastern Chukchi Sea belugas may preferentially migrate within 65 km of shore (Delarue et al. 2011). The detection pattern of fall 2011 suggests belugas fanned out from Barrow as they headed west-southwest toward the northern Chukotkan coast and the Bering Strait.

The relatively short beluga detection period ended on 2 Dec at CL50; however, one detection occurred on 20 Jan at PL50, which is the latest detection of the fall beluga migration of all the winter programs (2007–2011). This detection coincides with the mid-Jan bowhead detections at CL50. All fall detections occurred in ice-free water or low to intermediate ice concentrations (i.e., forward or near the encroaching ice edge; Figures 59 to 61).

In spring 2011, beluga calls were detected at all operational recording stations. Detections started on 9 and 11 Mar at PL50 and CL50, respectively. These are the earliest spring detections of all the winter programs (2007–2011). Beluga calls were first recorded at PLN80, one of the northernmost stations, on 22 Mar. Detections continued at a relatively constant rate at CL50 until the third week of May. At the other stations, detections were scattered throughout Apr and May, with PL50, W50, and PLN80 accounting for most detection days (Table 15, Figure 58). B05 had the most detection days of all the stations ($n = 52$) with three moderately distinct migration waves: the first wave occurred 10–23 Apr; the second wave, the longest and most sustained, occurred 26 Apr through 15 May; and the third wave occurred 15–28 May. There were a few isolated detections until the program's end.

The end of the main beluga detection period at B05 coincided with the end of beluga detections at the other stations. This suggests that the spring beluga detections before the end of May were eastern Beaufort Sea belugas, which migrated past Barrow on their way to the Mackenzie River Delta (on the Beaufort Sea) where they aggregate in late spring and early summer.

It is still unknown when in spring eastern Chukchi Sea belugas arrive in the northeastern Chukchi Sea. Their arrival may coincide with their aggregation in Kasegaluk Lagoon (near Point Lay), typically starting in late Jun. Our recorders did not detect migrating beluga calls along the coast (which may be the shortest, and thus favored, route from the Bering Strait) because the recorders are located more than 90 km from shore.

All detections until mid-May occurred in heavy ice concentration.. B05 had the highest call counts. There were fewer call counts further from shore (Figures 62 to 68).

The detected beluga calls include a variety of whistles, buzzes, chirps, and other high-frequency calls (Figure 69; Sjare and Smith 1986, Karlsen et al. 2002, Belikov and Bel'kovich 2006, 2008).

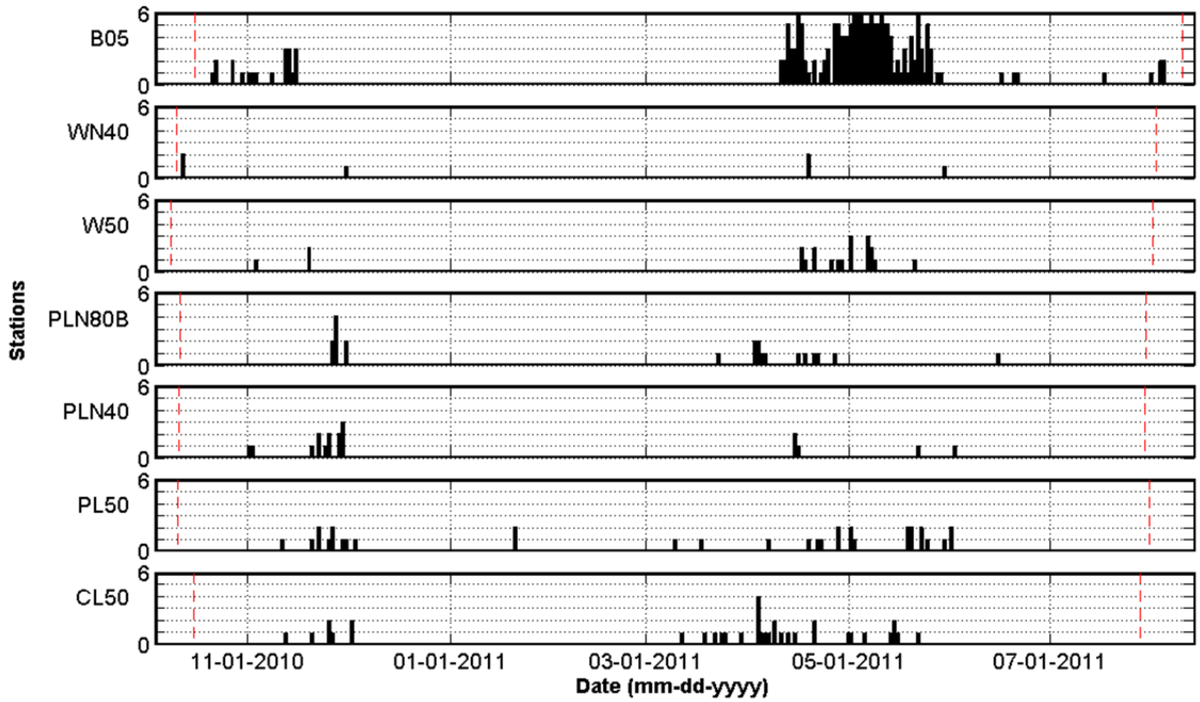

Figure 58. Winter 2010–2011 Daily Beluga Whale Call Detections: Daily number of sound files (six 40-min files recorded per day) with call detections based on the manual analysis of 5% of the acoustic data recorded mid-Oct 2010 through early Aug 2011 in the northeastern Chukchi Sea for each station. Red dashed lines indicate when the recording started and ended.

Table 15. Winter 2010–2011 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 40 min of every 4 h.

Station	Record start	Fall–Winter 2010–2011			Spring 2011			Record end
		First detection	Last detection	Detection days	First detection	Last detection	Detection days	
B05	16 Oct	21 Oct	15 Nov	12	10 Apr	03 Aug	52	06 Aug
WN40	10 Oct	12 Oct	30 Nov	2	18 Apr	29 May	2	31 Jul
W50	10 Oct	03 Nov	19 Nov	2	16 Apr	20 May	11	30 Jul
PLN80	11 Oct	26 Nov	30 Nov	3	22 Mar	14 Jun	11	28 Jul
PLN40	11 Oct	01 Nov	29 Nov	8	14 Apr	01 Jun	4	27 Jul
PL50	11 Oct	11 Nov	20 Jan	9	09 Mar	31 May	15	28 Jul
CL50	15 Oct	12 Nov	02 Dec	5	11 Mar	21 May	22	26 Jul

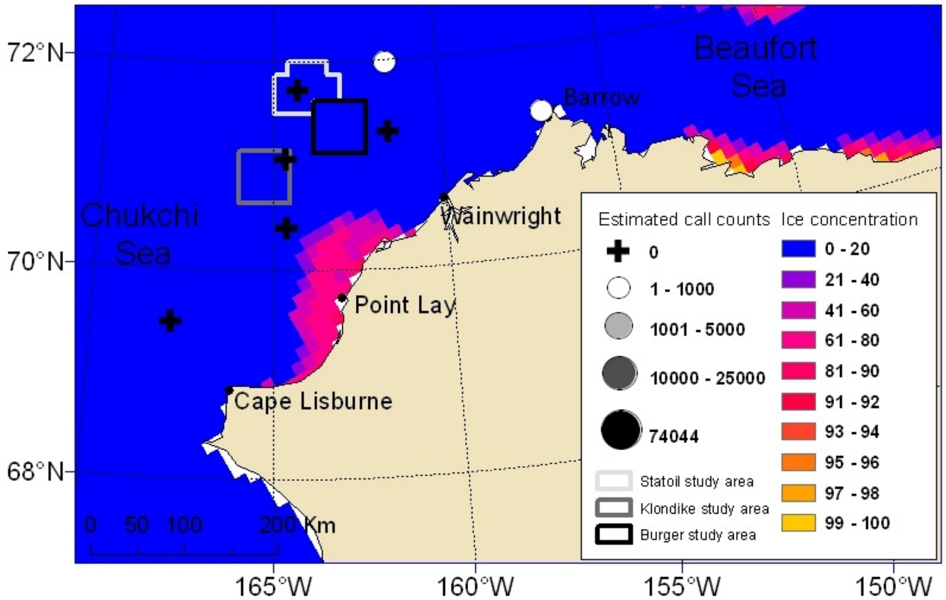

Figure 59. Beluga whale call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for 12–31 Oct 2010 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 22 Oct 2010 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

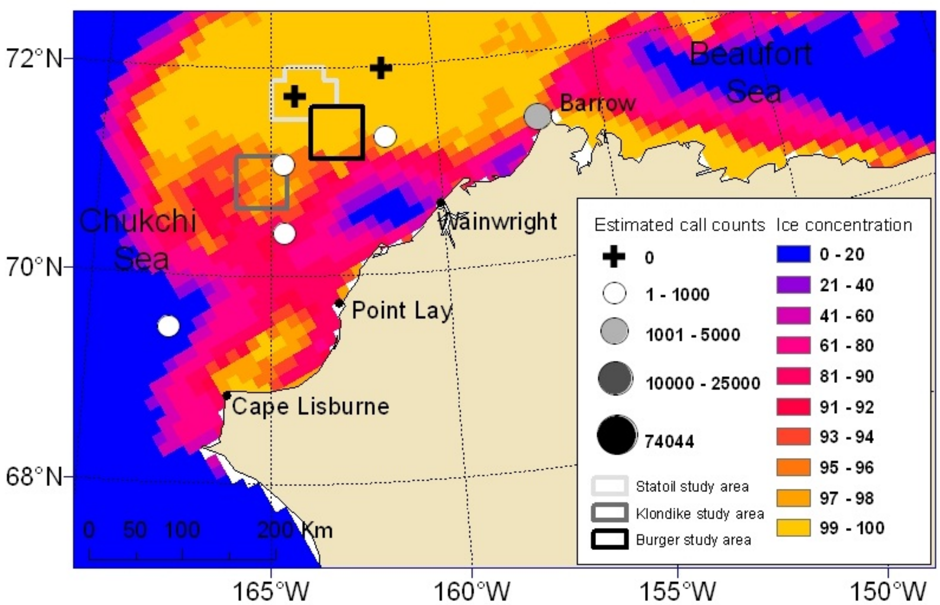

Figure 60. Beluga whale call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for 1–15 Nov 2010 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 7 Nov 2010 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

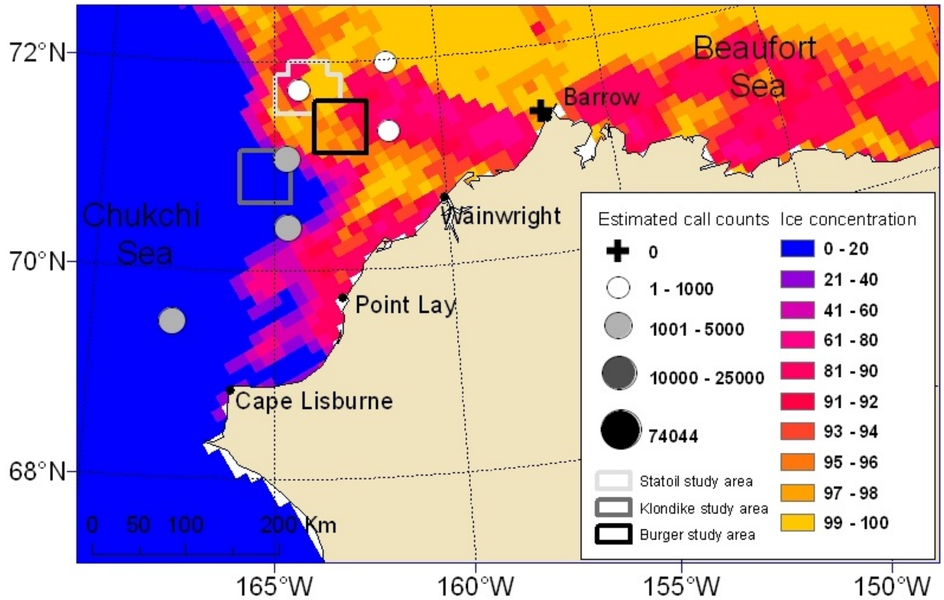

Figure 61. Beluga whale call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for 16 Nov through 2 Dec 2010 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 22 Nov 2010 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

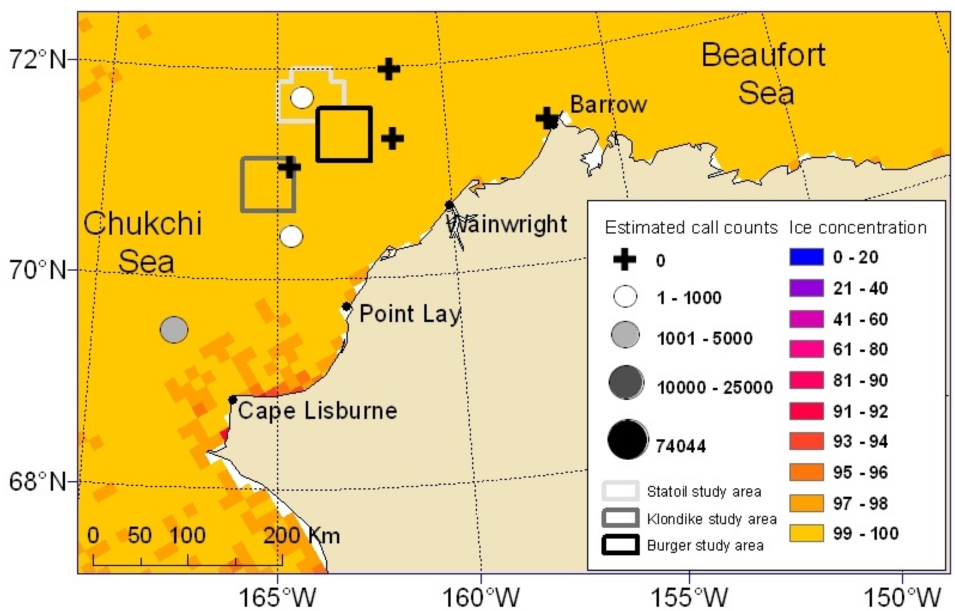

Figure 62. Beluga whale call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for Mar 2011 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 15 Mar 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

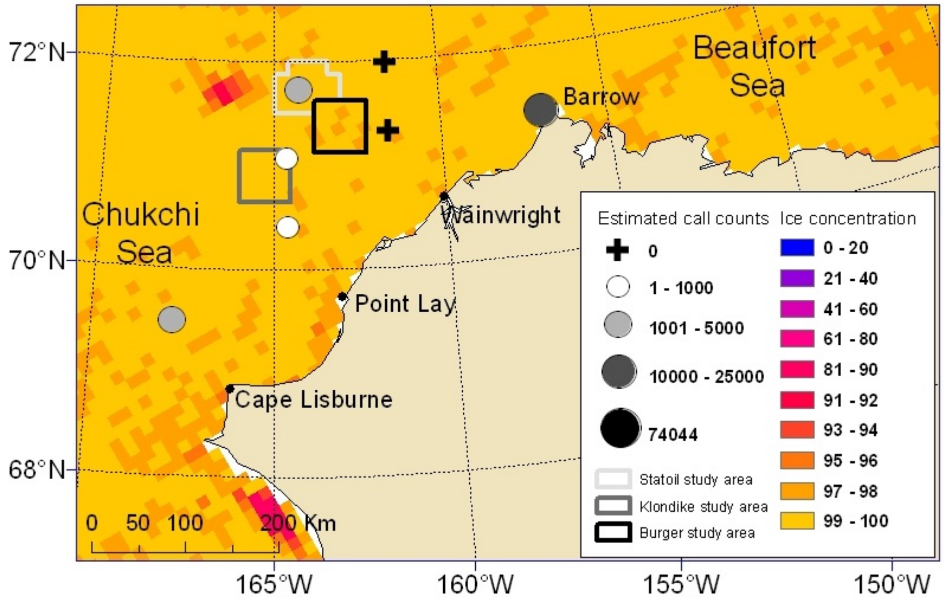

Figure 63. Beluga whale call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for 1–15 Apr 2011 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 7 Apr 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

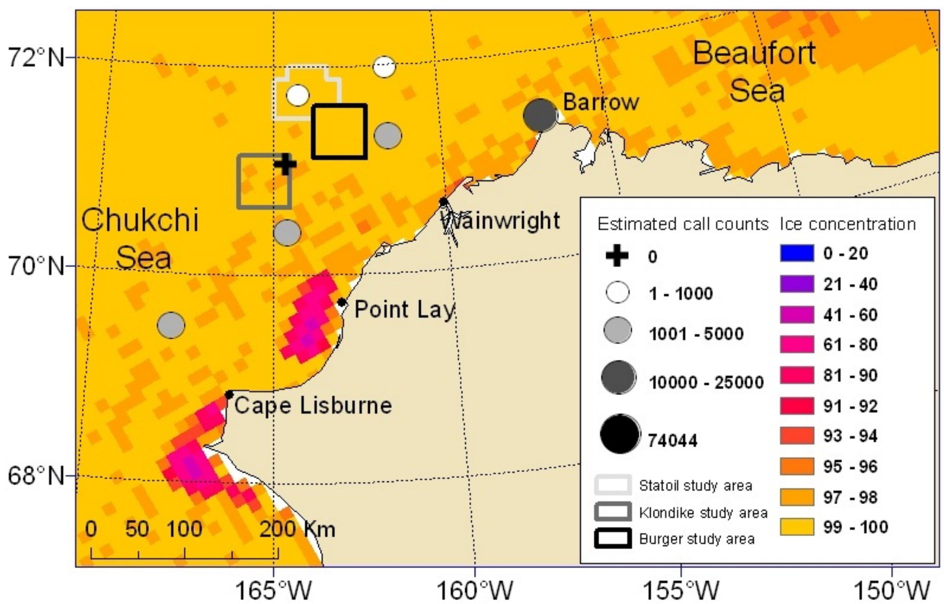

Figure 64. Beluga whale call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for 16–30 Apr 2011 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 22 Apr 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

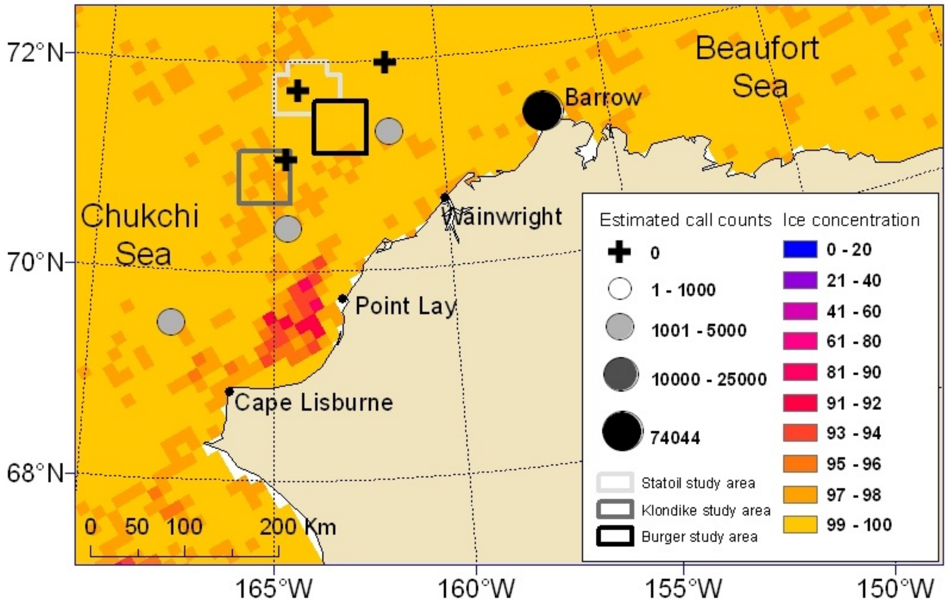

Figure 65. Beluga whale call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for 1–15 May 2011 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 7 May 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

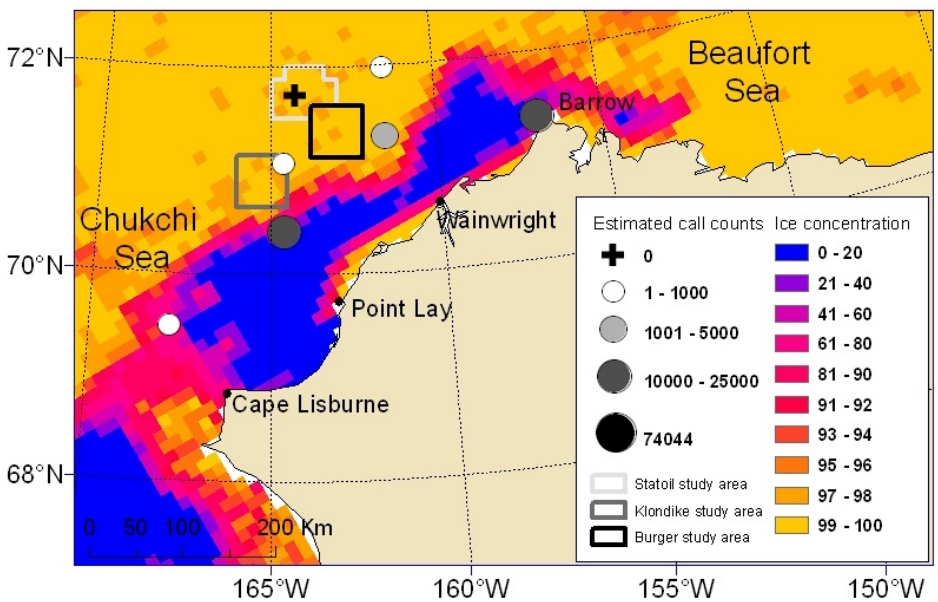

Figure 66. Beluga whale call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for 16–31 May 2011 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 22 May 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

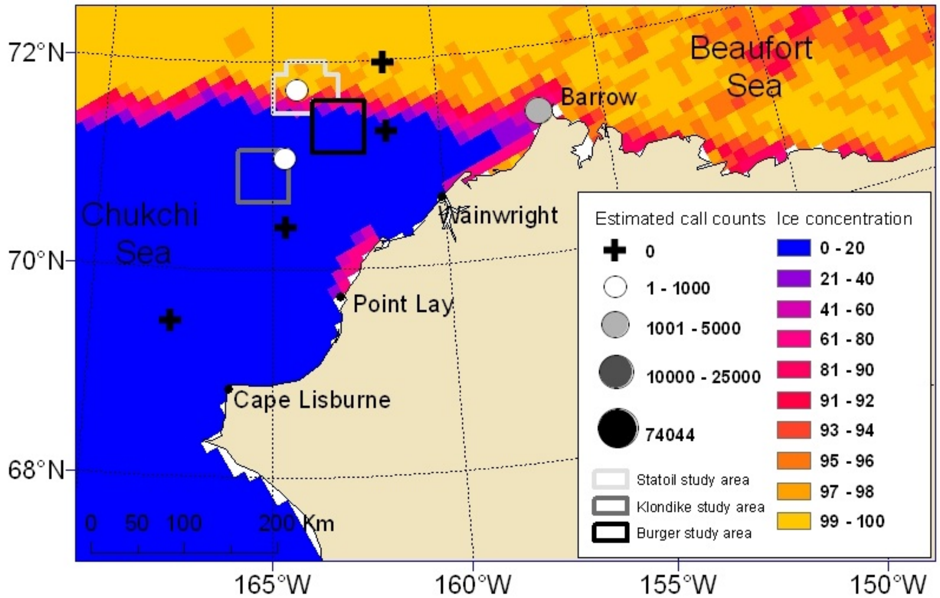

Figure 67. Beluga whale call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for Jun 2011 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 15 Jun 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

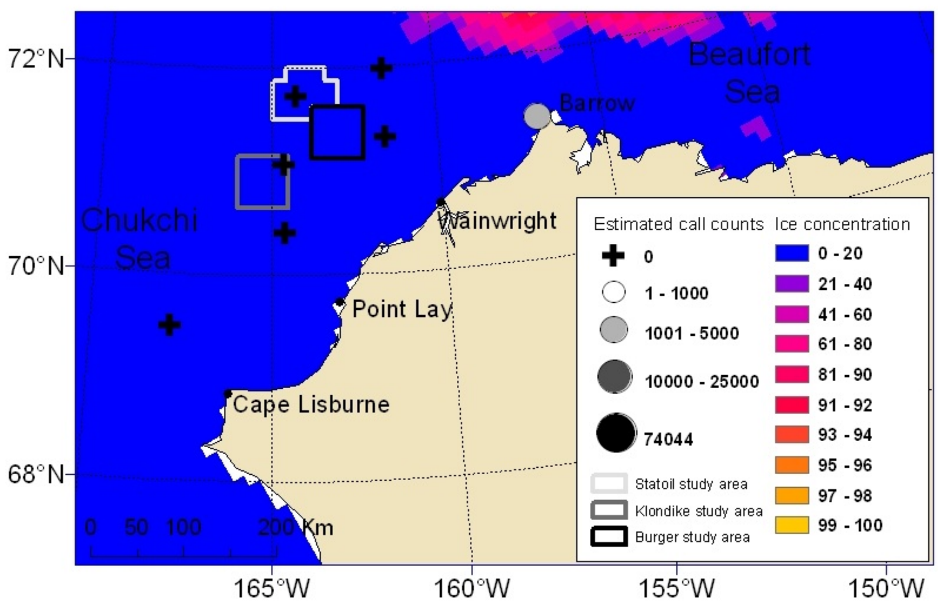

Figure 68. Beluga whale call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for Jul 2011 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 15 Jul 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

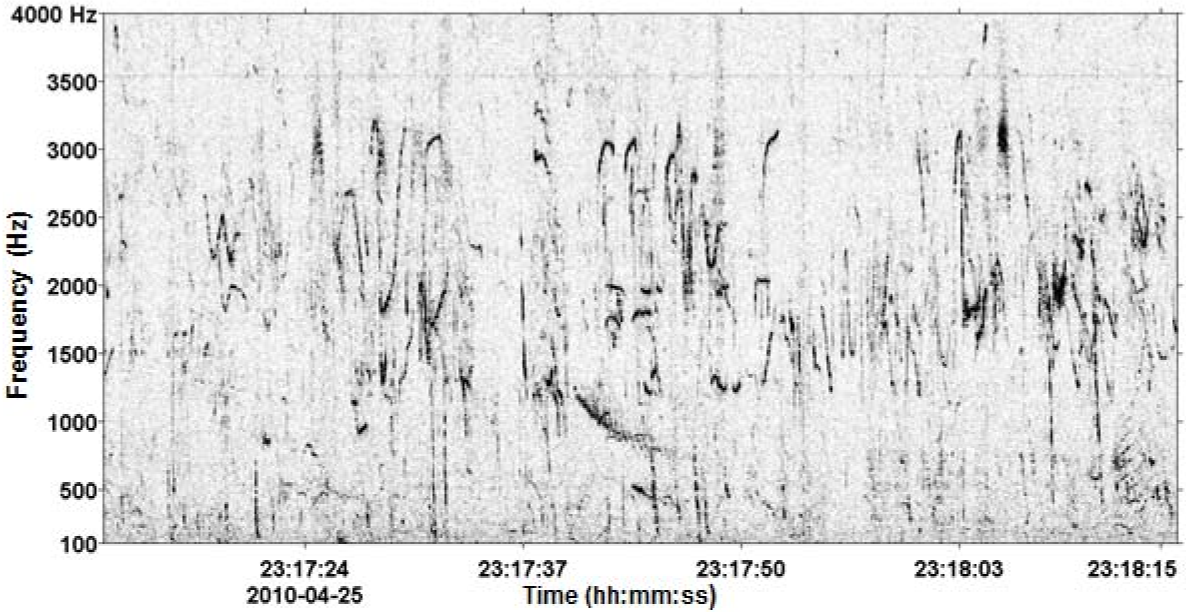

Figure 69. Spectrogram of beluga calls recorded 25 Apr 2010 at winter 2009–2010 Station PLN40 (4096 pt FFT, 4096 real pts, 1024 pt advance, Hamming window; Delarue et al. 2011).

3.5.5.2. Summer 2011 Program

Beluga calls were detected at 10 of the 24 operational summer 2011 stations. Stations B05 and B15 accounted for 59% of the detections, which were mainly in the first three weeks of Aug and in Oct. Some belugas forage in or near Barrow Canyon in Aug (Suydam et al. 2001, 2005). Previous winter datasets demonstrated belugas also migrate past Barrow in Oct and Nov (Delarue et al. 2011). The Wainwright stations (W05, W20, and WN40) accounted for an additional 24% of call detections, 83% of which occurred at W05 and W20 before 14 Aug, presumably from belugas leaving Kasegaluk Lagoon and its nearby waters. Belugas are also common in the nearshore waters off Wainwright (Ireland et al. 2009). In the first week of Oct, 15% of the detections occurred offshore (CLN90, and the PLN stations); these are likely fall migrants (Figure 70, Table 16).

The detected calls, which consistent mainly of whistles, confirm the relatively low occurrence of belugas in the northeastern Chukchi Sea, except near Barrow where they were detected more often than in previous years (Delarue et al. 2011; Figure 74).

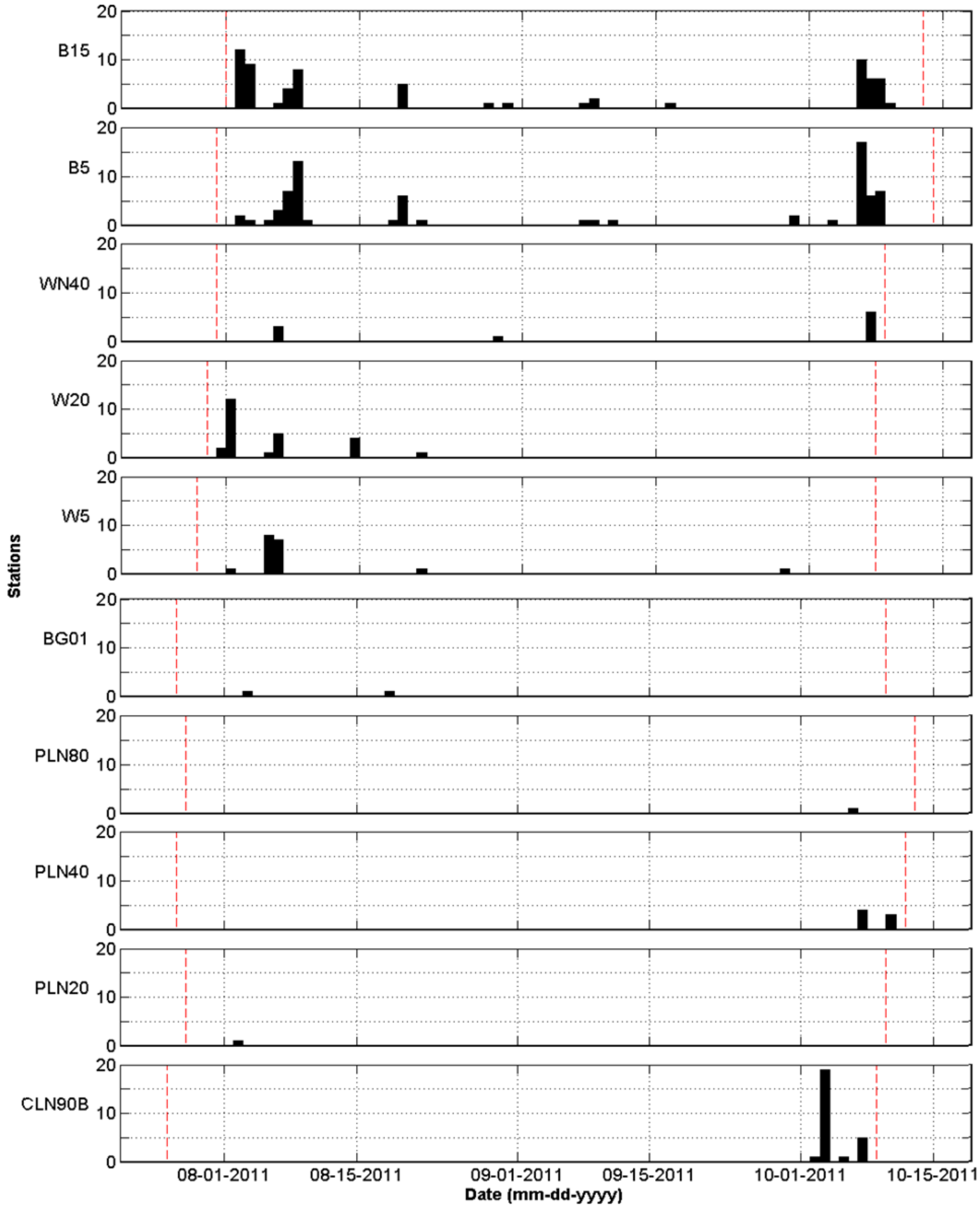

Figure 70. Summer 2011 Daily Beluga Call Detections: Daily number of sound files (six 40-min files recorded per day) with call detections based on the manual analysis of 5% of the acoustic data recorded late Jul through mid-Oct 2011 in the northeastern Chukchi Sea for each station. Red dashed lines indicate recording start and end. Stations without call detections were omitted.

Table 16. Summer 2011 Beluga 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 for each recording station in the northeastern Chukchi Sea. Stations without call detections were omitted.

Beluga Whale					
Station	Record start	First detection	Last detection	Record end	Detection days
B15	01-Aug	02-Aug	09-Oct	12-Oct	15
B05	31-Jul	02-Aug	08-Oct	13-Oct	18
WN40	31-Jul	06-Aug	07-Oct	08-Oct	3
W20	30-Jul	31-Jul	21-Aug	07-Oct	6
W05	29-Jul	01-Aug	28-Sep	07-Oct	5
BG01	27-Jul	03-Aug	18-Aug	09-Oct	2
PLN80	28-Jul	06-Oct	06-Oct	12-Oct	1
PLN40	27-Jul	07-Oct	10-Oct	11-Oct	2
PLN20	28-Jul	02-Aug	02-Aug	09-Oct	1
CLN90	26-Jul	02-Oct	07-Oct	08-Oct	4

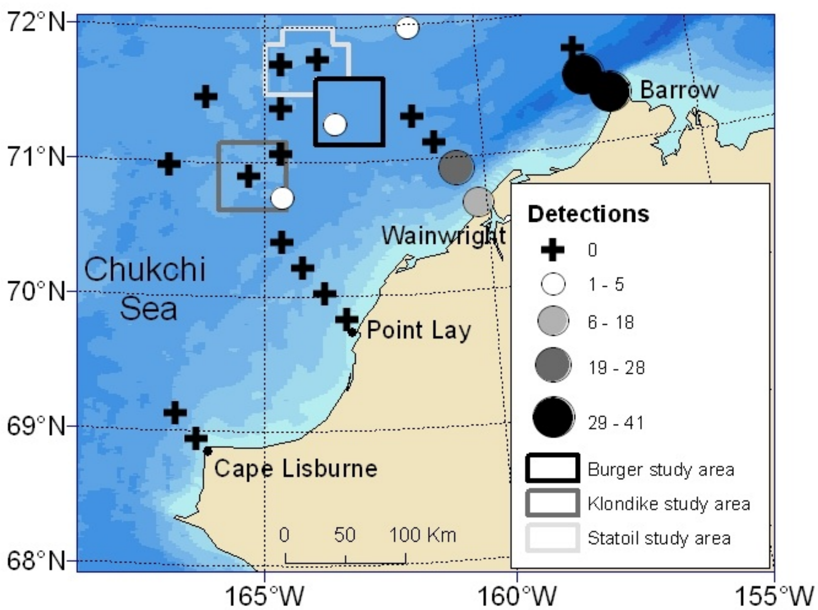

Figure 71. Number of 30-min sound file containing beluga whale acoustic detections for 27 Jul through 1 Aug at all summer 2011 recording stations in the northeastern Chukchi Sea.

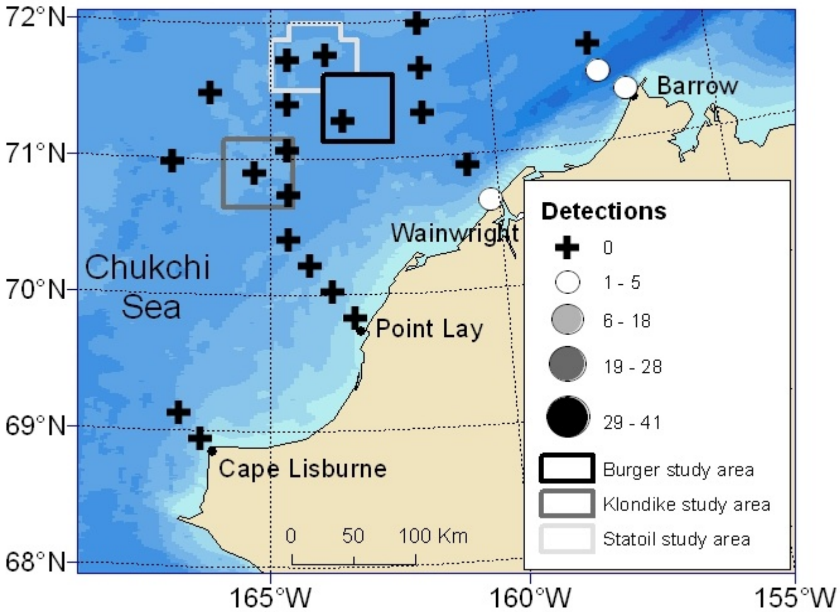

Figure 72. Number of 30-min sound file containing beluga whale acoustic detections for 1–30 Sep at all summer 2011 recording stations in the northeastern Chukchi Sea.

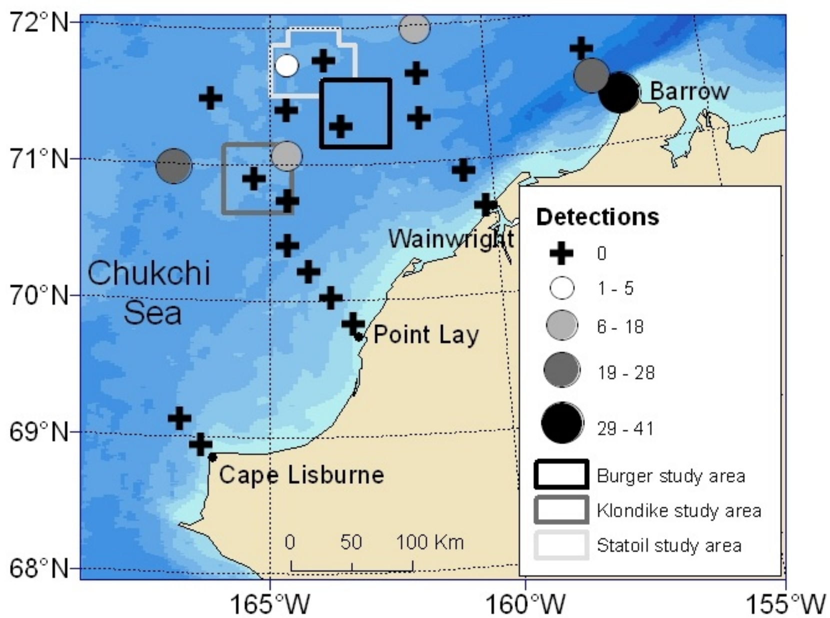

Figure 73. Number of 30-min sound file containing beluga whale acoustic detections for 1–12 Oct at all summer 2011 recording stations in the northeastern Chukchi Sea.

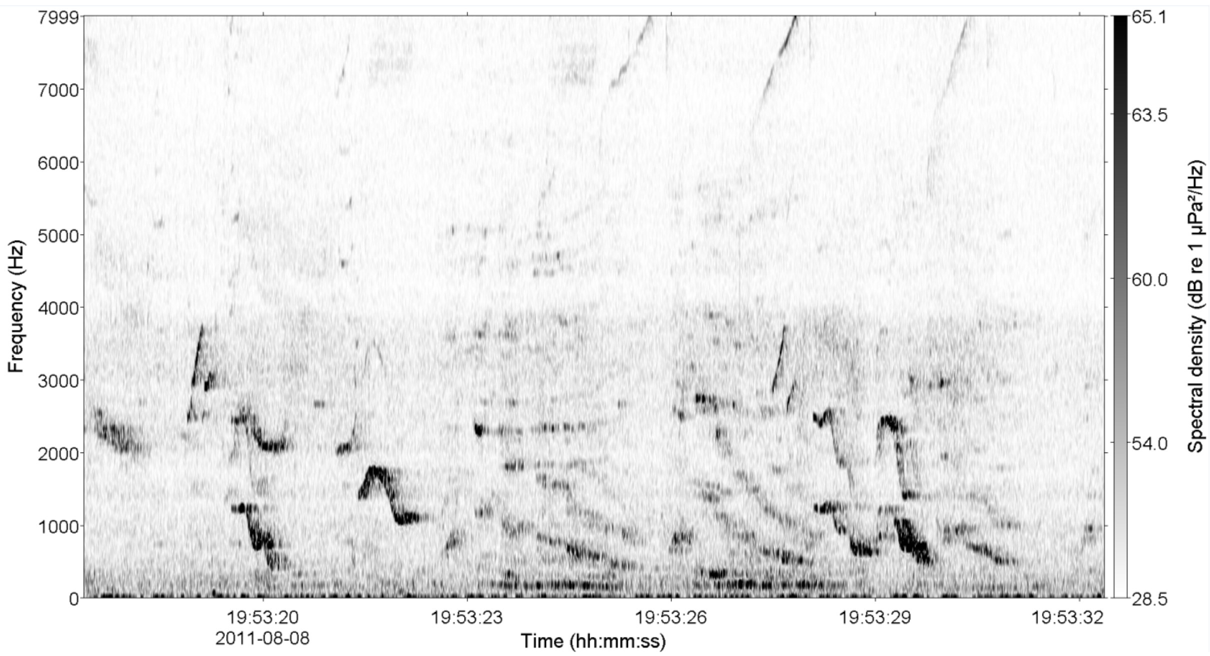

Figure 74. Beluga calls detected at B05 on 8 Aug 2011 (4096 pt FFT, 256 real pts, 128 pt advance, Reisz window).

3.5.6. Bearded Seal Call Detections

3.5.6.1. Winter 2010–2011 Program

Bearded seal (*Erignathus barbatus*) calls were detected at all winter 2010–2011 stations. The number of detection days ranged from 144 at CL50 to 224 at PLN80 (Figure 75, Table 17), which makes them the most commonly detected species of the winter program. The detections follow the pattern observed in previous years: rare and sporadic in Oct and Nov, increasing in Dec, and daily as of early Jan, except at CL50 where bearded seal call detections were infrequent until early Feb. Bearded seal calls were detected at B05, W50, PLN80, and PLN40 in most files between early Mar and the end of the detection period. At the other stations, detections increased more gradually in Mar and Apr and started occurring in almost all files in May and Jun. The end of the detection period started at CL50 on 20 Jun and ended on 4 Jul at PLN80 and 5 Jul at B05. Calls were not detected thereafter, except at W50 in late Jul. Detections stopped later at stations farther north and east.

As indicated by the estimated call count plots (Figures 76 to 85), bearded seal detections were relatively uniformly distributed throughout the program area for most of the detection period. Exceptions include lower call counts at CL50 in Dec and Jan (Figure 78, Figure 79) and higher call counts at PLN80 and WN40 (Figure 84). The latter might be because these two stations are nearest the ice edge. In Jun 2010, the two stations farthest from the receding ice edge also had fewer call counts than May (Delarue et al. 2011).

The detected calls consist primarily of upsweeping and downsweeping trills (Figure 86; Van Parijs et al. 2001).

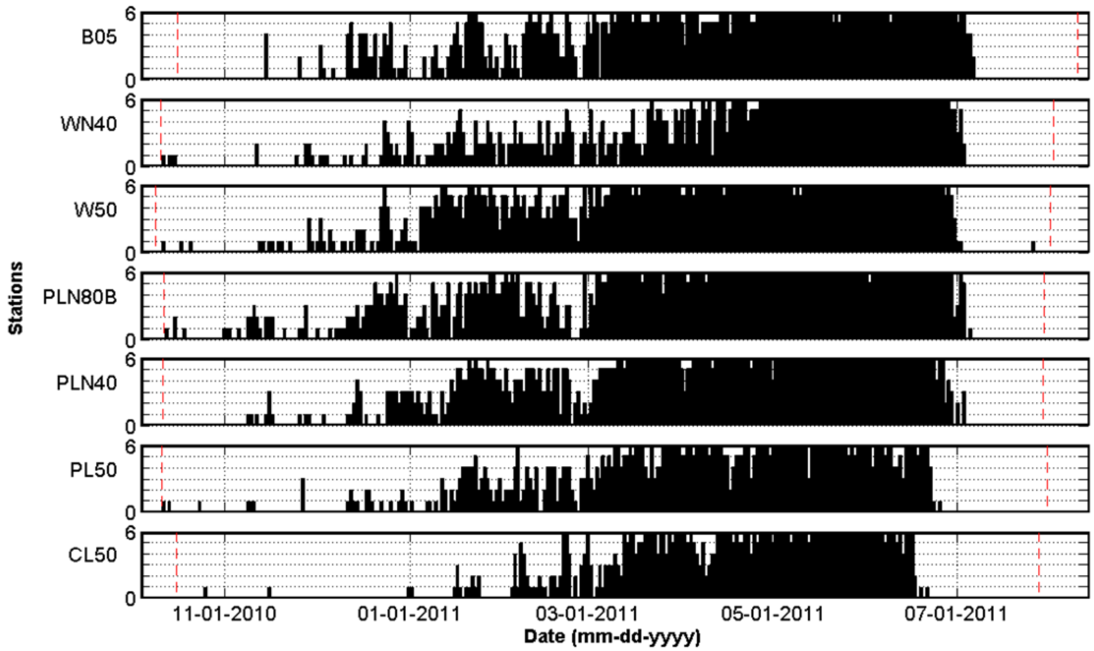

Figure 75. Winter 2010–2011 Daily Bearded Seal Call Detections: Daily number of sound files (six 40-min files recorded per day) with call detections based on the manual analysis of 5% of the acoustic data recorded mid-Oct 2010 through early Aug 2011 in the northeastern Chukchi Sea for each station. Red dashed lines indicate when the recording started and ended.

Table 17. Winter 2010–2011 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 40 min of every 4 h.

Station	Record start	First detection	Last detection	Detection days	Record end
B05	16 Oct	14 Nov	05 Jul	197	06 Aug
WN40	10 Oct	11 Oct	02 Jul	199	31 Jul
W50	10 Oct	11 Oct	25 Jul	216	30 Jul
PLN80	11 Oct	12 Oct	04 Jul	224	28 Jul
PLN40	11 Oct	08 Nov	02 Jul	204	27 Jul
PL50	11 Oct	11 Oct	24 Jun	185	28 Jul
CL50	15 Oct	25 Oct	20 Jun	144	26 Jul

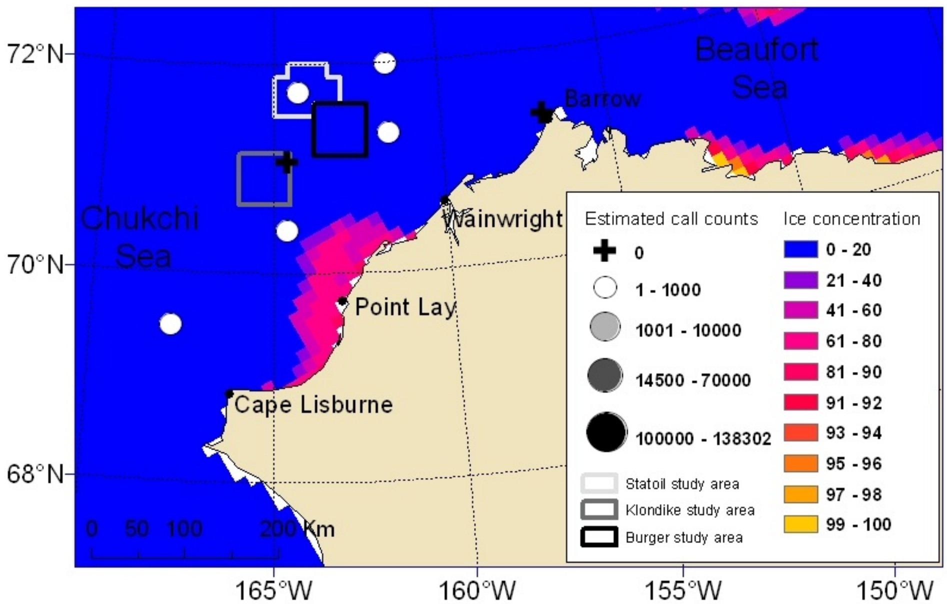

Figure 76. Bearded seal call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for 12–31 Oct 2010 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 22 Oct 2010 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

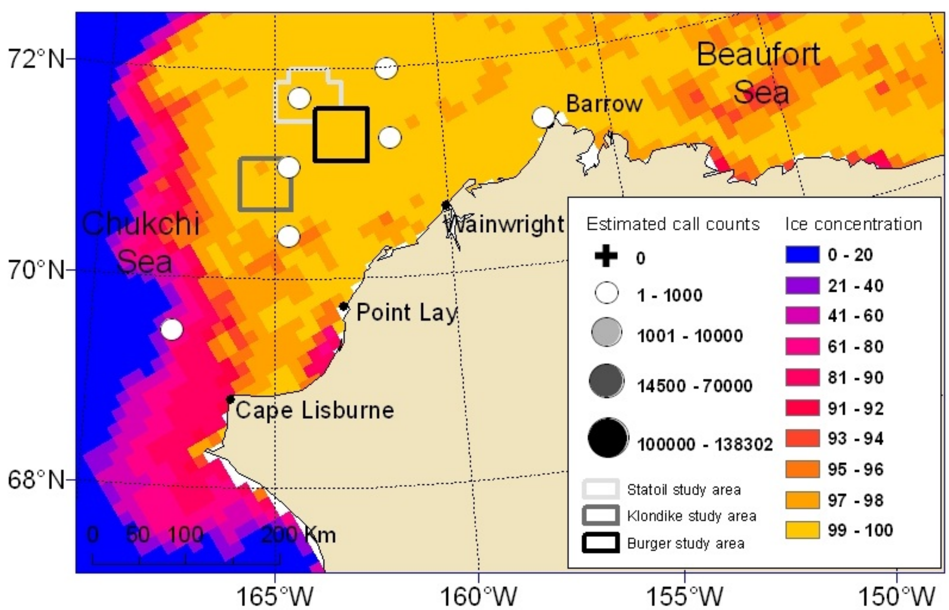

Figure 77. Bearded seal call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for Nov 2010 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 15 Nov 2010 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

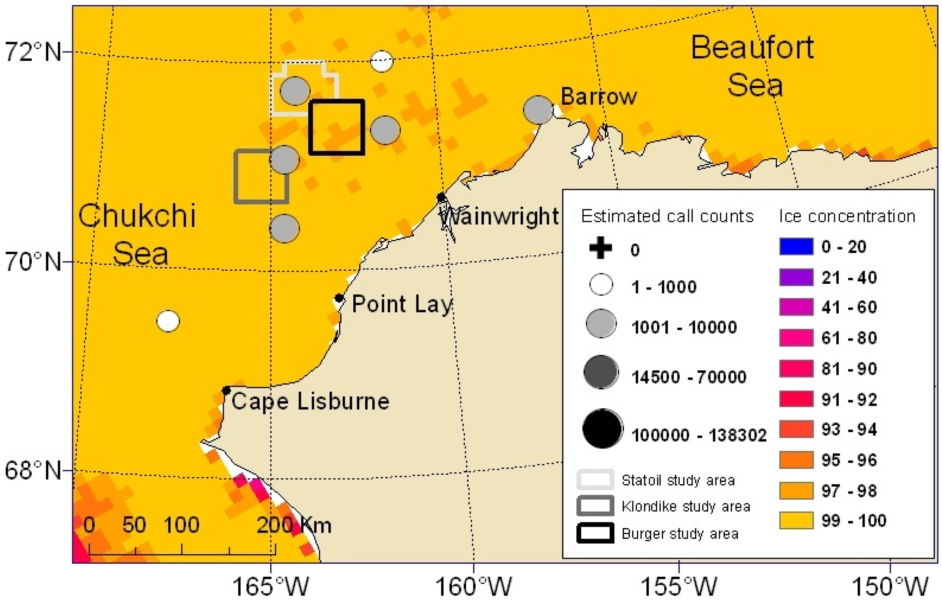

Figure 78. Bearded seal call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for Dec 2010 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 15 Dec 2010 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

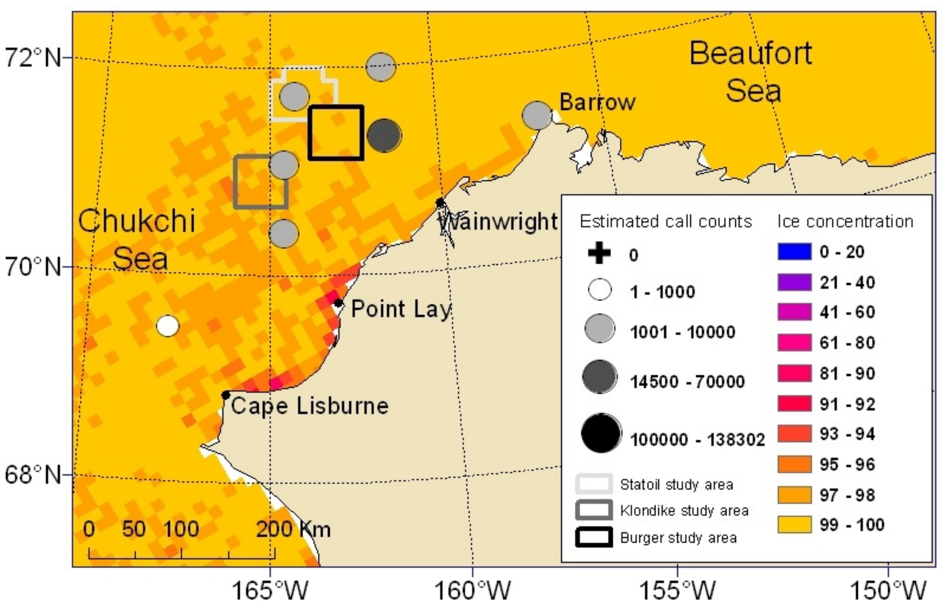

Figure 79. Bearded seal call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for Jan 2011 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 15 Jan 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

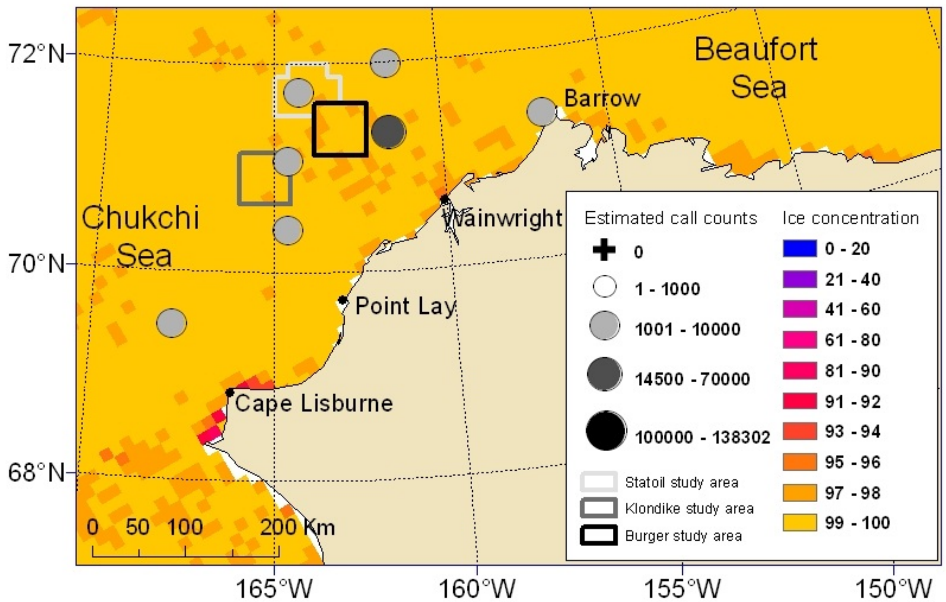

Figure 80. Bearded seal call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for Feb 2011 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 15 Feb 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

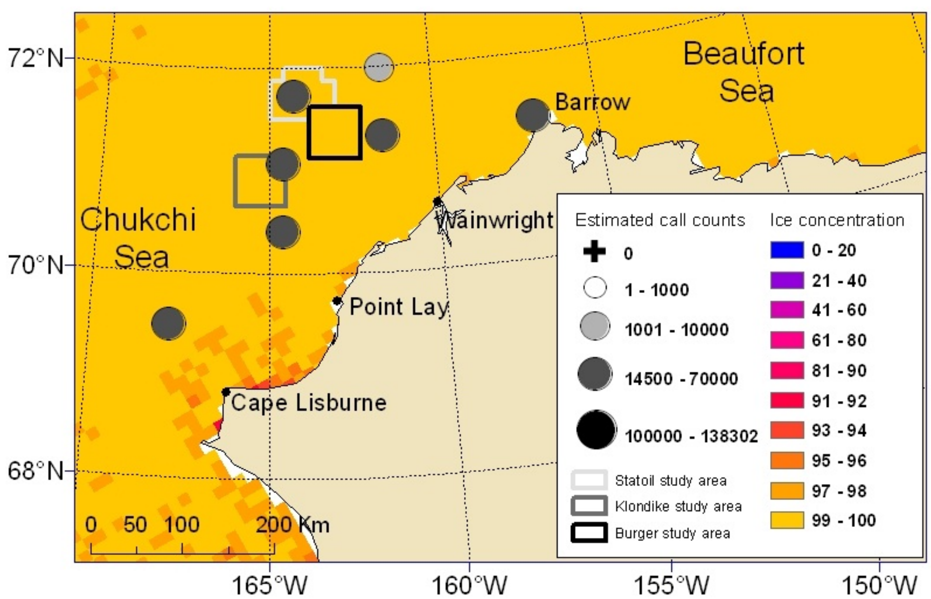

Figure 81. Bearded seal call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for Mar 2011 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 15 Mar 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

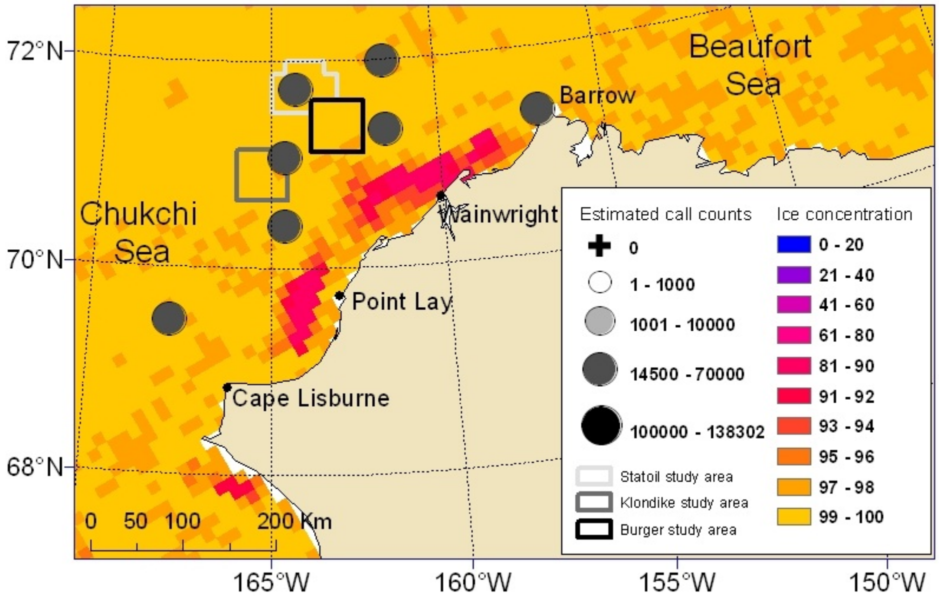

Figure 82. Bearded seal call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for Apr 2011 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 15 Apr 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

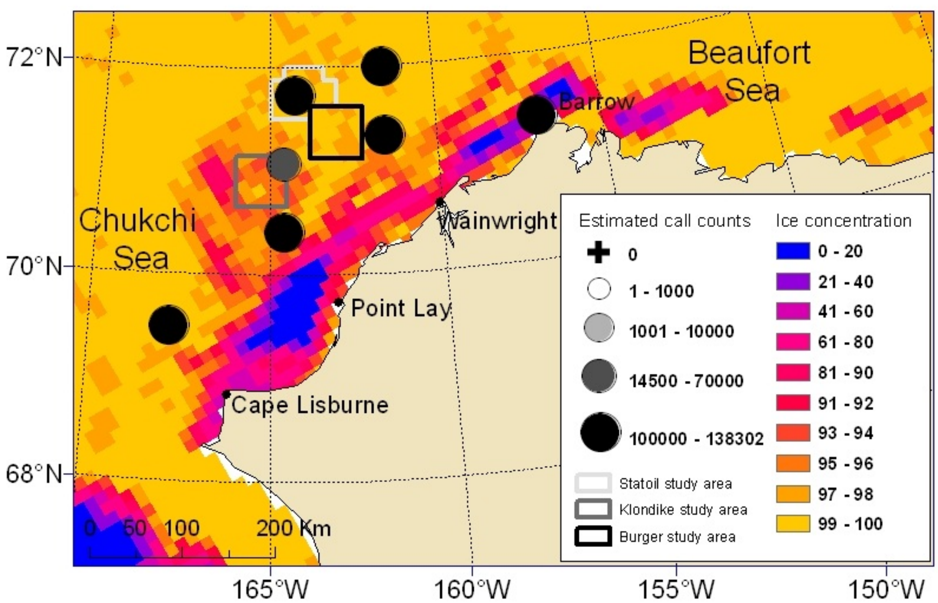

Figure 83. Bearded seal call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for May 2011 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 15 May 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

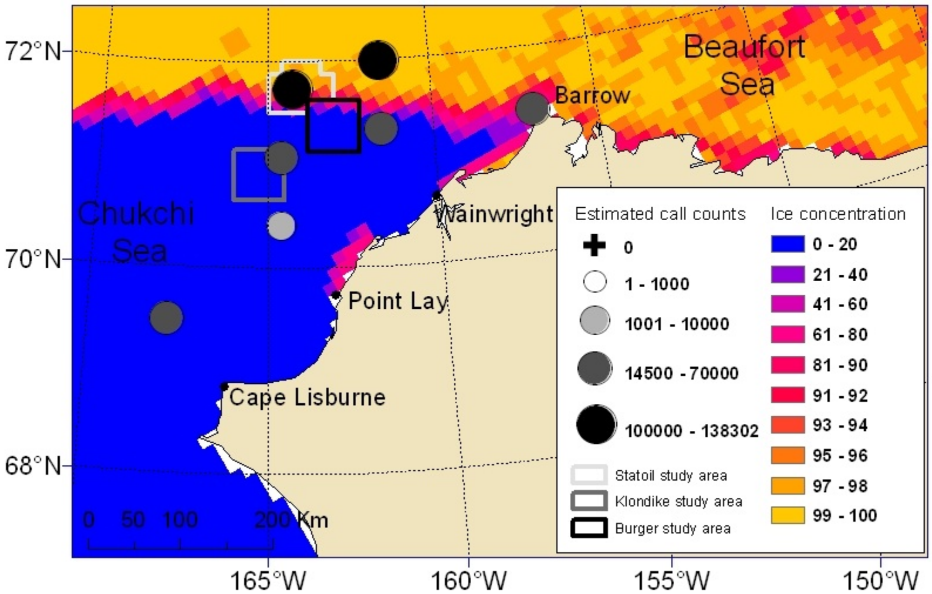

Figure 84. Bearded seal call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for Jun 2011 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 15 Jun 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

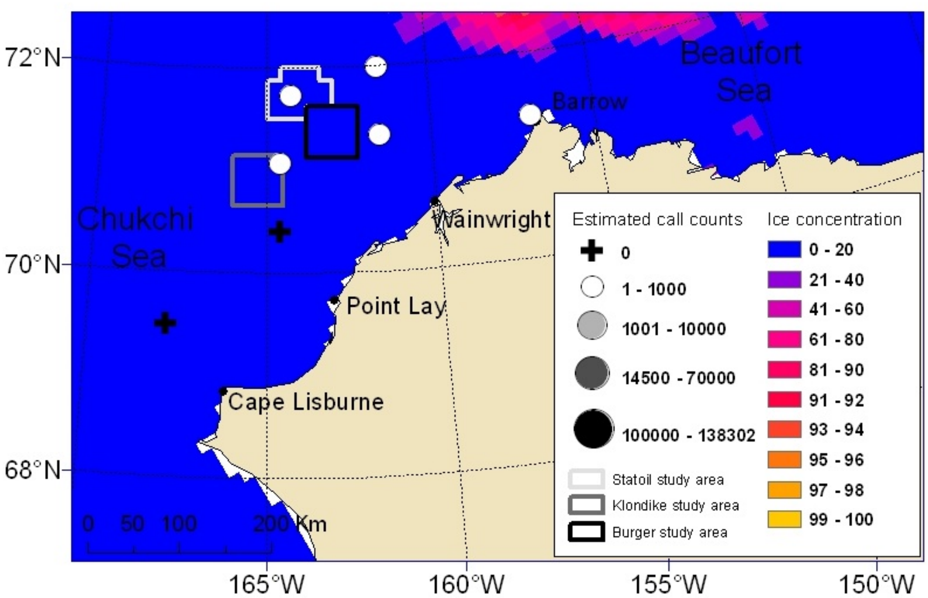

Figure 85. Bearded seal call count estimates (corrected sum of automated call detections in all files with manual detections) in the Chukchi Sea for Jul 2011 at the seven operational winter 2010–2011 recording stations. Ice concentration data are for 15 Jul 2011 (Cavalieri et al. 2004). Note: the scale emphasizes heavy ice concentration.

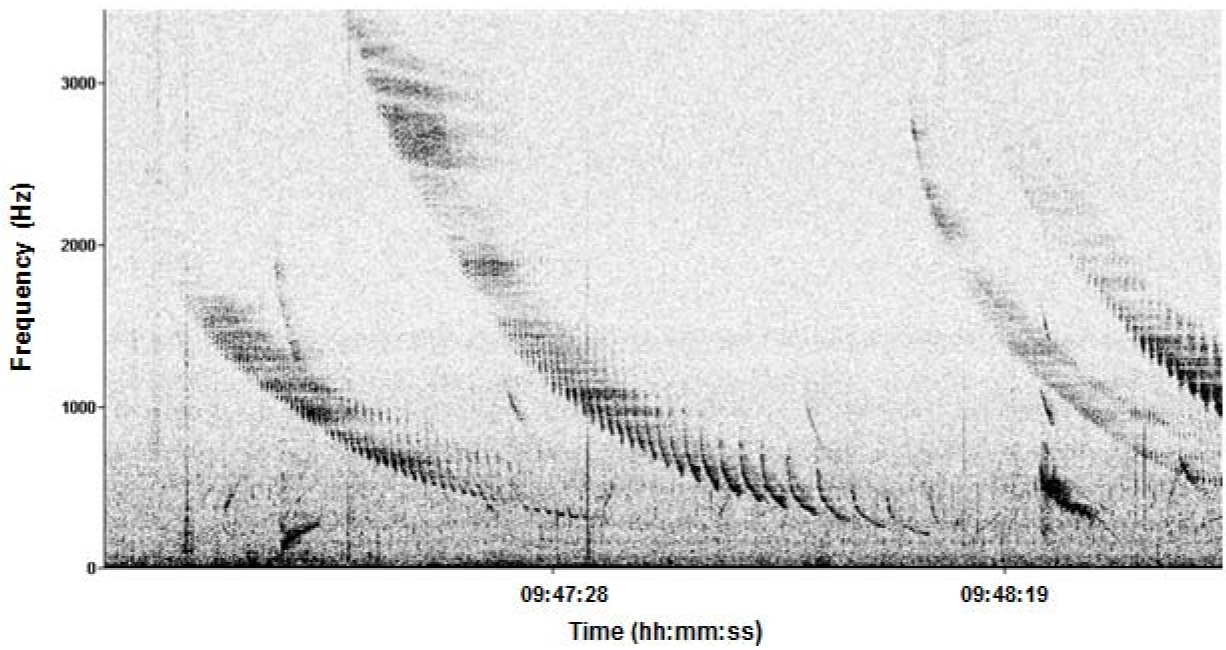

Figure 86. Spectrogram of bearded seal calls recorded 8 Jun 2009 at winter 2008–2009 Station W50 (8192 pt FFT, 4096 real pts, 1024 pt advance, Hamming window; Delarue et al. 2011).

3.5.6.2. Summer 2011 Program

Bearded seal calls were detected at all but one (CL05) station. The number of detection days ranged between 2 (CL20) and 47 (WN40) with a mean of 20.3 (Figure 87, Table 18). Detections increased with time at all stations, peaking in Oct prior to the retrieval of the instruments. Only 5.8% of the detections occurred before 31 Aug, with 81% of the detections occurring from 20 Sep onwards, a point that marks the onset of a sustained detection period throughout the program area. Most detections before 20 Sep were concentrated first near the PLN stations (Figure 88) then off Wainwright, with a shift offshore between late Aug and early Sep (Figure 89, Figure 90). WN40 had daily detections from 24 Aug until the end of the recording period and the highest number of detections in the first half of Sep (Figure 90). In the second half of Sep, the core of the detection area shifted to the east but remained far offshore (Figure 91). The number of detections increased in Oct. Detections were highest offshore near PLN80 and CLN120B, but bearded seal detections increased inshore, possibly indicating a southward movement of bearded seals.

Detected bearded seal calls were narrowband, short downsweeping trills (Figure 93) produced irregularly and in small numbers. These calls were different from the long, complex spiraling songs that are common during the spring breeding period, and were detected in the winter 2009–2010 data (Ray et al. 1969, Van Parijs et al. 2001).

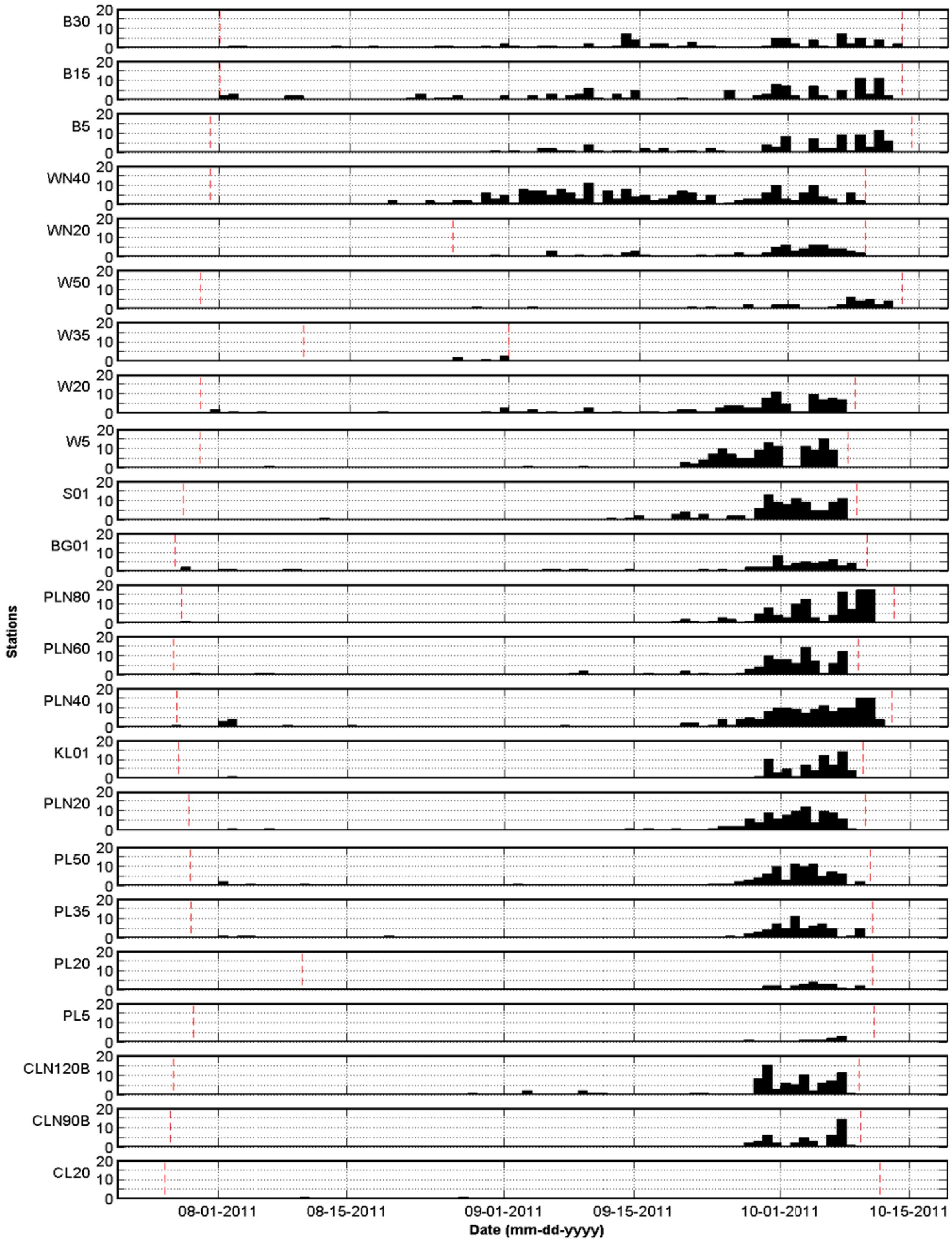

Figure 87. Summer 2011 Daily Bearded Seal Call Detections: Daily number of sound files (six 40-min files recorded per day) with call detections based on the manual analysis of 5% of the acoustic data recorded late Jul through mid-Oct 2011 in the northeastern Chukchi Sea for each station. Red dashed lines indicate recording start and end. Stations without call detections were omitted.

Table 18. Summer 2011 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 for each recording station in the northeastern Chukchi Sea. Stations without call detections were omitted.

Bearded Seal					
Station	Record start	First detection	Last detection	Record end	Detection days
B30	01 Aug	02 Aug	12 Oct	12 Oct	33
B15	01 Aug	01 Aug	11 Oct	12 Oct	32
B05	31 Jul	30 Aug	11 Oct	13 Oct	30
WN40	31 Jul	19 Aug	08 Oct	08 Oct	47
WN20	26 Aug	30 Aug	08 Oct	08 Oct	24
W50	30 Jul	28 Aug	11 Oct	12 Oct	15
W35	30 Jul	26 Aug	11 Oct	13 Oct	3
W20	30 Jul	31 Jul	06 Oct	07 Oct	34
W05	29 Jul	06 Aug	06 Oct	07 Oct	20
S01	28 Jul	12 Aug	07 Oct	08 Oct	20
BG01	27 Jul	28 Jul	09 Oct	09 Oct	25
PLN80	28 Jul	28 Jul	10 Oct	12 Oct	21
PLN60	27 Jul	29 Jul	07 Oct	08 Oct	20
PLN40	27 Jul	27 Jul	11 Oct	11 Oct	27
KL01	27 Jul	02 Aug	08 Oct	08 Oct	12
PLN20	28 Jul	02 Aug	08 Oct	09 Oct	21
PL50	28 Jul	01 Aug	09 Oct	09 Oct	20
PL35	29 Jul	01 Aug	09 Oct	09 Oct	17
PL20	29 Jul	29 Sep	09 Oct	09 Oct	9
PL05	29 Jul	27 Sep	07 Oct	09 Oct	6
CLN120B	27 Jul	28 Aug	08 Oct	08 Oct	18
CLN90	26 Jul	27 Sep	08 Oct	08 Oct	10
CL20	26 Jul	10 Aug	27 Aug	10 Oct	2

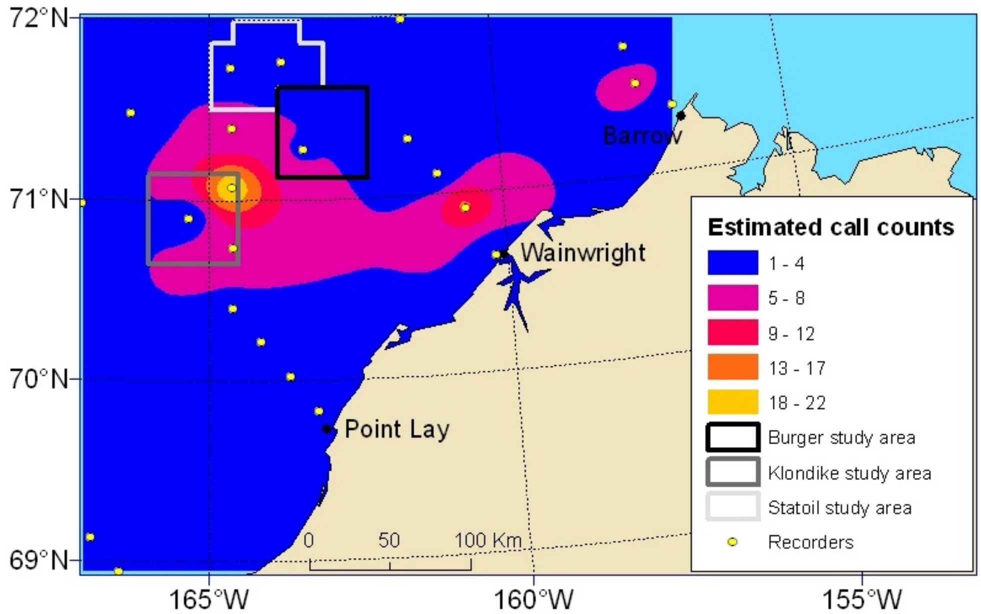

Figure 88. Interpolated bearded seal call count contour plot based on the sum of automated call detections in all files with manual detections for 27 Jul through 15 Aug at all summer 2011 recording stations in the northeastern Chukchi Sea.

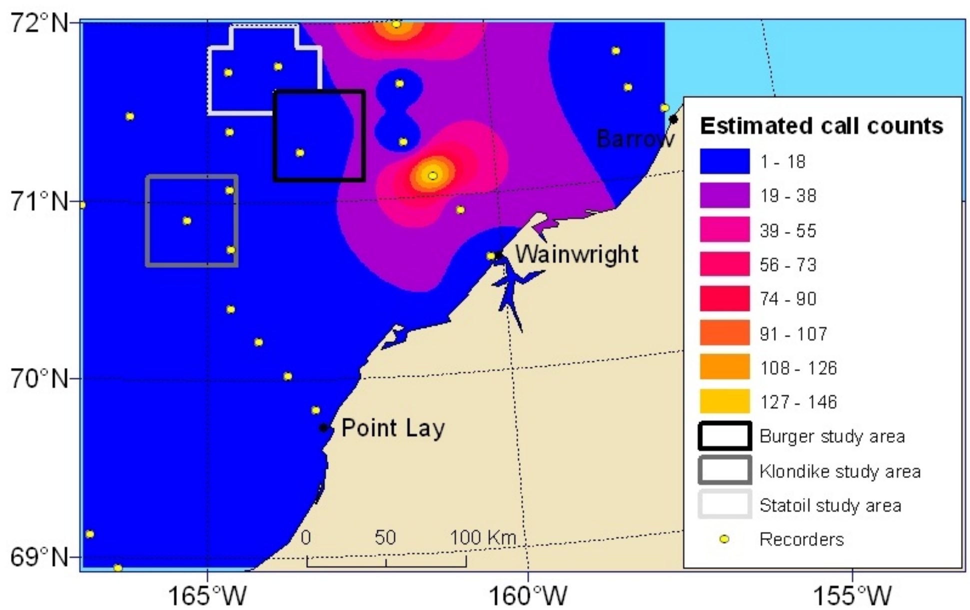

Figure 89. Interpolated bearded seal call count contour plot based on the sum of automated call detections in all files with manual detections for 16–31 Aug at all summer 2011 recording stations in the northeastern Chukchi Sea.

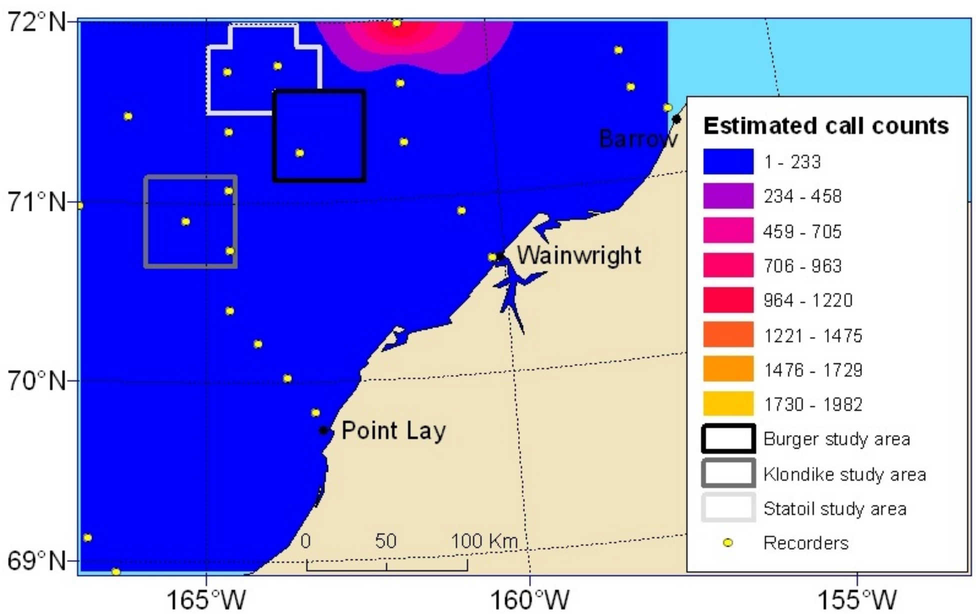

Figure 90. Interpolated bearded seal call count contour plot based on the sum of automated call detections in all files with manual detections for 1–15 Sep at all summer 2011 recording stations in the northeastern Chukchi Sea.

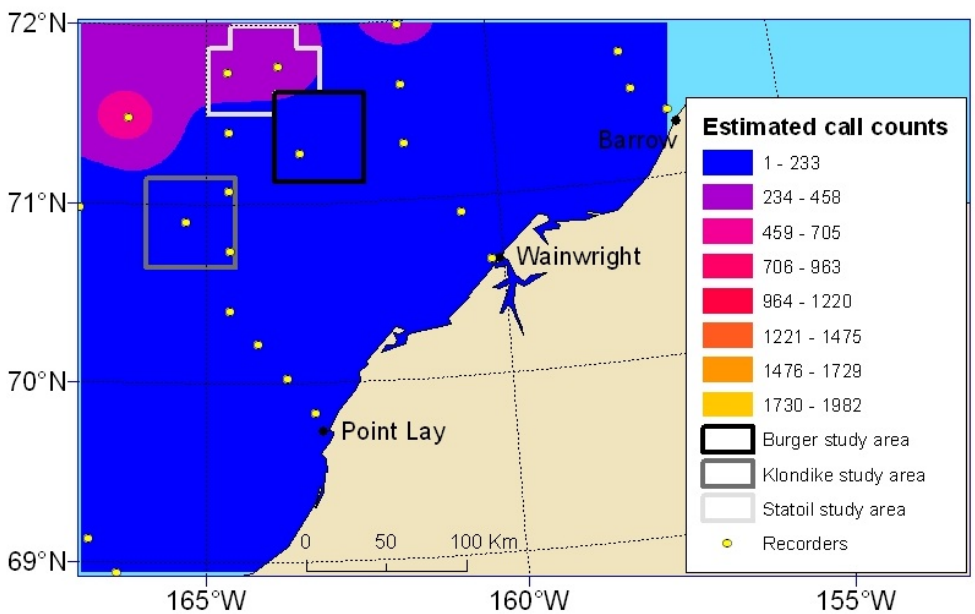

Figure 91. Interpolated bearded seal call count contour plot based on the sum of automated call detections in all files with manual detections for 16–30 Sep at all summer 2011 recording stations in the northeastern Chukchi Sea.

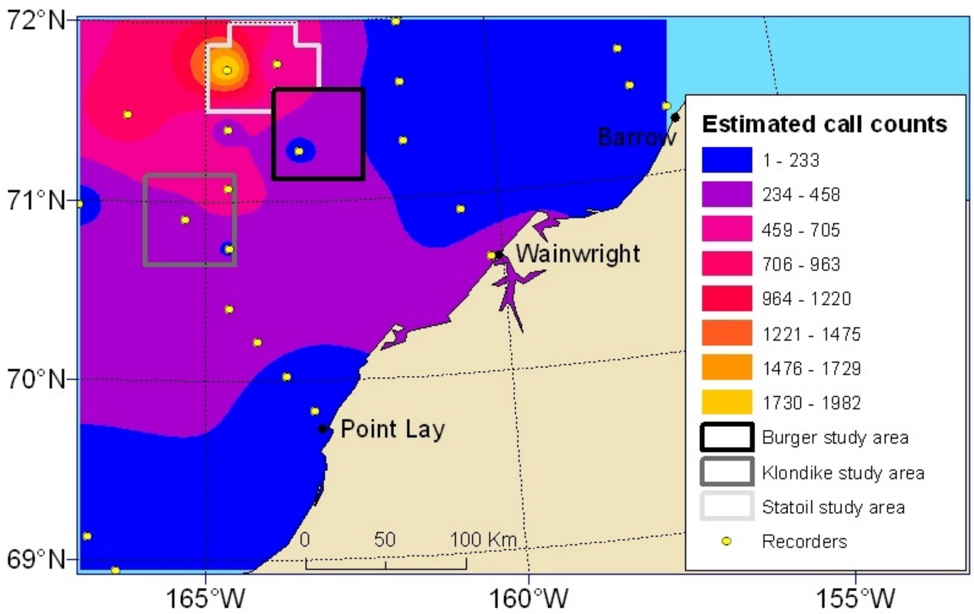

Figure 92. Interpolated bearded seal call count contour plot based on the sum of automated call detections in all files with manual detections for 1–11 Oct at all summer 2011 recording stations in the northeastern Chukchi Sea.

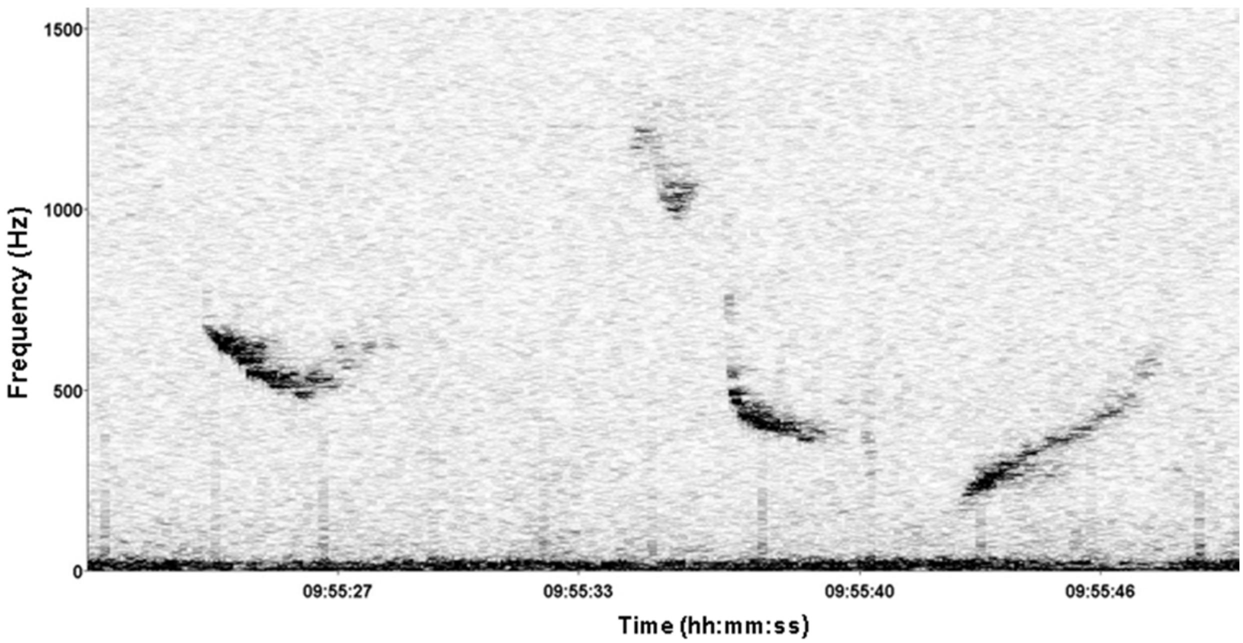

Figure 93. Spectrogram of bearded seal calls detected at Station W20, 10 Oct 2009 (8192 pt FFT, 4096 real pts, 1024 pt advance, Hamming window; Delarue et al. 2011).

3.5.7. Fin Whale Call Detections

3.5.7.1. Winter 2010–2011 Program

Fin whale calls were not detected in the winter 2010–2011 dataset.

3.5.7.2. Summer 2011 Program

Fin whale (*Balaenoptera physalus*) calls (Figure 94) were detected at Station CLN120B on 2 Aug and Station PL50 on 8 Aug 2011. Station CL50 had the highest number of detection days in 2009 and in 2010 (Delarue et al. 2011); however because we did not deploy a recorder at CL50 this year, there were fewer detections in this year's data. In 2010, Stations PL50 and CLN90 (nearest to CLN120B) had two detection days each. These results confirm that fin whales are uncommon in the northeastern Chukchi Sea.

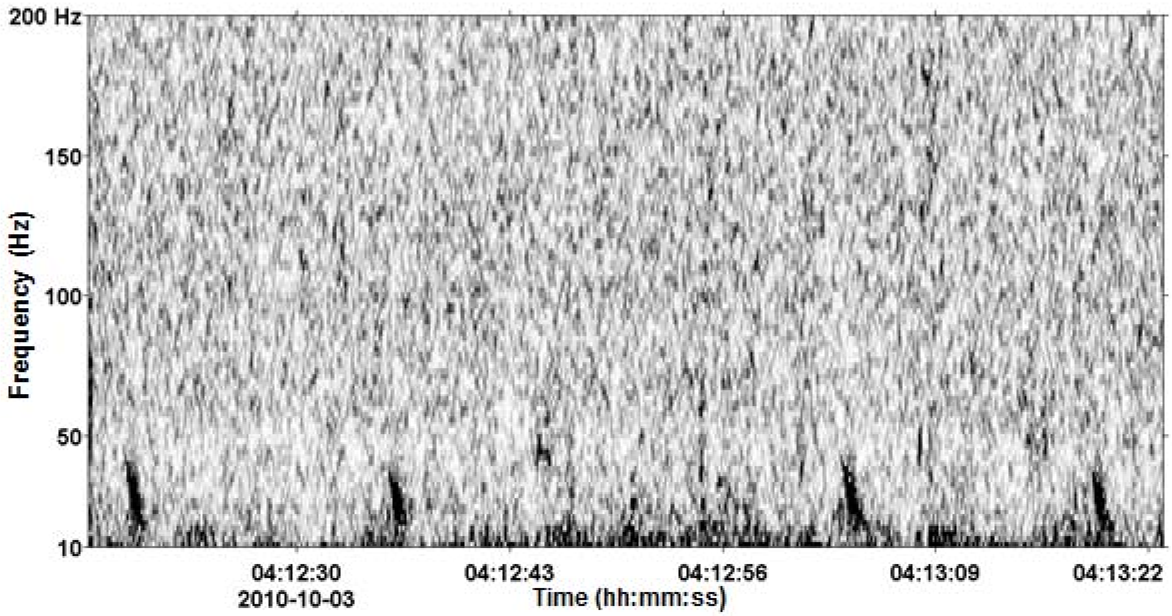

Figure 94. Spectrogram of fin whale calls detected at Station PL50, 3 Oct 2010 (4096 pt FFT, 8192 real pts, 1024 pt advance, Hamming window; Delarue et al. 2011).

3.5.8. Gray Whale Call Detections

3.5.8.1. Winter 2010–2011 Program

Gray whale calls were not detected in the winter 2010–2011 dataset.

3.5.8.2. Summer 2011 Program

Gray whale (*Eschrichtius robustus*) calls were detected at all stations during the summer 2011 program (Figure 95, Table 19). The mean number of detection days was 7.7. Station W20 had the maximum number of detection days (n = 41) followed by W05 (n = 19), then B05 (n = 17). Generally, gray whale detections were most abundant within a 90 km strip along the shore between Barrow and Icy Cape (Figure 96). The narrower width of the strip off Barrow, due to the small number of detections at B15 and B30, may be related to the greater depth of these stations. Hanna Shoal (i.e., WN40), where gray whales were seen regularly in the 1980s and 1990s, but where recent aerial surveys yielded few sightings (Clarke and Ferguson 2010), had an above average number of detections days (n = 10 at WN40). The area between PL35 and PL50 also had an above-average number of detection days. Detections occurred throughout the recording period, without any obvious peak (Figure 95).

Increases in detection occurrence and distribution in summer 2011 compared with previous years (Delarue et al. 2011) do not represent an increase in the abundance of gray whales in the northeastern Chukchi Sea, but can be largely attributed to the following factors:

- More sounds in the 10–50 Hz band were detectable because the electronic background noise of the AMARs used for summer 2011 is much lower than in previous years.
- Until now, gray whales were identified almost exclusively by their knocking sounds, but they also produce moan-type sounds with very low frequency components (fundamental/peak frequencies between 10 and 50 Hz; Figure 97). In 2011, we more easily identified these calls, but in previous years if we detected these calls, we likely classified most as unknown because they resembled noise.

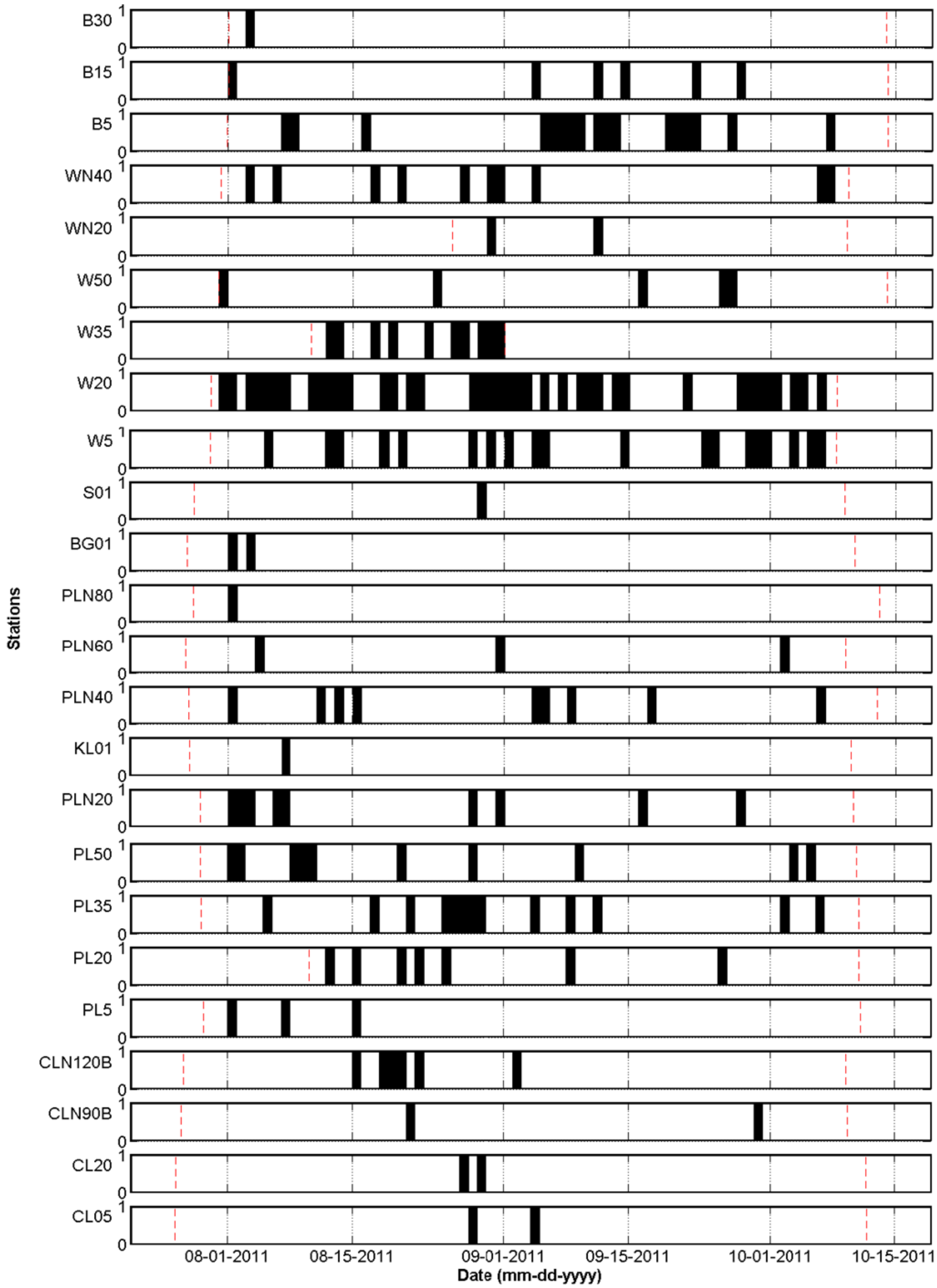

Figure 95. Summer 2011 Daily Gray Whale Call Detections: Daily number of sound files (six 40-min files recorded per day) with call detections based on the manual analysis of 5% of the acoustic data recorded late Jul through mid-Oct 2011 in the northeastern Chukchi Sea for each station. Red dashed lines indicate recording start and end. Stations without call detections were omitted.

Table 19. Summer 2011 Gray Whale Call Detections: Dates of first and last call detections, both possible (i.e., record start and end) and actual, and the number of days on which a call was detected for each recording station in the northeastern Chukchi Sea. Stations without call detections were omitted.

Gray Whale					
Station	Record start	First detection	Last detection	Record end	Detection days
B30	01 Aug	03 Aug	03 Aug	12 Oct	1
B15	01 Aug	01 Aug	27 Sep	12 Oct	6
B05	31 Jul	07 Aug	07 Oct	13 Oct	17
WN40	31 Jul	03 Aug	07 Oct	08 Oct	10
WN20	26 Aug	30 Aug	11 Sep	08 Oct	2
W50	30 Jul	31 Jul	26 Sep	12 Oct	5
W35	30 Jul	12 Aug	31 Aug	13 Oct	10
W20	30 Jul	31 Jul	06 Oct	07 Oct	41
W05	29 Jul	05 Aug	06 Oct	07 Oct	19
S01	28 Jul	29 Aug	29 Aug	08 Oct	1
BG01	27 Jul	01 Aug	03 Aug	09 Oct	2
PLN80	28 Jul	01 Aug	01 Aug	12 Oct	1
PLN60	27 Jul	04 Aug	02 Oct	08 Oct	3
PLN40	27 Jul	01 Aug	06 Oct	11 Oct	9
KL01	27 Jul	07 Aug	07 Aug	08 Oct	1
PLN20	28 Jul	01 Aug	27 Sep	09 Oct	9
PL50	28 Jul	01 Aug	05 Oct	09 Oct	10
PL35	29 Jul	05 Aug	06 Oct	09 Oct	13
PL20	29 Jul	29 Jul	25 Sep	09 Oct	9
PL05	29 Jul	01 Aug	15 Aug	09 Oct	3
CLN120B	27 Jul	15 Aug	02 Sep	08 Oct	6
CLN90	26 Jul	21 Aug	29 Sep	08 Oct	2
CL20	26 Jul	27 Aug	29 Aug	10 Oct	2
CL05	26 Jul	28 Aug	04 Sep	10 Oct	2

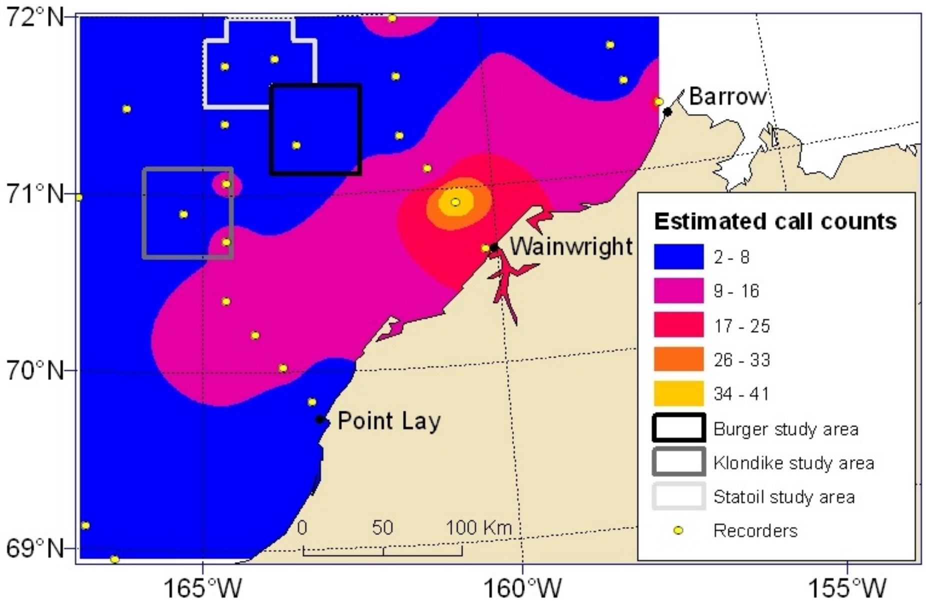

Figure 96. Interpolated gray whale detection day contour plot based on the sum of detection days for 27 Jul through 11 Oct at all summer 2011 recording stations in the northeastern Chukchi Sea.

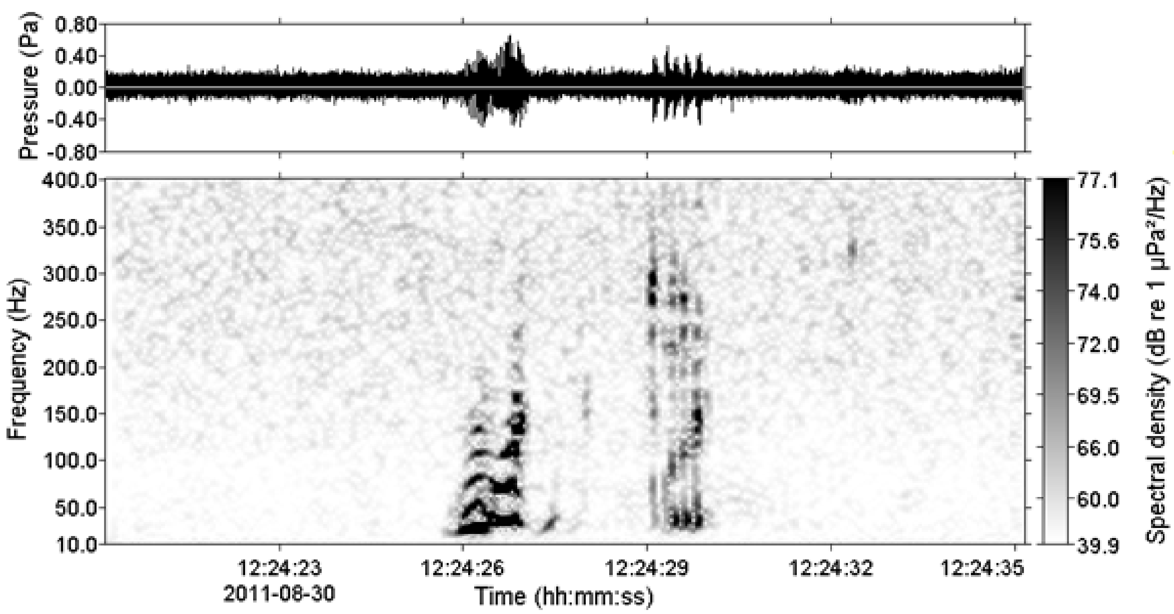

Figure 97. Gray whale moans and knocks recorded on 30 Aug 2011 at Station W05 (16384 pt FFT, 3200 pts real data, 80 pt advance; Reisz window).

3.5.9. Humpback Whale Call Detections

3.5.9.1. Winter 2010–2011 Program

Humpback whale calls were not detected in the winter 2010–2011 dataset.

3.5.9.2. Summer 2011 Program

Humpback whale (*Megaptera novaeangliae*) calls (example in Figure 98) were detected at Station PLN60 on 4 Aug, and at WN40 on 8 Aug and 9 and 13 Sep 2011.

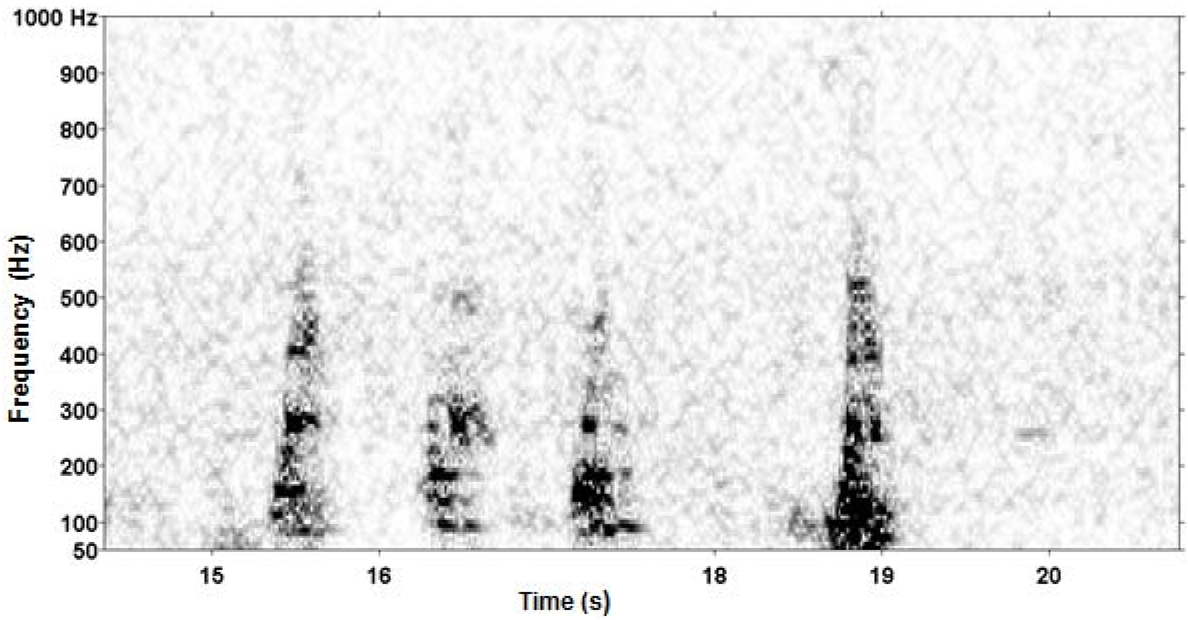

Figure 98. Humpback whale calls recorded at CL50 on 7 Aug 2010 (2048 pt FFT, 2048 real pts, 256 pt advance, Hamming window; Delarue et al. 2011).

3.5.10. Killer Whale Call Detections

3.5.10.1. Winter 2010–2011 Program

Killer whale calls were not detected in the winter 2010–2011 dataset.

3.5.10.2. Summer 2011 Program

Killer whale (*Orcinus orca*) calls were detected at 11 of the 24 operational stations: the Cape Lisburne stations, five of the eight Point Lay stations, BG01, and KL01. As in 2009, KL01, in the Klondike study area, had the most detection days of all stations (*n* = 4). Killer whale calls were detected once at seven stations and twice at three stations (Figure 99, Table 20). Detections occurred 7 Aug through 8 Oct, although half the detections occurred at six stations between 6 and 8 Oct. Although some of the latter detections at adjacent stations may have been of the same pods or individuals, stations with detections span such a large area that the same individuals could not have visited them all in a single day. This suggests there were at least three killer whale pods present in the northeastern Chukchi Sea over these three days.

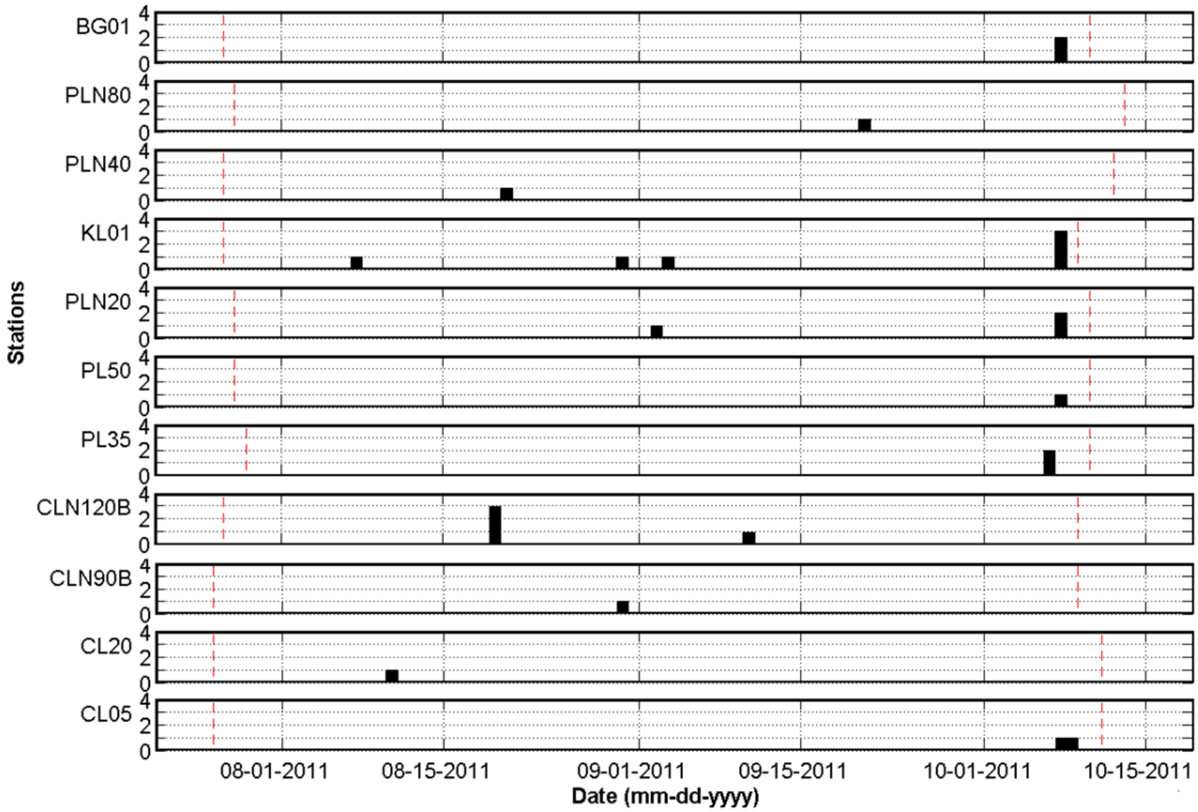

Figure 99. Summer 2011 Killer Whale Call Detections: Daily number of sound files (six 40-min files recorded per day) with call detections based on the manual analysis of 5% of the acoustic data recorded late Jul through mid-Oct 2011 in the northeastern Chukchi Sea for each station. Red dashed lines indicate recording start and end. Stations without call detections were omitted.

Table 20. Summer 2011 Killer 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 for each recording station in the northeastern Chukchi Sea. Stations without call detections were omitted.

Killer Whale					
Station	Record start	First detection	Last detection	Record end	Detection days
BG01	27 Jul	07 Oct	09 Oct	12 Oct	1
PLN80	28 Jul	20 Sep	20 Sep	12 Oct	1
PLN40	27 Jul	20 Aug	20 Aug	11 Oct	1
KL01	27 Jul	07 Aug	07 Oct	08 Oct	4
PLN20	28 Jul	02 Sep	07 Oct	09 Oct	2
PL50	28 Jul	07 Oct	07 Oct	09 Oct	1
PL35	29 Jul	06 Oct	06 Oct	09 Oct	1
CLN120B	27 Jul	19 Aug	10 Sep	08 Oct	2
CLN90	26 Jul	30 Aug	30 Aug	08 Oct	1
CL20	26 Jul	10 Aug	10 Aug	10 Oct	1
CL05	26 Jul	07 Oct	08 Oct	10 Oct	2

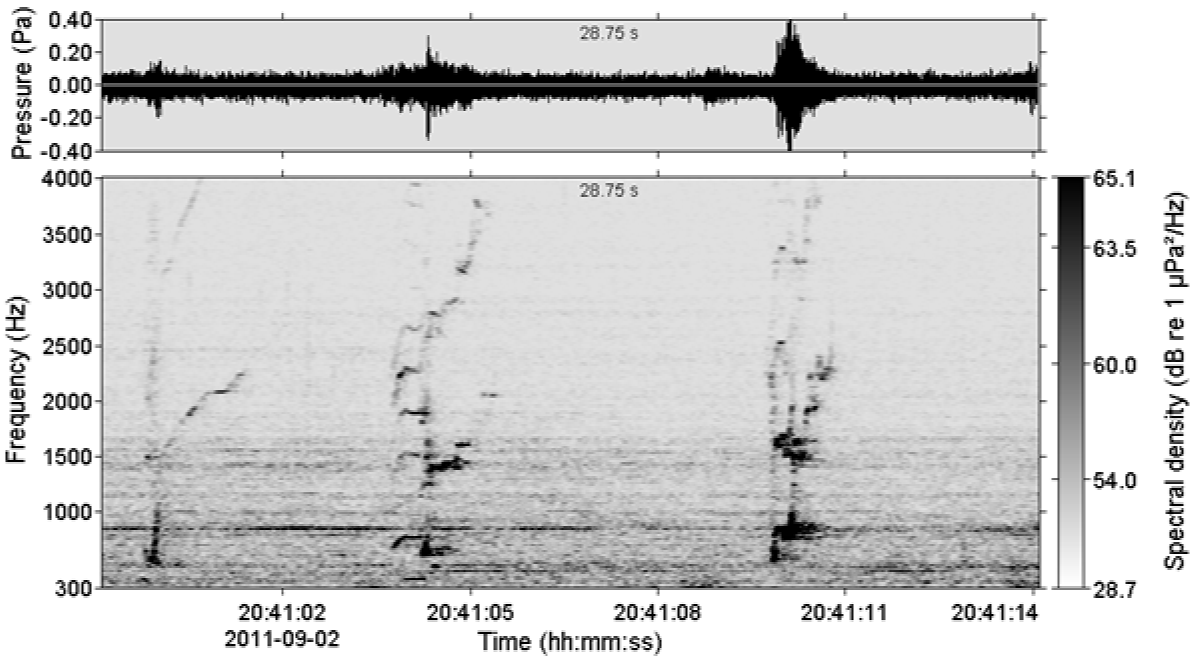

Figure 100. Killer whale call spectrogram from detection at summer Station PLN20, 2 Sep 2011 (32 768 pt FFT, 2000 pts real data, 1024 pt advance, Reisz window).

3.5.11. Minke Whale Call Detections

3.5.11.1. Winter 2010–2011 Program

Minke whale calls were not detected in the winter 2010–2011 dataset.

3.5.11.2. Summer 2011 Program

Minke whale (*Balaenoptera acutorostrata*) boing sounds were detected on 8 Aug at PLN60; on 7 Oct at PLN40, PLN20, and KL01; and on 8 Oct at CL20. These are the first summer detections of minke whales of all the acoustic monitoring programs in the northeastern Chukchi Sea.

Table 21. Summer 2011 Minke 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 for each recording station in the northeastern Chukchi Sea. Stations without call detections were omitted.

MINKE WHALE					
Station	Record start	First detection	Last detection	Record end	Detection days
PLN60	27 Jul	08 Aug	08 Aug	08 Oct	1
PLN40	27 Jul	07 Oct	07 Oct	11 Oct	1
KL01	27 Jul	07 Oct	07 Oct	08 Oct	1
PLN20	28 Jul	07 Oct	07 Oct	09 Oct	1
CL20	26 Jul	08 Oct	08 Oct	10 Oct	1

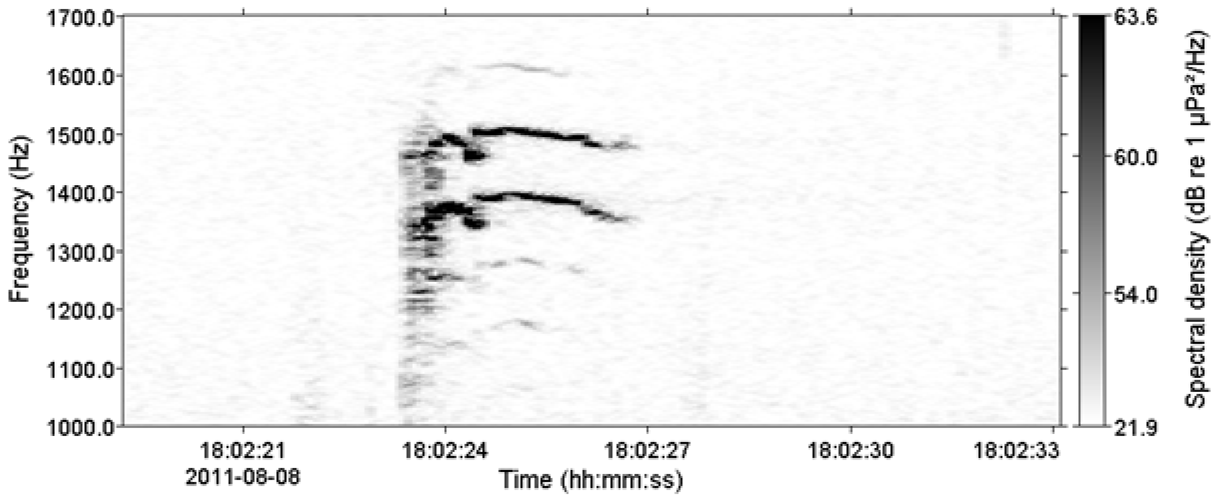

Figure 101. Minke whale boing sound recorded 8 Aug 2011 at Station PLN60 (16384 pt FFT, 4000 pts real data, 1024 pt advance, Reisz window).

3.5.12. Ribbon Seal Call Detections

3.5.12.1. Winter 2010–2011 Program

Ribbon seal calls were not detected in the winter 2010–2011 dataset.

3.5.12.2. Summer 2011 Program

Ribbon seal (*Histriophoca fasciata*) calls were detected once on 10 Oct 2011 at PLN40 and twice on 29 Sep 2011 at CLN90. Ribbon seals are a pelagic species. Little is known about their distribution in summer or fall. Recent satellite tagging experiments confirmed their presence in the Chukchi Sea in summer (Boveng et al. 2008), although sightings along the northeastern Chukchi coast are considered unusual (Moore and Barrowclough 1984).

Two types of ribbon seal calls were detected: (1) intense downsweeping sounds, with and without harmonic structure, corresponding to the short and medium sweeps (described by Watkins and Ray 1977); and (2) loud “puffing” sounds that sounded like a roar (Figure 102; described by Watkins and Ray 1977).

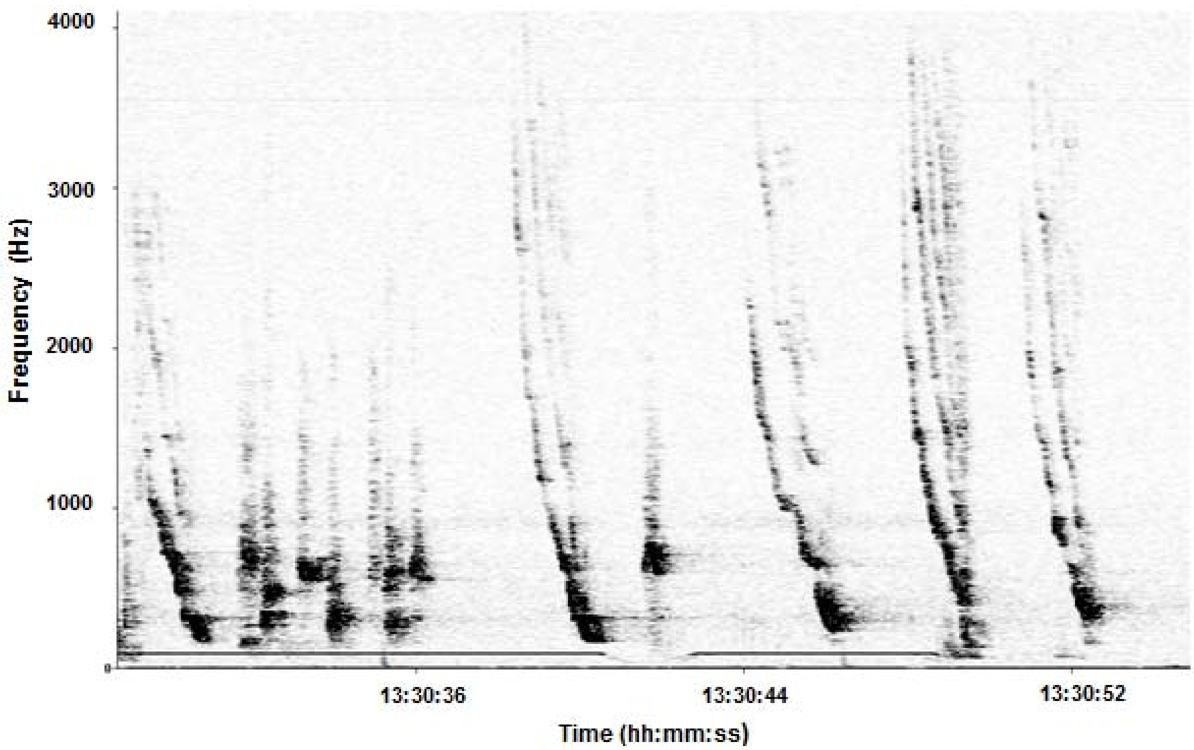

Figure 102. Spectrogram of ribbon seal calls recorded 4 Nov 2008 at Station CL50 (8192 pt FFT, 4096 real pts, 1024 pt advance, Hamming window; Hannay et al. 2009).

3.5.13. Ringed Seal Call Detections

3.5.13.1. Winter 2010–2011

The first detection of ringed seal (*Pusa hispida*) calls in the Chukchi Sea acoustic monitoring programs was in the winter 2009–2010 dataset. Ringed seal calls were not detected in previous years' datasets because the call types were largely unknown, not because the seals were not in the program area. The calls the analysts targeted were mainly barks and yelps (described by Stirling 1973; Figure 104). Ringed seals likely produce other call types, but the descriptions of those call types are inadequate to confidently detect these animals.

Ringed seal calls were detected at all stations. All but four detections occurred before end of Jan. Most detections were at Stations W50 and WN40 (Figure 103, Table 22). The detection probability for ringed seal calls using the 5% manual analysis protocol is low (22%, see Section 3.5.1, p 30); due to low calling rates, the results presented here likely under-represent the occurrence of ringed seal calls. These results differ from those of the winter 2009–2010 program (Delarue et al. 2011) in that ringed seal calls were not detected throughout the winter and spring. There are no plausible explanations why so few ringed seal calls were detected from Feb onward.

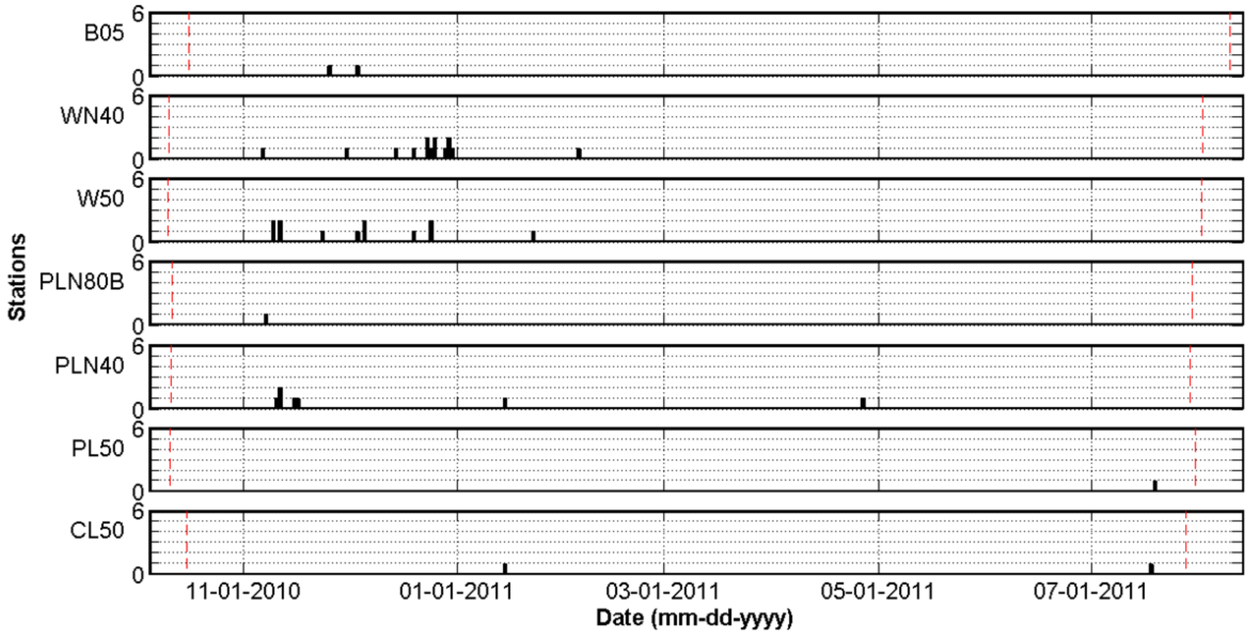

Figure 103. Winter 2010–2011 Daily Ringed Seal Call Detections: Daily number of sound files (six 40-min files recorded per day) with call detections based on the manual analysis of 5% of the acoustic data recorded mid-Oct 2010 through early Aug 2011 in the northeastern Chukchi Sea for each station. Red dashed lines indicate when the recording started and ended.

Table 22. Winter 2010–2011 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 40 min of every 4 h.

Station	Record start	First detection	Last detection	Detection days	Record end
B05	16 Oct	25 Nov	03 Dec	2	06 Aug
WN40	10 Oct	06 Nov	02 Apr	14	31 Jul
W50	10 Oct	09 Nov	22 Jan	15	30 Jul
PLN80	11 Oct	07 Nov	7 Nov	1	28 Jul
PLN40	11 Oct	10 Nov	16 Apr	6	27 Jul
PL50	11 Oct	18 Jul	18 Jul	1	28 Jul
CL50	15 Oct	14 Jan	17 Jul	1	26 Jul

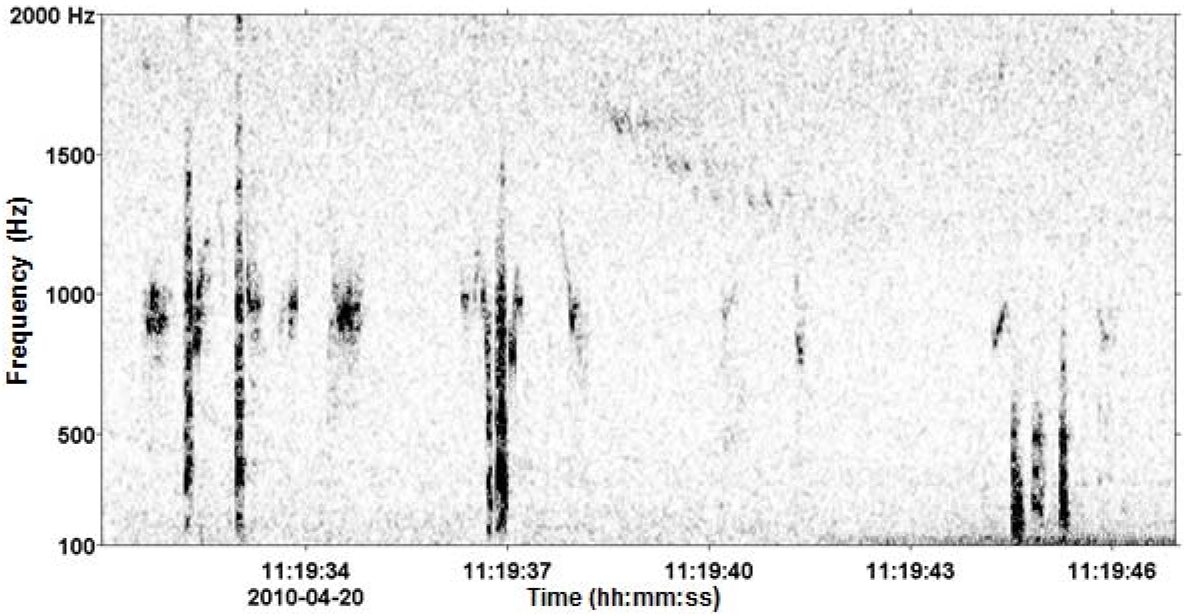

Figure 104. Spectrogram of ringed seal calls recorded 20 Apr 2010 at Station CL50 (2048 pt FFT, 512 pt advance, Hamming window; Delarue et al. 2011).

3.5.13.2. Summer 2011 Program

Ringed seal calls were detected at 11 stations between 27 Jul and 10 Oct 2011 (Table 23, Figure 105). The number of detection days at each station was low (1–8 days, mean = 3 days). The three Barrow stations accounted for 50% of the detections and had the largest number of detection days. Detection probability and calling rates were low. The results presented here underestimate the spatial and possibly temporal distributions of ringed seals in the program area.

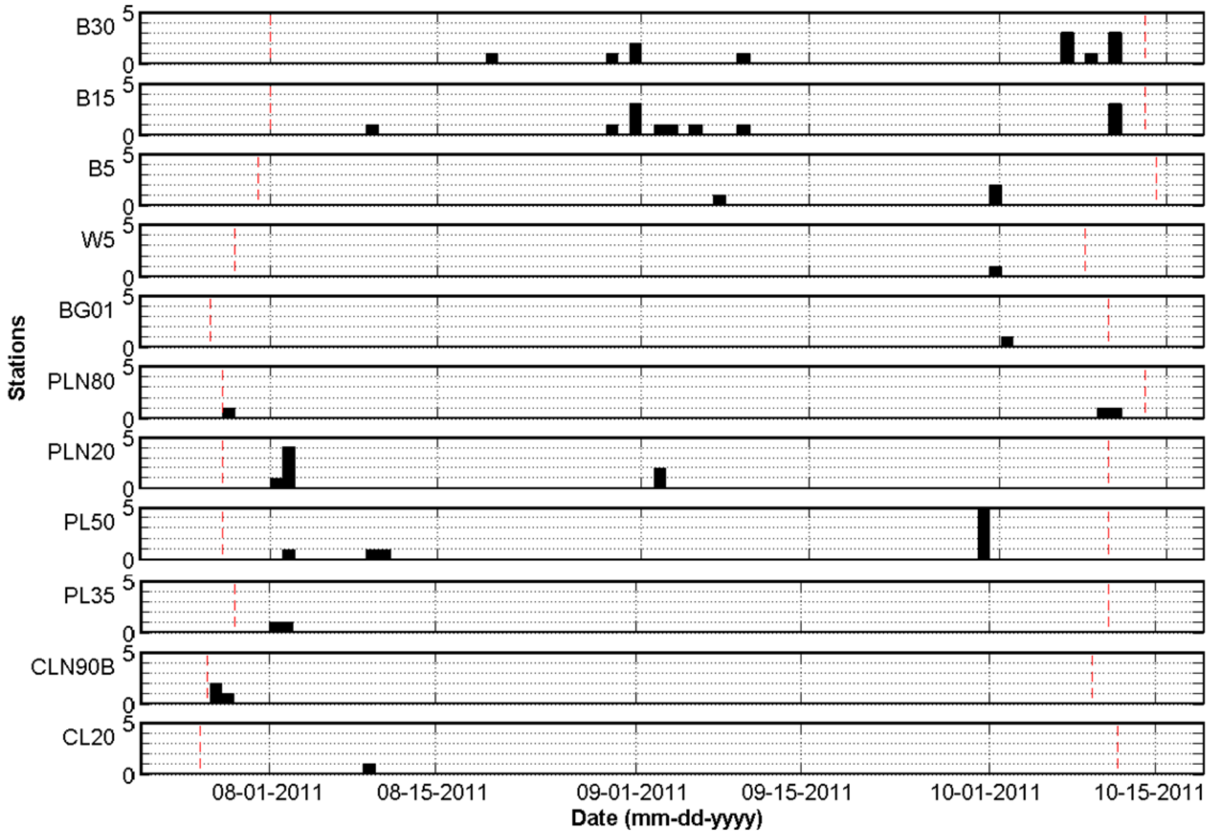

Figure 105. Summer 2011 Daily Ringed Seal Call Detections: Daily number of sound files (six 40-min files recorded per day) with call detections based on the manual analysis of 5% of the acoustic data recorded late Jul through mid-Oct 2011 in the northeastern Chukchi Sea for each station. Red dashed lines indicate recording start and end. Stations without call detections were omitted.

Table 23. Summer 2011 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 for each recording station in the northeastern Chukchi Sea. Stations without call detections were omitted.

Ringed Seal					
Station	Record start	First detection	Last detection	Record end	Detection days
B30	01 Aug	19 Aug	10 Oct	12 Oct	7
B15	01 Aug	09 Aug	10 Oct	12 Oct	8
B05	31 Jul	07 Sep	30 Sep	13 Oct	2
W05	29 Jul	30 Sep	30 Sep	07 Oct	1
BG01	27 Jul	01 Oct	01 Oct	09 Oct	1
PLN80	28 Jul	28 Jul	10 Oct	12 Oct	3
PLN20	28 Jul	01 Aug	02 Sep	09 Oct	3
PL50	28 Jul	02 Aug	29 Sep	09 Oct	4
PL35	29 Jul	01 Aug	02 Aug	09 Oct	2
CLN90	26 Jul	27 Jul	28 Jul	08 Oct	2
CL20	26 Jul	09 Aug	09 Aug	10 Oct	1

3.5.14. Spotted Seal Call Detections

Spotted seal calls were not manually detected in the winter 2010–2011 or summer 2011 datasets because of a lack of knowledge about their calls. The lack of detections do not, however, suggest seals are absent from the program areas as they are regularly seen in the area in summer (e.g., Funk et al. 2009). By placing dedicated recorders near known spotted seal summer haul-outs (e.g., in Kasegaluk Lagoon passes; Frost et al. 1993), researchers might be better able to understand spotted seal calls and to assess the feasibility of acoustically surveying this species. If their calls could be identified, the 2007–2011 Chukchi acoustic datasets could be reanalyzed to determine the spatial and temporal distributions of spotted seals.

3.6. Seismic Survey Sounds and Marine Mammals

3.6.1. Walrus

There were no discernible effects on walrus detections from seismic sounds from the Statoil shallow hazards survey. The stations on which airgun sounds were detected include S01, PLN80, PLN60, PLN40, CLN120B, and BG01. Walrus were detected throughout the seismic survey at all these stations, although the number of detections was typically low, except at BG01 (Figure 50). The detection gaps observed at some of these stations (Figure 50) during the seismic survey did not appear related to the survey itself. They may be explained by foraging-related movements; similar patterns were observed in previous years (e.g., Delarue et al. 2011). All of these stations lie outside the areas walrus used most heavily during summer 2011 (Figures 52 to 56). Local walrus densities near the Statoil lease areas are presumably lower than on the southern side of Hanna Shoal, leading to lower and less consistent detections. BG01 was closest to the edge of the core area near Hanna Shoal.

3.6.2. Bowhead Whales

There was little overlap in time between the bowhead detection period and the Statoil seismic survey at the start of the survey and none at the end. The beginning of the survey (7 Aug 2011, 19:00 UTC) coincided with the end of the early bowhead detection period (27 Jul to 9 Aug 2011). At BG01, where bowheads had been detected daily (except on 3 and 5 Aug) between 2-16 times per day, the number of 30 min periods with detections dropped from six to one between 7 and 8 Aug 2011, after which there were no detections. Detections at S01 (in the survey area), PLN80, and PLN60 (closest stations to the survey area) stopped on 6 Aug before the survey started, but these stations had had more sporadic detections than stations farther south. Of the four stations that had detections into 9 Aug, three were too distant for the survey to detect and one was 100 km away, at which distance the sound levels were close to ambient noise levels. Thus, it is difficult to assess whether bowheads left the program area because of the seismic survey.

Bowheads are expected to react less to airgun sounds when feeding than when migrating. The detected bowhead whales were likely feeding based on the length of the detection period and the time of year. Because this survey used a low airgun array volume, the sound levels bowhead whales experienced were low so they may have reacted to other cues when leaving the area around 8 Aug. Bowhead calls were not detected until 21 Sep, after the survey was over.

4. Discussion: 2007–2011 Trends

4.1. Ambient Noise

Underwater sound is made up of ambient and anthropogenic noise. Ambient noise is produced by wind and waves, ice cracking events, geological seismic events, and biological sounds including those from marine mammals, whereas anthropogenic noise is human-created sounds. Although anthropogenic noise also contributes to the total underwater sound field, is often considered separately; however, our discussion and treatment of ambient noise includes both natural and anthropogenic sounds.

This study compares ambient sound levels at Station PLN40 throughout the summer and the winter deployments from 2007 through 2011. Ambient sound levels for summer 2011 are compared across several stations.

4.1.1. Station PLN40 Multi-Year Analysis

The 2007–2011 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 106 for Station PLN40 for all recordings from summer 2007 to summer 2010. Station KL11 was used for summer 2009 since PLN40 was not deployed in 2009 and KL11 was the closest recorder to PLN40. Spectrograms for the recordings are shown in Figures 107 and 108, grouped by summer and winter periods to more easily compare among years.

Ambient noise levels below 1 kHz increased in mid-Aug and late Sep 2011 (Figure 107). This is likely attributed to increased wind speeds (Figure 8). Distant shipping tonals, attributed to the *Duke,* occurred from early Aug to mid-Sep. For summer 2010, the spectrogram shows seismic activity up to 200 Hz. 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 occurring later in the season coinciding with more wind and storms. Summer 2009 was similar to summer 2008, with only a restricted period of shallow hazards seismic activity. Despite an extensive seismic program in Sep, summer 2007 had extended quiet periods, which led to lower overall noise levels compared with other years.

Ambient noise levels over the three winter periods are similar, with all linearly decreasing from 40 Hz to 2 kHz. The loudest periods of all three correspond with ice formation and break up. The relatively high levels below 100 Hz are attributed to wind noise propagating through the ice.

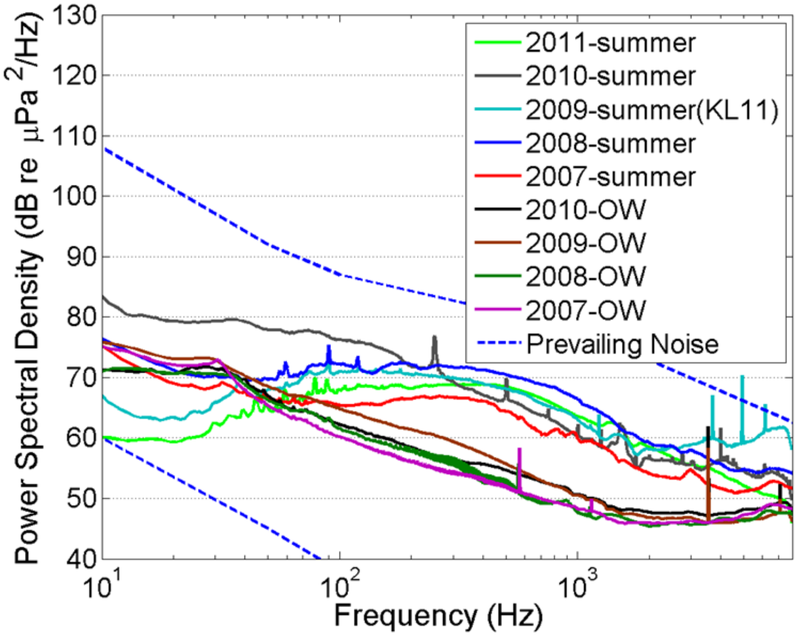

Figure 106. Percentile 1 min power spectral density levels at PLN40, for the monitoring periods from summer 2007 to summer 2011. KL11 was used for summer 2009 since the PLN40 data are unavailable for that period.

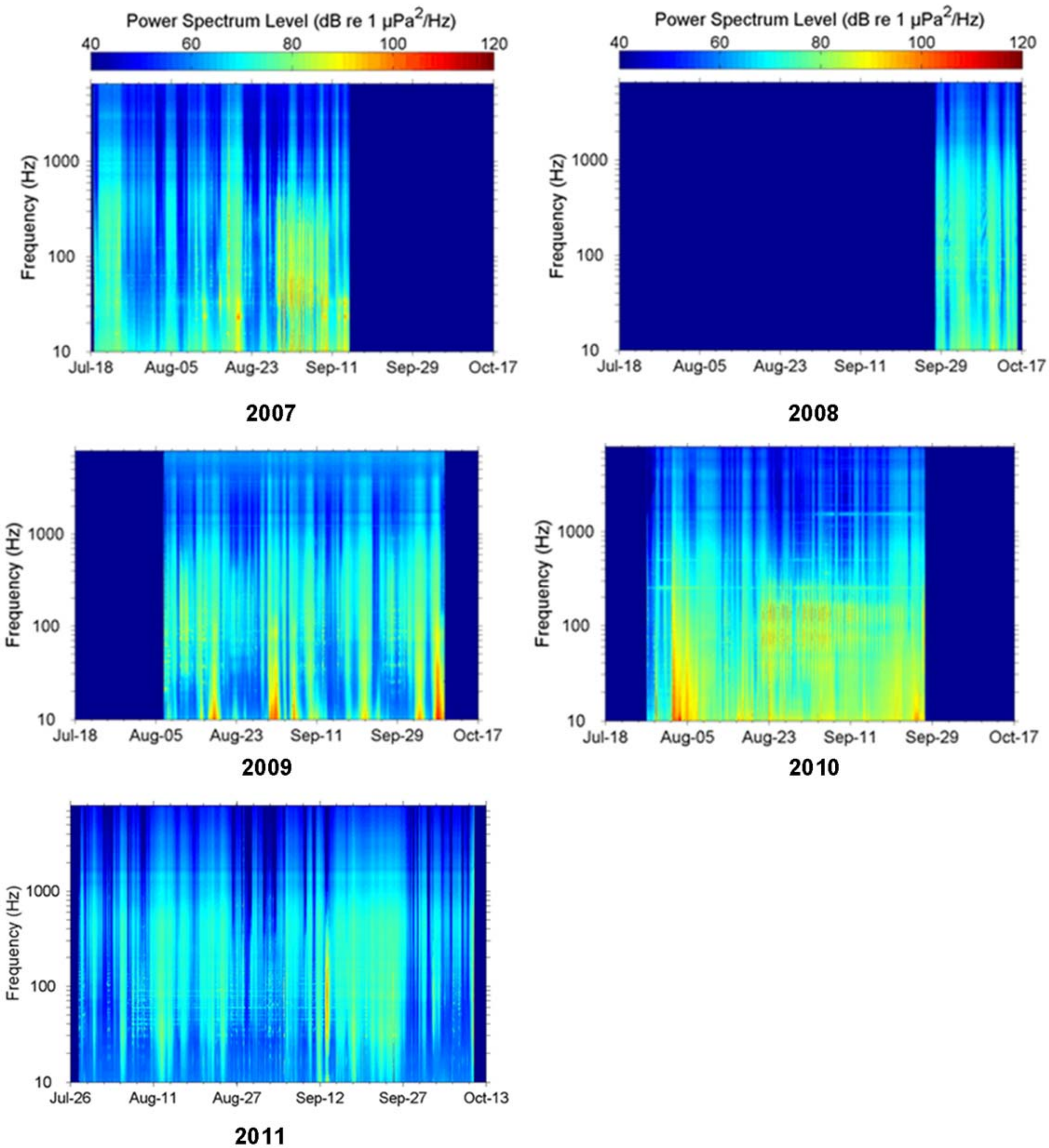

Figure 107. Spectrogram of underwater sound at PLN40 for the summer deployments.

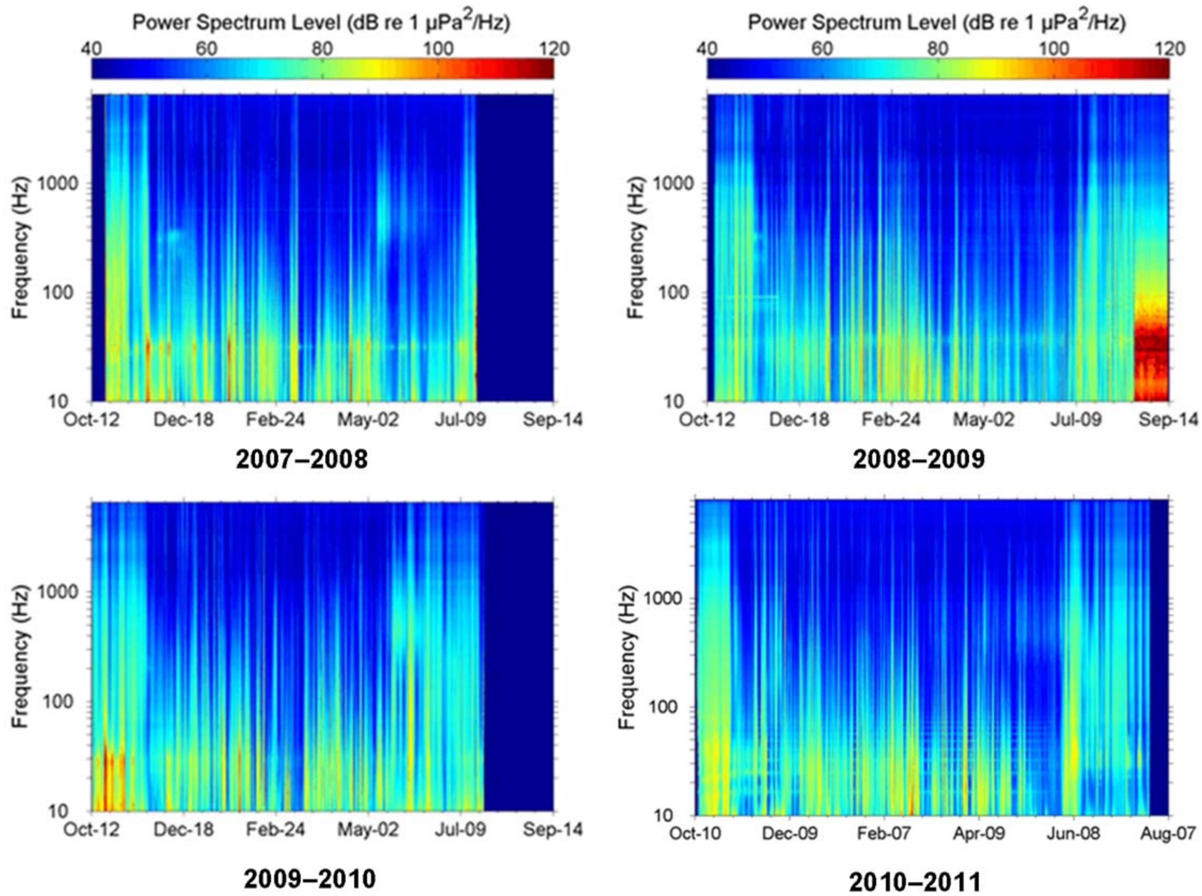

Figure 108. Spectrogram of underwater sound at Station PLN40 for the winter programs.

4.1.2. Summer 2011 Program

The 50th percentile power spectral density levels are plotted for stations along a roughly east-west line from the summer 2011 program in Figure 109 and the corresponding spectrograms for the recorders are shown in Figure 110. Examining the spectrograms, seismic activity is observed at PLN80 and S01. The spectrograms and the percentile plot show prominent tonals from the shipping activity at PLN80 and S01, and more faintly in CLN120B and B30. The shipping and seismic activity leads to higher levels from 30 to 500 Hz at those stations. Station B30 experienced much lower levels due to the lack of seismic activity in the area, but also because it is in a much deeper location; Station B30 was situated at a depth of 63 m, while the other recorders were at a depth of about 40 m. The greater depth of B30 decreases the effect of meteorological factors such as wind and rain.

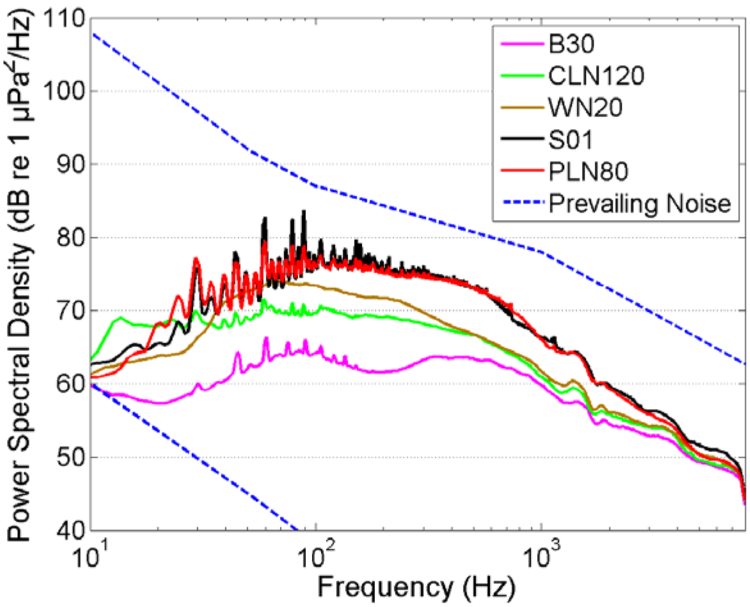

Figure 109. Percentile 1 min power spectral density levels at stations along a roughly east-west line across the Chukchi Sea for summer 2011.

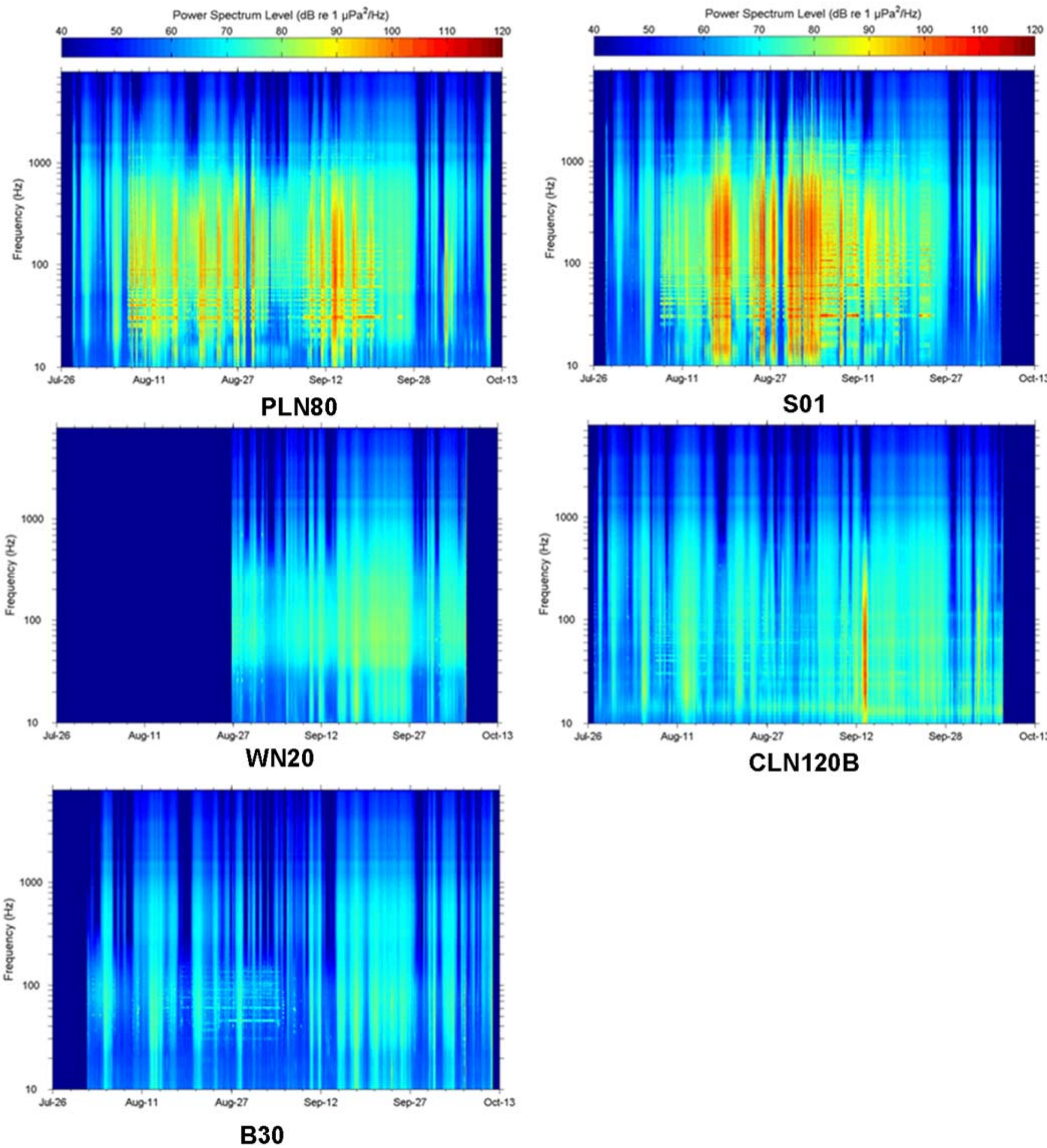

Figure 110. Spectrogram of underwater sound for the summer 2011 program.

4.2. Marine Mammal Vocalization Detections

By deploying recorders at the same or similar locations each year since 2007, we were able to directly compare yearly results of marine mammal vocalizations[4]. 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 eight in 2009–2010.

4.2.1. Bowhead Whales

4.2.1.1. Winter Acoustic Monitoring Programs

The four winter acoustic monitoring programs revealed slight differences in the timing of the fall migration. Because in all years the migration was already underway when the winter recorders were deployed, the information that can be derived from the winter data are limited to the middle and end of the migration. Bowhead call detections started almost systematically upon deployment, except at Stations PL50 and CL50. This suggests that CL50 and PL50 lie outside of the migration corridor until later in the migration when the southward progress of the ice edge presumably forces individuals farther south. The last detections always occurred at one of these two stations; dates varied by about two weeks, ending as early as 15 Dec in 2009 and as late as 17 Jan in 2011. Annual variations in the timing of sea ice formation presumably drive the differences in timing of the migration. Barrow whaling captains noted that fall migration occurs later in years with little or no ice than in years with heavy ice, with whales remaining near Barrow until late Oct (Huntington and Quakenbush 2010). The delayed fall migration in 2007 and 2011, the two years with the lowest sea ice extent on record, are consistent with these observations.

Since the start of fall 2009, when a recorder was placed at Station B05, the fall detections at B05 stopped in the first week of Nov. Interestingly, they last at least a month longer off Wainwright, at the northernmost station, and even longer farther southwest. In 2008, a few detections occurred at Station B35 into the second half of Nov. Although the results at these two Barrow stations are not directly comparable because they are from different years, they may indicate that bowheads continue to enter the Chukchi Sea after the first week of Nov farther offshore (i.e., more than 15 km from Barrow, which is a reasonable estimate of the detection range of the B05 recorder). However, the northeastern Chukchi Sea in fall is not simply a transit area for fall migrating bowheads; some bowheads may interrupt their migration to engage in other activities such as feeding and socializing. The constant display of songs from late Nov as well as

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

uninterrupted detections at some stations (e.g., at CL50 throughout Dec 2010 and again from 10-17 Jan 2011) support that hypothesis.

In all four years of the winter program, the highest call counts occurred in the second half of Nov or the first half of Dec. This is in part due to songs that trigger more detections than the sequences of moans produced earlier in fall. In addition, the relatively predictable advance of the ice edge at that time may funnel all the late migrants past the acoustic recorders, thereby contributing to an increase in call counts. Overall, because of the increased calling rates observed as the migration progresses, and particularly with the onset of singing in Nov, the call counts compiled from Sep to Jan cannot be directly used to evaluate the temporal variation of bowhead numbers during the fall migration through the Chukchi Sea (about 3-4 months). The period during which most individuals transit through the study area remains unclear.

It is difficult to comment on specific fall migration paths using the winter data due to the sparse distribution of sensors. The largest call counts generally occur at stations proximal to 71° N (e.g., W35, W50, PLN40) with relatively less detections farther north (PLN80, WN40) or south (CL50, PL50), at least until the end of the detection period in the latter case, when ice forces whales farther south. In 2011, however, PLN80 had consistently high detections, suggesting that a number of bowheads were migrating close to 72° N. Overall, this is consistent with results from late in the summer programs (2009 and 2010; Delarue et al. 2011) suggesting that the main migration corridor usually lie between 71° and 72° N.

Bowhead whale spring detections typically occur between mid-Apr and the end of Jun. In the last two years of the program, the first detections occurred around 29–30 Mar. The number of spring detection days was always smaller than in fall except at station B05. The latter is mainly because the area near Barrow appears to act as funneling point for most spring migrating bowhead whales when this is less the case in fall. Annual variations in the number of detection days were pronounced in spring. For instance, the number of detection days was larger in spring 2010 at all stations than in the three other years. This suggests that a larger proportion of whales migrated offshore in 2010. The coastal lead forming inshore in Apr between Point Hope and Point Barrow is believed to be the normal migration route for bowheads in spring (Moore and DeMaster 1998). This is in agreement with the observation of a long, continuous detection period at B05 contrasting with few sporadic detections at the offshore stations. Although the 2010 results may be an exception to the norm, some bowheads can be reliably expected in the lease area every spring, though in much smaller numbers than in fall.

4.2.1.2. Summer Acoustic Monitoring Programs

An unusual finding of the 2011 summer recording results is that bowhead detections occurred throughout the study area (though most concentrated off Point Lay) from late Jul to 8 Aug. The lengthy detection period suggests the animals were feeding in the Chukchi during this period. Though not conclusive, the spatio-temporal distribution of these detections suggests the animals left the area via west-northwest. Bowheads typically forage in the Beaufort Sea in summer. However, in 2010 a whale with a satellite tag swam from Barrow to the Chukotkan coast between late Jul and early Aug 2010, and spent the rest of the summer in this area (J. Citta, pers. comm.). A similar pattern may have occurred in 2011.

There were few detections in the study area before the end of Sep 2011. In both 2009 and 2010 the main migration corridor was between 71° and 72° N, although call counts were lower at the stations near 72° N, which suggests that most whales migrate closer to 71° N (Figure 111 for 2009 and Figure 112 for 2010). A similar pattern was observed in 2011 (Figure 113) when Klondike lay on the southern edge of the corridor, with Burger and Statoil in the migration corridor. The factors that determine the location of the migration path are unclear. The path in the Chukchi Sea is, to some extent, constrained by its start (Barrow area) and end points. After leaving Barrow, most tagged fall migrating bowheads appear to head for an area between Wrangel Island and Cape Schmidt (Quakenbush et al. 2010, 2011), which puts the Klondike prospect on the southern edge, and the Burger and Statoil prospects directly within, the migration corridor.

At a finer spatial scale, behavioral and environmental factors, such as water composition and currents, could determine where bowheads migrate. Differences in water composition could affect their migration distribution by affecting the distribution of their prey if they feed during migration. Hydrographic differences between the Klondike and Burger lease areas were noted in 2008 and 2009 (Weingartner and Danielson 2010). Although these differences support the idea that behavioral and environmental factors can affect migration, further research is needed before any correlation can be established.

Considerably fewer call counts recorded in 2011 during the period associated with the fall migration indicate that, although the onset of the migration throughout the study area was similar to the previous two years, far fewer whales migrated through the area. In fall 2007, the timing of the migration was delayed (Hannay et al. 2012 in review). This also seems to be the case for many whales in 2011. Both years were characterized by record-low sea ice.

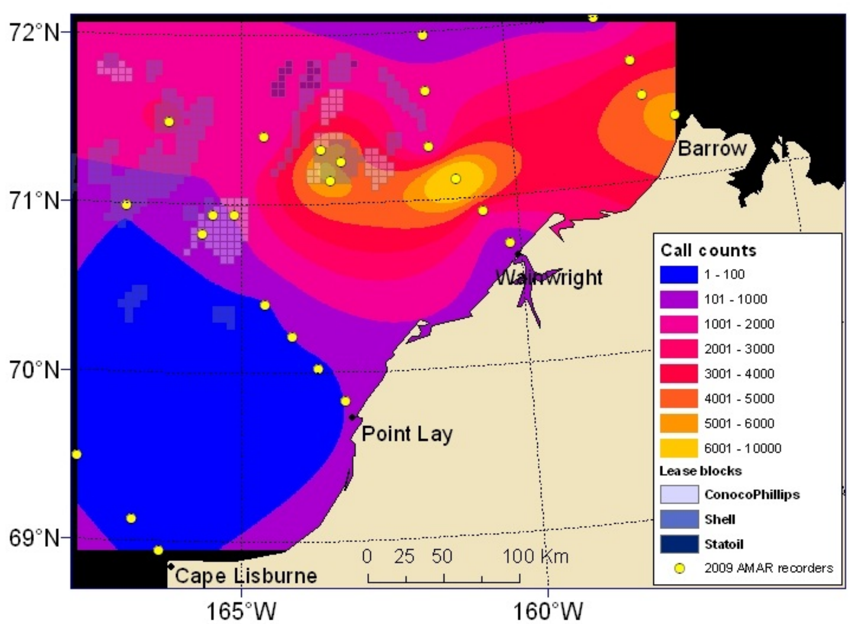

Figure 111. Summer 2009 bowhead whale call counts, 5 Aug through 15 Oct: Interpolated call counts based on the sum of automated call detections in all files with manual detections at all summer recording stations in the northeastern Chukchi Sea. Kriging interpolation was used.

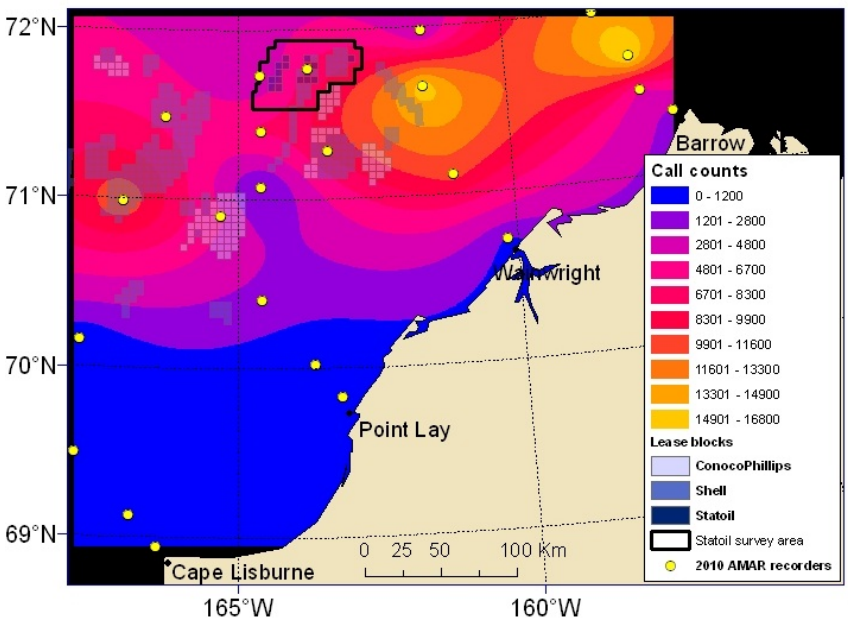

Figure 112. Summer 2010 bowhead whale call counts, 25 Jul through 15 Oct: Interpolated call counts based on the sum of automated call detections in all files with manual detections at all summer recording stations in the northeastern Chukchi Sea. Kriging interpolation was used.

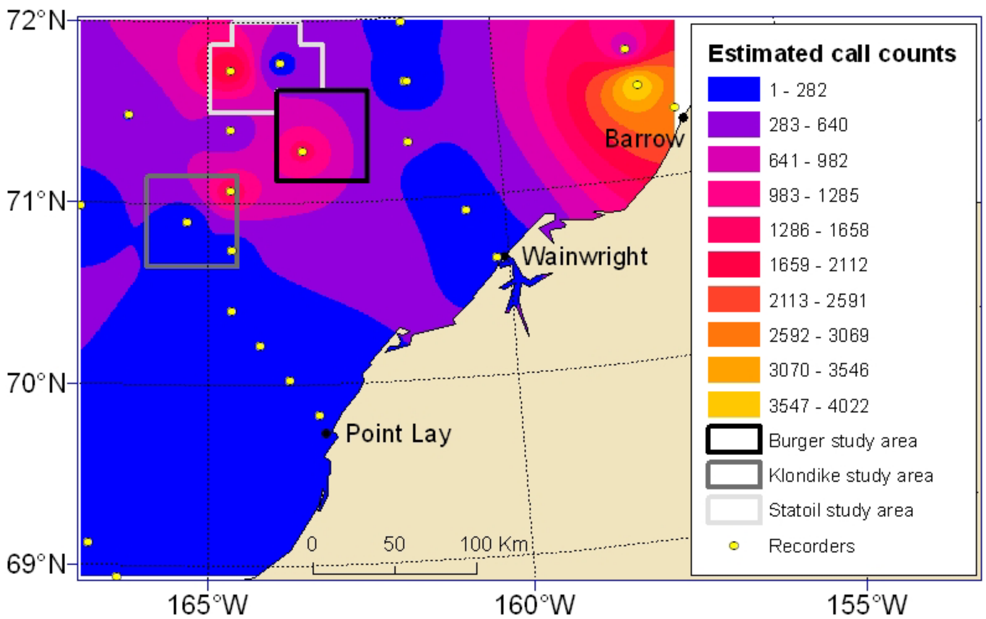

Figure 113. Summer 2011 bowhead whale call counts, 16 Aug through 12 Oct: Interpolated call counts based on the sum of automated call detections in all files with manual detections at all summer recording stations in the northeastern Chukchi Sea. Inverse-distance interpolation was used.

4.2.2. Walrus

4.2.2.1. Winter Acoustic Monitoring Programs

Walrus have been detected increasingly later in the fall during the four winter acoustic monitoring programs. The latest winter detections occurred on 27 Feb 2011 at Station PLN40, 22 Jan 2010 at Station PLN40, 30 Dec 2008 at Station W50, and 27 Nov 2007 at Station WN20 (Hannay et al. 2009). However, walrus occurrence in the fall was low and detections isolated in all years, suggesting that most of the walrus population vacates the program area earlier in the fall.

In spring, walrus were detected in the first half of Jun in 2008, 2009, and 2010. The first detections occurred 14 May at Station PLN40 (which is also where the latest fall detections occurred in the last two years). Except for this early detection, most of the detections followed a pattern similar to previous years (Delarue et al. 2011). Walrus were progressively detected farther northeast, following the retreat of sea ice (Figures 45 to 48). However, they remained in the Hanna Shoal area (near Stations WN40 and W50) in the second half of Jul when the ice edge was farther north, confirming this is a key foraging area for walrus in the northeastern Chukchi Sea. Differences in when walrus arrive in the northeastern Chukchi Sea are likely due to differing ice conditions they encounter when migrating.

Little is known about when walrus move into the Chukchi Sea in spring. An ongoing tagging and tracking program by the US Geological Survey (Jay et al. 2011) is expected to provide new information on the topic. In all fours years, walrus first traveled to locations offshore of Wainwright, from where they later radiated out after the retreat of sea ice from Hanna Shoal.

4.2.2.2. Summer Acoustic Monitoring Programs

A feature common to the 2007, 2009, 2010, and 2011 programs is the consistently high number of walrus acoustic detections off Wainwright and mainly south of Hanna Shoal, between Stations W50 and WN40 (Figures 114 to 116). In 2010 and 2011, there were many detections off Point Lay as a result of a haul-out consisting of thousands of walrus throughout summer. Call count estimates were typically lower on either side of a corridor connecting Hanna Shoal and the coast between Point Lay and Wainwright, suggesting decreasing densities farther from this area. Call counts were also lower between Hanna Shoal and the coast, indicating that walrus mostly transit and do not spend much time foraging between these areas (Figures 114 to 116). Consistently high call counts at Station CL05 in the last three years suggest there is a haul-out in this area. Walrus also appear to leave the study area by following the coastline between Point Lay and Cape Lisburne, where they might rest before crossing the Chukchi Sea toward the northern Chukotkan coast where large numbers of walrus are observed in fall.

Walrus call counts peaked in the Chukchi Sea in Aug and early Sep. The last three summer deployments provided evidence of a southwesterly movement from mid-Sep on, which probably indicate the onset of the migration out of the study area. Although the winter data indicate that some walrus remain in the Chukchi Sea until winter, most of the population vacates the area in Oct.

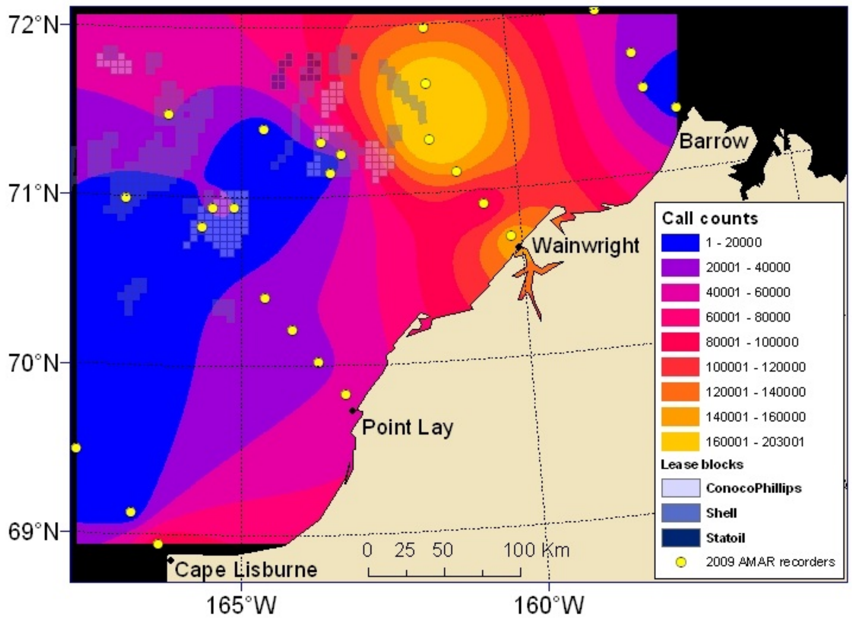

Figure 114. Summer 2009 walrus call counts, 5 Aug through 15 Oct: Interpolated call counts based on the sum of automated call detections in all files with manual detections at all summer recording stations in the northeastern Chukchi Sea. Krigging interpolation was used.

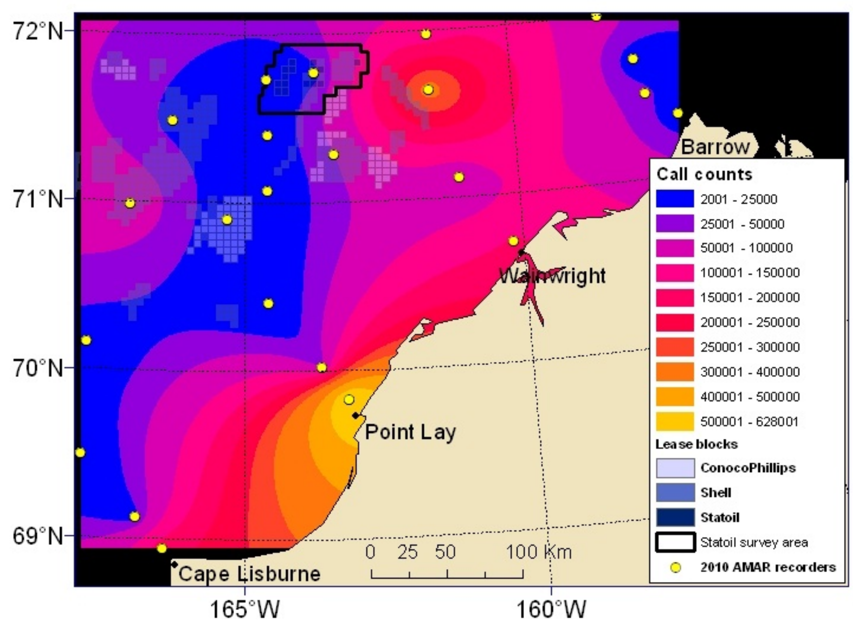

Figure 115. Summer 2010 walrus call counts, 25 Jul through 15 Oct: Interpolated call counts based on the sum of automated call detections in all files with manual detections at all summer recording stations in the northeastern Chukchi Sea. Krigging interpolation method was used.

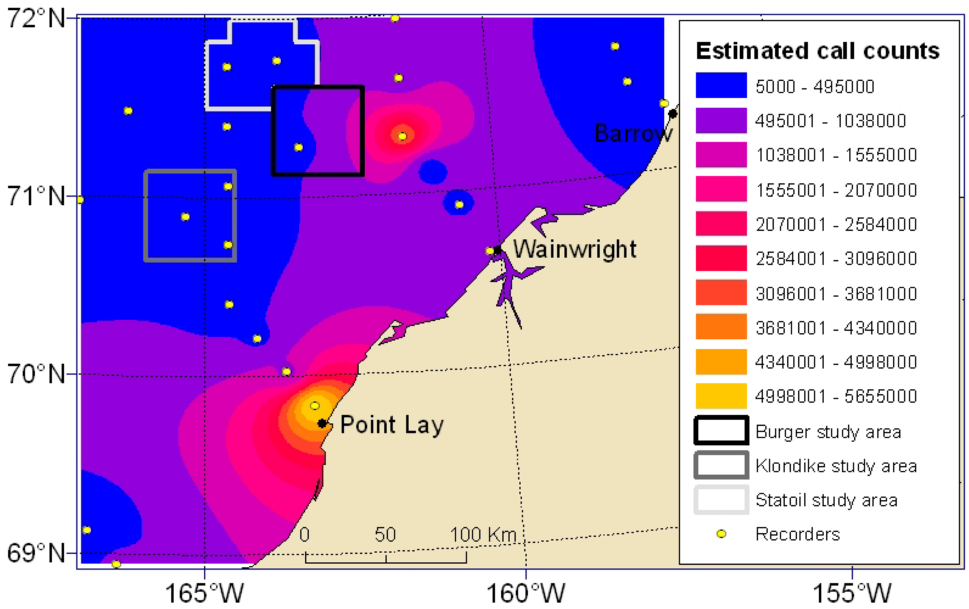

Figure 116. Summer 2011 walrus call counts, 27 Jul through 12 Oct: Interpolated call counts based on the sum of automated call detections in all files with manual detections at all summer recording stations in the northeastern Chukchi Sea. An inverse-distance interpolation method was used.

4.2.3. Beluga Whales

4.2.3.1. Winter Acoustic Monitoring Programs

The three winter programs yielded consistent results of the spatio-temporal distribution of beluga acoustic detections. Fewer beluga acoustic detections occurred past mid-Oct in the program area. Detections were attributed to eastern Chukchi Sea belugas because eastern Beaufort Sea belugas are known to migrate earlier and north of the program area (Richard et al. 2001). In fall 2010, belugas were detected for 20 days at B05 but to a maximum of four days at the other stations, which suggested that they may be preferentially migrating inshore in fall and are therefore missed by the winter recorders, which are at least 56 km from shore. In 2011, several detections occurred in the second half of Nov primarily off Point Lay and Cape Lisburne. Thus, the migration route of eastern Chukchi Sea belugas in fall appears to vary annually.

In spring 2011, the first beluga detections started around 10 Mar at CL50 and PL50, at least three weeks earlier than in previous years. The number of detection days was lower than 2010, but comparable to other years. As explained in Section 3.5.5.1, p 63, a recorder at Station B05 supplied data that indicates the migration schedules of eastern Chukchi Sea and eastern Beaufort Sea belugas are segregated. Adding an inshore recorder near Point Lay could help confirm this observation. Overall, the results of the four winter programs indicate that belugas migrate widely through the program area in spring. Annual variations in the number of detection days at each station are presumably related to differences in ice conditions from their respective distance to shore.

4.2.3.2. Summer Acoustic Monitoring Programs

The comparison of 2007, 2009, 2010, and 2011 summer program data confirms belugas are relatively rare in summer months in the Chukchi Sea, even though a small increase in the number of detection days was noted in 2011. They are primarily detected:

- In late Jul and Aug at the inshore Wainwright stations, presumably as they head northeast from Kasegaluk lagoon toward Barrow Canyon
- In Aug off Barrow when they are known to forage in Barrow Canyon (Suydam et al. 2005, Delarue et al. 2011)
- In Oct with the onset of the eastern Chukchi Sea beluga fall migration. These detection patterns are consistent with results from a satellite-telemetry study (Suydam et al. 2005) and visual sightings obtained as part of the Chukchi Joint Acoustic Monitoring Program (Ireland et al. 2009).

4.2.4. Killer Whales

Killer whales were acoustically detected in the 2009, 2010, and 2011 summer datasets, as first observed in 2007 (Delarue et al. 2010a). Killer whales were detected predominantly off Cape Lisburne and Point Lay in all three years with a few detections off Wainwright. Further analysis revealed that mammal-eating killer whales were the source of the detected calls (Delarue et al. 2010a), which is consistent with observations of killer whale predation on marine mammals in the Chukchi Sea (George and Suydam 1998). Unique calls have been detected in multiple years, indicating that the same pods or individuals belonging to the same community return to the northeastern Chukchi Sea in different years.

4.2.5. Fin Whales

Fin whale acoustic detections in the 2009, 2010, and 2011 summer datasets have confirmed the presence of fin whales in the Chukchi Sea. These whales were first observed in 2007. In all years, fin whales were only at the offshore Cape Lisburne stations, with the exception of Station PL50. There was as steep drop in the number of detections between 2007 and 2009 with detections remaining rare since then, which indicates fin whales do not commonly come to the northeastern Chukchi Sea.

4.2.6. Gray whales

A large increase in gray whale detections was noted in 2011 owing to a new call type used to identify gray whales and improvements in the recorders that made this call type easier to detect. The observed pattern of gray whale detections (i.e., widely distributed but most abundant inshore between Icy Cape and Barrow) more closely coincides with the latest information on gray whale distribution based on aerial surveys (Clarke and Ferguson 2010).

4.2.7. Bearded Seals

4.2.7.1. Winter Acoustic Monitoring Programs

There was little difference in temporal or spatial distributions between the four winter programs. The typical temporal distribution of detections consists of a steady increase in calling rates from Oct, peaking in May and Jun, which coincides with the mating season. As in 2010, the decrease in estimated call counts observed in Jun may be related to the early retreat of sea ice. Call detections usually stop abruptly in late Jun–early Jul, with very sporadic, or no detections until the end of the recordings. 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 Jul and Aug and a steady increase in detections in Sept peaking in Oct. As in 2010, the detections in Sep and after were concentrated in the northern parts of the study area (Figure 118, Figure 119). In 2009, bearded seal calls were widely detected offshore, but were most often detected near Wainwright (Figure 117). In Oct 2011, these detections started spreading south, possibly indicative of a southern movement of bearded seals in the fall. However, the winter data demonstrate the yearlong presence of this species in the northeastern Chukchi Sea. As for bowheads in the fall, the steady increase in calling rate from Sep to May makes it difficult to compare estimated call counts between months. Fewer detections in Jul and Aug are attributed to behavior; this does not necessarily mean decreased abundance.

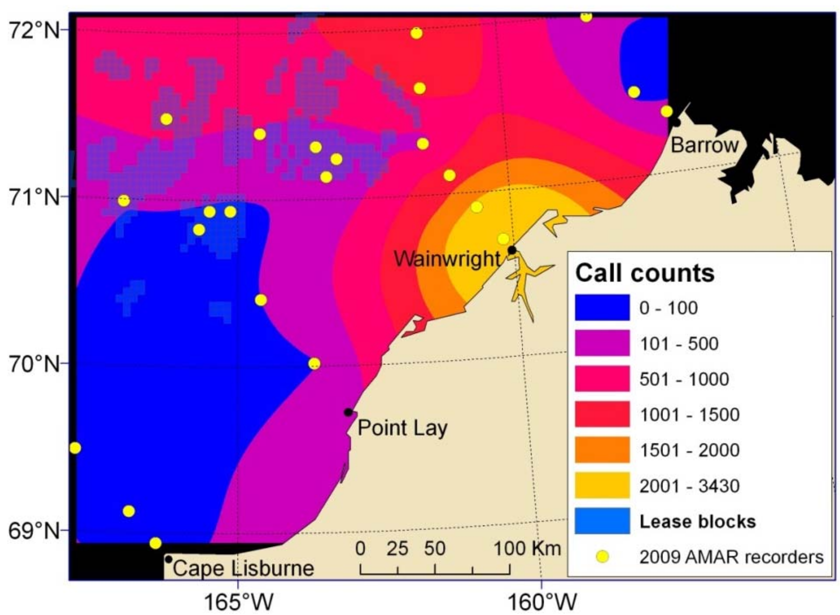

Figure 117. Summer 2009 Bearded Seal Call Counts, 5 Aug through 15 Oct: Interpolated call counts based on the sum of automated call detections in all files with manual detections at all summer recording stations in the northeastern Chukchi Sea. Krigging interpolation was used.

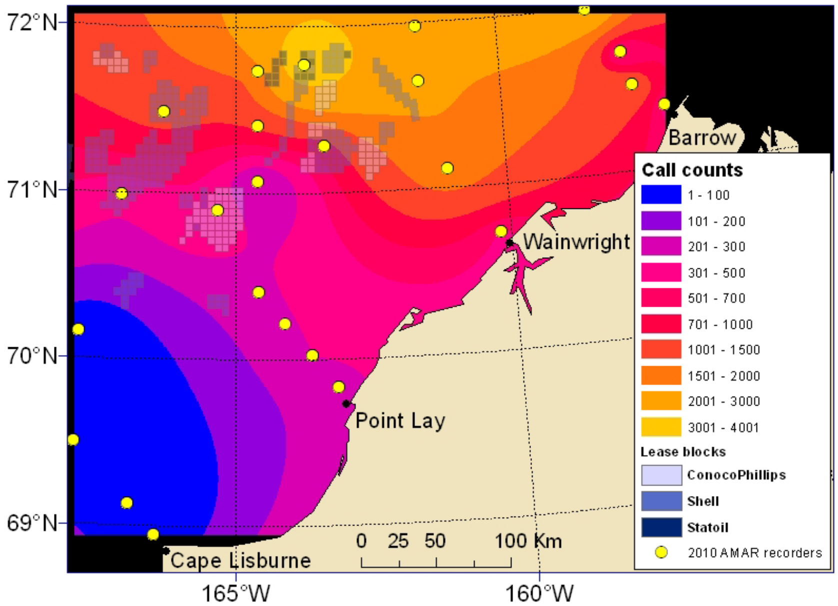

Figure 118. Summer 2010 Bearded Seal Call Counts, 25 Jul through 15 Oct: Interpolated call counts based on the sum of automated call detections in all files with manual detections at all summer recording stations in the northeastern Chukchi Sea. Krigging interpolation was used.

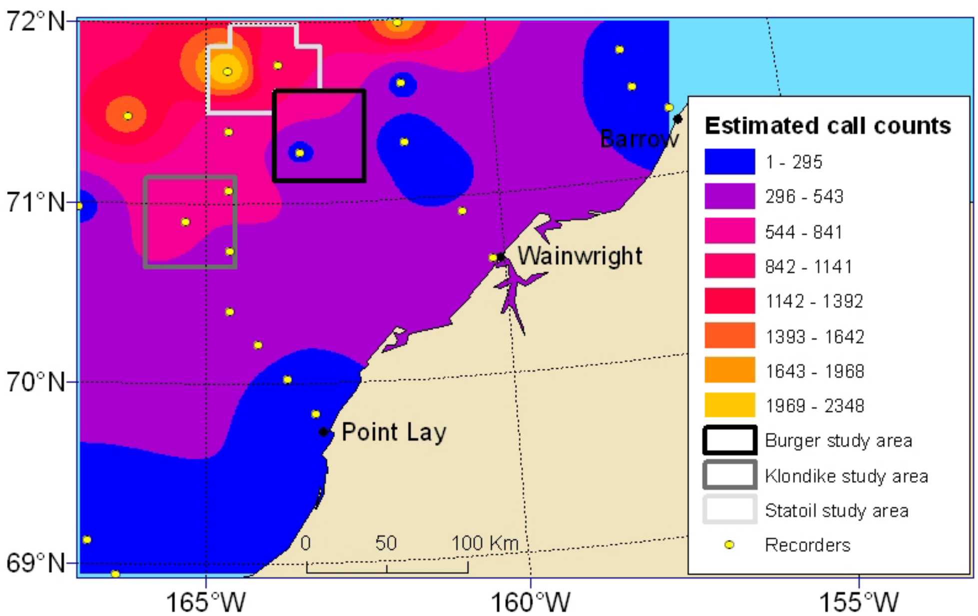

Figure 119. Summer 2011 Bearded Seal Call Counts, 27 Jul through 12 Oct: Interpolated call counts based on the sum of automated call detections in all files with manual detections at all summer recording stations in the northeastern Chukchi Sea. Inverse-distance interpolation was used.

4.3. Seismic Survey Sounds and Marine Mammals

There were no confirmed effects of seismic survey sounds on marine mammals in 2011, possibly due in large part to the lower airgun array volume used this year.

Evidence from the 2010 programs suggest the decrease in walrus detections in the presence of airgun sounds may be primarily due to increased ambient noise levels caused by reverberating airgun sounds. Masking may have prevented analysts from detecting walrus calls; however, walrus also reduced their calling rate and/or moved away from the recorders during parts of the survey. If masking did reduce detections, the 2010 survey may have reduced the communication space of walrus. The magnitude of this reduction and its consequences on walrus are not currently known.

5. Conclusion

5.1. Winter 2010–2011 Program

The winter 2010–2011 Joint Acoustic Monitoring Program provided information about ambient noise levels and biological sounds including marine mammal vocalizations[5] in the northeastern Chukchi Sea from Oct 2010 to Aug 2011. Key results and conclusions are presented below:

- 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 (Appendix B.1). Median winter ambient levels varied less than 5 dB across the frequency band of 10 Hz to 8 kHz at Station PLN40 between 2007–2008, 2008–2009, and 2009–2010.
- Recordings revealed continual marine mammal presence throughout the winter. Bearded seal sounds were a major contributor to ambient noise in spring, and were detected continuously from Oct until early Jul. Bowhead whale calls were predominant from mid-Oct until 1 Dec 2010.
- All three species known to migrate through the area in the fall and spring (bowheads, belugas, and walrus) were detected later in the fall and earlier in the spring than in any other program years.
- The timing and distribution of the beluga and bowhead whale acoustic detections were generally consistent with those from previous years. Notable differences included bowhead detections lasting until 17 Jan 2011 at CL50; an early onset of the beluga spring migration, starting near 10 Mar 2011; and few bowhead detections offshore (i.e., near the prospect areas) during spring. These differences are likely partly driven by annual variations in the presence of sea ice. In addition, an unprecedented two-week detection period at PLN40 in the second week of Jul was observed.
- Walrus acoustic presence in the fall and winter was limited. Some walrus were present as late as 27 Feb 2011 at Station PLN40. The first walrus were detected in the middle of May. From early Jun onwards, their calls were detected continuously moving from the southwest to the northeast.
- Ringed seal calls were detected mostly from early Nov until early Feb, but our analysis protocol most likely underestimates the occurrence of this species.

5.2. Summer 2011 Program

The summer 2011 Joint Acoustic Monitoring Program in the northeastern Chukchi Sea provided marine mammal and seismic airgun acoustic detection results, and compared them with results

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

from previous years' acoustic monitoring programs. The following list summarizes the key findings:

- Median ambient sound levels in the Chukchi Sea vary considerably between years at frequencies below 1 kHz due to variations in anthropogenic activity and weather (wind). Differences of up to 16 dB have been measured.
- An unprecedented number of bowheads were detected from late Jul to 8 Aug 2011. These detections followed the bowhead detections at Station PLN40 in the second half of Jul. Between Jul and 24 Sep, bowhead detections were restricted to the Barrow recorders, when the first fall migrants were observed moving through the study area. Although the start of migration was comparable to 2009 and 2010, smaller call counts indicate far fewer individuals transited though the northeastern Chukchi Sea, which suggests a delay in the overall migration schedule.
- The main migration corridor during the fall bowhead migration appeared to be located between 71° and 72° N, which includes the Burger and Statoil lease areas with the Klondike lease area on the southern edge of the corridor. Analyzing the 2009 and 2010 summer data revealed similar findings.
- Walrus were the most commonly detected species in the Chukchi Sea in summer. They were most commonly detected offshore of Wainwright on Hanna Shoal and near coastal haul-outs at Station PL05 and possibly CL05. Estimated call counts decreased on either side of an area connecting Hanna Shoal and the coast between Wainwright and Point Lay. In the second half of Sep walrus began migrating out of the program area. Some walrus appeared to follow the coast to Cape Lisburne before crossing west to the Chukotkan coast.
- Beluga detections are often absent from the Chukchi Sea in Aug and Sep when belugas forage in the northern Chukchi and Beaufort Seas. The exceptions are off Barrow where some belugas forage in summer months, and near the coast off Wainwright. Their fall migration takes them back through the Chukchi Sea in Oct and Nov although acoustic detections are usually sporadic in those months.
- Fin, humpback, and minke whales were each detected acoustically on two or three occasions in summer 2011. These were the first minke whale detections since the beginning of the summer programs. These findings are consistent with the paucity of fin and humpback whale visual sightings and the relatively small numbers of minke whale sightings. Killer whale detections were more common and only off Cape Lisburne and Point Lay in 2011.
- A large increase in gray whale detections was noted in 2011 owing to a new call type used to identify gray whales and improvements in the recorders' electronic noise that made this call type more easily detectable. The observed pattern of gray whale detections (i.e., widely distributed but most abundant inshore between Icy Cape and Barrow) coincides more with the latest information on gray whale distribution based on aerial surveys (Clarke and Ferguson 2010).
- Bearded seal acoustic detections were rare before Sep and more common in the northern parts of the program area, before spreading south in Oct. Ribbon seals were detected once during summer 2011. Ringed seal calls were more commonly detected. Ringed seals are present in the program area in summer but vocalize infrequently, thus the current results

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.

Acknowledgments

The authors acknowledge Dr. Julie Oswald for her contribution to the development of the bowhead and beluga call detectors. Del Leary provided support and advice throughout the development of the bowhead and walrus detectors and wrote the algorithm used to perform the detection probability analysis. Briand Gaudet and Trent Johnson were instrumental in developing and maintaining the software used to complete the manual analyses. Many thanks to the manual data analysts: Craig Evans, Frederic Paquet, Xavier Mouy, Jennifer Wladichuk, and Eric Lumsden.

Abbreviations and Acronyms

90% rms	root-mean-square pressure within the time window containing the center 90% (from 5% to 95%) of the pulse energy
AM	amplitude-modulated
AMAR	Autonomous Multichannel Acoustic Recorder (by JASCO Applied Sciences)
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
Buoy	meteorological buoy operated by Shell
B*XX*	regional array recorder station *XX* nmi from Barrow
BG01	the Burger lease recorder station
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
ESA	Endangered Species Act of 1973 (US)
FFT	fast Fourier transform
FM	frequency-modulated
GB	gigabyte (1GB = 1024^3 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
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
SEL	sound exposure level (dB re 1 $\mu Pa^2 \cdot s$)
Shell	Shell Exploration and Production Company
SO01	the Statoil lease recorder station
SPL	sound pressure level (dB re 1 μPa)
Statoil	Statoil USA Exploration and Production Inc.
TB	terabyte (1TB = 1024^4 bytes)
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

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. *Acoust. Phys.* 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. *Acoust. Phys.* 54:115–123.

Blackwell, S.B., W.J. Richardson, C.R. Greene Jr., and B. Streever. 2007. Bowhead whale (*Balaena mysticetus*) migration and calling behaviour in the Alaskan Beaufort Sea, autumn 2001-2004: An acoustic localization study. *Arctic* 60(3).

Blackwell, S.B., C.S. Nations, T.L. McDonald, A. Thode, K.H. Kim, C.R. Greene, and A.M. Macrander. 2010. Effects of seismic exploration activities on bowhead whale call distribution in the Alaskan Beaufort Sea. *Alaska Marine Science Symposium*, Anchorage, AK.

Boveng, P. L., J. L. Bengtson, T. W. Buckley, M. F. Cameron, S. P. Dahle, B. A. Megrey, J. E. Overland, and N. J. Williamson. 2008. *Status review of the ribbon seal* (*Histriophoca fasciata*). U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-191, 115 pp.

Cavalieri, D., T. Markus, and J. Comiso. 2004. *AMSR-E/Aqua Daily L3 12.5 km Brightness Temperature, Sea Ice Concentration, & Snow Depth Polar Grids V002 (updated daily)*. National Snow and Ice Data Center, Boulder, CO. Digital media.

Charrier, I., T. Aubin, and N. Mathevon. 2010. Mother–calf vocal communication in Atlantic walrus: a first field experimental study. *Animal Cognition* 13:471–482.

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.

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.

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

Delarue, J., M. Laurinolli, and B. Martin. 2009*a*. Bowhead whale (*Balaena mysticetus*) songs in the Chukchi Sea between October 2007 and May 2008. *J. Acoust. Soc. Am.* 126:3319–3328.

Delarue, J., M. Laurinolli, and B. Martin. 2009*b*. Acoustic detections of fin whales in the Chukchi Sea. *Arctic Acoustics Workshop, 18th Biennial Conf. on Biology of Marine Mammals*, Quebec City, QC.

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, and D. Hannay. 2010*b*. Chukchi Sea Joint Acoustic Monitoring Program. *In*: Funk, D.W., D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.). 2010. *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 pp.

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

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*). *J. Acoust. Soc. Am*. 122:2893–2905.

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).

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., R. Rodrigues, D.S. Ireland, and W.R. Koski (eds.). 2007. *Joint Monitoring Program in the Chukchi and Beaufort Seas, July-November 2006*. LGL Alaska Report P891-2. Report from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences Inc., Bioacoustics Research Program, Cornell University, and Bio-Wave Inc. for Shell Offshore Inc., ConocoPhillips Alaska Inc., and GX Technology, and National Marine Fisheries Service, US Fish and Wildlife Service. 316 pp.

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 pp.

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

Greene, C.R. and B.M. Buck. 1979. Influence of atmospheric pressure gradient on under-ice ambient noise. *J. Acoust. Soc. Am.* 66(S1):S25.

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., Greenridge 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 pp.

Hannay, D., J. Delarue, X. Mouy, B. Martin, D. Leary, and J. Oswald. 2012. *In review* "Marine mammal acoustic detections in the northeastern Chukchi Sea, September 2007–July 2011." Submitted to *Continental Shelf Research*.

Huntington, H.P. and L.T. Quakenbush. 2010. *Traditional Knowledge of Bowhead Whale Migratory Patterns near Kaktovik and Barrow, Alaska*. Report to the Barrow and Kaktovik Whaling Captains Associations and the Alaska Eskimo Whaling Commission. 13 pp.

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 pp.

Jay, C., A. Fischbach, A. Kochnev, and J. Garlich-Miller. 2011. Pacific walrus behaviors during summer and autumn, 2007-2010. *Alaska Marine Science Symposium*, Anchorage, AK.

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. doi: 10.1007/s00300-002-0415-6.

Kelly, B.P. 1988. Ribbon seal, *Phoca fasciata*. pp. 96–106 *In*: J.W. Lentfer (ed.). *Selected Marine Mammals of Alaska. Species Accounts with Research and Management Recommendations*. Marine Mammal Commission, Washington, DC.

Ljungblad, D.K., P.O. Thompson, and S.E. Moore. 1982. Underwater sounds recorded from migrating bowhead whales, *Balaena mysticetus*, in 1979. *J. Acoust. Soc. Am.* 71:477–482.

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 pp. http://www-static.shell.com/static/usa/downloads/alaska/2007_jmp_final_comprehensive_report.pdf

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. *J. Acoust. Soc. Am.* 129(6):4055-4061.

Miller, E.H. 1985. Airborne acoustic communication in the walrus *Odobenus rosmarus*. *Natl. Geogr. Res.* 1:124–145.

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 and Demaster 1998 Cetacean habitats in the Alaskan Arctic. Journal of Northwest Atlantic Fisheries Science 22, 55–69.

Moore, S.E., J.C. George, G. Sheffield, J. Bacon, and C.J. Ashjian. 2010. Bowhead whale distribution and feeding near Barrow, Alaska,

in late summer 2005–06. Arctic 63(2):195-205.

Morse, L., J. Clarke, and D. Rugh. 2009. Marine mammal occurrence in the northeastern Chukchi Sea, Alaska summer 2008. *Alaska Marine Science Symposium*, Anchorage, AK.

National Climatic Data Center. 2011. *U.S. Climate Reference Network, Station 1007 AK Barrow 4 ENE*. National Oceanic and Atmospheric Administration, US Department of Commerce. http://www.ncdc.noaa.gov/crn/

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

Oppenheim, A.V. and R.W. Schafer. 1999. *Discrete-Time Signal Processing*. 2nd edition. Prentice-Hall. 870 pp.

Quakenbush, L.T., J. Citta, J.C. George, R.J. Small, M.P. Heide-Jørgensen, L. Harwood, and H. Brower. 2010. Western Arctic bowhead whale movements and habitat use throughout their migratory range: 2006-2009 satellite telemetry results. *Alaska Marine Science Symposium*, Anchorage, AK.

Quakenbush, L.T., J. Citta, J.C. George, R.J. Small, H. Brower, and M.P. Heide-Jørgensen. 2011. Inter-annual variability and exceptional movements of western arctic bowhead whales from satellite telemetry, 2006-2010. *Alaska Marine Science Symposium*, Anchorage, AK.

Rankin, S. and J. Barlow. 2005. Source of the North Pacific "boing" sound attributed to minke whales. *J. Acoust. Soc. Am*. 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.

Richardson, W.J., B. Wursig, and C.R. Greene Jr. 1986. Reactions of bowhead whales, *Balaena mysticetus*, to seismic exploration in the Canadian Beaufort Sea. *J. Acoust. Soc. of Am.* 79:1117–1128.

Schusterman, R.J. and C. Reichmuth. 2008. Novel sound production through contingency learning in the Pacific walrus (*Odobenus rosmarus divergens*). *Animal Cognition* 11:319–327.

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

Stafford, K.M., S.E. Moore, K.L. Lairdre, and M.P. Heide-Jørgensen. 2008. Bowhead whale springtime song off West Greenland. *J. Acoust. Soc. Am*. 124:3315–3323.

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*). *Can. J. Zool.* 65:2311–2321.

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. *J. Acoust. Soc. Am.* 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).

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.

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

Weingartner, T and S. Danielson. 2010. Physical oceanographic measurements in the Klondike and Burger survey areas of the Chukchi Sea: 2008 and 2009. Report prepared for ConocoPhillips, Inc., Shell Exploration & Production Company, and Statoil, Inc. 50 pp.

Wenz, G.M. 1962. Acoustic ambient noise in the ocean: Spectra and sources. *J. Acoust. Soc. Am.* 34:1936–1956.

Würsig, B. and C.W Clark. 1993. *The Bowhead Whale*. Burns, J.J., J.J. Montague, and J.C. Cowles (Eds.). Society for Marine Mammalogy, Allen, Lawrence, KS, Special Publication No. 2, pp. 157–199.

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:

1. For each frequency bin, compute the average level over the entire file.
2. For each time step, compute a moving average of the results from Step 1, with a frequency bandwidth of 200 Hz.
3. 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.