NORTHEASTERN CHUKCHI SEA JOINT ACOUSTIC MONITORING PROGRAM 2009–2010

Prepared for

ConocoPhillips Company
Anchorage, Alaska

Shell Exploration & Production Company
Anchorage, Alaska

Statoil USA E&P, Inc.
Anchorage, Alaska

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Jeff MacDonnell, Jonathan Vallarta,
Nicole E. Chorney and David Hannay (Ed.)
JASCO Applied Sciences
Dartmouth, Nova Scotia
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DRAFT REPORT
Version 1.0

5 December 2011

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Cover page photos - left to right: JASCO Autonomous Multi-channel Acoustic Recorder (AMAR); bearded seal (U.S. Fish and Wildlife Service); bowhead whale (Department of Fisheries and Oceans Canada); and Pacific walrus (Eric Lumsden).

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1. Introduction

1.1. Overview

ConocoPhillips Company (ConocoPhillips) and Shell Exploration & Production Company (Shell) began baseline passive acoustic monitoring programs in the Chukchi Sea in summer 2006 as a key component of their arctic marine mammal research studies. Statoil USA Exploration and Production, Inc. (Statoil) became a sponsoring member of the programs in summer 2010. The acoustic monitoring programs have been performed by JASCO Applied Sciences (2007 – 2011) and the Bioacoustics Research Program based at the Cornell Laboratory of Ornithology (BRP, 2006). Consecutive summer and winter programs have been performed since summer 2007 and are continuing to the present. The goals of the Chukchi Sea acoustic monitoring programs are to document baseline ambient noise conditions, to characterize sounds produced by oil and gas exploration and to examine the spatial and temporal distribution of marine mammals based on acoustic detections of their vocalizations[1].

The marine mammal acoustic programs address knowledge gaps related to spatial and temporal distributions, habitat use, calling behaviors and migration paths of several marine mammal species in the Chukchi Sea. The overall bowhead migration patterns within a few tens of miles from the Chukchi coast are well known by local bowhead whalers, but a lack of understanding of bowhead migration paths exists for more offshore areas which have been the focus of oil and gas exploration. Therefore, a goal of the acoustics program is to provide information about the locations of vocalizing bowheads further offshore. There is also a lack of information about walrus habitat use in the north-eastern Chukchi Sea. The results from the 2007 program (Martin *et al.* 2008) provided new information about walrus presence and timing, and the 2008 (Hannay *et al*. 2009) and 2009 (Delarue *et al.* 2010b) program reports contribute to that information. This report also provides new information about possible walrus calling behavior modifications in the presence of seismic survey sounds recorded in September 2010.

The acoustic programs are performed with autonomous acoustic recording systems deployed on the seabed for extended periods over large areas of the Alaskan Chukchi Sea. Acoustic monitoring studies require that marine mammals make identifiable sounds that can be detected in acoustic recordings. The acoustic programs have successfully identified vocalizations from several marine mammal species, including bowhead (*Balaena mysticetus*), beluga (*Delphinapterus leucas)*, gray (*Eschrichtius robustus*), fin (*Balaenoptera physalus*), and killer (*Orcinus orca*) whales, walrus (*Odobenus rosmarus)*, and bearded (*Erignathus barbatus*) and ribbon (*Histriophoca fasciata*) seals. Ringed seals (*Pusa hispida*), minke whales (*Balaenoptera acutorostrata*) and humpback whales (*Megaptera novaeangliae*) were detected for the first time in the winter 2009–2010 and summer 2010 program data presented in this report. Some low-frequency sounds, possibly produced by fish, have also been detected but have yet to be classified.

The acoustic monitoring programs continue to provide new information about marine mammal presence in the Chukchi Sea. For example, the 2007–2008 winter program showed bowhead presence later into the winter than previously thought and provided insight into the timing and distribution of the bowhead and beluga spring migrations; and the 2009–2010 winter data reported here identified the earliest calls by spring migrating bowhead and beluga whales The winter programs also provide information about bearded seal presence and vocalizations in the winter and spring. The summer programs target marine mammals present during the open-water season, a time when anthropogenic activity in the north-eastern Chukchi Sea increases. Previous programs have established the importance of this area to walrus in summer, and were able to acoustically monitor the transit of walrus from Hanna Shoal to shore haul-outs in late August 2007. The summer programs have consistently demonstrated the relatively limited acoustic occurrence of bowheads and belugas in the eastern Chukchi Sea in July and August and their return in late September and October with the onset of the fall migration in the area. The programs have indicated a preferred fall migration corridor for vocalizing bowheads approximately along 71 degrees north. This corridor moves further offshore as it continues west past Barrow.

This report provides the results from the winter 2009–2010 and summer 2010 acoustic program data. The winter data were acquired with eight Autonomous Underwater Recorder for Acoustic Listening Model 2 (AURAL, by Multi-Electronique Ltd.) recorders deployed offshore of Cape Lisburne, Point Lay, Wainwright, and Barrow from mid-October 2009 through early August 2010. The summer data were acquired with 44 JASCO Autonomous Multi-channel Acoustic Recorders (AMAR) deployed from late July through mid-October 2010 throughout the north-eastern Chukchi Sea. The recorders were positioned in a regional array and in three cluster arrays. The regional array recorders were deployed along four lines extending offshore from Cape Lisburne, Point Lay, Wainwright, and Barrow. The three cluster arrays each consisted of seven recorders deployed near the Klondike and Burger prospects and on the Statoil lease area.

The acquired acoustic data were analyzed to quantify ambient sound levels, presence of anthropogenic activity (shipping and seismic surveys), and the acoustic presence of marine mammals. The program focus has remained on bowhead whales, walrus and beluga whales, but many other species are detected and discussed in the result sections. Recordings acquired near the Burger and Klondike prospects and the Statoil lease area were further processed to localize bowhead calls. These localization results are compared with the 2009 results and similar localization results reported in 2008 from Cornell BRP.

1.2. Acoustic Monitoring Program History

The first joint passive acoustic monitoring program was performed in summer 2006 with Marine Autonomous Recording Units (MARUs) deployed by BRP in two phases: (1) six recorders deployed from mid-July to mid-August 2006, sampling on a duty cycle at 10 kHz and (2) 22 recorders deployed from mid-August to mid-October 2006, sampling continuously at 2 kHz. Consecutive summer and winter programs have been performed by JASCO since July 2007 using AMARs and AURALs, sampling at a rate of 16 kHz.

The summer acoustics programs have included 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; in 2008 BRP deployed clusters of 13 MARUs each, and in 2009 JASCO deployed clusters of 12 AMARs each, near the Klondike and Burger wellsites. In summer 2010, JASCO deployed clusters of seven AMARs each at the Burger site, Klondike site, and near the Statoil lease areas.

The winter acoustics programs have involved 5 to 8 recorders deployed throughout the study area. JASCO performed the winter programs in 2007, 2008 and 2009. A 2010 winter program is also underway with eight recorders that will be retrieved in summer 2011. The 2009–2010 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. The recorders in these winter programs were deployed in mid-October and retrieved in July and August of the following year. The recorders typically operated between 7 and 10 months and were limited mainly by battery capacity with the specified duty cycle settings.

2. Methods

2.1. Data Acquisition

The 2009-2010 winter program employed AURAL acoustic recorders deployed at 8 stations. The 2010 summer program employed AMAR acoustic recorders deployed at 44 stations.

2.1.1. Equipment

AURALs (Autonomous Underwater Recorders for Acoustic Listening Model 2 by Multi-Electronique Ltd.) were used to record acoustic data in the winter 2009–2010 program. The AURALs incorporate a single omnidirectional hydrophone and are powered by 64 D-cell alkaline battery packs. Data were recorded onto a single 160 GB hard drives at 16-bit resolution with 16,384 samples per second. The AURALs were fitted with HTI-96 hydrophones that have a nominal sensitivity of -164 dB re 1 V/µPa and were set for a gain of 22 dB. The spectral density noise floor 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 each consecutive 4 h period, so they were actively recording 1/6 of the time (*i.e.*, a 16.7% duty cycle). Duty cycling was required due to the limited data storage and battery power capacity of the recorders.

Each AURAL was deployed with four floats (Figure 1) and fastened by 1.5 m of rope to a 120 lb steel anchor weight so that 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 entire system including anchor weights, was winched onto the ship's deck. No material was left on the seafloor.

The summer 2010 program was conducted with JASCO's AMARs (Autonomous Multi-channel Acoustic Recorders; Figure 1). Acoustic data were recorded continuously at 24-bit resolution at 16,000 samples per second. The AMARs were fitted with GTI-M15B hydrophones that have a nominal sensitivity of -160 dB re 1 V/µPa and were set for a gain of 18 dB. The spectral density noise floor of the AMARs in this configuration is approximately 42 dB re 1 µPa, and the usable bandwidth is 10–7600 Hz. Data were stored directly onto internal 384 GB compact flash memory. Because these systems do not use hard-drives, which generate noise and require more power, they were able to operate continuously for the full deployment period.

Each AMAR was deployed with a float collar (Figure 1) and fastened by 1.5 m of rope to a 120 lb steel anchor weight so that 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 approximately 100 m away. For retrieval, a grapple hook was dragged across the ground line, and the entire system including anchor weights, was winched onto the ship's deck. All recorders were successfully retrieved and no material was left behind.

Figure 1. AURAL Recorder ready for deployment (left) and AMAR deployment from the Westward Wind during the summer 2009 in the Alaskan Chukchi Sea (right).

2.1.2. Winter 2009–2010 Deployments

Acoustic recorders were deployed at eight stations during the winter 2009–2010 program (Figure 2). The geographic coordinates, deployment dates and recording times of each recorder are given in Table 1. The recorders were deployed by 16 Oct 2009 and were retrieved in late July and August 2010. The recorders operated as expected, with the exception of the PLN80 recorder which stopped functioning 21 March 2010. The CL50 recorder acquired data until 21 May 2010. The remaining six stations recorded past the second week of July 2010.

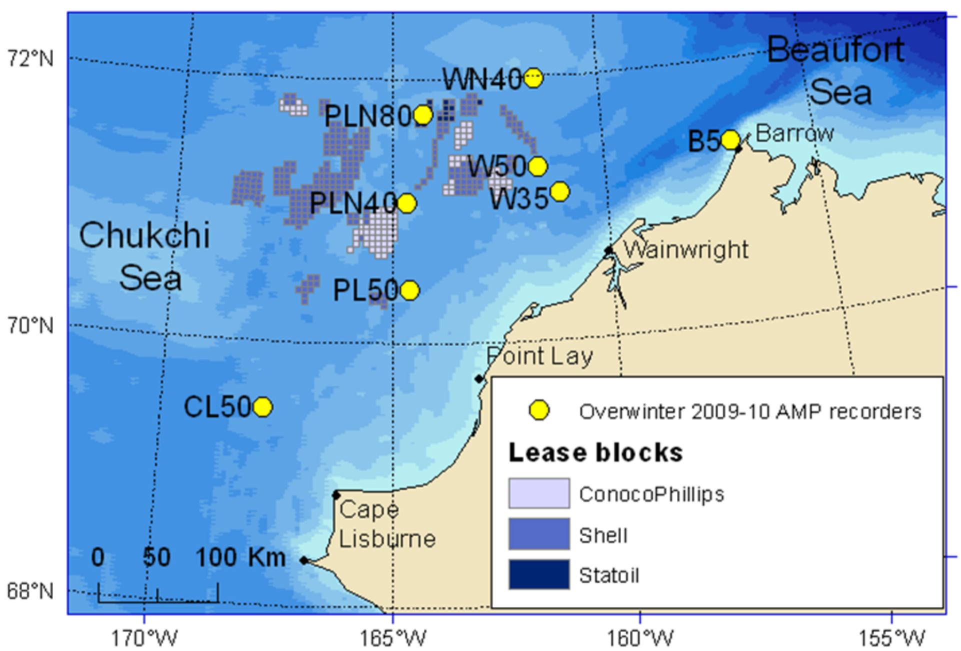


Figure 2. Locations of the winter 2009–2010 program recorder stations in the north-eastern Chukchi Sea. Shades of blue represent water depth.

Table 1. Deployment locations and recording periods of the winter 2009–2010 program acoustic recorders (AURALs) in the north-eastern Chukchi Sea. The AURALs operated on a 1/6 duty cycle (recording 40 min of every 4 h), from record start (*i.e.*, time of deployment) to record end (*i.e.*, time of retrieval or battery depletion—the latter in bold).

Station	Latitude (°N)	Longitude (°W)	Record start	Record end	Recording days	Retrieval
B5	71.363	156.933	12-Oct-09	29-Jul-10	290	5-Oct-10
CL50	69.496	167.783	16-Oct-09	18-Jul-10	275	27-Jul-10
PL50	70.404	164.589	16-Oct-09	21-May-10	217	27-Jul-10
PLN40	71.061	164.629	13-Oct-09	26-Jul-10	286	27-Jul-10
PLN80	71.725	164.238	14-Oct-09	21-Mar-10	158	30-Jul-10
W35	71.103	161.049	14-Oct-09	21-Jul-10	280	30-Jul-10
W50	71.311	161.534	14-Oct-09	7-Jul-10	266	30-Jul-10
WN40	71.974	161.538	13-Oct-09	17-Aug-10	308	17-Aug-10

2.1.3. Summer 2010 Deployments

Recorder deployments for the summer 2010 program included a regional array configuration of 23 recorders nominally spaced at 10's of kilometers (Figure 3) and a more focused clustered array configuration (Figure 4) which consisted of three clusters of seven recorders each with 8 km spacing on triangular grids near the Klondike, Burger, and Statoil wellsites:

1. Regional Array: acoustic recorders were deployed along lines off Cape Lisburne, Point Lay, Wainwright, and Barrow, in a geographic configuration similar to the 2006–2009 summer regional programs. These lines extend perpendicularly out from the coastline for 50 nautical miles (nmi) and then continue northerly out to approximately 120 nmi offshore (Figure 3). As in 2009, the northernmost Cape Lisburne stations (CLN90B and CLN120B) were shifted east to place them on Shell's lease block areas. The only deviation from the deployment plan was that the recorder planned for Station W20 was deployed at Station WN20 (which was already instrumented), leading to a duplicate recorder at WN20 and no recorder at W20.
2. Cluster Arrays: seven acoustic recorders each were deployed near ConocoPhillips (Klondike), Shell (Burger), and Statoil lease blocks (Figure 4). Recorders were spaced on an 8 km (5 mi) triangular grid to allow for localization of bowhead whale vocalizations.

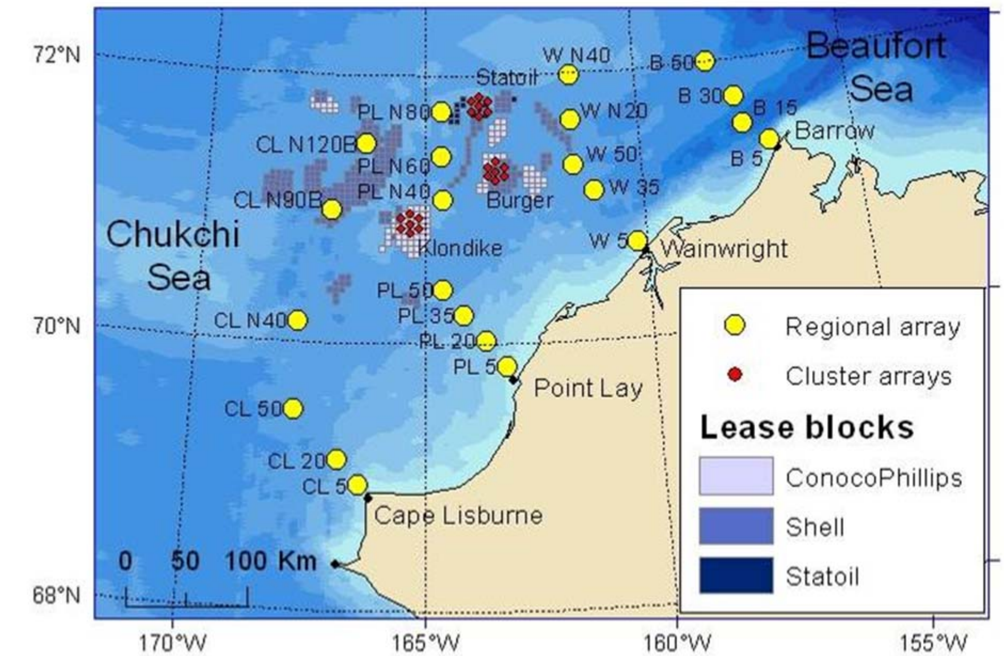


Figure 3. Locations of the summer 2010 program regional array recorder stations (yellow circles) and the Klondike, Burger and Statoil cluster arrays (red circles) in the Alaskan Chukchi Sea. Two recorders were deployed at WN20. Shades of blue represent bathymetry.

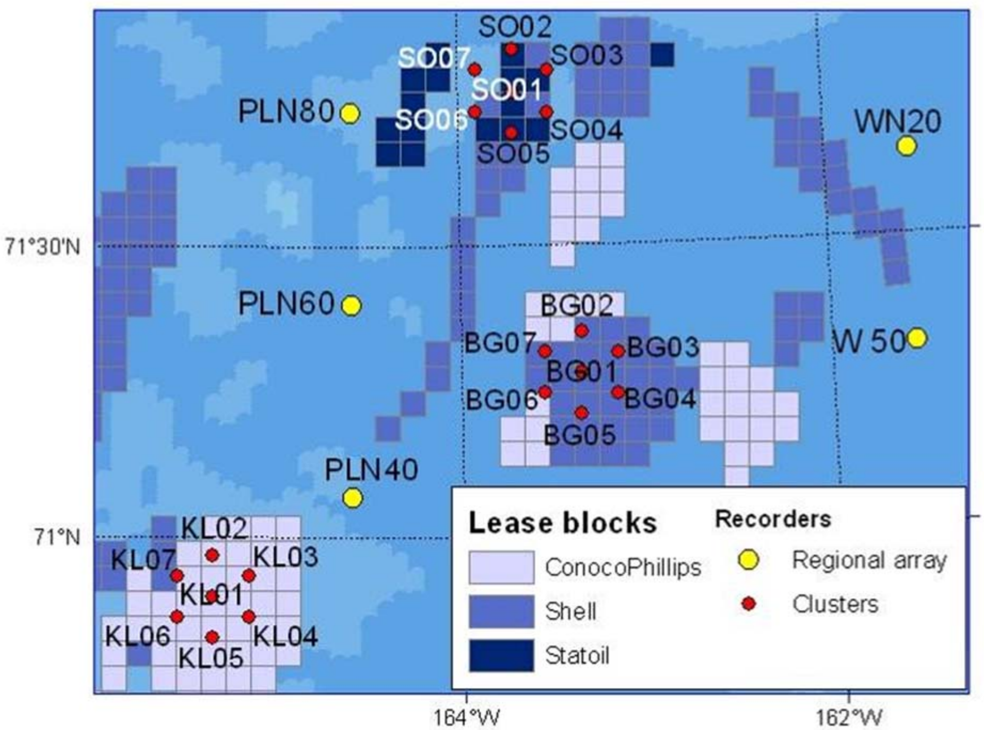


Figure 4. Locations of the summer 2010 program cluster array stations (red circles) near the Klondike (KL), Burger (BG), and Statoil (SO) lease blocks in the Chukchi Sea. Shades of blue represent bathymetry.

The location and time of deployments and retrievals for all summer recorders of the regional array and cluster arrays are provided in Table 2 and Table 3, respectively. All recorders were deployed between 25 Jul and 1 Aug 2010, except for the station WN40 deployment that was delayed to 17 Aug due to ice presence in early August. All recorders were retrieved between 10-16 Oct 2010. Most recorders operated as expected, however, the recorder at W50 acquired no data. Seven recorders stopped before retrieval but only two stopped prior to 27 Sep.

Table 2. Deployment locations and recording periods of the summer 2010 program regional array acoustic recorders (AMARs) in the Alaskan Chukchi Sea. The AMARs recorded continuously from record start (*i.e.*, time of deployment) to record end (*i.e.*, time of retrieval or battery depletion—the latter in bold).

Station	Latitude (°N)	Longitude (°W)	Record start (UTC)	Record end (UTC)	Recording days
Regional array					
B05	71.36311	156.93723	1-Aug-10 15:20	16-Oct-10 07:01	76
B15	71.50413	157.50105	1-Aug-10 16:57	16-Oct-10 09:29	76
B30	71.71164	157.64861	1-Aug-10 18:31	16-Oct-10 11:12	76
B50	71.98851	158.23675	1-Aug-10 20:49	16-Oct-10 13:29	76
CL05	68.94155	166.37507	25-Jul-10 21:00	**30-Sep-10 22:30**	67
CL20	69.12757	166.83663	25-Jul-10 23:43	**13-Oct-10 20:00**	80
CL50	69.49563	167.78370	26-Jul-10 03:05	15-Oct-10 21:35	81
CLN40	70.98820	167.10000	26-Jul-10 17:44	**6-Oct-10 08:40**	72
CLN90B	70.15899	167.78342	26-Jul-10 08:09	11-Oct-10 23:24	77
CLN120B	71.48573	166.35000	26-Jul-10 21:20	11-Oct-10 19:45	77
PL05	69.82358	163.20332	28-Jul-10 02:01	10-Oct-10 18:04	74
PL20	70.01798	163.65623	28-Jul-10 00:00	10-Oct-10 15:46	74
PL35	70.21118	164.11766	27-Jul-10 22:04	**17-Aug-10 17:30**	21
PL50	70.40313	164.58782	27-Jul-10 20:13	11-Oct-10 01:23	76
PLN40	71.06700	164.58763	27-Jul-10 06:16	**27-Sep-10 22:30**	62
PLN60	71.39892	164.58782	27-Jul-10 02:00	11-Oct-10 17:10	76
PLN80	71.73084	164.58820	29-Jul-10 00:56	11-Oct-10 14:06	74
W05	70.70824	160.18007	31-Jul-10 21:17	**7-Oct-10 03:30**	68
W35	71.31065	161.53758	1-Aug-10 02:53	10-Oct-10 08:09	70
W50*	71.64270	161.53750	1-Aug-10 05:02	10-Oct-10 12:53*	0*
WN20B	71.97473	161.53750	1-Aug-10 05:02	10-Oct-10 17:00	70
WN20A	71.97473	161.53750	30-Jul-10 02:19	10-Oct-10 16:00	72
WN40	70.70824	160.18007	17-Aug-10 03:30	10-Oct-10 19:16	54

* No data were recorded.

Table 3. Deployment locations and recording periods of the summer 2010 program cluster array acoustic recorders (AMARs) on the Burger, Statoil, and Klondike leases, in the Alaskan Chukchi Sea. The AMARs recorded continuously from record start (*i.e.*, time of deployment) to record end (*i.e.*, time of retrieval or battery depletion—the latter in bold).

Station	Latitude (°N)	Longitude (°W)	Record start (UTC)	Record end (UTC)	Recording days
Burger (Shell) Cluster Array					
BG01	71.27739	163.34978	28-Jul-10 17:03	12-Oct-10 07:03	76
BG02	71.34909	163.34367	28-Jul-10 14:35	12-Oct-10 17:21	76
BG03	71.20569	163.35585	28-Jul-10 15:11	**11-Sep-10 23:30**	45
BG04	71.31484	163.54041	28-Jul-10 15:51	12-Oct-10 19:10	76
BG05	71.24313	163.54579	28-Jul-10 12:35	12-Oct-10 19:53	76
BG06	71.31144	163.15309	28-Jul-10 13:18	12-Oct-10 20:38	76
BG07	71.23975	163.15989	28-Jul-10 14:00	12-Oct-10 16:39	76
Statoil Cluster Array					
SO01	71.76515	163.69688	29-Jul-10 16:30	12-Oct-10 19:56	75
SO02	71.83686	163.69192	29-Jul-10 15:32	12-Oct-10 21:54	75
SO03	71.69345	163.70181	29-Jul-10 14:38	12-Oct-10 21:03	75
SO04	71.80225	163.89312	29-Jul-10 12:35	12-Oct-10 18:11	75
SO05	71.73054	163.89731	29-Jul-10 11:06	12-Oct-10 17:06	75
SO06	71.79956	163.49572	29-Jul-10 10:00	12-Oct-10 19:17	75
SO07	71.72786	163.50142	29-Jul-10 09:00	13-Oct-10 00:51	76
Klondike (ConocoPhillips) Cluster Array					
KL01	70.89727	165.32875	27-Jul-10 13:38	12-Oct-10 07:03	77
KL02	70.96900	165.32994	27-Jul-10 12:55	12-Oct-10 03:32	77
KL03	70.82554	165.32757	27-Jul-10 12:16	12-Oct-10 04:16	77
KL04	70.93270	165.51936	27-Jul-10 11:21	12-Oct-10 04:58	77
KL05	70.86097	165.51749	27-Jul-10 10:38	12-Oct-10 05:39	77
KL06	70.93337	165.13932	27-Jul-10 09:54	12-Oct-10 06:19	77
KL07	70.86164	165.13882	27-Jul-10 09:11	12-Oct-10 02:50	77

2.1.4. Non-Acoustic Data Collection

Wind speed and air temperature were acquired for the Barrow station of the U.S. Climate Reference Network (National Climatic Data Center 2010). 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).

2.2. Data Analysis

Marine mammal vocalizations were detected and classified by both manual analysis and JASCO's automated detection and classification software suite. Three species of key interest—bowhead whale, beluga whale, and walrus—were analyzed more thoroughly than other species using manual and automatic approaches, due to their conservation status and importance to the North Slope Communities. Bearded seals were also automatically detected but calls of other species of seals were catalogued only by manual analysis of a fraction of the dataset. Vocalization rates can vary among individuals and over time, and may depend on age and/or sex class. Thus, numbers of calls per species do not necessarily represent relative abundances of species.

Manual analysis, as described below, was performed on a fraction of the data to establish the acoustic occurrence of marine mammal species, and to characterize call types for use in evaluating the performance of the automated detection and classification methods. The automated detection and classification suite processed the entire dataset to estimate the magnitude (in number of detected calls) of acoustic calling activity as a function of time at each station. The automated suite also yields results not easily achieved with manual analysis such as individual seismic pulse detections, seismic signal levels, and ambient sound level calculations.

2.2.1. Manual Data Analysis

Manual analysis was conducted by six trained analysts. Two of the analysts had more than two years of experience and two others had one year of experience classifying arctic marine mammal vocalizations in previous Chukchi Sea datasets. The two remaining analysts had previous experience identifying marine mammal soundsbut had limited experience with calls from arctic species. The latter two analysts were trained by the lead analyst using a standard set of files containing vocalizations from all of the species of interest from the previous year Chukchi Sea acoustic dataset.

The objectives of the manual analysis were to:

1. Detect and classify marine mammal calls in a subset of the data to allow performance assessments of the automated classifiers. Performance was assessed quantitatively using Precision and Recall methods, described in Appendix A, that compare the outputs of the automatic classifiers with the manual classifications for each species.
2. Review a fraction of the data through the entire recording period to assess where and when the target species (walrus, bowhead and beluga whales) are acoustically present in the Chukchi Sea. This allows for the identification of periods and/or stations at which significant or unexpected detections of marine mammals occur, which might command further, more detailed analysis.
3. Identify non-target and extra-limital species. Several species observed less frequently in the Chukchi Sea (*e.g.*, killer whales and fin whales) were recorded in previous programs. Acoustic detections of such species are valuable as they contribute to our understanding of their present habitat use and changes in habitat use over time, which could be an indication of environmental changes, including ice conditions and prey availability. Automatic classifiers have not been developed for these species, and hence the manual analysis is especially important in this context.

2.2.1.1. <u>Manual Analysis Protocol</u>

Five percent of the 2009–2010 winter data on all eight regional array recorders were analyzed manually. For consistency, the middle 2 min data sample of each 40 min data file was selected (winter recorders produced duty-cycled recordings of 40 min every 4 h). For five of the eight stations (CL50, B05, PL50, W35, and WN40), analysts annotated *all* identified marine mammal vocalizations in the first 2 min sample of every day and *one* call per species in each of the remaining five samples of every day. This corresponds to analyzing 17% of the of the 2 min samples at a high level of detail, and 83% at a moderate-level of detail. This protocol generated enough fully-annotated samples to evaluate the performance of the automated detectors (see

Appendix A). Therefore, to minimize the manual analysis time, only *one* call per species per sample was annotated for all samples at the remaining three stations (PLN40, PLN80, and W50).

Five percent of the summer 2010 data from all 21 regional array recorders and three cluster-array recorders (KL01, BG01, and SO01) were analyzed manually. The first 90 s sample of each 30 min file per station each day was selected for analysis. Analysts annotated *all* identified marine mammal vocalizations in the first (starting between 12:00am and 12:30am) and middle (starting between 12:00pm and 12:30pm) samples of each day for 10 of the 24 recorders. This translates into reviewing 96% of the 90 s samples at a moderate-level of detail and 4% at a higher level of detail for these 10 stations. This protocol generated enough fully-annotated samples to evaluate the performance of the automated detectors. Only *one* call per species per sample was annotated for all samples of the other 14 stations.

In case of doubt regarding species identification within a sample, the source file of the sample was examined for the presence of more easily identifiable calls. The manual analysis was performed with a custom software tool (JASCO's SpectroPlotter) allowing standardized annotations and consistency of approach among analysts. Calls were identified by species and call type (Table 4).

The *ou-ou*–like calls that are similar to those attributed to bowhead whales in the Beaufort Sea by Blackwell *et al.* (2007) are attributed to walrus sounds in the Chukchi (Delarue *et al.* 2010*b*). Bowhead were identified exclusively by their narrowband, frequency modulated moans (comprising the call categories "upsweep", "downsweep", "constant", "concave", and "convex"; Table 4) and the more complex calls (*i.e.*, broadband and pulsed; Clark and Johnson 1984) produced alone or as song units. Analysts annotated individual sounds and did not distinguish or characterize songs for this analysis.

Table 4. Call types by species annotated during manual analysis of the winter 2009–2010 and summer 2010 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.

(cont'd.) Table 4. Call types by species annotated during manual analysis of the winter 2009–2010 and summer 2010 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.
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.
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.
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 grunty-like knocks.
	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.
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.
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.
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*.).
Unknown	Un-described	Any biological sound that cannot be classified as one of the above species; includes isolated calls that can't 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 that do not appear to be produced by walrus.

2.2.1.2. Analysis Validation

The lead analyst, Julien Delarue (JD), aided the other analysts in classifying calls that were difficult to attribute to a known call type. JD also reviewed a random subset of annotations from all analysts to ensure accurate classification of calls by species and to provide feedback to the analysts. Any inaccurate classifications found by JD were corrected, and in those cases the analysts were consulted to ensure that other similar errors would also be corrected.. JD consulted with external researchers when new or unknown call types were detected.

Emphasis was placed on verifying annotations, identifying the three target species (bowhead whale, walrus, and beluga whale) and at flagging notable or suspicious annotations for review (*i.e.*, those referring to uncommon species or those outside the expected range or residency period of the given species). In 2010 particular attention was given to reviewing unknown sounds thought to be produced by ice seals, as new information allowing for reliable identification of ringed seals was presented by other researchers working on arctic acoustic data during a meeting at the Alaska Marine Science Symposium (held in Anchorage 17-21 January 2011). JD also reexamined many of the calls originally classified as "unknown" (see Table 9 and Table 10) and in some cases was able to assign those to known call types..

2.2.1.3. Probability of Detection by Manual Analysis

The effectiveness of the manual analysis protocol in quantifying the acoustic occurrence of marine mammals within the monitored area was assessed. The objective of this analysis was to determine whether the manual review of just 5% of the data provided an accurate estimate of the acoustic occurrence of marine mammal calls within a 24-hour period. A sample of 60 files (over 30 hours of data) containing calls of the commonly detected species (bowhead whale, walrus, beluga whale, bearded seals, and ringed seals) was randomly selected. These files were fully annotated by the manual analysts so that all calls were identified. A random start time within the file was then chosen, and the next 5% of the file was searched for manual 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 therein. This analysis was performed using sample sizes equal to 1%, 2%, 5% and 10% of the entire file.

2.2.2. Automated Data Analysis

Due to the large amount of acoustic data collected (> 13 TB), the analysis of ambient noise, seismic survey sounds, vessel noise and specific marine mammal calls was performed automatically.

Ambient noise, seismic survey and vessel noise, and bearded seal calls were automatically analyzed on a specialized computing platform that operated at approximately 800 times the real-time of recording (e.g. 800 hours of recorded data could be analyzed in 1 hour of computing time). Figure 5 shows a block diagram outlining the stages of the automated process. Beluga, bowhead and walrus calls were detected and classified with algorithms that were coded in Matlab, and executed separately on the computing platform.

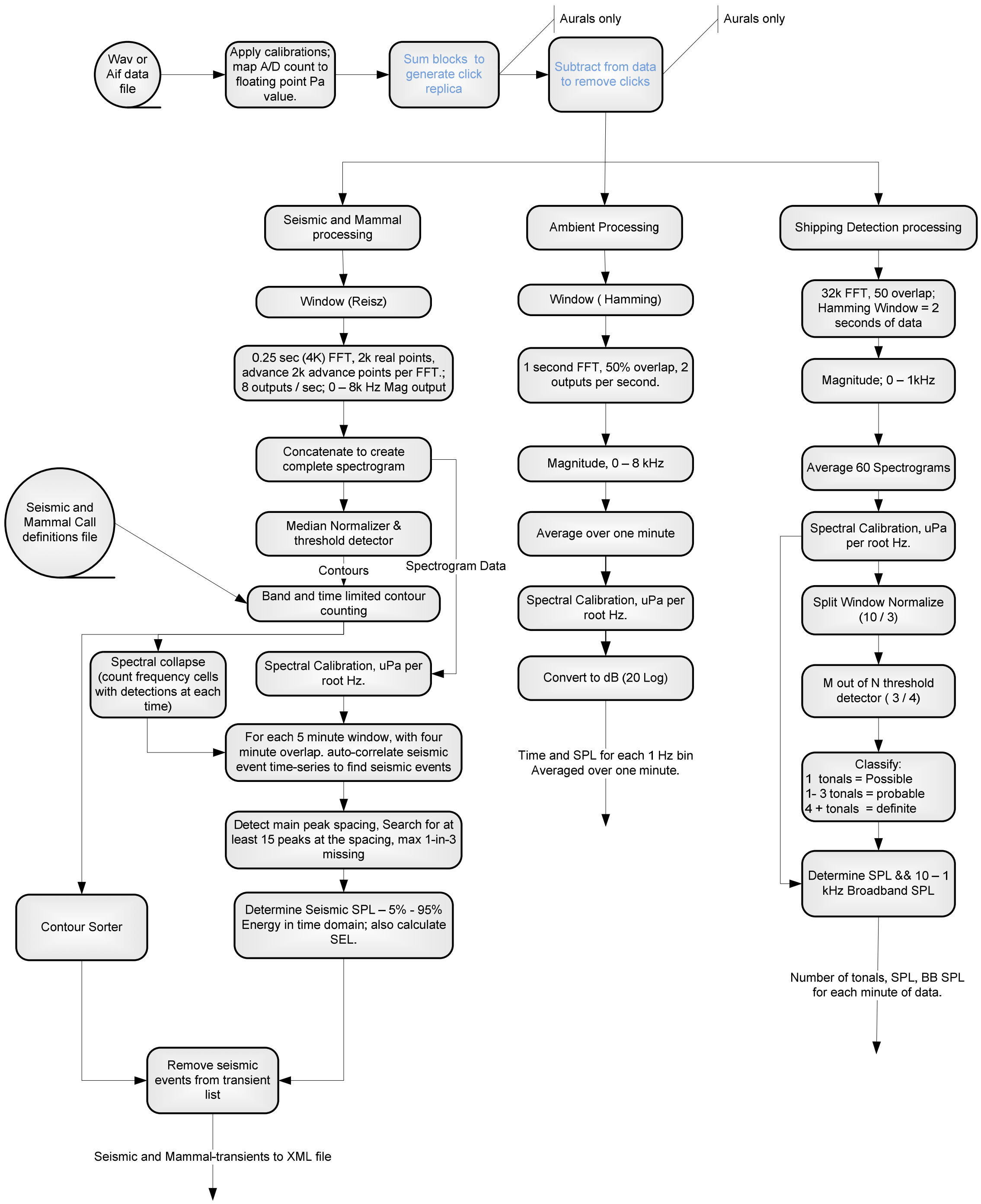


Figure 5. Major stages of the automated acoustic processing system.

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

2.2.2.1. Ambient Noise Processing

Ambient noise levels at all winter 2009-2010 and all summer 2010 recording stations were examined to document baseline underwater sound conditions in the Chukchi Sea. Ambient noise at each of these stations was analyzed by Hamming-windowed fast Fourier transforms (FFTs) with 1 Hz resolution and 50% window overlap. 120 FFTs performed this way were averaged to yield 1 min average spectra.

Ambient noise levels at each recording station are presented as:

1. Broadband and approximate-decade-band sound pressure levels (SPLs) over time for the frequency bands: 10 Hz–8 kHz, 10 Hz–100 Hz, 100 Hz–1 kHz, and 1–8 kHz.
2. Spectrograms of the 1 min average spectra (computed as described above).
3. Spectral level percentiles: Histograms of each frequency bin for all 1 min data from each recorder were computed. The 5th, 25th, 50th, 75th, and 95th percentiles were plotted. The 95th percentile curve describes the frequency dependent levels exceeded by 5% of the 1 min averages. Equivalently, 95% of the 1 min spectral levels are below the 95th percentile curve.

The 50th percentile (median of 1 min spectral averages) can be compared to the well-known Wenz ambient noise curves shown in Figure 6. The Wenz curves show ranges of variability of ambient spectral levels as a function of frequency based on measurements off the Pacific coast of the United States over a range of weather, vessel traffic, and seismic conditions. The Wenz curve levels are general and are used for approximate comparisons only. Weather and ice coverage conditions during the deployment periods are provided, and the correlations of ambient sound levels with these data are discussed.

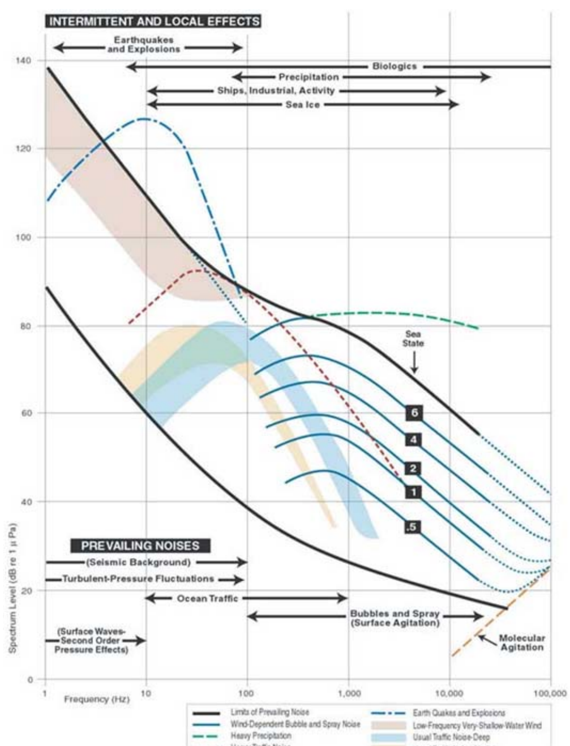


Figure 6. Wenz curves describing pressure spectral density levels of marine ambient noise from weather, wind, geologic activity, and commercial shipping (Ocean Studies Board 2003 adapted from Wenz 1962). Thick black lines indicate limits of prevailing noise.

2.2.2.2. Seismic Survey Analysis

Automatic detection of seismic pulses was performed in the time-frequency domain based on the periodicity of the seismic pulses. First, the spectrogram was computed by using consecutive 0.25 s frames overlapped by 50% and normalized using a median-based normalizer (see Section 6.1 for detailed description of the spectrogram calculation and normalization). A Reisz window was applied to the data in each analysis frame before calculating the FFT. The Reisz window provides a good compromise between sidelobe suppression and equivalent noise bandwidth and the ability to analyze transient events. The median-based normalization was performed in each frequency band using a 120 s sliding window (see Section 6.1). Second, the normalized spectrogram was binarized by setting all the time-frequency bins exceeding a normalized amplitude of 4 (no unit) to 1 and the other bins to 0. The values of the binary spectrogram in the 30 – 500 Hz frequency band were summed for each time step. The autocorrelation function of the resultant time series was then calculated to define its periodicity. The spacing of peaks in the autocorrelation function defined the spacing of a possible seismic sequence. The summed spectrogram time series were then searched to find sequences of peaks at the possible spacing. Once a sequence of periodical events was identified, the following conditions are applied to trigger the detection:

1. The pulse time separation was between 3.5 s and 20 s (empirical bounds for shallow hazards and 3-D seismic surveys, respectively).
2. The sequence contained at least 15 pulses (in a 300 s window).
3. No more than one pulse in three could be missing from the sequence.

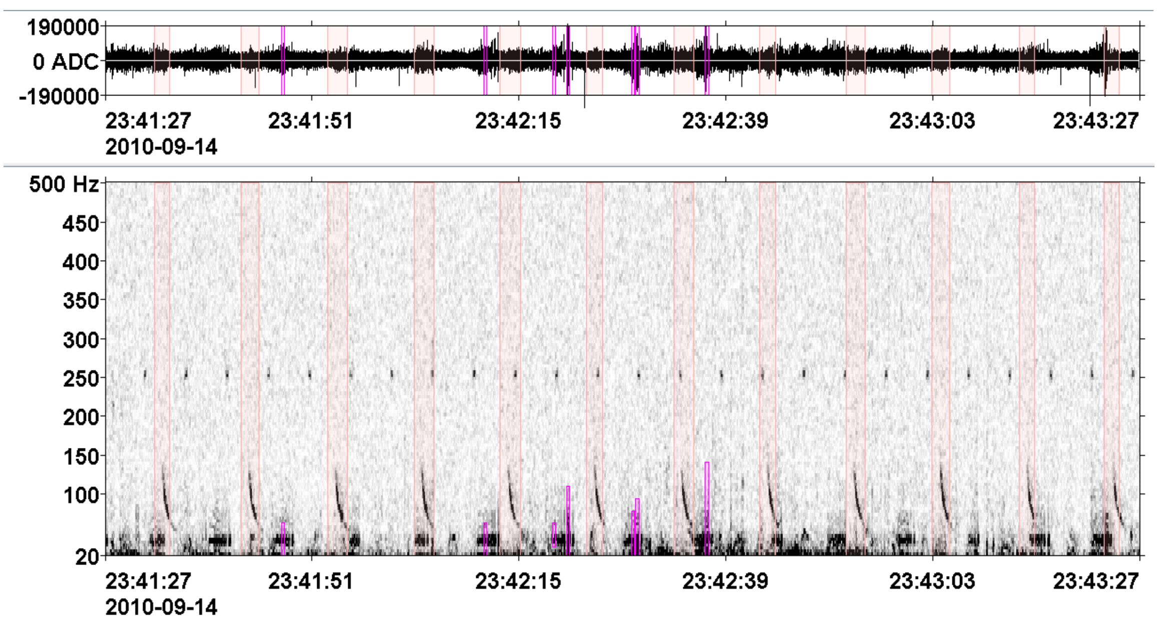


Figure 7. Pressure versus time (top) and spectrogram (bottom) of automated detections of weak seismic survey pulse events (pink) in the presence of periodic mooring noise at B05 (black events at ~30 Hz, occasionally identified by magenta boxes as ‘unknown’), 14 September 2010 (0.25 s FFT, 0.25 s of real data, 0.0625 s advance, Reisz window).

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-pulse sound exposure levels (SEL) were also computed. The detector was effective even for weak seismic pulses in the presence of louder vocalizations and noise as shown in Figure 7.

2.2.2.3. Vessel Noise Detection

The vessel detector was designed to locate narrow tonal peaks that are characteristic of vessel motors, pumps, and gearing (Arveson and Vendittis 2000). A typical spectrogram of noise from a vessel is shown in Figure 8. The vessel detector calculated spectra using a 2 s FFTs with a Hamming window and 50% overlap. Sixty of these FFT's were averaged to create 1 min average spectra. The spectra between 1 Hz and 1000 Hz were normalized in frequency using a split-window normalizer and then searched for narrowband peaks. A positive detection is indicated when a peak occurs in three out of four adjacent 1 min intervals. The SPLs of the detected vessel tonal line were calculated. All automatically detected vessel events were verified manually.

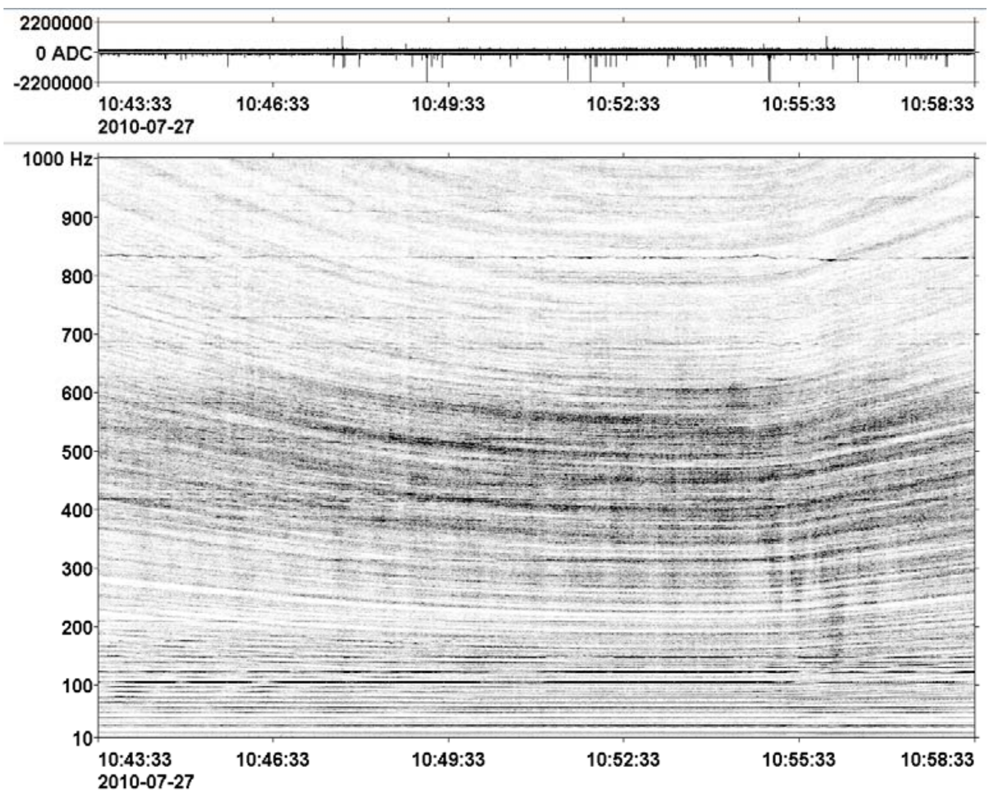


Figure 8. Pressure in digital units (top) and spectrogram (bottom) of tonal vessel noise from the *Westward Wind*, 27 Jul 2010, at PLN60 (2 s FFT, 1.75 s overlap, Hamming window). Upward curved pattern is due to the Lloyd mirror effect as the vessel passes through a closest point of approach. In this case the Westward Wind was steaming past station PLN60..

2.2.2.4. Detection and Classification of Marine Mammal Sounds

2.2.2.4.1. Bowhead and Beluga Calls

Bowhead moans and beluga whistles are auto-detected and classified in two steps. First, time-frequency contours are detected and extracted from a normalized spectrogram using a tonal detector developed by Mellinger *et al.* (2009). Second, each contour is represented by 46 features and presented to two-class random forest classifiers (*i.e.,* bowhead *vs*. 'other', beluga *vs*. 'other'). Detection and classification of bowhead and beluga sounds is performed separately. Random forest classifiers were trained using the manually annotated calls. A full technical description of the detection and classification process is given in Appendix A.

The detected bowhead calls included a variety of simple moans, as described by Clark and Johnson (1984) and Ljungblad *et al.* (1982). Although many song notes are structurally different and more complex than the moans targeted by the detector, most songs incorporate some moans in at least one of their phrases (Delarue *et al.* 2009*a*), making them detectable by this method. The ability to detect songs is important, as songs are a dominant feature of the bowhead acoustic repertoire in fall, winter, and spring (Delarue *et al.* 2009*a*). Figure 9 shows an example of output from the bowhead detector/classifier.

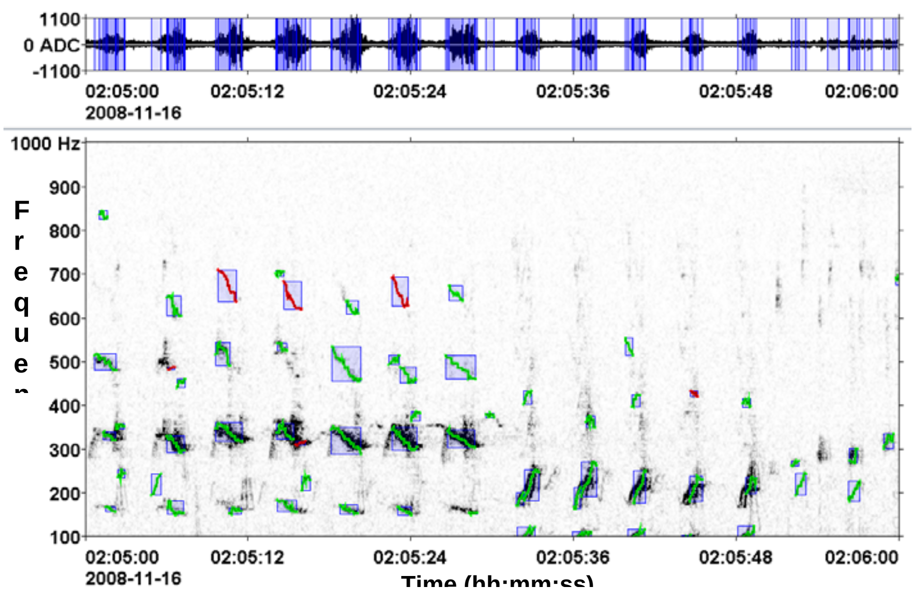


Figure 9. Pressure versus time (top) and spectrogram (bottom) of automated detections and classifications of bowhead vocalizations. The first step of the process identifies time-frequency contours representing candidate vocalizations (blue boxes). The second step classifies contours into two categories, "bowhead" (green contours) and "other" (red contours), using a random forest classifier. Some misclassifications can occur; the three red contours on the left side of the spectrogram are related to the bowhead calls but were incorrectly identified as "other".

2.2.2.4.2. Walrus Grunts

The walrus grunt detector/classifier is also based on time-frequency representation of the acoustic signal. The spectrogram is calculated and then analyzed in consecutive 0.7 s time windows (frames) overlapped by 50%. For each of these frames, 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 are 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.

2.2.2.4.3. Bearded Seal Calls

The automated detection and classification of bearded seal vocalizations is performed in three steps. First, the spectrogram is calculated and binarized. Second, adjacent bins of the binary spectrogram are grouped together to create time-frequency "objects". Third, each object is represented by a set of features including the maximum and minimum frequency and duration. Finally, each object is classified based on a set of rules empirically defined. The bearded seal detector/classifier is part of the Java automated process (See section 2.2.2). A detailed description of the detection and classification process is given in Appendix A.

2.2.2.4.4. Detectors/Classifiers Performance Evaluation

The performance of the various marine mammal detectors/classifiers, described above, was assessed by comparing the automated detection/classifications with manual detections for all fully-annotated manually analyzed recordings. For the winter 2009–2010 data, marine mammal calls were fully annotated in the first 2 min of each day for recordings from Stations B05, CL50, PL50, W35, and WN40. This yielded a test dataset of 1376 2 min fully-annotated samples. For the summer 2010 data, marine mammal calls were fully manually annotated for Stations B05, B30, W05, W35, WN20A, CL20, CLN90, KL01, PL20, PL50, and SO01. This yielded a test dataset of 1779 1.5 min fully-annotated samples. The performances of the detectors were measured by calculating the *precision* (P) and *recall* (R) indices (see 6.2.Appendix A). These values characterize the relationship between the detector/classifier and the dataset. P can be seen as a measure of exactness, and R as a measure of completeness. P and R were also calculated separately for vocalizations with signal-to-noise (SNR) ratios of <0 dB, 0–5 dB, 5–10 dB, and > 10 dB and those results are presented in Appendix A. Table 5 summarizes the performance of the detectors used for each species for all detected vocalizations, with majority SNR of 0-5 dB.

Table 5. Performance of the automatic detectors/classifiers (precision, P and recall, R) applied to the winter 2009–2010 and summer 2010 datasets.

Species	Winter 2009–2010			Summer 2010		
	R (%)	P (%)	Detection/classification method	R (%)	P (%)	Detection/classification method
Bowhead	44	50	Tonal detector + random forest classifier	22	84	Tonal detector + random forest classifier
Walrus	26	52	Grunt detector	26	52	Grunt detector
Beluga	26	66	Tonal detector + random forest classifier	–	–	n/a
Bearded seal	50	68	Contour follower/sorter	17	65	Contour follower/sorter

2.2.3. Marine Mammal Detection and Classification Result Compilation

Marine mammal acoustic occurrence throughout the study area is presented in the result section as the daily number of sound files with manual detections for each species. This information is plotted only for stations with at least one detection of the species in question (see Table 9 and Table 10).

Species-specific call count estimate plots, depicting abundance of marine mammal acoustic detections throughout the recording period, are also presented. The data used in these plots were compiled based on manual detection results; if no call was manually detected for a species in a given file, then the automated detection count, if any, was zeroed for that file and species. The remaining automated detection numbers were corrected using P and R values (see Appendix6.2.A.3). After correction, the number of automated detections represents more closely the actual number of vocalizations for a given species. Corrected automatic detection numbers were then summed over a given time period (Table 6) and mapped to produce call count estimate plots.

Table 6. Periods over which the number of acoustic detections was summed for each species whose call count estimates were plotted.

Species	Fall 2009	Spring 2010	Summer 2010
Bowhead whale	Every 2 weeks [b]	Every 2 weeks [b]	Every 2 weeks [b]
Walrus	– [d]	Every 2 weeks [b]	Every 2 weeks [b]
Beluga whale	Every 2 weeks [b]	Every 2 weeks [b]	– [d]
Bearded seal	Monthly [b]	Monthly [b]	Monthly [b]
Gray whale	– [a]	– [a]	– [d]
Fin whale	– [a]	– [a]	– [d]
Killer whale	– [a]	– [a]	– [d]
Ringed seal	Monthly [c]	Monthly [c]	– [d]

[a] Not detected in this period.
[b] Call count estimate.
[c] Acoustic detection index.
[d] No bubble plots.

For each species a spatially-interpolated call count surface plot is presented. These plots were produced by summing the call count estimates for each station over the entire recording period.

2.2.4. Bowhead Acoustic Localization

The acoustic localization of bowhead whales in the Arctic has been the subject of much research (e.g. Cummings and Holliday, 1985; Clark *et al.,* 1986; Clark and Ellison, 1989; Clark *et al.,* 1996). The objective of localizing bowhead whales was to determine positions of calling bowhead whales near the Klondike, Burger and Statoil wellsites. Of specific interest was investigating bowhead migration paths near or through the central lease areas in early October 2010, during the early part of migration and just prior to retrieval of the summer acoustic recorders. The localization processing approach assumed that bowhead vocalizations would be detected on several recorders simultaneously. Because underwater sound travels at a finite speed, the vocalizations arrive at nearby recorders sooner than at more distant recorders. The speed of sound underwater in the Chukchi Sea is 1450–1470 m/s, so the time difference between bowhead calls on two adjacent cluster recorders separated by 8 km could be as much as 5.5 s. Under certain conditions, the differences in arrival times of calls among three or more recorders can be used to determine the location of the calling animal.

Absolute call arrival time differences were determined for all automatically detected bowhead calls and used to compute their originating locations. The analysis consisted of the following steps:

1. Time-alignment. Time-align the recorder's clocks to an accuracy better than 0.1 seconds using known external events such as seismic pulses.
2. Data extraction. Broadband acoustic call detections from the automated processor at all of the recording stations are extracted.
3. Call associated with multiple recorders. All call detections are sorted and classified using the time-frequency characteristics of the call spectrograms.
4. TDOA Synchronization. Measure the time difference of arrival (TDOA) of a single call at three or more recorders. The TDOA's define intersecting hyperbola that localize the call origin. The localization method calculates all the possible different pair sets of TDOA combinations for the same associated call.
5. Source localization. Determine the eccentricity of the hyperbolas, which provides a measure of the accuracy of the localizations.

The specific method for bowhead call localizations near the Burger and Klondike cluster arrays is described in Appendix B.

3. Results

3.1. Meteorological and Ice Conditions, and Ambient Noise

Meteorological data from the Barrow station of the U.S. Climate Reference Network (National Climatic Data Center 2010), and ice concentration data 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) is provided. Ambient noise data from one representative recording station (PLN40) is provided as an example of the ambient noise conditions present during this study. The ambient data for all other stations are presented in 6.2.Appendix C.

3.1.1. Winter 2009–2010 Meteorological and Ice Conditions

Air temperature and wind speed data for October 2009 through August 2010 are shown in Figure 10. During the winter program, air temperature varied from -42 to 19 °C, with a mean of -11.5 °C. Reported wind speeds were as high as 14.2 m/s and averaged 4.4 m/s. No wind data were reported between December 7 and March 19.

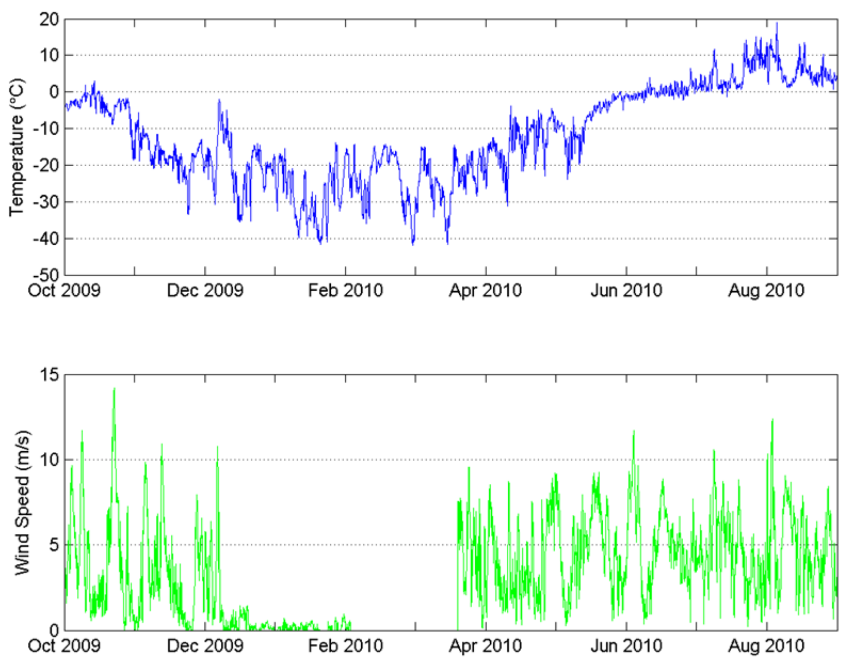


Figure 10. Air temperature in °C (top) and wind speed in m/s (bottom) at the Barrow station of the U.S. Climate Reference Network, 1 Oct 2009 to 31 Aug 2010 (National Climatic Data Center 2010). No wind data were reported between 7 Dec and 19 Mar.

Ice concentration data for November and December 2009 are shown in Figure 11. Ice coverage increased in November and by 1 Dec the entire study area was more than 90% ice covered. Initial break-up started at the end of May, along the shore between Cape Lisburne and Barrow, and progressed offshore and to the north, as shown in Figure 12. The study area was largely ice-free by the beginning of August except for extreme northern areas.

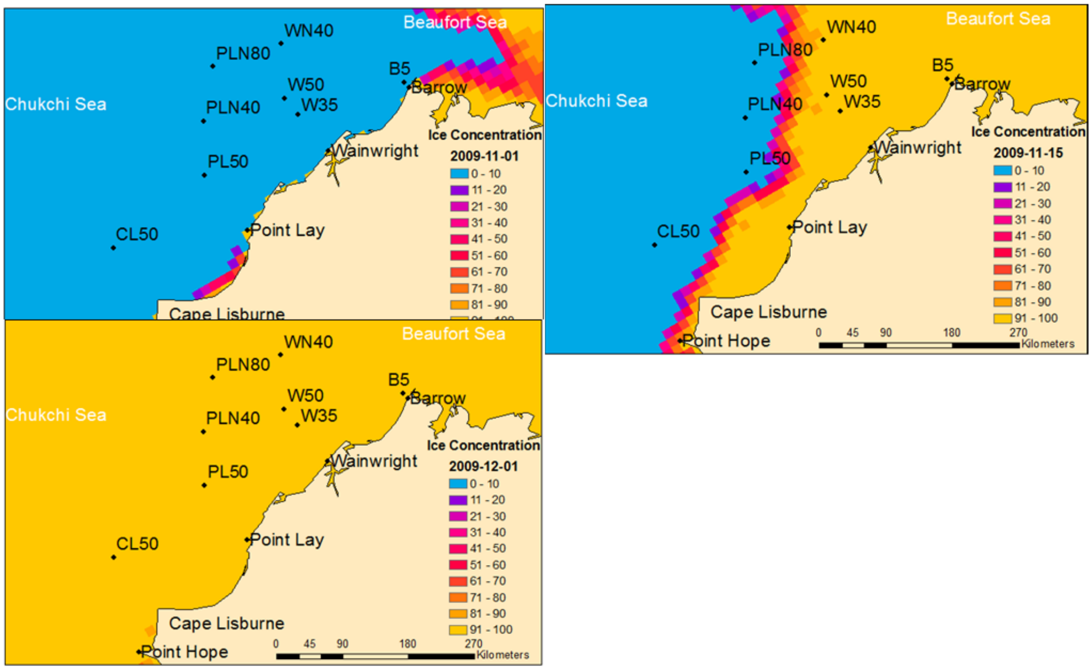


Figure 11. Ice concentration (%) in the Chukchi and Beaufort Seas on 1 Nov (top left), 15 Nov (top right), and 1 Dec 2009 (bottom). The winter 2009–2010 recording station positions are shown for reference. Source: (AMSR-E).

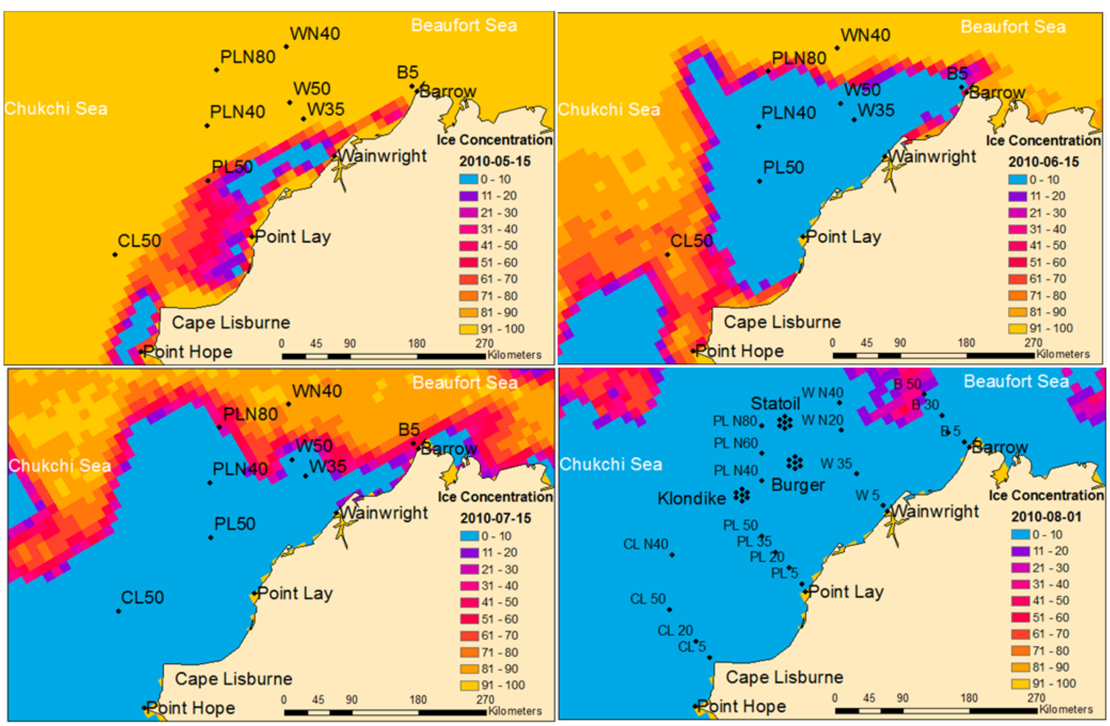


Figure 12. Ice concentration (%) in the Chukchi and Beaufort Seas on 15 May 2010 (top left), 15 Jun 2010 (top right), 15 Jul 2010 (bottom left), and 1 Aug 2010 (bottom right). 2009 winter acoustic stations are shown except in the 1 Aug 2010 plot, which shows the summer 2010 acoustic stations. Source: (AMSR-E).

3.1.2. Winter 2009–2010 Ambient Noise

The percentile spectral levels of ambient noise for the PLN40 winter recording period (October 2009 to August 2010) are shown in Figure 13. Generally, the spectral levels decreased almost linearly with increasing frequency from 10 Hz to 2 kHz and leveled off at higher frequencies. The 50th percentile can be compared with the Wenz curves (see Figure 6). The dashed lines in the percentile plots indicate the limits of prevailing noise taken from the Wenz curves.

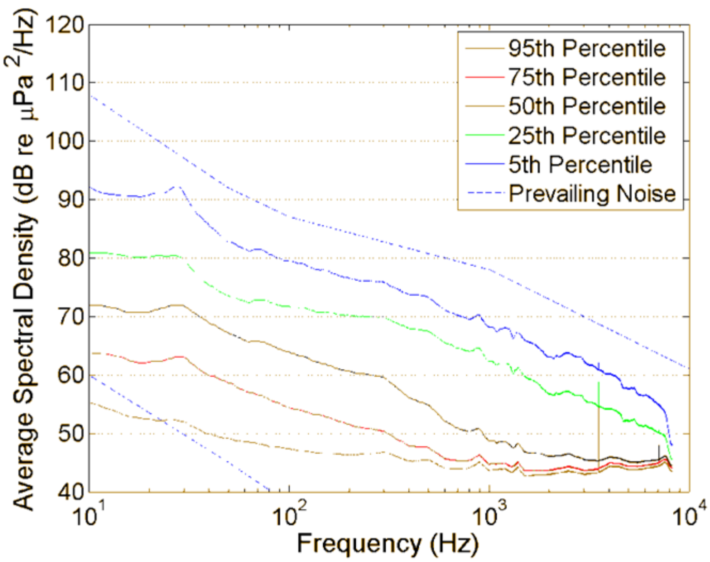


Figure 13. Percentile 1 min power spectral density levels (dB re 1 µPa2/Hz) for the PLN40 AURAL winter recording period from October 2009 to August 2010. Lower percentile results are influenced by the recorder's electronic noise floor. The dashed lines represent the 'Limits of Prevailing Noise' from the Wenz curves, Figure 6.

Figure 14 shows decade band sound pressure levels (SPLs), and Figure 23 shows a spectrogram, for the entire winter recording period at station PLN40. An electronic noise spike can be seen at 3.5 kHz with a harmonic at 7 kHz.

The higher broadband noise levels (Figure 14 and Figure 15) observed from the beginning of the recording period to mid-November, and from late May to the end of the recording, are attributed to ice free periods (Figure 11 and Figure 12) during which wind (Figure 10) and wave action dominate noise levels. In addition, bowhead vocalizations contribute to the noise in the 10–1000 Hz band during both periods and bearded seal vocalizations contribute in the same band from late May to the end of the recording period (Figure 29 and Figure 91).

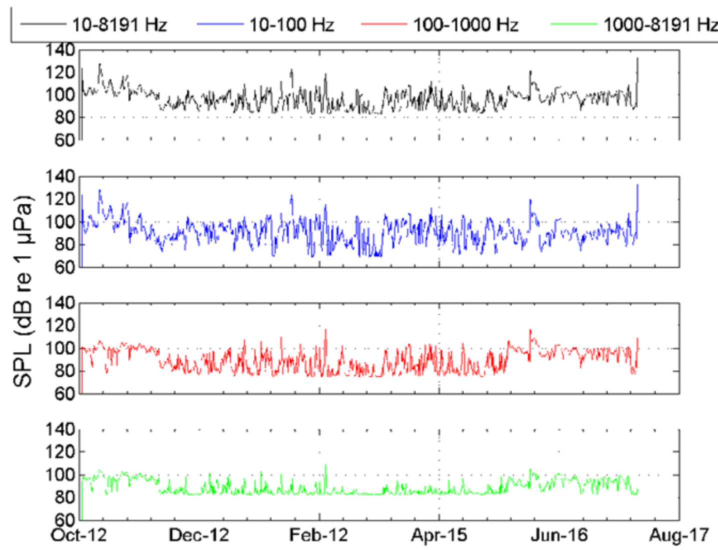


Figure 14. Broadband (top) and decade band sound pressure levels (SPL) for PLN40 from the October 2009 to August 2010 winter recording period.

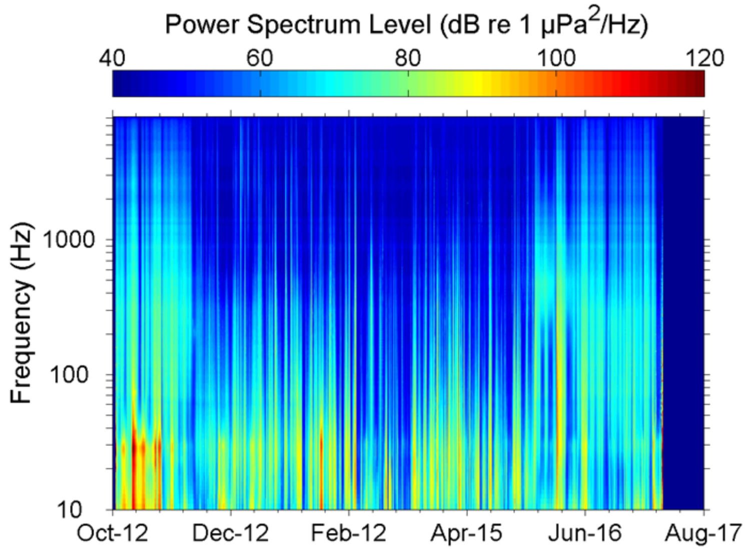


Figure 15. Spectrogram of underwater sound at PLN40 from the October 2009 to August 2010 winter recording period.

3.1.3. Summer 2010 Meteorological and Ice Conditions

Air temperature and wind speed for July to October 2010 are shown in Figure 16. Air temperature onshore varied over the study period from -12 to 19 °C, averaging 2.2 °C. Wind speeds were between 0 and 12 m/s and averaged 5.1 m/s.

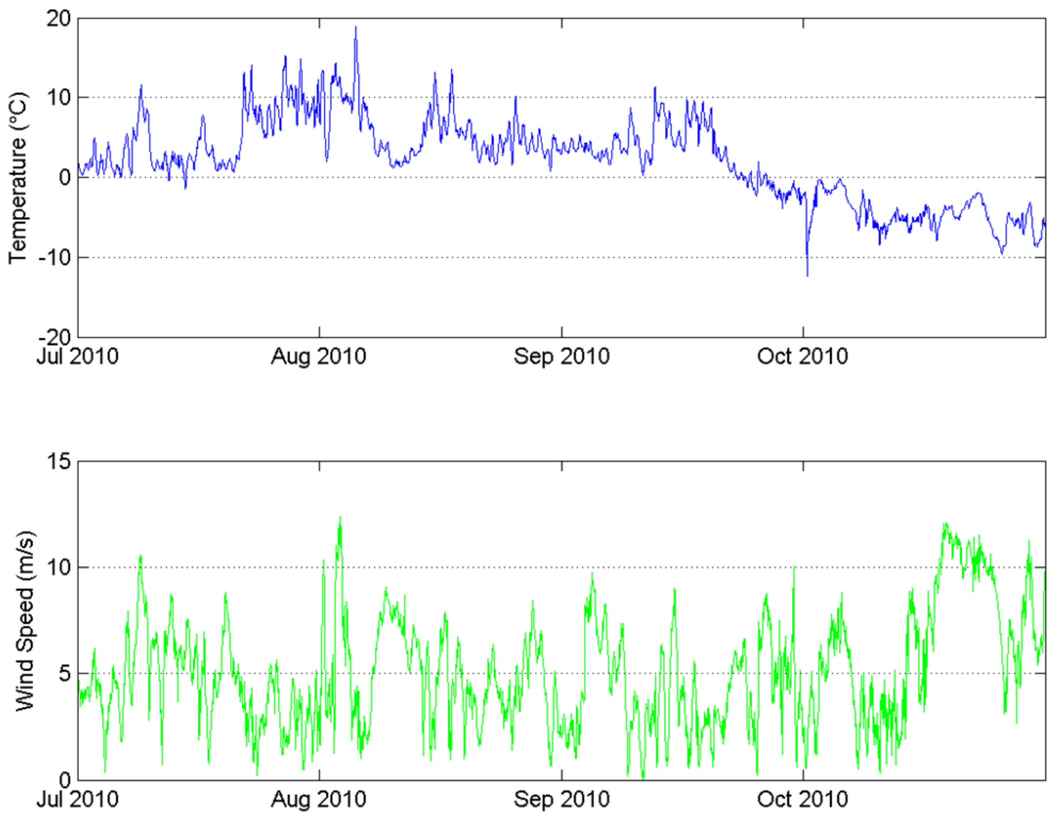


Figure 16. Air temperature (°C; top) and wind speed (m/s; bottom) at the Barrow station of the U.S. Climate Reference Network, July to October 2010 (National Climatic Data Center 2010).

Ice concentration data for before and after the summer are shown in Figure 17. With the exception of a few northern areas early in the deployment, the study area was ice-free during the 2010 summer deployment period.

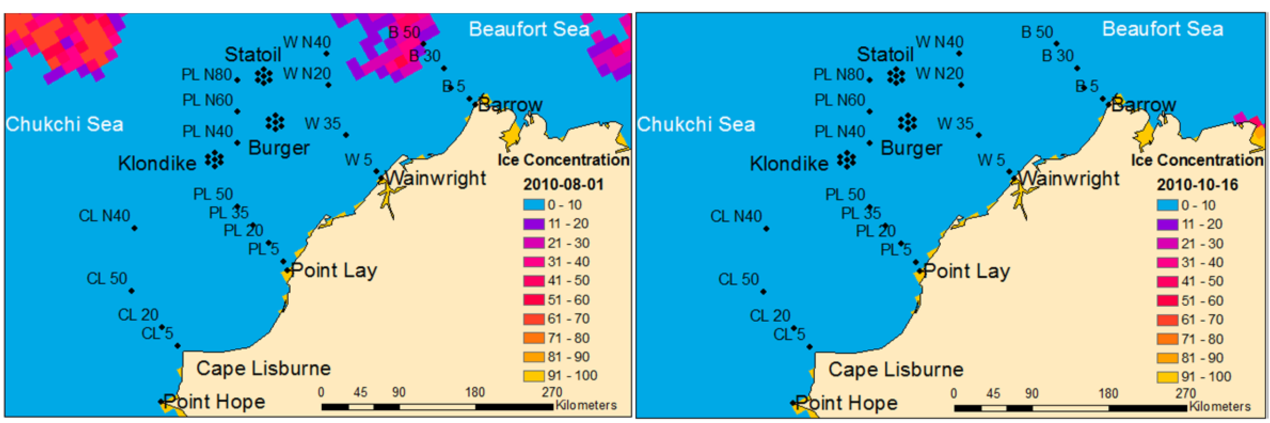


Figure 17. Ice concentration (%) in the Chukchi and Beaufort Seas on (left) 1 Aug and (right) 16 Oct 2010 (AMSR-E data collected as discussed by Cavalieri *et al.* 2004) relative to the summer 2010 recording stations.

3.1.4. Summer 2010 Ambient Noise

Figure 18 shows the percentile spectral levels of ambient noise for the PLN40 summer recording period (July to September 2010). Generally, the spectral levels decreased almost linearly with increasing frequency from 10 Hz to 3 kHz, which is a common characteristic of ambient noise spectral data. Ambient spectral levels were expected to continue to decrease or at least level off above 3 kHz, but spectral levels showed a slight increase with frequency above 3 kHz. This increase was attributed to the electronic noise floor of the recorders.

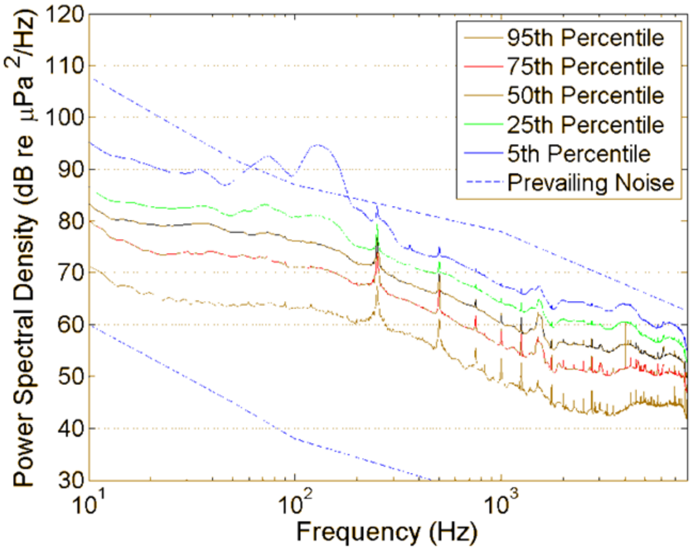


Figure 18. Percentile 1 min power spectral density levels (dB re 1 µPa^2/Hz) for the PLN40 summer recording period from July 2010 to September 2010. The dashed lines are the 'Limits of Prevailing Noise' from the Wenz curves, Figure 6.

Figure 19 shows broadband and decade-band SPLs and Figure 20 shows the spectrogram for the PLN40summer recording period. The elevated sound levels visible in the spectrogram in the 10–100 Hz band in early August are attributed to wind and wave break noise and also partially to water movement against the hydrophone due to seafloor currents induced by winds (Figure 16). In general, increased wind speed is associated with higher sound levels in shallow water (Greene and Buck 1979). Seismic activity can be clearly observed from approximately 30–200 Hz in both the band level and spectrogram plots from mid-August onward.

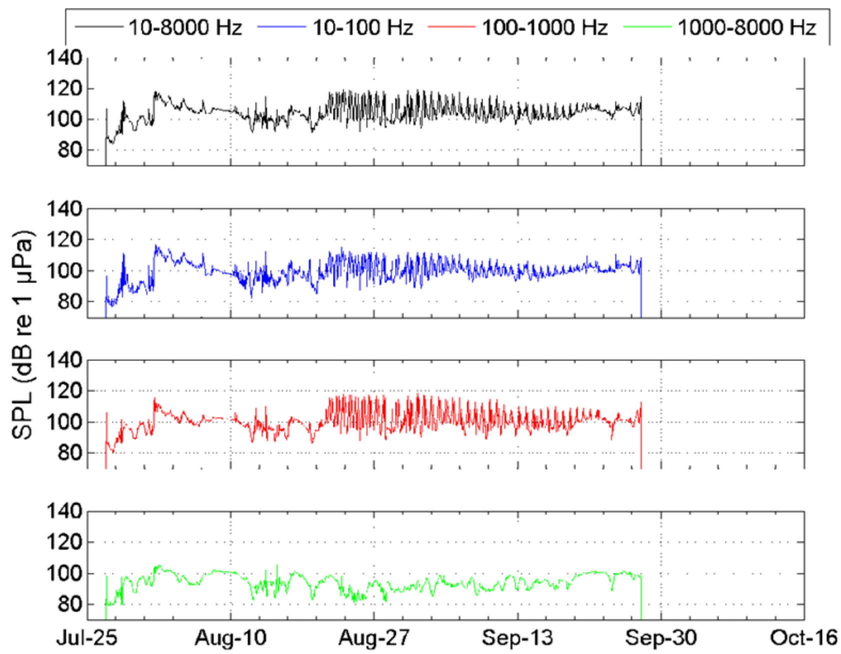


Figure 19. Broadband (top) and decade band sound pressure levels (SPL) for the summer PLN40 recording period from July 2010 to September 2010. Seismic survey noise is apparent from late August through September.

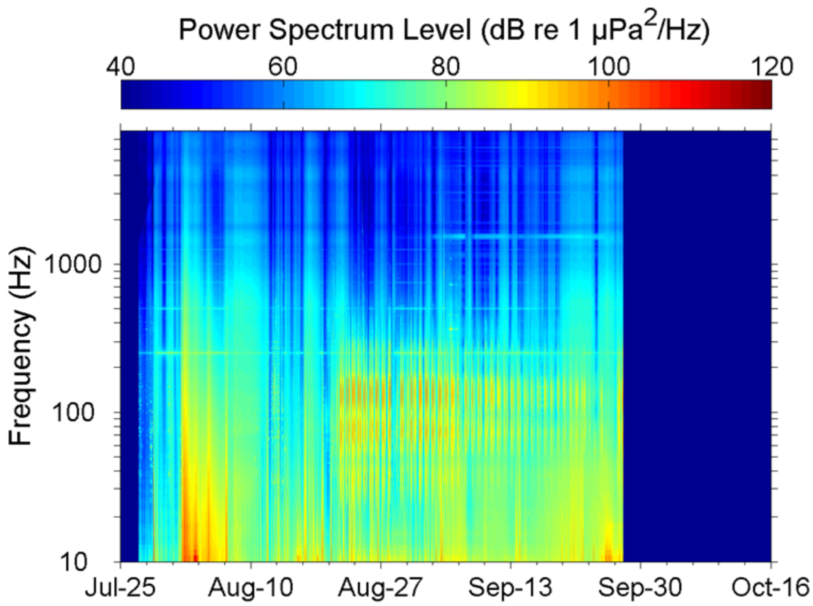


Figure 20. Spectrogram of underwater sound for the summer station PLN40 recording from July 2010 to September 2010.

3.2. Seismic Survey Detections

3.2.1. Winter 2009-2010

No seismic survey events were detected manually or automatically during the winter acoustic monitoring period from early October 2009 through July 2010.

3.2.2. Summer 2010

3.2.2.1. Statoil 3-D Seismic Survey Program

The main seismic survey source detected was the Statoil 3-D program performed from survey vessel *Geo-Celtic* during the period of August 22 – September 30. The survey used a 3000 in^3 flip-flop airgun array at a nominal shot repetition rate of 10 s. The mitigation gun was 60 in^3 in volume. Seismic survey detections are clearly visible on recordings from stations on a line (roughly east to west) across the Chukchi (CLN120, PLN80, S01, WN20, and B30) (Figure 21). The seismic survey was detected throughout the central section of the Chukchi, but not detected at stations on the Barrow line, or at the land-ward stations of the Cape Lisburne, Point Lay, and Wainwright lines. A section of Figure 21 from the first week in September 2010 is shown in Figure 22. A sample of strong seismic survey pulse detections is shown in

Figure 23.

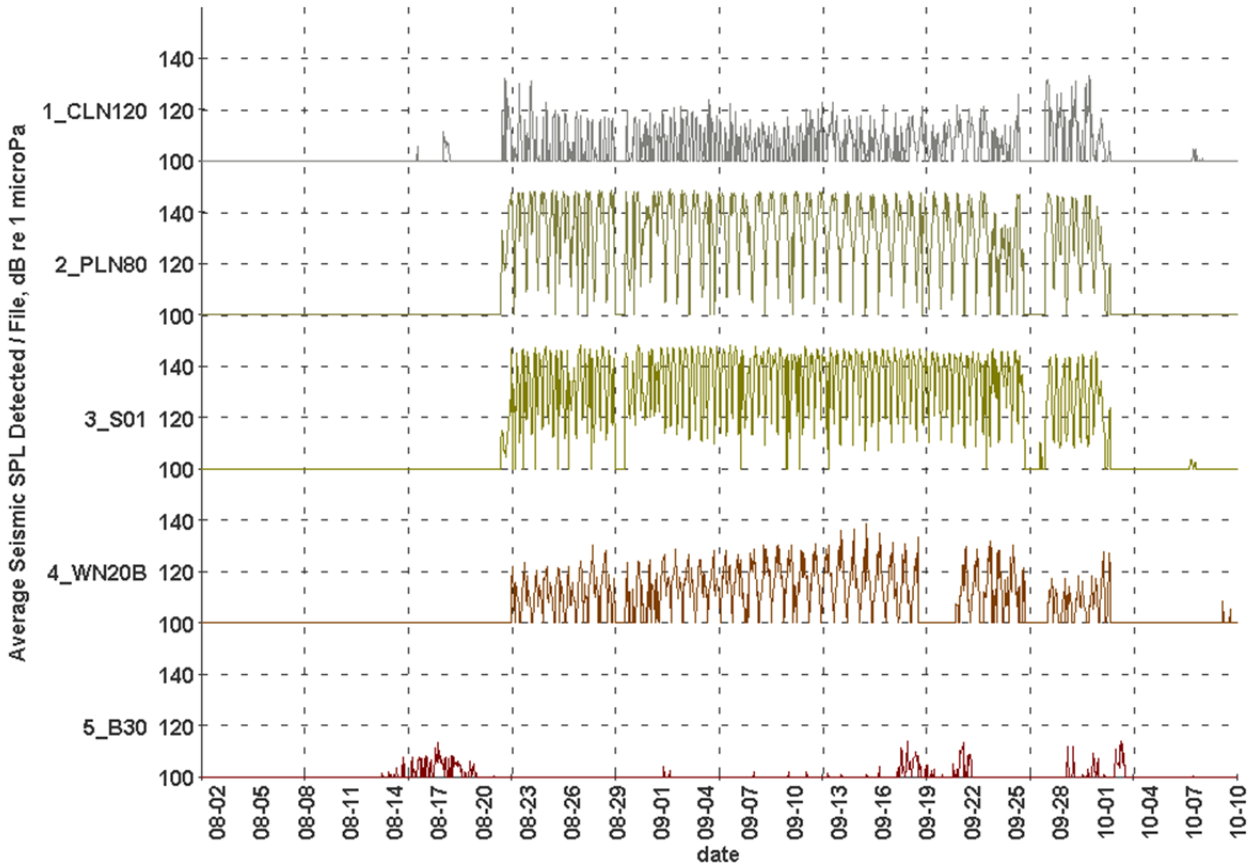


Figure 21. Average seismic survey SPLs (per-pulse rms_90, when detected by the automatic seismic pulse detector) per 30-min interval from the *Geo-Celtic* 3000-in^3 airgun array, at statioons along a roughly east-west line (CLN120, PLN80, S01, WN20, and B30). Survey sounds were not detected at station B30; the events at B30 are attributed to UNCLOS surveys further offshore in the Canada Basin (See section 3.2.2.2).

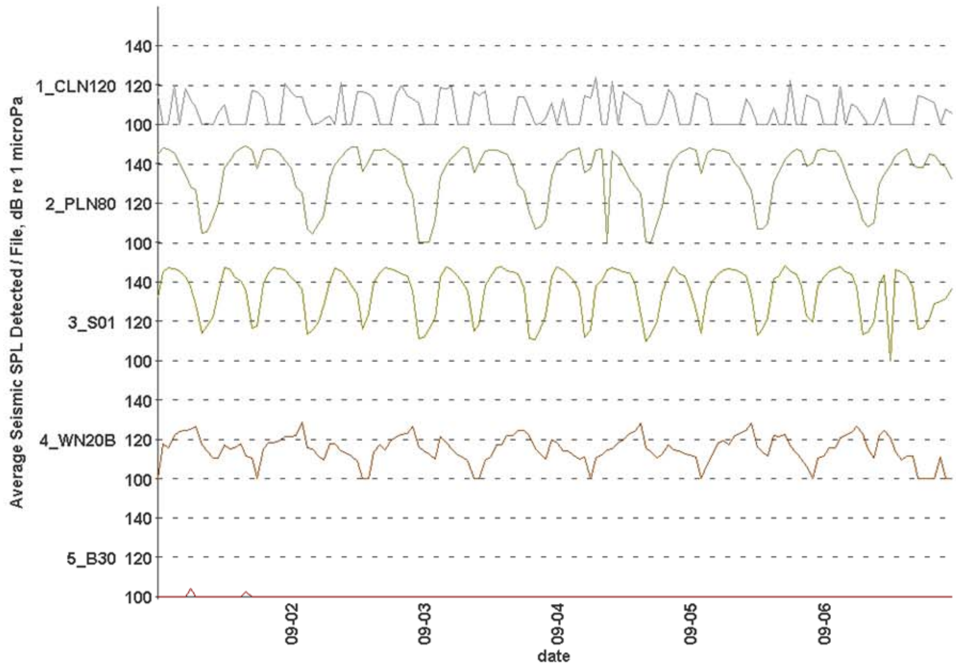


Figure 22. Average seismic survey pulse SPLs (rms-90) per 30 min interval at stations CLN120, PLN80, SO01, WN20 and B30 from Statoil's 3000 in^3 airgun array during the first week of September 2010. The survey was not detected at B30. Only the mitigation gun is used in turns. It is unclear why the SPL dropped more significantly during turns at SO01 than at PLN80.

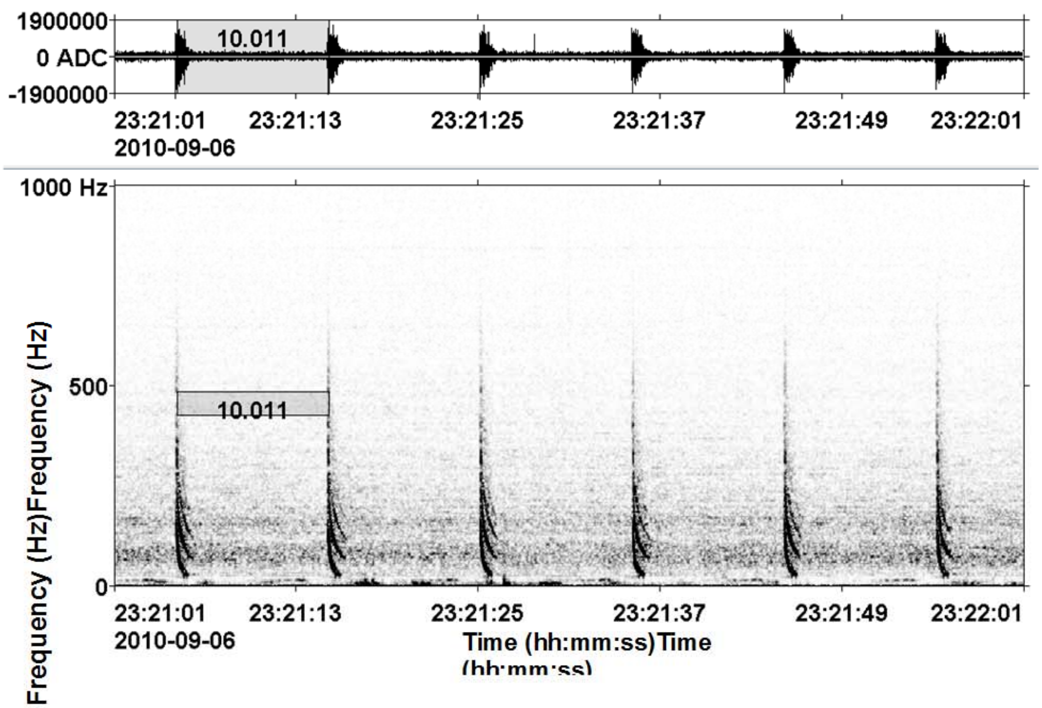


Figure 23. Pressure in digital units (top), and spectrogram (bottom) of seismic pulses from the Geo-Celtic's airgun array (3000 in^3), 6 Sep 2010 at Station PLN80 (4096-pt FFT, 4096 real-pts, 1024-pt advance).

3.2.2.1.1. Evaluation of the Seismic Footprint

The footprint of the airgun array determined by:

1. Measuring the received SPLs at each sensor in the AMAR array at a particular time; two times were chosen, once when the airgun array was at full power, and once with only the mitigation guns active;
2. Creating a geo-referenced grid and inserting the measured levels as known values;
3. Inserting a derived source representing the *Geo-Celtic* airgun array, with source level 138 dB re 1 μPa at its known position;
4. Inserting four points around the *Geo-Celtic* into the grid that represent the edges of the 160 dB zone as measured during the program's sound-source verification (O'Neill et al., 2010); and
5. Interpolating between these data points to obtain a seismic footprint.

The results of this analysis are shown for the full array in Figure 24. Note that there appears to be more power radiating north-south than east-west. This is expected since the *Geo-Celtic* was transiting east at the sample time, and the array propagates more power along the broadside direction than the end-fire direction. The results for only the mitigation guns are shown in Figure 25. This plot shows more omni-directional sound propagation which was expected for a single airgun. Both Figures show a significant decrease in received levels at CLN120 (west of the *Geo-Celtic*). This is due to a bathymetric rise between the ship's location near Station PLN80 and CLN120 attenuating the sound. The bathymetry is shown in Figure 26.

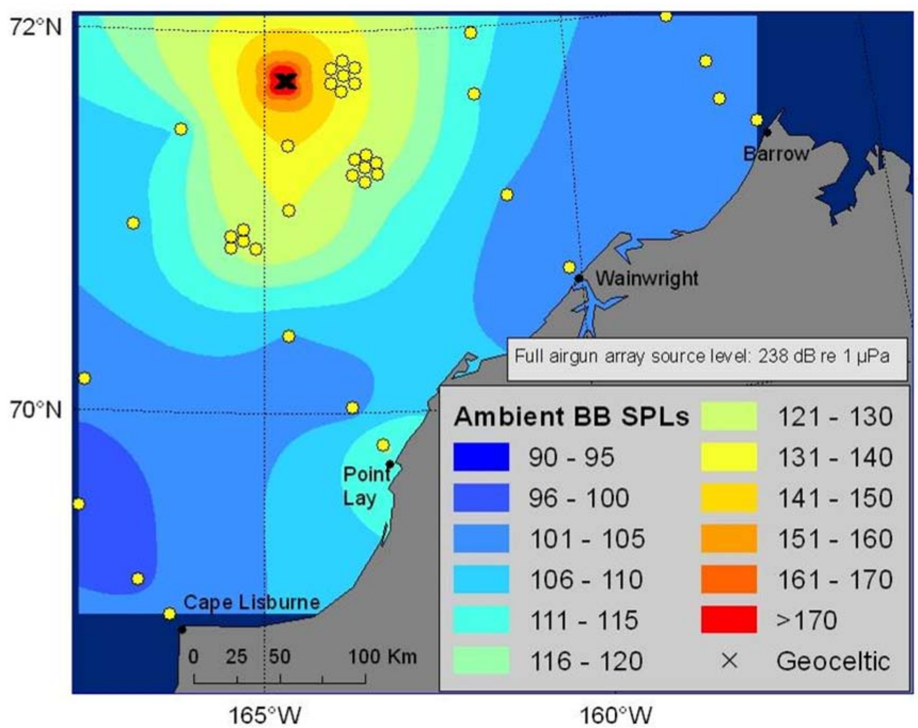


Figure 24. Measured seismic survey and ambient sound pressure levels (SPL rms-90 where pulses were detected and rms otherwise) during full-power operation of the *Geo-Celtic's* airgun array at 00:00 on 6 Sep 2010. High sound levels near Point Lay are due to a large concentration of Walrus calls at station PL05. See text for description of methods used to estimate sound levels near the source.

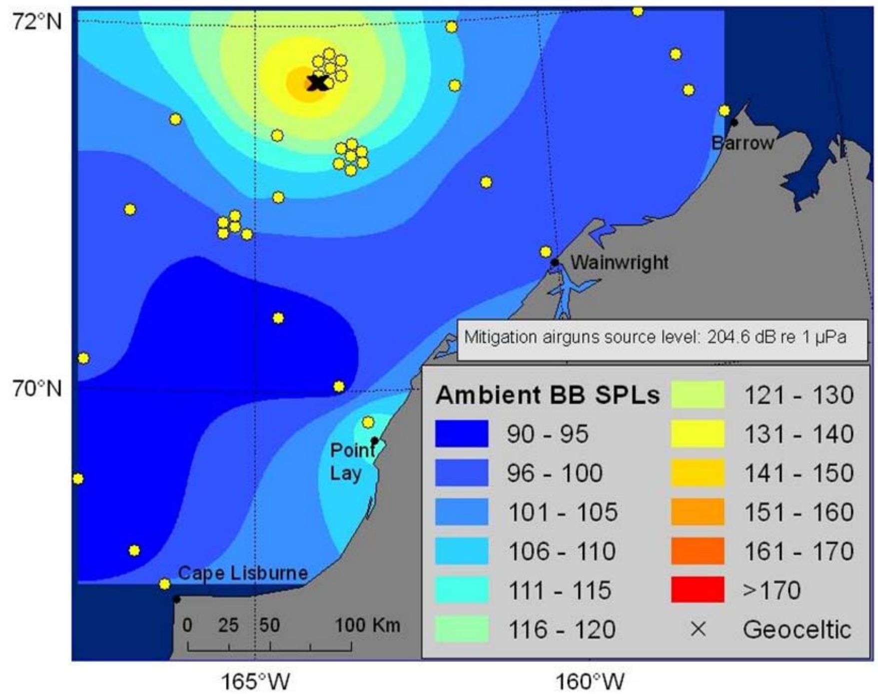


Figure 25 Measured seismic survey and ambient sound pressure levels (SPL rms-90 where pulses were detected and rms otherwise) during operation of the *Geo-Celtic's* mitigation airguns only, 00:00 7 Sep 2010. High sound levels near Point Lay are due to a large concentration of Walrus calls at station PL05. See text for description of methods used to estimate sound levels near the source.

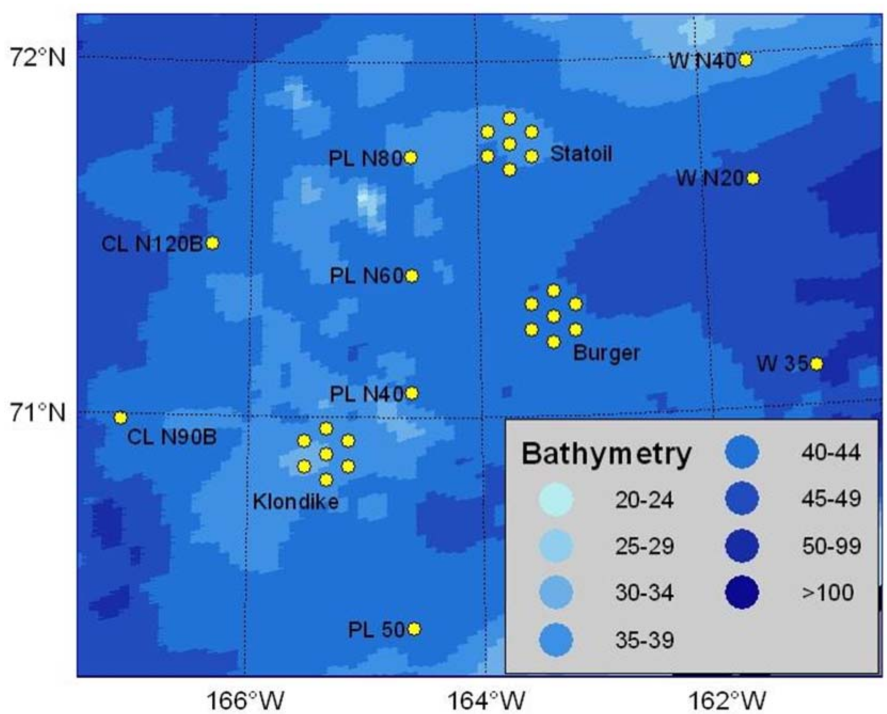


Figure 26. Detailed view of the bathymetry around the seismic lease areas. The shallow area between Stations PLN80 and CLN120 may be responsible for lower seismic levels received at station CLN120B.

3.2.2.2. Non-Statoil Seismic Survey Activity

Stations B50 and B30 recorded intermittent distant seismic activity with a repetition rate of about 17.5 s during summer 2010. These are attributed to surveys conducted in the Canada Basin as part of the United Nations Convention on Law of the Sea (UNCLOS) continental shelf mapping. As shown in Figure 27, the detected events have modal components that arrive as much as 5 seconds before the main seismic energy. This time dispersion is typical of long distance sound propagation through the deep water sound channel which occurs when there is a minimum in the sound speed profile. A sound channel can occurs in summer in the top few hundred meters of arctic waters due to warming of surface waters and resulting sound speed increases. Sound speeds increase also with depth, due to increased hydrostatic pressure, leading to a sound speed minimum below the surface that tends to trap sound energy. This profile promotes long-range sound propagation with relatively low attenuation rates. The low frequency modes arrive at the recorders sooner because their longer wavelengths extend further above and below the sound speed channel axis and hence travel through higher sound speed waters..

The sound pressure levels and spectrograms of the sequences detected 27 September – 3 October at B50 are shown in Figure 28. The spectrograms clearly show the earlier arrival of low frequency sound energy and later arrivals of higher frequency sounds. Interestingly, this is the opposite effect that modal propagation has over the shallow Chukchi Shelf environment as seen, for example, in Figure 23.

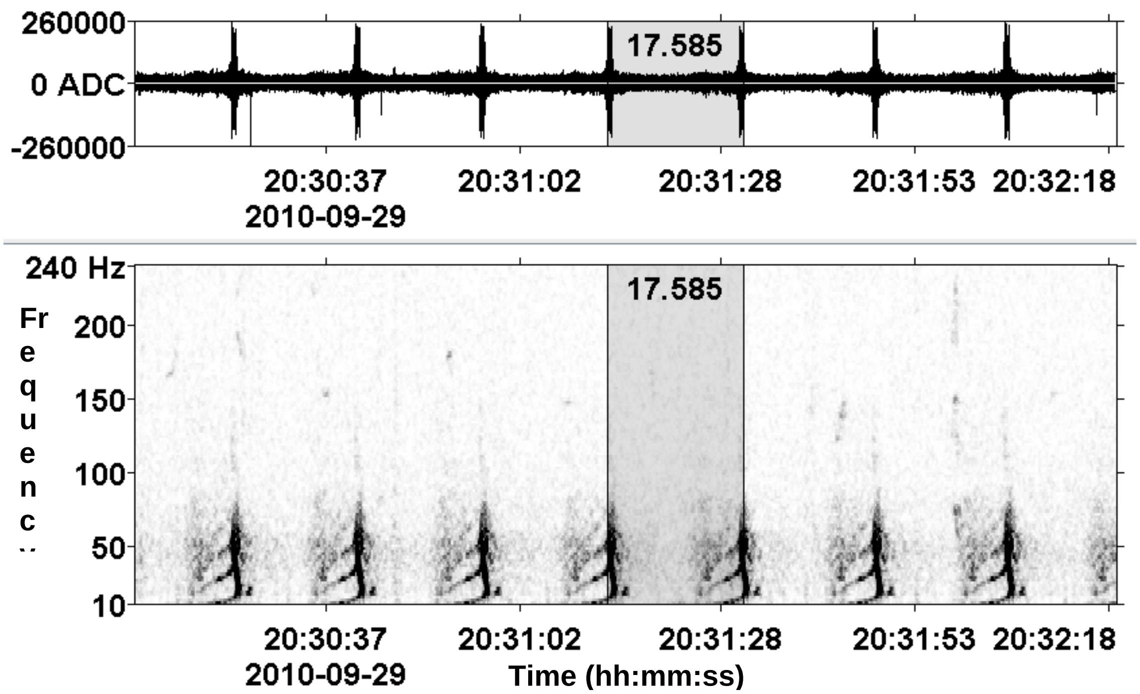


Figure 27. Pressure in digital units (top), and spectrogram (bottom) showing sequence of seismic airgun pulses with 17 s interval from UNCLOS source recorded 29 Sep 2010 at Station B50 (4096-pt FFT, 4096 real pts, 1024-pt advance). Note the early arrival of low frequency modes.

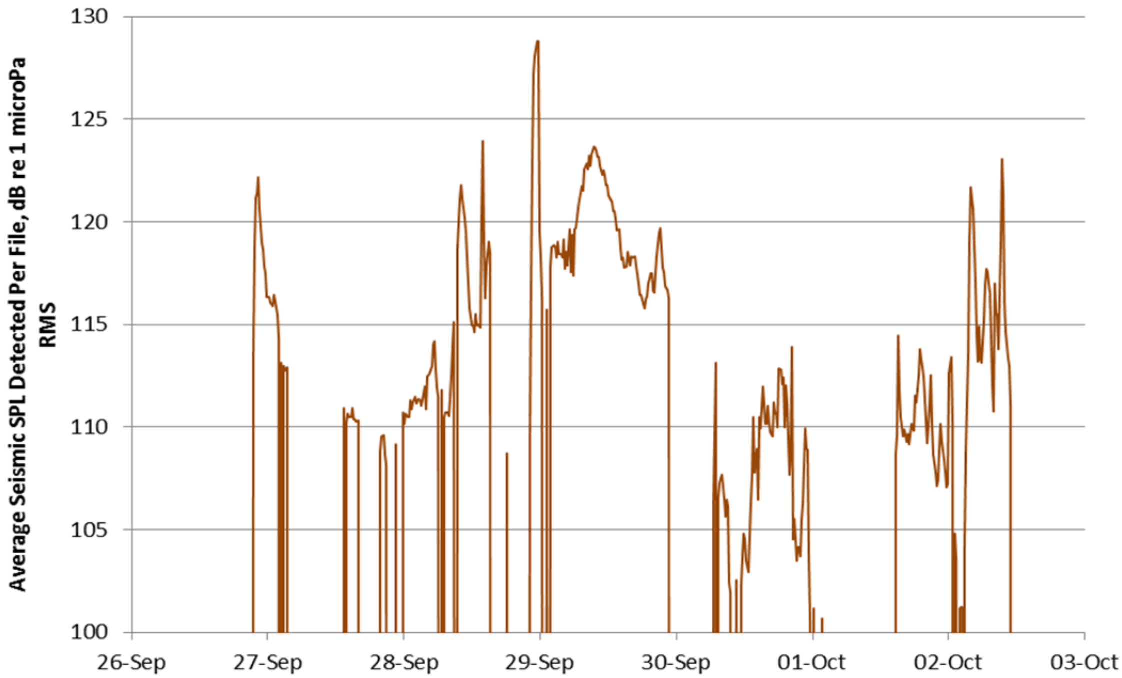


Figure 28: Seismic pulse levels (rms-90) measured at Station B50, 26 Sep to 3 Oct 2010, likely from distant UNCLOS seismic survey.

3.3. Marine Mammal Vocalization[1] Detections

3.3.1. Manual Analysis Detection Probability

As discussed in Section 2.2.1, samples of data of 5% of each file were manually analyzed to determine the presence or absence of calls from each species in the winter 2009–2010 and summer 2010 datasets. In this section we present the results of estimating the probability that the manual analysis protocol will detect each species, as a function of season. This analysis has been done to assess and validate the protocol of manual examination of only a fraction of the datasets. Detection probabilities (DP) are also used as an indicator of calling rate. Section 2.2.1.3 describes how a random selection of files was used to determine the probability that the manual analysis protocol would detect different species of marine mammals. The selection of 5% manual analysis is compared to 1, 2, and 10% manual analysis in this section (Table 7, Table 8).

The estimated detection probabilities for selected files containing bowhead, beluga, ringed and bearded seal (Table 7) and walrus (Table 8) calls indicate that the performance of the manual analysis protocol (*i.e.*, the probability that a randomly selected 90 s or 2 min (summer/winter) sample will contain calls of a given species if calls are present within its 30 min/40 min (summer/winter) source file) varies with species and season.

Bowhead whale calls had a high DP from late October until June (>61%), presumably due to high calling rates associated with singing. In summer (July and August), bowheads had a low DP (<30%), presumably because they are largely absent from the Chukchi and few calls were

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

available to detect. From late September until November, bowhead DP increased following an increase in calling rate as the migration progressed through the Chukchi Sea (Table 7).

Bearded seals had a high DP from late October until late June–early July, when they stopped vocalizing abruptly. In summer and early fall, DPs were typically low, with a few exceptions (Table 7).

Beluga calls had a high DP during the spring and fall migrations. This was expected as these are the periods of highest beluga occurrence in the north-eastern Chukchi Sea (Delarue *et al.* 2011). Alternatively, beluga calls had a low DP in August (Table 7), which corresponds to times when they are thought to be largely absent from the Chukchi.

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 that the current analysis protocol underestimates the presence of ringed seal calls in the data.

Walrus calls had 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 ($p < 0.029$), suggesting that calling rate or detectability decreases with increasing airgun pulse SPL. Walrus are thus less likely to be detected during seismic surveys. Summer files with faint or no airgun sounds were characterized by a high DP.

Table 7. Manual analysis detection probability (DP) 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.

Species	Station	Date and Time	DP (1%)	DP (2%)	DP (5%)	DP (10%)
Bowhead whale	B05	10/21/2009 03:00	27.4	39.8	61.1	85.4
	CL50	12/12/2009 00:00	86.6	95.3	98.8	100.0
	PL50	4/13/2010 11:00	19.7	33.3	61.1	86.9
	B05	5/10/2010 03:00	99.4	100.0	100.0	100.0
	W35	6/19/2010 19:00	40.3	58.2	92.1	98.9
	PLN40	7/11/2010 15:00	6.3	11.6	22.2	36.2
	CLN120	7/28/2010 16:36	7.5	15.9	22.3	26.1
	B50	8/18/2010 07:29	7.8	13.0	28.1	38.5
	WN40	9/8/2010 01:29	1.9	4.2	8.9	15.4
	B30	9/15/2010 20:43	9.0	13.7	26.3	38.1
	CLN90	9/24/2010 04:36	8.5	16.5	37.1	62.0
	W35	10/1/2010 00:12	32.9	51.5	82.5	98.8
	PL50	10/8/2010 08:31	46.8	66.3	90.5	98.5
Bearded seal	W50	10/27/2009 11:00	20.5	33.6	67.4	94.6
	B05	11/24/2009 16:00	62.5	84.5	98.2	100.0
	PLN80	1/8/2010 20:00	25.4	41.4	69.2	87.0
	CL50	2/15/2010 16:00	74.4	87.6	100.0	100.0
	WN40	3/27/2010 07:00	25.6	44.2	65.1	74.0
	W35	5/5/2010 03:00	100.0	100.0	100.0	100.0
	PLN40	6/18/2010 23:00	100.0	100.0	100.0	100.0
	PL20	7/28/2010 21:26	5.6	9.4	16.1	28.3
	W05	8/16/2010 14:36	5.6	8.8	11.1	15.2
	PLN60	9/10/2010 12:43	1.8	3.4	5.1	4.3
	B50	9/20/2010 13:44	47.5	70.3	96.0	100.0
	S01	10/1/2010 14:57	11.8	21.0	42.4	65.1
	CL50	10/11/2010 15:11	1.0	1.7	4.6	9.0
Beluga whale	B05	10/27/2009 3:00	100.0	100.0	100.0	100.0
	CL50	11/22/2009 16:00	15.0	26.7	40.9	68.2
	PLN40	4/10/2010 19:00	100.0	100.0	100.0	100.0
	W35	5/3/2010 03:00	100.0	100.0	100.0	100.0
	WN40	6/10/2010 23:00	32.5	46.9	64.5	82.4
	B05	7/11/2010 11:00	78.7	92.6	100.0	100.0
	W05	8/5/2010 05:51	5.5	10.5	22.2	31.8
	B05	8/31/2010 21:01	4.4	7.2	14.0	22.9
	B05	10/8/2010 12:01	34.1	52.7	81.2	93.9
Ringed seal	WN40	11/17/2009 16:00	2.5	5.6	11.8	23.5
	PLN80	12/22/2009 16:00	2.8	4.3	11.1	23.4
	W35	1/14/2010 8:00	7.3	14.7	30.1	45.8
	PLN40	2/10/2010 4:00	3.6	5.4	9.5	15.2
	B05	3/14/2010 11:00	15.1	23.7	48.3	65.6
	CL50	4/20/2010 11:00	8.0	12.2	25.1	44.8
	PL50	5/7/2010 3:00	9.9	11.0	19.0	31.6

Table 8. Manual analysis detection probability (DP) of walrus 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. When airgun pulses were detected, the 30 min mean airgun pulse rms SPL (dB re 1 µPa) is provided.

Station	Date and time	DP (1%)	DP (2%)	DP (5%)	DP (10%)	30 min mean rms SPL
CL50	12/16/2009 16:00	76.8	89.8	99.7	100.0	n/a
PLN40	1/22/2010 08:00	71.0	92.1	100.0	100.0	n/a
CL50	6/18/2010 03:00	94.7	99.3	100.0	100.0	n/a
W35	7/10/2010 03:00	96.9	99.7	100.0	100.0	n/a
CLN90	7/27/2010 06:06	60.4	77.0	94.5	98.7	n/a
WN40	8/5/2010 19:00	97.2	100.0	100.0	100.0	n/a
WN20	8/11/2010 10:24	86.6	97.2	100.0	100.0	n/a
CL05	8/23/2010 14:29	100.0	100.0	100.0	100.0	n/a
BG01	8/24/2010 07:55	4.7	9.1	16.4	22.7	137.9
S01	8/28/2010 03:27	10.7	11.9	10.7	11.9	151.4
S01	8/28/2010 03:57	9.1	12.2	18.3	23.7	155.3
PLN80	8/28/2010 14:21	5.3	7.5	13.0	21.1	137.8
S01	8/30/2010 04:57	3.8	6.5	9.9	15.0	145.8
BG01	9/2/2010 02:04	11.1	20.4	44.6	67.8	129.6
PL20	9/5/2010 00:26	73.8	87.1	99.3	100.0	99.5
PLN80	9/7/2010 13:21	4.1	5.6	11.3	24.4	147.8
PLN60	9/9/2010 06:43	40.1	50.9	69.5	80.8	132.0
BG01	9/9/2010 14:34	31.7	54.9	85.5	100.0	130.0
PLN80	9/11/2010 14:36	19.8	29.1	44.3	59.3	130.7
B50	9/19/2010 01:14	28.0	40.2	57.3	71.1	111.5
BG01	9/19/2010 07:34	18.4	32.4	54.0	80.3	129.7
BG01	10/2/2010 02:34	56.2	70.8	92.1	100.0	n/a
S01	10/11/2010 03:57	31.1	40.1	56.7	73.6	n/a

3.3.2. Manual Analysis Detection Results

Over 20,000 sounds in winter and 25,000 sounds in summer were annotated manually, of which 18,869 (Table 9) and 20,222 (Table 10) were respectively classified as marine mammal calls. During the winter program, station W35 had the most marine mammal detections, largely comprised of bearded seal calls. Stations PLN80 and PL50 had the least marine mammal detections likely because they stopped recording on 21 March and 21 May 2010, respectively, while other stations were active until at least the second week of July. Bearded seals were by far the most commonly detected species in the winter dataset. Smaller numbers of walrus, bowhead, and beluga calls, in similar numbers, were detected in these data. In the summer program data, walrus was the species most represented with close to 13,000 manual annotations, followed by bowheads and bearded seals. The contributions of other species were negligible in comparison. PL05 had the most manual annotations, largely due to a high numbers of walrus calls.

Table 9. Marine mammal acoustic detections based on manual analysis of 5% of the winter 2009–2010 data from each recording station.

Station	Bowhead whale	Beluga whale	Gray whale	Minke whale	Walrus	Bearded seal	Ringed seal	Ribbon seal	All mammals	Unknown
B05	476	925			12	2105	16		3534	522
CL50	482	481	5	3	162	1624	40	7	2804	170
PL50	269	225	1			818	28		1341	55
PLN40	155	45			88	843	22		1153	313
PLN80	53	2				392	3		450	6
W35	562	357			223	4002	8		5152	210
W50	157	145			62	1017	20		1401	57
WN40	77	20			1527	1382	28		3034	429
Total	**2231**	**2200**	**6**	**3**	**2074**	**12,183**	**165**	**7**	**18,869**	**1762**

Table 10. Marine mammal acoustic detections based on manual analysis of 5% of the summer 2010 data from each recording station.

Station	Bowhead whale	Beluga whale	Gray whale	Fin whale	H/B whale	Killer whale	Walrus	Bearded seal	Ringed seal	Ribbon seal	All mammals	Unknown
B05	392	34					50	72			548	430
B15	375	7					201	117	2		702	293
B30	810						371	21	7		1209	192
B50	974						532	116	1		1623	150
CL05			4			8	849	1	1		863	291
CL20			1			19	338				358	362
CL50			15	14	6	14	67	4	1		121	468
CLN120	370					9	284	107		6	776	89
CLN40	33					12	75	1			121	39
CLN90	333			5			493	25			856	338
BG01	278					3	402	69			752	73
S01	206						363	92			661	99
KL01	271		1				240	55			567	126
PL05			52				2354	15			2421	109
PL20	10		29			23	1003	30	2		1097	182
PL35			30			15	1	2	2		50	24
PL50	235		4	4		14	310	38			605	429
PLN40	6		7				85	3			101	270
PLN60	201						179	67	4		451	162
PLN80	137						186	93			416	57
W05	74	13	1			16	801	41			946	50
W35	478					14	983	109			1584	173
WN20	286		2			1	1678	70			2037	1133
WN40	160					9	1059	129			1357	66
Total	**5629**	**54**	**146**	**23**	**6**	**157**	**12,904**	**1277**	**20**	**6**	**20,222**	**5605**

3.3.3. Manual and Automated Detection Results by Species.

3.3.3.1. Bowhead Whales

Winter 2009–2010 Program

The winter recorder deployment period for 2009-2010 was in mid-October 2009 and covered much of the fall migration of bowheads through the Chukchi Sea, towards the Bering Sea. The first part of the migration, starting in late September 2009, is discussed in the 2008-2009 Chukchi Acoustic Monitoring Project report (Delarue et al., 2010). Bowheads were detected at all stations during the portion of the migration acoustically detected here. Bowheads were detected at Station PLN40 as soon as recording started on 13 Oct 2009. Detections ended on 15 Dec at Station CL50 (Figure 29, Table 11). First and last detection days occurred later at stations southwest of the study area (*e.g.,* PL50 and CL50) than at the north-eastern stations. This trend is consistent with the overall west-southwest migration of bowheads through the Chukchi Sea in the fall. The number of detection days at each station ranged from 11 (WN40) to 33 (PLN40, Table 11) and was presumably driven by the proximity of each recorder to the main migration corridor. Between 12 and 31 Oct, the largest call counts were recorded at Stations PLN40, W35, and W50, with lower counts to the north and south (Figure 30). In the first half of November (Figure 31), the highest call counts were recorded at Stations W35 and W50, while in the second half of November counts were highest at PLN40 (Figure 32). These observations seem to suggest that the center of the migration corridor was in the vicinity of these stations, which are located just north of 71° N. This is consistent with the results of the 2009 summer data, which suggest that the migration corridor was centered between 71° N and 72° N (Delarue *et al.* 2010*b*). In the second half of November, the relative increase in call counts in the southwestern half of the study area highlights the progression of the migration in that direction, which was likely influenced by the advance of the ice edge at that time (Figure 32). The second half of November also had the highest call counts overall. This may not necessarily reflect a larger number of whales in the area but rather the more consistent production of songs which, due to their continuous nature, trigger a more acoustic detections. In the first half of December, bowheads were detected only at Station CL50 (except on 1 Dec at Station PL50), most animals having vacated the area, presumably as a result of increasing ice cover (Figure 33).

During the 2010 spring migration through the Chukchi Sea, towards the Beaufort Sea, bowheads were detected between 30 March at Station CL50 and 17 July at Station W35 (Table 11, Figure 29). Bowheads were also detected at Station B05 from 1 April, suggesting that some animals went undetected during their transit between Cape Lisburne and Barrow. The number of detection days ranged between two at WN40 and 67 at B05. Except in July, B05 consistently high call counts (Figure 34 to Figure 39). This is likely because most, if not all, bowheads migrating toward the Beaufort Sea in the spring pass within a few miles of Barrow. Based on station B05 detections, the core of the 2010 spring migration in the Chukchi Sea was completed by 9 June with only few detection days in late June and early July. Call counts peaked in the first half of May (Figure 36) and gradually decreased after that, with a marked drop in July (Figure 40, Figure 41). Except in July, Station WN40 remained devoid of detections, which suggests few bowheads pass over the top of Hanna Shoal. In April, when the ice cover was very high and relatively uniform throughout the area, there were no obvious differences in call counts at each station (Figure 34, Figure 35). In early May, when areas of lower ice cover became available inshore as a result of the lead forming between Cape Lisburne and Barrow, detections were concentrated at the stations closest to the ice edge (PL50, W35; Figure 36); there were considerably less or no detections further offshore (*e.g.,* W50, PLN40). In the second half of May, detections were also concentrated at the stations near the ice edge (PLN40, W50, and W35), which had receded further offshore. Station PL50, which was in a low ice over (<25%) area, had no detections (Figure 37). This pattern was less obvious later on as ice receded further offshore.

Most of the bowhead calls detected consisted of FM, narrowband moans (typically without harmonics), moans with harmonic structure, and complex calls which were defined as broadband, pulsed, and often strident calls (Ljungblad *et al.* 1982, Clark and Johnson 1984). In the fall, these calls became increasingly organized into stereotyped sequences called songs as the migration progressed (Figure 42; Delarue *et al.* 2009*a*). From mid-November, detections at all stations consisted exclusively of songs. In the spring, detections usually started with songs. These songs were typically less stereotyped than in late November and December and their structure became increasingly disorganized. By June, all detections usually consisted of non-song, non-stereotyped moans, and complex call sequences. Calling rates also decreased after June (Table 7).

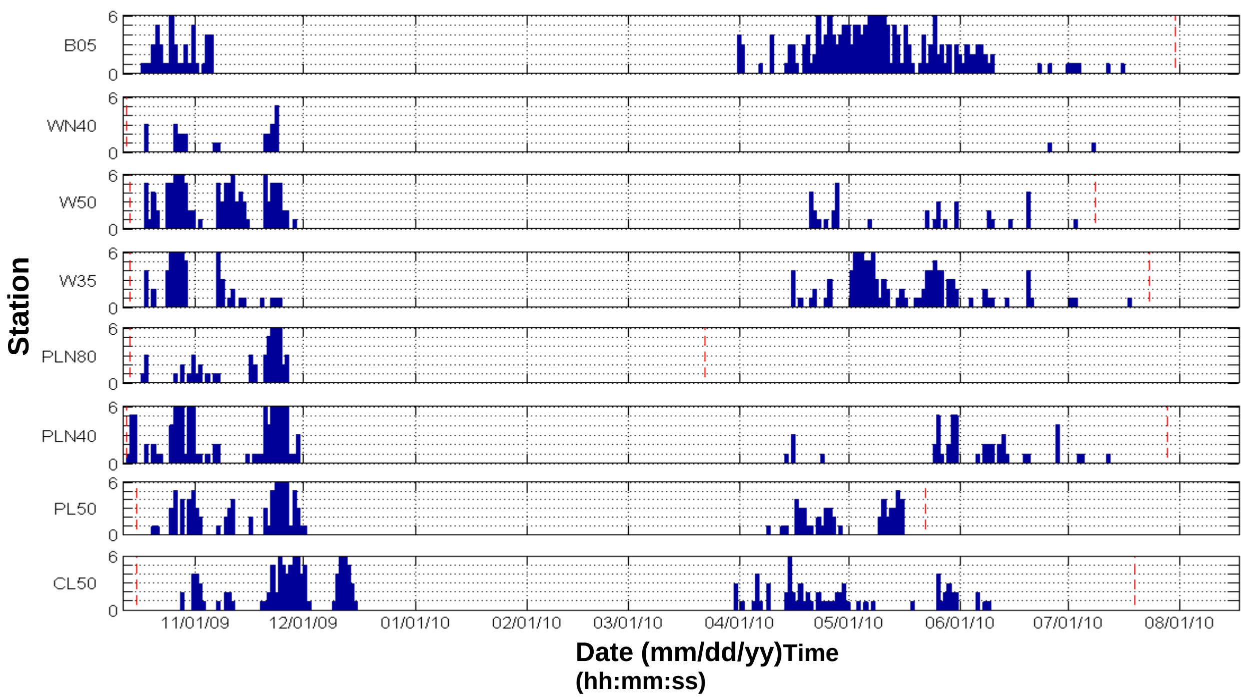


Figure 29. Daily number of sound files (six 40-minute files recorded per day) with bowhead detections based on the manual analysis of 5% of the data from mid-October 2009 to early August 2010. Red dashed lines indicate recorder start and end dates.

Table 11. Listing of the first possible date for bowhead call detection (Record start), date when a bowhead call was first detected (First detection) and last detected (Last detection), the last possible date for detection (Record end) and the total number of days on which a bowhead call was detected (Detection days) at all winter 2009–2010 recording stations, divided by fall and spring detections.

BOWHEAD WHALE								
		Fall 2009			Spring 2010			
Station	Record start	First detection	Last detection	Detection days	First detection	Last detection	Detection days	Record end
B05	12-Oct	17-Oct	5-Nov	19	31-Mar	15-Jul	67	29-Jul
WN40	13-Oct	18-Oct	23-Nov	11	25-Jun	7-Jul	2	17-Aug
W50	14-Oct	18-Oct	28-Nov	30	20-Apr	2-Jul	17	7-Jul
W35	14-Oct	18-Oct	24-Nov	18	15-Apr	17-Jul	41	21-Jul
PLN80	14-Oct	17-Oct	26-Nov	20			0	21-Mar
PLN40	13-Oct	13-Oct	29-Nov	33	13-Apr	11-Jul	22	26-Jul
PL50	16-Oct	20-Oct	1-Dec	26	8-Apr	15-May	21	21-May
CL50	16-Oct	28-Oct	15-Dec	30	30-Mar	8-Jun	36	18-Jul

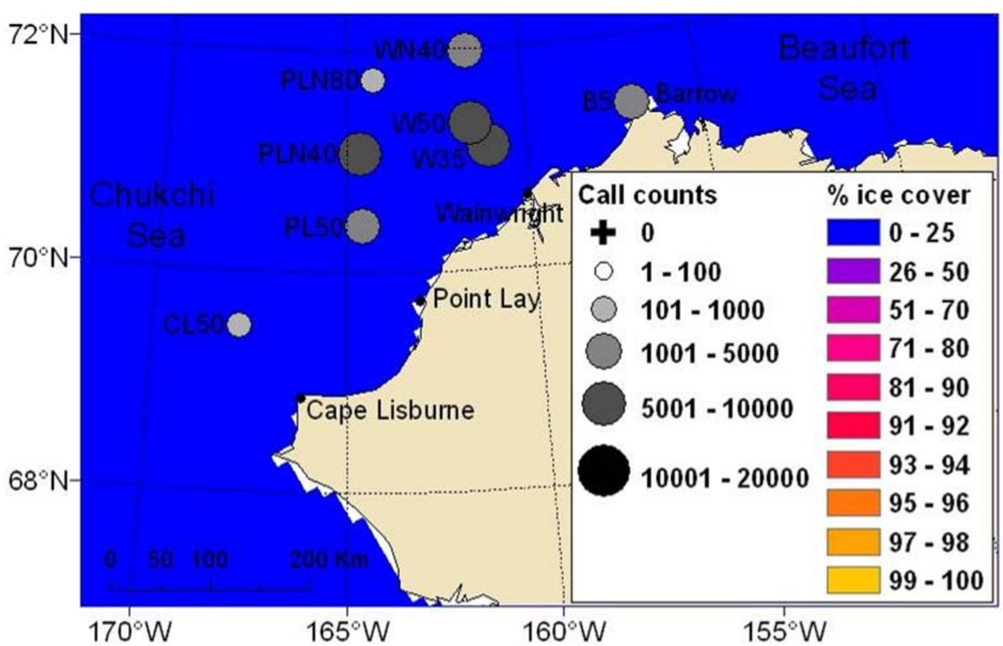


Figure 30. Bowhead whale call count estimates in the Chukchi Sea for 12–31 Oct 2009 based on manual analysis and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 23 Oct 2009. Note that the scale emphasizes heavy ice concentration.

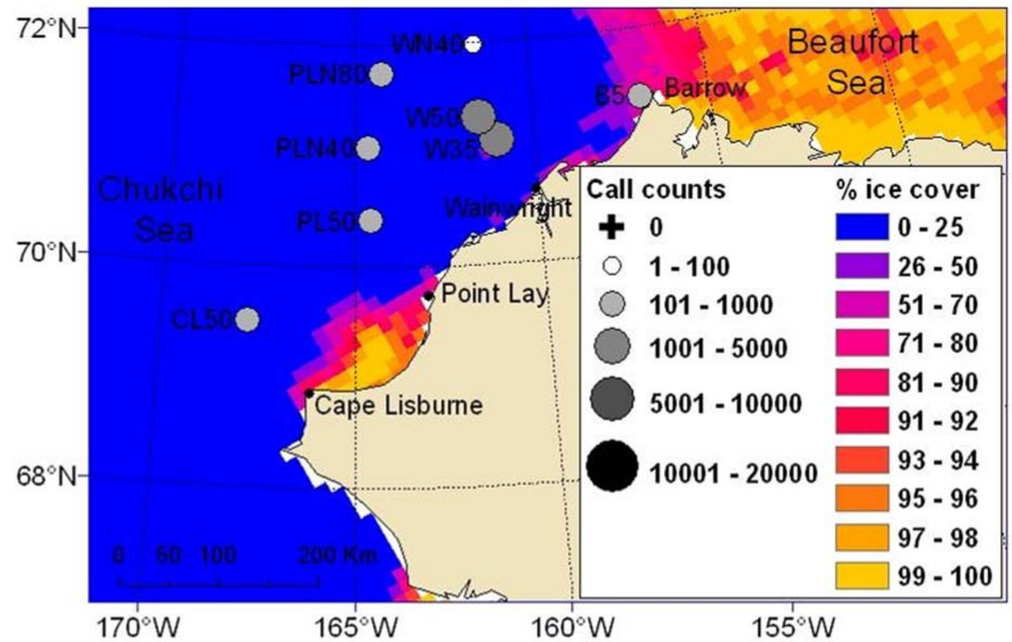


Figure 31. Bowhead whale call count estimates in the Chukchi Sea for 1–15 Nov 2009 based on manual analysis and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 7 Nov 2009. Note that the scale emphasizes heavy ice concentration.

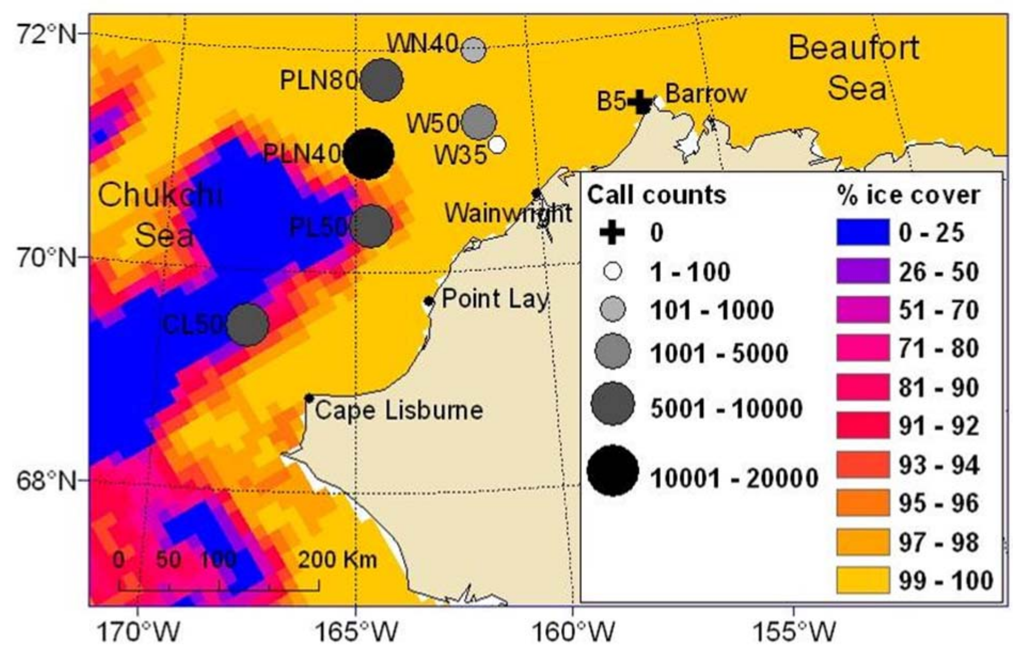


Figure 32. Bowhead whale call count estimates in the Chukchi Sea for 16–30 Nov 2009 based on manual analysis and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 23 Nov 2009. Note that the scale emphasizes heavy ice concentration.

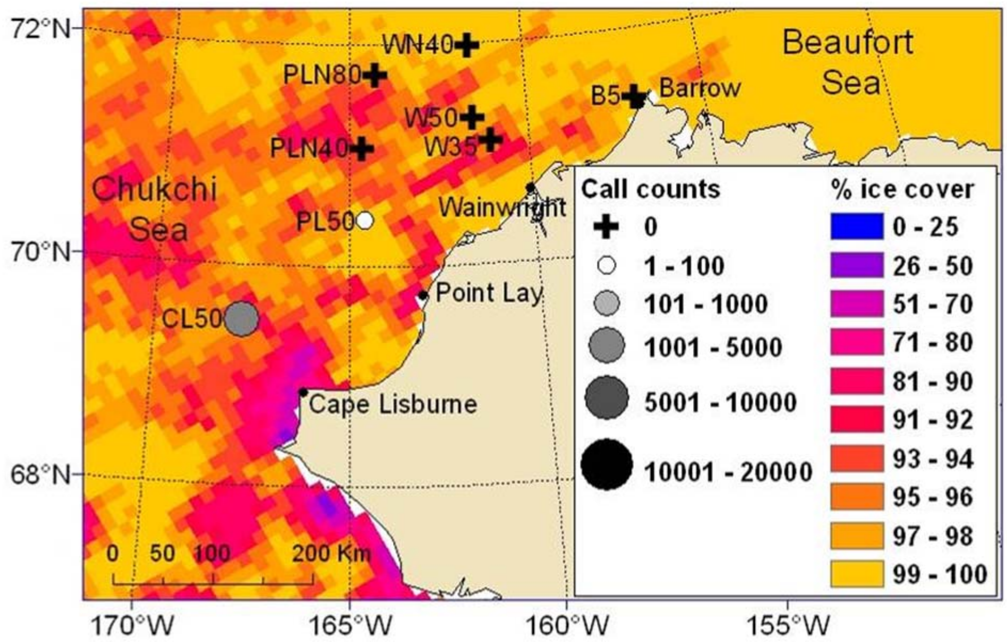


Figure 33. Bowhead whale call count estimates in the Chukchi Sea for 1–15 Dec 2009 based on manual analysis and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 7 Dec 2009. Note that the scale emphasizes heavy ice concentration.

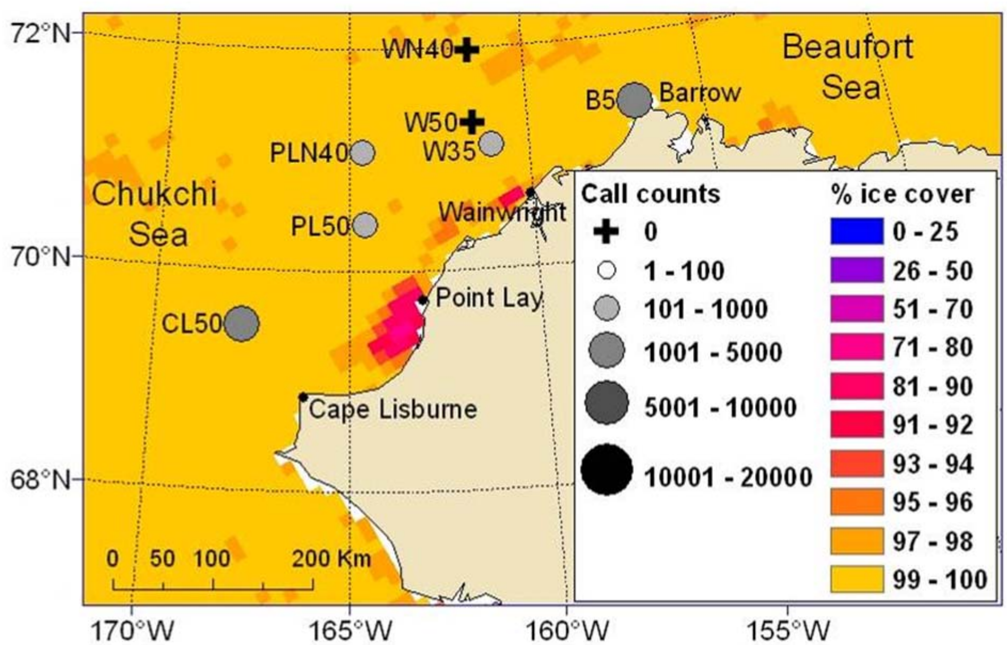


Figure 34. Bowhead whale call count estimates in the Chukchi Sea for 30 Mar to 15 Apr 2010 based on manual analysis and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 7 Apr 2010. Note that the scale emphasizes heavy ice concentration.

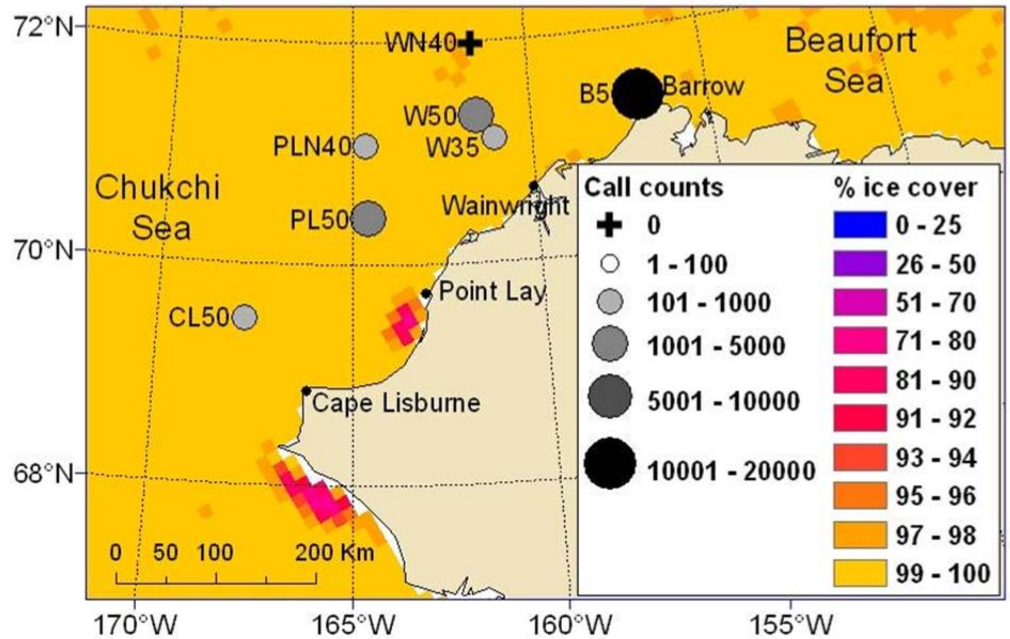


Figure 35. Bowhead whale call count estimates in the Chukchi Sea for 16–30 Apr 2010 based on manual analysis and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 22 Apr 2010. Note that the scale emphasizes heavy ice concentration.

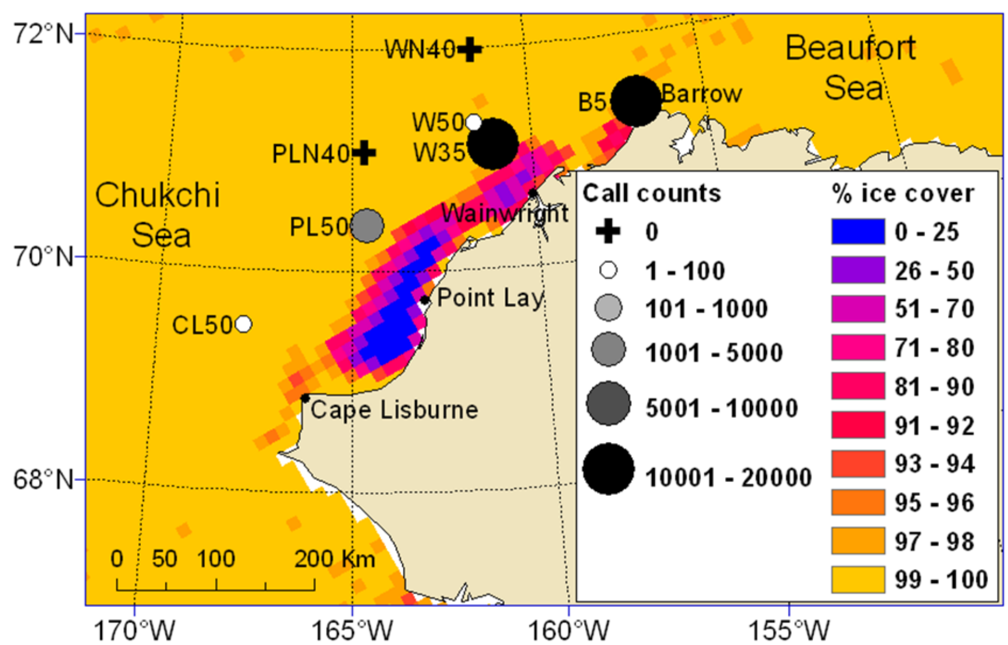


Figure 36. Bowhead whale call count estimates in the Chukchi Sea for 1–15 May 2010 based on automated manual analysis and automated call at the eight winter 2009–2010 recording stations. Ice concentration data are for 7 May 2010. Note that the scale emphasizes heavy ice concentration.

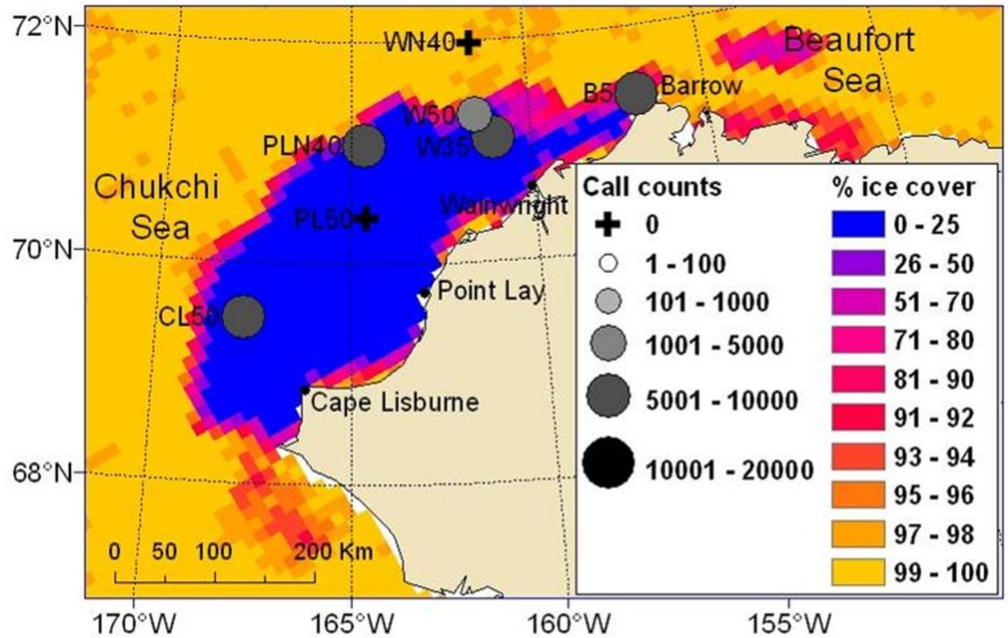


Figure 37. Bowhead whale call count estimates in the Chukchi Sea for 16–31 May 2010 based on manual analysis and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 22 May 2010. Note that the scale emphasizes heavy ice concentration. Recording stopped on 21 May at PL50.

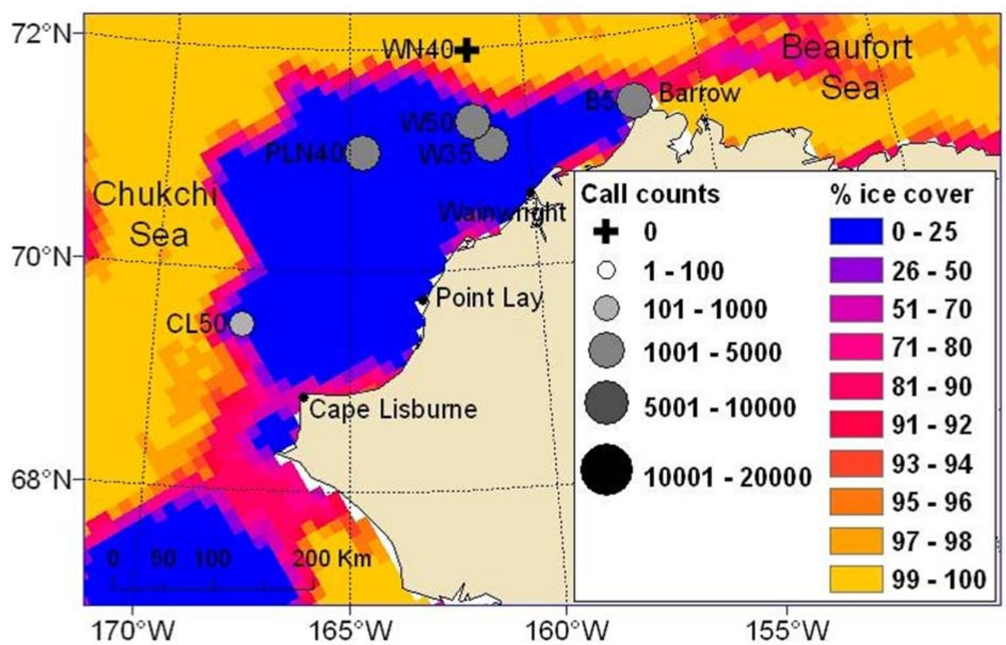


Figure 38. Bowhead whale call count estimates in the Chukchi Sea for 1–15 Jun 2010 based on manual analysis and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 7 Jun 2010. Note that the scale emphasizes heavy ice concentration.

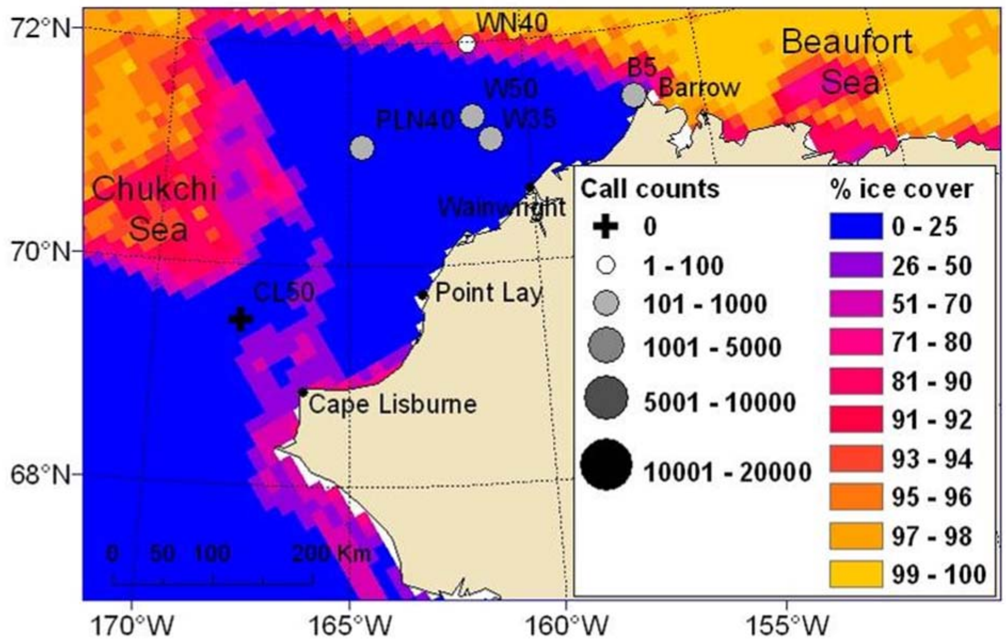


Figure 39. Bowhead whale call count estimates in the Chukchi Sea for 16–30 Jun 2010 based on manual analysis and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 22 Jun 2010. Note that the scale emphasizes heavy ice concentration.

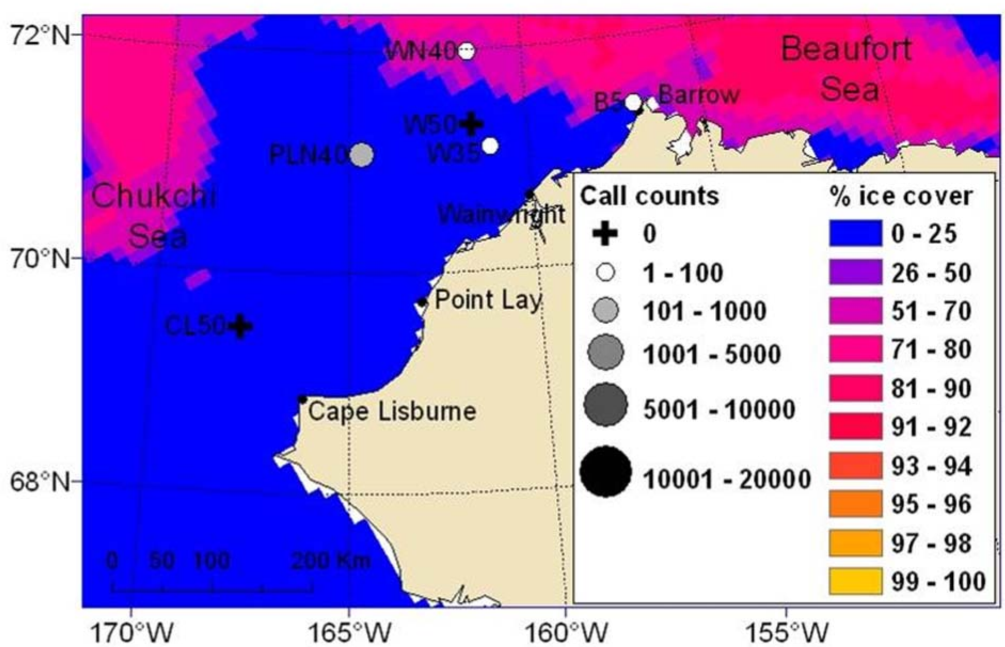


Figure 40. Bowhead whale call count estimates in the Chukchi Sea for 1–15 Jul 2010 based on manual analysis and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 7 Jul 2010. Note that the scale emphasizes heavy ice concentration.

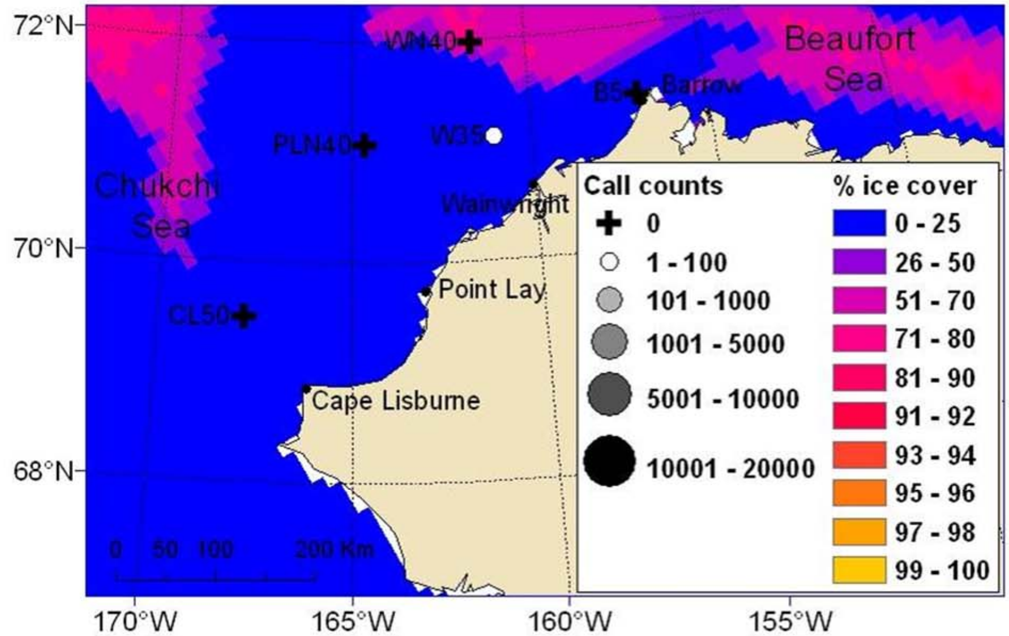


Figure 41. Bowhead whale call count estimates in the Chukchi Sea for 16–31 Jul 2010 based on manual analysis and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 22 Jul 2010. Note that the scale emphasizes heavy ice concentration.

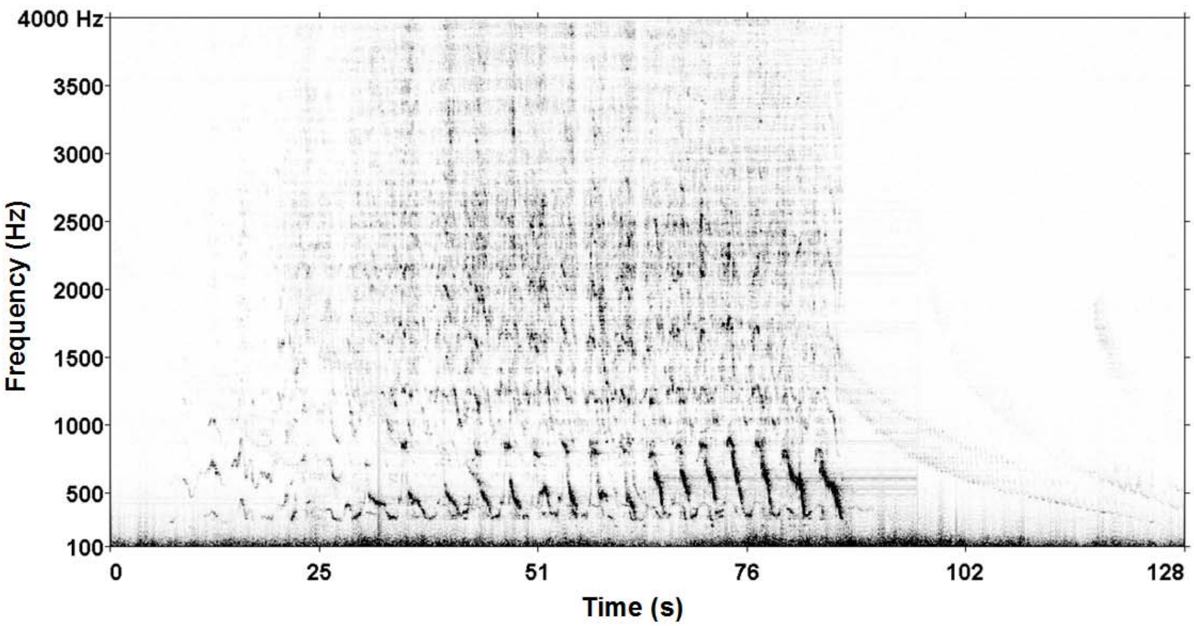


Figure 42. Spectrogram of a complex bowhead song recorded at winter 2009–2010 Station B05, 1 Apr 2010 (4096-pt FFT, 8192 real data pts, 1024-pt overlap, Hamming window).

Summer 2010 Program

Bowhead vocalizations were manually detected in the summer 2010 dataset at all analyzed stations except PL05, CL05, CL20, and CL50 (Figure 43, Table 12). The first detection occurred on 28 Jul at Station CLN120. However, this detection was unique, as 98% of files containing bowhead calls were recorded after 4 Sep and 77% were recorded after 21 Sep. Nevertheless, these calls were confidently attributed to being produced by a bowhead, as a whale equipped with a satellite tag was tracked in the vicinity of Station CLN120 at the time the calls were detected (Quakenbush *et al.* 2011). This detection may represent a whale (or group of whales) that was traveling from Barrow to the Chukotka coast. The detections from 18 Aug through late August at B50 could represent bowheads foraging offshore of Barrow, and/or migrants heading from Barrow toward Wrangle Island. The 2009 results of the bowhead satellite tracking program (Quakenbush *et al.* 2010) provided some evidence in support of the later hypothesis.

Acoustic detections of bowheads during the fall migration showed a trend of increasingly later arrivals at more western stations (Figure 46 to Figure 48). Details of the progress of the migration in September are given in Figure 119 to Figure 122. Detections of bowheads at stations west of Barrow were delayed in 2010 by 10-14 days relative to previous years. The reasons for this delay are unknown, but high numbers of feeding bowheads were observed east of Barrow in late September and the good feeding opportunity there could have influenced the migration timing past Barrow into the Chukchi Sea. Statoil's seismic program operated 130-150 miles north of Point Lay through to 1 Oct. A small pulse of bowhead detections occurred at Wainwright and Point Lay's offshore recorders on 2 Oct, but the main migration pulse crossed this area a few days later on Oct 7-12. The latest acoustic detection of bowhead calls in the 2010 summer program occurred on 16 Oct 2010, the same day the recorders were retrieved.

An interpolated call count surface plot (Figure 49) indicates that the main migration corridor was located between 71° and 72° N. This is supported by locations of the stations with the highest call counts (Figure 48). The absence of recorders further north prevents us from knowing whether bowheads are migrating beyond 71° and 72° N. However, the order of magnitude decrease in call counts from WN20 to WN40 in October (Figure 48) tends to suggest that the number of migrating bowheads is lower near 72° N than further south. Some individuals appeared to be migrating along the coast at least until Point Lay, instead of heading west from Barrow (Figure 48 and Figure 49). The lack of detections at the inshore Cape Lisburne stations (CL05, CL20, and CL50) suggests that once they reach Point Lay, these individuals may head west, towards CLN40. Bowheads were indeed first detected at CLN40 24 h later than at PL20.

The detected calls consisted mostly of simple moans (Figure 50) although an increasing proportion of complex calls were noted toward the end of the recording period.

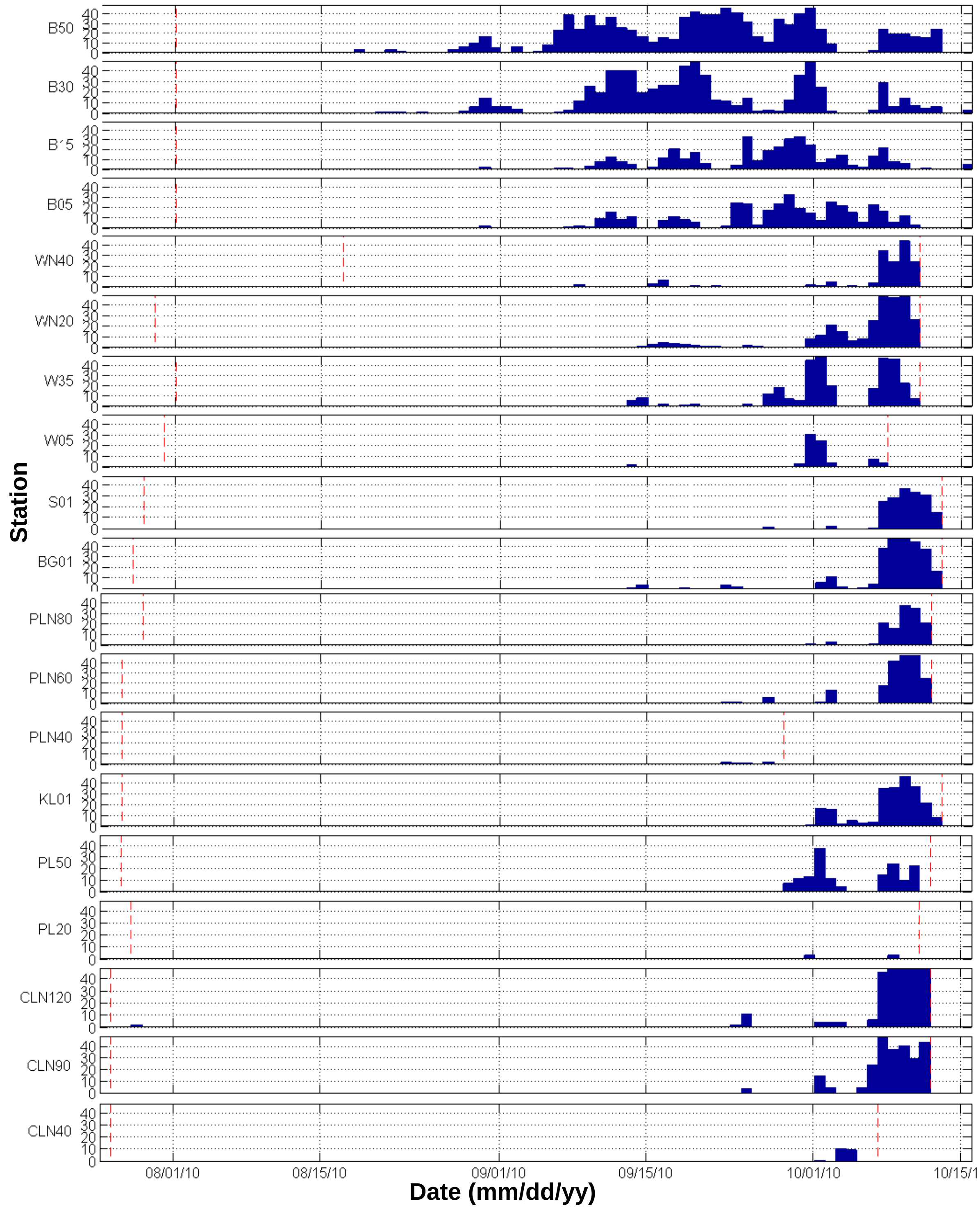


Figure 43. Daily number of sound files with bowhead detections based on the manual analysis of 5% of acoustic data recorded in the Chukchi Sea, late July to mid-October 2010. Red dashed lines indicate recording start and end.

Table 12. Listing of the first possible date for bowhead whale call detection (Record start), date when a bowhead call was first detected (First detection) and last detected (Last detection), the last possible date for detection (Record end) and the total number of days on which a bowhead sound was detected (Detection days) at summer 2010 recording stations. Data are presented only for those stations where bowhead sounds were detected.

BOWHEAD WHALE					
Station	Record start	First detection	Last detection	Record end	Detection days
B50	01-Aug	18-Aug	11-Oct	16-Oct	45
B30	01-Aug	20-Aug	16-Oct	16-Oct	46
B15	01-Aug	30-Aug	16-Oct	16-Oct	34
B05	01-Aug	30-Aug	10-Oct	16-Oct	31
WN40	17-Aug	08-Sep	10-Oct	10-Oct	14
WN20	30-Jul	14-Sep	10-Oct	10-Oct	21
W35	01-Aug	13-Sep	10-Oct	10-Oct	18
W05	31-Jul	13-Sep	07-Oct	07-Oct	7
S01	29-Jul	26-Sep	12-Oct	12-Oct	9
BG01	28-Jul	13-Sep	12-Oct	12-Oct	16
PLN80	29-Jul	30-Sep	11-Oct	11-Oct	8
PLN60	27-Jul	22-Sep	11-Oct	11-Oct	10
PLN40	27-Jul	22-Sep	26-Sep	27-Sep	4
KL01	27-Jul	30-Sep	12-Oct	12-Oct	13
PL50	27-Jul	28-Sep	10-Oct	11-Oct	10
PL20	28-Jul	30-Sep	08-Oct	10-Oct	2
CLN120	26-Jul	28-Jul	11-Oct	11-Oct	12
CLN90	26-Jul	24-Sep	11-Oct	11-Oct	10
CLN40	26-Jul	01-Oct	04-Oct	06-Oct	3

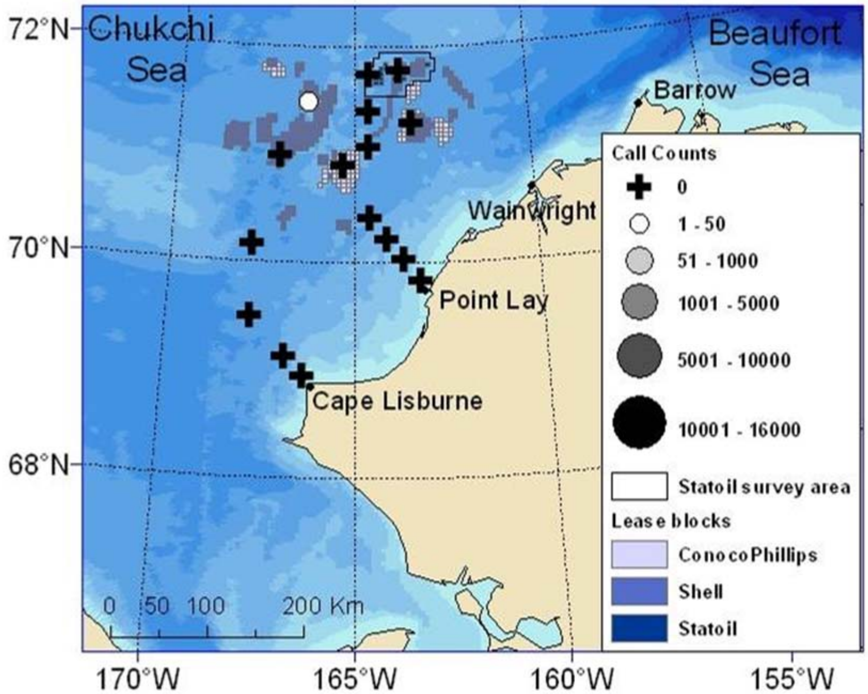


Figure 44. Bowhead whale call count estimates in the Chukchi Sea for 25-31 Jul 2010 based on manual analysis and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.

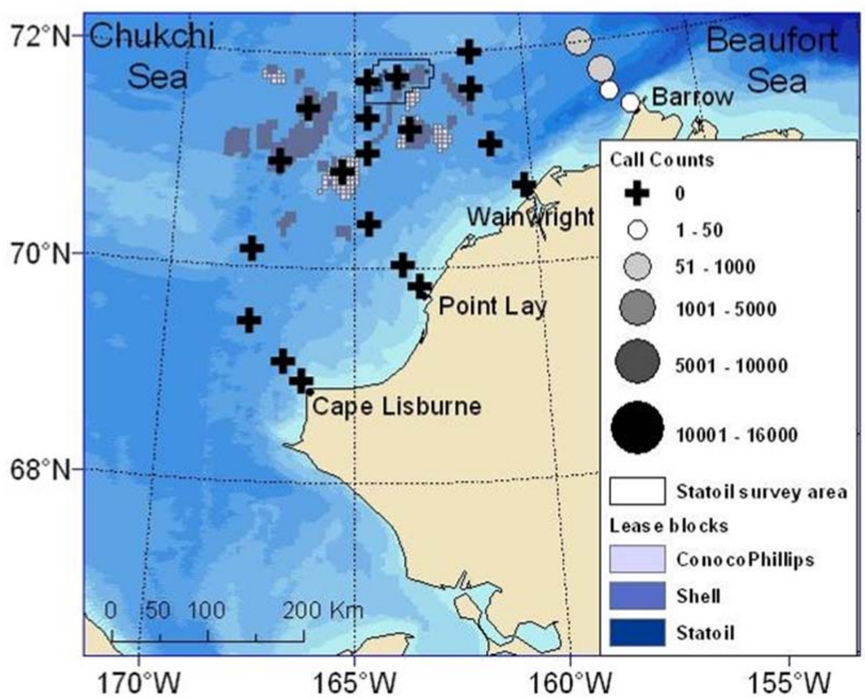


Figure 45. Bowhead whale call count estimates in the Chukchi Sea for 15-31 Aug 2010 based on manual analysis and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.

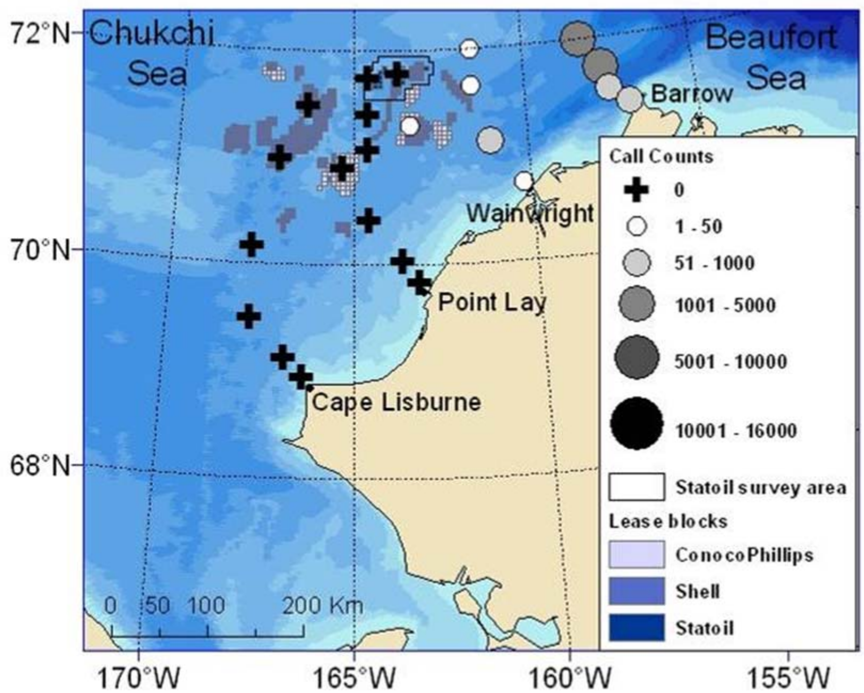


Figure 46. Bowhead whale call count estimates in the Chukchi Sea for 1-15 Sep 2010 based on manual analysis and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.

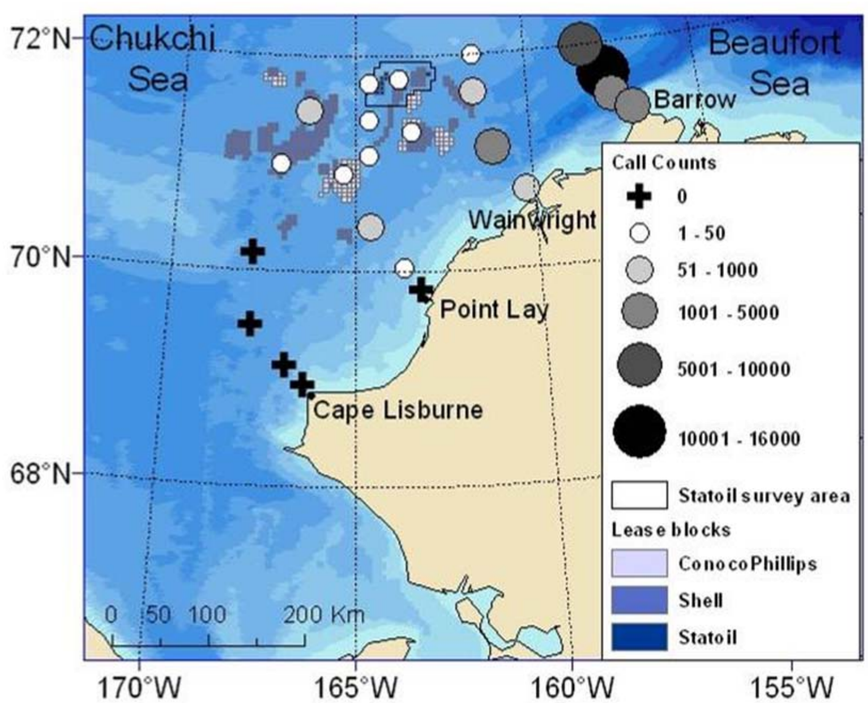


Figure 47. Bowhead whale call count estimates in the Chukchi Sea for 16–30 Sep 2010 based on manual analysis and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.

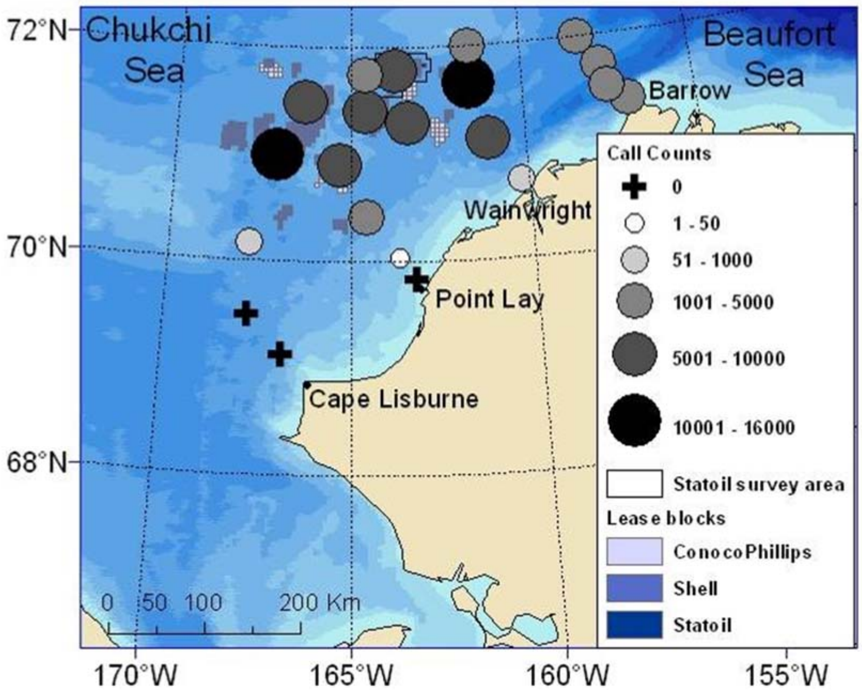


Figure 48. Bowhead whale call count estimates in the Chukchi Sea for 1–15 Oct 2010 based on manual analysis and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.

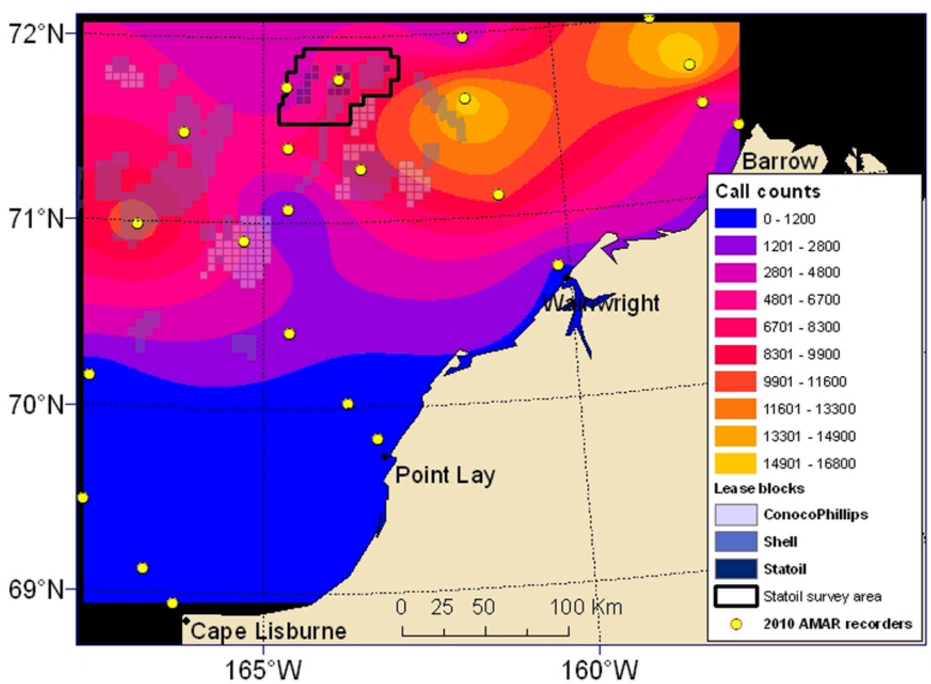


Figure 49. Interpolated bowhead call count surface plot for 25 Jul to 15 Oct based on the sum of call counts at all 2010 summer recorders in the Chukchi Sea.

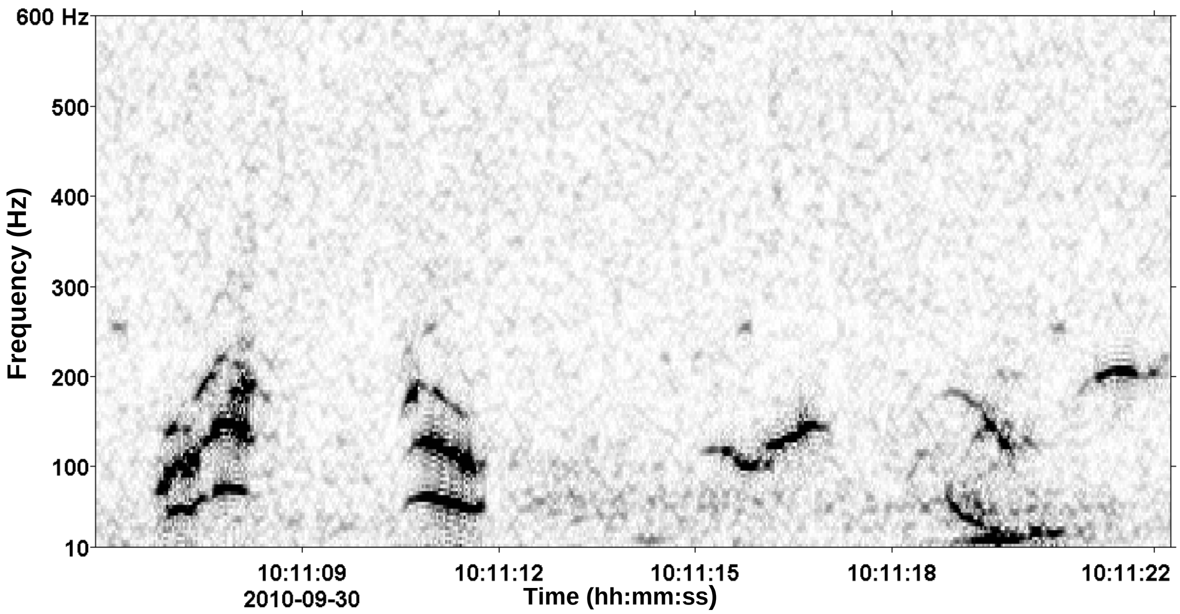


Figure 50. Spectrogram of bowhead moans at summer 2010 Station B50, 30 Sep 2010 (2048-pt FFT, 4096 real pts, 1024-pt advance, Hamming window).

3.3.3.2. Walrus

Winter 2009–2010 Program

In the fall and early winter, walrus calls were detected at Station W50 on 18 Nov 2009, at PLN40 on 23 Dec 2009 and 22 Jan 2010, and at CL50 on 16 Dec 2009 (Figure 51, Table 13). These detections indicate that some individuals remain in the north-eastern Chukchi Sea considerably longer than most of the population, which typically leaves the area by mid-October. The 22 Jan detection is the latest detection that has been recorded in the Chukchi Sea since the beginning of the winter acoustics program.

In spring 2010, walrus calls were recorded at all stations that were still operational in June. Walrus were first detected at CL50 on 12 Jun and between 20 and 22 Jun at all the other stations except B05, which recorded its first detection on 17 Jul (Figure 51, Table 13). Once initially detected, walrus were present until the end of the recording periods at all stations. After mid-June, the highest call counts were always recorded at WN40, and a distribution shift toward that station is observed, with progressively less detections to the southwest (Figure 53 to Figure 56).

Most of the calls detected consisted of a variety of grunt-like sounds; knocks and bell sounds were present intermittently (Figure 57; Stirling *et al.* 1983, 1987, Schusterman and Reichmuth 2008).

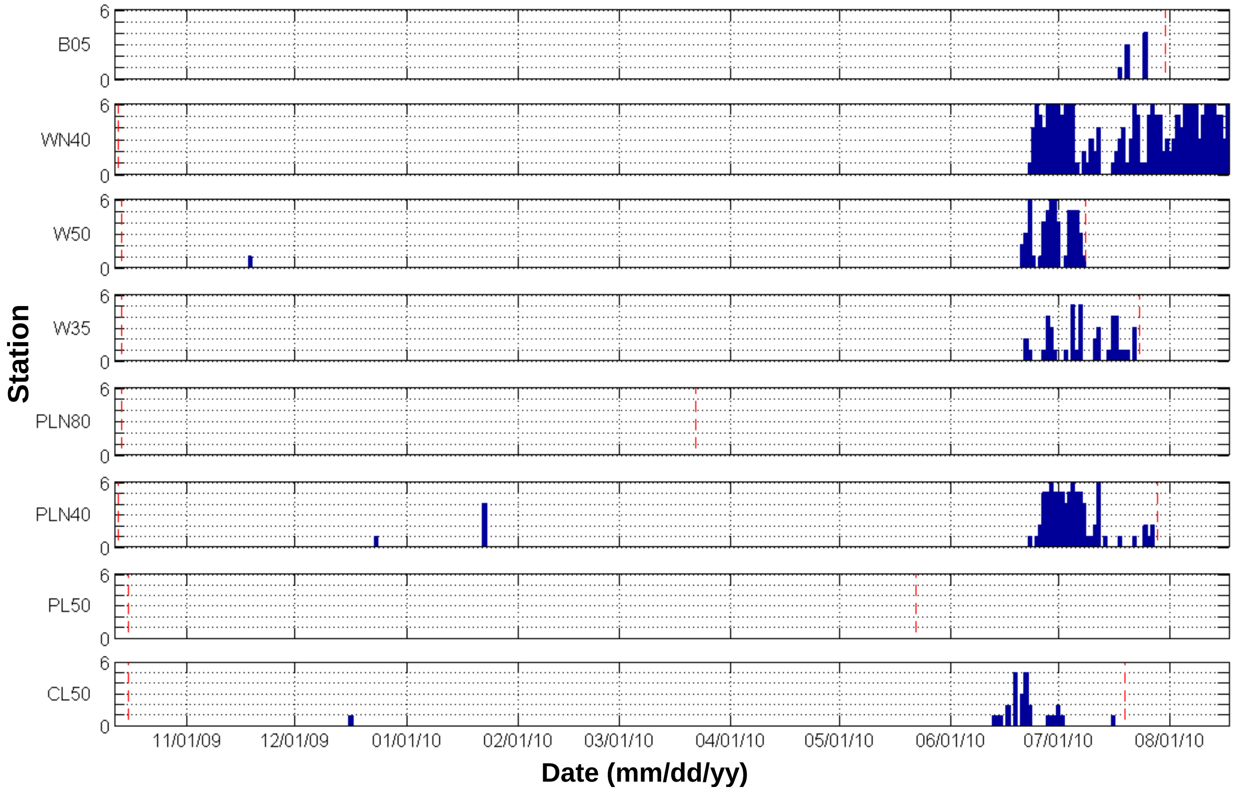


Figure 51. Daily number of sound files with walrus detections based on the manual analysis of 5% of acoustic data recorded in the Chukchi Sea from mid-October 2009 through early August 2010. Red dashed lines indicate recording start and end.

Table 13. List of the first and last dates of walrus detections, and the total number of days on which a walrus calls were detected at all winter 2009–2010 recording stations.

WALRUS								
Station	Record start	Fall			Spring			Record end
		First detection	Last detection	Detection days	First detection	Last detection	Detection days	
B05	12-Oct			0	17-Jul	24-Jul	3	29-Jul
WN40	13-Oct			0	22-Jun	17-Aug	53	17-Aug
W50	14-Oct	18-Nov	18-Nov	1	20-Jun	7-Jul	16	7-Jul
W35	14-Oct			0	21-Jun	21-Jul	19	21-Jul
PLN80	14-Oct			0			0	21-Mar
PLN40	13-Oct	23-Dec	22-Jan	2	22-Jun	26-Jul	25	26-Jul
PL50	16-Oct			0			0	21-May
CL50	16-Oct	16-Dec	16-Dec	1	12-Jun	15-Jul	14	18-Jul

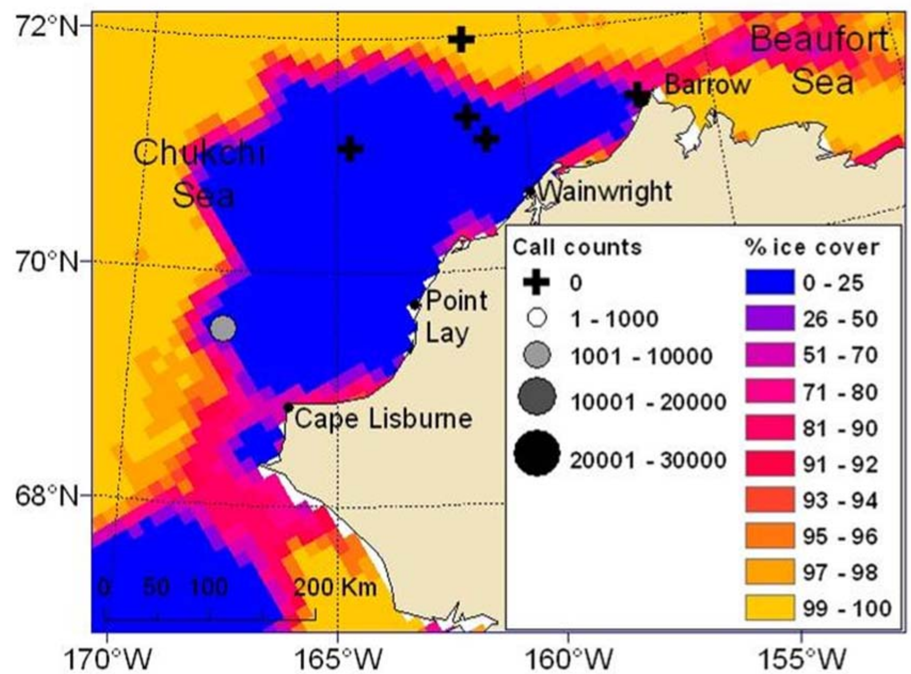


Figure 52. Walrus call count estimates in the Chukchi Sea for 1-15 Jun 2010 based on manual and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are from 7 Jun 2010. Note that the scale emphasizes heavy ice concentration.

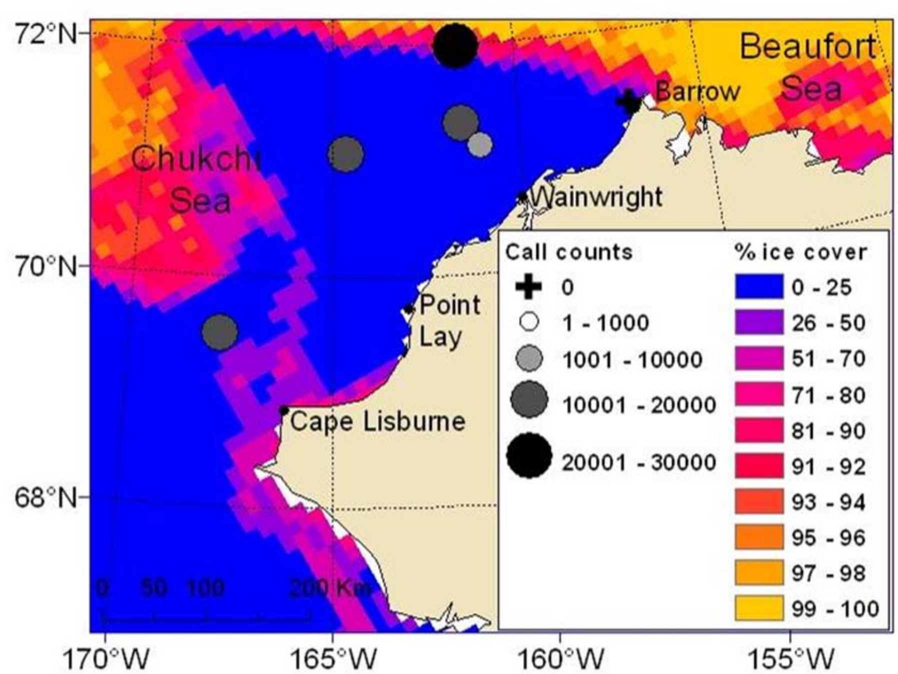


Figure 53. Walrus call count estimates in the Chukchi Sea for 16-30 Jun 2010 based on manual and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 22 Jun 2010. Note that the scale emphasizes heavy ice concentration.

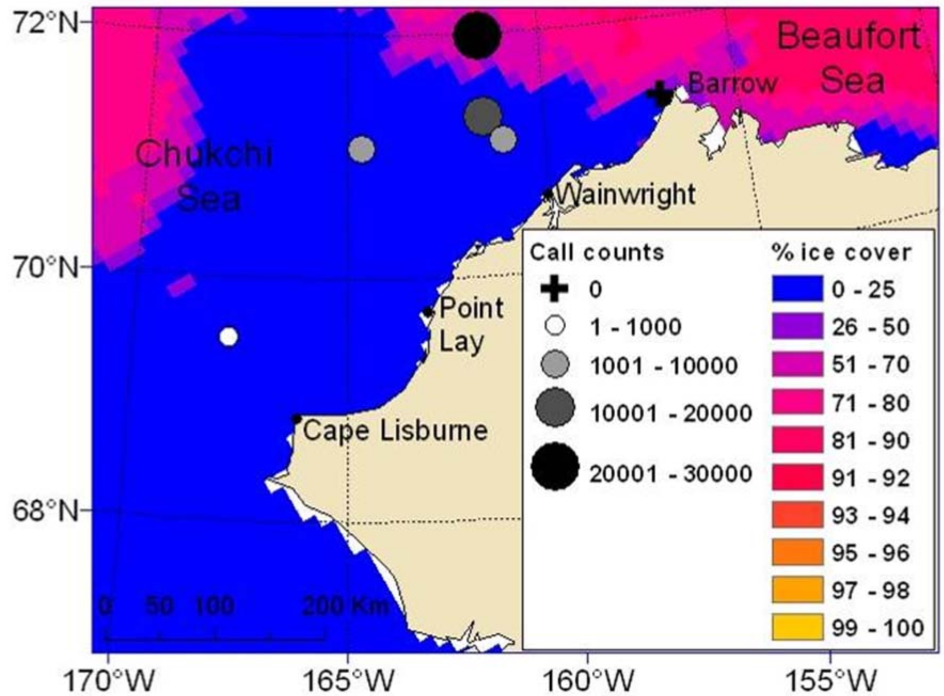


Figure 54. Walrus call count estimates in the Chukchi Sea for 1-15 Jul 2010 based on manual and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 7 Jul 2010. Note that the scale emphasizes heavy ice concentration.

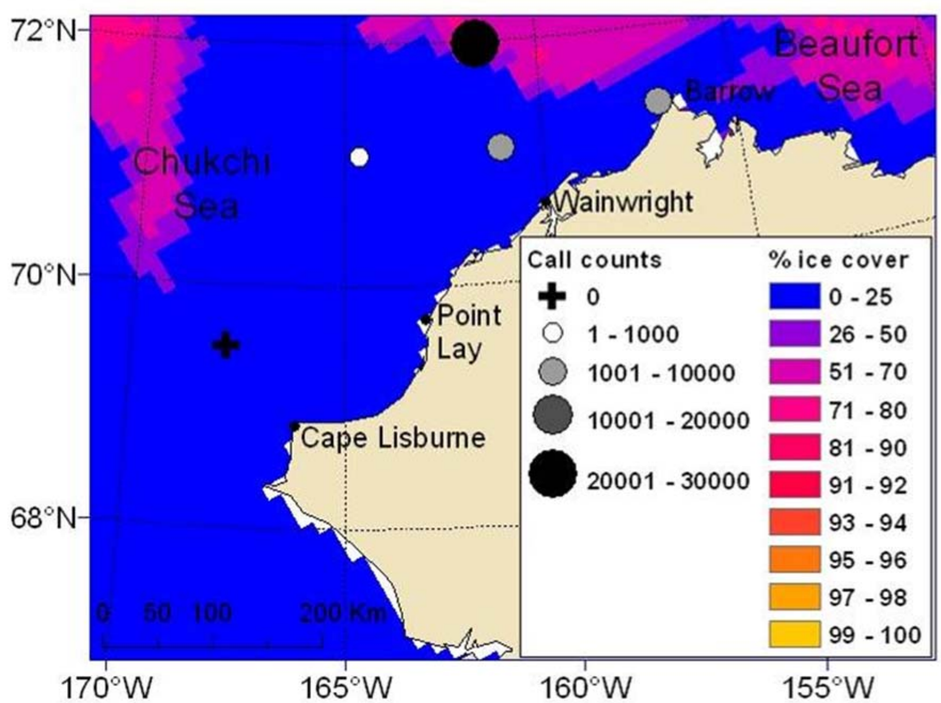


Figure 55. Walrus call count estimates in the Chukchi Sea for 16-31 Jul 2010 based on manual and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 23 Jul 2010. Note that the scale emphasizes heavy ice concentration.

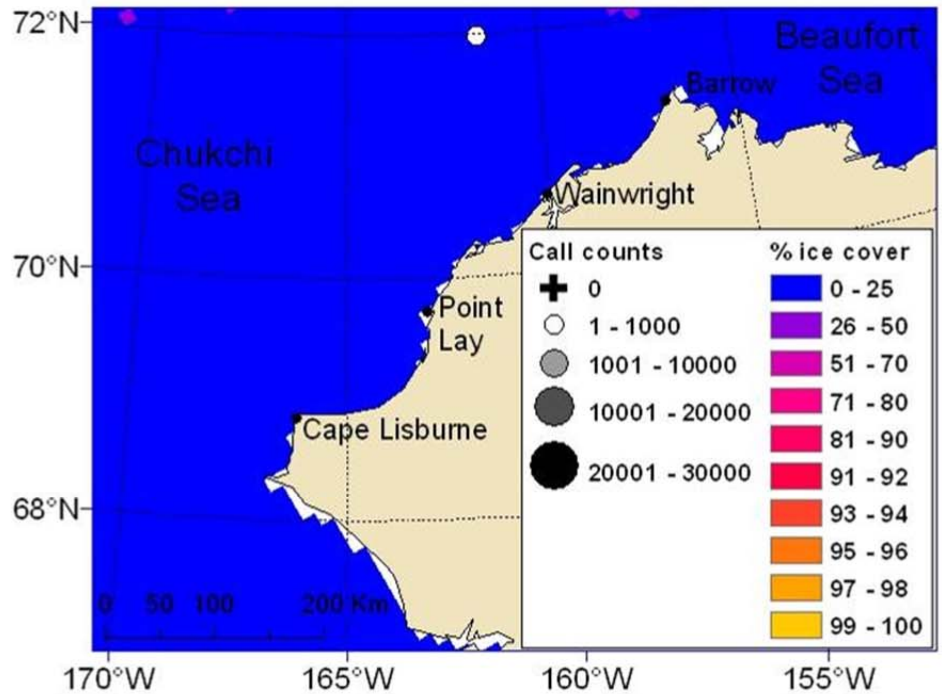


Figure 56. Walrus call count estimates in the Chukchi Sea for 1–17 Aug 2010 based on manual and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 7 Aug 2010. Note that the scale emphasizes heavy ice concentration.

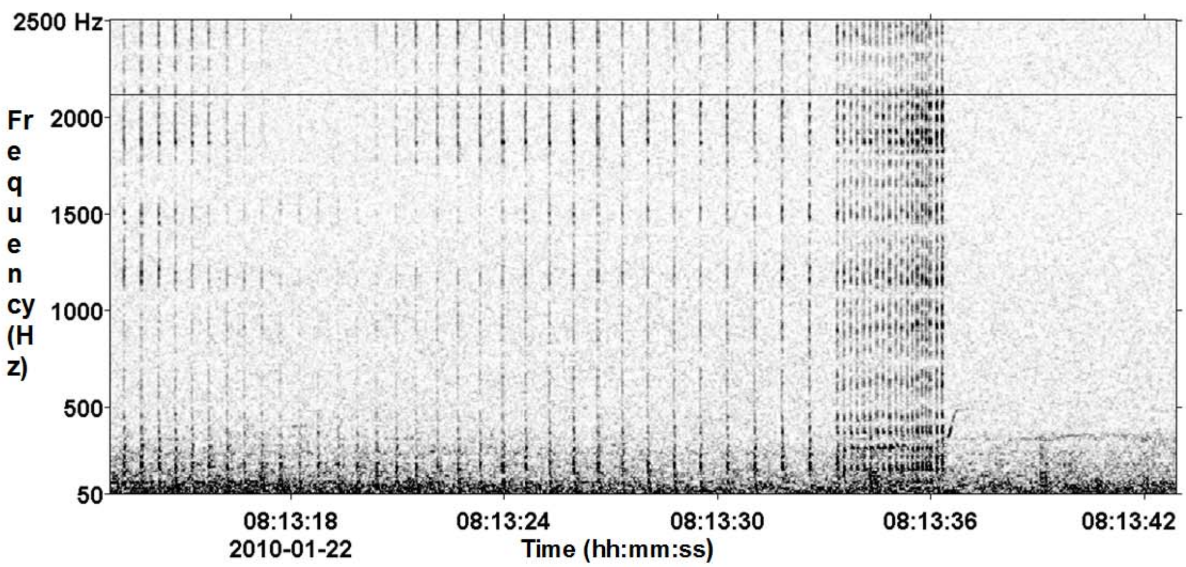


Figure 57. Time series (top) and spectrogram (bottom) of walrus knocks and bell sound recorded at winter 2009–2010 Station PLN40, 22 Jan 2010 (2048-pt FFT, 2048 real pts, 512-pt advance, Hamming window).

Summer 2010 Program

Walrus were detected acoustically at all stations. The first detection occurred on 26 Jul at CLN90 and the last one occurred on 11 Oct at SO01 and CLN120. Excluding PL35, which stopped prematurely, walrus were detected on between 14 (B05 and CLN40) and 66 (WN20) days. Walrus calls were detected on an average of 31 days per station with a mean recording duration of 71 days. Stations with notably high numbers of detection days included PL05 (59), BG01 (45), CL05 (41) and WN40 (40), though the latter two had shorter recording periods (Figure 58, Table 14). There were no days without at least two stations with detections throughout the entire recording period. The period of most widespread distribution was 21 Aug to 19 Sep with a daily average of 16 (range: 10–23) stations with detections (Figure 58, Table 14).

From start of recording until mid-August, walrus were concentrated primarily offshore, presumably remaining with the receding ice edge (Figure 59, Figure 60). After mid-August, detections became more evenly distributed across the stations, and walrus were detected continuously and at a high rate at PL05, which is located near a walrus haul-out. Call counts decreased after mid-September (Figure 63, Figure 64), likely due to the onset of migration toward Chukotka and the Bering Strait.

The area off Wainwright experienced a large number of detections from mid-August until late September (Figure 59 to Figure 63) which confirms walrus' affinity for this area (Martin *et al* 2008, Hannay *et al* 2009, Delarue *et al* 2010). Station PL05 yielded the highest automatically detected call counts (and the largest number of manual annotations) starting around 20 Aug and continuing until the recorder's retrieval (Figure 61 to Figure 64). This can be explained by the presence of a walrus haul out near Point Lay and foraging-associated movements of walrus in and out of this area. The temporal pattern of detections observed at PL20 and PL50 was comparable to PL05 although the daily number of files with detections decreased with increasing distance from shore. CL05 also had high call counts from 23 Aug until 12 Sep, after which detections continued although at a lower rate. These detections could suggest the presence of a haul-out near Cape Lisburne and/or migration of walrus out of the study area along the coast. Walrus' affinity for the Wainwright / Hanna Shoal area, the significance of the haul-out near Point Lay and the likely existence of a coastal migration corridor are apparent in the total call count distribution map of Figure 65.

A simultaneous gap in acoustic detections between 1 and 8 Sep was noted at all the offshore stations (bottom eight stations in Figure 58). This did not correspond to any obvious inshore movements as detected in 2007 (Martin *et al.* 2008). However, a review of tagging data collected by the U.S. Geological Survey (available online) suggests that walrus were concentrated near Hannah Shoal until approximately 1 Sep before dispersing widely, presumably due to the disappearance of sea ice.

The manually detected walrus calls included various grunts as well as knocks and bell calls (Stirling *et al.* 1983, 1987, Schusterman and Reichmuth 2008). The automated detection method specifically targeted grunts, as a result of their prevalence and longer detection range (JASCO, unpublished data; Figure 66).

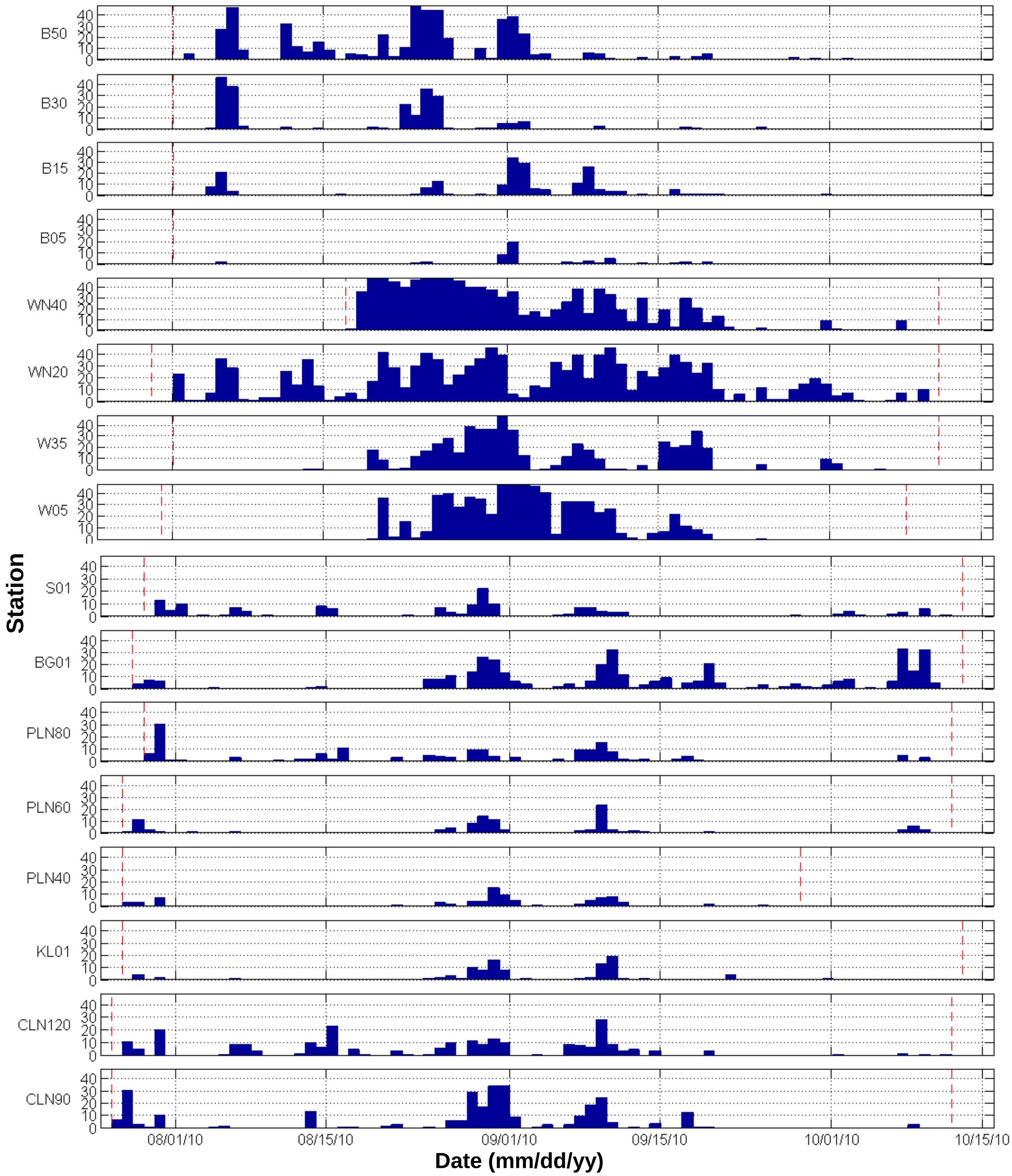
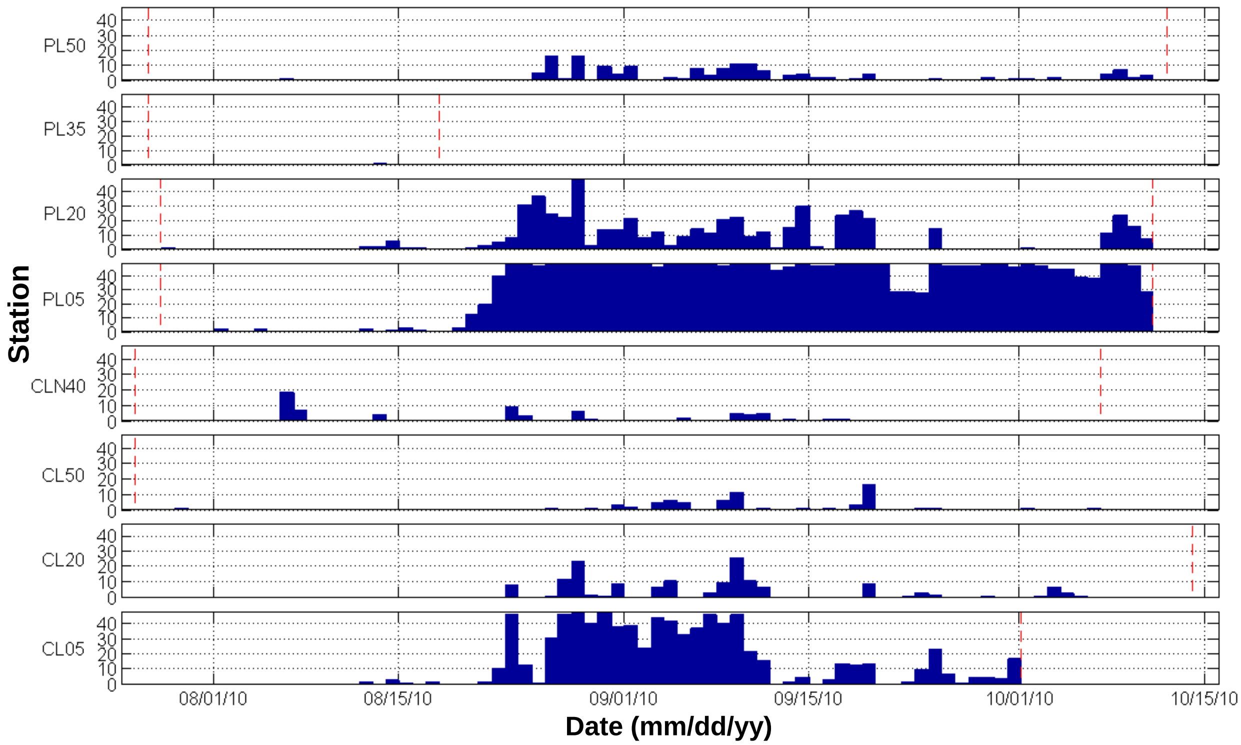


Figure 58. Daily number of sound files with walrus detections based on the manual analysis of 5% of acoustic data recorded in the Chukchi Sea, late July to mid-October 2010. Red dashed lines indicate recording start and end dates.



(Con't) Figure 58. Daily number of sound files with walrus detections based on the manual analysis of 5% of acoustic data recorded in the Chukchi Sea, late July to mid-October 2010. Red dashed lines indicate recording start and end dates.

Table 14. List of first and last dates with walrus call detections, and the total number of detection days on each summer 2010 recording station. Data are presented only for the stations where walrus sounds were detected.

WALRUS					
Station	Record Start	First detection	Last detection	Record end	Detection days
B50	01-Aug	02-Aug	02-Oct	16-Oct	36
B30	01-Aug	04-Aug	24-Sep	16-Oct	22
B15	01-Aug	04-Aug	30-Sep	16-Oct	26
B05	01-Aug	05-Aug	19-Sep	16-Oct	14
WN40	17-Aug	17-Aug	07-Oct	10-Oct	40
WN20	30-Jul	01-Aug	09-Oct	10-Oct	66
W35	01-Aug	13-Aug	05-Oct	10-Oct	35
W05	31-Jul	19-Aug	24-Sep	07-Oct	32
S01	29-Jul	30-Jul	11-Oct	12-Oct	32
BG01	28-Jul	28-Jul	10-Oct	12-Oct	45
PLN80	29-Jul	29-Jul	09-Oct	11-Oct	32
PLN60	27-Jul	27-Jul	09-Oct	11-Oct	23
PLN40	27-Jul	27-Jul	24-Sep	27-Sep	19
KL01	27-Jul	28-Jul	30-Sep	12-Oct	20
PL50	27-Jul	06-Aug	10-Oct	11-Oct	31
PL35	27-Jul	13-Aug	13-Aug	17-Aug	1
PL20	28-Jul	28-Jul	10-Oct	10-Oct	42
PL05	28-Jul	01-Aug	10-Oct	10-Oct	59
CLN120	26-Jul	27-Jul	11-Oct	11-Oct	36
CLN90	26-Jul	26-Jul	08-Oct	11-Oct	33
CLN40	26-Jul	06-Aug	17-Sep	06-Oct	14
CL50	26-Jul	29-Jul	06-Oct	15-Oct	19
CL20	25-Jul	23-Aug	05-Oct	13-Oct	23
CL05	25-Jul	12-Aug	30-Sep	30-Sep	41

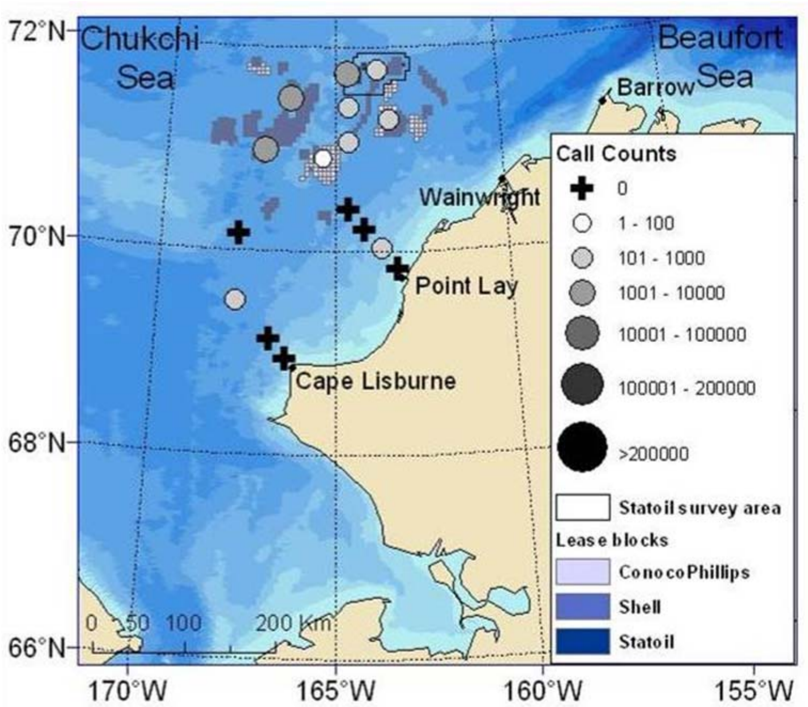


Figure 59. Walrus call count estimates in the Chukchi Sea for 25–31 Jul 2010 based on manual and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.

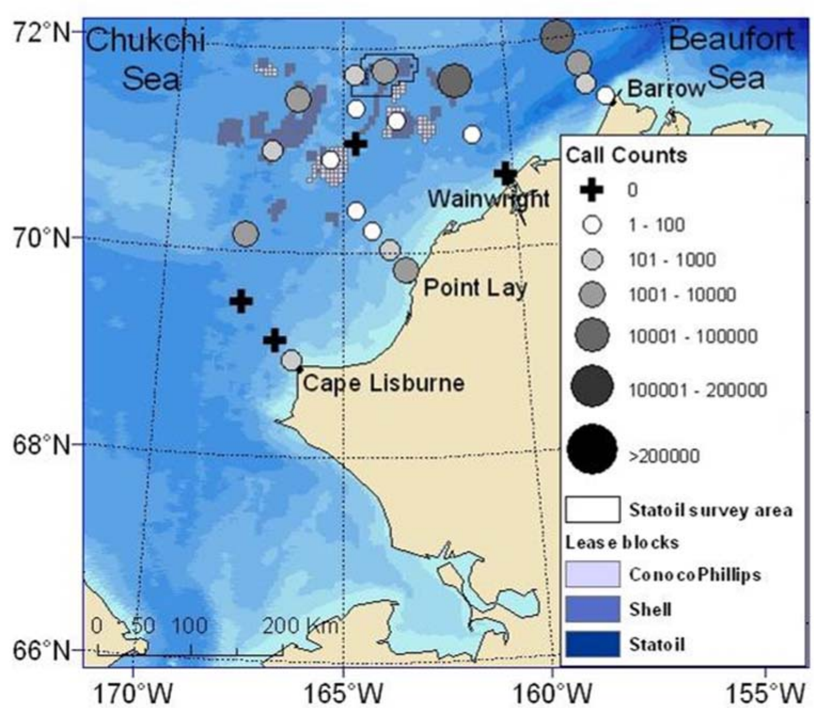


Figure 60. Walrus call count estimates in the Chukchi Sea for 1–15 Aug 2010 based on manual and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.

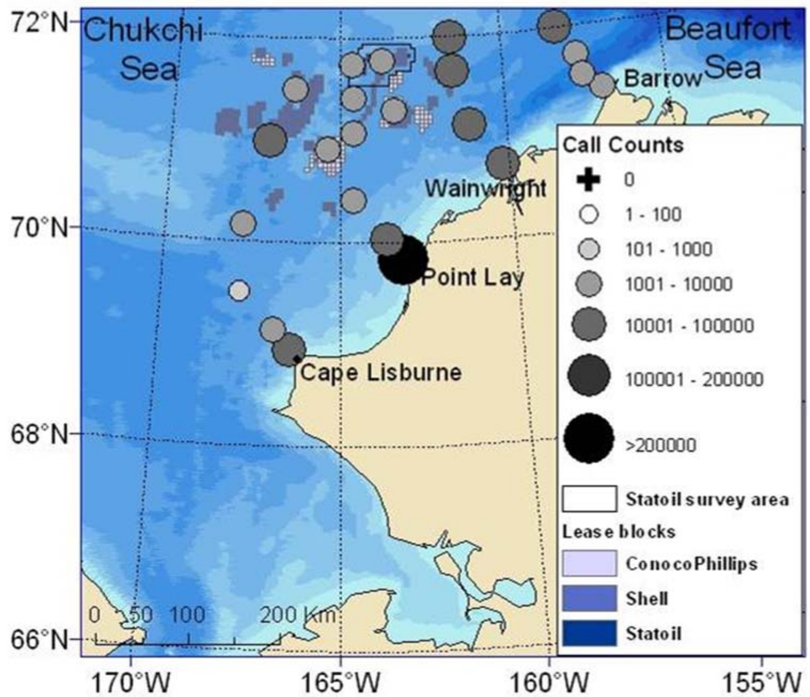


Figure 61. Walrus call count estimates in the Chukchi Sea for 16–31 Aug 2010 based on manual and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.

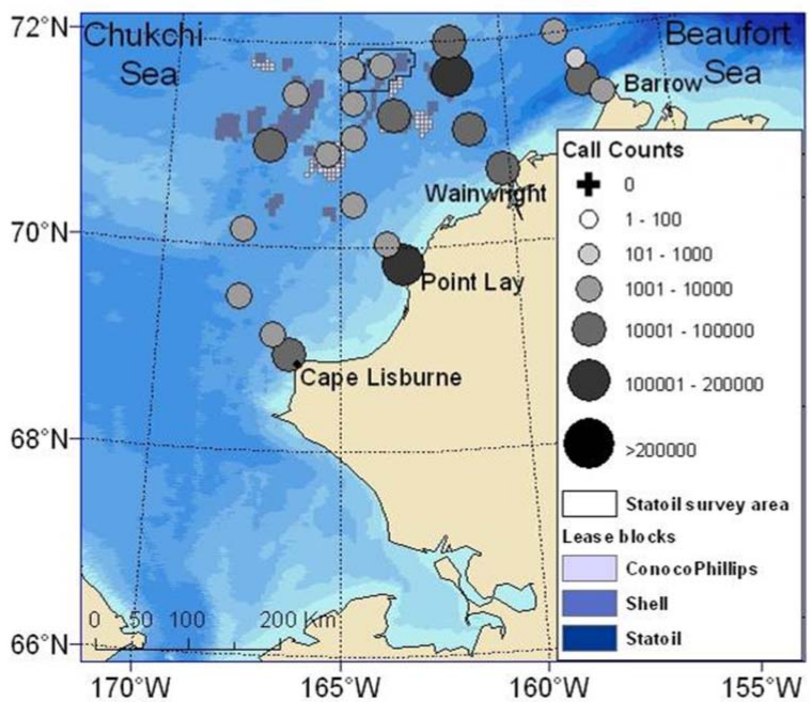


Figure 62. Walrus call count estimates in the Chukchi Sea for 1–15 Sep 2010 based on manual and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.

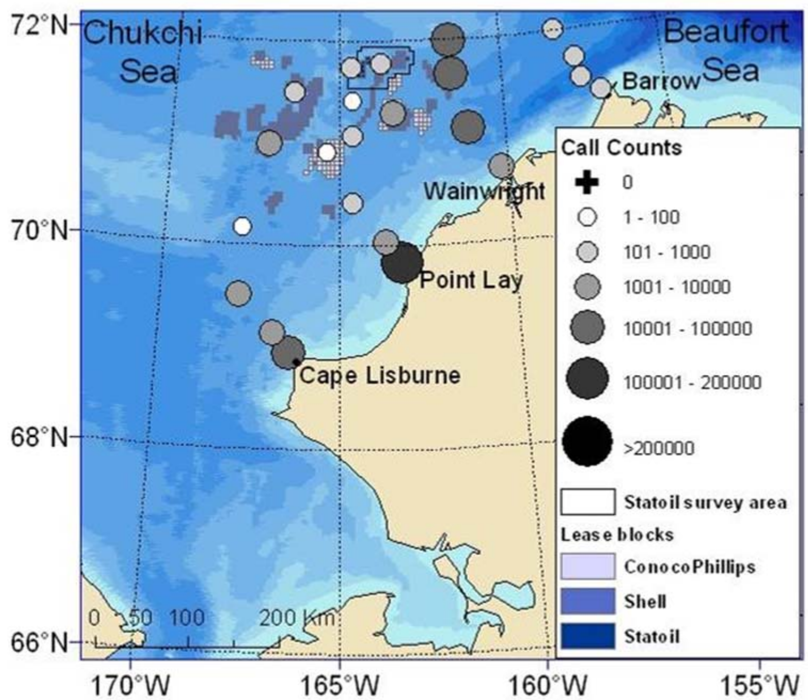


Figure 63. Walrus call count estimates in the Chukchi Sea for 16–30 Sep 2010 based on manual and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.

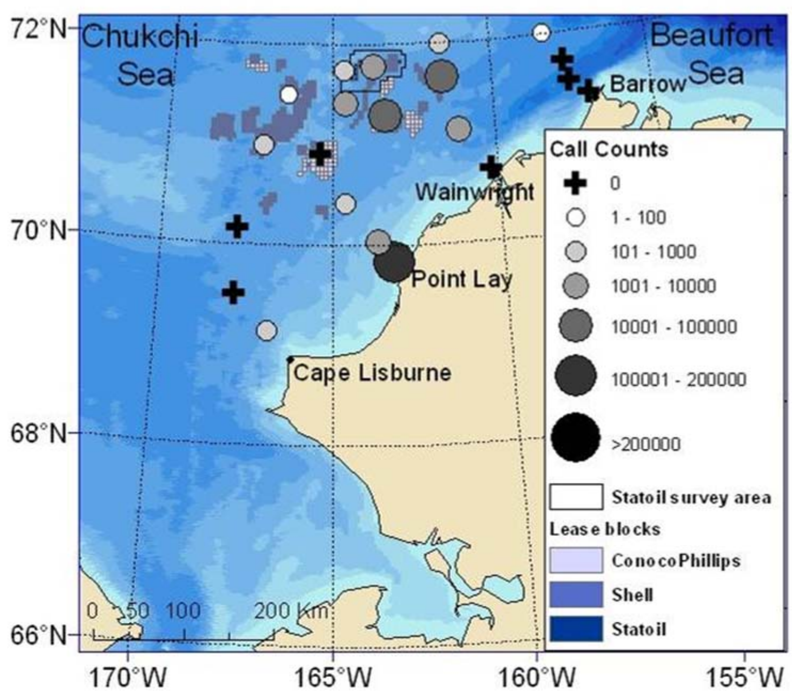


Figure 64. Walrus call count estimates in the Chukchi Sea for 1–15 Oct 2010 based on manual and automated call detections at the summer 2010 recording stations. Most recorders were retrieved between 10 and 12 Oct. Shades of blue represent bathymetry.

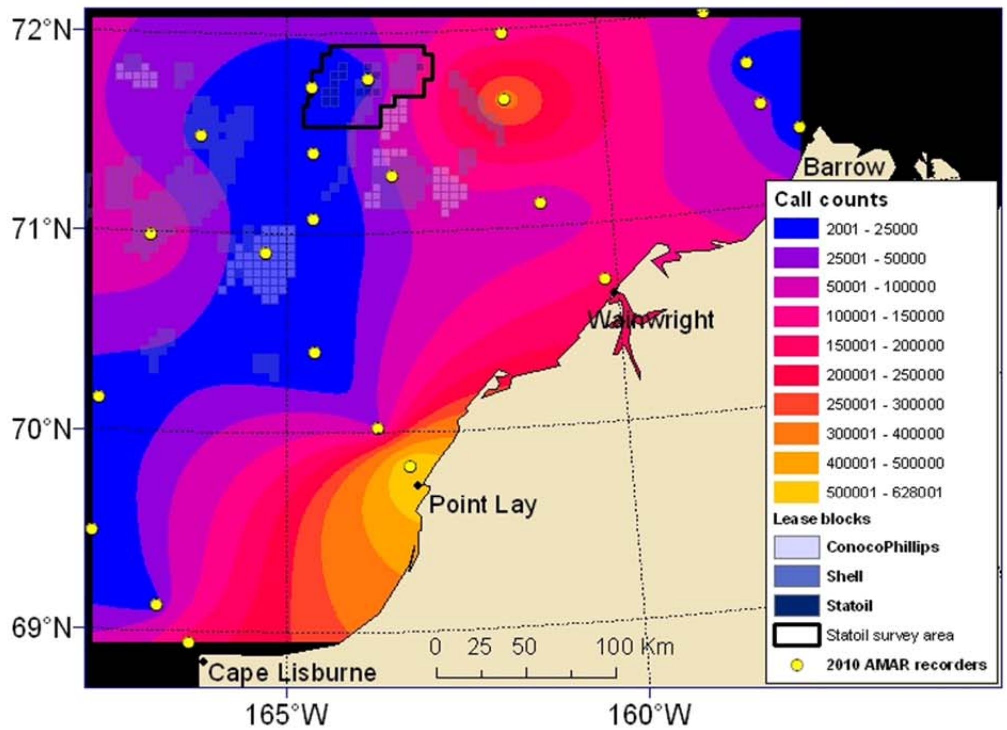


Figure 65. Interpolated walrus call count surface plot based on the sum of call counts at all 2010 summer recorders in the Chukchi Sea from 25 Jul to 15 Oct.

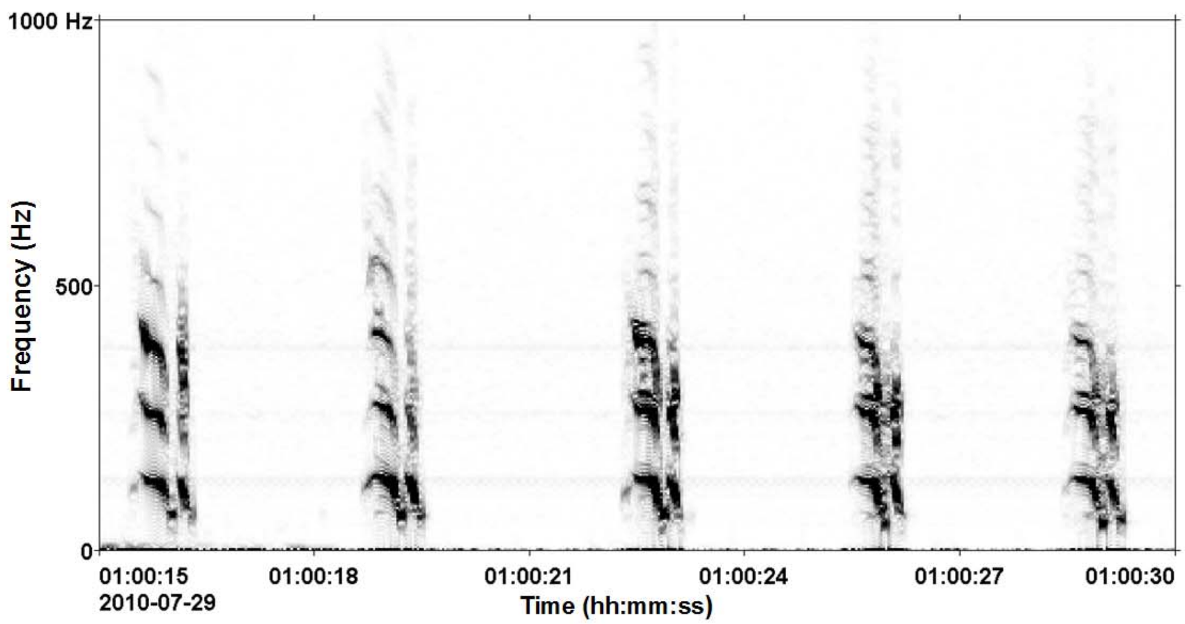


Figure 66. Spectrogram of walrus grunts recorded at summer 2010 Station CL50, 29 Aug 2010 (2048-pt FFT, 4096 real pts, 512-pt advance, Hamming window).

3.3.3.3. Beluga Whales

Winter 2009–2010 Program

In the fall 2009, belugas were detected at all stations except PLN40 and PL50. Detections started on 12 Oct at B05 and ended on 24 Nov at CL50 (Figure 67, Table 15). The timing of these detections suggests that the detected belugas belonged to the eastern Chukchi Sea (ECS) stock (Suydam *et al.* 2005; Delarue *et al.* 2011). Eastern Beaufort Sea (EBS) belugas usually migrate past Barrow in late August-early September and travel west from there, thus remaining out of the instrumented area (Richard *et al.* 2001).

The B05 detections occurred in three clusters separated by 3–4 days with no detections (Figure 67). At the other stations, detections were extremely sporadic. Detection days numbered from one to four, but B05 had 20. This suggests that after passing Point Barrow, ECS belugas may preferentially travel within 35–50 miles from shore, thus remaining largely out of range of our recorders. However, there were some detections west of Barrow in late October and early November (Figure 68 and Figure 69) indicating that some individuals travel through the study area. The only late November detection occurred at CL50 (Figure 70).

In the spring, belugas were detected at all operational recorders. Detections started on 1 Apr at CL50 and ended on 28 Jul at B05 (Figure 67, Figure 71 to Figure 78, Table 15). Detections typically started later at stations further to the northeast, with the notable exceptions of B05, where the first beluga calls were detected on 2 Apr. This suggests that some animals went undetected on their way from Cape Lisburne to Barrow.

Although the detections started as early as 2 Apr at B05, belugas were not detected consistently until 29 Apr (only 8% of the files with detections occurred prior to 29 Apr). 84% of all files with detections occurred between 29 Apr and 11 Jun. At B05, this spring migration peak was followed by a 22-day gap in detections, which resumed on 4 Jul and continued until 28 Jul. This gap is attributed to the segregation in the migratory schedules of the two beluga stocks (Eastern Chukchi Stock, ECS and Eastern Beaufort Stock, EBS) known to migrate through the Chukchi Sea. These stocks were initially distinguished based on their summer aggregation sites. EBS belugas aggregate in early summer in the Mackenzie River delta (adjacent to the Beaufort), while ECS belugas aggregate in early summer in Kasegaluk Lagoon (adjacent to the Chukchi). Both stocks tend to aggregate in late June and early July. Due to the much greater distance separating the Bering Sea wintering grounds and summer aggregation areas, and the similar arrival time to these aggregation sites, EBS belugas are the most likely candidate for the early spring detections, in particular at B05. The detections starting on 4 Jul are presumably from ECS animals heading into Barrow canyon and further north, as shown by previous satellite tagging experiments (Suydam *et al.* 2005).

At CL50 a similar 2-week gap in detections between the first dense detection period (1 Apr to 10 May) and the next detection period (24 May to June 17) was observed. The resumption of sporadic detections during this second period can also be attributed to the arrival of ECS belugas in the Chukchi Sea. The fact that the second wave of migrating belugas (ECS animals) yielded fewer detections, is arguably the result of a smaller stock size (ECS: n=3,700; EBS: n=30,000 animals) and the fact that animals from that stock may migrate preferentially inshore as open-water becomes available, thus putting them out of range of the recorders.

As seen in previous years, the first part of the spring migration took part in very heavy ice conditions (Figure 71 to Figure 73). However, belugas can navigate in narrow leads which cannot be identified at the resolution of the ice charts plotted here (12.5 km × 12.5 km).

Beluga calls detected included a variety of whistles, buzzes, chirps, and other HF calls previously described for that species (Figure 79; Sjare and Smith 1986, Karlsen *et al.* 2002, Belikov and Bel'kovich 2006, 2008).

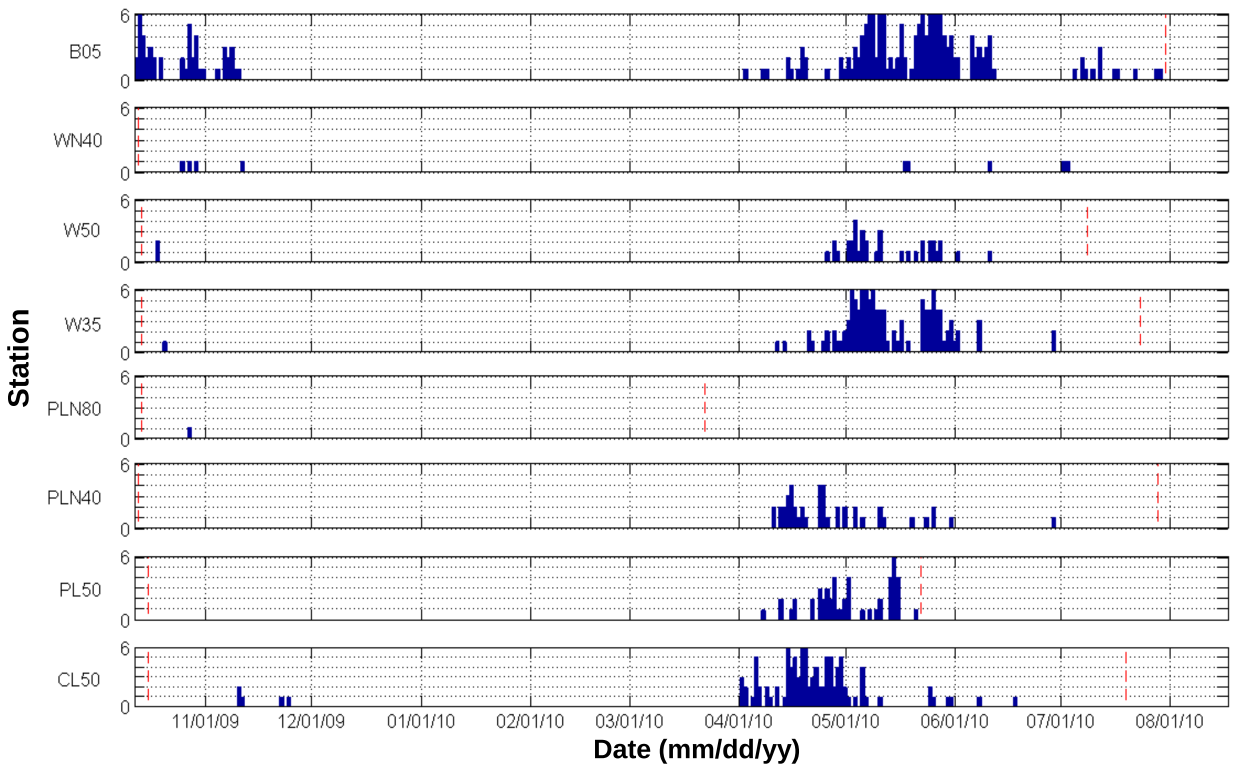


Figure 67. Daily number of sound files with beluga detections based on the manual analysis of 5% of acoustic data recorded in the Chukchi Sea from mid-October 2009 through early August 2010. Red dashed lines indicate recording start and end dates.

Table 15. List of the first and last dates of beluga call detections, and the total number of detection days of beluga calls at all winter 2009–2010 recording stations.

Beluga Whale								
		Fall 2009			Spring 2010			
Station	Record start	First detection	Last detection	Detection days	First detection	Last detection	Detection days	Record end
B05	12-Oct	12-Oct	10-Nov	20	2-Apr	28-Jul	59	29-Jul
WN40	13-Oct	25-Oct	11-Nov	4	17-May	2-Jul	5	17-Aug
W50	14-Oct	18-Oct	18-Oct	1	25-Apr	10-Jun	21	7-Jul
W35	14-Oct	20-Oct	20-Oct	1	11-Apr	28-Jun	39	21-Jul
PLN80	14-Oct	27-Oct	21-Nov	2			0	21-Mar
PLN40	13-Oct			0	10-Apr	28-Jun	23	26-Jul
PL50	16-Oct			0	7-Apr	20-May	22	21-May
CL50	16-Oct	10-Nov	24-Nov	4	1-Apr	17-Jun	37	18-Jul

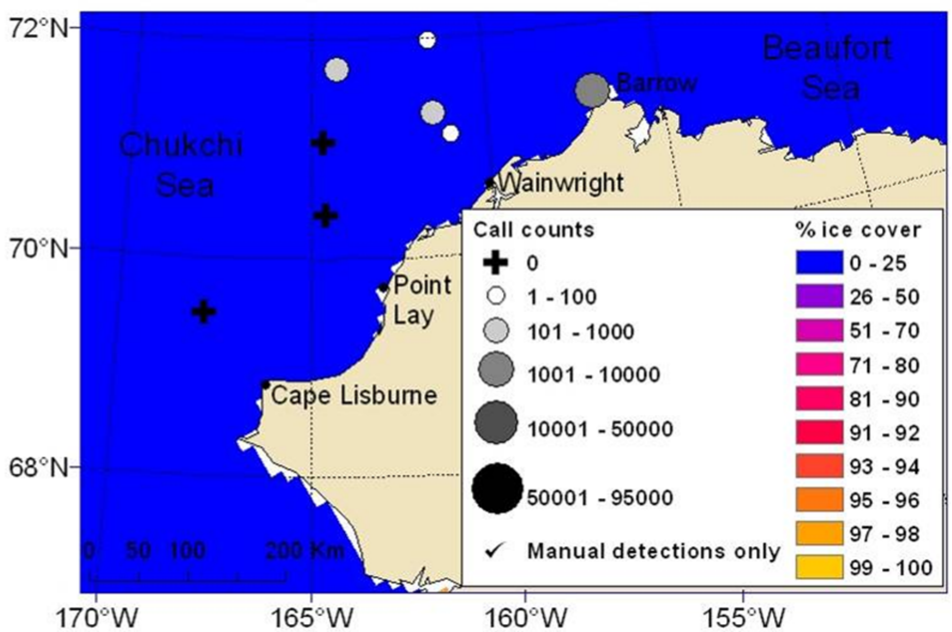


Figure 68. Beluga whale call count estimates in the Chukchi Sea for 12–31 Oct 2009 based on manual and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 23 Oct 2009. Note that the scale emphasizes heavy ice concentration.

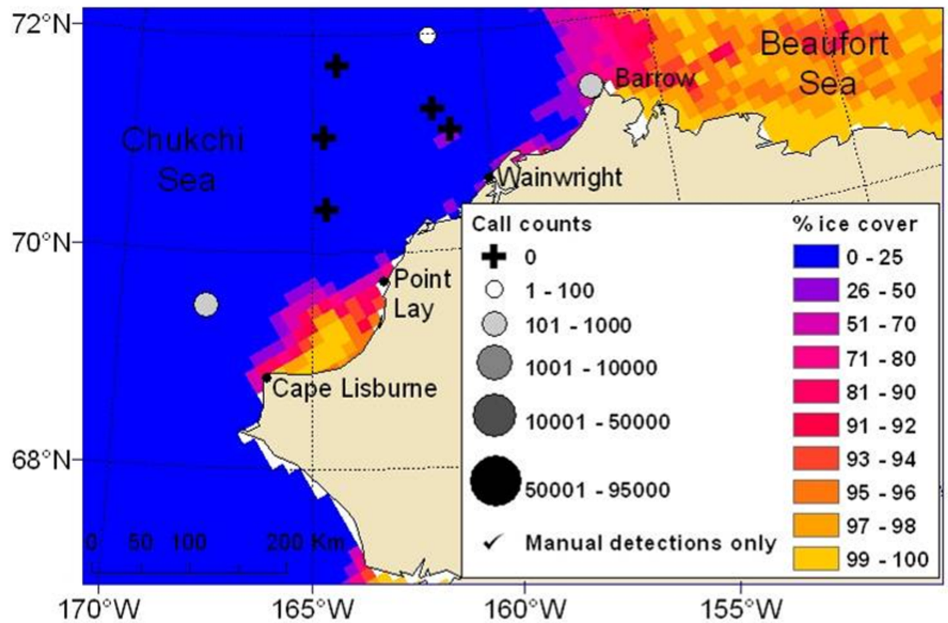


Figure 69. Beluga whale call count estimates in the Chukchi Sea for 1–15 Nov 2009 based on manual and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 7 Nov 2009. Note that the scale emphasizes heavy ice concentration.

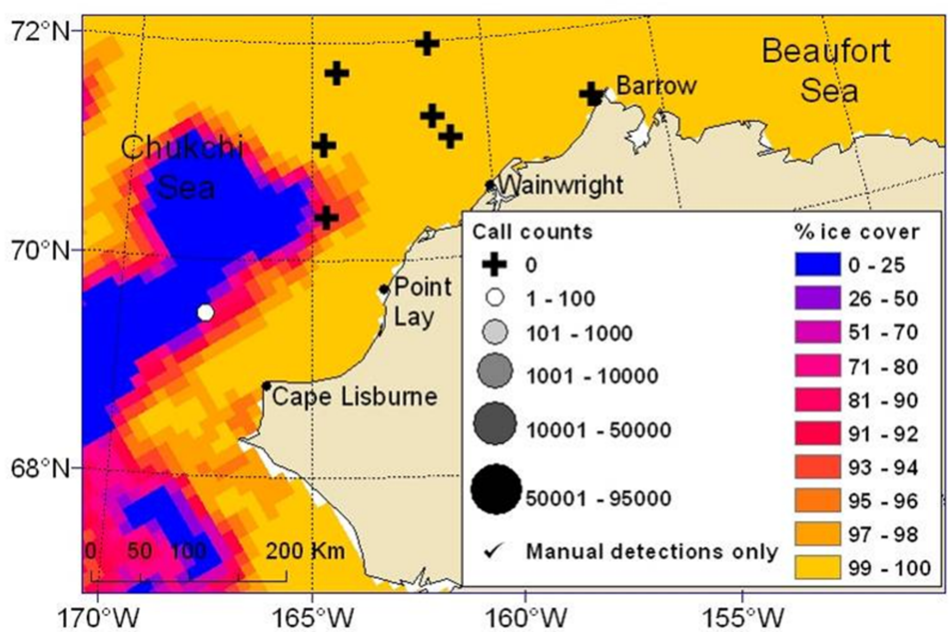


Figure 70. Beluga whale call count estimates in the Chukchi Sea for 16–30 Nov 2009 based on manual and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 23 Nov 2009. Note that the scale emphasizes heavy ice concentration.

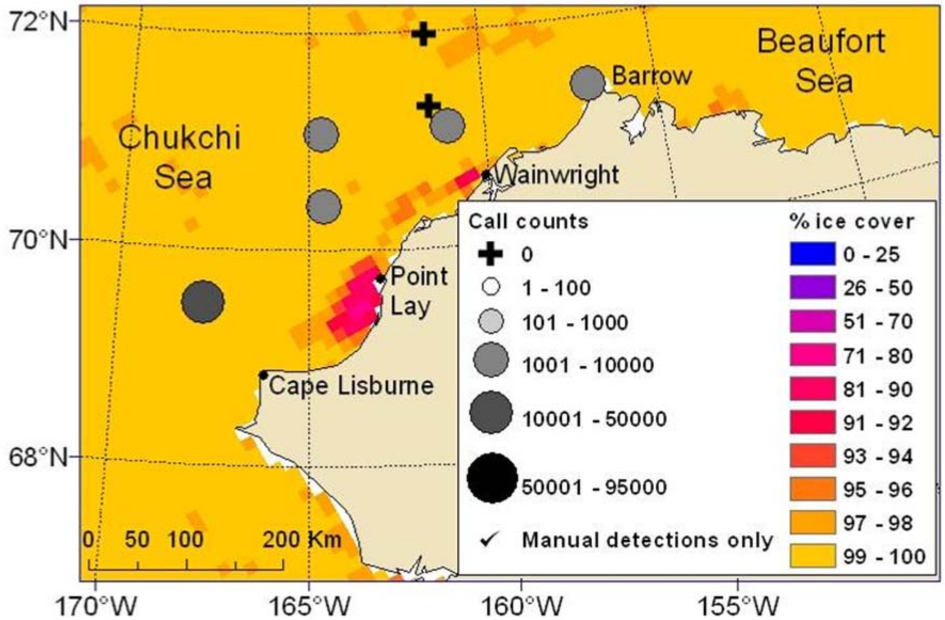


Figure 71. Beluga whale call count estimates in the Chukchi Sea for 1–15 Apr 2010 based on manual and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 7 Apr 2010. Note that the scale emphasizes heavy ice concentration.

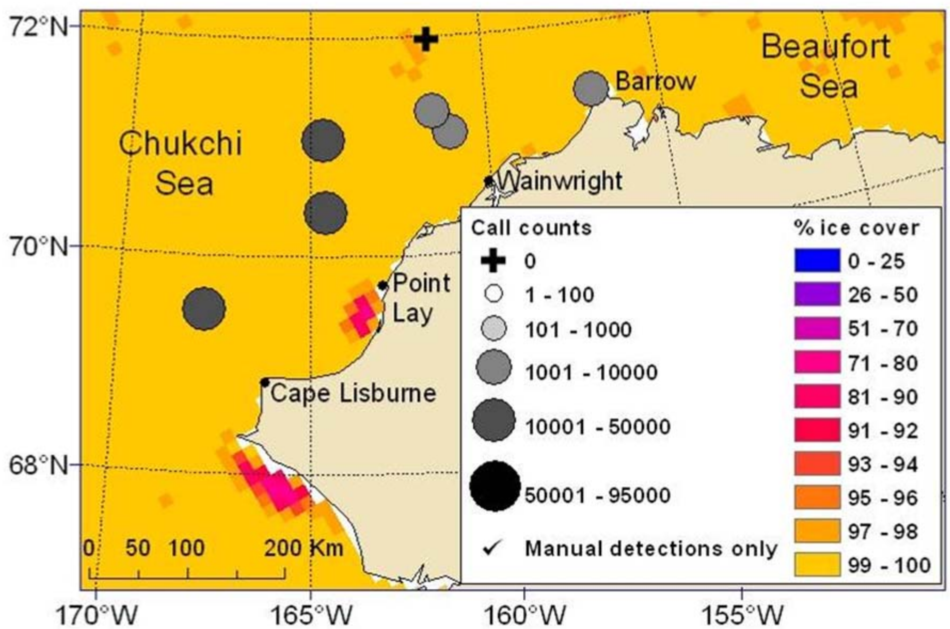


Figure 72. Beluga whale call count estimates in the Chukchi Sea for 16–30 Apr 2010 based on manual and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 22 Apr 2010. Note that the scale emphasizes heavy ice concentration.

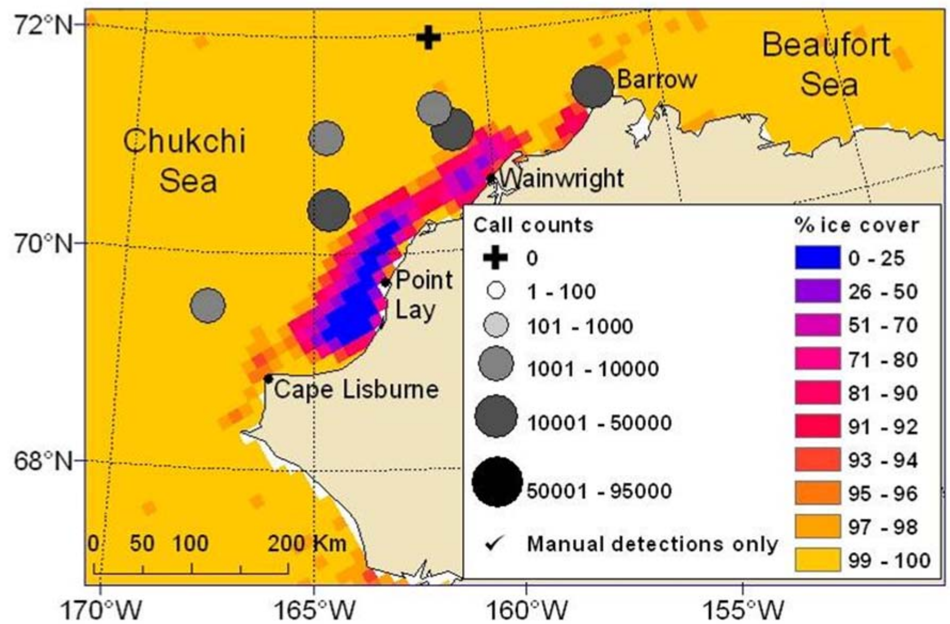


Figure 73. Beluga whale call count estimates in the Chukchi Sea for 1–15 May 2010 based on manual and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 7 May 2010. Note that the scale emphasizes heavy ice concentration.

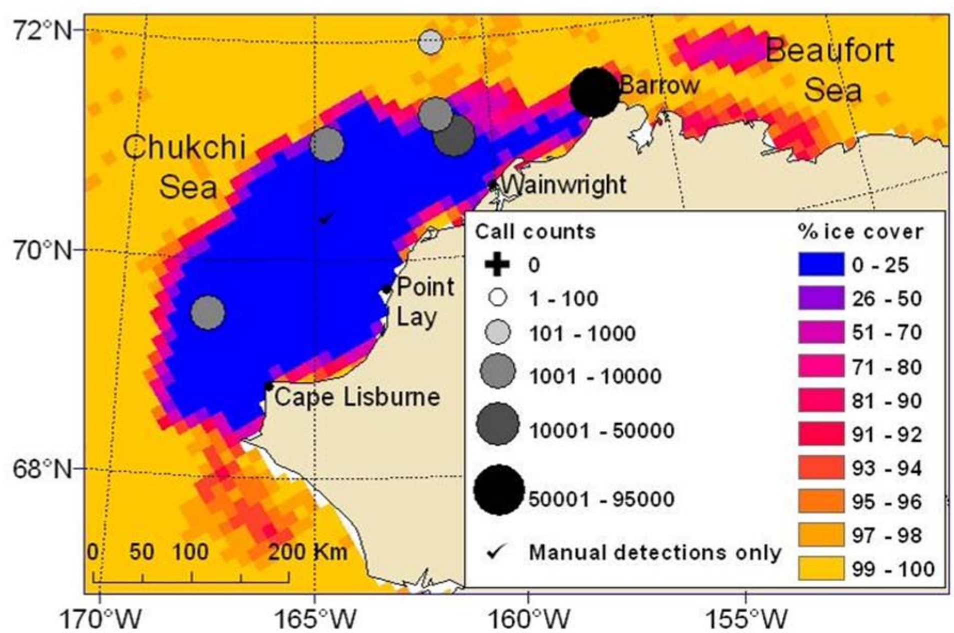


Figure 74. Beluga whale call count estimates in the Chukchi Sea for 16–31 May 2010 based on manual and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 23 May 2010. Note that the scale emphasizes heavy ice concentration.

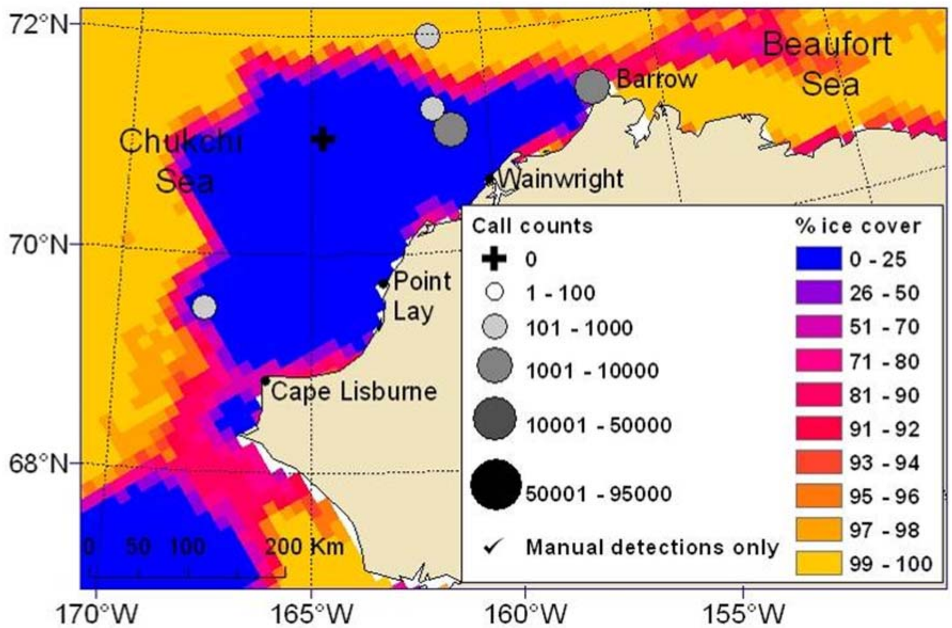


Figure 75. Beluga whale call count estimates in the Chukchi Sea for 1-15 Jun 2010 based on manual and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 7 Jun 2010. Note that the scale emphasizes heavy ice concentration.

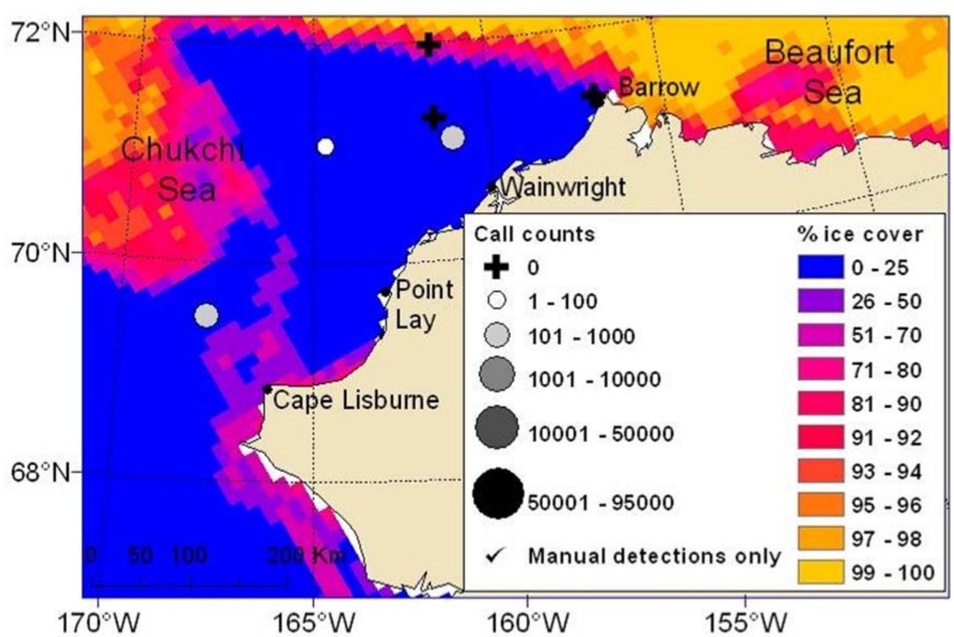


Figure 76. Beluga whale call count estimates in the Chukchi Sea for 16–30 Jun 2010 based on manual and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 22 Jun 2010. Note that the scale emphasizes heavy ice concentration.

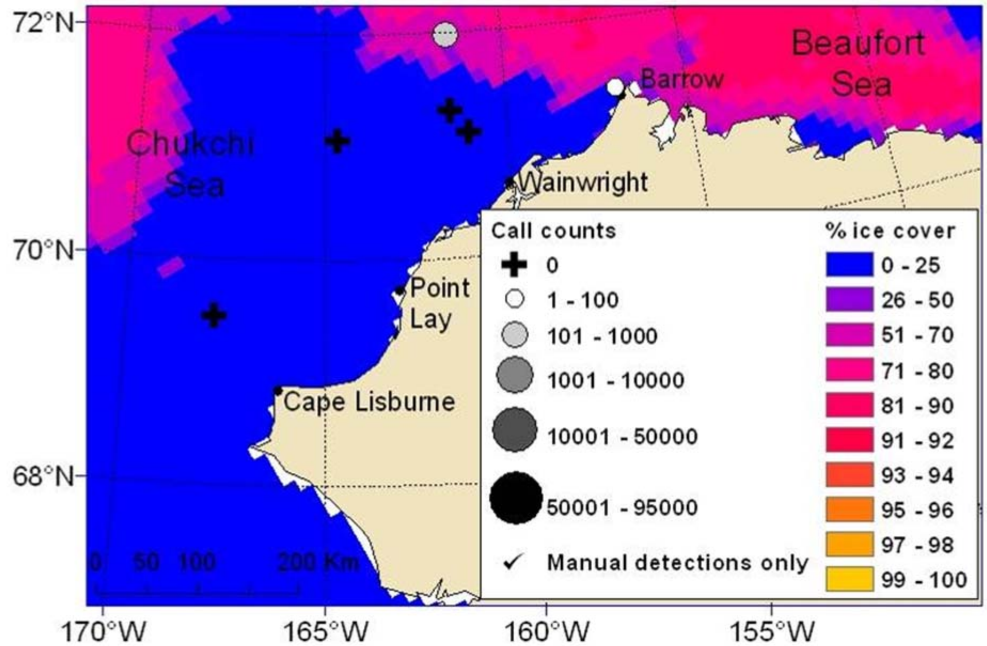


Figure 77. Beluga whale call count estimates in the Chukchi Sea for 1–15 Jul 2010 based on manual and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 7 Jul 2010. Note that the scale emphasizes heavy ice concentration.

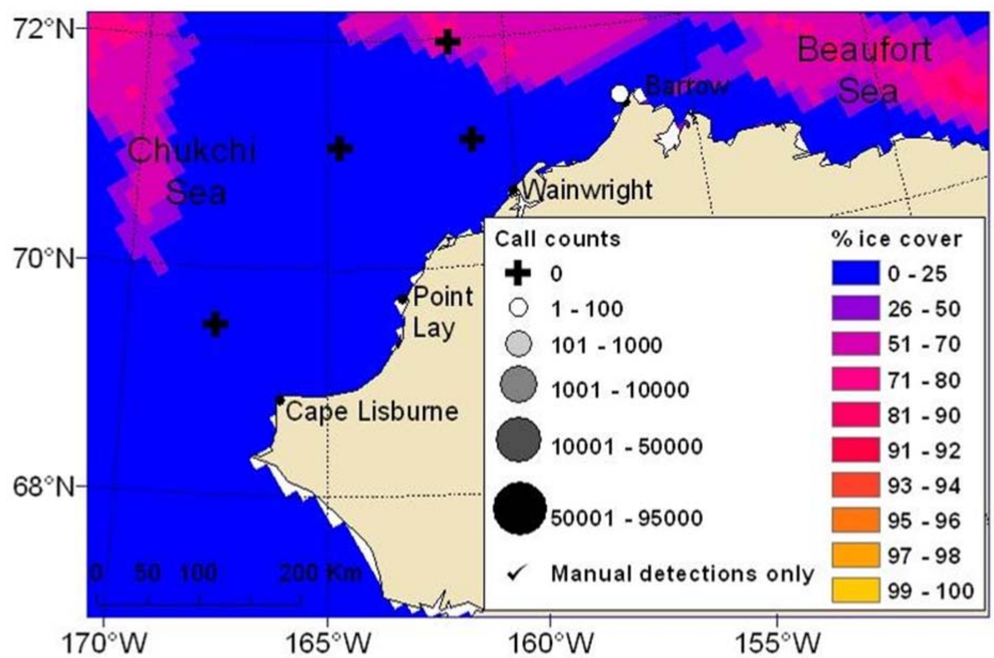


Figure 78. Beluga whale call count estimates in the Chukchi Sea for 16–31 Jul 2010 based on manual and automated call detections at the eight winter 2009–2010 recording stations. Ice concentration data are for 23 Jul 2010. Note that the scale emphasizes heavy ice concentration.

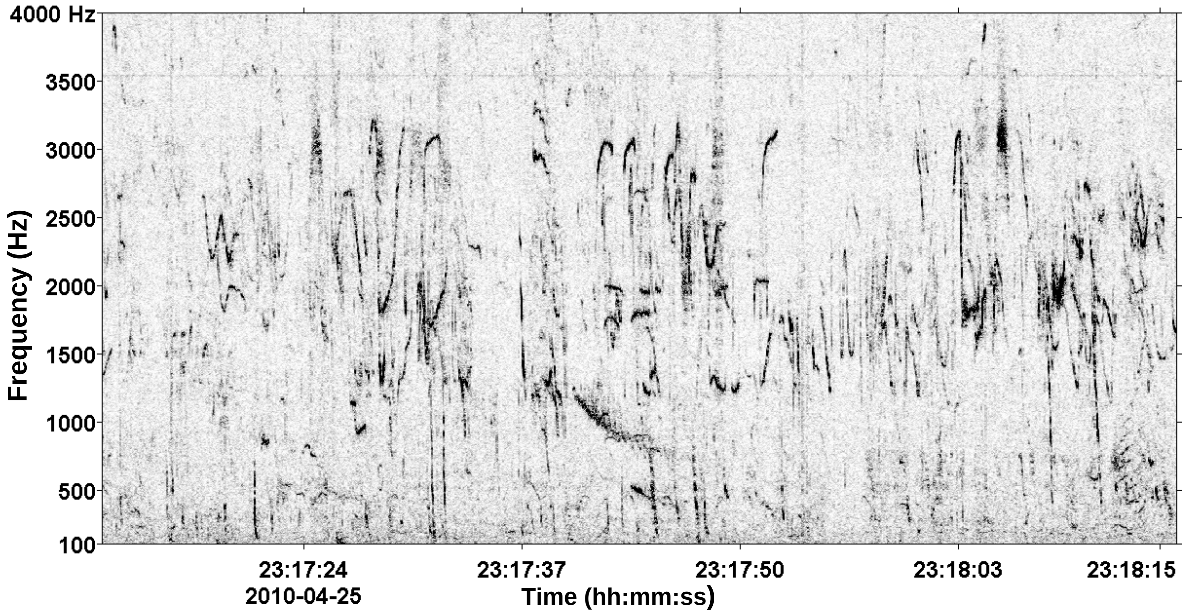


Figure 79. Spectrogram of beluga calls recorded on 25 Apr 2010 at winter 2009–2010 Station PLN40 (4096-pt FFT, 4096 real pts, 1024-pt advance, Hamming window).

Summer 2010 Program

Belugas were detected (Figure 81) only at Stations B05, B15, and W05 in summer 2010. The number of detection days ranged from three to nine (Figure 80, Table 16), confirming the low occurrence of Beluga's in much of the north-eastern Chukchi Sea in summer. The August to early September detections are likely from ECS animals heading to or foraging in Barrow Canyon, as previously observed using satellite telemetry. Although animals typically leave the Kasegaluk Lagoon area by late July, visual sightings of that species in near-shore waters off Wainwright are not uncommon (Ireland *et al.* 2010). The October detection at B05 could be of ECS animals returning to the Chukchi Sea.

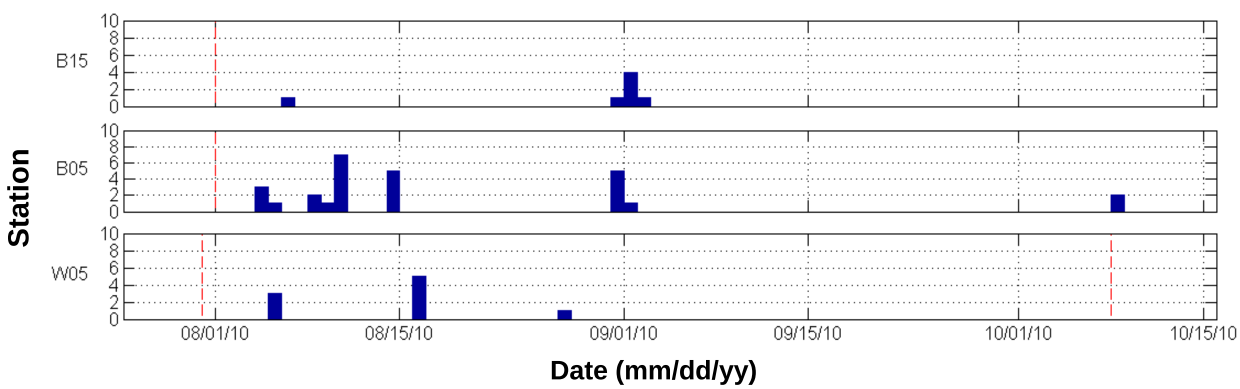


Figure 80. Daily number of sound files with beluga detections based on the manual analysis of 5% of acoustic data recorded in the Chukchi Sea, late July to mid-October 2010. Red dashed lines indicate recorder deployment and retrieval.

Table 16. List of the first and last dates of beluga call detections and the total number of detection days at summer 2010 recording stations. Data are presented only for those stations where beluga sounds were detected.

BELUGA WHALE					
Station	Record start	First detection	Last detection	Record endl	Detection days
B15	01-Aug	06-Aug	02-Sep	16-Oct	4
B05	01-Aug	04-Aug	08-Oct	16-Oct	9
W05	31-Jul	05-Aug	27-Aug	07-Oct	3

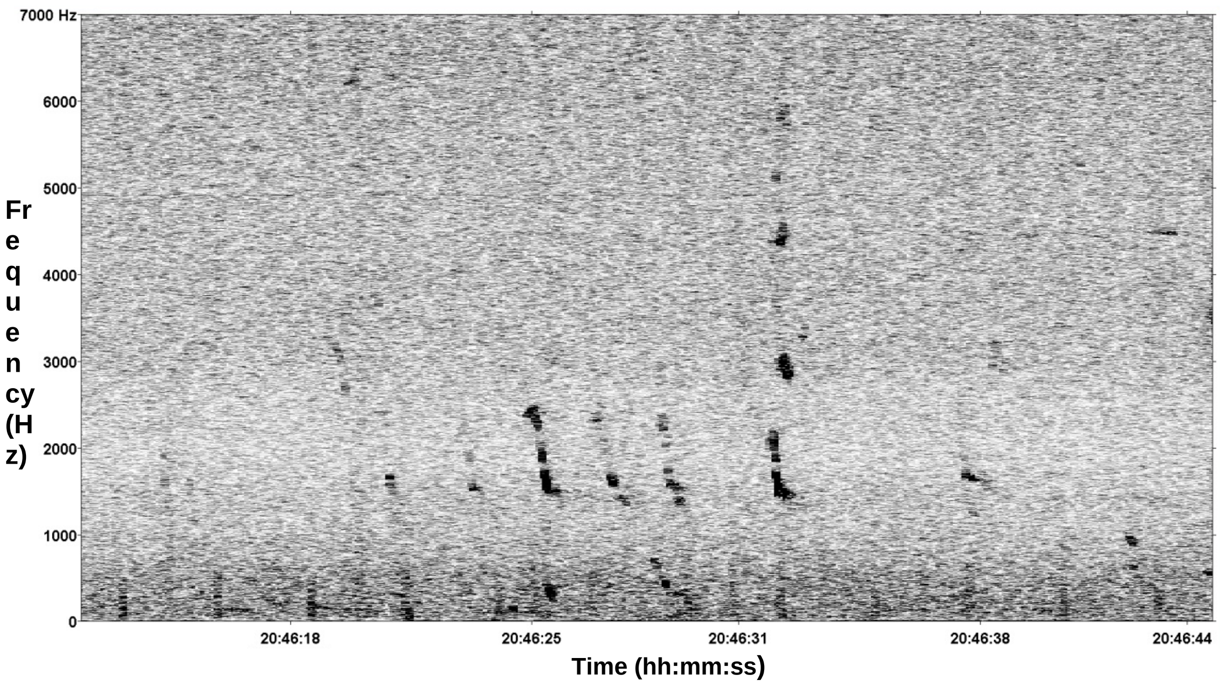


Figure 81. Beluga calls detected at B15, 11 Oct 2009 (8192-pt FFT, 4096 real pts, 1024-pt advance, Hamming window).

3.3.3.4. Killer Whales

Winter 2009–2010 Program

There were no killer whale detections during the winter 2009–2010 program.

Summer 2010 Program

Killer whales were manually detected on the Burger array and off Cape Lisburne, Point Lay and Wainwright stations. Detections started at Stations CL05, CL20 and CL50 on 29–31 Jul and ended on 25 Sep at CL20 (Figure 82, Table 17). The number of detection days was highest at the inshore stations (<50 nm) although killer whales were detected as far north as CLN120 and WN40. Killer whale calls (Figure 83) were detected in presence of other species' calls (gray whales and walrus) on several occasions.

A large number of detections had low signal-to-noise ratio (SNR) and were thus poorly detected by the automatic detector. Therefore, we were unable to derive automated call counts and call count plots are not presented here. The detections with high SNR provided an opportunity to verify that they matched killer whale calls recorded in 2009, confirming that some pods or at least individuals belonging to the same community return the Chukchi Sea for several years.

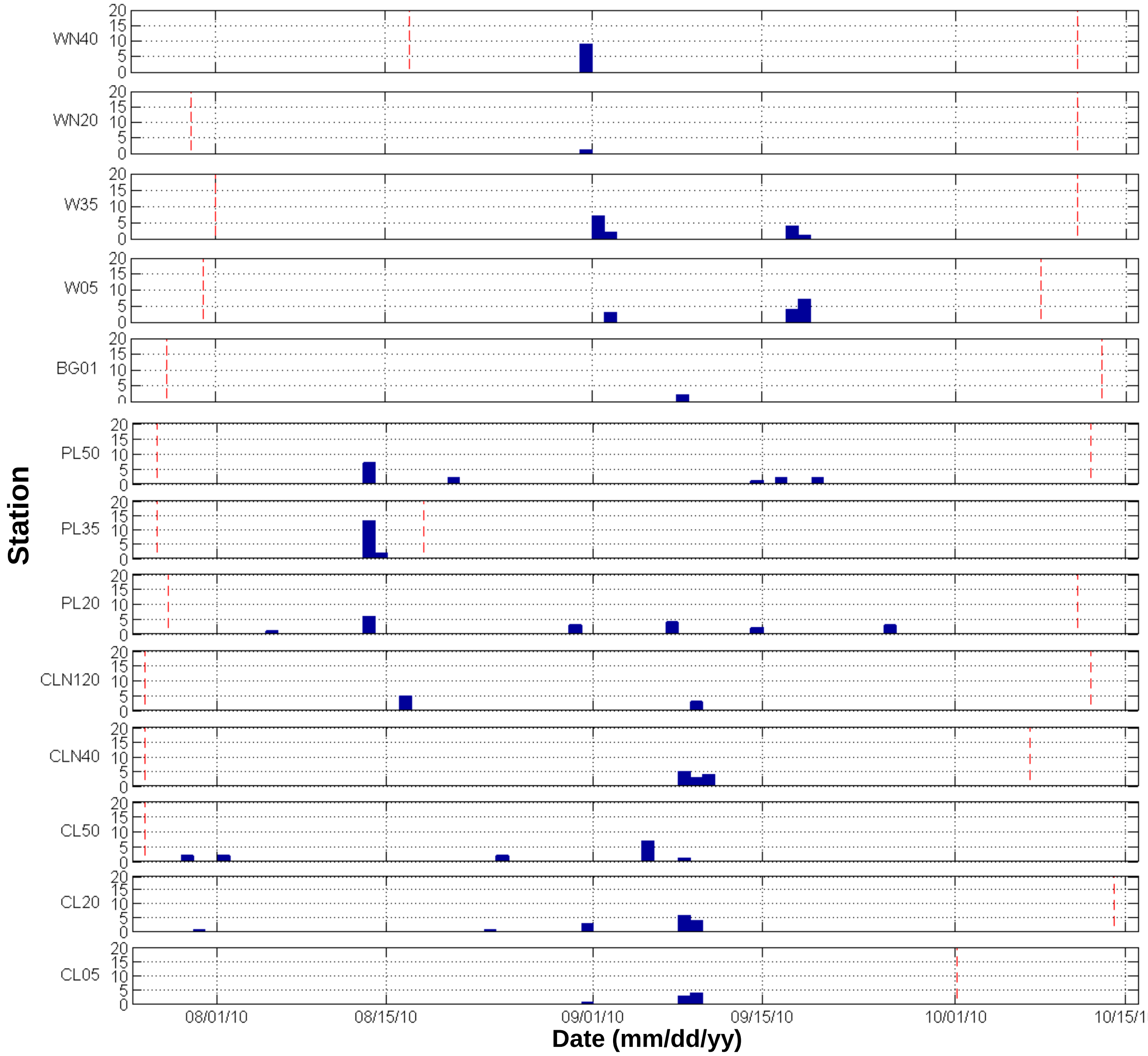


Figure 82. Daily number of sound files with killer whale detections based on the manual analysis of 5% of acoustic data recorded in the Chukchi Sea, late July to mid-October 2010. Red dashed lines indicate recorder deployment and retrieval dates.

Table 17. List of the first and last detections of killer whales, and the total number of detection days at summer 2010 recording stations. Data are presented only for those stations where killer whale sounds were detected.

KILLER WHALE					
Station	Record start	First detection	Last detection	Record end	Detection days
WN40	17-Aug	31-Aug	31-Aug	10-Oct	1
WN20	30-Jul	31-Aug	31-Aug	10-Oct	1
W35	01-Aug	01-Sep	18-Sep	10-Oct	4
W05	31-Jul	02-Sep	18-Sep	07-Oct	3
BG01	28-Jul	08-Sep	08-Sep	12-Oct	2
PL50	27-Jul	13-Aug	19-Sep	11-Oct	5
PL35	27-Jul	13-Aug	14-Aug	17-Aug	2
PL20	28-Jul	05-Aug	25-Sep	10-Oct	6
CLN120	26-Jul	16-Aug	09-Sep	11-Oct	2
CLN40	26-Jul	08-Sep	10-Sep	06-Oct	3
CL50	26-Jul	29-Jul	08-Sep	15-Oct	5
CL20	25-Jul	30-Jul	09-Sep	13-Oct	5
CL05	25-Jul	31-Aug	09-Sep	30-Sep	3

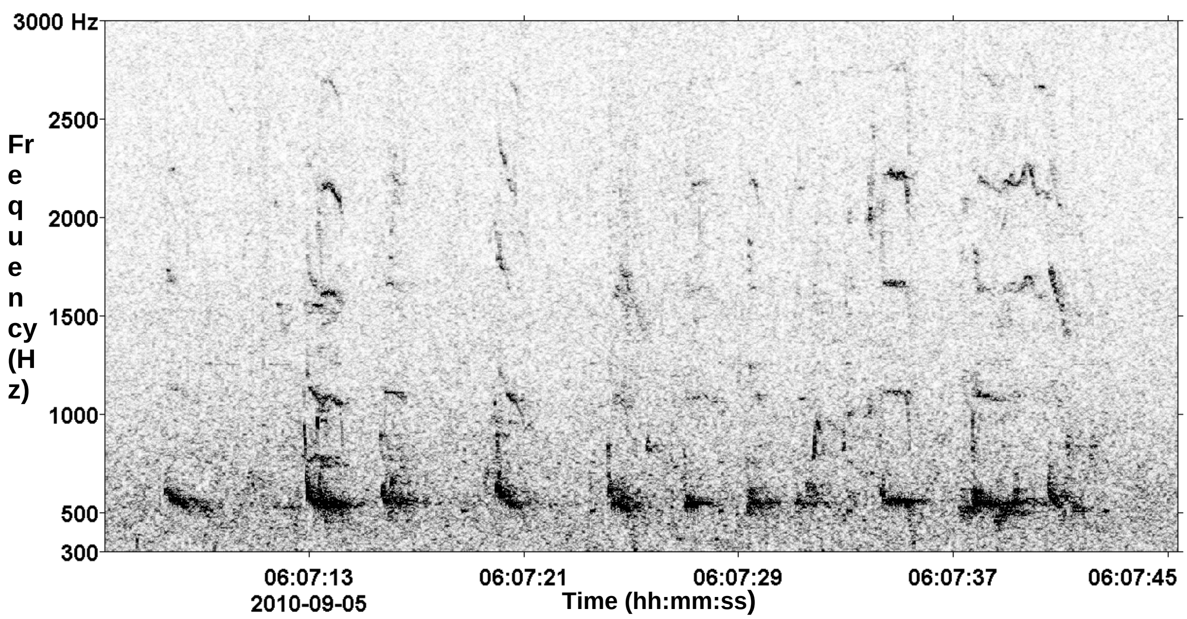


Figure 83. Killer whale call spectrogram from detection at Station CL50, 5 Sep 2010 (4096-pt FFT, 4096 real pts, 1024-pt advance, Hamming window).

3.3.3.5. Gray Whales.

Winter 2009–2010 Program

Gray whale calls were detected once at Station PL50 on 1 Nov 2009 and four times at Station CL50 between 18 Oct and 22 Nov 2009 (Figure 84). There were no detections in spring and early summer.

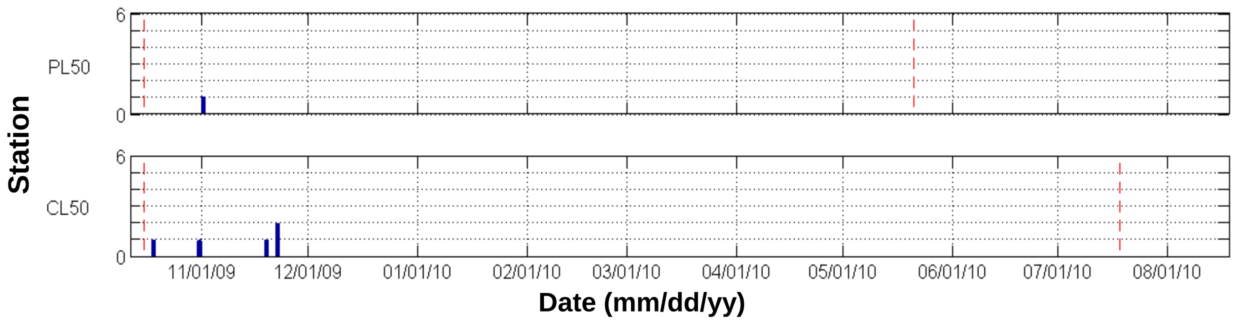


Figure 84. Daily number of sound files with Gray whale detections based on the manual analysis of 5% of acoustic data recorded in the Chukchi Sea from mid-October 2009 through early August 2010. Red dashed lines indicate recording start and end.

Summer 2010 Program

Gray whale knock calls (

Figure 86) were detected at 11 stations during the 2010 summer program (Figure 85, Table 18). They were detected between 25 and 31 Jul at all operational stations except W05 and WN20, suggesting that gray whales were widely distributed in the southwestern half of the study area at the start of the recording period. Detections became rare and sporadic thereafter, possibly as a result of increased presence of killer whales in Aug and Sep, a shift in gray whale distribution, or a change in their calling behavior. Ninety percent of gray whale call detections occurred between 26 Jul and 1 Aug.

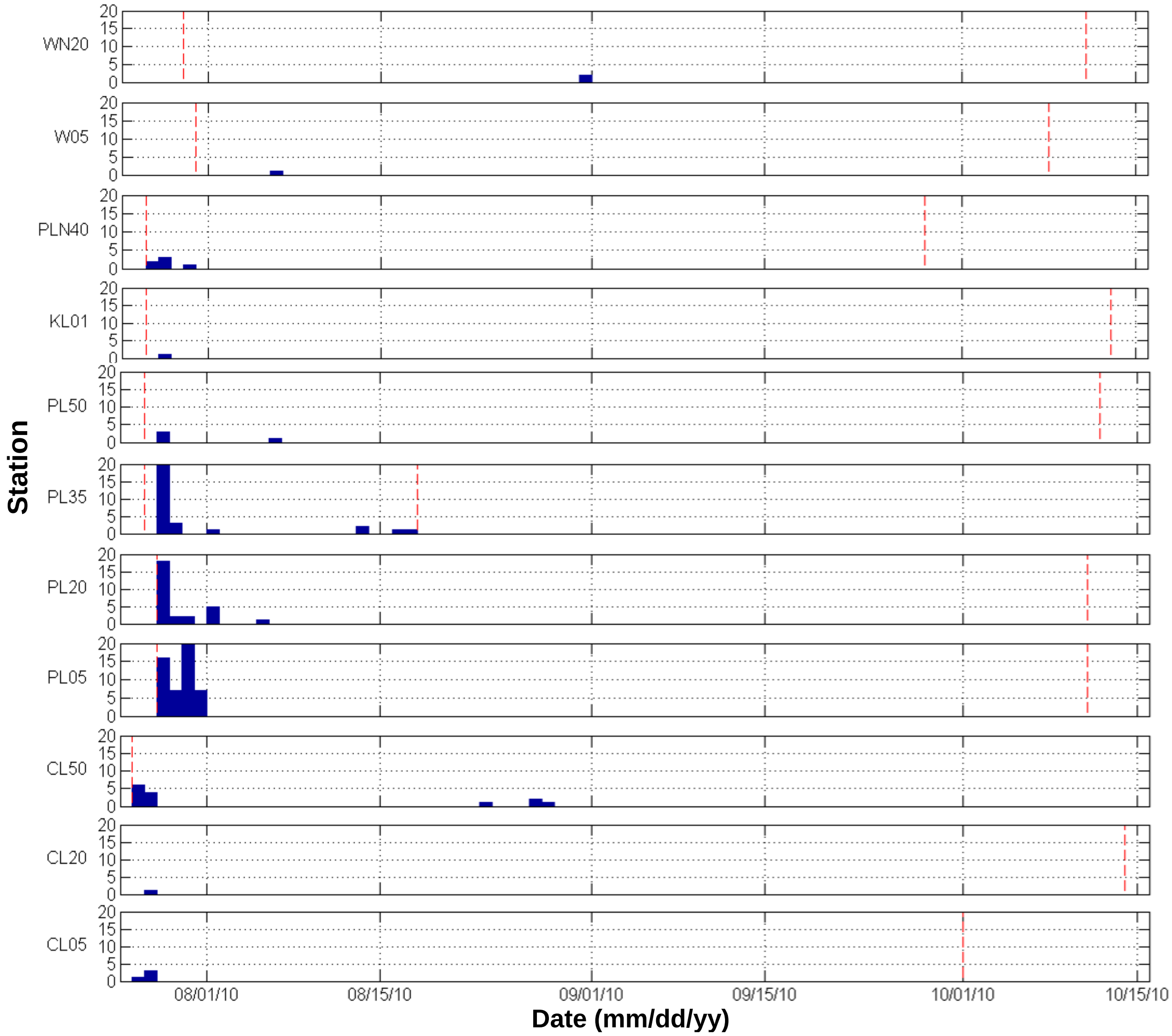


Figure 85. Daily number of sound files with gray whale detections based on the manual analysis of 5% of acoustic data recorded in the Chukchi Sea, late July to mid-October 2010. Red dashed lines indicate recorder deployment and retrieval dates.

Table 18. List of the first and last Gray Whale call detections, and the total number of detection days at all summer 2010 recording stations. Data are presented only for those stations where gray whale calls were detected.

GRAY WHALE					
Station	Record start	First detection	Last detection	Record end	Detection days
WN20	30-Jul	31-Aug	31-Aug	10-Oct	1
W05	31-Jul	06-Aug	06-Aug	07-Oct	1
PLN40	27-Jul	27-Jul	30-Jul	27-Sep	3
KL01	27-Jul	28-Jul	28-Jul	12-Oct	1
PL50	27-Jul	28-Jul	06-Aug	11-Oct	2
PL35	27-Jul	28-Jul	17-Aug	17-Aug	6
PL20	28-Jul	28-Jul	05-Aug	10-Oct	5
PL05	28-Jul	28-Jul	31-Jul	10-Oct	4
CL50	26-Jul	26-Jul	28-Aug	15-Oct	5
CL20	25-Jul	27-Jul	27-Jul	13-Oct	1
CL05	25-Jul	26-Jul	27-Jul	30-Sep	2

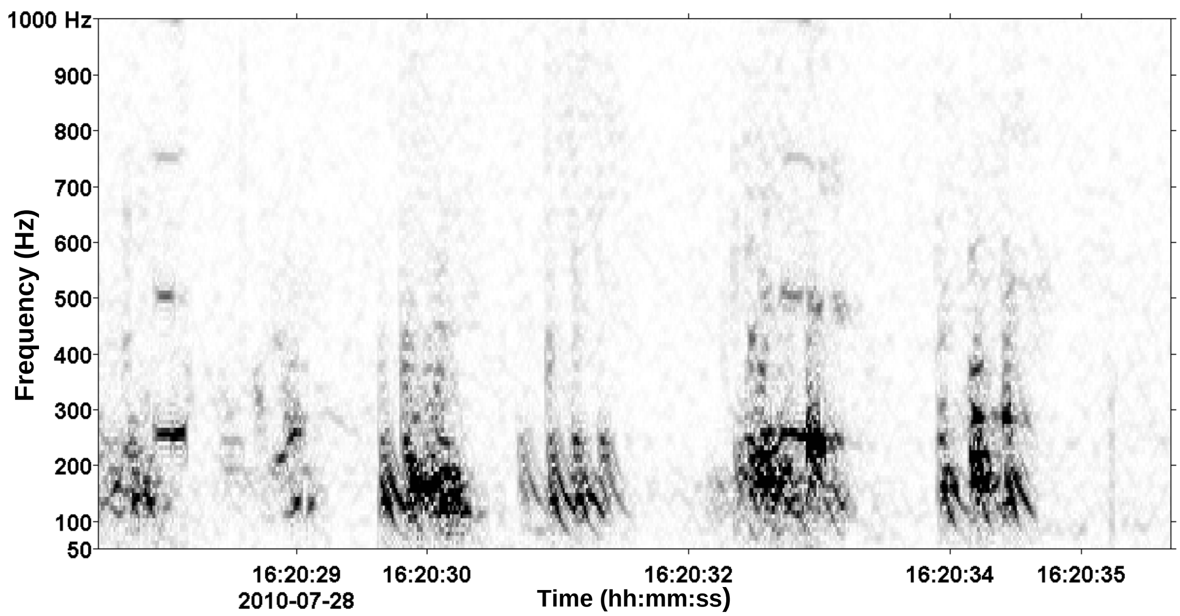


Figure 86. Gray whale calls recorded 28 Jul 2010 at Station PL35 (2048-pt FFT, 2048 real pts, 256-pt advance, Hamming window).

3.3.3.6. Fin Whales

Winter 2009–2010 Program

There were no fin whale detections during the winter 2009–2010 program.

Summer 2010 Program

Fin whale calls (

Figure 88) were detected at Stations PL50, CL50, and CLN90 between 7 Aug and 3 Oct 2010 (Figure 87, Table 19). All detection bouts lasted less than 2 h and were characterized by relatively low calling rates, suggesting that the detected fin whales were in transit. The 3 Oct detection at PL50 consisted of short song bouts similar to those described in the 2007 data (Delarue *et al.* 2009*b*).

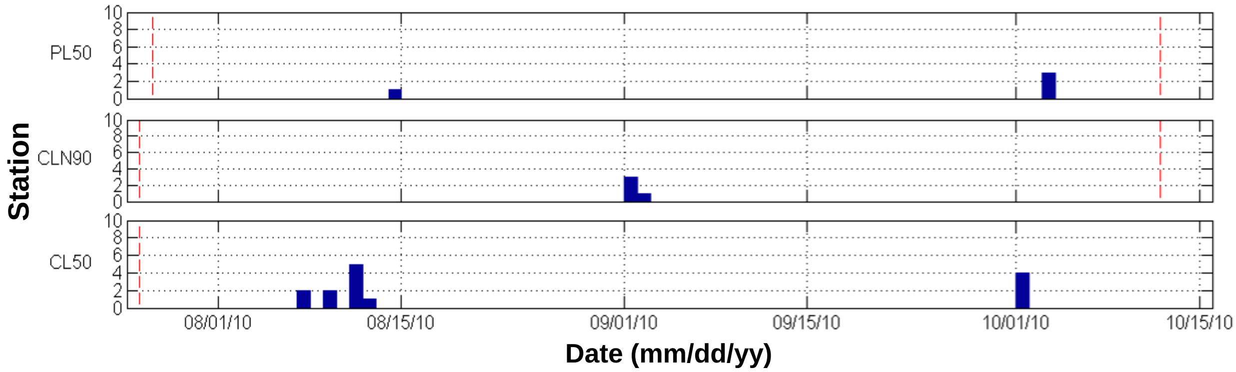


Figure 87. Daily number of sound files with fin whale detections based on the manual analysis of 5% of acoustic data recorded in the Chukchi Sea, late July to mid-October 2010. Red dashed lines indicate recorder deployment and retrieval.

Table 19. List of the first and last detections of Fin Whale calls, and the total number of detection days on which fin whale calls were detected at all summer 2010 recording stations. Data are presented only for those stations where fin whale calls were detected.

Fin Whale					
Station	Record start	First detection	Last detection	Record end	Detection days
PL50	27-Jul	14-Aug	03-Oct	11-Oct	2
CLN90	26-Jul	01-Sep	02-Sep	11-Oct	2
CL50	26-Jul	7-Aug	01-Oct	15-Oct	5

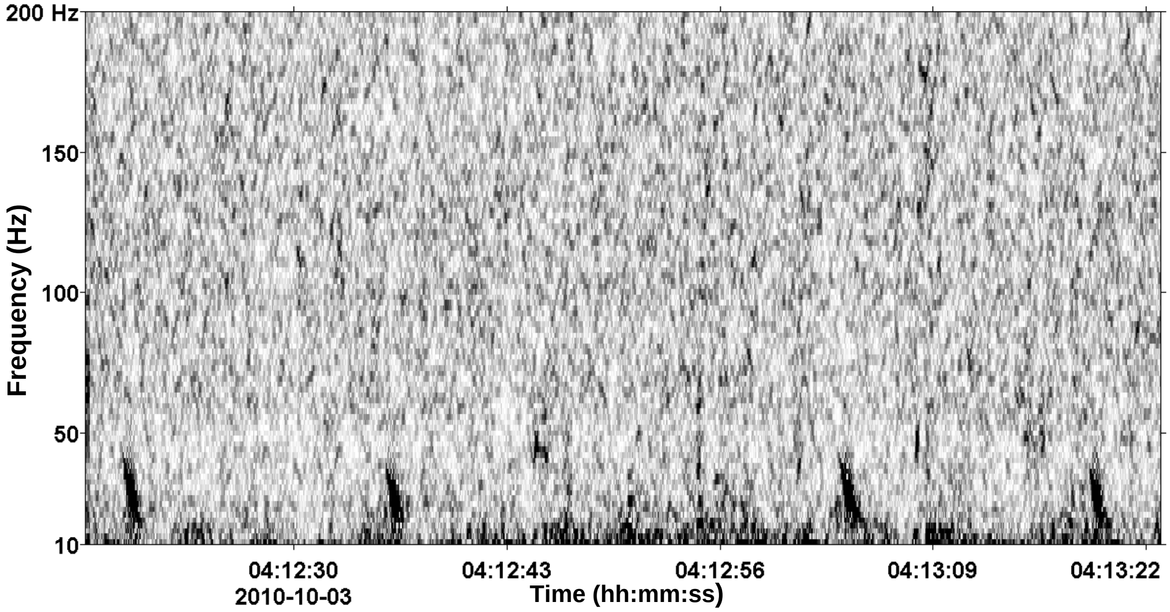


Figure 88. Spectrogram of fin whale calls detected at Station PL50, 3 Oct 2010 (4096-pt FFT, 8192 real pts, 1024-pt advance, Hamming window).

3.3.3.7. Minke Whales

Winter 2009–2010 Program

Minke whales were detected only on 31 Oct and 1 Nov 2009 at Station CL50. The detected calls were the 'boing' calls described by Rankin and Barlow (2005;

Figure 89). These were the first acoustic detections of minke whales since the beginning of the acoustics program in 2006 despite the fact that minke whales have been commonly sighted in the study area (though not in high numbers) by visual observers (Ireland *et al.* 2010).

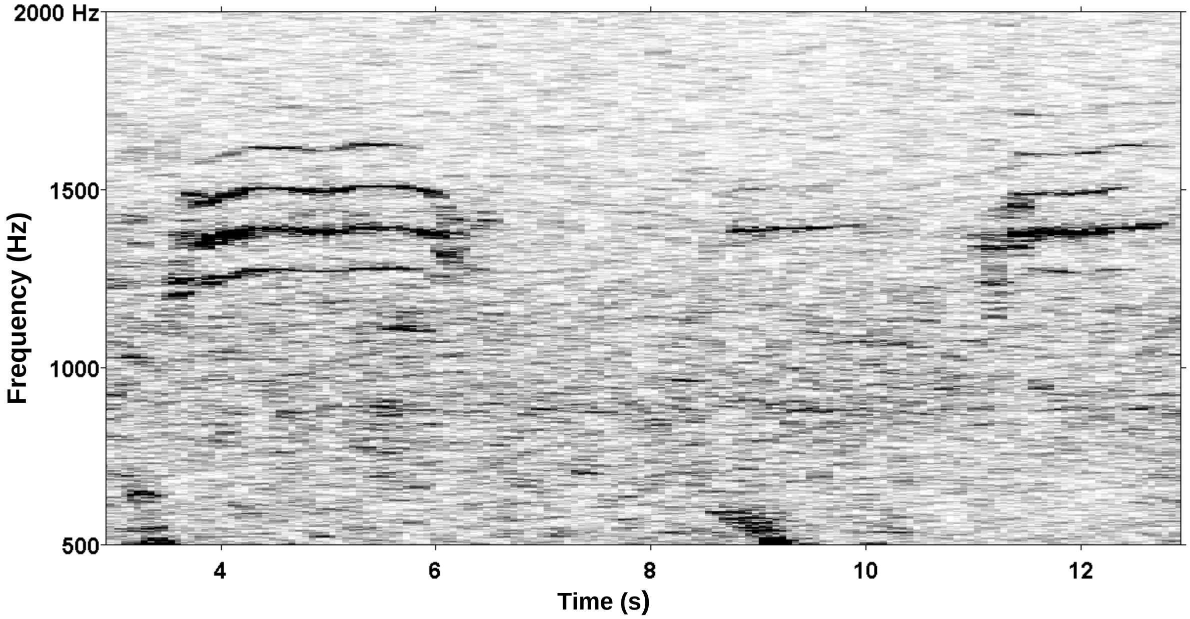


Figure 89. Minke whale boing calls recorded at CL50 on 31 Oct 2009 (4096-pt FFT, 8192 real pts, 1024-pt advance, Hamming window).

Summer 2010 Program

There were no minke whale acoustic detections during the summer 2010 acoustic data.

3.3.3.8. Humpback Whales

Winter 2009–2010 Program

No humpback whales were detected in the 2009–2010 winter acoustic data.

Summer 2010 Program

Humpback whale calls (

Figure 90) were detected at Station CL50 on 7 and 17 Aug 2010. These are the first acoustic detections of humpback whale in the north-eastern Chukchi Sea since the beginning of the acoustics program, although a few visual sightings have been reported over the last three summers.

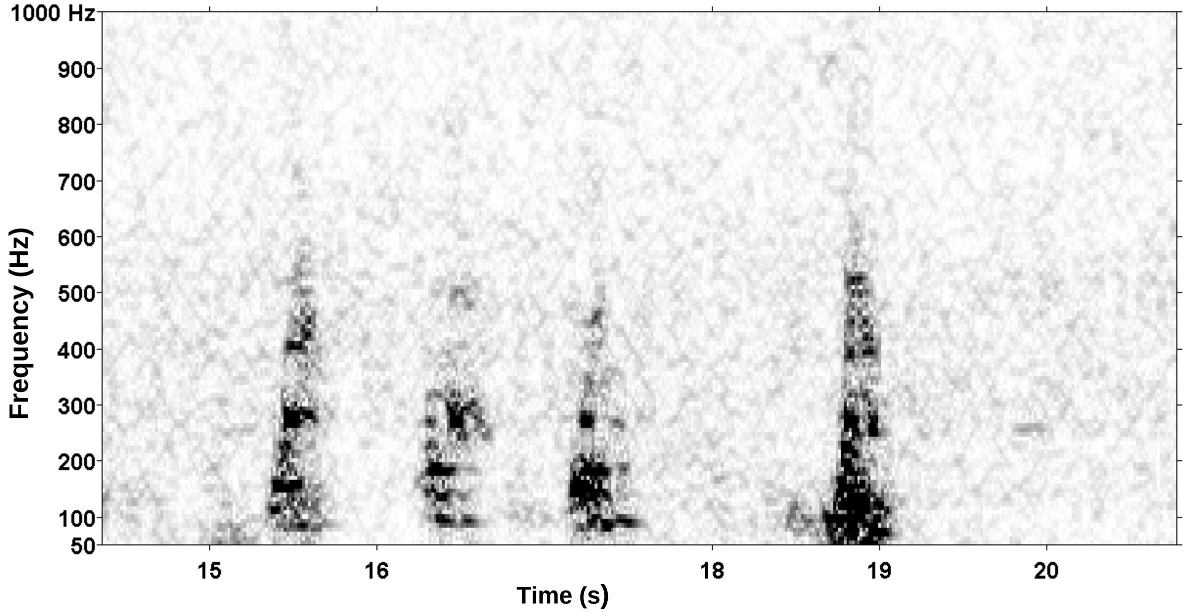


Figure 90. Humpback whale calls recorded at CL50 on 7 Aug 2010 (2048-pt FFT, 2048 real pts, 256-pt advance, Hamming window).

3.3.3.9. Bearded Seals

Winter 2009–2010 Program

Bearded seals were detected at all winter 2009–2010 stations. The first detection occurred on 12 Oct 2009 and the last one on 6 Jul 2010. Bearded seals were the most commonly detected marine mammal species in the winter data; they were recorded for a maximum of 230 days (out of 266 days of recording effort) at Station W50 (Figure 91, Table 20). There was a general, gradual increase in acoustic detections throughout the recording period. A peak in detections was first reached in January and February, followed by a slight recession in call counts in March. This was followed by a strong increase in detections in April, peaking in May and June during the bearded seal's breeding period. Detections stopped almost simultaneously at Stations W35, W50, WN40, and B05 (4–6 Jul), and a few days earlier at PLN40 (29 Jun) and CL50 (26 Jun). Overall, there was a trend toward higher call counts at the Wainwright (mostly W35 and W50) and Barrow (B05) stations (Figure 92 to Figure 101).

As defined for the purpose of this study, ice presence had no obvious effect on bearded seal presence, as they were detected throughout the winter. However, ice presence may have an effect on distribution at a smaller scale.

Detected calls consisted primarily of downsweeping trills (Figure 102; Van Parijs *et al.* 2001).

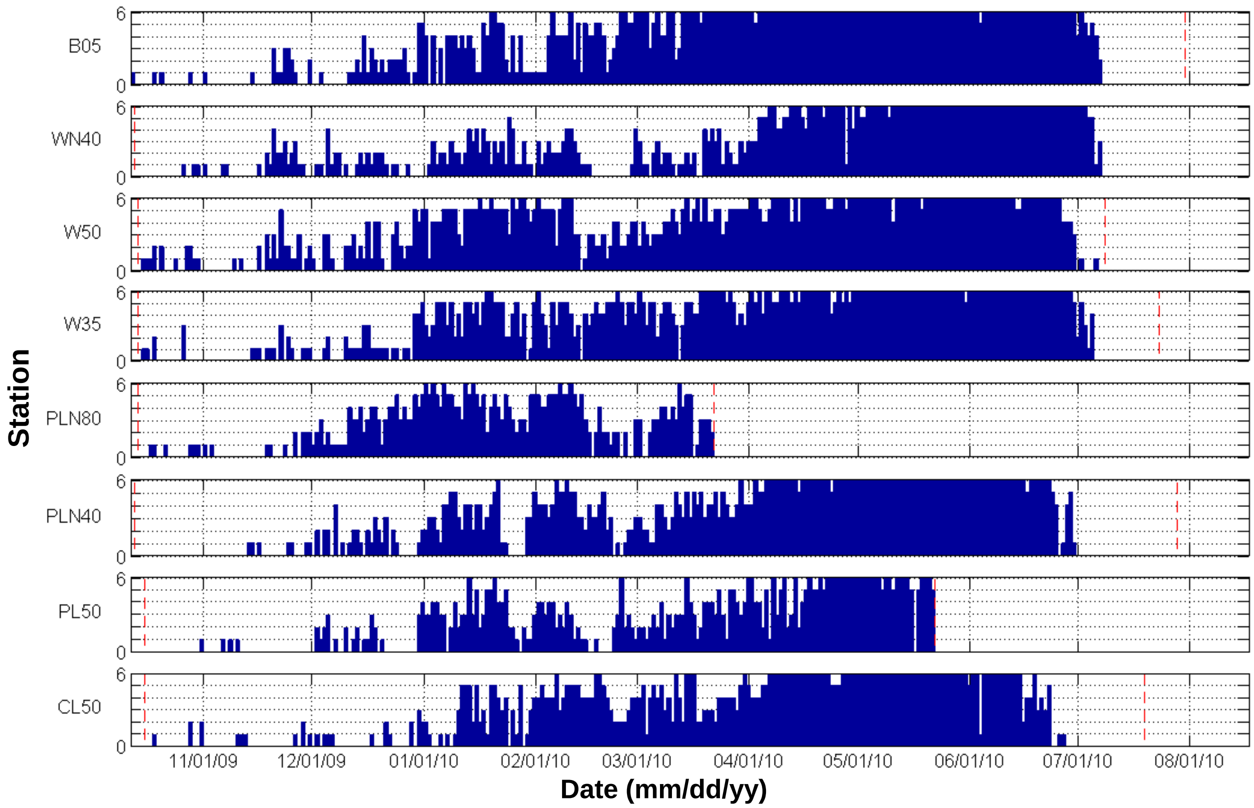


Figure 91. Daily number of sound files with bearded seal detections based on the manual analysis of 5% of acoustic data recorded in the Chukchi Sea from mid-October 2009 to early August 2010. Red dashed lines indicate recording start and end dates.

Table 20. List of the first and last detections of Bearded Seal calls, and the total number of detection days on which bearded seal calls were detected at all winter 2009–2010 recording stations.

Bearded Seal					
Station	Record start	First detection	Last detection	Detection days	Record end
B05	12-Oct	12-Oct	6-Jul	219	29-Jul
WN40	13-Oct	26-Oct	6-Jul	207	17-Aug
W50	14-Oct	15-Oct	5-Jul	230	7-Jul
W35	14-Oct	15-Oct	4-Jul	219	21-Jul
PLN80	14-Oct	17-Oct	21-Mar	119	21-Mar
PLN40	13-Oct	13-Nov	29-Jun	198	26-Jul
PL50	16-Oct	31-Oct	21-May	151	21-May
CL50	16-Oct	18-Oct	26-Jun	188	18-Jul

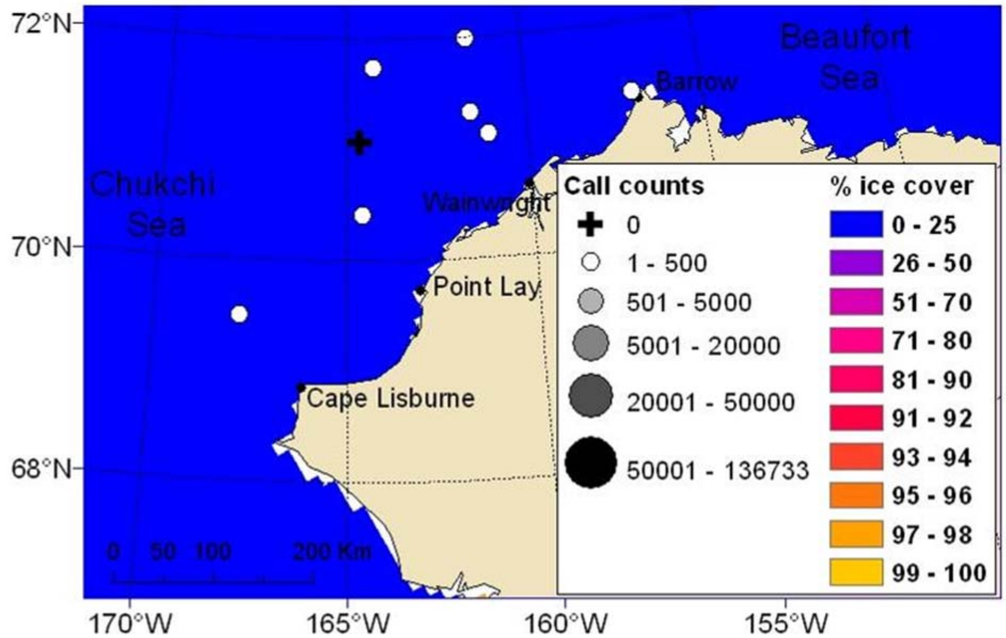


Figure 92. Bearded seal call count estimates, based on manual and automated call detections, in the Chukchi Sea for 12–31 Oct 2009. Ice concentration data are for 23 Oct 2009. Note that the scale emphasizes heavy ice concentration.

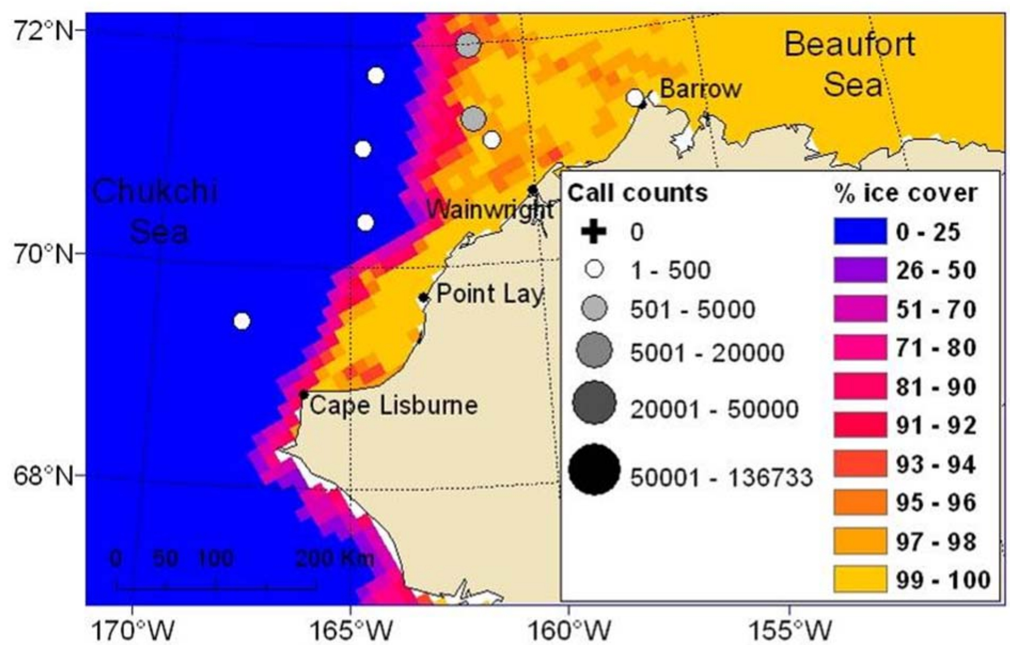


Figure 93. Bearded seal call count estimates, based on manual and automated call detections, in the Chukchi Sea for November 2009. Ice concentration data are for 15 Nov 2009. Note that the scale emphasizes heavy ice concentration.

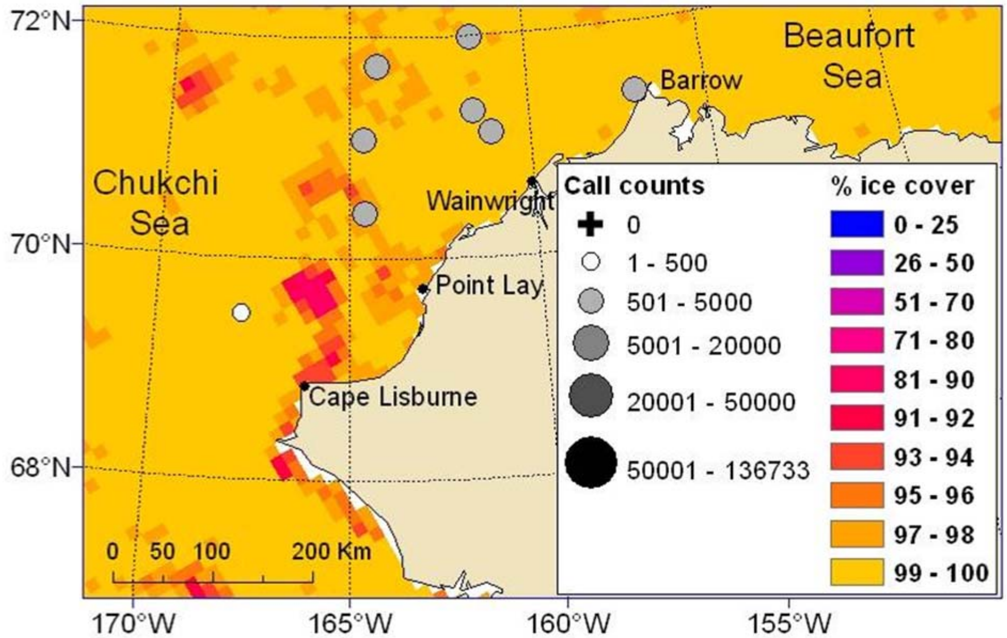


Figure 94. Bearded seal call count estimates, based on manual and automated call detections, in the Chukchi Sea for December 2009. Ice concentration data are for 15 Dec 2009. Note that the scale emphasizes heavy ice concentration.

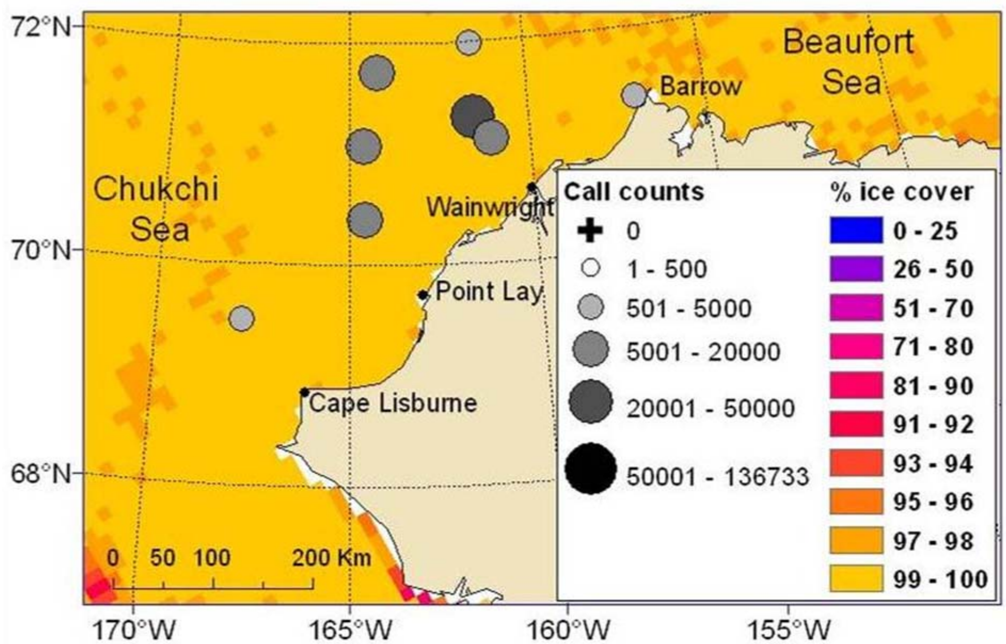


Figure 95. Bearded seal call count estimates, based on manual and automated call detections, in the Chukchi Sea for January 2010. Ice concentration data are for 15 Jan 2010. Note that the scale emphasizes heavy ice concentration.

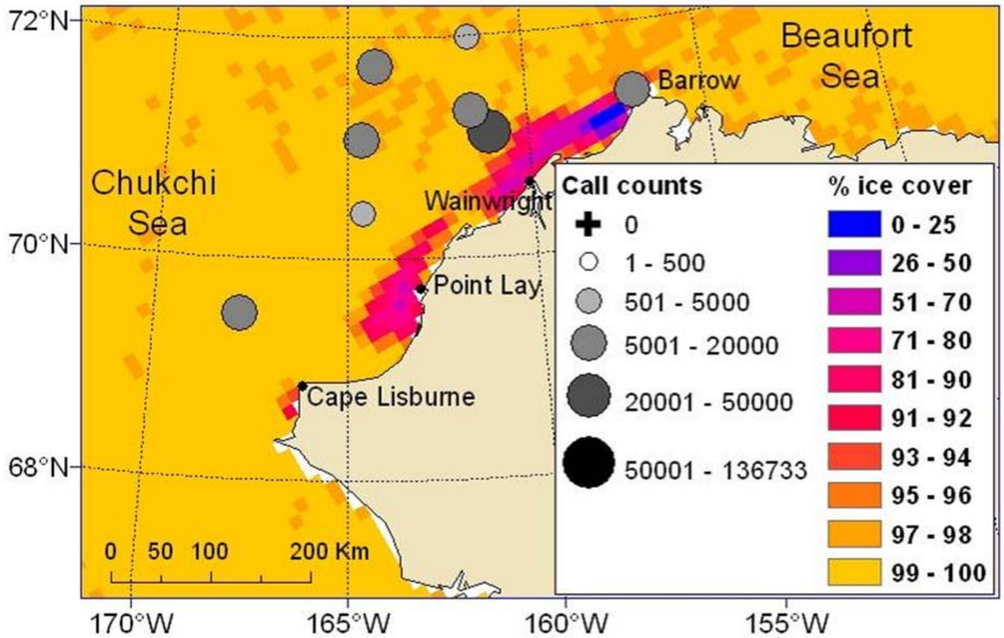


Figure 96. Bearded seal call count estimates, based on manual and automated call detections, in the Chukchi Sea for February 2010. Ice concentration data are for 15 Feb 2010. Note that the scale emphasizes heavy ice concentration.

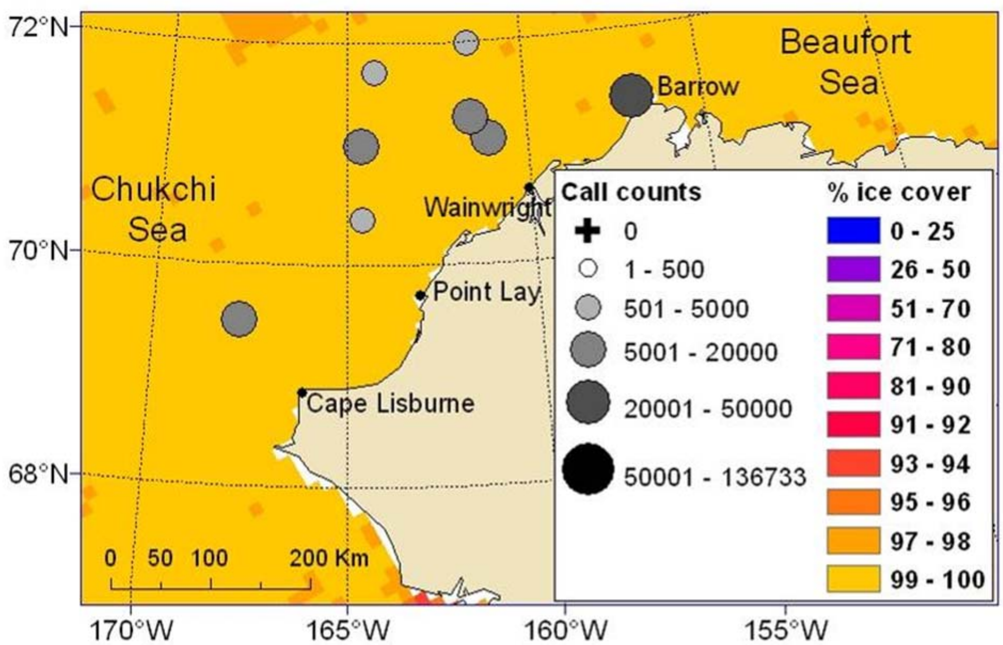


Figure 97. Bearded seal call count estimates, based on manual and automated call detections, in the Chukchi Sea for March 2010. Ice concentration data are for 15 Mar 2010. Note that the scale emphasizes heavy ice concentration.

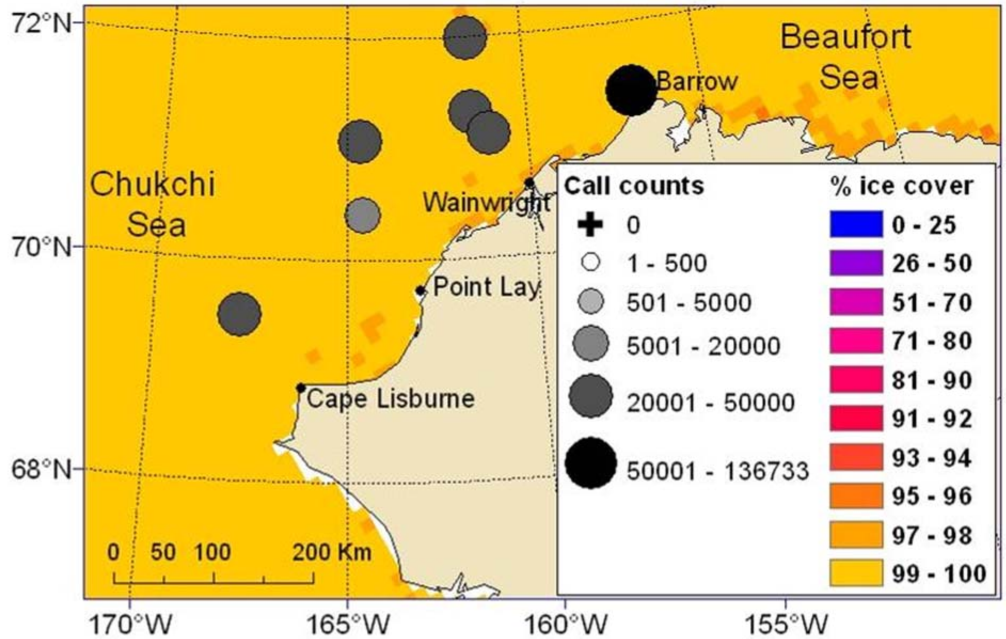


Figure 98. Bearded seal call count estimates, based on manual and automated call detections, in the Chukchi Sea for April 2010. Ice concentration data are for 15 Apr 2010. Note that the scale emphasizes heavy ice concentration. Station W35 stopped recording 13 Apr.

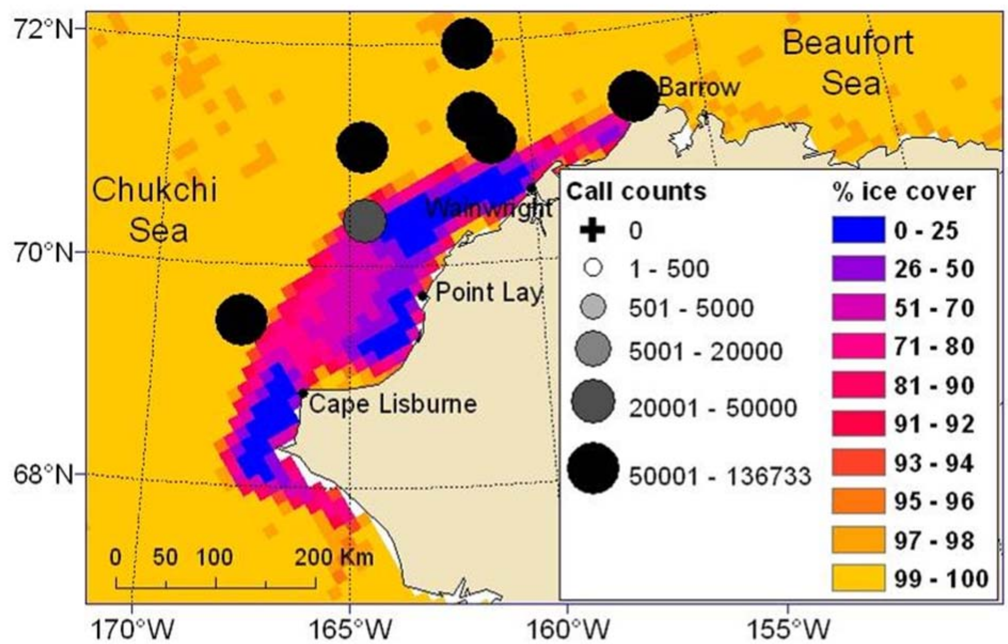


Figure 99. Bearded seal call count estimates, based on manual and automated call detections, in the Chukchi Sea for May 2010. Ice concentration data are for 15 May 2010. Note that the scale emphasizes heavy ice concentration. Station W35 was inactive.

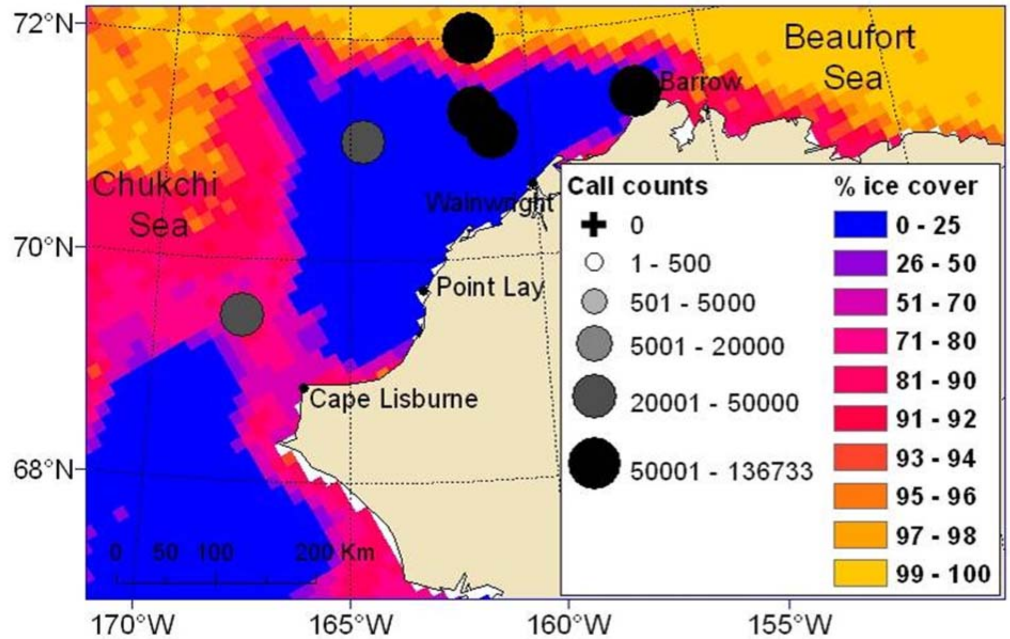


Figure 100. Bearded seal call count estimates, based on manual and automated call detections, in the Chukchi Sea for June 2010. Ice concentration data are for 15 Jun 2010. Note that the scale emphasizes heavy ice concentration. Stations W35 and CL50 were inactive. Recording stopped 4 Jun at Station PLN80.

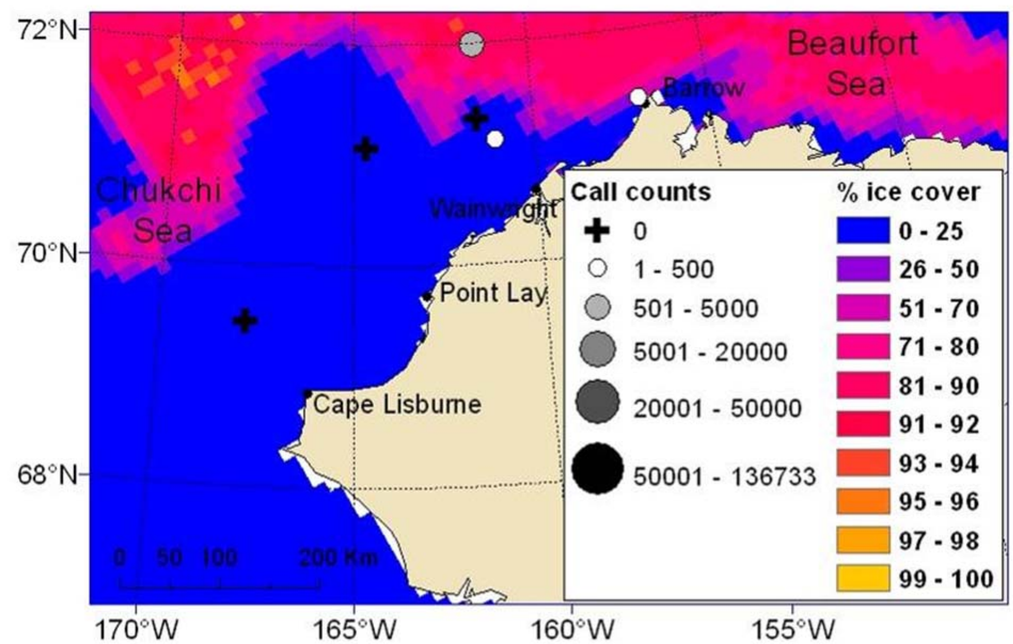


Figure 101. Bearded seal call count estimates, based on manual and automated call detections, in the Chukchi Sea for July 2010. Ice concentration data are for 15 Jul 2010. Note that the scale emphasizes heavy ice concentration. Stations W35, CL50, and PLN80 were inactive.

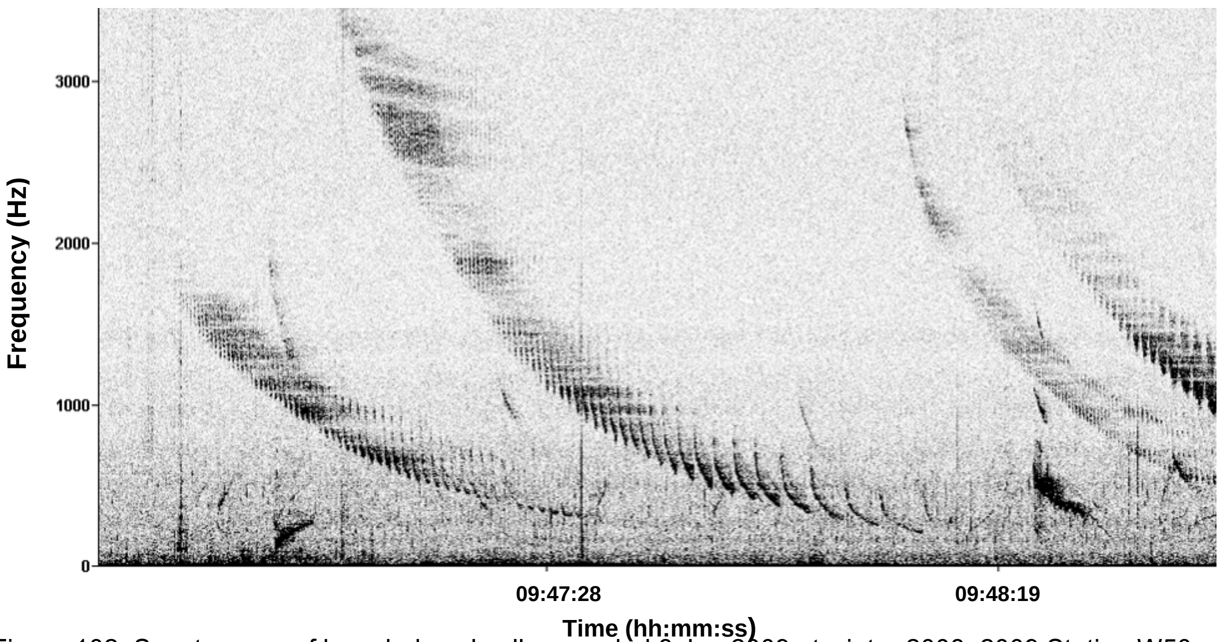


Figure 102. Spectrogram of bearded seal calls recorded 8 Jun 2009 at winter 2008–2009 Station W50 (8192-pt FFT, 4096 real pts, 1024-pt advance, Hamming window).

Summer 2010 Program

Bearded seals were detected at all but one (CL20) analyzed station (Figure 103, Table 21). Three trends in detections were noted: (1) detections increased with time at all stations, peaking in October prior to the retrieval of the instruments; (2) this increase in detections started earlier at the north-eastern stations and progressively spread toward the southwest; and (3) there were a few late July–early August detections which were restricted mostly to the inshore stations of Point Lay. These early detections were followed by an almost complete absence of detections until the onset of the steady increase in detections described above (Figure 103 to Figure 107). The number of detection days ranged from one (CLN40 and CL05) to 40 (B05). 68% and 95% of files with bearded seal detections occurred after 1 Oct and 1 Sep, respectively. The southwest-northeast, inshore-offshore gradient of acoustic occurrence is visible in Figure 101.

Detected bearded seal calls were narrowband, short downsweeping trills (Figure 109) that were 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).

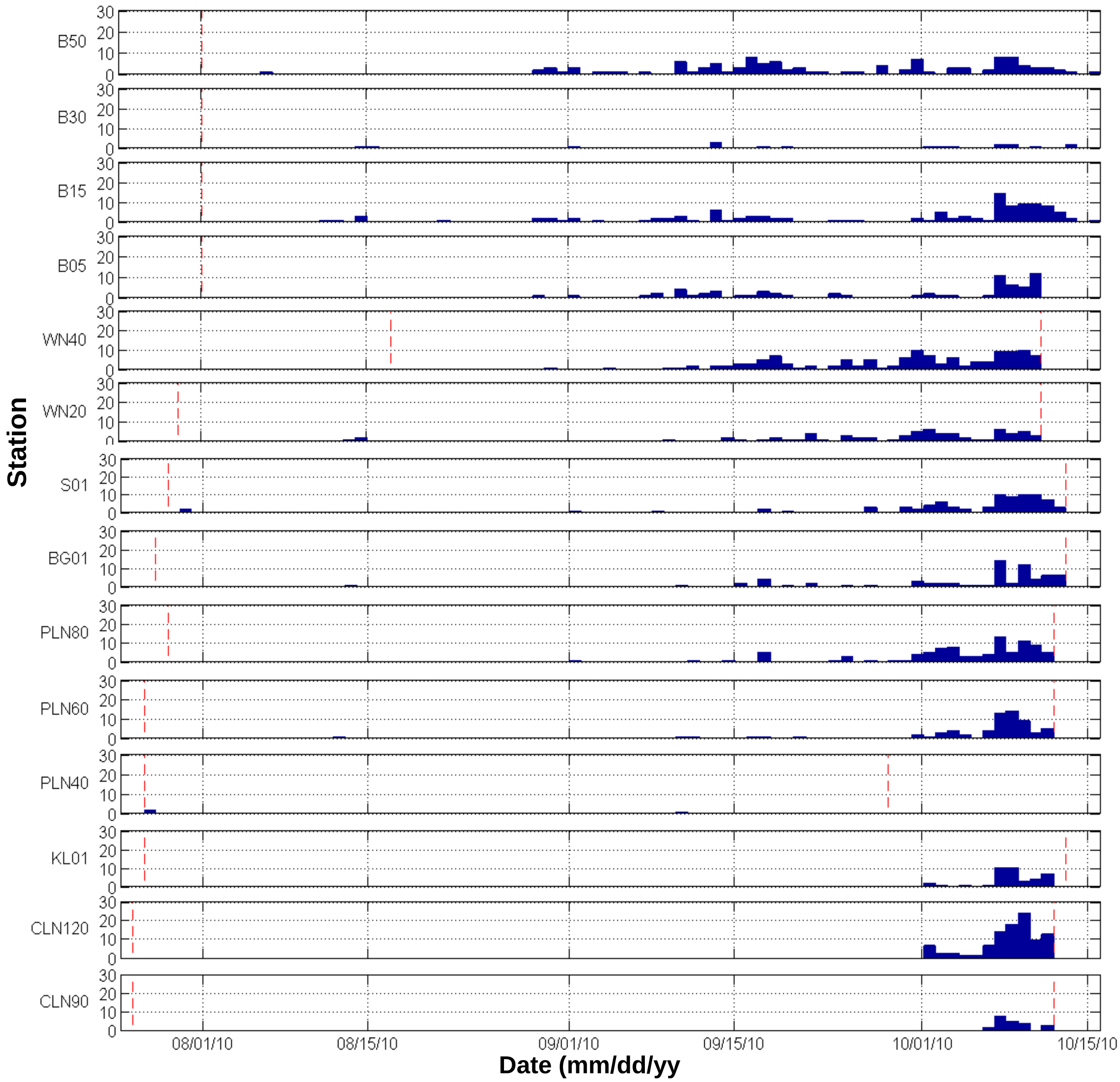
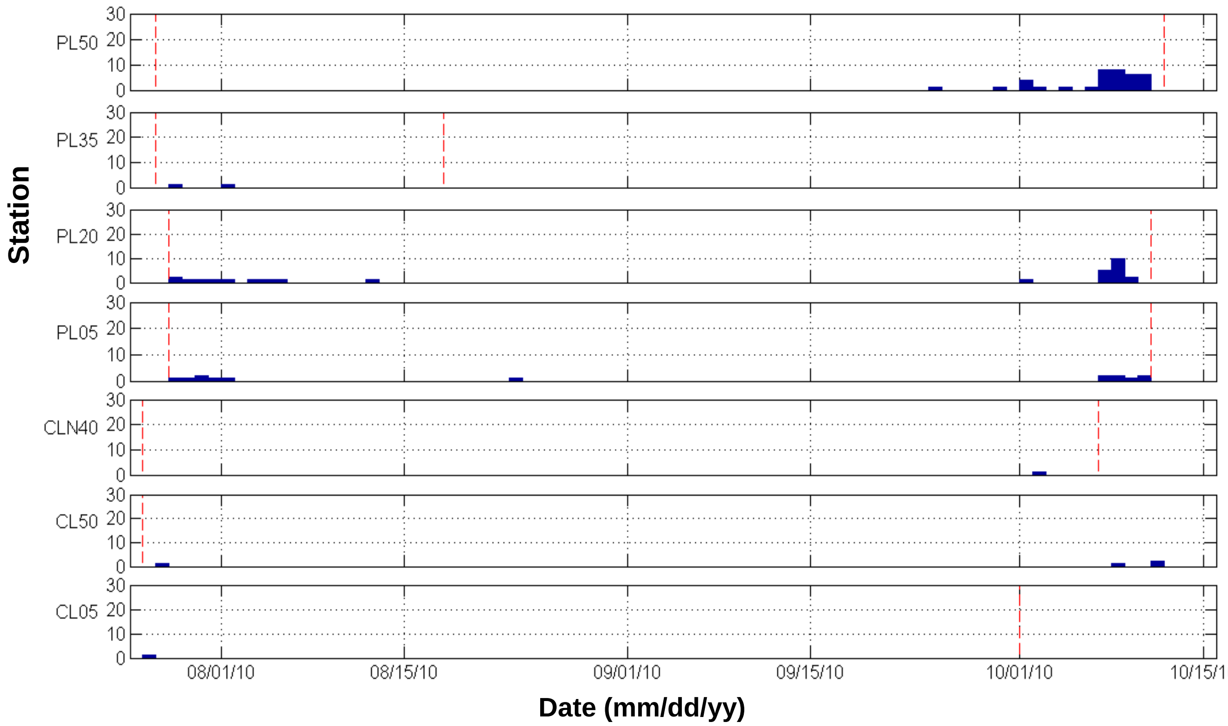


Figure 103. Bearded seal call count estimates in the Chukchi Sea for 25–31 Jul 2010 based on manual and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.



(Con't) Figure 103. Bearded seal call count estimates in the Chukchi Sea for 25–31 Jul 2010 based on manual and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.

Table 21. List of the first and last Bearded Seal call detections, and the total number of days on which bearded seal calls were detected at all summer 2010 recording stations. Data are presented only stations where bearded seal sounds were detected.

Bearded Seal					
Station	Record start	First detection	Last detection	Record end	Detection days
B50	01-Aug	06-Aug	16-Oct	16-Oct	40
B30	01-Aug	14-Aug	13-Oct	16-Oct	13
B15	01-Aug	11-Aug	15-Oct	16-Oct	39
B05	01-Aug	29-Aug	10-Oct	16-Oct	24
WN40	17-Aug	30-Aug	10-Oct	10-Oct	32
WN20	30-Jul	13-Aug	10-Oct	10-Oct	27
W35	01-Aug	13-Aug	10-Oct	10-Oct	25
W05	31-Jul	01-Aug	06-Oct	07-Oct	14
S01	29-Jul	30-Jul	12-Oct	12-Oct	19
BG01	28-Jul	13-Aug	12-Oct	12-Oct	21
PLN80	29-Jul	01-Sep	11-Oct	11-Oct	21
PLN60	27-Jul	12-Aug	11-Oct	11-Oct	17
PLN40	27-Jul	27-Jul	10-Sep	27-Sep	2
KL01	27-Jul	01-Oct	11-Oct	12-Oct	9
PL50	27-Jul	24-Sep	10-Oct	11-Oct	10
PL35	27-Jul	28-Jul	01-Aug	17-Aug	2
PL20	28-Jul	28-Jul	09-Oct	10-Oct	13
PL05	28-Jul	28-Jul	10-Oct	10-Oct	10
CLN120	26-Jul	01-Oct	11-Oct	11-Oct	11
CLN90	26-Jul	06-Oct	11-Oct	11-Oct	5
CLN40	26-Jul	02-Oct	02-Oct	06-Oct	1
CL50	26-Jul	27-Jul	11-Oct	15-Oct	3
CL05	25-Jul	26-Jul	26-Jul	30-Sep	1

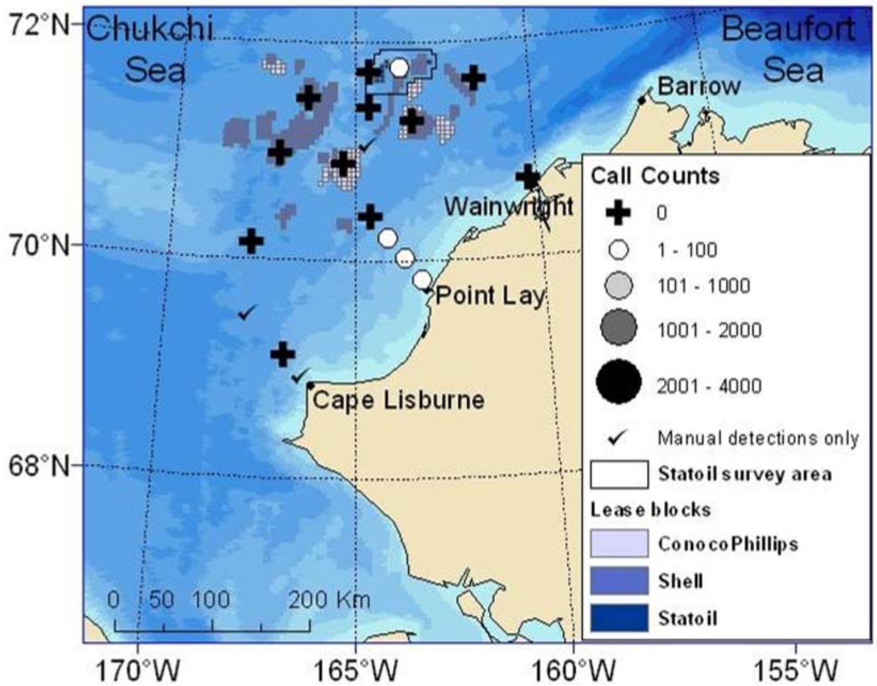


Figure 104. Bearded seal call count estimates in the Chukchi Sea for 25–31 Jul 2010 based on manual and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.

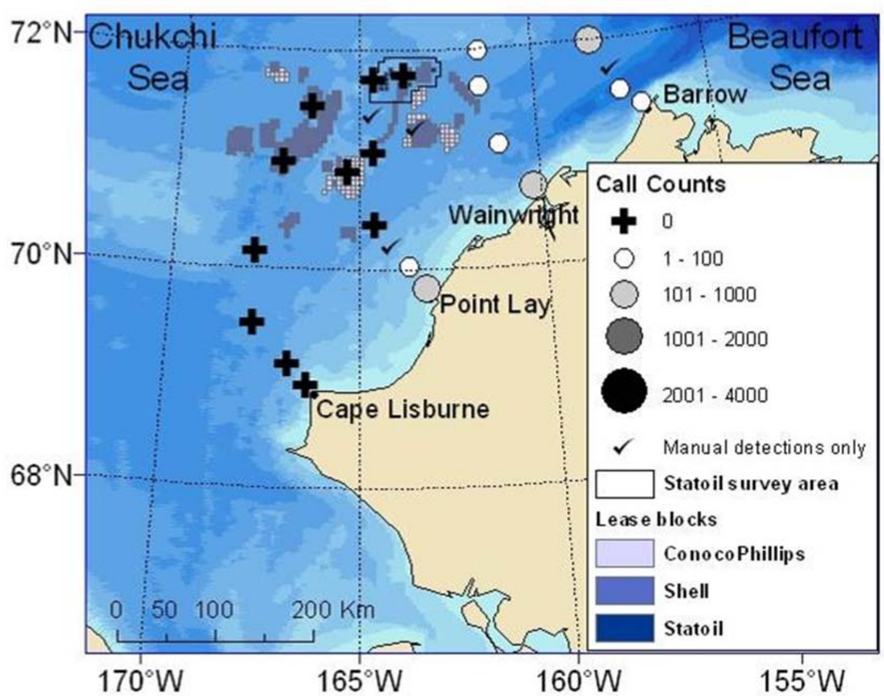


Figure 105. Bearded seal call count estimates in the Chukchi Sea for Aug 2010 based on manual and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.

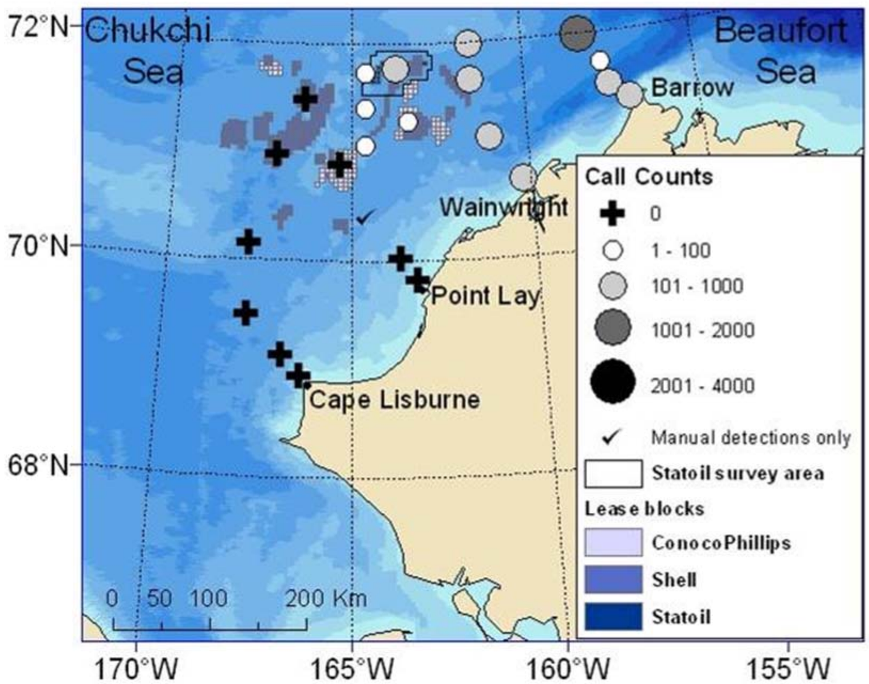


Figure 106. Bearded seal call count estimates in the Chukchi Sea for Sep 2010 based on manual and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.

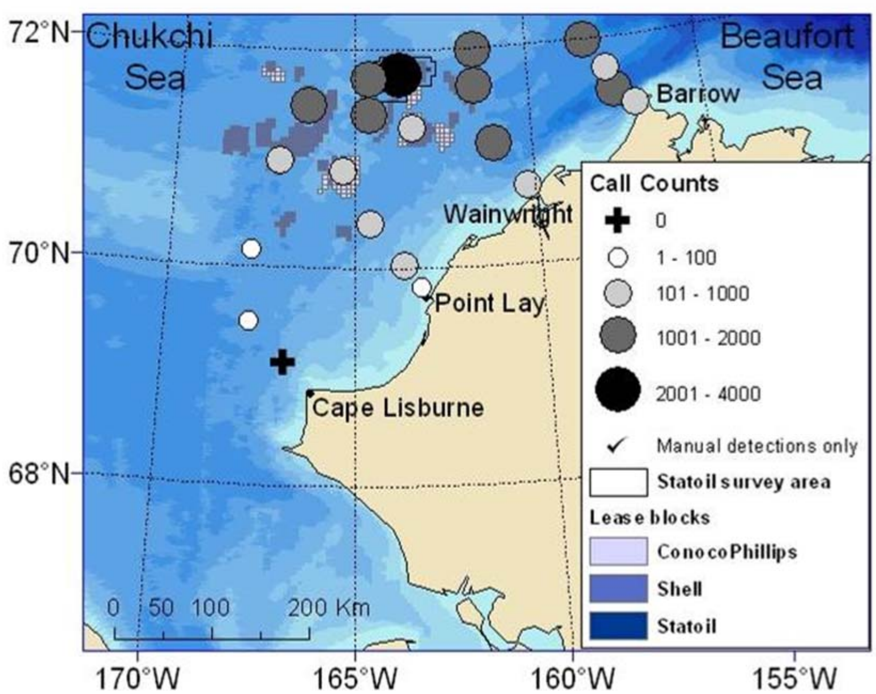


Figure 107. Bearded seal call count estimates in the Chukchi Sea for 1–15 Oct 2010 based on manual and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.

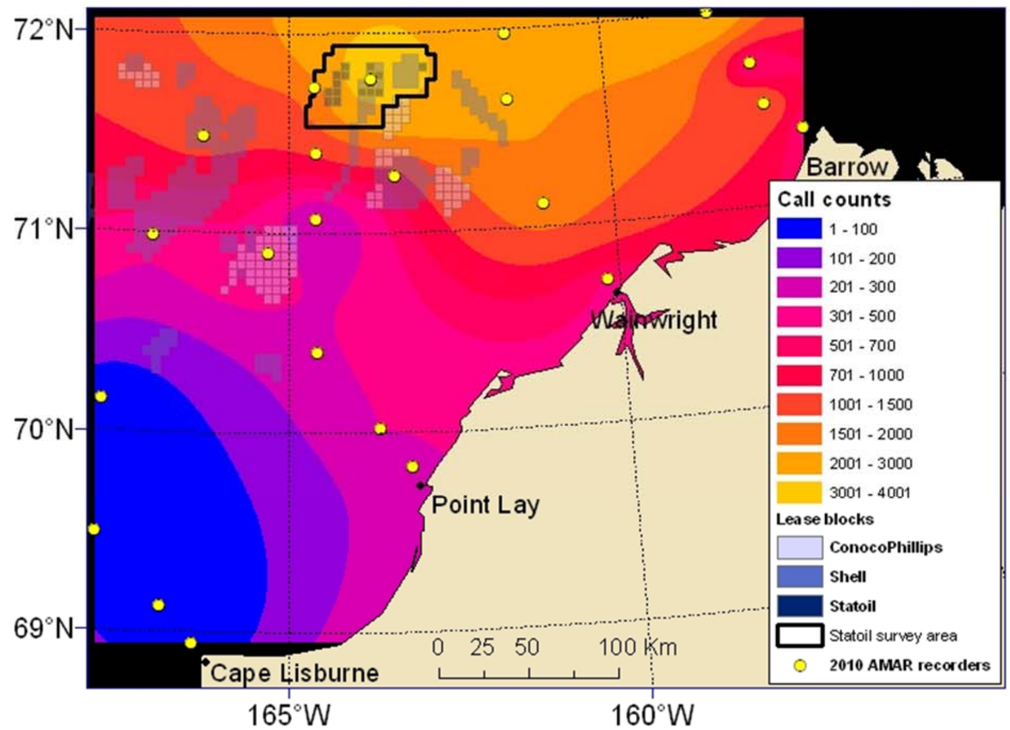


Figure 108. Interpolated bearded seal call count surface plot based on the sum of call counts at all 2010 summer recorders in the Chukchi Sea from 25 Jul to 15 Oct.

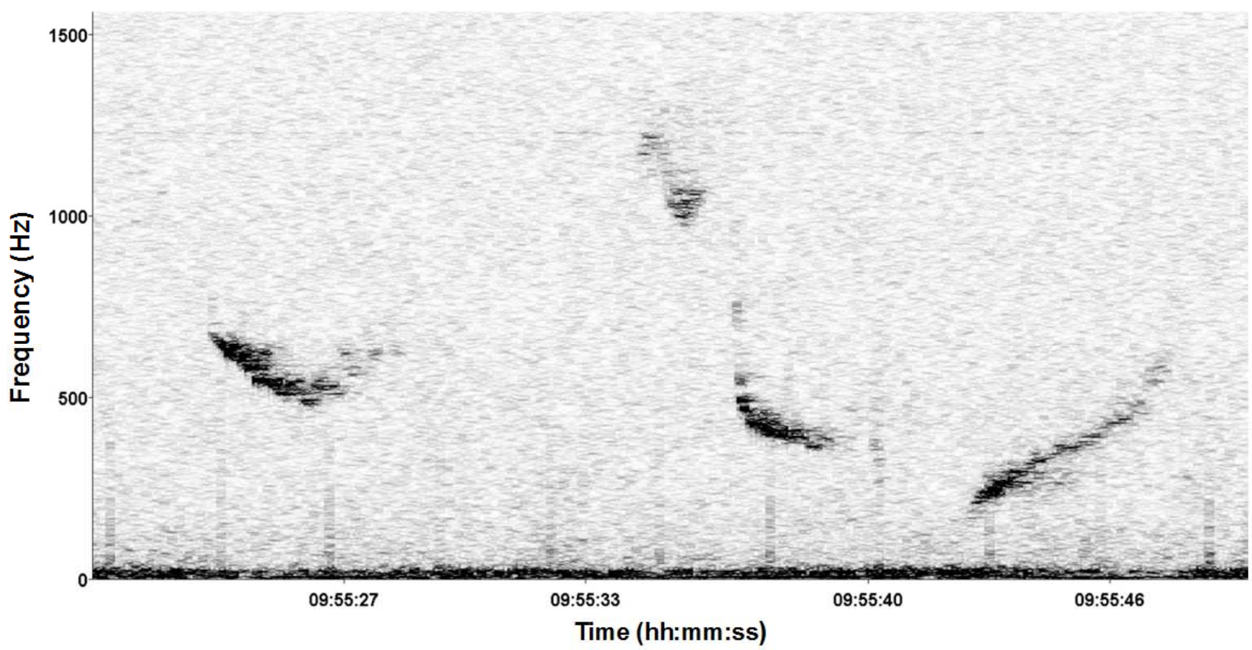


Figure 109. Spectrogram of bearded seal calls detected at Station W20, 10 Oct 2009 (8192-pt FFT, 4096 real pts, 1024-pt advance, Hamming window).

3.3.3.10. Ribbon Seals

Winter 2009–2010 Program

Ribbon seals were detected in the winter 2009-2010 data only on four days between 28 Oct and 16 Nov 2009 at Station CL50.

Little is known about ribbon seals in summer and fall except that they are present in the Chukchi and western Beaufort Seas (Moore and Barrowclough 1984, Kelly 1988). Their presence in the Chukchi Sea in summer has been confirmed by recent satellite tagging experiments by NOAA (Boweng *et al.* 2011), but sightings along the Alaskan Chukchi coast are considered unusual (Moore and Barrowclough 1984) and they are regarded as a pelagic species. The detections in the winter 2009-2010 data are believed to be of migrating animals heading to the Bering Sea.

Two types of calls were detected: (1) intense downsweeping sounds, with or without harmonic structure, corresponding to the short and medium sweeps described by Watkins and Ray (1977); and (2) loud "puffing" sounds, as described by Watkins and Ray (1977) but which sounded rather like a roar (

Figure 110).

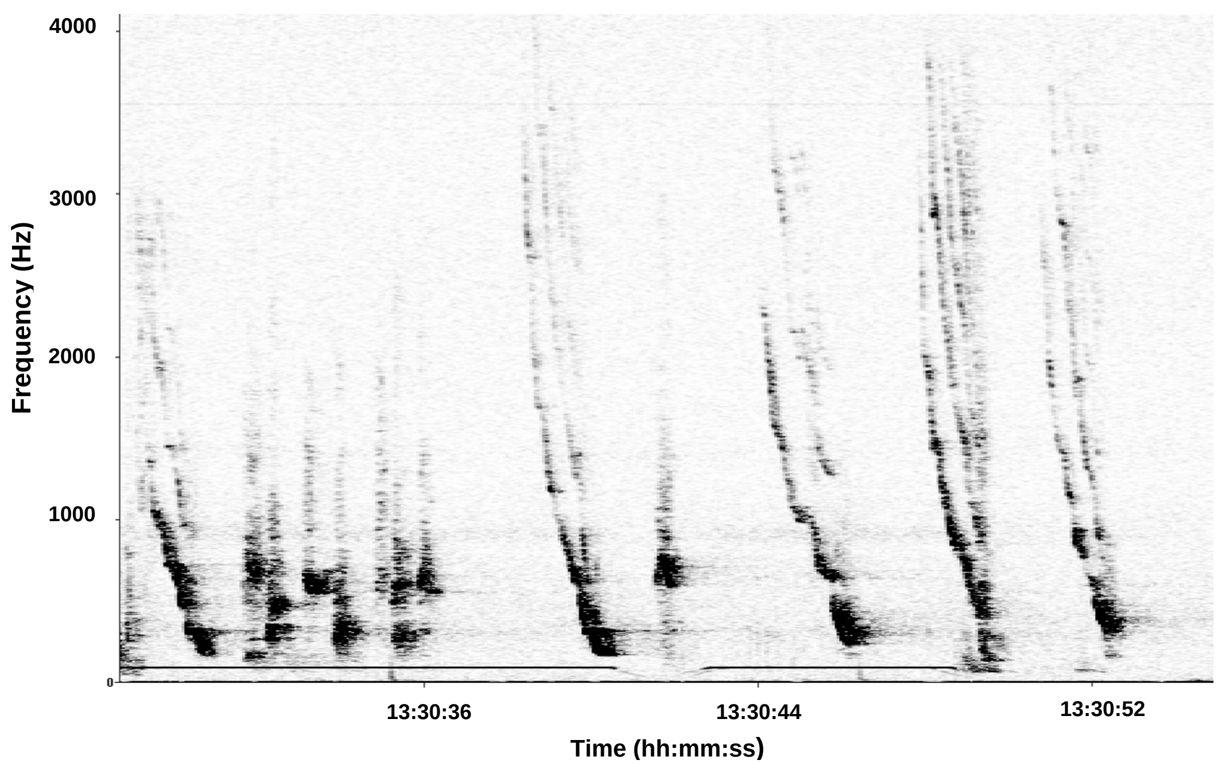


Figure 110. Spectrogram of ribbon seal calls recorded 4 Nov 2008 at Station CL50 (8192-pt FFT, 4096 real pts, 1024-pt advance, Hamming window).

Summer 2010 Program

Ribbon seals were detected once in the summer 2010 data at Station CLN120 on 11 Oct 2010.

3.3.3.11. Ringed Seals

Winter 2009–2010

The first detection of ringed seals in a Chukchi Sea acoustic monitoring program occurred in the winter 2009-2010 data. The absence of ringed seal acoustic detections in previous years' data sets resulted from a lack of knowledge of the types of calls produced by this species. It is not due to the absence of ringed seals from the study area in those years. The calls targeted by the automated detection methods were primarily the bark-yelp sequence (Figure 112; Stirling 1973). Ringed seals probably produce other call types but we felt that descriptions of those call types are not yet reliable enough to use for uniquely and confidently detecting these animals.

Ringed seals were detected at all stations throughout the recording period, although detections decreased dramatically in June and were completely absent in July. The first detection occurred on 31 Oct at Station PL50 and the last one on 9 Jun at WN40. The maximum number of detection days was 25 at CL50 (Figure 111, Table 22). There was no obvious peak in calling rates during the recording period. However, as noted above, the detection probability for this species using the 5% manual analysis protocol is very low (22%), as a result of low calling rates, and the results presented here most likely under-represent the occurrence of ringed seal calls. These results can only be used to demonstrate that some ringed seals are present in the Chukchi Sea in the fall, winter, and spring.

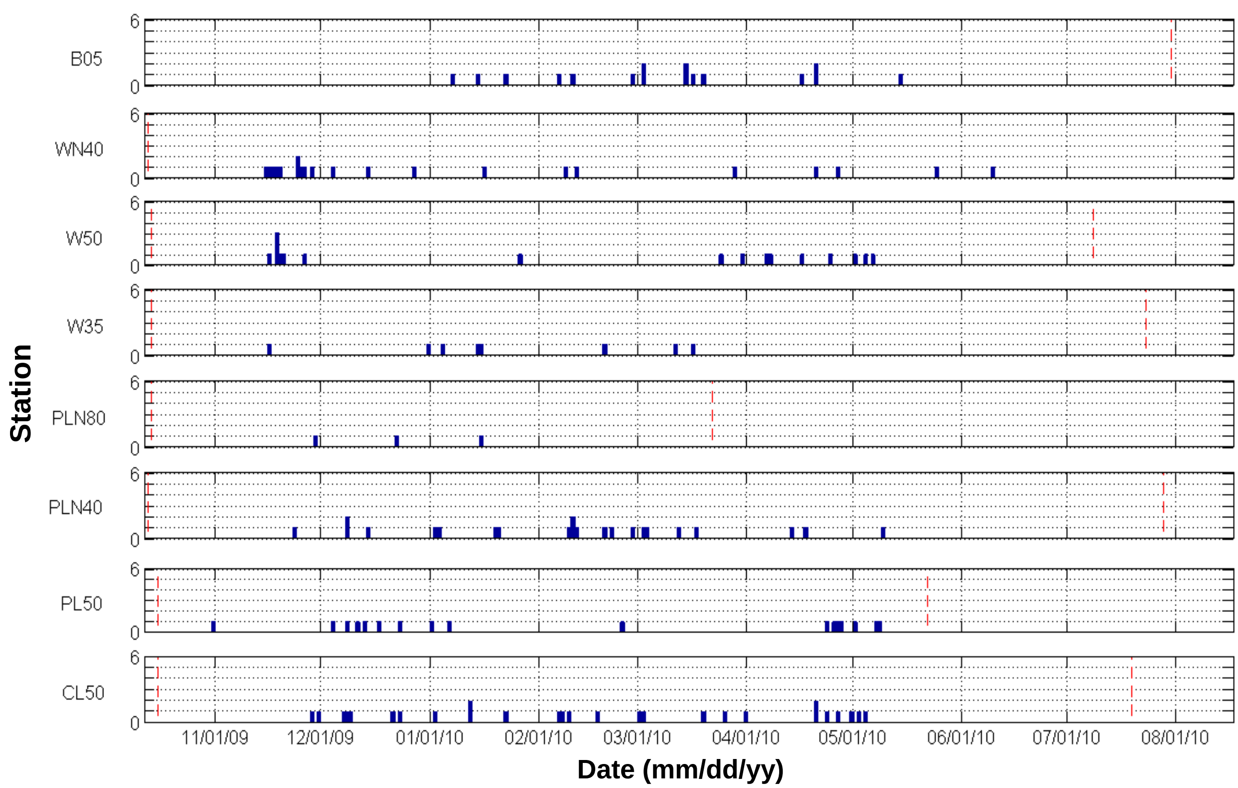


Figure 111. Daily number of sound files with ringed seal detections based on the manual analysis of 5% of acoustic data recorded in the Chukchi Sea from mid-October 2009 to early August 2010. Red dashed lines indicate recording start and end.

Table 22. List of the first and last Ringed Seal acoustic detections, and the total number of detection days at all winter 2009–2010 recording stations.

Ringed Seals					
Station	Record start	First detection	Last detection	Detection days	Record end
B05	12-Oct	7-Jan	14-May	13	29-Jul
WN40	13-Oct	15-Nov	9-Jun	20	17-Aug
W50	14-Oct	16-Nov	6-May	15	7-Jul
W35	14-Oct	16-Nov	16-Mar	8	21-Jul
PLN80	14-Oct	29-Nov	15-Jan	3	21-Mar
PLN40	13-Oct	23-Nov	9-May	20	26-Jul
PL50	16-Oct	31-Oct	8-May	17	21-May
CL50	16-Oct	28-Nov	4-May	25	18-Jul

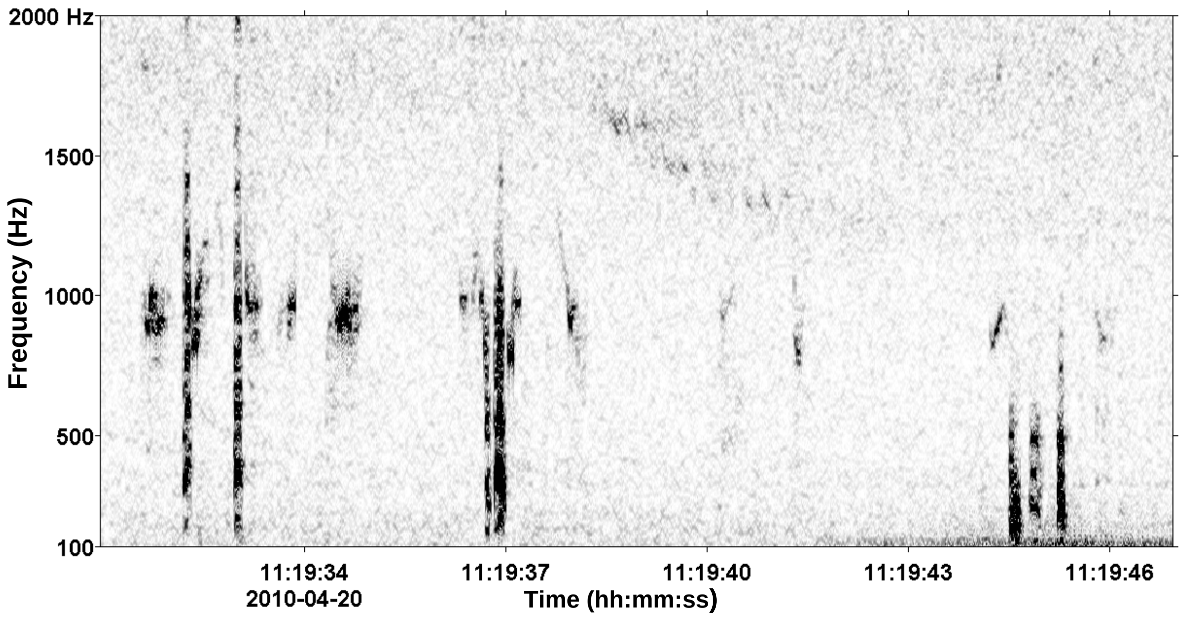


Figure 112. Spectrogram of ringed seal calls recorded 20 Apr 2010 at Station CL50 (2048-pt FFT, 512-pt advance, Hamming window).

Summer 2010 Program

Ringed seals were detected throughout summer 2010 data at all eight stations (Table 23,

Figure 113). The number of detection days at each station was low (1–4) and detections occurred from 27 Jul through 8 Oct. As for the 2009–2010 winter data, detection probability and calling rates were low, and these results underestimate the spatial and possibly temporal distributions of ringed seals in the study area.

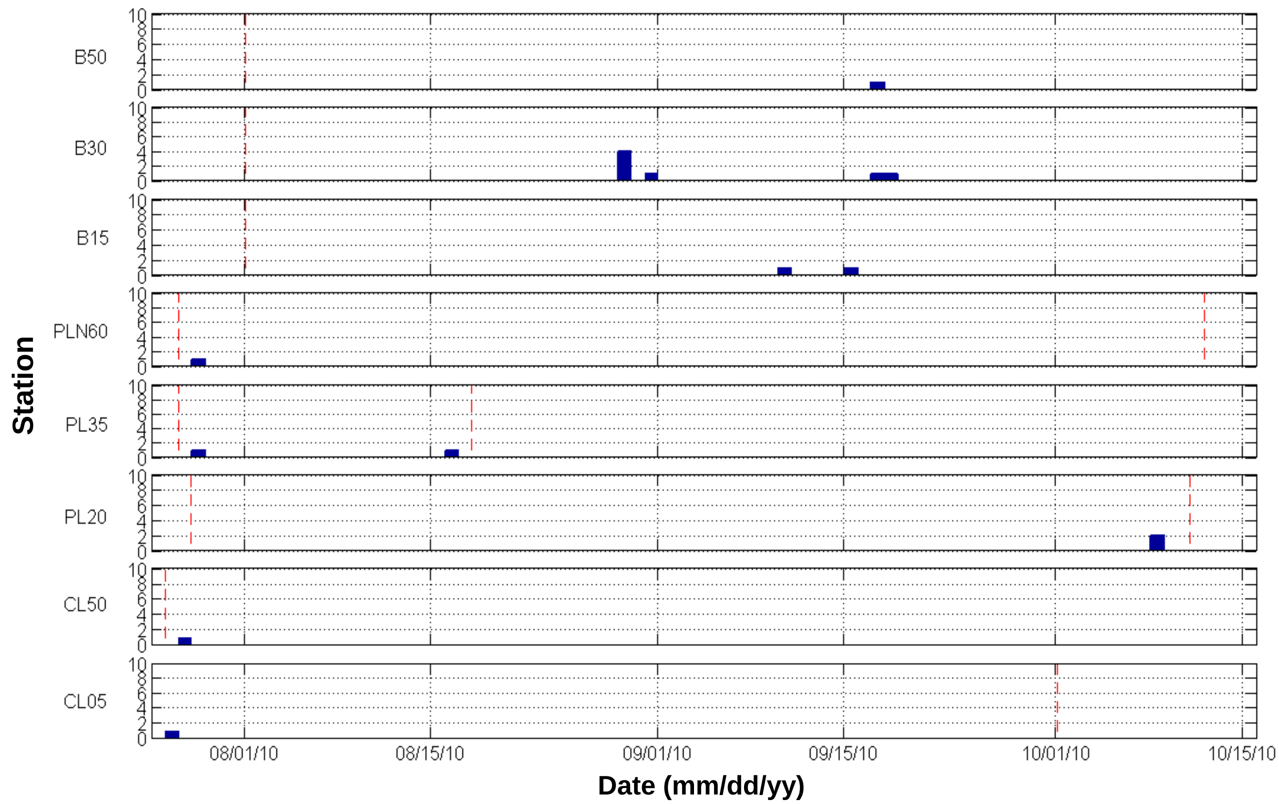


Figure 113. Daily number of sound files with ringed seal detections based on the manual analysis of 5% of acoustic data recorded in the Chukchi Sea, late July to mid-October 2010. Red dashed lines indicate recorder deployment and retrieval.

Table 23. List of the first and last acoustic detections of Ringed Seals, and the total number of detection days at all summer 2010 recording stations.

RINGED SEAL					
Station	Record start	First detection	Last detection	Record end	Detection days
B50	01-Aug	17-Sep	17-Sep	16-Oct	1
B30	01-Aug	29-Aug	18-Sep	16-Oct	4
B15	01-Aug	10-Sep	15-Sep	16-Oct	2
PLN60	27-Jul	28-Jul	28-Jul	11-Oct	1
PL35	27-Jul	28-Jul	16-Aug	17-Aug	2
PL20	28-Jul	08-Oct	08-Oct	10-Oct	1
CL50	26-Jul	27-Jul	27-Jul	15-Oct	1
CL05	25-Jul	26-Jul	26-Jul	30-Sep	1

3.3.3.12. Spotted Seals

Winter 2009–2010 Program

While bearded, ribbon and ringed seals were detected in the winter 2009–2010 program data, the lack of spotted seal detections can at least partly be explained by the lack of knowledge regarding their calls and should not be used to infer that they are absent from the study area.

Summer 2010 Program

Similar to the winter, bearded, ringed and ribbon seals were detected in the summer 2010 data. The lack of spotted seal detections can at least partly be explained by the lack of knowledge regarding their calls and should not be used to infer that they are absent from the study area. In fact, spotted seals are regularly sighted in the study area in summer (*e.g.,* Funk *et al.* 2009). Dedicated recorders placed near known spotted seal summer haul-outs (*e.g.,* in Kasegaluk Lagoon passes; Frost *et al.* 1993) could allow researchers to gain a better understanding of their calls, which will aid in assessing the validity of surveying this species acoustically. If their call types could be identified, the 2007-2011 Chukchi acoustic datasets could be reanalyzed for the purpose of determining spatial and temporal distributions of Spotted Seals.

3.4. Effects of Seismic Sound on Marine Mammals

The effects of airgun noise on walrus and bowhead whale call detections during the 21 Aug to 1 Oct 2010 Statoil 3-D seismic survey (using a 3000 in^3 airgun array) were investigated. The effects on walrus are of interest because walrus are the most commonly detected species during the seismic survey time period. Few bowheads are thought to be in the Chukchi until late September, so only a short overlap of the seismic program and bowhead migration of approximately one week was expected. The summer 2009 program measurements indicated an absence of walrus call detections at the Burger prospect area while airgun sounds associated with a shallow-hazard survey were detected (Delarue *et al.* 2010*b*). The effects of airgun sounds on bowhead calling behavior during fall migration in the Beaufort Sea were investigated in a related study (Blackwell et al., 2010).

3.4.1. Walrus

Figure 114 to Figure 118 show the occurrence of walrus calls detected by manual analysis of the data as a function of 30-min average airgun pulse rms-90 SPL at five stations during selected periods of the Statoil seismic survey. All call types were annotated but most of the calls encountered were grunts and snorts (Table 4). Stations PLN80 and SO01 were within the Statoil seismic survey area and experienced the highest seismic SPLs. Stations PLN60, BG01, and WN20 were outside the Statoil survey area at increasing distances from the survey area, and therefore received airgun pulses at increasingly lower SPLs. The repeated rise and fall of SPLs at each station corresponds to the movement of the seismic vessel toward and away from, the recording stations. At Stations PLN80 and SO01, walrus calls were for the most part only detected when the airgun pulse SPLs were at their lowest levels, near 120 dB re 1 µPa (Figure 114, Figure 115); few calls were detected after SPL reached a certain threshold (described below). This pattern is still observed, though is less pronounced, at Station PLN60 (Figure 116). It is less apparent at Station BG01 (Figure 117), where walrus were more continuously detected. Airgun pulses did not seem to have any effects on walrus call detection rates at WN20 (Figure 118), where airgun pulse SPLs rarely exceeded 130 dB re 1 µPa (rms-90).

The overall effect is a negative trend between walrus call detection probability and the airgun pulse SPL (Table 8). To evaluate the seismic SPL threshold at which walrus acoustic detections begin to decrease, we examined the distribution of the number of files with both walrus and seismic detections as a function of 30 min rms SPL average for Stations PLN60, PLN80, and SO01. 100%, 99%, and 92% of detections, at these respective stations, occurred when airgun pulse SPL were below 140 dB re 1 µPa (Table 24). The distribution of the number of files with both walrus and seismic detections as a function of airgun SPLs was found to be independent of the distribution of the per-file airgun pulse SPL averages for all sound files within the survey period (Chi-square test, $p < 0.001$, all stations except WN20, $p = 0.102$). This suggests that the observed distribution of acoustic detections is non-random. Very few calls are detected when mean airgun pulse SPL is near 140 dB re 1 µPa (rms-90).

Seismic survey sound levels were determined at the recorders' locations and the walrus producing the effected calls may have been exposed to slightly different SPL's. Walrus calls can be detected in some cases to several kilometers distance. Received seismic survey SPL levels of 140 dB re 1 µPa (rms-90) occurred at distances of between 32 and 52 km (20 - 32 mi) from the survey, depending on direction relative to the tow direction of airgun array (O'Neill et al., 2010). Higher sound levels are produced to the sides of the array than to its front and back. The observed reduction in call detections occurred at more than 32 km (20 mi) from the airgun array. Funk et al. (2007, 2009) observed reduced walrus density within 1 km (0.6 mi) of a shallow hazards survey airgun source relative to the densities at 1 to 15 km (0.6 - 9 mi). This finding suggests walrus might move away from high seismic survey sound levels. The distances corresponding to the reduced call detection effects observed here are well beyond the distances examined by Funk et al., and it is unlikely that moderate walrus movements at those distances could achieve significant reduction in sound exposures. The observation of resumption of call detections on subsequent seismic sound level minima, typically less than 15 hours apart, suggests that walrus did not leave the area during the passes of the survey vessel that produced the higher sound levels.

The reduction of detected walrus calls with increased received airgun pulse SPLs may be influenced both by reduced ability to detect calls caused by masking by the seismic noise, and by changes to walrus' calling behavior. Changes in calling behavior that could cause this observation include reduction of call amplitudes and/or reduction of calling rates. The movement of walruses out of detection range from the recorders could also produce a similar effect, although reduction of detections occurred when the seismic vessel was more than 40 km distant, and consequently the net movement of walruses would likely not change their densities near the recording stations. The actual cause of the reduced call detection rates is likely a combination of call production rate reduction and masking. To assess the influence of masking, we created 12 test datasets by adding actual seismic acoustic data to sample periods of walrus detections. The test datasets included three nominal walrus sound levels (weak, intermediate and strong) and four seismic masking sound levels: (no-seismic, 120, 130 and 140 dB re 1 μPa_{rms90}). All 12 datasets were passed to three separate analysts who were asked to manually detect walrus calls using the same protocols applied in the original analyses. The results between analysts were highly consistent; weak walrus call detections were reduced by more than 90% in the presence of the 120 dB re 1 µPa seismic noise and by at least 95% at 130 dB re 1 µPa. Intermediate walrus call detection rates were reduced by 60% for both the 120 and 130 dB re 1 µPa noise and by 75% by the 140 dB re 1 µPa noise level. Detection rates of strong walrus calls were reduced by 20%, 30% and 40% by the respective addition of 120, 130 and 140 dB re 1 µPa seismic noise levels. This finding suggests that masking is responsible for the majority of walrus call detection rate reductions observed, but it may not explain the full reduction. A more careful analysis of the distribution of received walrus call amplitudes must be carried out to confirm that call production rates or calling amplitudes are reduced in the presence of seismic survey noise.

The biological significance of these observations is currently unknown. Some of the reduction in call detections may be due to masking of the calls by the higher seismic sound levels; masking occurs when seismic signals obscure the calls, making them more difficult to detect both audibly and in spectrograms. Masking also reduces walrus' ability to hear calls produced by other walrus. The more careful examination of acoustic data during periods of higher seismic levels, discussed above, found few additional calls. This suggests that reduced call detection rates are at least partially due reduced call production (either in rate or amplitude). Mothers and calves have been found to rely almost exclusively on acoustic cues to maintain their association (Charrier *et al.* 2010). When separated, and upon reuniting, they exchange individual-specific barks (Miller 1985). In-air and underwater calls are also used to maintain herd integrity (Miller 1985, Charrier *et al.* 2010). Thus, possible consequences of masking and/or vocal reductions (either in rate or amplitude) may be that herd members or mother-calf pairs could become separated. More analysis of these potential affects is warranted.

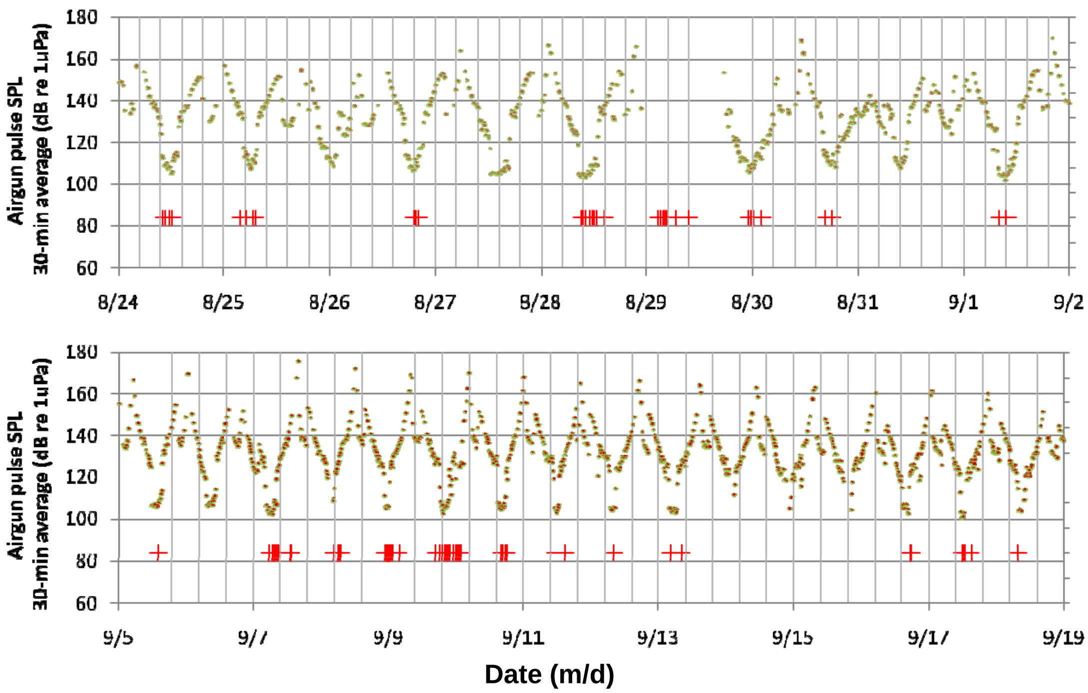


Figure 114. Occurrence of walrus calls (+) detected by manual analysis of 5% of each 30 min data file and airgun pulse sound pressure levels (rms pulse SPL, 30 min average, ●) at Station PLN80 during selected periods of the summer 2010 program in the Chukchi Sea.

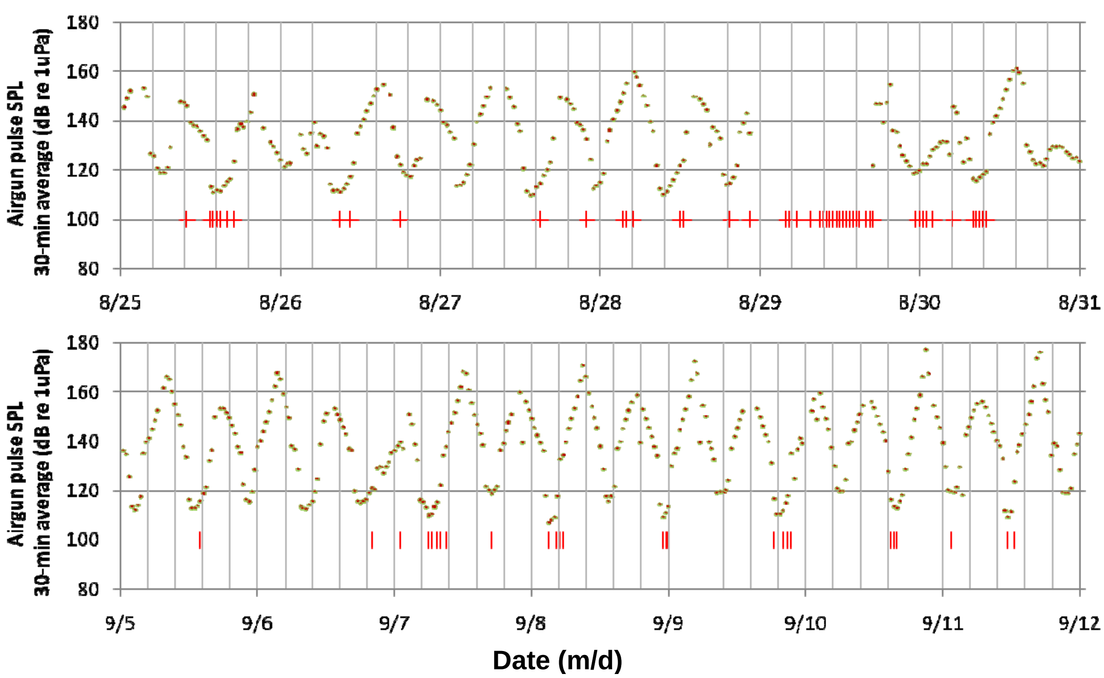


Figure 115. Occurrence of walrus calls (+) detected by manual analysis of 5% of the data and airgun pulse sound pressure levels (rms SPL, 30 min average, ●) at Station SO01 during selected periods of the summer 2010program in the Chukchi Sea.

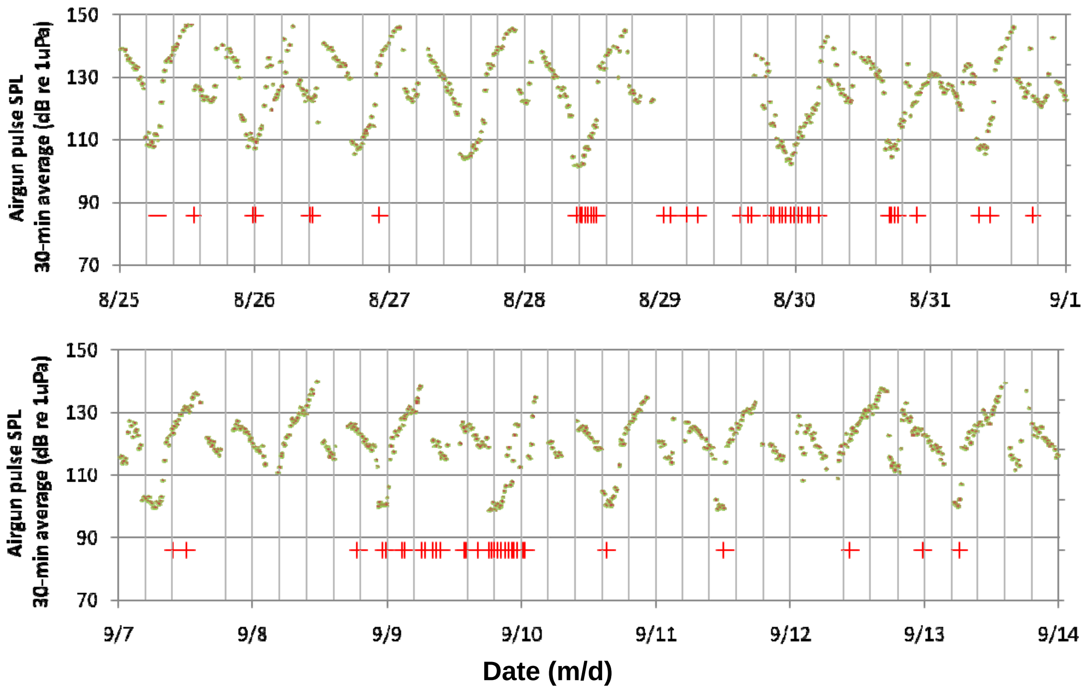


Figure 116. Occurrence of walrus calls (+) detected by manual analysis of 5% of the data and airgun pulse sound pressure levels (rms SPL, 30 min average, ●) at Station PLN60 during selected periods of the summer 2010program in the Chukchi Sea.

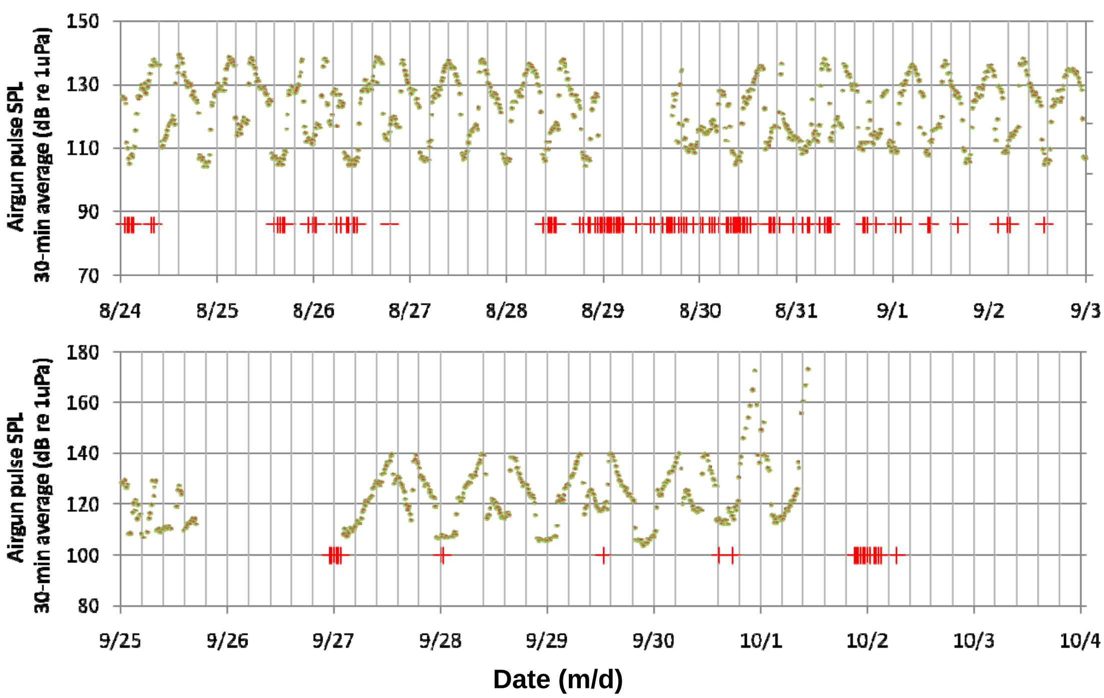


Figure 117. Occurrence of walrus calls (+) detected by manual analysis of 5% of the data and airgun pulse sound pressure levels (rms SPL, 30 min average, ●) at Station BG01 during selected periods of the summer 2010 program in the Chukchi Sea.

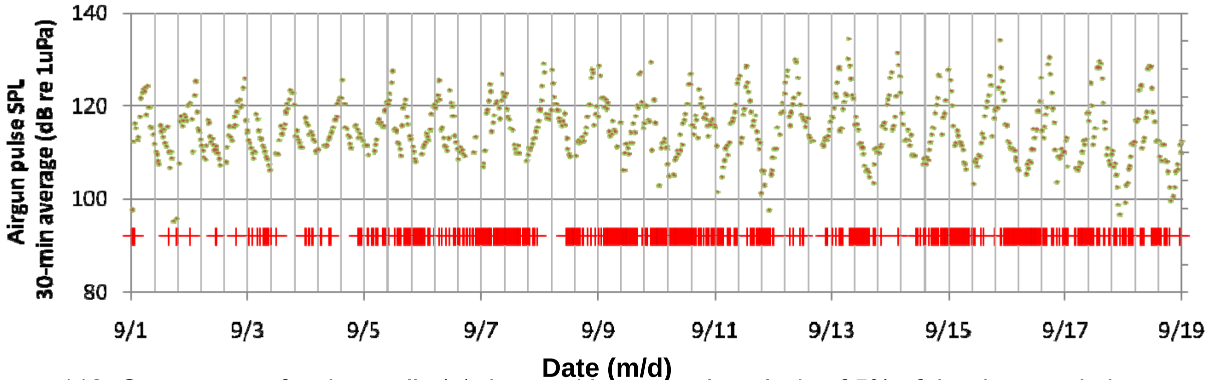


Figure 118. Occurrence of walrus calls (+) detected by manual analysis of 5% of the data and airgun pulse sound pressure levels (rms SPL, 30 min average, ●) at Station WN20 during a selected period of the summer 2010 program in the Chukchi Sea.

Table 24. Listing of the cumulative percentage of sound files with both walrus and seismic detections occurring at airgun pulse rms SPL below selected values, total number of sound files included and maximum airgun pulse SPL at SO01, PLN80 and PLN60 during the 3-D seismic survey conducted at Statoil's lease area between 21 Aug and 1 Oct 2010 in the Chukchi Sea.

rms SPL (dB re 1 µPa)	Cumulative Proportion (%)		
	SO01	PLN80	PLN60
100–110	0	0	6
110	5	53	45
120	58	71	71
130	77	90	97
140	92	99	100
150	95	100	100
160	100	100	100
n	**60**	**78**	**66**
MAX SPL	**178**	**180**	**152**

3.4.2. Bowhead whales

Bowhead presence was examined during Statoil's 3-D seismic survey from 21 Aug through 1 Oct 2010. No bowheads were detected in August (except in the last few days at the Barrow stations). Weekly bowhead whale call counts for September at all analyzed summer 2010 stations are shown in Figure 119 through Figure 122. During the first week of September, acoustic detections occurred at three of the four Barrow stations (Figure 119). By mid-September, bowheads reached the Wainwright stations, including WN40, and the Burger cluster array (Figure 120). During the third week of September, bowhead calls were detected as far west as the northern Cape Lisburne stations (CLN90 and CLN120; Figure 121). No bowhead calls were detected at the two stations within the Statoil seismic survey area (PLN80 and SO01) during this week, although all the neighboring stations to the east, south and west did record bowhead calls. In the last week of September, call counts increased off Barrow and bowheads were finally detected at Stations PLN80 and SO01 (Figure 122), but only once at each station (26 Sep at SO01 and 30 Sep at PLN80). By then, the seismic vessel was at the southern edge of the survey area, and the received rms sound pressure levels at Stations PLN80 and SO01 would have been 140–150 dB re 1 µPa. After the survey was complete, bowhead call detection rates at these two stations returned to values similar to those at adjacent stations (Figure 48).

These observations could be a result of several causes; bowheads may have avoided the Statoil survey area while the survey remained in progress, they may have reduced call production rates or amplitude, or seismic noise masking could have reduced the ability to detect calls. The influence of masking due to seismic noise is discussed in Section 3.2 with reference to reductions of walrus detection rates that were correlated with seismic sound level. Call detection rates at stations PLN80 and SO01 may therefore have been lowered by seismic sound masking. Bowheads migrating in the fall in the Beaufort Sea have been shown to either display reduced calling rates or course changes as a result of exposure to airgun sounds (Blackwell *et al.* 2010). Although a direct correlation between call counts and abundance has not been established for bowheads, low call counts at most stations likely indicate that few bowheads were transiting through the Chukchi Sea at that time. The first significant wave of migrants to the survey area did not start until 7 October, after the completion of the survey.

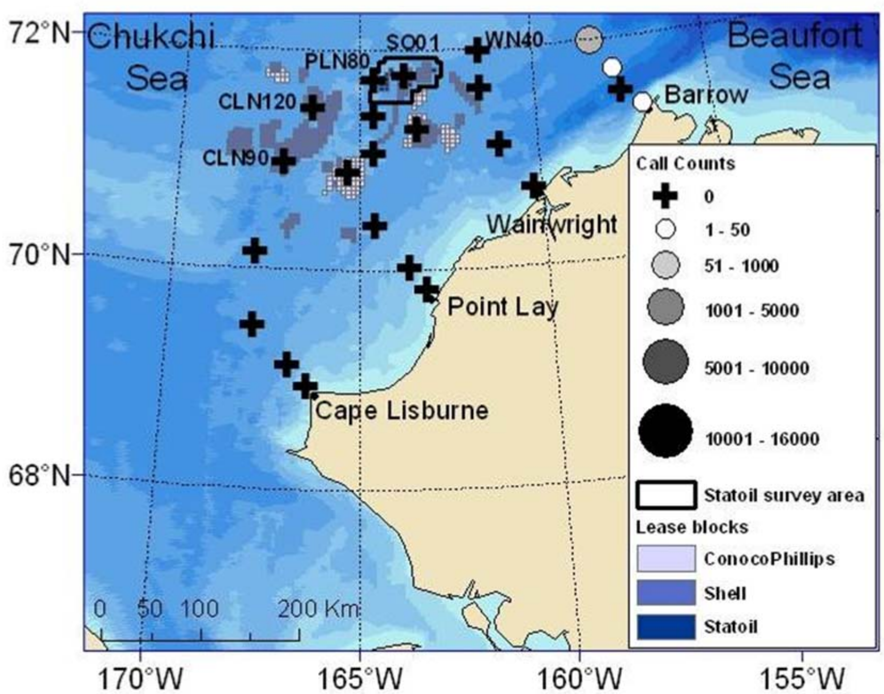


Figure 119. 1–7 Sep 2010: Bowhead whale call count estimates in the Chukchi Sea based on manual and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.

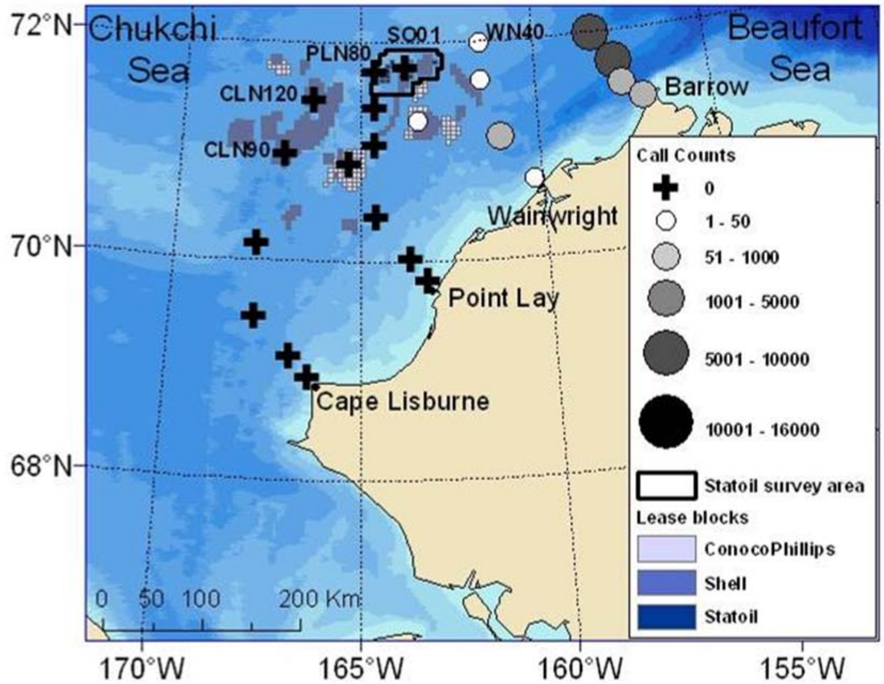


Figure 120. 8–15 Sep 2010: Bowhead whale call count estimates in the Chukchi Sea based on manual and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.

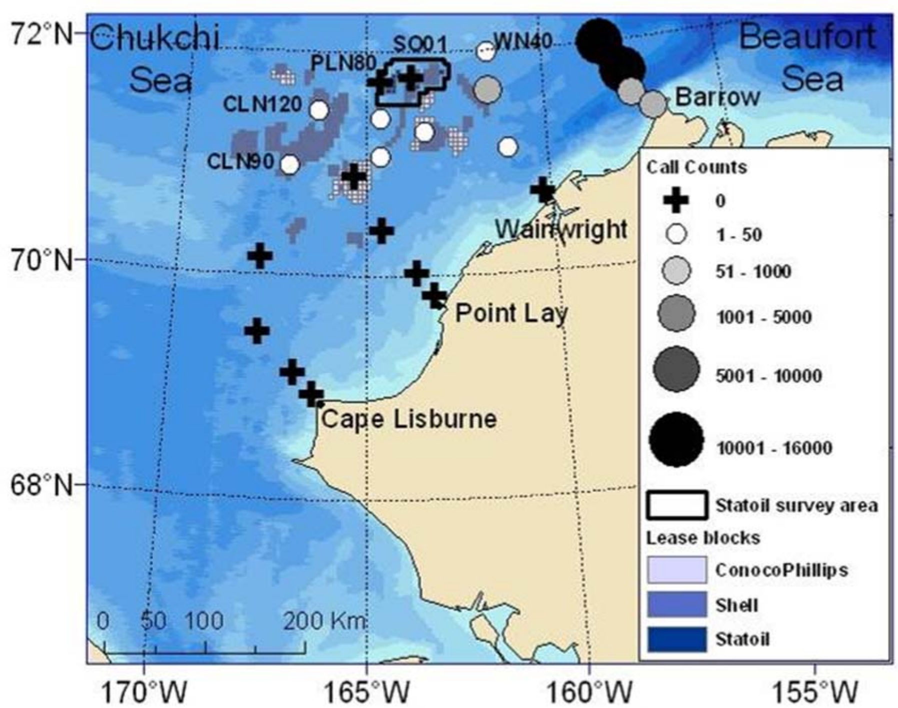


Figure 121. 16–23 Sep 2010: Bowhead whale call count estimates in the Chukchi Sea based on manual and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.

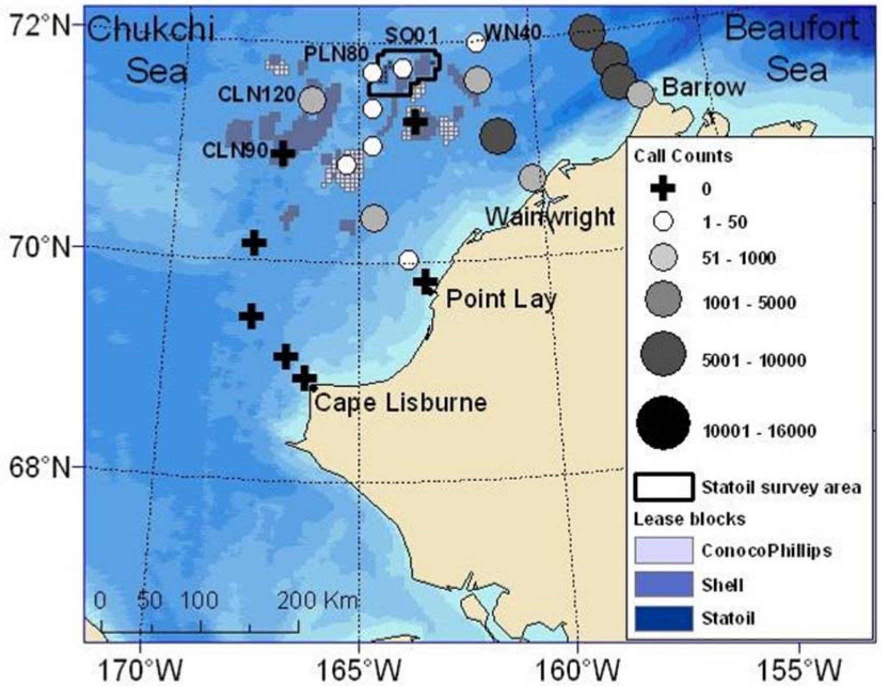


Figure 122. 24–30 Sep 2010: Bowhead whale call count estimates in the Chukchi Sea based on manual and automated call detections at the summer 2010 recording stations. Shades of blue represent bathymetry.

3.5. Vessel Noise Detections, Summer 2010 Program

Vessel noise was detected from the ships *Westward Wind* and *Norseman II* chartered by Olgoonik-Fairweather for the Joint Science Program sponsored by ConocoPhillips, Shell and Statoil, and by Statoil's 3-D seismic survey vessel *Geo-Celtic* and support/PAM vessel *Norseman I*. A large amount of vessel activity was also detected near Barrow, but the source of those detections is presently unknown.

3.5.1. Tonal Detections

Figure 123 shows a spectrogram of a recording of noise from the Joint Science Program vessel *M/V Westward Wind* near Station PLN40 on 29 Jul 2010. The figure exhibits the typical Lloyd's mirror interference pattern that occurs at the closest point of approach (CPA) to a recorder.

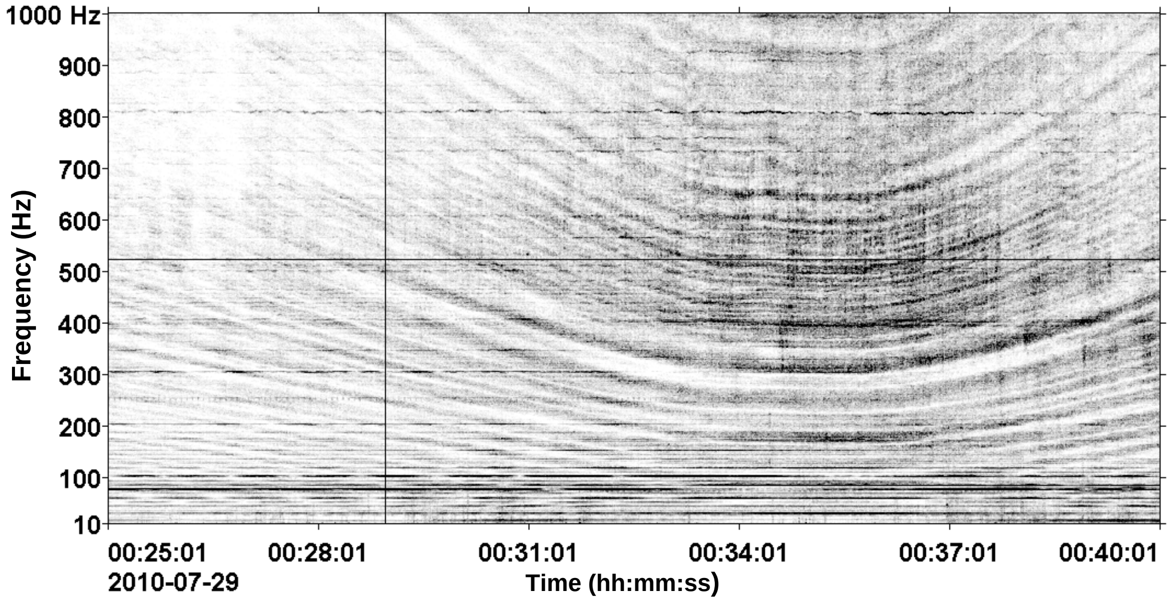


Figure 123. Spectrogram exhibiting narrow-band tonals (horizontal banding) from the *Westward Wind*, recorded at PLN40, 29 Jul 2010. The curved pattern is known as a Lloyd's mirror interference pattern, where the vessel's CPA is at the inflection point (8192-pt FFT, 8192 data pts, 4096 pts advance, Hamming window).

The automated vessel detector (described in Section 2.2.2.3) detects steady tonal frequencies that are produced by transiting vessels. The tones appear as horizontal lines in spectrograms and several can be seen, for example, in the spectrogram of noise from the *M/V Westward Wind* in Figure 123. A sample of detected tonal counts across a line of recorders near the top of the regional array is shown in Figure 124. Regular vessel detections in the vicinity of Stations PLN80–S01, were attributed to the science program vessels and the Statoil seismic survey vessel *Geo-Celtic* during the period of August 22 – September 30. Fewer vessel detections were made at Stations CLN120 and WN20, which were not regularly sampled as part of the science program, and were far enough from the seismic survey to not detect survey vessels. Detections of vessels associated with the seismic survey can be seen at Stations PLN80 and S01 as well. The weather in late September was particularly stormy, and noise from wind and waves masked vessel sounds, thereby limiting the number of detections during that period. Detections of the *Norseman I* near PLN80 and S01 on 1 and 2 Oct as part of Statoil's towed Passive Acoustic Monitoring project were observed.

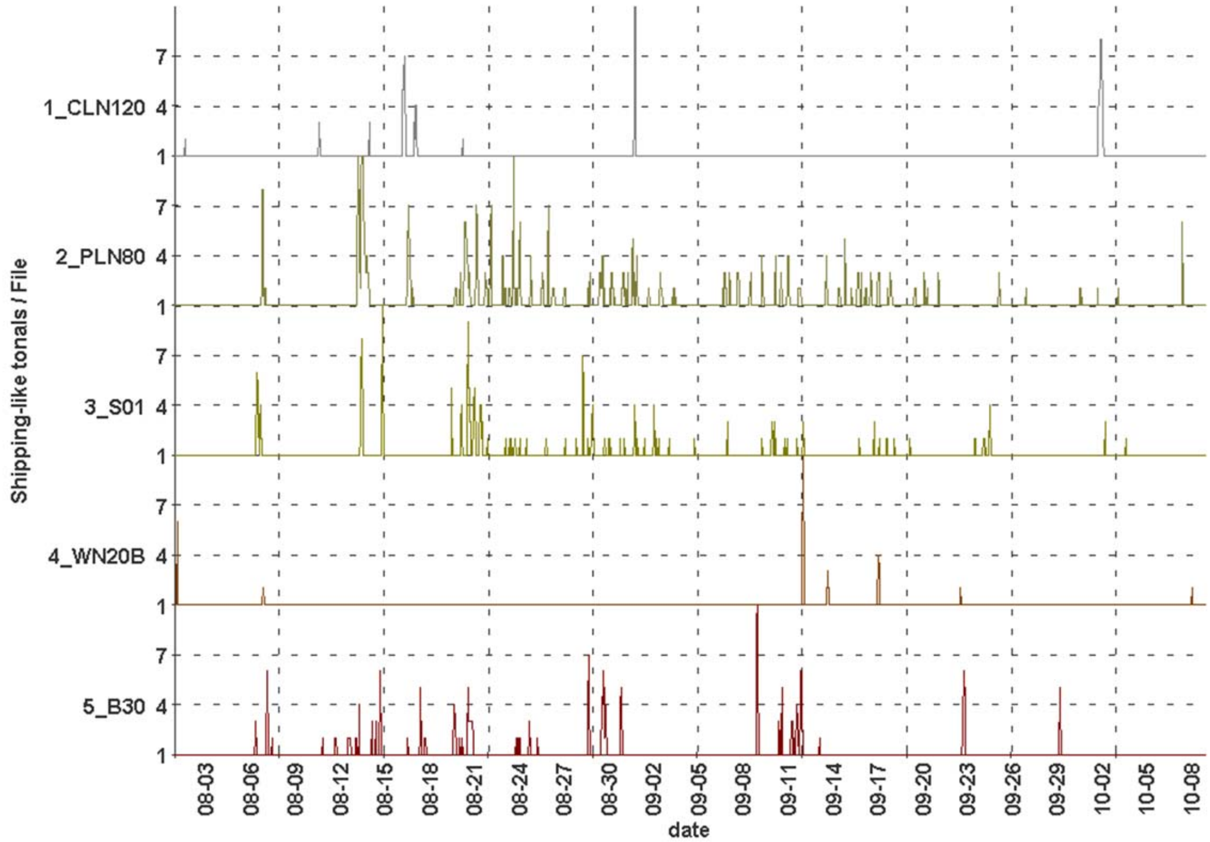


Figure 124. Number of vessel tones detected (per 30 minute file) from 5 recorders in the period 1 Aug to 10 Oct 2010.

The total vessel tone detections at each station have been displayed on a contour map in Figure 125 that represents total vessel activities detected throughout the summer 2010 recording period.

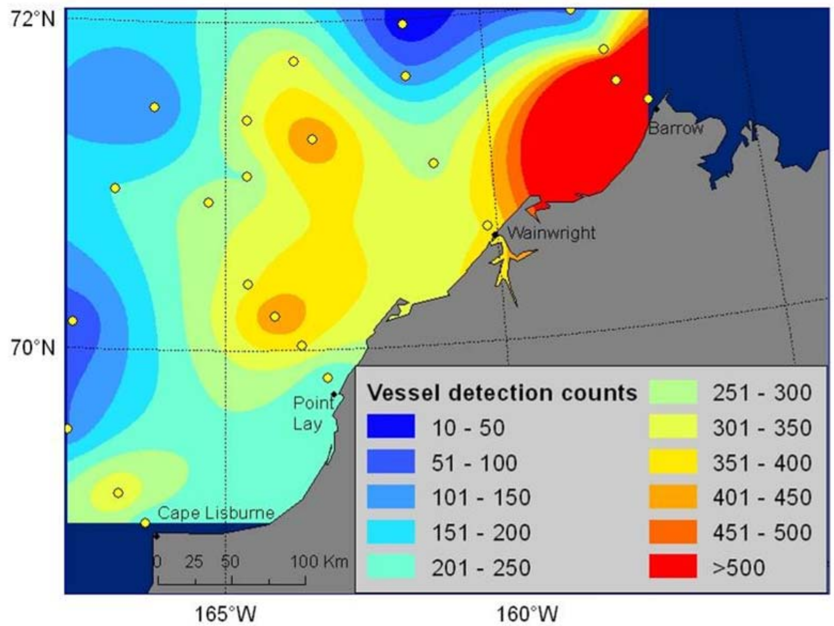


Figure 125. Total detections of shipping throughout the Chukchi, 1 Aug to 10 Oct 2010. Units are the number of 15 min intervals in which shipping was detected. The total number of intervals was 6820. The peak value at Station B05 was 1245, or 18% of the recorded time period.

The number of tonals detected at B05 as a function of time is shown in

Figure 126. There are nearly constant detections from 11–24 Aug which are likely associated with the *Annika Marie* preparing for and performing the BOWFEST/AON survey. Analysis of the vessel acoustic signature that produced these detections indicates the vessel was equipped with twin screws and either six or 12 cylinder engines. The *Annika Marie* matches that description. The BOWFEST/AON survey occurred on schedule from 19 Aug to 18 Sep (pers. comm., Carin Ashjian) with tracklines directly over and to the east of the Barrow recording stations.

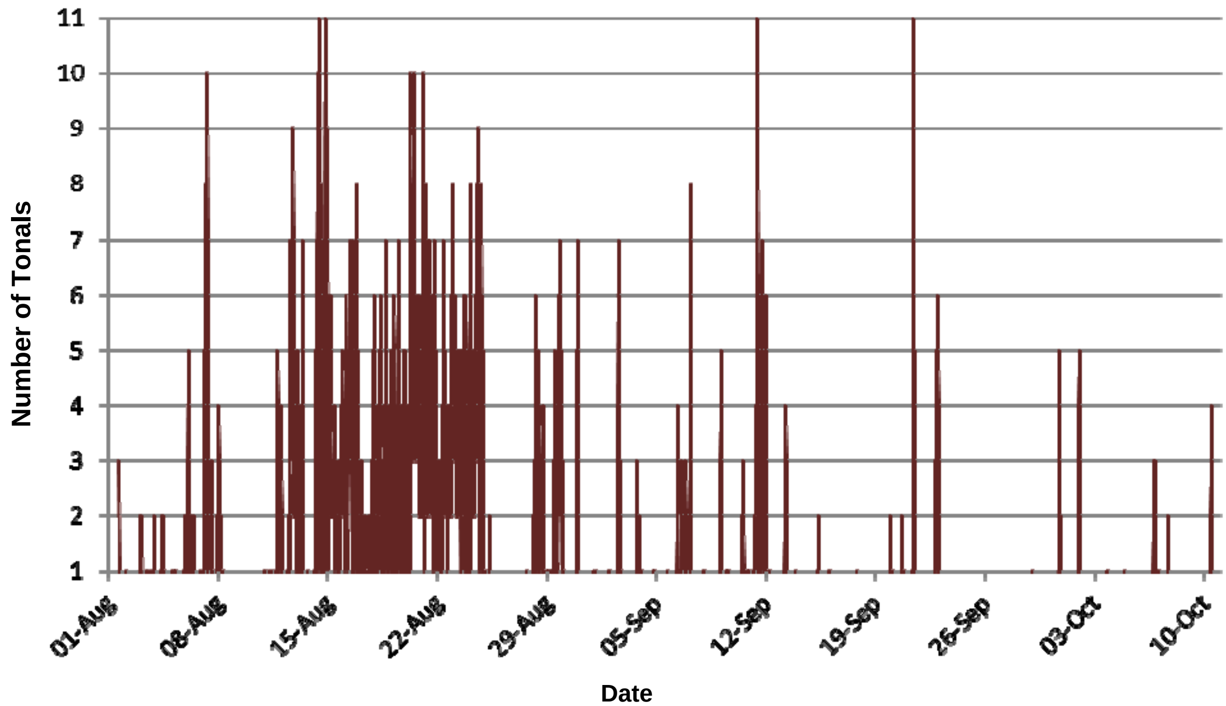


Figure 126. Tonal detections at B05. Vertical axis is the number of tonals detected per 15-min interval of time.

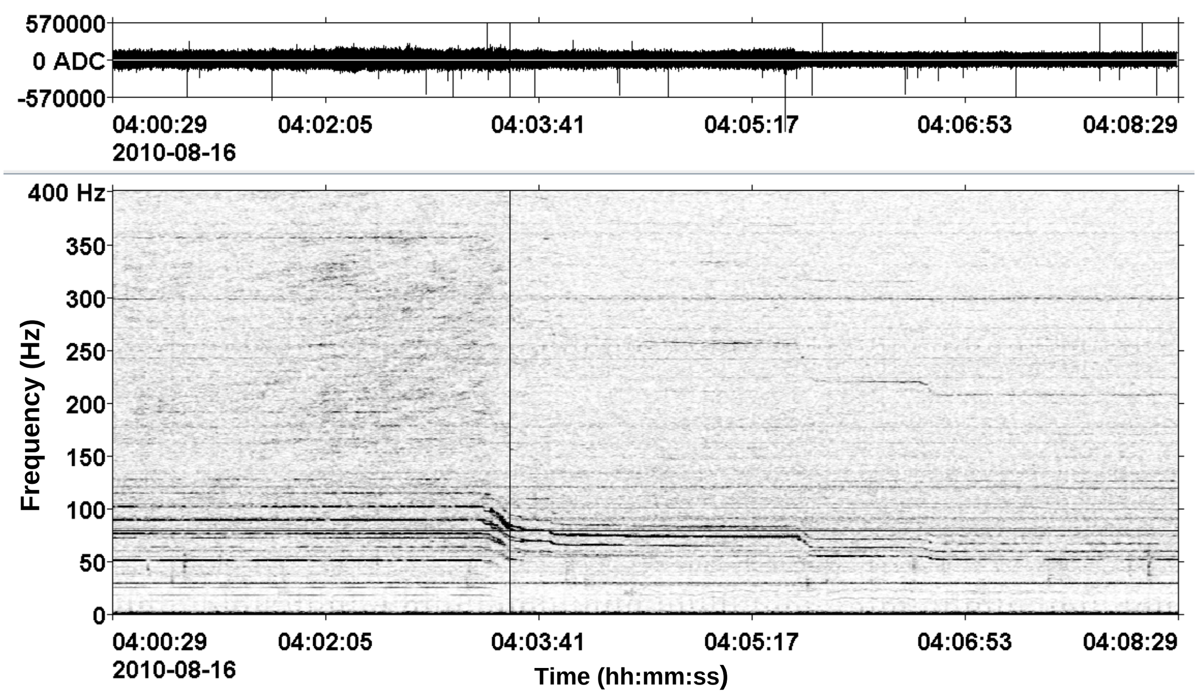


Figure 127: Pressure versus time (top) and spectrogram (bottom) of a vessel detected multiple times at Station B05 from 11–24 Aug 2010 (16384 point FFT, 16384 real data points, 2048 point advance, Hamming window).

3.6. Bowhead Acoustic Localization, Summer 2010 Program

Table 25 lists the daily number of bowhead calls associated (detected simultaneously on more than one recorder) and localized (step three in Section 2.2.4). The total number of calls processed as potential locations were 7929 for Burger, 6334 for Klondike and 3572 for Statoil cluster arrays.

Bowhead calls detected on the Burger, Klondike and Statoil cluster arrays for the 1 Oct to 12 Oct period were localized. One recorder in the Burger cluster array (BG03) stopped recording on 11 Sep 2010 so it was not included in this analysis. Location analysis yielded 2119 accurate locations (See Appendix B) for Burger, 1761 for Klondike and 572 for Statoil cluster arrays (Table 26). Figure 128, Figure 129 and Figure 130 show bowhead acoustic locations for the Burger, Klondike and Statoil cluster arrays.

A first pulse of bowhead calls were detected and localized at Burger and Klondike on 2 Oct, 2010. This was followed by a period of fewer detections from 3 – 6 Oct. A second pulse of detections and localizations occurred at all three cluster arrays on 7 - 12 Oct. The number of associations (detections that could not be accurately localized – See Appendix B) and accurate localizations are presented for each day from 1-12 Oct for the three arrays in Figure 131 to Figure 133. Overall, accurate locations were obtained from 23.5% of the associated bowhead call detections.

Table 25. Number of associated bowhead calls per day for the period 1-12 Oct, 2010 within the Burger, Klondike and Statoil cluster arrays.

Date	Burger	Klondike	Statoil
Oct 1	12	94	0
Oct 2	126	60	0
Oct 3	0	5	0
Oct 4	0	2	0
Oct 5	0	3	0
Oct 6	2	4	0
Oct 7	636	1445	129
Oct 8	2611	1579	110
Oct 9	2492	2017	1807
Oct 10	1342	703	517
Oct 11	510	400	779
Oct 12	198	22	230
Total	**7929**	**6334**	**3572**

Table 26. Number of bowhead calls localized for the period 1-12 Oct, 2010 on the Burger, Klondike and Statoil cluster arrays.

Date	Burger	Klondike	Statoil
Oct 1	0	41	0
Oct 2	33	25	0
Oct 3	0	0	0
Oct 4	0	0	0
Oct 5	0	1	0
Oct 6	0	0	0
Oct 7	185	576	18
Oct 8	743	546	20
Oct 9	527	421	375
Oct 10	382	124	70
Oct 11	190	27	69
Oct 12	59	0	20
Total	**2119**	**1761**	**572**

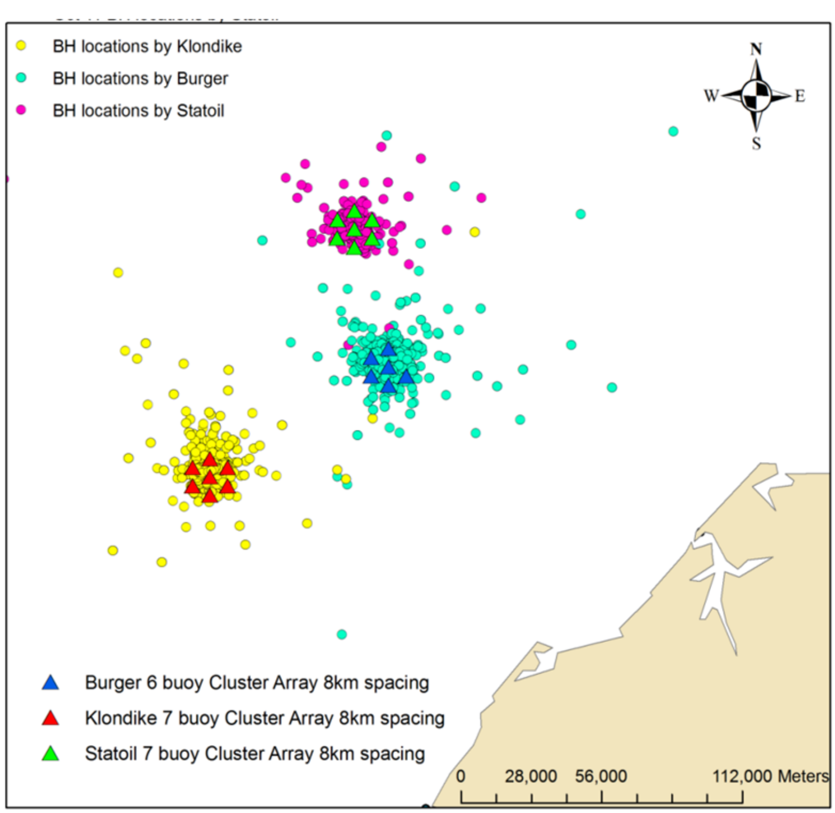


Figure 128. Bowhead call localizations within the Burger, Klondike and Statoil cluster arrays, for the period of 1 – 12 Oct, 2010.

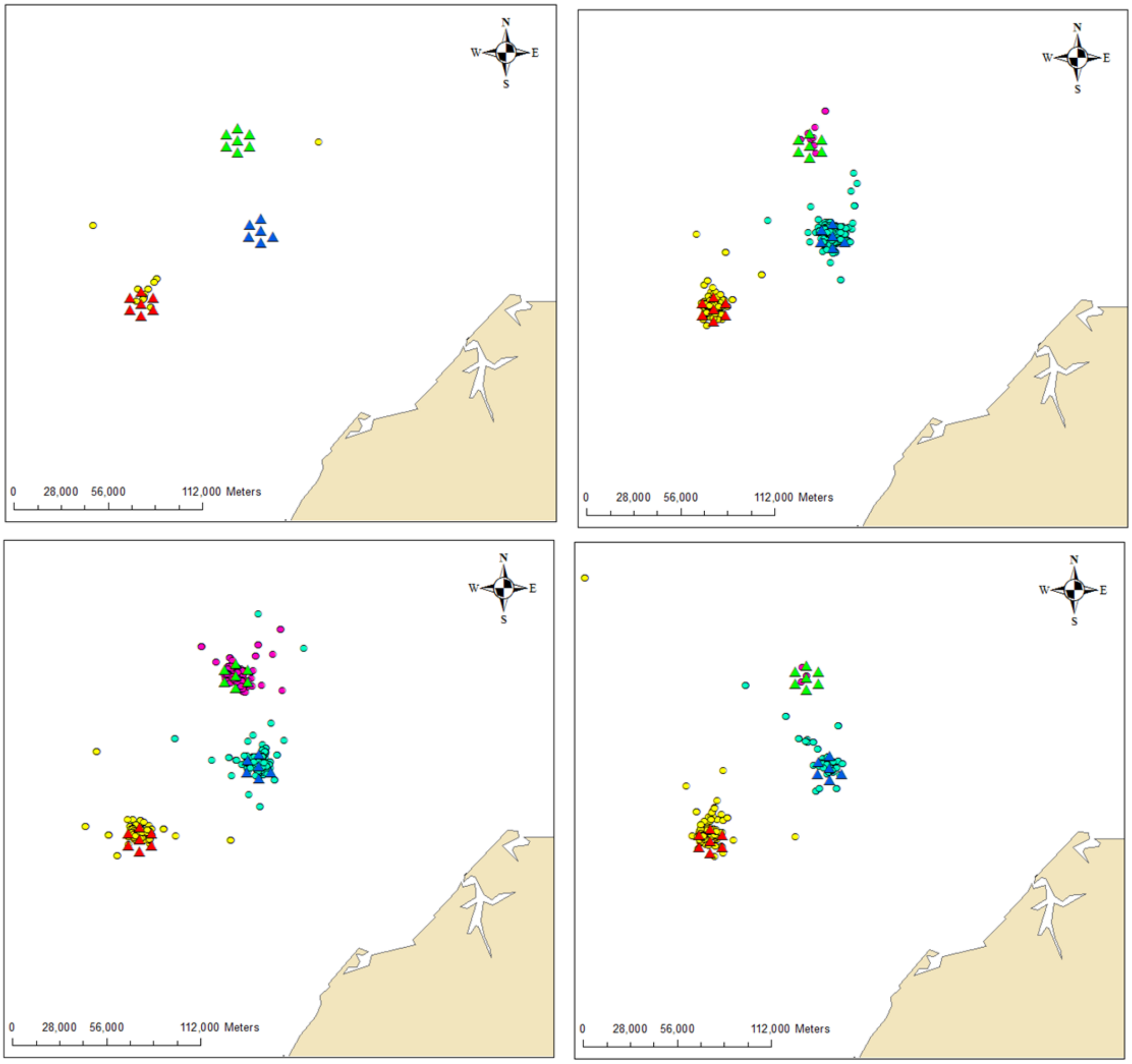


Figure 129. Bowhead call localizations within the Burger, Klondike and Statoil cluster arrays. From left top to right bottom (1 Oct, 2 Oct, 7 Oct, 8 Oct, 2010)

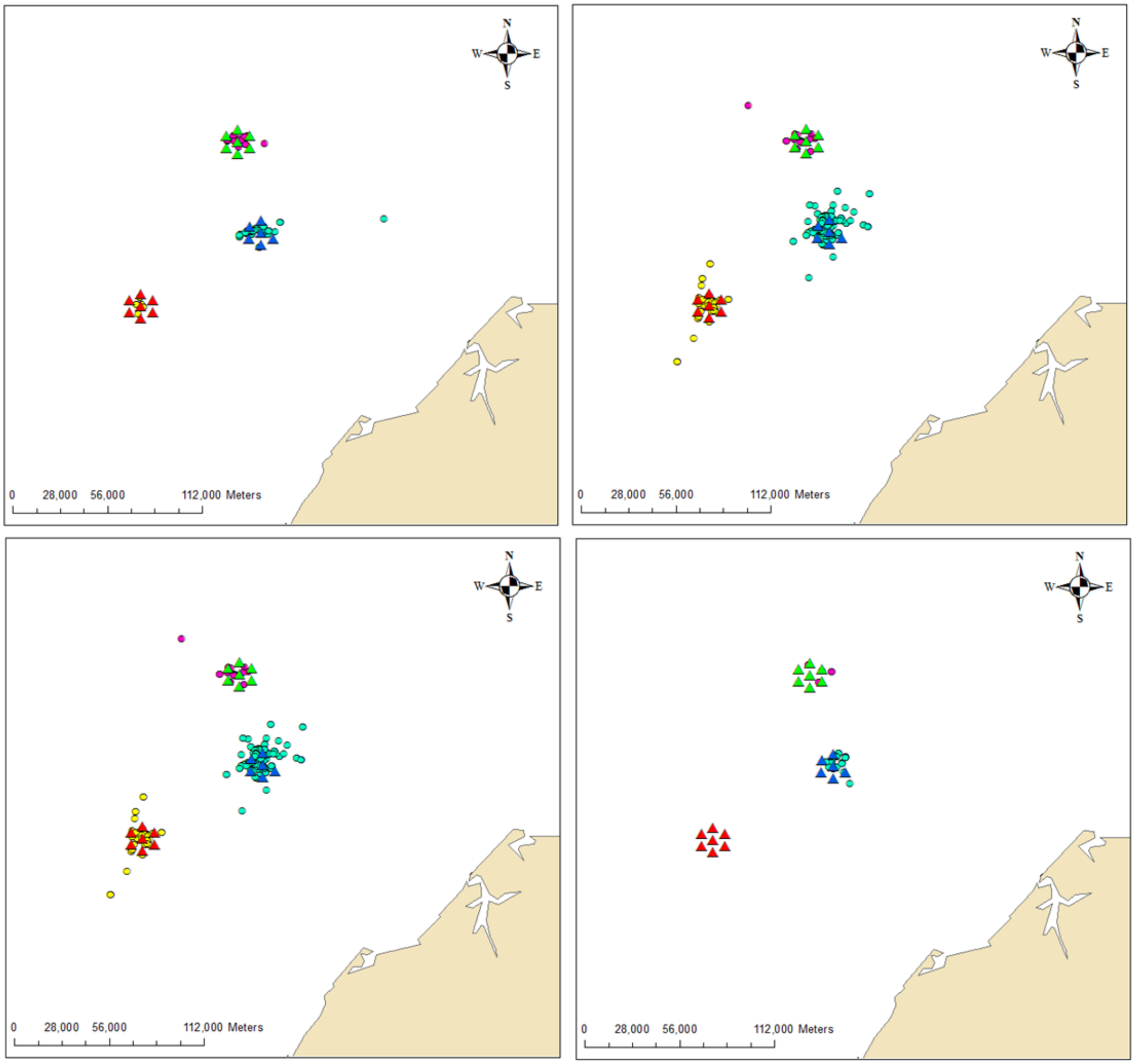


Figure 130. Bowhead call localizations within the Burger, Klondike and Statoil cluster arrays. From left top to right bottom (9 Oct, 10 Oct, 11 Oct, 12 Oct)

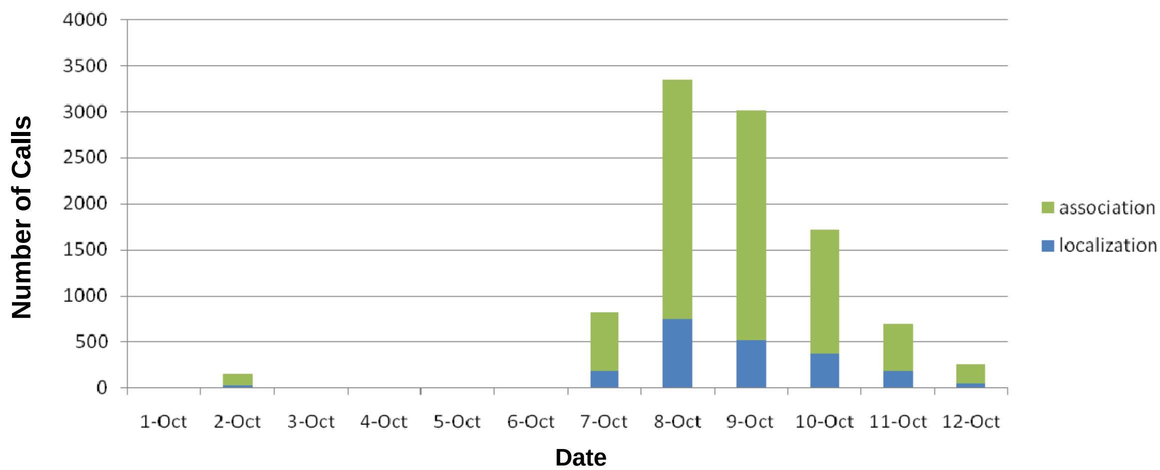


Figure 131. Occurrence of bowhead call events within Burger cluster array.

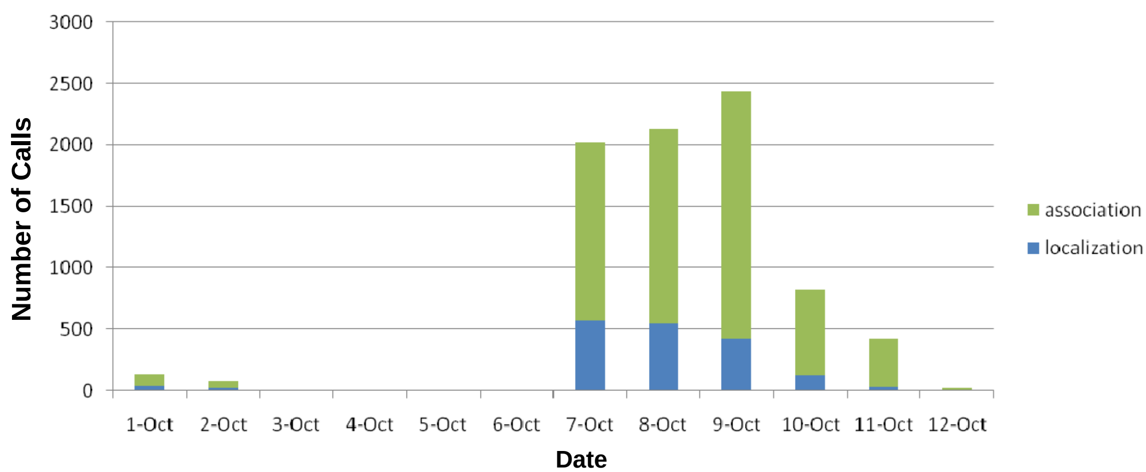


Figure 132. Occurrence of bowhead call events within Klondike cluster array.

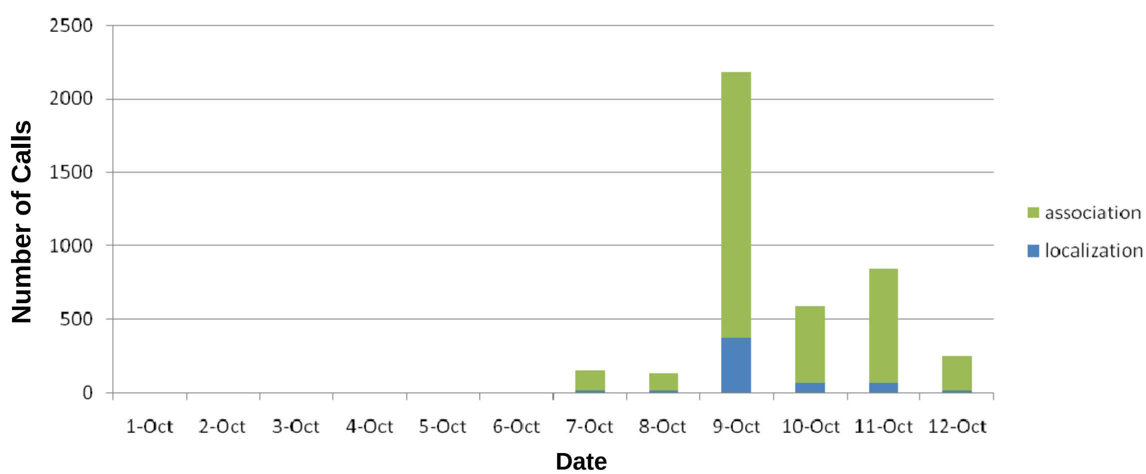


Figure 133. Occurrence of bowhead call events within Statoil cluster array.

It is helpful to characterize the localization system in terms of its relative ability to localize bowhead calls at distance from the recorders. **Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.** show bowhead detection/localization densities per square kilometer as a function of distance from the centroid of the three recorders on which each of the localizations were made in 2010. These densities were determined by first finding the number of localizations in a set of concentric annular rings about the tri-recorder centroids and having inner and outer radii differences of ½ km. The counts were divided by the corresponding areas of the annular rings to give actual detections per square kilometer within each annulus. These localization densities were plotted as a function of the annulus radii (or equivalently, distances from the tri-recorder centroids).

If bowhead call distributions were spatially uniform and we were able to detect 100% of the calls, then the localizations per square kilometer would be near constant for all ranges. However, detection probabilities decrease with distance from each recorder and the number of localizations per unit area eventually also decreases with distance. The analysis indicates that the ability to detect and localize bowhead calls falls off quite rapidly with distance beyond just 3-5 kilometers (2-3 mi) from centroids of the recorder triplets. This result suggests that localization capabilities should be relatively constant everywhere inside the hexagonal cluster arrays, but that localization ability drops off rapidly outside the hexagons. For example, according to **Error! Reference source not found.**, the localization density was approximately 3-7 call localizations per square kilometer for distances less than 5 km from each centroid. At 10 km distance it was less than 0.5 localizations per square kilometer. It is possible that real spatial variations in bowhead densities might have influenced these estimates of localization densities, but they are based on actual calls received from all directions relative to the cluster of recorders, so that is unlikely. Finally, while localization densities drop off rapidly with distance away from the arrays, the areas within each distance interval increase with the square of the distance. Consequently many detections are present at relatively long distances from the recorder arrays (Figure 128).

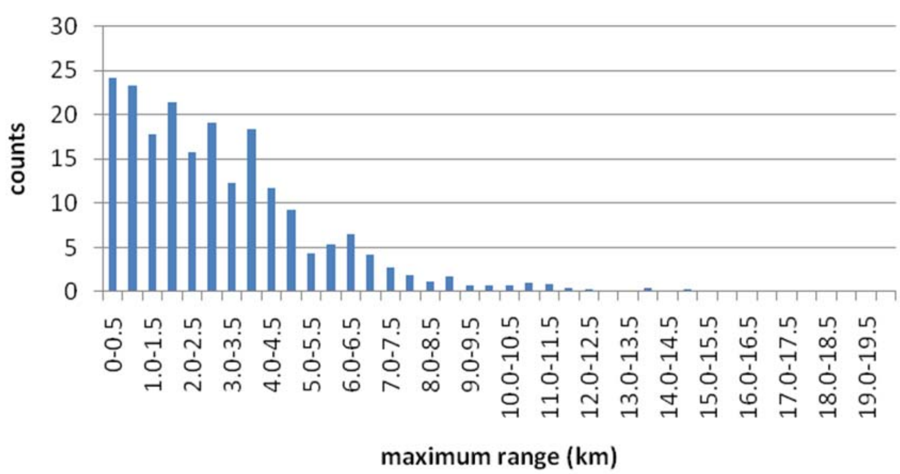


Figure 134. Localization densities in detections per square kilometer from the Burger cluster array as a function of distance from the centroids of the groups of 3 recorders upon which each localization was based.

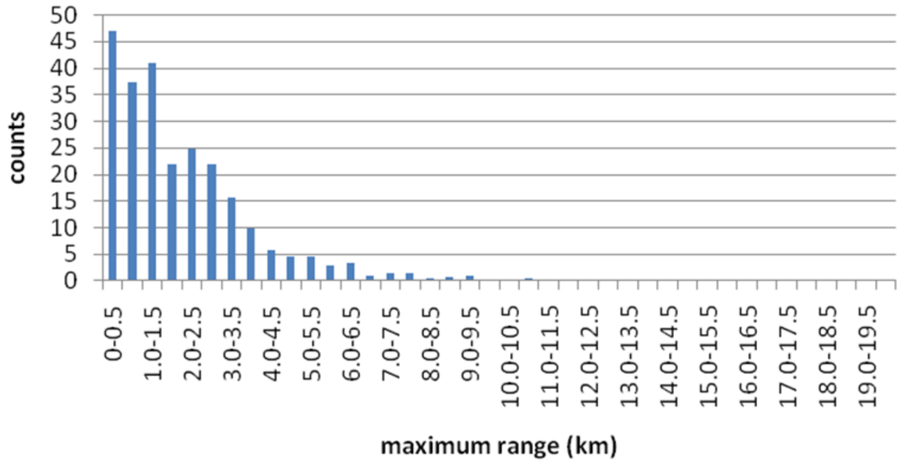


Figure 135. Localization densities in detections per square kilometer from the Klondike cluster array as a function of distance from the centroids of the groups of 3 recorders upon which each localization was based.

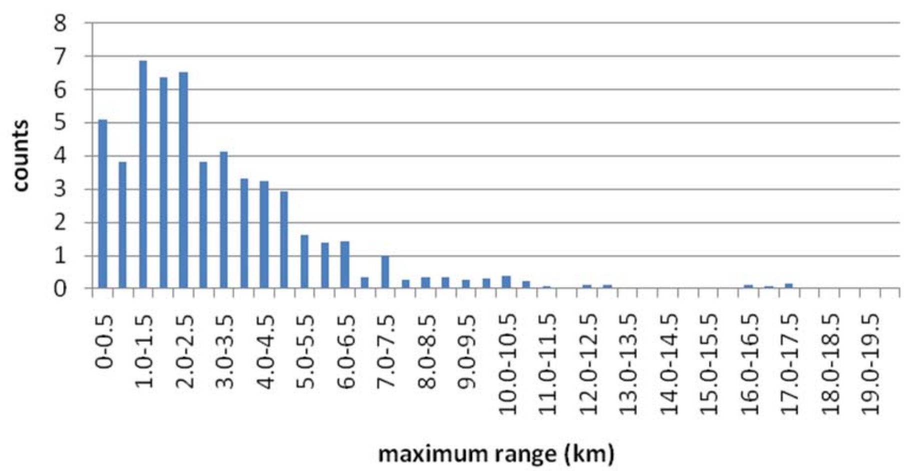


Figure 136. Localization densities in detections per square kilometer from the Statoil cluster array as a function of distance from the centroids of the groups of 3 recorders upon which each localization was based.

4. Discussion: 2007–2010 Trends

4.1. Ambient Noise

Ambient noise is produced by wind and waves, ice cracking events, geological seismic events, and biological sounds including those from marine mammals. Anthropogenic noise also contributes to the total underwater sound field but is often considered separately. Our discussion and treatment of ambient noise includes both natural and anthropogenic sounds. This discussion examines the measured sound levels at Station PLN40 throughout the 2007–2010 deployments, provides a month-to-month review of the winter 2009-2010 noise levels at PLN40 to show how they change as a function of ice and mammal activity, and finally compares data from several stations from summer 2010.

4.1.1. Station PLN40 Multi-Year Analysis

The 2007–2010 open-water 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 137 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 in proximity to PLN40. Spectrograms for the recordings are shown in Figure 138 and Figure 139, grouped by summer and winter periods for easier comparison among years.

Seismic activity up to 200 Hz can be seen in the spectrogram for the summer 2010 spectrogram (Figure 138). The summer 2008 recording period was much shorter than the others, and contained moderate broadband noise that is attributed to bowhead whales calling during migration, as well as the effects of early fall weather. The relatively high noise levels are also due to the fact that the recording period occurred late in the season, when higher levels of noise are expected due to more wind and storms. Summer 2009 was similar to summer 2008, with only a restricted time-frame of shallow hazards seismic activity. Summer 2007 had extended quiet periods, which led to lower overall noise levels compared to the other years even though an extensive seismic program occurred in September of that year.

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

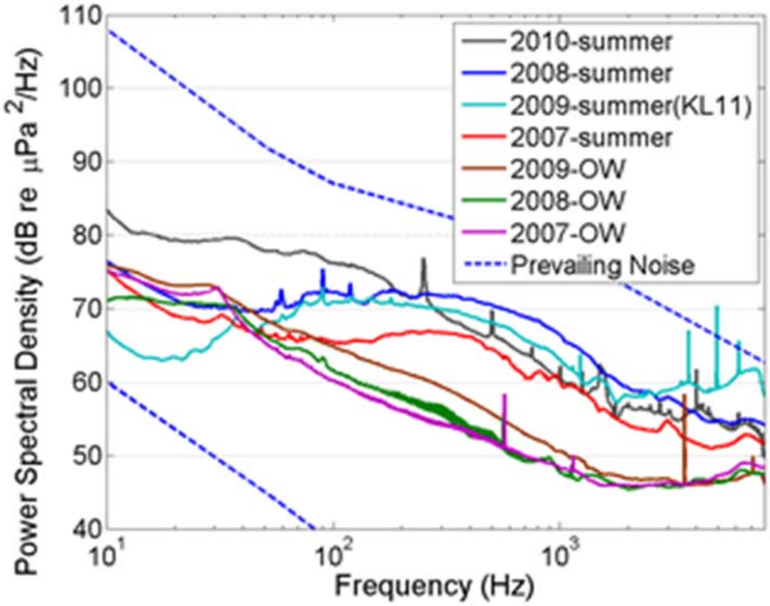


Figure 137: Percentile 1 min power spectral density levels (dB re 1 µPa2/Hz) at PLN40, for the monitoring periods from summer 2007 to summer 2010. KL11 was used for summer 2009 since the PLN40 data were not available for that period.

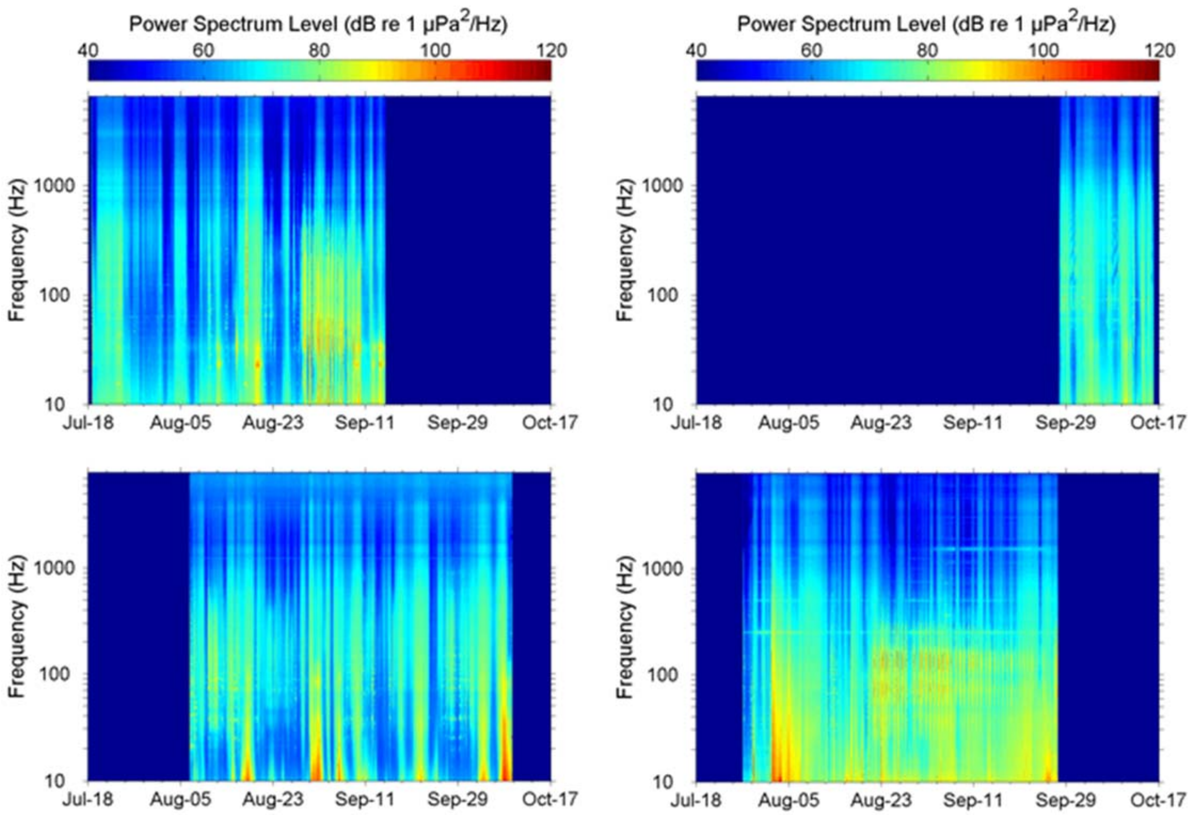


Figure 138. Spectrogram of underwater sound at PLN40 for the summer deployments for (top left) 2007, (top right) 2008, (bottom left) 2009 (KL11), and (bottom right) 2010.

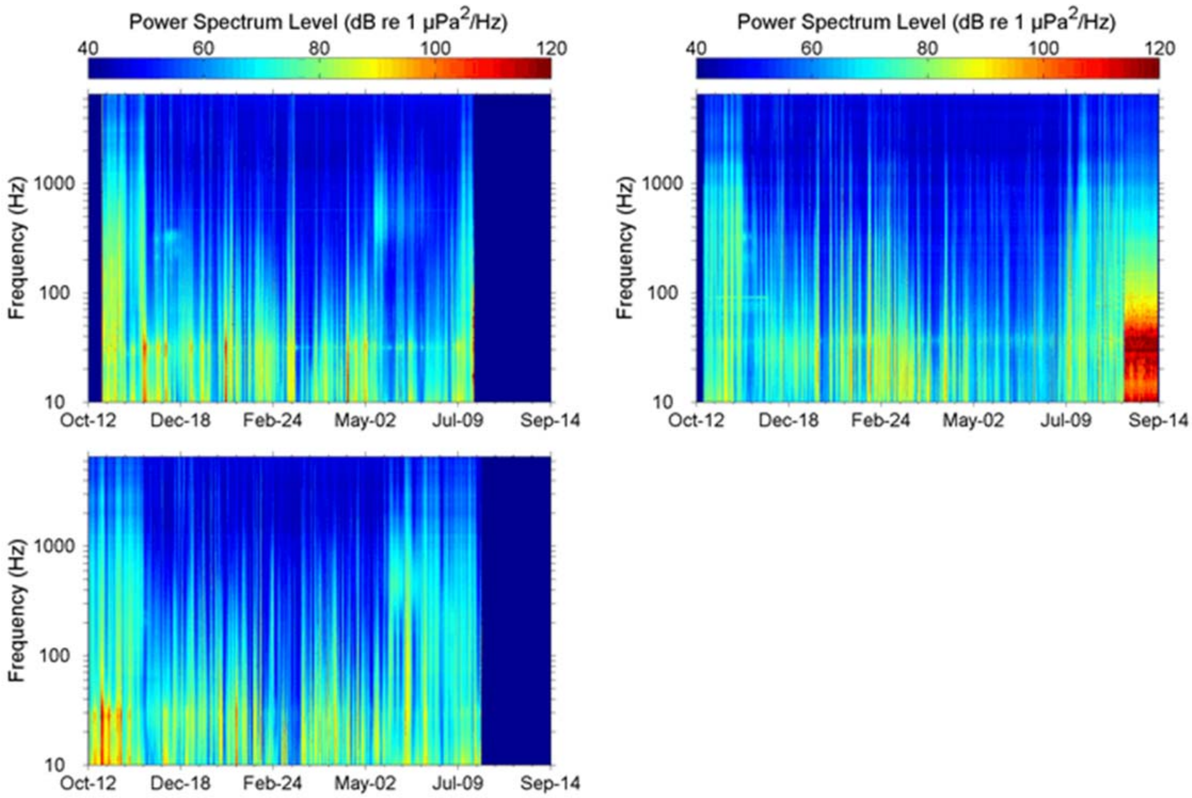


Figure 139. Spectrogram of underwater sound at Station PLN40 for the winter programs in (top left) 2007–2008, (top right) 2008–2009, and (bottom) 2009–2010.

4.1.2. Winter 2009–2010 Program

The monthly percentiles for the winter 2009–2010 data at Station PLN40 are shown in Figure 140 and Figure 141. In November 2009, the 50th percentile levels are elevated in the 100–1000 Hz band. This is a result of the transition from open water to ice covered water. While the water is open, wind and weather have influence on sound levels, but as the ice moves in, extensive creaking and groaning during the formation of pack ice affects sound levels. The next three months are very quiet as the ice settled and there was little biological activity occurring in the area.

In May 2010 the 50th percentiles are still essentially the same as the previous months, but the 75th percentile is elevated between 200–3000 Hz due to the constant calling of bearded seals during breeding season. An example of bearded seal calls is shown in

Figure 142. In June and July, the 50th percentile levels are elevated from 50–2000 Hz due to the breakup of the ice. The newly open water will be influenced once again by weather.

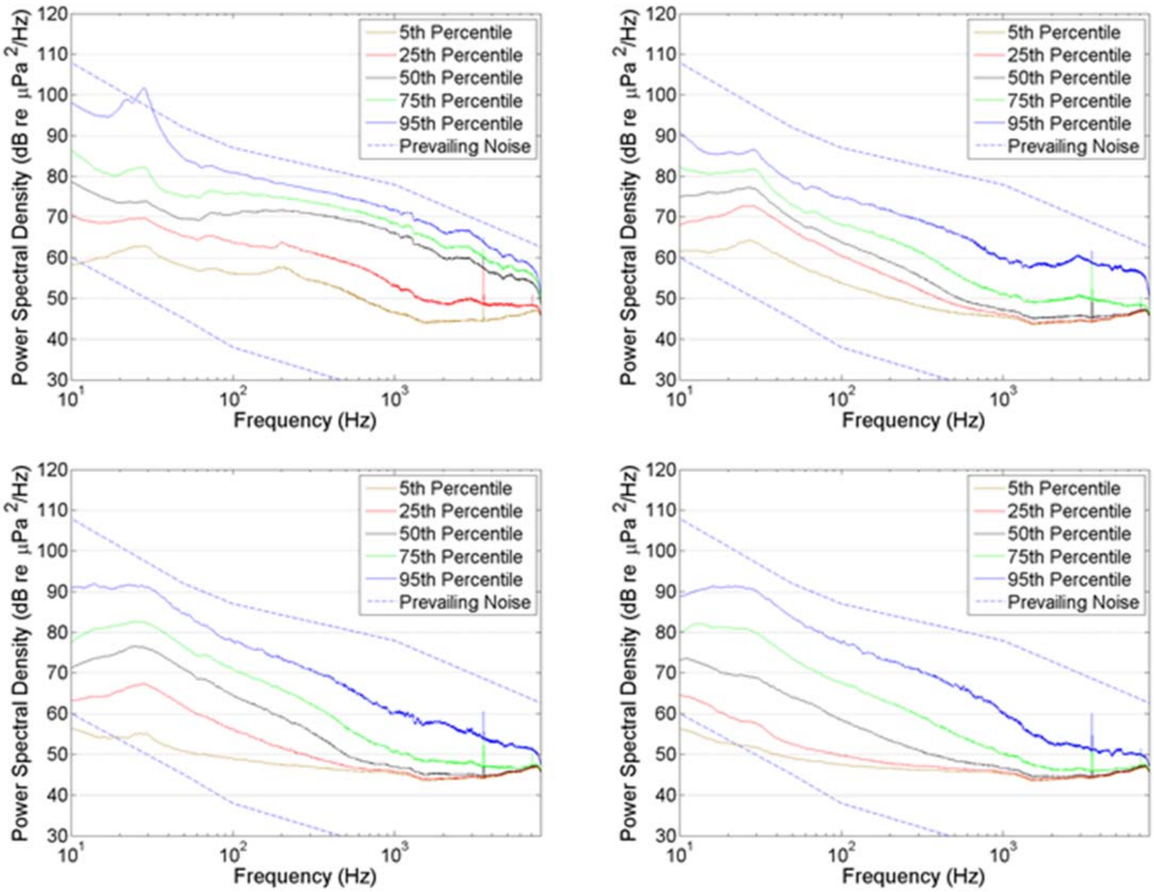


Figure 140. Monthly percentile 1 min power spectral density levels (dB re 1 µPa^2/Hz) for PLN40 for the winter 2009–2010 program, (top left) November 2009, (top right) December 2009, (bottom left) January 2010 and (bottom right) February 2010.

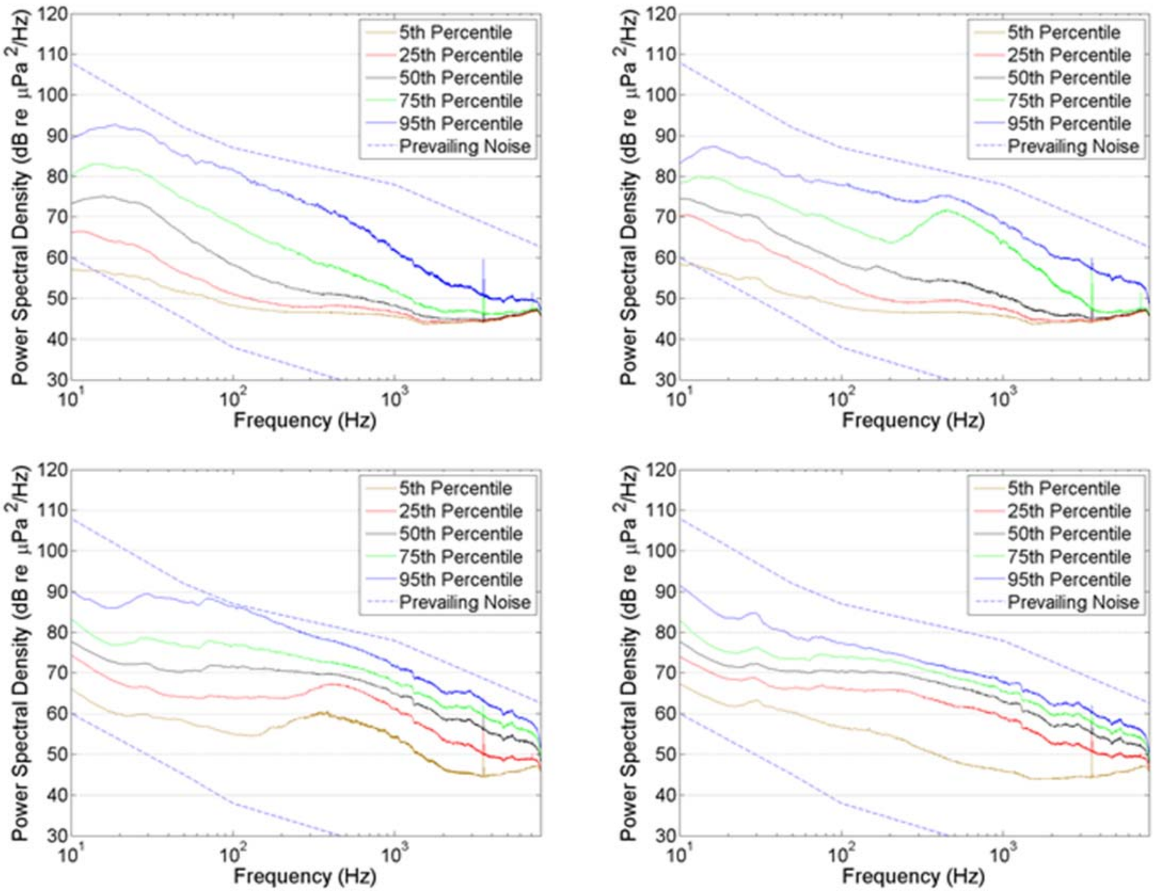


Figure 141. Monthly percentile 1 min power spectral density levels (dB re 1 µPa2/Hz) for PLN40 for the winter 2009–2010 program, (top left) April 2010, (top right) May 2010, (bottom left) June 2010, and (bottom right) July 2010.

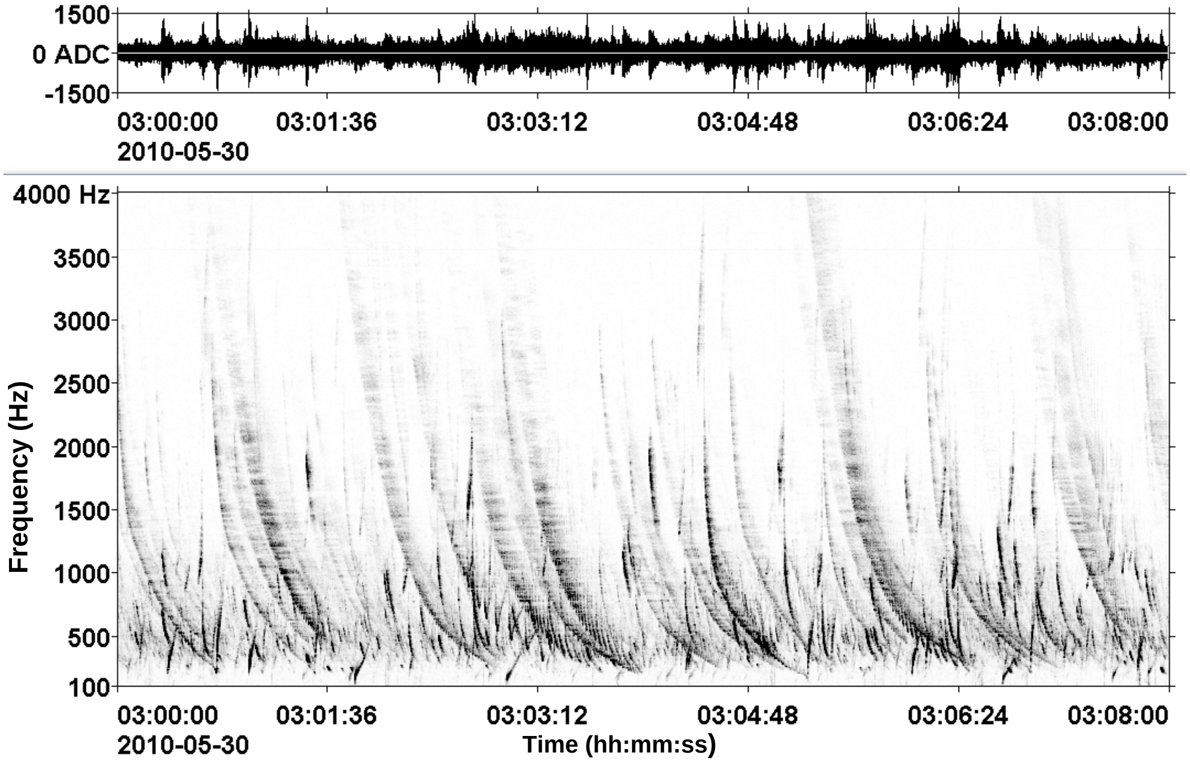


Figure 142: Pressure in digital units (top) and spectrogram (bottom) of a sample of bearded seal calls in May 2010 at Station PLN40 (4096-pt FFT, 1024-pt advance, Hamming window).

4.1.3. Summer 2010 Program

The 50th percentile power spectral density levels are plotted for a latitudinal cross section of recorders from the summer 2010 program in Figure 143 and the corresponding spectrograms for the recorders are shown in Figure 144. Examining the spectrograms, seismic activity is observed at all stations except B30. It is most prominent in Stations PLN80 and S01, leading to the higher levels from 50 to 500 Hz. Seismic noise is observed on WN20B and CLN120, but is less prominent on CLN120 because the recorder lies behind an underwater rise of the sea floor, as discussed in section 3.2. 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.

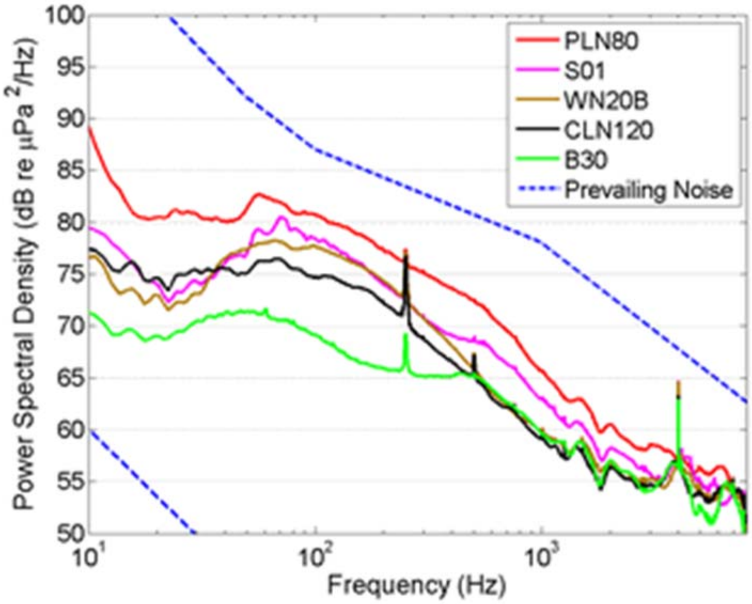


Figure 143. Percentile 1 min power spectral density levels (dB re 1 µPa2/Hz) for recorders on a latitudinal cross section across the Chukchi Sea for summer 2010.

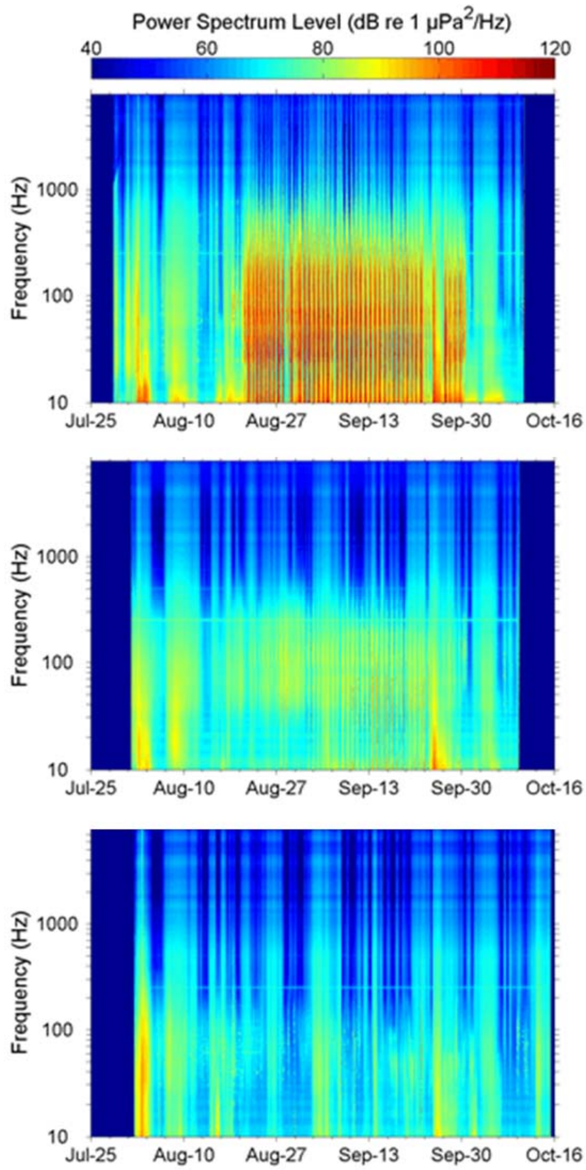


Figure 144. Spectrogram of underwater sound at (top left) PLN80, (top right) S01, (middle left) WN20B, (middle right) CLN120, and (bottom) B30 for the summer 2010 program.

4.2. Marine Mammal Vocalization[2] Detections

Recorders have been deployed at the same or similar locations each year since 2007, allowing for direct comparisons of results between different years. The 2008 summer dataset was restricted to five recorders late in the season (26 Sep to 16 Oct 2008) and is not discussed further. The summer 2007 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

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

directly comparable to the 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. 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 Programs

The three winter acoustics programs have revealed slight differences in the timing of the fall migration. The first and last detection dates varied by about 2 weeks, ending as early as 15 Dec in 2009 and as late as 31 Dec in 2007 and 2008. The last detections consistently occur at the southwestern-most station (PL50 or CL50). Inter-year variations in the timing of sea ice formation presumably drive the differences in timing of the migration between years. Barrow whaling captains note 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 October (Huntington and Quakenbush 2010).

In all three years, the largest number of stations with concurrent detections and the highest call counts occurred during the second half of November. This is in part due to the appearance of songs which trigger more detections than the irregular sequences of moans produced earlier in the fall. On the other hand, the relatively predictable advance of the ice edge at that time may funnel all the late migrants past the acoustic recorders at that time, which should also contribute 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 November, the call counts compiled throughout the fall migration cannot be meaningfully compared on a year-by-year basis. The temporal variation of bowhead numbers through the fall migration through the Chukchi Sea (~3 months) remains unclear, but overall call counts per time period give at least a rough indication of that distribution.

It is difficult to comment on specific bowhead 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 further north (PLN80, WN40) or south (PL50). This is consistent with results from late in the summer programs (2009 and 2010) suggesting that the main migration corridor occurs near or slightly north of 71° N.

The first bowhead spring migration detections in the Chukchi Sea occurred on the same day in 2008 and 2009, but at stations 300 km (186 mi) apart: 16 Apr 2008 at W50; and 16 Apr 2009 at CL50. In 2010 detections started earlier, on 30 and 31 Mar at CL50 and B05 respectively. The number of detection days was also considerably larger in the spring of 2010 at all stations than in previous years. This suggests that a larger proportion of whales migrated offshore in 2010. The coastal lead forming inshore in April between Point Hope and Point Barrow is believed to be the normal migration route for bowheads in the spring (Moore and DeMaster 1998), so the 2010 results may be an exception. A slight delay in lead formation combined with an earlier migration onset (at least as detected acoustically) may explain the increase in offshore detections in 2010.

Simple and complex songs were encountered in the fall (Figure 145) and spring of all three winter data sets. Unique songs were identified and compared within and between years. The current understanding is that singing is part of bowhead whales' breeding behavior (Stafford *et al.* 2008) and that songs change every year (Wursig and Clark 1993). The latter is based on the analysis of songs recorded in the springtime off Barrow, AK, but it is also accepted that spring songs may be somewhat degraded in comparison to those produced in winter when bowheads are most sexually active. We detected one unique song in the fall of 2007, 2008 and 2009, and another in 2007 and 2008 and possibly in the spring of 2010 as a slightly modified version. What appear to be small variations of a unique song were also detected in the spring and fall of 2008 and in the spring of 2010. Minor inter-annual variations in fall songs are likely the result of a difference in song maturity caused by bowheads' different departure times from the instrumented area in all three years. Indeed bowheads' complex songs become progressively established during November. The differences between the fall and spring versions of apparently-related songs were more pronounced than differences between songs recorded in consecutive falls, which may be due to variations occurring during the winter. This finding strongly suggests that, when starting to sing in the fall, western arctic bowheads display the same songs every year. Variations occurring throughout the winter could explain the previously observed differences in spring songs at Barrow. Western arctic bowheads' singing behavior is unique in that this population displays multiple songs over multiple years. It is expected that as monitoring continues, new song types will be identified.

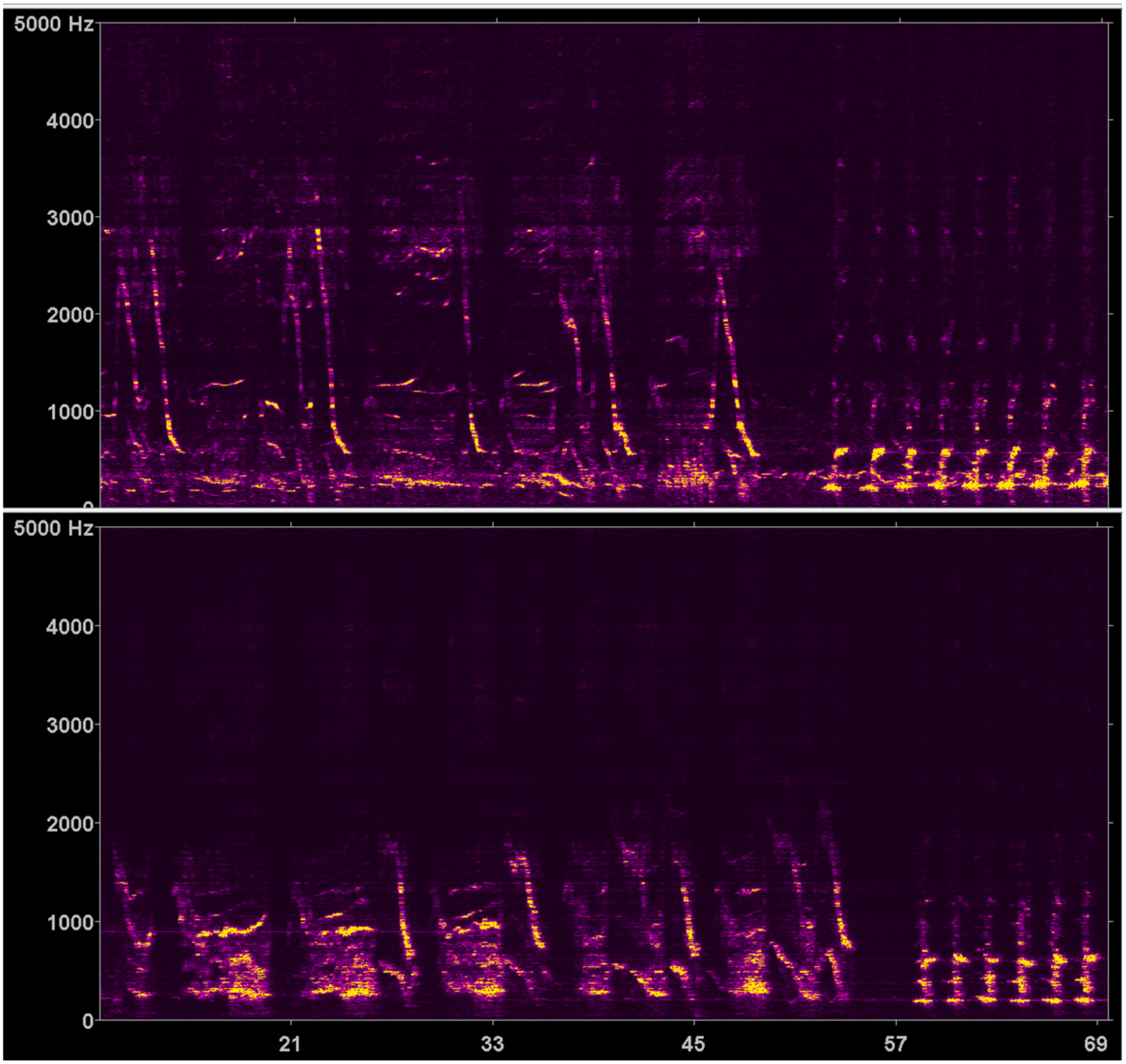


Figure 145. Spectrogram of a bowhead song recorded in fall 2007 (top) and 2008 (bottom) in the north-eastern Chukchi Sea (4096-pt FFT, 1024-pt overlap, Hamming window).

4.2.1.2. Summer Acoustics Programs

The results from the summer 2007 deployment must be considered carefully because the bowhead detections included some walrus grunts as explained by Martin *et al.* (2008). For this discussion, we compare only the 2009 and 2010 bowhead results. An isolated mid-summer detection occurred at the Klondike cluster array on 8 Aug 2009. Delarue *et al.* 2010b considered this detection an isolated event; however, the finding of a similarly isolated detection on 28 Jul 2010 at Station CLN20 suggests this may be a recurrent pattern. In fact, a whale equipped with a satellite tag traveled from Barrow to the Chukotka coast between late July and early August 2010, and spent the rest of the summer in this area (Quakenbush *et al.* 2011). Thus a small segment of the western arctic bowhead population might be leaving the Beaufort Sea and for the Chukotka coast at least one month before the beginning of the "normal" fall migration.

In both 2009 and 2010 the core of the migration corridor was located between 71 and 72° N, although call counts were lower at the stations near 72° N, suggesting that most whales migrate closer to 71° N (see Figure 146 for 2009 and Figure 147 for 2010). Some migrating bowheads were detected at near-shore stations at Barrow and Wainwright but not near shore at Point Lay. The main migration path appears to be west-southwest starting from Barrow, leading through the center of the lease sale 193 area. In 2009, and to a lesser extent in 2010, call counts were lower at the Klondike cluster array than at the Burger array; Klondike apparently lies on the southern edge of the bowhead migration corridor's core. The factors determining the location of the migration path remain 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 appeared to be heading for an area between Wrangel Island and Cape Schmidt (Quakenbush et al. 2010; 2011), which indeed puts the Klondike prospect on the southern edge, and the Burger prospect directly within the migration corridor. At a finer spatial scale, the factors determining the location of migrating bowheads may be behavioral and/or environmental; differences in water composition could affect bowheads' distribution (either directly or as a result of prey distribution). Hydrographic differences between the Klondike and Burger prospect areas were noted in both 2008 and 2009 (Weingartner and Danielson, 2010), lending support to this hypothesis, but more work is needed before any correlation (or lack thereof) can be established.

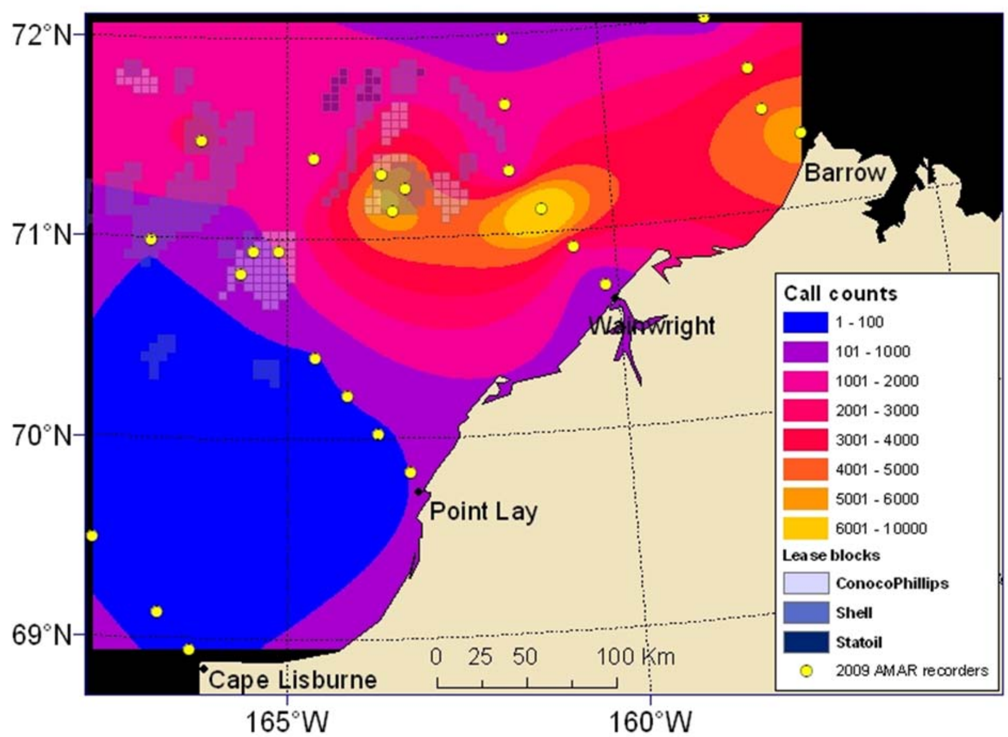


Figure 146. Interpolated bowhead call count surface plot based on the sum of call counts at 2009 summer recorders in the Chukchi Sea from 5 Aug to 15 Oct.

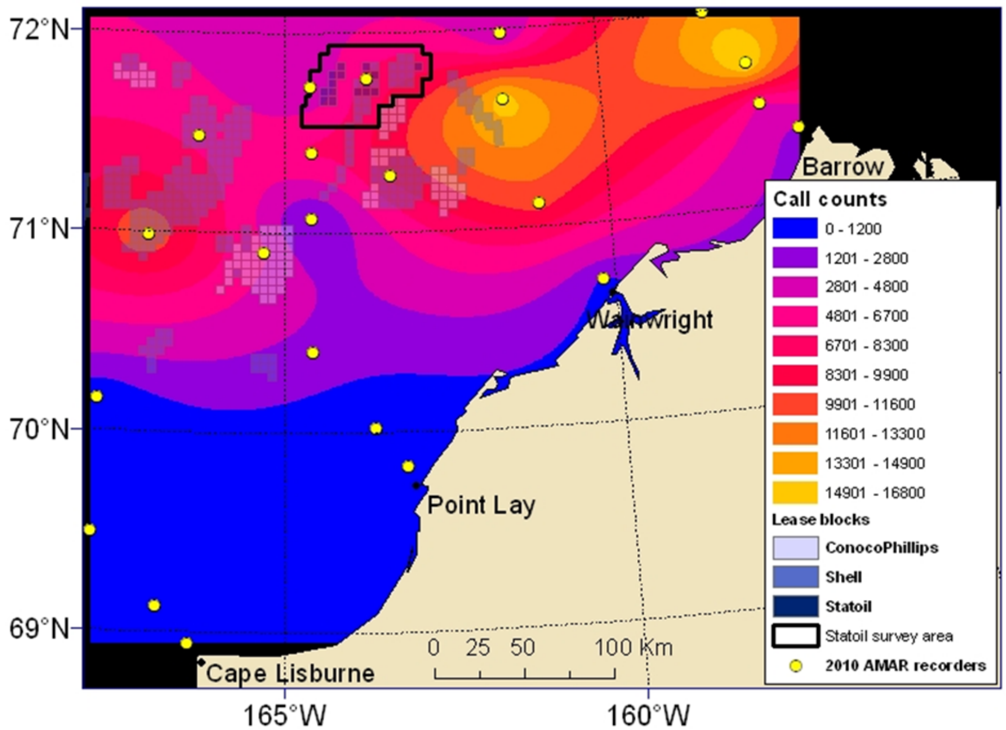


Figure 147. Interpolated bowhead call count surface plot based on the sum of call counts at 2010 summer recorders in the Chukchi Sea from 25 Jul to 15 Oct.

4.2.2. Walrus

4.2.2.1. Winter Acoustics Programs

Walrus have been detected increasingly later in the fall during the 2007, 2008 and 2009 winter deployment acoustic programs. The latest winter detections occurred on 22 Jan 2010 at Station PLN40, 30 Dec 2008 at Station W50, 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 study area earlier in the fall.

In spring, walrus were detected in the first half of June in 2008, 2009 and 2010. The 2010 detections occurred first at Station CL50 and then at Station W50, where walrus were also first detected in 2008 and 2009. Differences in arrival time are likely due to differences in ice conditions during migration.

Little is known of the timing of walrus movement into the Chukchi Sea in spring. An ongoing tagging and tracking program by the U.S. Geological Survey (Jay *et al.* 2011) is expected to provide new information on the topic. In all three 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 Acoustics Programs

A feature common to the 2007, 2009 and 2010 programs is the consistently high number of walrus acoustic detections off Wainwright. In 2009, the stations located between W35 and WN40 had the highest call count estimates (Figure 148). In 2010, this pattern held, but the inshore stations at Wainwright and Point Lay also had very large call count estimates, reflecting the presence of large coastal walrus haul-outs caused by the retreat of ice beyond the continental shelf (Figure 149). Consistently high call counts at Station CL05 in both years indicates either a haul-out or that this area is used as a migration corridor for walrus transiting to Chukotka. Walrus call counts peaked in the Chukchi Sea in August and September. The 2009 data provided evidence of a southwesterly movement from mid-September on, probably indicative of the onset of the migration toward the Bering Strait. By mid-October, the number of walrus in the study area was decreasing in all years but the winter data indicate that some walrus remain in the Chukchi Sea until December or January.

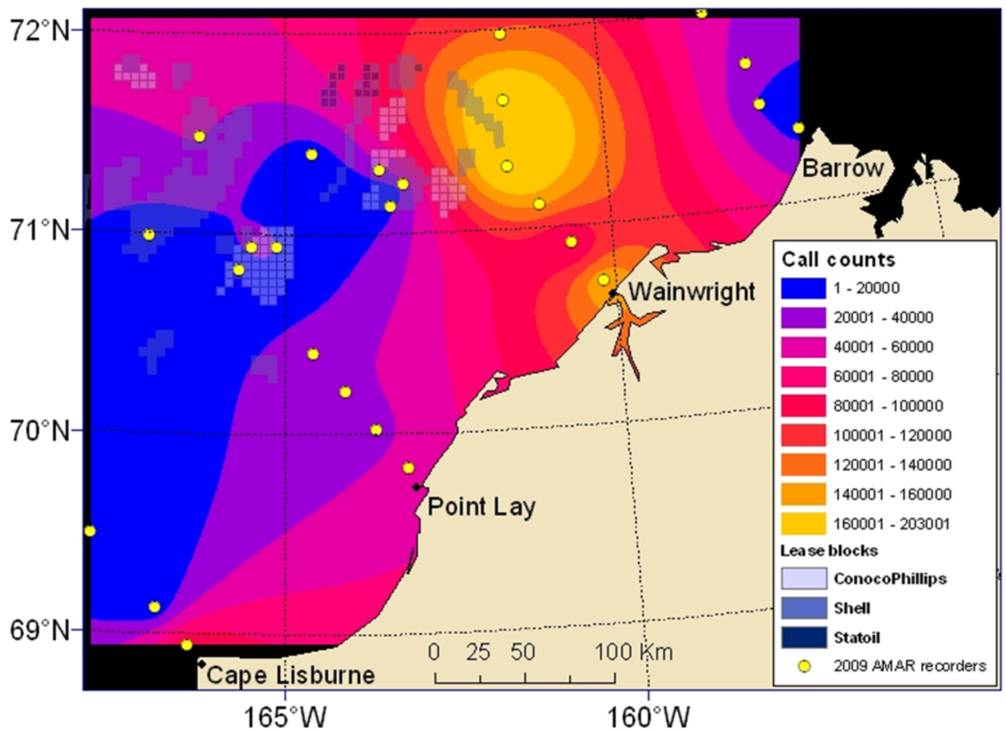


Figure 148. Interpolated walrus call count surface plot based on the sum of call counts at all 2009 summer recorders in the Chukchi Sea from 5 Aug to 15 Oct.

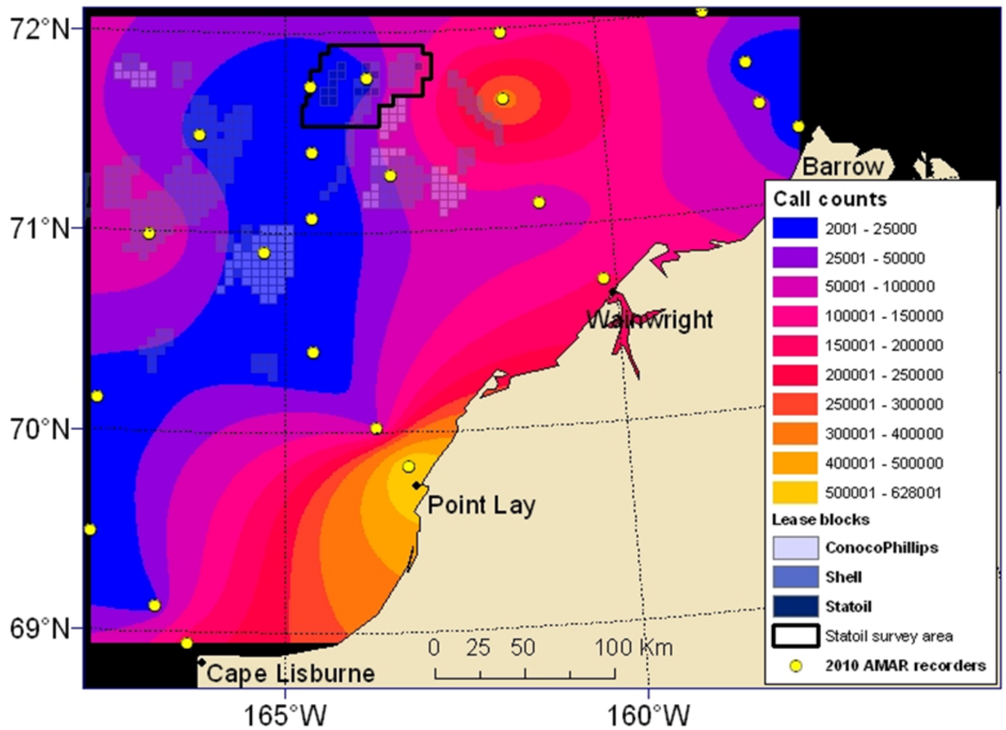


Figure 149. Interpolated walrus call count surface plot based on the sum of call counts at all 2010 summer recorders in the Chukchi Sea from 25 Jul to 15 Oct.

4.2.3. Beluga Whales

4.2.3.1. Winter Acoustics Programs

The three winter programs have yielded consistent results of the spatio-temporal distribution of beluga acoustic detections. Few acoustic detections of belugas occur past mid-October in the study area. Detections have been attributed to Eastern Chukchi Sea (ECS) beluga stock because Eastern Beaufort Sea (EBS) belugas are known to migrate earlier and north of the recorder deployment area (Richard *et al.* 2001). The addition of the recorder at B05 during the 2009–2010 winter program provided new information about the migration path of ECS belugas. Belugas were detected for 20 days at B05 but only for four days or less at any of the other stations. This suggests that they may be preferentially migrating inshore in the fall and therefore are missed by the winter recorders that are at least 35 mi from shore.

Like bowheads, the first 2010 spring detections of belugas occurred two weeks earlier than in previous years, possibly because ice conditions forced more animals to migrate offshore, closer to the recorders. The number of detection days was much larger than in 2009, but comparable to the number from 2008. The 2009 spring migration may have occurred further inshore. As explained previously (section 3.3.3.3), the addition of a recorder at Station B05 brought evidence of segregation in the migration schedule of ECS and EBS belugas. The addition of an inshore recorder near Point Lay would be extremely valuable to confirm this observation. Overall, the results of the three winter programs indicate that belugas migrate widely through the study area in the spring. The differences in the distance to shore of the main migration corridor, and migration timing, likely explain the inter-annual differences in the number of detection days at each station.

4.2.3.2. Summer Acoustics Programs

The comparison of 2007, 2009 and 2010 summer program data confirms that belugas are relatively rare in summer months in the Chukchi Sea. They are primarily detected in late July and August at the inshore Wainwright stations, presumably as they head northeast from Kasegaluk lagoon toward Barrow Canyon; in August off Barrow when they are known to forage in Barrow Canyon (Suydam *et al.* 2005; Delarue *et al.* 2011); and in October 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 Monitoring program (Ireland *et al.* 2010).

4.2.4. Killer whales

Killer whales were acoustically detected in the 2009 and 2010 summer datasets, as first observed in 2007 (Delarue *et al.* 2010*a*). Killer whales were detected predominantly off Cape Lisburne and Point Lay in all three years, though a few detections occurred off Wainwright. Further analysis revealed that mammal-eating killer whales were the source of the detected calls (Delarue *et al.* 2010*a*), 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 north-eastern Chukchi Sea in different years.

4.2.5. Fin whales

Fin Whale acoustic detections in the 2009 and 2010 summer datasets have confirmed the presence of fin whales in the Chukchi Sea first observed in 2007. In 2007, fin whales were detected at Stations CL35, CL50, CLN80, and PL50 from mid-August to mid-September (Delarue *et al.* 2009*b*). In 2009 and 2010, detections occurred at CL50, CLN90, and PL50 and ranged from early August until early October. The number of detections in these two years was much lower than in 2007. Based on these acoustic data, it appears that fin whales are restricted to the southwestern part of the study area and primarily offshore, although a fin whale was sighted near Cape Lisburne on 2 Jul 2008 (Morse *et al.* 2009).

4.2.6. Bearded Seals

4.2.6.1. Winter Acoustics Programs

There was little inter-annual difference in temporal and spatial distributions between the three winter programs. Bearded seal acoustic detections were most abundant off Wainwright and Barrow, particularly in the spring. The typical temporal distribution of detections consists of a steady increase in calling rates from October, peaking in May and June, which coincides with the mating season. Call detections usually stop abruptly in late June–early July, with sporadic or no detections until the end of the summer recordings. Bearded seals are the most common acoustically-detected marine mammal species in the winter programs.

4.2.6.2. Summer Acoustics Programs

During the summer of 2009 bearded seal call count estimates were highest off Wainwright, but they were present throughout the area. Bearded seal distribution was not analyzed in the summer 2007 data. In 2010, we observed an increase in calling rates at the end of the deployment, with no or very few detections before 1 Sep. The beginning of the consistent detection period at each station occurred earlier at stations further to the northeast.

4.3. Effects of Seismic Survey Sound on Marine Mammals

Effects of airgun sounds on walrus vocal behavior were observed in 2009 and 2010 near seismic surveys. In 2009, walrus call detections at three recording stations in the vicinity of a shallow-hazard survey stopped, with few exceptions, each time airgun pulses were detected. The exceptions occurred only during times of low received airgun pulse sound pressure levels (SPL) below 130 dB re 1 µPa (rms pulse SPL, 30 min average). In 2010, call detection rates during a larger 3-D seismic survey were found to be negatively correlated with airgun pulse rms SPL, and nearly all acoustic detections stopped when sound levels reached approximately 140 dB re 1 µPa at the recorder. Although previous evidence exists indicating that walrus swim away from active seismic surveys, here the timing of the 2010 detections suggests that some walrus remained near the recorders but stopped vocalizing or could not be detected due to masking as airgun pulse SPLs increased. No effects of airgun sounds on walrus acoustic detections were observed at stations more distant from the survey where SPLs remained below 130 dB re 1 µPa. The potential impacts to walrus from calling rate reductions or acoustic masking are unclear. Repeated disruptions of vocal communication could potentially affect the maintenance of mother-pup bonds and herd integrity. Mother-pup pairs and herds rely almost exclusively on calls to remain in contact when separated (*e.g.*, during foraging trips or as a result of predator disturbance).

4.4. Bowhead Acoustic Localization

Table 27 provides the number of bowhead call localizations made on each of the three cluster arrays deployed at Burger, Klondike and Statoil. The 2008 results from Clark (2010) are given for the Burger and Klondike sites for comparison. No localization arrays were deployed in Statoil’s lease areas in 2008. The 2009 cluster array localization results for Burger and Klondike sites are not presently suitable for this comparison.

Table 27. Number of bowhead calls localized in 2008 and 2010 within the Burger, Klondike and Statoil cluster arrays. The Statoil cluster array was deployed for the first time in 2010.

Date	Burger 2010	Burger 2008*	Klondike 2010	Klondike 2008*	Statoil 2010
Oct 1	0	33	41	0	0
Oct 2	33	0	25	0	0
Oct 3	0	0	0	0	0
Oct 4	0	0	0	0	0
Oct 5	0	0	1	0	0
Oct 6	0	372	0	166	0
Oct 7	185	253	576	385	18
Oct 8	743	0	546	45	20
Oct 9	527	575	421	206	375
Oct 10	382	82	124	0	70
Oct 11	190	382	27	0	69
Oct 12	59	174	0	14	20
Oct 13	-	1610	-	183	-
Total	**2119**		**1761**		**572**

* Results from (Clark, 2010)

The localization results indicate relatively uniform spatial distributions of bowhead call localizations near Burger and Statoil. However, the Klondike localization spatial distribution shows a strong skew to the north. This skew is likely caused by the positioning of Klondike south of the core of the migration corridor. Nevertheless, there were approximately three times as many bowhead call localizations made from the Klondike array (1761) than from the Statoil array (572). The Burger array localized the highest number of calls (2119), likely as a result of its positioning closer to the core of the migration corridor. The uniform spatial localization distribution near the Statoil array suggests the northern side of the migration corridor does not have a clear boundary and could extend further north than the Statoil array. Lower migration densities appear to be present there, but if the corridor extends much further north, that part of the corridor could support a significant fraction of the total migration.

5. Conclusions

5.1. Winter 2009–2010 Program

The Chukchi Sea winter 2009–2010 Acoustic Monitoring Program provided information about ambient noise levels and biological sounds including marine mammal vocalizations in the Chukchi Sea from October 2009 to August 2010. Some of the key results and conclusions of findings from analyses of these data 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 (see Figure 6; Wenz 1962). Median winter ambient levels varied by at most 5 dB across the frequency band of 10–8000 Hz at Station PLN40 between the corresponding periods of 2007–2008, 2008–2009 and 2009–2010.
- The winter recordings revealed continuous marine mammal presence throughout the winter. Bearded seal sounds were a major contributor to ambient noise in the spring, and were detected continuously from October until early July. Bowhead whale calls were predominant from mid-Oct until 1 Dec 2010.
- The timing of the beluga and bowhead whale acoustic detections was generally consistent with detection timing from previous years. The few observed differences, such as an earlier departure of bowheads in the fall of 2009 and the earlier returns in the spring of 2010, and the higher number of spring detection days for both species are likely partly driven by inter-annual variations in ice presence and timing.
- Walrus acoustic presence in the fall and winter was limited. Some walrus were present as late as 22 Jan 2011 at Station PLN40. In the spring the first animals were detected in early June and continuously thereafter at all operational recorders, though call counts were always highest off Wainwright.
- Ringed seal calls were detected from late-October until early June, but the occurrence of this species is most likely underestimated by our analysis protocol.

5.2. Summer 2010 Program

The summer 2010 open-water Acoustic Monitoring Program provided the largest dataset of the joint summer programs performed in the Alaskan Chukchi Sea since 2006. This report provides marine mammal and seismic airgun acoustic detection results, and compares them with results from previous years' acoustics programs. The following list summarizes the key findings:

- Median ambient levels in the Chukchi Sea show significant variability among years at frequencies below 1000 Hz due to variations in anthropogenic activity and average weather (wind) differences between years. Differences of up to 16 dB have been measured.
- Bowheads were acoustically detected sporadically in the Chukchi during summer, before the onset of the fall migration in late September. Detections peaked in early October.
- The main migration corridor during the fall bowhead migration appeared to be centered around, or slightly north of 71° N. Some whales also appeared to follow the coast as far west as Point Lay. Clear migratory routes were not identified in the 2007 and 2008 summer data.

The 2010 findings are comparable to the migration corridor revealed by the analysis of the 2009 summer data. Some individuals may cross the study area in late July–early August en route to the Chukotka coast.

- Walrus are the most commonly detected species in the Chukchi Sea in summer. They are most commonly detected offshore Wainwright on Hanna Shoal in August before moving to coastal haul-outs (*e.g.,* near Point Lay in 2010) when ice retreats off the shoal. The migration out of the study area starts in late September. Some walrus appear to follow the coast to Cape Lisburne before crossing west to the Chukotka coast.
- Belugas are usually absent from the Chukchi Sea during August and September when they forage in the northern Chukchi and Beaufort seas. The exception is off Barrow where some belugas are known to forage in summer months. The fall migration takes them back through the Chukchi Sea in October and November although acoustic detections are usually sporadic in those months.
- Fin, killer and gray whales were occasionally detected acoustically and are regular summer visitors to the Chukchi Sea. Fin whale call detections were limited and restricted to the southwestern part of the study area. Killer whales were mostly detected off Cape Lisburne and Point Lay; a few detections occurred off Wainwright. Most gray whale acoustic detections occurred before 31 Jul 2010. The presence of Killer whales or a lack of recording stations near known Gray whale summer feeding areas in Peard Bay are potential causes for the lack of acoustic detections of gray whales later in summer.
- Bearded seals appear to be year-long residents of the Chukchi Sea, although more acoustic detections occur in the north-eastern part of the study area. Their vocal activity peaks in May and June during the mating season. Detections occur throughout the rest of the year but at significantly lower rates. Ribbon seals were detected once during the summer of 2010. Ringed seal calls were more common but still rare. Ringed seals are known to be present in the study area in summer but vocalize infrequently. Passive acoustic monitoring may be an appropriate survey tool for ringed seals only if calls can be efficiently automatically detected, and/or if a larger proportion of data can be manually reviewed.
- The effects of anthropogenic noise were most pronounced in 2010 in the vicinity of Statoil's seismic survey operations and near vessel operations associated with the joint scientific studies program. The BOWFEST program survey vessel produced significant noise in late August through mid-September off Barrow.
- The cluster arrays deployed near Burger, Klondike and on Statoil's lease area detected larger numbers of bowhead calls than the arrays deployed in previous years. The Klondike array detected more calls on its north side, and this is attributed to its relative positioning south of the key migration corridor. The Burger array localized the most bowhead calls, with the spatial distribution uniform and centered on the array. The Statoil array received the lowest number of localized bowhead calls and also showed a spatially-uniform distribution. This is likely indicative of lower animal densities north of the core of the migration corridor.

6. Notes

6.1. Spectrogram Processing

This report contains many gray-scale spectrograms representing the spectral evolution with time of sounds recorded during the winter 2009–2010 and summer 2010 acoustics programs in the Alaskan 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 have been 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. Each figure contains a description of how it was processed, including:

1. 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.
2. 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.
3. 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.
4. Window: Type of windowing function applied to the data before FFT to reduce spectral leakage. Generally the Tukey window, which has minimal impact on the main lobe and -22 dB side-lobes. There are stronger windows appropriate for sinusoidal data; however this window has proved well suited to transient data analysis.
5. 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:
   a. For each frequency bin compute the average level over the entire file.
   b. For each time step, compute a moving average of the results from step (a), with a frequency bandwidth of 200 Hz.
   c. Normalize each time–frequency bin by the average of (a), and the value of (b) that is 300 Hz above the current frequency.

6.2. Acronyms and Abbreviations

AM	Amplitude-modulated
AMAR	Autonomous Multi-channel Acoustic Recorder (by JASCO Applied Sciences)
AMSR-E	Advanced Microwave Scanning Radiometer - Earth Observing System sensor on NASA's Aqua satellite
AURAL	Autonomous Underwater Recorder for Acoustic Listening (by Multi-Electronique)
BRP	Bioacoustics Research Program (based at Cornell Laboratory of Ornithology)
B*XX*	Regional array recorder station *XX* nmi from Barrow
BG*XX*	Burger lease cluster array recorder, station number *XX*
CL*XX*	Regional array recorder station *XX* nmi from Cape Lisburne
CLN*XX*	Regional array recorder station *XX* nmi north of CL50
CPA	Closest point of approach
ConocoPhillips	ConocoPhillips Company
dB	Decibel
EFR	Engine firing rate (of a vessel)
FFT	Fast Fourier transform
FM	Frequency-modulated
GB	Gigabyte (1024^3 bytes)
HF	High-frequency
Hz	Hertz, standard unit of frequency, 1 Hz = 1 s^{-1}
KL*XX*	Klondike lease cluster array recorder, station number *XX*
LF	Low-frequency
μPa	micropascal
MARU	Marine Autonomous Recording Unit
min	Minute
nmi	Nautical mile, 1 nmi = 1.852 km = 1.15 mile
NSIDC	National Snow and Ice Data Center
PL*XX*	Point Lay recorder station, *XX* nmi from shore
PLN*XX*	Point Lay recorder station, *XX* nmi north of PL50
pt	Point
rms	Root-mean-square
rms-90	Root-mean-square pressure within the time window containing 90% of pulse’s SEL.
s	Second
SEL	Sound exposure level (dB re 1 $\mu Pa^2 \cdot s$)
Shell	Shell Exploration and Production Company
SO*XX*	Statoil lease cluster array recorder, station number *XX*
SPL	Sound pressure level (dB re 1 μPa)
SR	Shaft rate (of a vessel)
Statoil	Statoil USA Exploration and Production, Inc.
UNCLOS	United Nations Convention on Law of the Sea
W*XX*	Regional array recorder station *XX* nmi from Wainwright
WN*XX*	Regional array recorder station *XX* nmi north of W50

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