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Acoustic detections of North Pacific humpback whales in the northern Bering and eastern Chukchi Seas, 2008-2015

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INTERNATIONAL WHALING COMMISSION

Acoustic detections of North Pacific humpback whales in the northern Bering and eastern Chukchi Seas; 2008-2015

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ABSTRACT

Data on the current latitudinal distribution of North Pacific humpback whales (*Megaptera novaeangliae*) in Arctic regions is becoming increasingly important as the population continues to recover, and climatic conditions continue to shift toward reduced or ice-free. Since 2006, the Alaska Fisheries Science Center's Marine Mammal Laboratory has deployed long-term acoustic recorders throughout the Bering, Chukchi and Beaufort seas in an effort to better understand marine mammal spatio-temporal distribution in the Alaskan Arctic and sub-Arctic. A subset of 7 years of these data (2008-2015) were analyzed to assess humpback whale seasonal occurrence in the high-latitude regions of their range. To provide the context needed to discriminate among species, all acoustic data (100% of the data; 17,416 days; 114,611 hrs) were analyzed manually. Humpback whales were consistently detected at moorings spanning from south of St. Lawrence Island in the northern Bering Sea (61.59°N, -171.33°W) to off Cape Lisburne in the eastern Chukchi Sea (69.32°N, -167.64°W), across all years sampled. The trend in calling activity varied within and among these locations by year, but in general consisted of variable bouts of calling activity during ice-free months. Overall, the time between ice retreat/arrival and humpback whale calling increased with latitude, consistent with the likely pattern of annual migration of animals among these locations. Humpback whale calling activity at known macrobenthic hotspots was consistently higher and more sustained in 2012 than in all other years, with the lowest levels in 2015. North of Cape Lisburne, humpback whales were detected in short bouts (days) at two locations: 110 nm offshore of Icy Cape in 2014 (18 Aug; ice free conditions) and three consecutive years at 22 nm offshore of Wainwright (Oct, June, July, 2013-2015; 30% ice cover, 68% ice cover, and ice-free, respectively). Humpback whale calling overlapped with ice presence at two locations in the northern Bering and two locations in the eastern Chukchi across years; however, all overlap occurred during ice formation or break-up. Overall, these data support the recurring presence of humpback whales in arctic and sub-arctic waters during ice-free or low ice conditions.

INTRODUCTION

Understanding the latitudinal distribution of humpback whales throughout the Arctic and sub-Arctic is becoming increasingly important as the population continues to recover from whaling (Barlow *et al*. 2011), and whales potentially expand into new or historically important habitats. Changing climatic conditions appear to support northward expansion of sub-arctic species (Clarke *et al*. 2013). Distribution of humpback whales in Arctic waters is almost certainly driven by food availability and access to specific habitats. Complex oceanographic interactions have resulted in distinct macrobenthic hotspots in the northern Bering and Chukchi seas that are consistently occupied by multiple marine mammal species during summer months for feeding (Grebmeier et al. 2015). Ice is assumed to be one of the primary initiating drivers of some humpback whale migration from high-latitude foraging areas, and has been decreasing in thickness and extent in the Arctic and sub-Arctic for the past decade (Stroeve *et al*. 2014). It is unknown how these changing climatic conditions are affecting humpback whale distribution in arctic waters.

The National Marine Fisheries Service (NMFS) has recently divided humpback whales (*Megaptera novaeangliae*) worldwide into fourteen Distinct Population Segments based upon breeding location (NMFS 2016). Consequently, many North Pacific humpback whales have either been removed from the U.S. list of endangered species or have been reclassified from ‘endangered’ to ‘threatened’; this classification is due in large part to extensive studies on high-latitude feeding grounds which aimed to better assess population recovery of humpback whales from commercial whaling (Calambokidis *et al.* 2008). Satellite tagging, photo-identification, and passive acoustic effort focused primarily in the Gulf of Alaska and southern Bering Sea have elucidated complicated migratory connections between breeding and feeding areas, and has shown high degrees of site fidelity of individuals to specific grounds (Calambokidis *et al*. 2008).

In contrast, effort has been limited in the northern Bering Sea and arctic waters. Soviet whalers documented the presence of hundreds of humpback whale between June and October off the Chukotka Peninsula between the late 1930s and early 1940s (Nikulin, 1946), but these numbers declined from the 1930s to the 1980s due to commercial whaling (Mel’nikov 1999). The extent to which humpback whales have occupied the northern Bering in recent years, and how their current distribution compares to that before exploitation, remains unclear. Multi-decadal aerial and vessel survey effort in the eastern Chukchi Sea (1979-present) [1] have allowed for documentation of humpback whale distribution north of the Bering Strait, and has detected a recent (10 year) increase in the abundance and extent of humpback whales in Arctic waters (Clarke *et al.* 2013). This work, however, has been limited to the summer and fall months, and each survey involved limited effort due to funding and visibility constraints. Passive acoustic monitoring remains a cost-effective tool to study the presence of vocal marine mammal species in hard to study regions across large spatio-temporal scales (Moore *et al*. 2006).

Since 2006, the Marine Mammal Laboratory (MML) of the Alaska Fisheries Science Center has deployed long-term acoustic recorders in the Bering, Chukchi, and Beaufort seas to monitor the spatio-temporal distribution of marine mammals in the Alaskan Arctic and sub-Arctic. To investigate the seasonal occurrence of humpback whales in the northern extent of their range, a subset of 7 years of data from the northern Bering to the far western Beaufort was analyzed. Here we present the results of that analysis, which documents the recurring presence of humpback whales in these high latitude habitats.

METHODS

Equipment and processing

A total of 51 recorder deployments from 2008 to 2015 were used in analysis (Table 1; Figure 1). These sub-surface bottom-mounted moorings were comprised of an anchor, acoustic release, passive acoustic recorder, and 30” steel subsurface float arranged in a linear configuration connected with chain, except at the M8 location where an Acoustic Doppler Current Profiler (ADCP), incased in a 36"syntactic float, was added inline above the 30"steel float. Autonomous Underwater Recorder for Acoustic Listening recorders (AURAL; Multi-Électronique, Rimouski, QC, Canada) were used for all moorings and years except for two deployments at BS1 (2010-2011, 2011-2012) which used Ecological Acoustic Recorders (EAR; Oceanwide Sciences Institute, Hawaii, USA). The AURALs, in the Bering Sea, originally sampled at 8,192 Hz on a duty cycle that ranged from 30-40%. In 2012 the Bering Sea AURAL’s sampling rate was changed to 16,384 Hz on a duty cycle ranging from 27-29%. All AURALs deployed in the Chukchi and Beaufort Seas sampled at 16,384 Hz on a duty cycle ranging from 27-32% (Tables 2-3). The EARs had a sampling rate of 4,096 Hz (nominal bandwidth from 10 Hz to 8 kHZ) on a 7% duty cycle. Deployment time varied by location and year (Tables 2-3).

After the recorders were retrieved, the raw data were converted into ten-minute wave files. Image files (.png) of spectrograms were pre-generated from recordings (FFT 1024, 0.85 overlap, Hamming window), which displayed 225 s of data from 0 to 800 Hz. This 225 s segment of data is the analysis *interval length* of the study.

[1] NOAA Fisheries, Marine Mammal Laboratory, Aerial Surveys of Arctic Marine Mammals (ASAMM) https://www.afsc.noaa.gov/nmml/cetacean/bwasp/index.php. 7 April 2017.

Analysis and species differentiation

Substantial overlap of call repertoires among baleen whales in the Arctic and sub-Arctic makes accurate classification of species using PAM difficult. To provide the context needed to discriminate humpback whale detections from those of other baleen whales, all acoustic data (100% of the image files; 17,416 days; 114,611 hrs; Table 1) were analyzed manually by experienced Arctic analysts for the presence of the following species: humpback, bowhead (*Balaena mysticetus*), gray (*Eschrichtius robustus*), minke (*Balaenoptera acutorostrata*), and North Pacific right whale (NPRW; *Eubalaena japonica*). Vessel noise and seismic airguns were also denoted in order to explore interactions of marine mammal presence and anthropogenic activity. No autodetection programs were used due to substantial overlap of the acoustic repertoires of many of these marine mammal species and the lack of stereotyped calls for most species, which has resulted in poor autodetector performance (Mocklin et al. 2016). Instead, an in-house MATLAB-based program (SoundChecker), which operates on pre-generated image files, was used for the manual analysis. For each image file, the analyst selects one of three options to indicate whether a species was detected in that file: yes, no, and maybe; only "yes" detections are reported here.

In order to differentiate among the marine mammal species, call characteristics (*i.e*. song structure, repetition, and frequency, slope, amplitude modulation, length of calls) and contextual clues (*i.e*. season, inter-call-interval, association with conspecific sounds) were used in tandem. For example, humpback whales were anticipated to produce frequency-modulated (FM) social calls of variable frequency (*e.g.,* 50 Hz to 4+ kHz) and amplitude modulation from spring through fall months (Thompson *et al*. 1986; McSweeney *et al*. 1989) before transitioning into song in late fall and early winter (McSweeney *et al*. 1989; Clark and Clapham 2004; Wright 2015). Bowhead whales were also anticipated to produce social calls of variable frequency (<400 Hz, Würsig and Clarke 1993) north of the Bering Strait in summer and fall months before transitioning into song. The latter is characterized by a multitude of short songs, often with repetitive, high-frequency (up to 5KHz) curving calls, during southbound migration into the northern Bering Sea (Clark *et al*. 1996; Stafford *et al*. 2008). Components of songs or individual calls that could not be identified to species with confidence were marked as "maybe" for all probable species. Gray whale calls were defined as either multiple harmonic FM moans (~0.5-1.5 s, 50-100 Hz) or higher frequency impulsive sounds, which have been referred to as 'bongo' calls and N1/S1 pulses (Cummings *et al*. 1968; Moore and Ljungblad 1984; Stafford et al. 2007). Minke whales were identified using the 'boing' call (Rankin and Barlow 2015) as well as pulse trains common in congeneric populations (Edds-Walton 1997). NPRW were identified using the 'up-call' (80-250 Hz), which often occurs in sets of 3-15 (> 5 s apart) with longer periods between sets (3-60+ min; McDonald and Moore 2002). A very conservative approach was used to positively identify all species in this analysis considering the present cacophony of marine mammal calling in the Arctic and sub-Arctic.

Due to the variety of duty cycles used (7-32%), sampling effort differed among days (Tables 2, 3). This was normalized by calculating daily *calling activity*, which is defined as the percentage of interval lengths with calls for each day (*e.g.*, for each day, interval lengths with calls / total interval lengths per day). It is important to note that calling activity does not indicate the number of call detections or number of animals vocalizing. Averages are presented as ± 1 SD.

Environmental Variables

Daily ice coverage was estimated for each mooring location from ice concentration data from the National Snow and Ice Data Center (NSIDC; http://nsidc.org/data/collections.html; Nov. 2015) using the bootstrap ice concentrations from Special Sensor Microwave Imager/Sounder (SSMI; 15 nm resolution, daily record; Comiso and Hall 2014). Ice was calculated as the daily average of all points within a 25 km radius around each mooring location per day. Daily averages were smoothed with a zero-phase three-day moving average.

RESULTS AND DISCUSSION

Out of the 51 analyzed recorder deployments (Figure 1), 26 had positive humpback acoustic detections (Table 1). Humpback whales were consistently detected at all moorings south of 70⁰N during predominantly ice-free conditions (Tables 4-5; Figures 1-2). These results are consistent with historical Soviet whaling data (Nikulin, 1946) as well as contemporary (2008-2016) aerial survey[1] and passive acoustic data (2007-2012; Clarke 2013; Hannay et al. 2013). These results are also consistent with known productivity of macrobenthic hotspots throughout the northern Bering and eastern Chukchi seas (Grebmeier et al. 2015; Figure 1).

Humpback whale calls were also detected in short bouts (i.e., days) at two locations north of 70⁰N (IC3, WT1; Table 5). At these northern locations, calling was sporadic, lasting only one to two days at a time and for short periods within each day (5-12% of day at WT1; 3% of day at IC3; Table 5, Figure 2). The IC3 calling occurred on 18 Aug 2014, and was the most northerly humpback whale detection. In contrast, calling at WT1 occurred in all three years analyzed (2013-2015), for days in October, June and July, respectively (Table 5; Figure 2). The persistent summer presence of humpback whales at WT1 suggests that individuals may be utilizing the resources in the northeastern Chukchi Sea hotspot (Figure 1). Previous studies in this region did not detect humpback whales north of 71⁰N (2007-2011; Hannay et al. 2013). However, when coupled together with our results, these data support the belief that humpback whales are rare, but recurring, seasonal species in the northeastern Chukchi Sea.

Humpback whale acoustic detections overlapped with ice presence at four mooring locations (M8, BS1, PH1, and WT1) over four years (2009, 2012-2014; Tables 4-5). However, all ice-associated acoustic detections occurred during the formation or retreat of ice; no calls were detected in over-wintering (100% ice cover) conditions (Figure 2), suggesting that humpback whales are seasonal visitors to the Arctic region. All M8 and BS1 ice overlap detections occurred for only for a few days (≤13) when percentage ice cover was low (< 30%; Table 4; Figure 2). At PH1, calling occurred on 23 May 2013 (78% ice cover; 19 days before the ice retreated), the first day ice coverage was below 90% (Table 5; Figure 2). At WT1, ice associated calling occurred on two days in different years, 31 October 2013 (30% ice cover; one day after ice arrived), and 05 June 2014 (68% ice cover; 49 days before the ice retreated (Table 5; Figure 2). The 2014 detection at WT1 coincided with a brief 5 day retreat of ice in which coverage dropped as low as 49%. Notably, the date of last calling increased at PH1 in 2014, where a short pulse of calling occurred days preceding ice formation in November (Table 5). These results suggest that humpback whales may be taking advantage of favorable conditions preceding or during ice formation/break-up (e.g., high productivity along the ice edge) at various northern locations before either being pushed out by the ice in fall or migrating further north with ice-melt in the spring.

While the number of individual animals calling was not discernable from this dataset, trends in the timing of peak calling activity among mooring locations appeared to loosely show the main migratory pulses of this population across years (Figure 3). In general, a trend of looser association between ice presence and first/last call occurred with increasing latitude (Tables 4-5), which was expected given that humpback whales are seasonal arctic species. Looking by year, a one-month delay in peak fall monthly percentages of humpback whale calling activity occurred among moorings from PH1 south to BS1 in 2012 and from CL1 south to KZ1 in 2015 (analysis ended Sept 2015; Table 6). For all years, the first day with calls detected appeared to support the belief of a spring migration of individuals from BS1 northward to KZ1 (Figure 3). Similarly, the last date with calls appeared to support the belief of a fall migration of individuals from CLI south to M8 for all years except 2014 (Figure 3). Trends in the calling activity results also appeared to show migration of humpback whales around St. Lawrence Island in the northern Bering Sea; consistently higher calling activity occurred at M8 (in SLIP hotspot) compared to BS1 (east of hotspot; Figure 1) in fall weeks preceding ice formation (Figure 4). Spring calling following ice retreat was similar at both locations for all years except 2015, when calling was much higher at BS1 (Figure 4). Taken together, these data suggest that humpback whales consistently migrate south in fall from 68⁰N down the eastern side of St. Lawrence Island (through the SLIP hotspot where M8 is located), whereas spring migration by St. Lawrence Island is more variable, but animals consistently occupied locations north of the Bering Strait up to 68ºN into the summer months (Figure 2).

Humpback whale calling occurred in all hotspots for all years analyzed (Figures 1-2). Within these hotspots, sustained calling (e.g., calling for multiple sequential days) overlapped in 2012 across months (May-Oct), supporting the idea of co-occurrence of humpback whales on distinct hotspots within a summer foraging season (Figures 4-5). In 2013, a one-month delay in peak calling occurred from NM1 to KZ1 (Table 6; Figure 5), which was followed by a two-month delay in peak calling between these two locations in 2014. However, in 2015, markedly lower calling activity occurred at all locations north of St. Lawrence Island, except KZ1 (Figure 5). Together, these data indicate annual variability in the presence and movement of humpback whales among hotspots.

Looking at calling frequency across all locations, the number of days with calls decreased with latitude, as expected, for most years; however, in 2015 calling was higher at CL1 than PH1 (Figure 2). These results suggest that humpback whales preferred CL1 (north of the southeastern Chukchi Sea hotspot) to PH1 (within the hotspot; Figure 1) during this year. It is not clear whether this was driven by a potential shift in resources. While primary productivity showed an increasing trend from 1988 to 2012 in the Bering and the Arctic (Arrigo and Dijken 2015), a recent string of unseasonably warm years (2014-present, 2013 transitional year[2]) throughout the northern Bering and Arctic may be impacting ecosystem dynamics in these regions. A trend in decreasing calling activity levels was seen across hotspots north of St. Lawrence Island for the years analyzed (2012-2015; Figure 5). M8 was the only hotspot location where calling activity was similar across sampled years (2008-2015; Figure 4). For all the other locations, the highest and most sustained peaks in calling activity (peaked at 100% calling activity) occurred in 2012 (Figure 5). When looking at the same months sampled across years, the lowest levels of calling activity for these moorings were seen in 2015 (Tables 4-5; Figures 4-5). In fact, KZ1 was the only location north of the Bering Strait in 2015 with daily calling activity percentages remotely similar to those of previous years for the same months sampled; all other locations had markedly lower calling activity percentages (> 20%; Figure 5). The dramatic reduction in duration and level of calling activity from 2012 to 2015 suggests a change in humpback whale presence. A shift in humpback whale presence was also observed in spring 2015 south of St. Lawrence Island; more humpback whale calls were detected east of the SLIP hotspot at BS1 than M8 (Figure 4). However, given the data, it is not possible to determine whether the reduced calling activity was due to a reduction of animals or a rapid passage of animals past that site. Regardless, the trend highlights a behavioral change in the species across multiple feeding grounds.

While the trend and level of calling activity varied among years at all locations, calling appeared most consistent at KZ1 (Figures 2, 5), suggesting that conditions in this hotspot may be less vulnerable to ecological changes than other regions. Alternatively, the consistent reduction in duration of calling from KZ1 north to CL1 across years (excluding 2015) suggests that KZ1 may simply reflect the existence of a preferred habitat for humpback whales in the eastern Chukchi Sea. KZ1 is located in the southeastern Chukchi Sea hotspot, which has had higher overall production than the other hotspot locations in recent (2000-2012) years (Grebmeier et al. 2015). While the inter-annual trend in calling activity levels was similar at KZ1, a shift in the timing of this calling still occurred at this location; the bulk of humpback whale calling occurred approximately one month earlier in 2013 (Aug) compared to all other years with data (Sep-Oct; Figure 5). With 2013 being a transitional year in the northern Bering Sea, it is unclear how or if these changing conditions may have affected the distribution and/or calling behavior of humpback whales at this location. It will be informative to compare these findings with oceanographic data in the future to explain the annual variability in humpback whale detections across locations.

We noted an increase in the number of ice-free days across almost all mooring locations north of the Bering Strait (excluding IC3), which did not translate into an increase in the number of days with detections across years for a given sampling location (Tables 4-5). Because of the type of data collected, we are unable to conclude whether this lack of trend with an increasing open-water period could be the

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result of a rapid passage of animals past this site or if individuals are simply calling less frequently. Alternatively, the lack of trend in number of days with calls with increasing open-water periods could be explained by individuals moving outside of the hydrophone range.

Altogether, the results of this report indicate recurring seasonal presence of humpback whales in the northern Bering and eastern Chukchi seas during predominantly ice-free conditions. The detection of humpback whales for three sequential years at WT1 in the northeastern Chukchi Sea supports the idea of rare but persistent occurrence of this species in this area. A decrease in overall calling activity across moorings located north of St. Lawrence Island from 2012 to 2015 might indicate a shift in the distribution of humpback whales in these regions. However, the limited knowledge of pre-whaling humpback whale distribution and absence of sampling prior to 2012, makes it impossible to determine if humpback whales are shifting their distribution in recent years or simply reoccupying pre-whaling habitats, including those outside of the detection range of our recorders. More years of data will be needed to help refine this conclusion. Furthermore, inclusion of all Bering Sea mooring sites will enable a fuller examination of North Pacific humpback whale spatio-temporal occurrence in Alaskan waters, especially in regard to their migratory timing.

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Table 1. Summary table of available acoustic data from all mooring locations (vertical axis; see Figure 1) by mooring deployment (2008-2015). Red squares indicate mooring deployments with positive humpback whale acoustic detections. Yellow squares indicate mooring deployments with no humpback whale detections. Also included are deployment years with acoustic data not yet analyzed (light gray), and periods when the mooring was not deployed (dark gray).

	Lat (^oN)	Long (^oW)	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015
BF2	71.751	154.491							
WT1	71.042	161.516							
WT2	71.780	161.855							
PB1	71.206	158.002							
HS1	72.427	161.629							
HS3	72.336	157.448							
IC1	70.817	163.136							
IC2	71.202	164.199							
IC3	71.829	166.072							
CL1	69.307	167.648							
PH1	67.909	168.195							
KZ1	67.125	168.602							
NM1	64.848	168.391							
NS1	63.400	166.241							
M8	62.196	174.660							
BS1	61.588	171.324							

Table 2. All long-term passive acoustic recorders, with humpback whale calling activity present, south of the Bering Strait (2008-2015).

Mooring	Mooring Year	Latitude (°N)	Longitude (°W)	Recorder Start Date	Recorder End Date	# Days w/Recordings	Sampling Rate (Hz)	Rec On (min)	Period (min)
BS1	2010-2011⁺	61.588	171.325	16 Sep 2010	18 Oct 2010	32	4096	4	60
	2011-2012⁺	61.587	171.324	04 Sep 2011	25 May 2012	264	4096	4	60
	2012-2013	61.587	171.324	13 Aug 2012	19 Aug 2013	371	16384	80	300
	2013-2014	61.587	171.328	21 Aug 2013	29 Sep 2014	404	16384	80	300
	2014-2015	61.587	171.328	29 Sep 2014	23 Sep 2015	342	16384	80	300
M8	2008-2009	62.196	174.659	01 Oct 2008	02 Jul 2009	274	8192	9	30
	2009-2010	62.196	174.659	30 Sep 2009	06 May 2010	218	8192	9	20
	2010-2011	62.196	174.659	03 Oct 2010	01 Feb 2011*	121	8192	8	20
	2011-2012	62.196	174.660	16 Aug 2011	25 Apr 2012	253	8192	80	300
	2012-2013	62.195	174.661	14 Aug 2012	20 Aug 2013	361	16384	80	300
	2013-2014	62.193	174.676	20 Aug 2013	15 Oct 2014	421	16384	80	300
	2014-2015	62.193	174.676	15 Oct 2014	23 Sep 2015	341	16384	80	300
NM1	2012-2013	64.847	168.390	20 Aug 2012	21 Aug 2013	366	16384	85	300
	2013-2014	64.848	168.391	22 Aug 2013	20 Sep 2014	394	16384	80	300
	2014-2015	64.848	168.391	22 Sep 2014	28 Sep 2015	332	16384	80	300

⁺ Ecological Acoustic Recorder (EAR)

* Did not record acoustic data on 23 and 24 Nov 2010, and recorder failed 01 Feb 2011

Table 3. All long-term passive acoustic recorders, with humpback whale calling activity present, north of the Bering Strait (2012-2015).

Mooring	Year	Latitude (°N)	Longitude (°W)	Recorder Start Date	Recorder End Date	# Days w/Data	Sampling Rate (Hz)	Rec On (min)	Period (mins)
IC3	2010-2011	71.833	165.903	10 Sep 2010	08 Jun 2011	272	16384	95	300
	2011-2012	71.831	165.901	29 Aug 2011	14 May 2012	260	16384	85	300
	2012-2013	71.829	166.072	28 Aug 2012	26 Aug 2013	364	16384	85	300
	2013-2014	71.831	166.074	28 Aug 2013	24 Sep 2014	395	16384	80	300
	2014-2015	71.831	166.078	25 Sep 2014	17 Sep 2015	358	16384	80	300
WT1	2012-2013	71.046	160.509	30 Aug 2012	28 Aug 2013	364	16384	85	300
	2013-2014	71.046	160.511	29 Aug 2013	10 Oct 2014	408	16384	80	300
	2014-2015	71.037	160.506	11 Oct 2014	13 Sep 2015	338	16384	80	300
CL1	2012-2013	69.307	167.648	23 Aug 2012	25 Aug 2013	368	16384	85	300
	2014-2015	69.317	167.630	26 Sep 2014	20 Sep 2015	360	16384	80	300
PH1	2012-2013	67.909	168.195	22 Aug 2012	23 Aug 2013	367	16384	85	300
	2013-2014	67.907	168.203	24 Aug 2013	15 Sep 2014	388	16384	80	300
	2014-2015	67.908	168.202	17 Sep 2014	21 Sep 2015	370	16384	80	300
KZ1	2012-2013	67.125	168.602	21 Aug 2012	22 Aug 2013	367	16384	85	300
	2013-2014	67.123	168.605	24 Aug 2013	24 Sep 2014	397	16384	80	300
	2014-2015	67.124	168.604	25 Sep 2014	21 Sep 2015	362	16384	80	300

Table 4. Humpback whale calling for acoustic recorders south of the Bering Strait (2008-2015). Dashed line indicate time periods when no calls were detected. E indicates # days excluded for years with incomplete acoustic data. Negative numbers in the # days columns indicate overlap of humpback whale calling activity and ice presence.

Mooring	Year	Day of Ice Retreat	First Day w/Calls	Last Day w/Calls	Day of Ice Formation	# Days b/t Ice Retreat and First Call	# Days b/t Last Call and Ice Formation	# Days w/Calls	# Days w/Recordings	% Days w/Calls
BS1	2010	10 May 2010	17 Sep 2010[%]	16 Oct 2010	30 Dec 2010	E	E	4	33	12.1
	2011	24 May 2011	10 Sep 2011	01 Dec 2011	02 Dec 2011	E	1	31	119	26.1
	2012	8 Jun 2012	13 Aug 2012	18 Dec 2012	12 Dec 2012	E	-6	67	287	23.3
	2013	25 May 2013	01 Jun 2013	12 Dec 2013	29 Dec 2013	7	17	103	365	28.2
	2014	10 May 2014	04 Jun 2014	24 Jan 2015*	27 Jan 2015*	25	3	72	349	20.6
	2015	13 May 2015	28 May 2015	06 Sep 2015[+]	23 Dec 2015	15	E	62	266	23.3
M8	2008	--	2 Oct 2008[%]	08 Dec 2008	24 Dec 2008	E	16	38	92	41.3
	2009	06 Jun 2009	13 Jun 2009	15 Dec 2009	02 Dec 2009	7	-13	54	276	19.6
	2010	15 May 2010	03 Oct 2010	06 Dec 2010	30 Dec 2010	E	24	57	214	26.6
	2011	3 Jun 2011	16 Aug 2011	12 Dec 2011	17 Dec 2011	E	5	75	170	44.1
	2012	26 May 2012	15 Aug 2012	16 Dec 2012	14 Dec 2012	E	-2	91	256	35.5
	2013	04 Jun 2013	03 Jun 2013	26 Dec 2013	27 Dec 2013	-1	1	124	356	34.8
	2014	10 May 2014	01 Jun 2014	2/9/2015*	7 Feb 2015*	22	-2	134	365	36.7
	2015	26 Apr 2015	31 May 2015	22 Sep 2015[+]	24 Dec 2015	35	E	86	266	32.3
NM1	2012	25 May 2012	20 Aug 2012[%]	13 Nov 2012	21 Nov 2012	E	8	58	134	43.3
	2013	28 May 2013	09 Jun 2013	06 Nov 2013	11 Dec 2013	12	35	95	360	26.4
	2014	24 May 2014	10 Jun 2014	21 Nov 2014	07 Dec 2014	17	16	134	365	36.7
	2015	21 May 2015	07 Jun 2015	20 Aug 2015[+]	9 Dec 2015	17	E	31	232	13.4

[%]Sampling started on 16 Sept 2010 (BS1), 1 Oct 2008 (M8) and 20 Aug 2012 (NM1)
*Year(s) when humpback whale calling activity and/or ice presence extended into the following calendar year
[+]Sampling ended on 23 Sep 2015 (BS1, M8) and 20 Aug 2015 (NM1)

Table 5. Humpback whale daily calling for acoustic recorders north of the Bering Strait (2012-2015). Dashed line indicate time periods when no calls were detected. E indicates # days excluded for years with incomplete acoustic data. Negative numbers in the # days columns indicate overlap of humpback whale calling activity and ice presence.

Mooring	Year	Day of Ice Retreat	First Date w/Calls	Last Date w/Calls	Day of Ice Formation	# Days b/t Ice Retreat and First Call	# Days b/t Last Call and Ice Formation	# Days w/Calls	# Days w/Recordings	% Days w/Calls
IC3	2010	16 Jul 2010	--	--	31 Oct 2010	E	--	0	113	0.00
	2011	05 Jul 2011	--	--	22 Nov 2012	--	--	0	284	0.00
	2012	27 Jul 2012	--	--	03 Nov 2012	--	--	0	261	0.00
	2013	21 Jul 2013	--	--	26 Oct 2013	--	--	0	364	0.00
	2014	30 Jul 2014	18 Aug 2014	18 Aug 2014	02 Nov 2014	19	76	1	365	0.27
	2015	30 Jun 2015	--	--	12 Nov 2015	--	E	0	260	0.00
WT1	2012	09 Aug 2012	--	--	01 Nov 2012	E	--	0	124	0.00
	2013	31 Jul 2013	05 Oct 2013	31 Oct 2013	30 Oct 2013	66	-1	3	365	0.82
	2014	24 Jul 2014	05 Jun 2014	05 Jun 2014	31 Oct 2014	-49	148	1	365	0.27
	2015	30 Jun 2015	19 Jul 2015	22 Jun 2015[+]	05 Oct 2015	19	E	2	256	0.78
CL1	2012	27 Jun 2012	13 Sep 2012[%]	25 Oct 2012	14 Nov 2012	E	20	6	131	4.58
	2013	21 Jun 2013	11 Jul 2013	02 Aug 2013[+]	24 Nov 2013	20	114	7	237	2.95
	2014	07 Jun 2014	--	--	29 Nov 2014	E	E	0	97	0.00
	2015	13 Jun 2015	21 Jun 2015	01 Sep 2015[+]	20 Nov 2015	8	E	25	263	9.51
PH1	2012	16 Jun 2012	22 Aug 2012[%]	09 Oct 2012	16 Nov 2012	E	38	31	132	23.48
	2013	11 Jun 2013	23 May 2013	05 Oct 2013	25 Nov 2013	-19	51	76	365	20.82
	2014	30 May 2014	15 Aug 2014	30 Nov 2014	07 Dec 2014	77	8	18	364	4.95
	2015	01 Jun 2015	19 Jun 2015	02 Sep 2015[+]	28 Nov 2015	18	E	9	264	3.41
KZ1	2012	09 Jun 2012	21 Aug 2012[%]	10 Nov 2012	16 Nov 2012	E	6	50	133	37.59
	2013	08 Jun 2013	30 Jun 2013	31 Oct 2013	26 Nov 2013	22	26	69	364	18.96
	2014	30 May 2014	16 Jun 2014	02 Nov 2014	11 Dec 2014	17	40	71	365	19.45
	2015	24 May 2015	22 Jun 2015	21 Sep 2015[+]	27 Nov 2015	29	E	16	264	6.06

[%]Sampling began on 23 Aug 2012 (CL1), 22 Aug 2012 (PH1) and 21 Aug 2012 (KZ1)
[+]Sampling ended on 13 Sep 2015 (WT1), 25 Aug 2013 (CL1), 20 Sep 2015 (CL1), 21 Sep 2015 (PH1) and 21 Sep 2015 (KZ1)

Table 6. Monthly humpback whale calling activity (i.e. the percentage of time intervals (225 s) with acoustic detections) for recorder locations and months with positive humpback whale acoustic detections; 2012-2015. Gray shading indicates months with the highest humpback whale calling activity for each location by calendar year.

	2012					2013								2014									2015			
	Au	Se	Oc	No	De	Ma	Ju	Ju	Au	Se	Oc	No	De	Ju	Ju	Au	Se	Oc	No	De	Ja	Fe	Ju	Ju	Au	Se
IC3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WT1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
CL1	0.0	0.4	0.1	0.0	0.0	0.0	0.7	0.2	NA	NA	NA	NA	NA	NA	NA	NA	0.0	0.0	0.0	0.0	0.0	0.0	0.2	5.0	3.0	0.1
PH1	3.9	32.1	0.2	0.0	0.0	0.1	0.3	6.2	2.7	5.2	0.1	0.0	0.0	0.0	0.0	0.8	0.8	0.4	0.4	0.0	0.0	0.0	0.0	0.2	1.0	0.1
KZ1	19.0	18.2	20.4	0.0	0.0	0.0	0.4	11.6	23.8	7.4	1.1	0.0	0.0	1.2	0.7	1.2	8.6	23.8	0.3	0.0	0.0	0.0	0.3	0.1	0.6	10.9
NM1	0.1	15.0	74.8	22.7	0.0	0.0	8.2	12.1	5.6	2.2	4.9	4.3	0.0	7.2	13.4	33.2	3.5	10.1	11.4	0.0	0.0	0.0	0.4	1.9	3.4	NA
M8	3.2	5.3	15.4	52.2	10.8	0.0	0.9	2.9	2.3	12.3	5.8	31.1	12.8	4.0	5.0	7.5	11.7	7.6	5.3	26.1	35.4	0.4	3.8	2.6	1.0	1.2
BS1	3.5	2.2	5.7	11.1	15.9	0.0	1.6	6.7	9.1	13.9	1.1	6.9	2.4	5.7	3.5	4.1	1.7	0.3	0.8	1.5	2.9	0.0	15.9	8.2	3.8	0.7

Figures

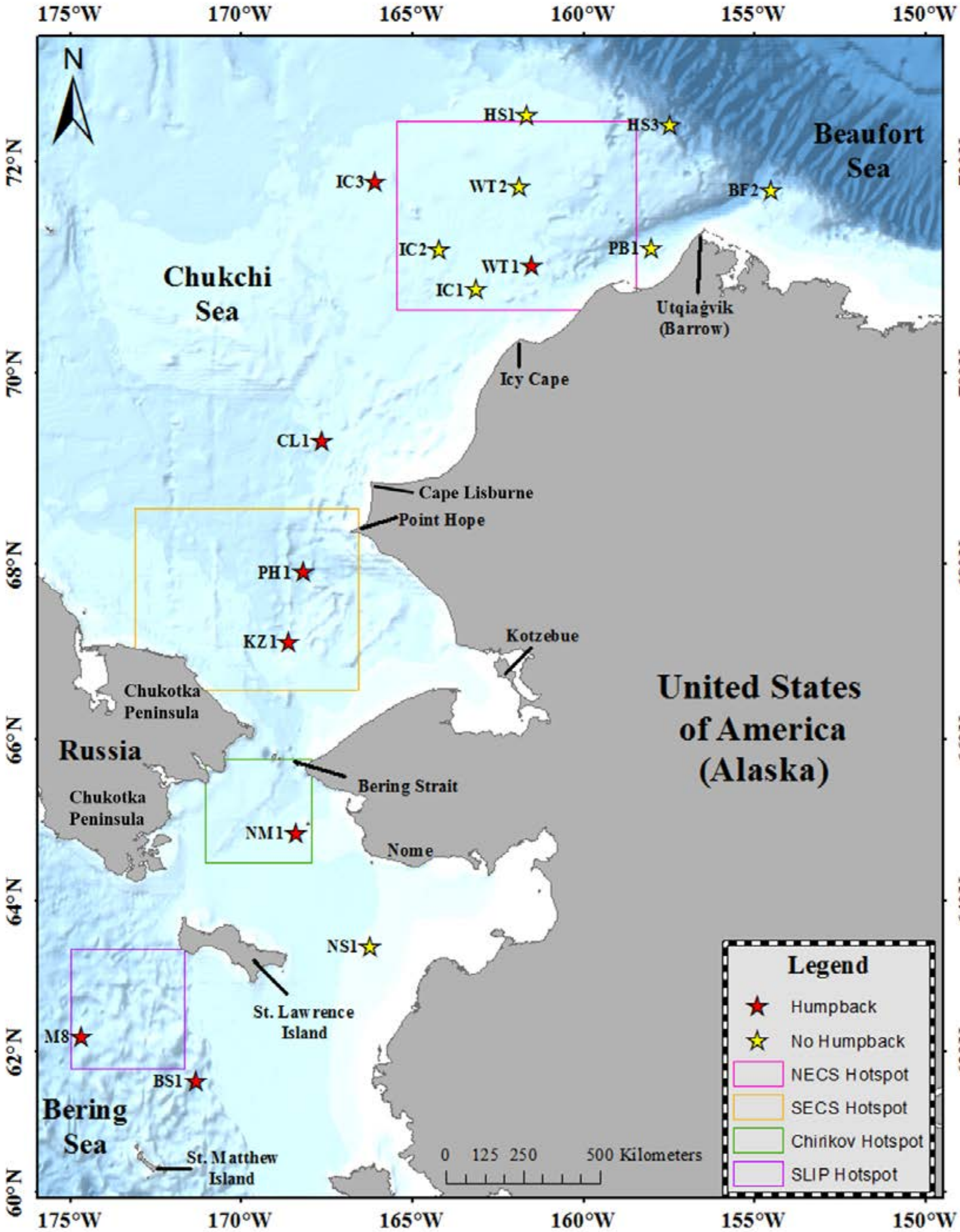

Figure 1. Map of deployment locations for all moorings. Red stars indicate moorings with humpback whale calling activity. Yellow stars indicate moorings with no humpback whale calling activity. Macrobenthic hotspots (Grebmeier *et al*. 2015) are depicted as follows; pink box indicates Northeast Chukchi Sea (NECS), orange box indicates Southeast Chukchi Sea (SECS), green box indicates Chirikov Basin, northern Bering Sea (Chirikov), and purple box indicates St. Lawrence Island Polynya region (SLIP).

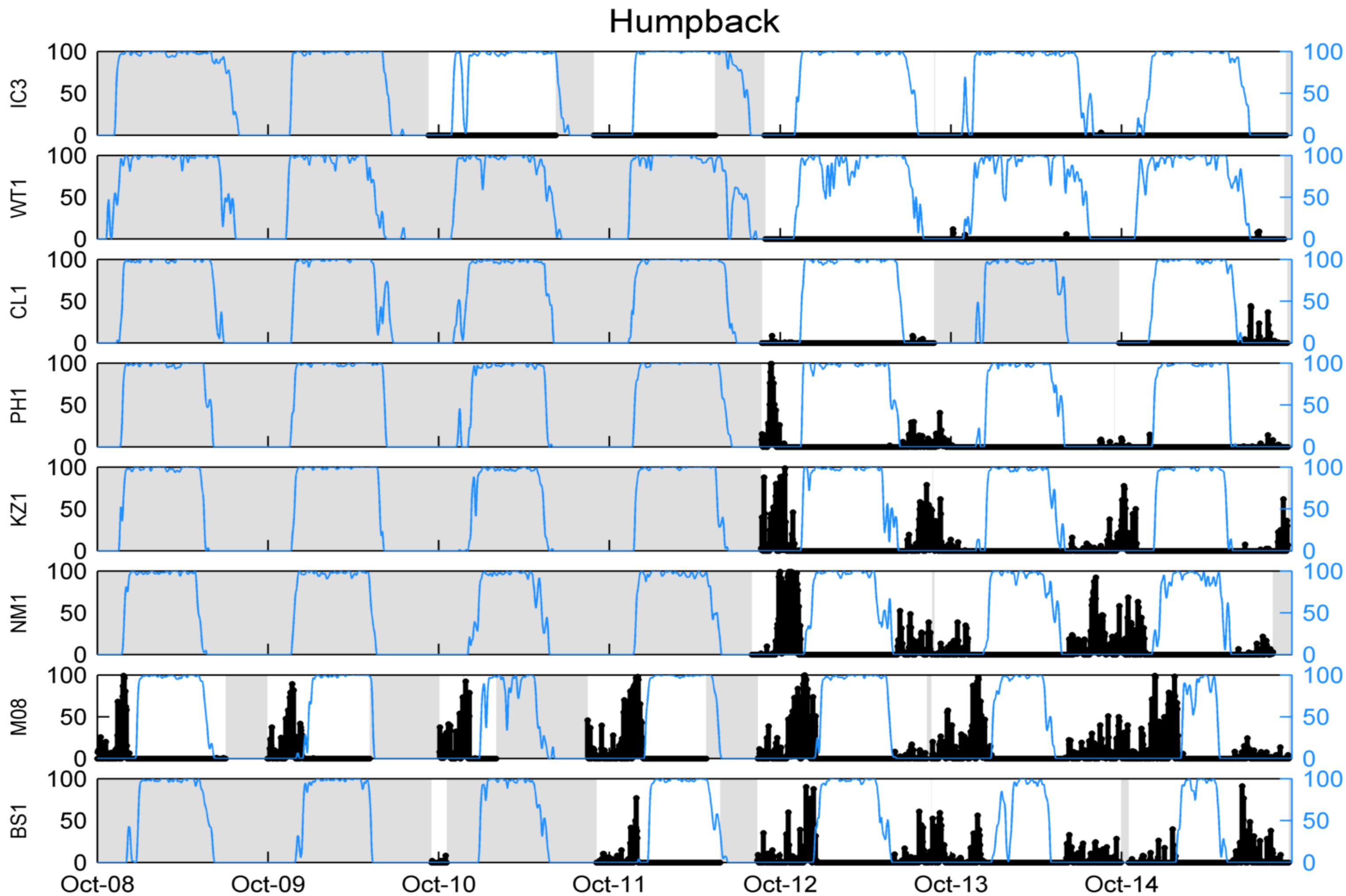

Figure 2. Humpback whale calling activity (i.e. the percentage of time intervals (225 s) with acoustic detections, black vertical bars) presented across years by mooring location. Blue line indicates percent ice cover (zero-phase, three-day moving average) and corresponds with secondary vertical axis. Light gray areas indicate times with no acoustic data.

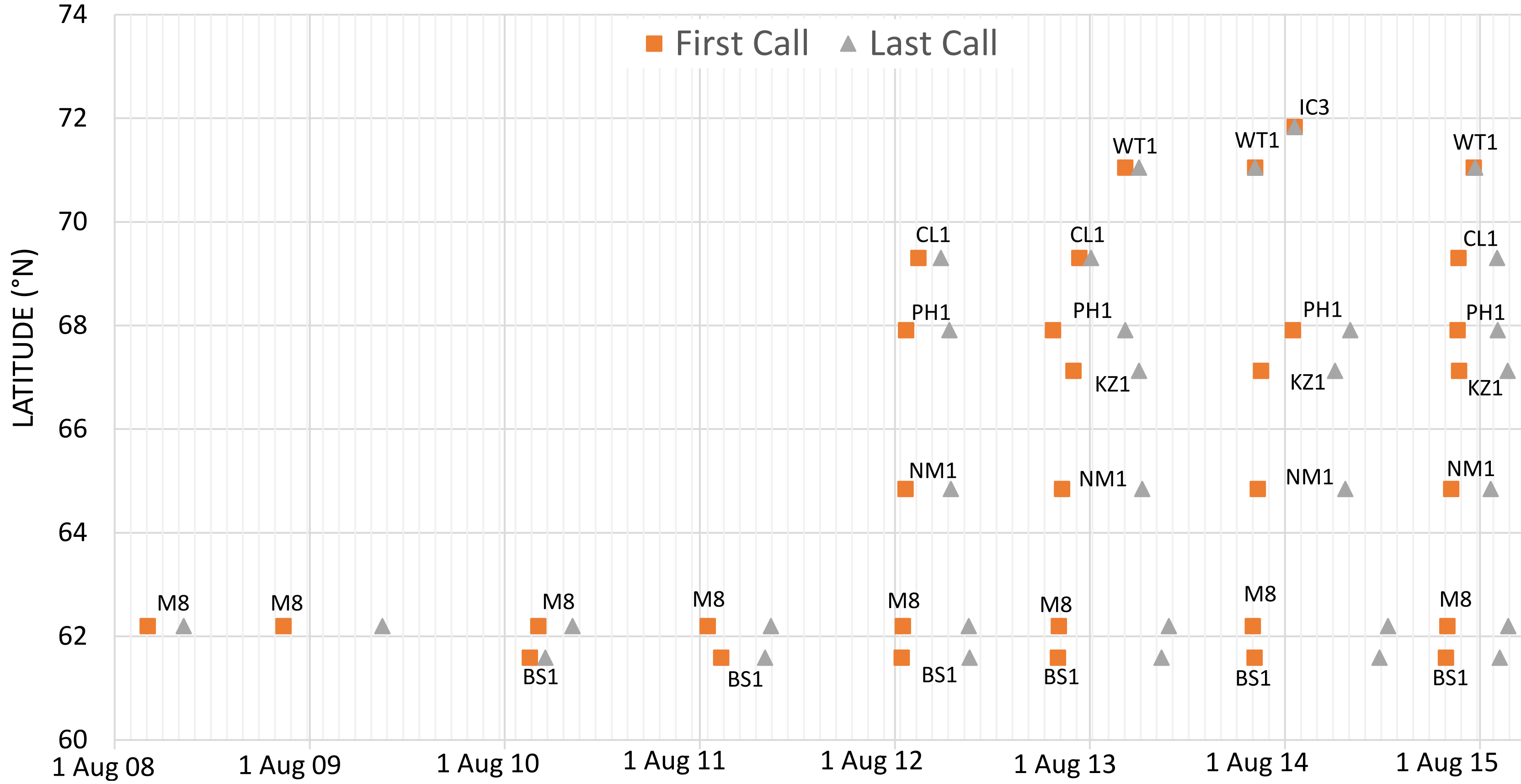

Figure 3. Date of first (orange square) and last (gray triangle) humpback whale call for moorings with positive humpback whale acoustic detections by latitude; 2008-2016. Thin vertical gray lines denote month and thick lines denote year (1 Aug). Please refer to Tables 2 and 3 for annual recorder deployment start and end dates.

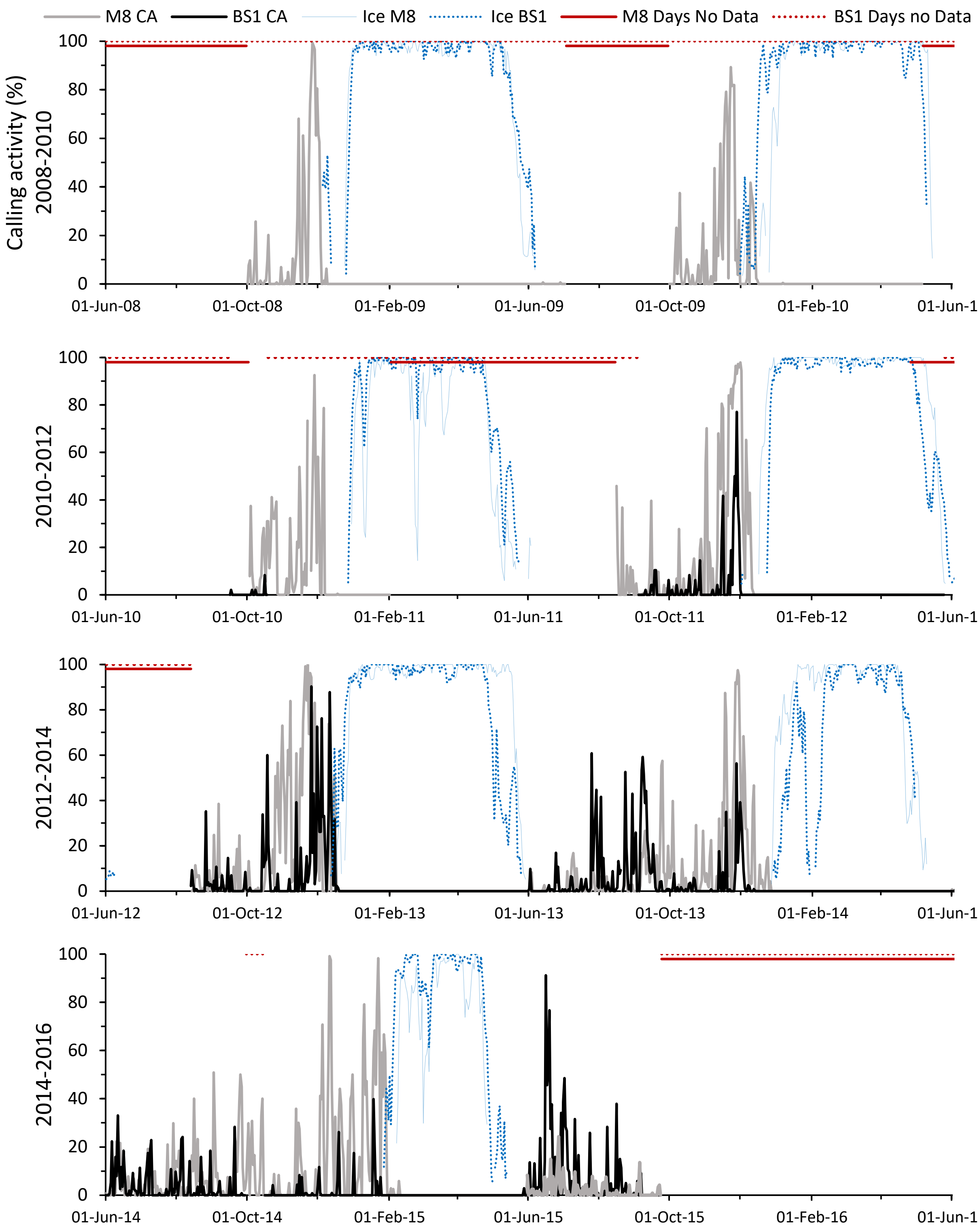

Figure 4. Humpback whale calling activity (i.e., the percentage of time intervals (225 s) with acoustic detections) for moorings south of St. Lawrence Island (M8 = gray and BS1 = black); 1 June 2008-2016. Blue lines indicate percent ice cover (M8 light blue, BS1 dark blue dashed) and correlates to the scale on the y-axis. Red horizontal lines indicate days with no acoustic data (M8, gray; BS1, dashed black) and do not correlate to the y-axis.

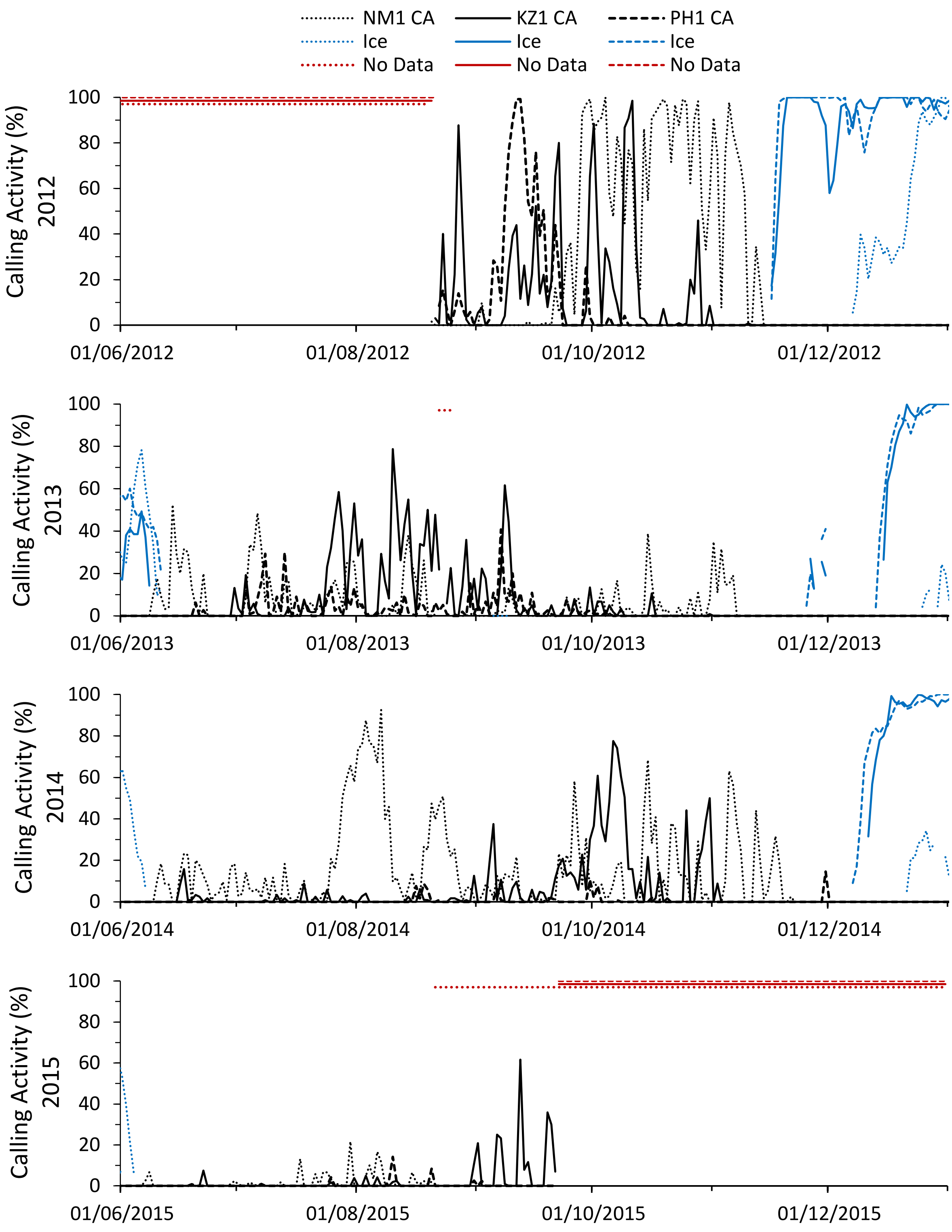

Figure 5. Humpback whale calling activity (i.e., the percentage of time intervals (225 s) with acoustic detections) for recorders located in known macrobenthic hotspots with sustained humpback whale calling north of St. Lawrence Island (NM1 = dotted, KZ1 = solid, and PH1 = dashed) from 1 June to 31 Dec; 2012-2015. Blue lines indicate percent ice cover and correlates to the scale on the y-axis. Red horizontal lines indicate days with no acoustic data and do not correlate to the y-axis.