Aquatic Mammals 2011, *37*(4), 464-471, DOI 10.1578/AM.37.4.2011.464

Seasonal Trends in Acoustic Detection of Ribbon Seal (*Histriophoca fasciata*) Vocalizations in the Bering Sea

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Abstract

The seasonal presence of ribbon seals (*Histriophoca fasciata*) on the central and southeastern Bering Sea shelf was determined from vocalizations recorded with a Passive Aquatic Listening (PAL) recorder at two sites along the 70-m isobath from 2007 to 2010. Ribbon seal vocalizations were identified as intense, stereotyped downsweeps, roars, and grunts. Acoustic detections were seasonal, with peak acoustic activity occurring in April at the southeastern site and May at the central shelf location. Ribbon seal acoustic presence was tightly coupled to sea ice presence, and onset of detection was associated with thicker, more extensive ice cover compared to the other Arctic pinnipeds (bearded seals [*Erignathus barbatus*] and walrus [*Odobenus rosmarus*]) detected in the region. Ribbon seal vocalizations were detected only when ice cover in the area exceeded 80%, suggesting that this species has a habitat preference or requirement for a more stable ice platform for some activities during the winter breeding season.

Key Words: ribbon seal, *Histriophoca fasciata,* acoustic detection, vocalization, Bering Sea

Introduction

The ribbon seal is an aquatic-mating species endemic to the North Pacific. There are three recognized populations: two in the Okhotsk Sea and one in the Bering Sea (Fedoseev, 2002). Ribbon seals are not able to maintain breathing holes in ice thicker than 10 to 15 cm, which limits their northern range and restricts habitat use in the Bering Sea to areas of thick, stable but broken ice near the ice-edge (Fedoseev, 2002). These animals rely heavily on ice for activities related to breeding and molting in the winter and spring. In the Bering Sea, ribbon seals become pelagic and remain in the area during the ice-free months (Burns, 1970). Compared to other aquatic-mating pinnipeds in polar regions such as the ringed (*Phoca hispida*), bearded (*Erignathus barbatus*), harp (*Pagophilus groenlandicus*), harbor (*Phoca vitulina*), and Weddell seals (*Leptonychotes weddellii*) and walrus (*Odobenus rosmarus*), relatively little is known about the mating system, foraging, or vocal behavior of ribbon seals (Watkins & Ray, 1977; Van Parjis, 2003; Van Opzeeland et al., 2010). This is most likely due to their pelagic and ice-edge associated existence, which makes direct observation, capture, and tagging difficult, unsafe, and, for the most part, logistically unfeasible.

Advances in acoustic technology and analysis techniques offer a non-invasive alternative to direct observation of animal presence and behavior when traditional survey methods are not possible (Mellinger et al., 2007). Long-term acoustic monitoring of an area has provided valuable insight into the presence of different species, migration patterns, foraging behavior, relative abundance, and mating strategies for both cetaceans and pinnipeds when extreme conditions prevent ship or aerial surveys (Van Parijs et al., 2001, 2004; Rogers, 2003; Burtenshaw et al., 2004; Širovic et al., 2004; Stafford et al., 2007; Van Opzeeland et al., 2010). To date, information resulting from the passive acoustic monitoring of ribbon seal vocalizations has been sparse because information about their vocal behavior and repertoire is limited. The authors are only aware of one study that describes the vocalizations recorded from ribbon seals (Watkins & Ray, 1977). Intense downward frequency sweeps and broadband "puffing" sounds were recorded in the presence of ribbon seals off the coast of St. Lawrence Island, Alaska, in the Bering Sea in 1967. A recent study by Miksis-Olds et al. (2010) used the detection of intense downsweeps described by Watkins & Ray (1977) to indicate ribbon seal presence in the central Bering Sea. This work builds upon previous research by describing new ribbon seal vocalizations, seasonal acoustic detections in the Bering Sea, and the relationship between acoustic detections and environmental conditions.

Materials and Methods

A Passive Aquatic Listener (PAL) was used to detect ribbon seal vocalizations in the Bering Sea. The PAL is an adaptive subsampling acoustic recorder with a temporal sampling strategy designed to allow the instrument to record data for up to 1 y (Nystuen, 1998; Nystuen et al., 2004; Miksis-Olds et al., 2010). The default sampling strategy was to record a 4.5 s acoustic time series, or soundbite, at a sampling rate of 100 kHz every 5 min. This corresponded to a 1.5% duty cycle. When sampling in the default mode, onboard processing algorithms subsampled the 4.5 s soundbite eight times and generated a power spectrum for each subsample. A preliminary detection algorithm identified signals of interest when a temporal feature of one or more of the eight subsampled power spectra in a soundbite exceeded one of three threshold criteria: (1) the matching of spectrum characteristics to known spectra, (2) exceeding a 12 dB threshold level between sequential samples indicating a transient source, or (3) the matching of predefined peaks (e.g., 300 Hz to 3 kHz) indicating possible tonal or click vocalizations from marine mammals. If no signals of interest were detected, the spectra were averaged, and a single spectrum was saved to the hard disk. The soundbite time series was not saved in the default sampling mode. During periods of increased acoustic activity where signals of interest triggered a modified sampling protocol, the sampling interval was decreased to 2-min intervals, and individual spectra plus the soundbites were saved to the hard disk. This corresponded to a 4% duty cycle. The PAL continued to operate in the 2-min interval, higher duty cycle mode until a signal of interest was not detected, at which point the PAL returned to the default sampling mode. Details on the adaptive sampling algorithms of the PAL are found in Miksis-Olds et al. (2010).

The PAL was deployed on a subsurface National Oceanic and Atmospheric Administration (NOAA) Fisheries-Oceanography Coordinated Investigations (FOCI) mooring along the 70-m isobath at site M5 (59° 54.58' N, 171° 42.47' W) in the central region of the eastern Bering Sea shelf from September 2007 through May 2009 (Stabeno et al., 2008, 2010). A second PAL was deployed at site M2 (56° 51.83' N, 164° 03.05' W) on the southeastern Bering Sea shelf from September 2009 through April 2010 (Figure 1). The PAL at M5 was deployed for a total of 595 d, and the PAL at M2 was deployed for 215 d. The PAL at M5 was retrieved annually, and a refurbished PAL was deployed on the same day, which limited data gaps to less than 6 h during the mooring maintenance period.

Every soundbite was reviewed by a human classifier and verified by a second independent human classifier blind to the results of the first reviewer. Sound sources present in the soundbites were identified from spectrograms (1,024 point FFT, Hamming window, 87.5% overlap) made from the original 100 kHz recordings using Adobe *Audition*, Version 3.0 (Adobe Systems Incorporated, San Jose, CA, USA). These settings provided a bandwidth of 61 Hz, with a frequency resolution of 47 Hz and a time resolution of 2.7 ms. The zoom function was used to display signals from 0 to 8 kHz during the classification and measurement processes. Biological signals were classified aurally and visually from the spectrograms by species (bowhead [*Balaena mysticetus*], walrus, ribbon seals, and bearded seals). Unknown signals were grouped into categories based on frequency and temporal structure. During initial analysis, only ribbon seal downsweeps were used to indicate species presence. It was noted that two categories of unknown signals were consistently detected in conjunction with the ribbon seal downsweeps: (1) grunts and (2) roars (Figure 2). Grunts were soft, short duration broadband signals that sounded like pig grunts. Roars were louder, longer duration broadband signals the sounded like a wildcat roar.

Vocal parameters were measured manually from the spectrogram by the two classifiers for each vocalization, as appropriate. Measurements for downsweeps included call duration, number of harmonics, start, end, and maximum and minimum frequency. Measurements for the potential ribbon seal broadband grunts and roars included call duration and maximum, minimum, and peak frequency. Values from only the primary analyst were used in statistical calculations unless the value from the second analyst differed by more than 10% (approximately two frequency resolution bins) of the primary analyst's measurement; in this case, the two values were averaged. Values differed by more than 10% for approximately 9% of all measurements.

A coefficient of association (COA) analysis was performed to explore the hypothesis that grunts and roars were made by ribbon seals, using the previously described downsweep as a benchmark. COA analyses are typically used with visual sighting data, and we have adapted the simple ratio index for use with acoustic data (Ginsberg & Young, 1992; Whitehead & Dufault, 1999):

$$\frac{X}{X + Y_{\mathrm{AB}} + Y_{\mathrm{A}} + Y_{\mathrm{B}}}$$

where X is the number of days during which signals A and B are detected together, Y_{A} is the number of days during which only signal A is detected,

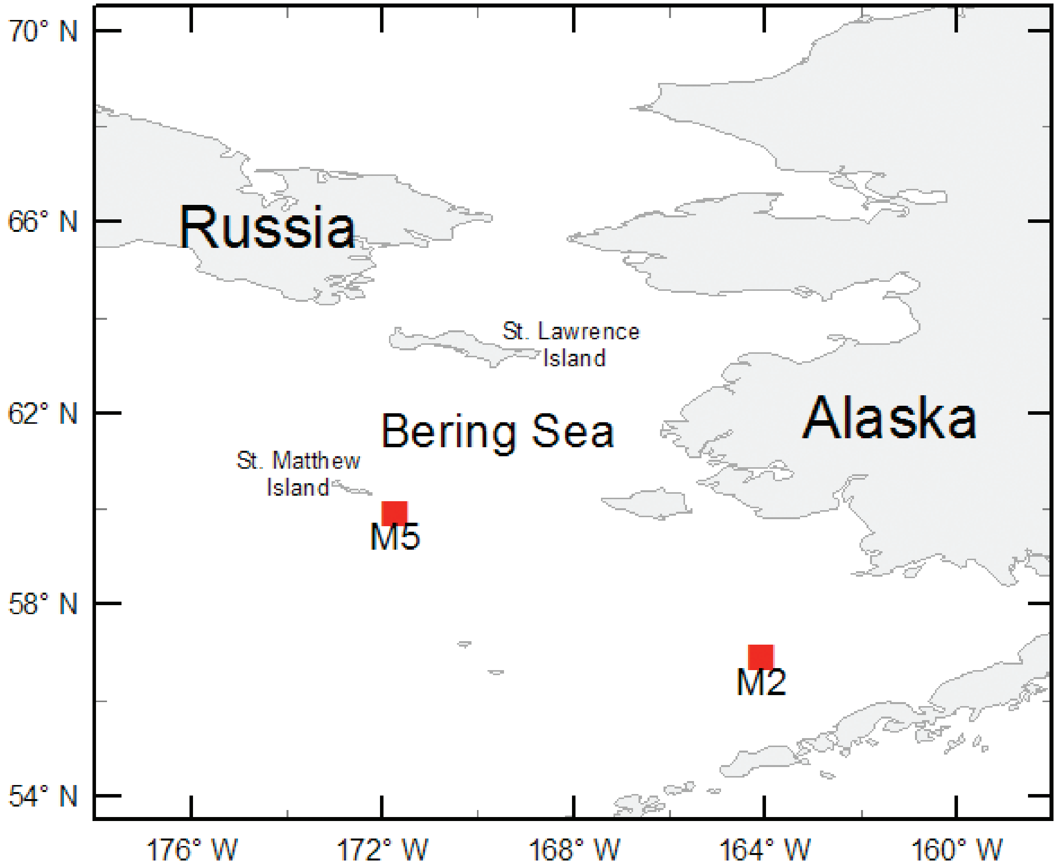

Figure 1. Location of mooring sites M2 and M5 along the 70-m isobath on the eastern Bering Sea shelf

and Y_B is the number of days that only signal B is detected. When applied to visual data, Y_{AB} is the number of observation periods (or days) during which individuals A and B are both observed in separate groups (Ginsberg & Young, 1992). The acoustic data in this study do not allow for spatial separation or range of the detected signals, so this variable was omitted from the calculation. Using this modified index, COA values for two vocalization categories range from zero (never detected together) to 1 (always detected together). Vocalization categories used in the COA analysis represented all identified categories of biologic sound recorded from January through June each year: (1) all bowhead calls, (2) walrus knocks and bells, (3) bearded seal trills, (4) ribbon seal downsweeps, (5) grunts, and (6) roars.

To examine ribbon seal acoustic detections in relation to local ice cover, ice characteristics were obtained from the National Weather Service (NWS) Alaska Sea Ice Program. Percentage of ice cover and ice thickness above the mooring was estimated over a 20 × 20 km area.

Results

Vocalizations attributed to ribbon seals were detected on 114 d over the 810 total d of PAL recordings between the two mooring locations. Ribbon seal downsweeps were detected on 105 d. Grunts and roars, which are also likely produced by ribbon seals, were recorded on 58 and 39 d, respectively. Grunts differed from roars aurally and visually in frequency and temporal characteristics. Grunts were shorter and lower frequency vocalizations than roars (Table 1; Figure 3). The peak energy of grunts was 440 Hz (± 100 Hz), whereas the peak energy of roars was distributed over three nonharmonically related frequency bands: 500 to 700 Hz, 1,000 to 1,200 Hz, and 1,700 to 2,000 Hz (Figure 3).

Initial examination of the data revealed a pattern of grunts and roars being closely associated with ribbon seal downsweeps at both recording locations. The COA analysis showed that grunts and roars were more closely associated with ribbon seal downsweeps than any other identified

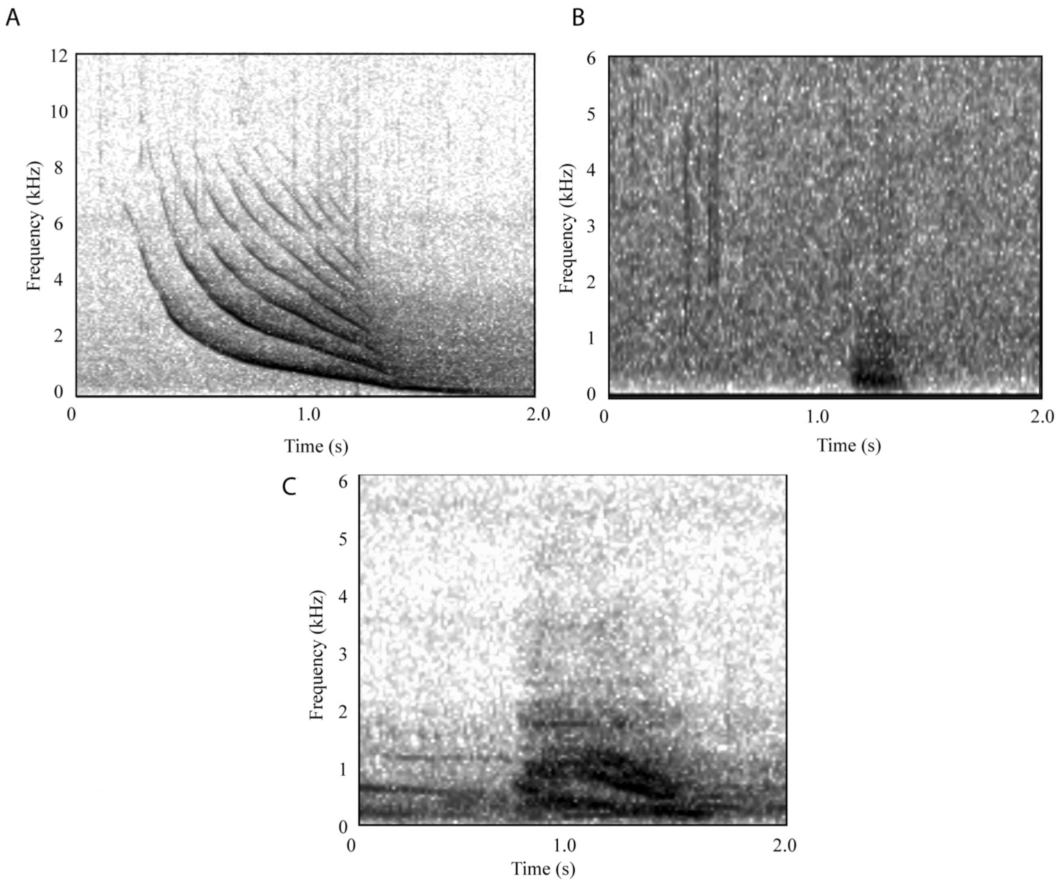

Figure 2. Spectrograms of ribbon seal (A) downsweep, and proposed ribbon seal (B) grunt and (C) roar; spectrograms were made from 100 kHz recordings downsampled to 44.1 kHz (1,024 point FFT; 50% overlap).

biological sound recorded over the winter/spring season (Table 2). There were no instances where roars were recorded on a day without the detection of downsweeps. There were only 5 d over the course of the entire study where grunts were detected in the absence of downsweeps.

Ribbon seal downsweeps and probable ribbon seal grunts and roars were detected at the southern and central locations each winter/spring of the study (Figures 4 & 5). The first acoustic detections coincided with ice conditions exceeding 80% cover with an average thickness of 50 cm. Ribbon seals were detected later in the season compared

Table 1. Summary table of the average parameter values for proposed ribbon seal (*Histriophoca fasciata*) vocalizations; values in parentheses represent the range for each parameter.

	Sample size (n)	Duration (s)	Minimum (Hz)	Maximum (Hz)	Start (Hz)	End (Hz)	Harmonics
Downsweeps	60	1.8 (0.93-2.75)	201 (136-313)	5,140 (1,893-12,041)	4,007 (1,893-6,822)	201 (136-313)	5 (3-12)
Roars	52	0.9 (0.6-2.2)	198 (104-302)	2,996 (1,998-5,134)	N/A	N/A	N/A
Grunts	88	0.4 (0.2-0.8)	202 (116-354)	922 (563-1,620)	N/A	N/A	N/A

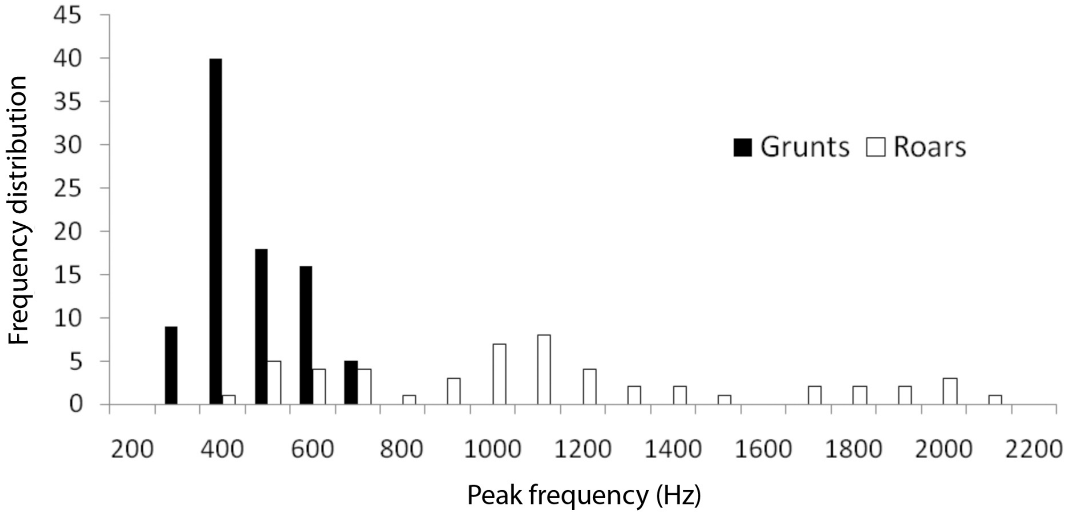

Figure 3. Peak frequency distribution of grunts and roars

Table 2. Coefficient of association (COA) values for vocalizations detected during the winter and spring (January through June) in the Bering Sea; the Bowhead category represents bowhead song, the Walrus category included knocks and bells, and the Bearded category included only bearded seal trills.

	Bowhead	Walrus	Bearded	Downsweep	Grunt	Roar
Bowhead	X	0.33	0.39	0.13	0.06	0.04
Walrus		X	0.34	0.19	0.15	0.10
Bearded			X	0.39	0.27	0.18
Downsweep				X	0.62	0.53
Grunt					X	0.57
Roar						X

Note: The shaded cells highlight the largest COA values between ribbon seal downsweeps and suspected ribbon seal grunts and roars.

to the onset of bearded seal and walrus detections. Acoustic detection of ribbon seal peaked in April at the southern location and in May at the central site. The visible decrease in ribbon seal detection in March 2009 at location M5 (Figure 4) corresponded to a temporary ice retreat at this location (Figure 5). Acoustic detection of ribbon seals resumed when the ice again reached an approximate 80% cover with a 50 cm or greater thickness. Bearded seals and walrus continued to be detected during the open water period of the rapid retreat. No ribbon seal acoustic detections were observed outside the winter/spring breeding and molting season of January through June.

Discussion

The ecology of ribbon seals, with a combination of pelagic and pack ice habitat associations, has made detailed observations of behavior in this species challenging. This study gives insight into the vocalizations potentially produced by ribbon seals as well as their seasonal vocal detection in two locations in the Bering Sea. Data from long-term passive acoustic recordings revealed an association of the distinctive ribbon seal downward frequency sweeps with two additional broadband sounds: (1) grunts and (2) roars. "Puffing" sounds have been attributed to ribbon seals by Watkins & Ray (1977) and were described as variable broadband sounds with frequencies below 5 kHz and durations of less than a second. The description of puffs by Watkins & Ray overlaps with vocal parameters for both grunts and roars identified in this study, yet the two sound types were audibly and quantitatively different (Table 1). Since it was not known whether both vocal types were included in the description of puffing sounds or whether only one type was recorded (Watkins & Ray, 1977), we made a clear distinction between the two call types with new labels that give an audible description of each vocalization category. The close association

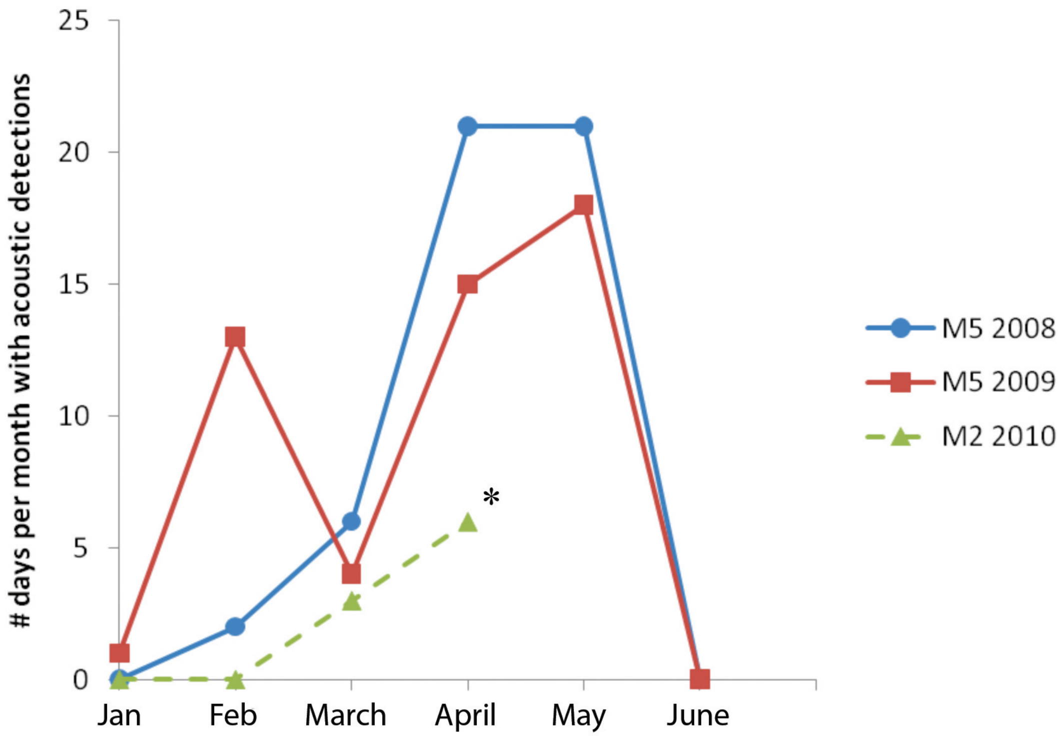

Figure 4. Detection summary of ribbon seal vocalizations from January through June in the central (M5) and southeastern (M2) Bering Sea; no detections were observed from July through December. Data represent uninterrupted deployment of the PAL at M5 from September 2007 through September 2009. Uninterrupted recordings were made from September 2009 through April 2010 at M2. No ribbon seal vocalizations were detected from mid-April 2010 to the end of the deployment at M2, denoted by the *.

of grunt and roar vocalizations described in this study with ribbon seal downsweeps does not definitively prove that grunts and roars were produced by ribbon seals as opposed to other vocal species known to overlap in time and space (e.g., bowheads, walrus, spotted seals [*Phoca largha*]). All sounds detected other than grunts and roars could be classified to known species. Given the close association of the grunts and roars with the ribbon seal downsweeps, and the low COA with calls from bowhead whales and walrus, our most parsimonious interpretation is that these sounds may be produced by ribbon seals.

Little is known about the mating system of the ribbon seal, though given its pelagic and ice associated ecology, it is presumed to have an aquatic-based mating system (Van Parijs, 2003). Males of aquatically mating pinnipeds, where data are available, all produce underwater vocalizations during the breeding season (Van Parijs, 2003). It is not known whether males or females produce the ribbon seal calls, but only males possess well-developed air sacs that function as a hydrostatic organ in phonation (Sokolov et al., 1968). Therefore, it is likely that the detected vocalizations are associated with the breeding behavior of males in this species. The acoustic observations in this study are in agreement with the currently understood ecology of the species. The detected vocalizations are associated with the presumed breeding season, from midwinter through the spring, peaking in April and May (Boveng et al., 2008). Differentiation of the proposed call types may become significant as more is learned about ribbon seal mating behaviors, sound production, and female-pup interactions.

The detection of vocalizations in this study indicates ribbon seal presence, with the acknowledgement that lack of acoustic detection does not imply animal absence. Data on the ice coverage and thickness at the mooring locations combined with the patterns of acoustic detection suggests that bearded seals and walrus are able to utilize habitats with a wider range of ice conditions than ribbon seals. Ribbon seals appear to require thicker ice with a greater percentage of cover.

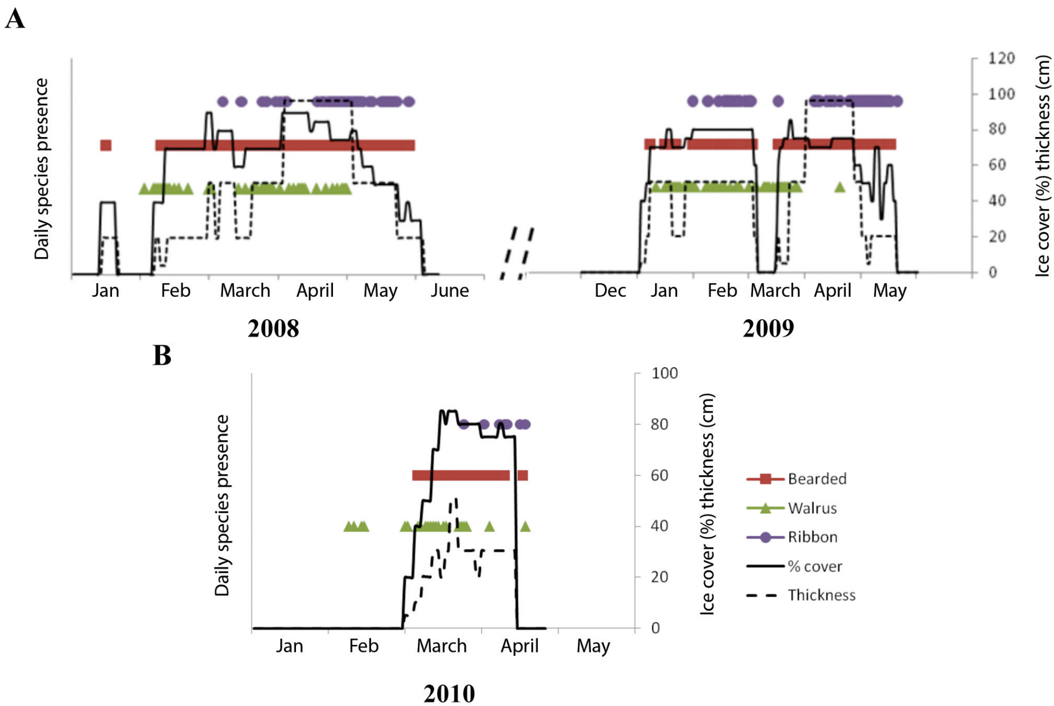

Figure 5. Acoustic presence of Arctic pinnipeds in the Bering Sea: (A) Detections from the central Bering Sea in 2008 and 2009; data represent uninterrupted deployment of the PAL at M5 from September 2007 through September 2009. (B) Detections from the southeastern region in 2010; uninterrupted recordings were made from September 2009 through April 2010 at M2. No ribbon seal vocalizations were detected from mid-April 2010 to the end of the deployment at M2. Solid and dotted lines indicated percent of ice cover and ice thickness, respectively. The acoustic presence of the species does not correspond to a numerical value on the y axes. The species-specific symbols reflect acoustic presence over time and are separated spatially for easy visualization.

These observations are consistent with previous observations that ribbon seals seem to haul out on moderately thick ice floes (Burns, 1970; Fay, 1974). This was particularly apparent in 2009 when a temporary ice retreat resulted in continued vocal detection of bearded seals and walrus, whereas a complete cessation of ribbon seal detections was observed until the ice cover returned to the location. Without concurrent visual data or GPS tag locations, it is not possible to know whether ribbon seals left the area in conjunction with the ice or whether vocal activity ceased while the animals remained in the area but engaged in behaviors other than mating displays. If the animals did leave the area, it is not known whether they did so passively by drifting on the ice or actively followed the ice edge. In summary, our study demonstrates that passive acoustic monitoring is an effective way to detect ribbon seals during the breeding season and will be instrumental in assessing the impact of climate change on this Arctic species. We propose that the distinctive downward frequency sweep is the most useful signal for detection, given its high intensity and distinctive frequency content and visual signature. However, detection of two other classes of sounds indicates a potentially more complex vocal repertoire in the ribbon seal that warrants further evaluation.

Acknowledgments

We gratefully acknowledge Phyllis Stabeno, Carol Dewitt, Bill Floering, and Rick Miller from PMEL/NOAA for including acoustics instruments on the NOAA FOCI moorings and for providing mooring logistical support. Thanks are also extended to the captain and crews of the NOAA ships and contract vessels that deployed and retrieved the mooring instruments. Holly Cleator, Jack Terhune, and Mary Ann Daher contributed sound clips for identification and verification of marine mammal vocalizations. Funding was provided by the ONR Marine Mammal Program under Award Numbers N000140810391 and N000140810394.

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