Polar Biology SHORT NOTE

Seasonal variations in the call presence of bearded seals in relation to sea ice in the southern Chukchi Sea

Mina Jimbo[1]
Daisuke Mizuguchi[2]
Hokuto Shirakawa[3]
Koki Tsujii[4]
Amane Fujiwara[5]
Kazushi Miyashita[3]
Yoko Mitani[3]

1 Graduate School of Veterinary Medicine, Hokkaido University
Kita 18, Nishi 9, Kita-ku Sapporo, Hokkaido, 060-0818, Japan
2 Japan Fisheries Research and Education Agency
116 Katsurakoi Kushiro, Hokkaido, 085-0802, Japan
*Present address: Korea Brain Research Institute
61, Cheomdan-ro, Dong-gu, Daegu, Republic of Korea, 41062
3 Field Science Center for Northern Biosphere, Hokkaido University
Hakodate Research Center for Fisheries and Oceans, 20-5 Benten-cho, Hakodate, Hokkaido, 040-0051, Japan
4 Graduate School of Environmental Science, Hokkaido University
20-5 Benten-cho, Hakodate, Hokkaido, 040-0051, Japan
5 Institute of Arctic Climate and Environment Research, Japan Agency for Marine-Earth Science and Technology
2-15 Natsushima-cho, Yokosuka, Kanagawa, 237-0061, Japan

Corresponding Author: Mina Jimbo
Tel: +81-011-706-5210
Email: jimbo.min56@gmail.com

Abstract

The seasonal habitat use of bearded seals is important information in terms of conservation of this species. However, their distribution outside the breeding season has not been well documented. We investigated seasonal variations in the call occurrence of bearded seals by using passive acoustic monitoring in the southern Chukchi Sea, which has some of the greatest benthic biomass in the Pacific sector of the Arctic Ocean. Underwater sounds were recorded between 2012 and 2015. Calls of bearded seals were detected from mid-September or early October to the end of each recording period (mid-May 2013, early March 2014, and mid-June 2015). Two peaks in call occurrence were noted; the first peak occurred during the open-water periods in November, and the second peak occurred during ice-covered periods. This suggest that bearded seals utilize the southern Chukchi Sea not only for the breeding site but also for the autumn foraging site. We could complement the information about the southward autumn migration pattern of bearded seals, and the southern Chukchi Sea was suggested as the south limit of bearded seals' autumn distribution. Additionally, their vocal activity during autumn in this site was suggested to have some role in social interaction. Our results indicated that the southern Chukchi Sea would be an important monitoring site for understanding the habitat use and the vocal activity of bearded seals especially outside the breeding season.

Keywords *Erignathus barbatus*・Passive acoustic monitoring・Sea ice・Vocal activity

Introduction

Bearded seals, *Erignathus barbatus*, are extant in the seasonal sea ice area in the Arctic and sub-Arctic Seas. They feed primarily on benthic organisms (Lowry et al. 1980), therefore they tend to prefer relatively shallow waters, typically less than 200 m, where they can reach the ocean floor to forage (Burns 1981). They rely on sea ice plat form and generally prefer pack ice to fast ice for breathing, hauling out, and access to prey (Simpkins et al. 2003). Sea ice is particularly important for bearded seals during the breeding season when they rear their pups on ice, and during the molting season when they haul out on ice to raise skin temperature (Burns 1981). Accordingly, recent loss of the Arctic sea ice due to global warming might negatively affect bearded seals in near future (Moore and Huntington 2008). Therefore, information on the ecology of bearded seals and the relation to sea ice is particularly important in terms of conservation of this species.

There are two recognized sub-species of bearded seals: *E. b. barbatus* inhabiting the Atlantic sector and *E. b. nauticus* inhabiting in the Pacific sector (Rice 1998). Of these, *E. b. nauticus* shows seasonal north-south migration pattern relating to sea ice extent. During spring breeding season, they extend the Beaufort, Chukchi, and Bering Seas (Burns 1981), and most of seals in the Bering and southern Chukchi Seas move northward as sea ice retreat during July and little seals remain in August (McClintock et al. 2017; Melnikov 2017). On the other hand, the southward autumn migration pattern is not clear. The information about the seasonal habitat use outside the breeding season is limited, since their distribution spread to the seasonally ice-covered Arctic Ocean, making it difficult to monitor widely and continuously by vessel or aerial-based visual surveys.

Passive acoustic monitoring is a powerful method for the long-term observation of bearded seals (e.g., MacIntyre et al. 2013, 2015; Frouin-Mouy et al. 2016). Bearded seals produce species-specific calls, which can be easily detected by visual inspection of the sound spectrogram. Three major types of call are recognized in the Pacific sector; "trill" is long cascading sound, "moan" is short descending tone with harmonics, and "ascent" is soaring sound defined as rapid rise in frequency (Risch et al. 2007) (refer to the supplementary material for an example of a sound spectrogram). For instance, highly developed trills start around a mean frequency of 5.28 kHz and descend in steps to a lower frequency of around 0.34 kHz, and the duration up to 1 min or more (Risch et al. 2007). They are known to vocalize most frequently during the breeding season, suggesting that their vocalization might have some role in their breeding strategy (e.g., Cleator et al. 1989; Van Parijis et al. 2003). In the Beaufort and the northern Chukchi Seas, their calls can be observed throughout the year (Frouin-Mouy et al. 2016). Therefore, the seasonal presence of bearded seals can be determined by detecting their vocal activity from recorded underwater sound.

The southern Chukchi Sea is one of the most productive areas of the world ocean, which is located on the north side of the Bering Strait (Fig. 1). Since the nutrient-rich water advected from the Pacific Ocean provides a large quantity of organic matter, some of the greatest benthic biomass can be found in the southern Chukchi Sea (Grebmeier 2012). Consequently, this area is considered an important biological hot spot for large benthic feeders including bearded seals (Feder et al. 2005). Although bearded seals are known to be in breeding status there from March to June (Burns 1981), it is unclear how they utilize this biological hot spot outside the breeding season. The present study aimed to investigate the seasonal presence and vocal activity of bearded seals in relation to the extent of sea ice in the southern Chukchi Sea by year-round observation using passive acoustic monitoring system.

Materials and methods

Underwater acoustic recording was conducted in Hope Valley in the southern Chukchi Sea (68.05˚N, 168.83˚W) from July 2012 to June 2015. The recording instrument was an AUSOMS ver.3.5 (Aqua Sound Inc., Japan). The AUSOMS had a model SH20K hydrophone, with the frequency response between 20 Hz and 20 kHz, and a sensitivity of -190 dB re 1 V μPa^{-1}. We recorded at 44.1 kHz sampling rate, 16 bits data resolution, a 20 kHz cutoff frequency of the low-pass filter, and a 60 dB gain. The recorder was installed at one mooring site by vessel in summer and switched three times during the entire survey period because of the memory capacity. We deployed the recorder at 67.72˚N, 168.83˚W at 52 m depth from July 16, 2012, to October 2, 2012, at 68.05˚N, 168.83˚W at 60 m depth from October 2, 2012, to May 15, 2013, July 20, 2013, to March 3, 2014, and July 20, 2014, to June 12, 2015 (Table 1). Underwater sounds were continuously recorded from July 16, 2012, to October 2, 2012, and periodically with a duty cycle of 6 h on, 16 h off from October 2, 2012, to May 15, 2013, and July 20, 2013 to March 3, 2014, and with a duty cycle of 5 h on, 14 h off from July 20, 2014, to June 12, 2015 (Table 1).

While the call detection range may change due to ambient factors, such as water depth, ice thickness, and noise, most bearded seal calls were likely produced within a distance ranging from 5 to 10 km of the instruments (Cleartor et al. 1989). Therefore, we considered that the 10-km resolution is of sufficient sensitivity to be within range of vocalizing bearded seals. The presence or absence of calls was examined for every 10-min section of the sound files (hereinafter referred to as 10-min sections), both aurally, and also visually by using spectrograms (Hamming with 50% overlap, Fast Fourier Transform size: 4096 points) in Adobe Audition CC 2015 (Adobe Systems Inc., USA). Bearded seal calls, including trills, ascent calls, and moans, were extracted based on the call characteristics, such as frequency and duration, described in Table A3 by Risch et al. (2007). Within each 10-min section, the listener stopped once one call had been identified and moved on to the next 10-min section, which allowed us to reduce the analysis time. Daily call presence rates were calculated by dividing the number of 10-min sections with at least one call by the total number of 10-min sections per day.

The sea ice concentration data at 10-km resolution were obtained as an AMSR2 standard sea ice concentration product from the Japan Aerospace Exploration Agency web portal (https://gportal.jaxa.jp/gpr/). The sea ice concentration (hereinafter referred to as SIC) was extracted from the single AMSR2 pixel at the mooring location. Periods of ice cover were defined as those periods when SIC >0%, and periods of open water were defined as those periods when SIC = 0%. In each period, the mean number of 10-min sections that had calls was calculated per hour and compared using the Kruskal–Wallis test to verify the diel patterns in call occurrence.

Results

The total duration recorded was 6,852 hours. Acoustic data were acquired for almost the whole year except from mid-June to mid-July. Sea ice cover began to form on the SCH around mid-November 2012, mid-December 2013, and early December 2014. Sea ice cover lasted until mid-June 2013, May 2014, and mid-May 2015.

Calls were first noted in late September or early October and detected continuously through to the end of each recording period until mid-May 2013, early March 2014, and mid-June 2015, although call presence rates fluctuated (Fig. 2). During the open-water periods, calls temporarily increased with a peak in November. Subsequently, the call presence rates decreased to <40% between late November and December, before sea ice formation. Following sea ice formation, calls increased again from January to February. Call presence rates reached their maximum value (100%) almost continuously from March to the end of recording in May. Calls were detected more frequently as breeding season approached, and several calls overlapped throughout the course of a day from March to May.

Diel patterns in call presence are shown in Fig. 3. In the open-water periods, there was a significant difference in the mean number of 10-min sections with calls in each hour (Kruskal–Wallis test, Chi-squared = 54.562, $p = 0.0002$). Few calls occurred in the daytime, but they increased between midnight and early morning. During the ice-covered periods, there were no clear diel patterns (Kruskal–Wallis test, Chi-squared = 10.715, $p = 0.986$).

Discussion

Our monitoring in the southern Chukchi Sea could complement the information about the southward autumn migration pattern of bearded seals. In the southern Chukchi Sea, calls of bearded seals were not detected in July or August. First detection of bearded seal calls in the southern Chukchi Sea was late September or early October, which is about a month later than in the northern Chukchi Sea (MacIntyre et al. 2015). These monitoring results indicate that some bearded seals gradually move southward from the Beaufort Sea to the southern Chukchi Sea from August to October. Additionally, little-to-no call activity was observed at any site in the Bering Sea prior to ice formation in December (MacIntyre et al. 2015); therefore, the southern Chukchi Sea is likely the south limit of bearded seals' autumn distribution. The distributional pattern of bearded seals in open-water areas is known to be consistent with a relationship with food availability (Aerts et al. 2013), and therefore, bearded seals might gather in the southern Chukchi Sea in autumn in order to forage for its rich benthic organisms.

In addition, further southward migration with sea ice expansion in early winter was suggested from the decrease in the call presence rate. The call presence rates, which reached almost 100% in November, dropped sharply in December just before sea ice formation in the southern Chukchi Sea. Taking into consideration that the first detection of calls was observed in Bering Sea at the same time (MacIntyre et al. 2015), it can be assumed that some seals move away from the southern Chukchi Sea to the Bering Sea. Bearded seals are known to stay in their own breeding site from December to the end of breeding season (Boveng and Cameron 2013); therefore, this means that bearded seals might move from the foraging site to the breeding site with sea ice formation.

During ice-covered periods, their vocal activity was more frequent. Maximum call presence rates occurred continuously from March to June, which corresponded to the breeding season of bearded seals in the Chukchi Sea (Burns 1981). This result is consistent with findings from other areas in the Bering, Chukchi, and Beaufort Seas

(MacIntyre et al. 2015; Frouin-Mouy et al. 2016). Although little is known about how their vocal activity develops from the non-breeding season moving to the breeding season, bearded seals might vocalize more frequently during the ice-covered periods as breeding season approaches.

The diel pattern in call occurrences was shown during the open-water periods, and calls increased between midnight and early morning and decreased during the daytime, which is similar to breeding season diel patterns that have been reported previously (Van Parijs et al. 2001; Frouin-Mouy et al. 2016). Calls of bearded seals are considered to have a role in protecting their breeding territory or attracting females (see Van Parijs 2003 for a review). Some researchers suggest that the presence of other individuals affects these seals' vocal activity (e.g., Terhune 1999; Van Parijs et al. 2001). For example, during the breeding season, male bearded seals are thought to vocalize more frequently when females are in the water, which cause the diel patterns in vocal activity (Van Parijs et al. 2001). Although the function of vocalization outside the breeding season is still unclear, it is possible that the diel pattern in call occurrences during the open-water periods suggests that vocalization during this season also plays some role in social interactions. On the other hand, the diel pattern in vocal activity was not found to be statistically significant during the ice-covered periods in our study, but this might be due to our method of measuring calling activity. Since several calls were found to overlap almost all day from March to May, the diel pattern could not be verified by the detecting the presence or absence of at least one call every 10 minutes.

Recent reductions in sea ice cover and seawater warming due to climate change are particularly significant in the southern Chukchi Sea, and consequently changes in the distribution of benthic organisms have also been reported (Grebmeier 2012). Such environmental changes may alter the habitat use and the seasonal migration of bearded seals. The present study indicated that the southern Chukchi Sea is a high utilization area for bearded seals of foraging and vocal activity outside the breeding season. Additionally, the passive acoustic monitoring in this area was considered essential to know their southward autumn migration pattern. These results give information about the existing state of bearded seals, and indicated the effectiveness of the passive acoustic monitoring in the southern Chukchi Sea to assess the ecological impacts of environmental changes in bearded seals in future continuous research.

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Compliance with Ethical Standards

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest in the preparation of this article.

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Table

Table 1 Details of our acoustic recording

Recording period	Call observed periods	Duty cycle
July 16, 2012–October 02, 2012		Continuous
October 2, 2012–May 15, 2013	October 3, 2012–May 15, 2013	6/22 hour
July 20, 2013–March 03, 2014	September 27, 2013–March 3, 2014	6/22 hour
July 20, 2014–June 12, 2015	September 21, 2014–June 12, 2015	5/19 hour

Figures

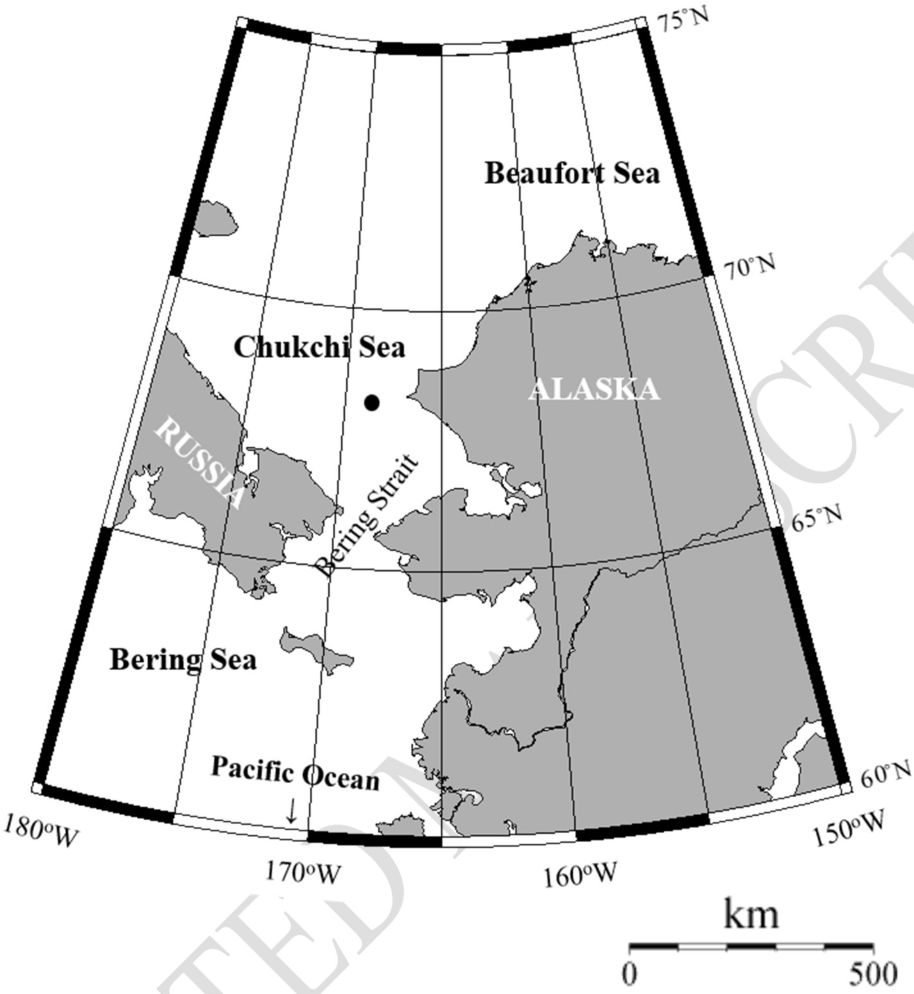

Fig. 1 Location of passive acoustic recorders on mooring at the southern Chukchi Sea (68.05˚N, 168.83˚W)

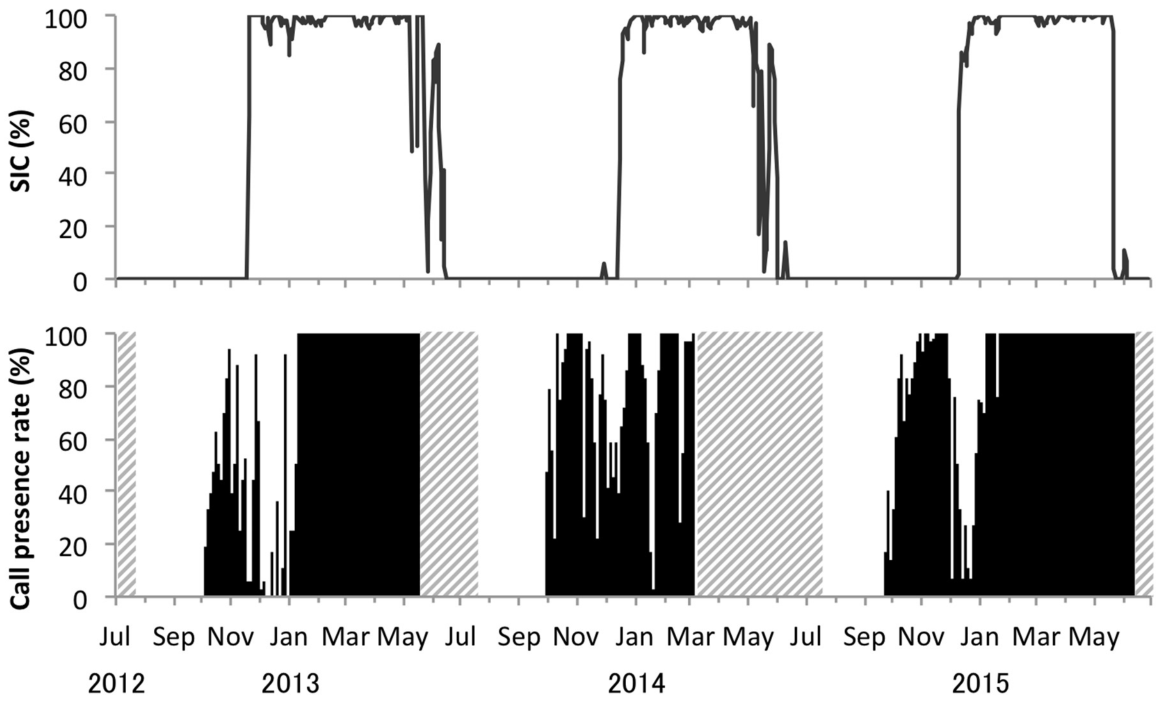

Fig. 2 The daily sea ice concentration (SIC, upper figure) and the call presence rates (proportion of 10-min sections with calls per day) of bearded seals (lower figure) between July 2012 and June 2015. Shaded areas indicate periods without acoustic data because of the lack of recording capacity.

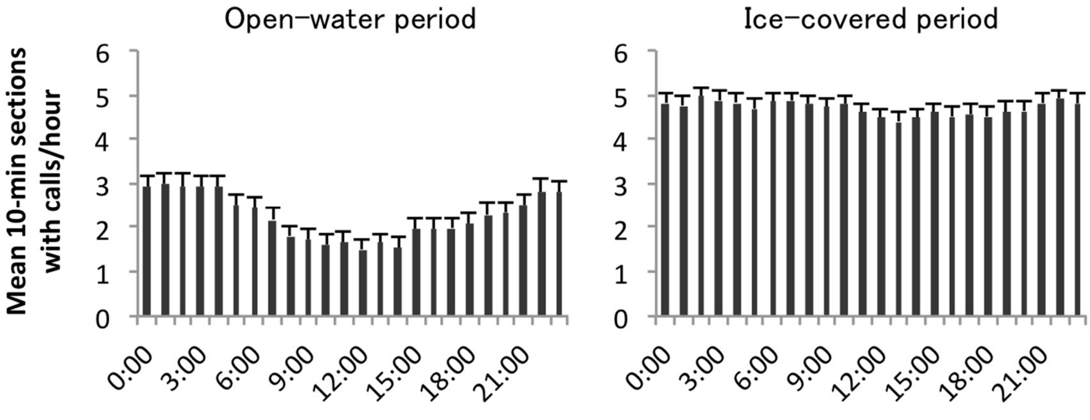

Fig. 3 Diel patterns in call occurrence in each period. Black bars indicate mean number of 10-min sections with calls per hour, with standard error.

Supplementary material

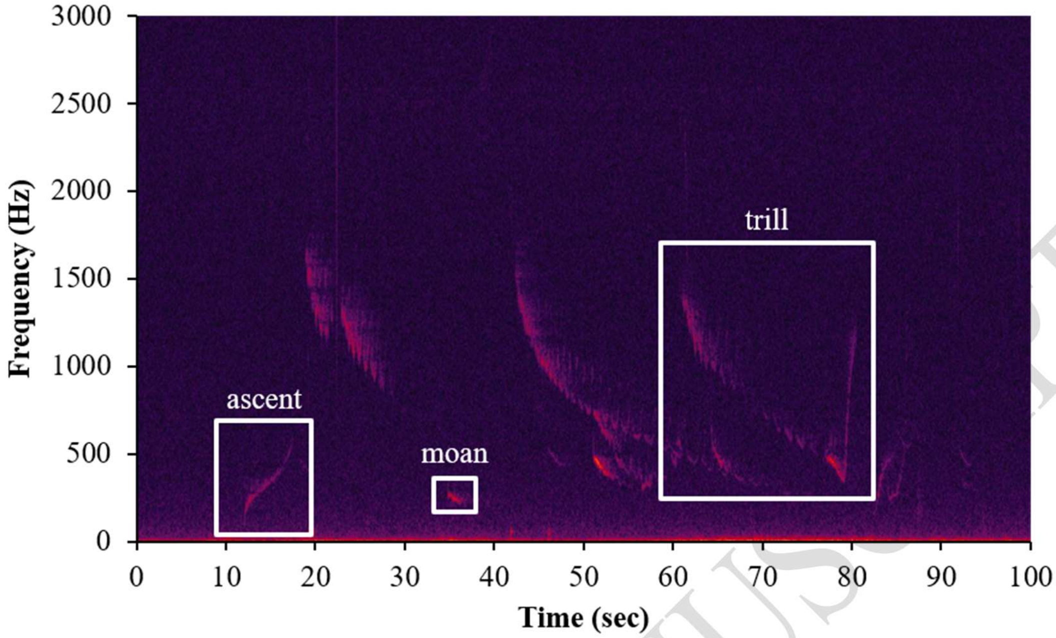

Fig. An example of a sound spectrogram of three major call types of bearded seals. X-axis represent time, Y-axis represent frequency, and color represent amplitude.