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

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29 **Abstract**

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

43

44 **Keywords** *Erignathus barbatus* • Passive acoustic monitoring • Sea ice • Vocal activity

45 **Introduction**

46 Bearded seals, *Erignathus barbatus*, are extant in the seasonal sea ice area in the Arctic and sub-Arctic Seas. They
47 feed primarily on benthic organisms (Lowry et al. 1980), therefore they tend to prefer relatively shallow waters,
48 typically less than 200 m, where they can reach the ocean floor to forage (Burns 1981). They rely on sea ice platform
49 and generally prefer pack ice to fast ice for breathing, hauling out, and access to prey (Simpkins et al. 2003). Sea ice
50 is particularly important for bearded seals during the breeding season when they rear their pups on ice, and during
51 the molting season when they haul out on ice to raise skin temperature (Burns 1981). Accordingly, recent loss of the
52 Arctic sea ice due to global warming might negatively affect bearded seals in near future (Moore and Huntington
53 2008). Therefore, information on the ecology of bearded seals and the relation to sea ice is particularly important in
54 terms of conservation of this species.

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

63 Passive acoustic monitoring is a powerful method for the long-term observation of bearded seals (e.g., MacIntyre
64 et al. 2013, 2015; Frouin-Mouy et al. 2016). Bearded seals produce species-specific calls, which can be easily
65 detected by visual inspection of the sound spectrogram. Three major types of call are recognized in the Pacific sector;
66 “trill” is long cascading sound, “moan” is short descending tone with harmonics, and “ascent” is soaring sound
67 defined as rapid rise in frequency (Risch et al. 2007) (refer to the supplementary material for an example of a sound
68 spectrogram). For instance, highly developed trills start around a mean frequency of 5.28 kHz and descend in steps
69 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
70 to vocalize most frequently during the breeding season, suggesting that their vocalization might have some role in
71 their breeding strategy (e.g., Cleator et al. 1989; Van Parijis et al. 2003). In the Beaufort and the northern Chukchi
72 Seas, their calls can be observed throughout the year (Frouin-Mouy et al. 2016). Therefore, the seasonal presence of
73 bearded seals can be determined by detecting their vocal activity from recorded underwater sound.

74 The southern Chukchi Sea is one of the most productive areas of the world ocean, which is located on the north
75 side of the Bering Strait (Fig. 1). Since the nutrient-rich water advected from the Pacific Ocean provides a large
76 quantity of organic matter, some of the greatest benthic biomass can be found in the southern Chukchi Sea (Grebmeier
77 2012). Consequently, this area is considered an important biological hot spot for large benthic feeders including
78 bearded seals (Feder et al. 2005). Although bearded seals are known to be in breeding status there from March to
79 June (Burns 1981), it is unclear how they utilize this biological hot spot outside the breeding season. The present

80 study aimed to investigate the seasonal presence and vocal activity of bearded seals in relation to the extent of sea
81 ice in the southern Chukchi Sea by year-round observation using passive acoustic monitoring system.

82

83 **Materials and methods**

84 Underwater acoustic recording was conducted in Hope Valley in the southern Chukchi Sea (68.05°N, 168.83°W)
85 from July 2012 to June 2015. The recording instrument was an AUSOMS ver.3.5 (Aqua Sound Inc., Japan). The
86 AUSOMS had a model SH20K hydrophone, with the frequency response between 20 Hz and 20 kHz, and a sensitivity
87 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
88 of the low-pass filter, and a 60 dB gain. The recorder was installed at one mooring site by vessel in summer and
89 switched three times during the entire survey period because of the memory capacity. We deployed the recorder at
90 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
91 October 2, 2012, to May 15, 2013, July 20, 2013, to March 3, 2014, and July 20, 2014, to June 12, 2015 (Table 1).
92 Underwater sounds were continuously recorded from July 16, 2012, to October 2, 2012, and periodically with a duty
93 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
94 cycle of 5 h on, 14 h off from July 20, 2014, to June 12, 2015 (Table 1).

95 While the call detection range may change due to ambient factors, such as water depth, ice thickness, and noise,
96 most bearded seal calls were likely produced within a distance ranging from 5 to 10 km of the instruments (Cleartor
97 et al. 1989). Therefore, we considered that the 10-km resolution is of sufficient sensitivity to be within range of
98 vocalizing bearded seals. The presence or absence of calls was examined for every 10-min section of the sound files
99 (hereinafter referred to as 10-min sections), both aurally, and also visually by using spectrograms (Hamming with
100 50% overlap, Fast Fourier Transform size: 4096 points) in Adobe Audition CC 2015 (Adobe Systems Inc., USA).
101 Bearded seal calls, including trills, ascent calls, and moans, were extracted based on the call characteristics, such as
102 frequency and duration, described in Table A3 by Risch et al. (2007). Within each 10-min section, the listener stopped
103 once one call had been identified and moved on to the next 10-min section, which allowed us to reduce the analysis
104 time. Daily call presence rates were calculated by dividing the number of 10-min sections with at least one call by
105 the total number of 10-min sections per day.

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

112

113 **Results**

114 The total duration recorded was 6,852 hours. Acoustic data were acquired for almost the whole year except from

115 mid-June to mid-July. Sea ice cover began to form on the SCH around mid-November 2012, mid-December 2013,
116 and early December 2014. Sea ice cover lasted until mid-June 2013, May 2014, and mid-May 2015.

117 Calls were first noted in late September or early October and detected continuously through to the end of each
118 recording period until mid-May 2013, early March 2014, and mid-June 2015, although call presence rates fluctuated
119 (Fig. 2). During the open-water periods, calls temporarily increased with a peak in November. Subsequently, the call
120 presence rates decreased to <40% between late November and December, before sea ice formation. Following sea
121 ice formation, calls increased again from January to February. Call presence rates reached their maximum value
122 (100%) almost continuously from March to the end of recording in May. Calls were detected more frequently as
123 breeding season approached, and several calls overlapped throughout the course of a day from March to May.

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

128

129 **Discussion**

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

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

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

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

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

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

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178 supported by Japan Society for the Promotion of Science KAKENHI Grant (15H05709).

179

180 **Compliance with Ethical Standards**

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

183

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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

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Figures

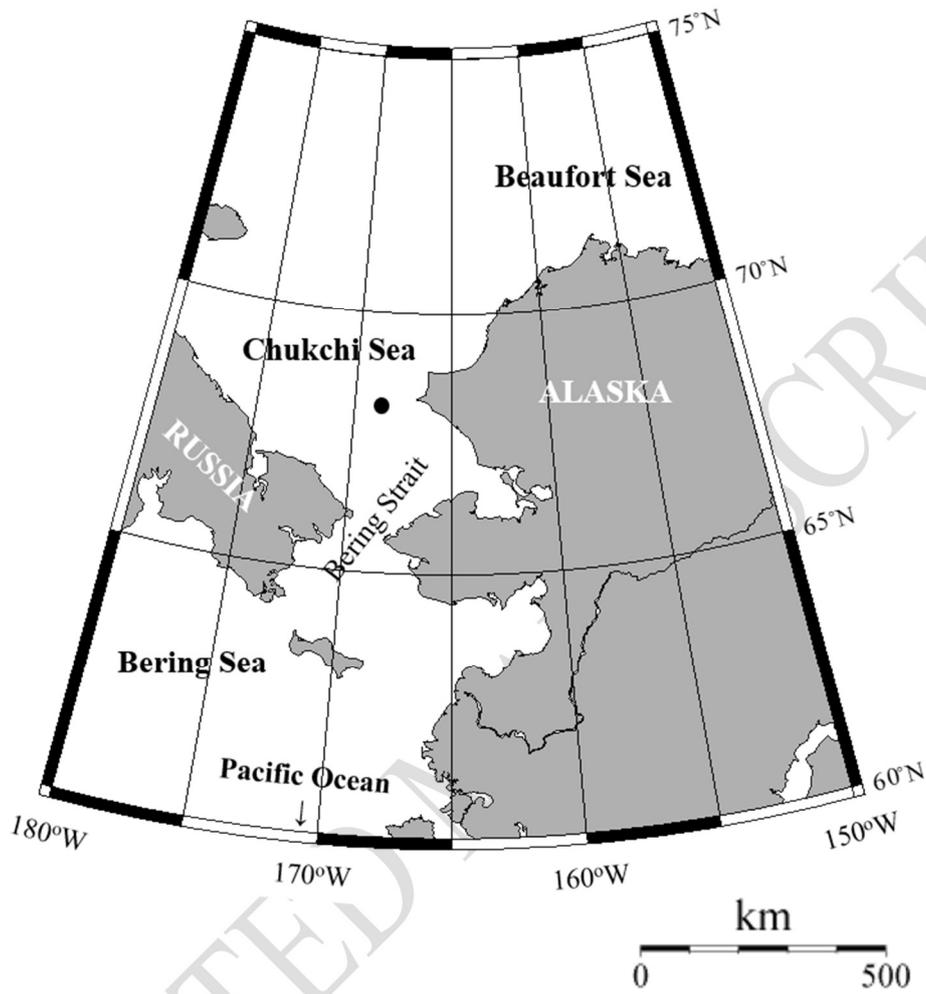


Fig. 1 Location of passive acoustic recorders on mooring at the southern Chukchi Sea (68.05°N, 168.83°W)

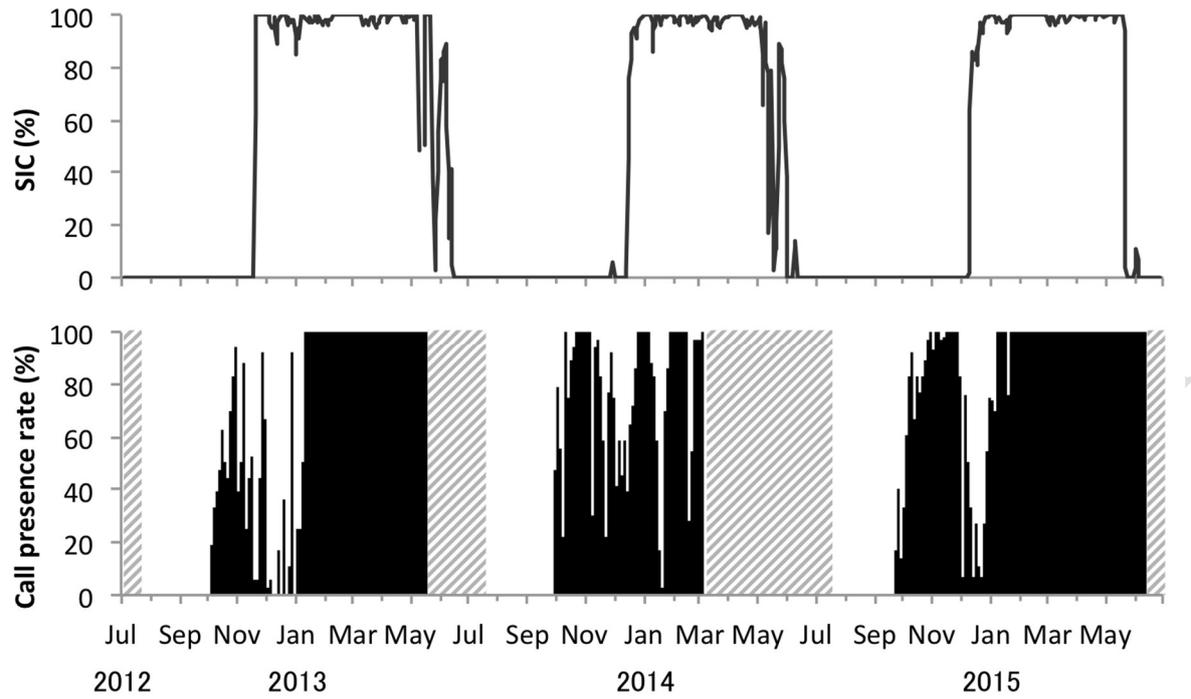


Fig. 2 The daily sea ice concentration (SIC, upper figure) and the call presence rates (proportion of 10-min sections with calls per day) of bearded seals (lower figure) between July 2012 and June 2015. Shaded areas indicate periods without acoustic data because of the lack of recording capacity.

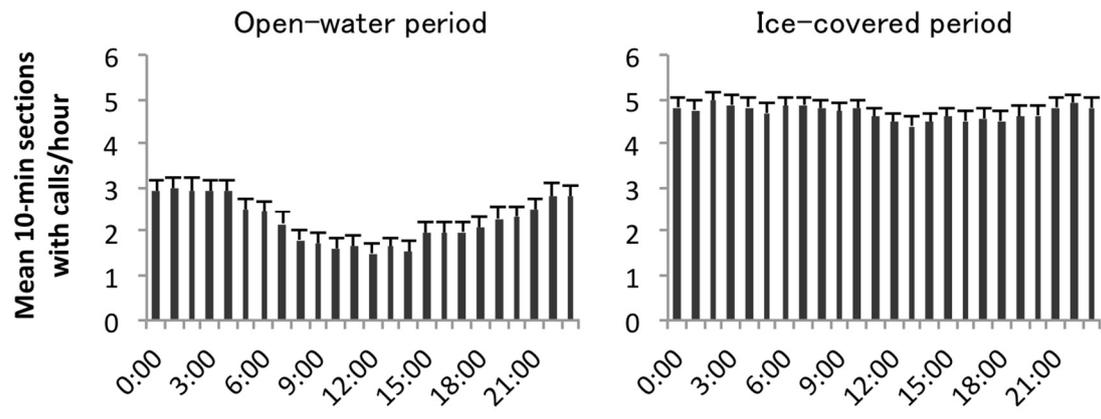


Fig. 3 Diel patterns in call occurrence in each period. Black bars indicate mean number of 10-min sections with calls per hour, with standard error.

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Supplementary material

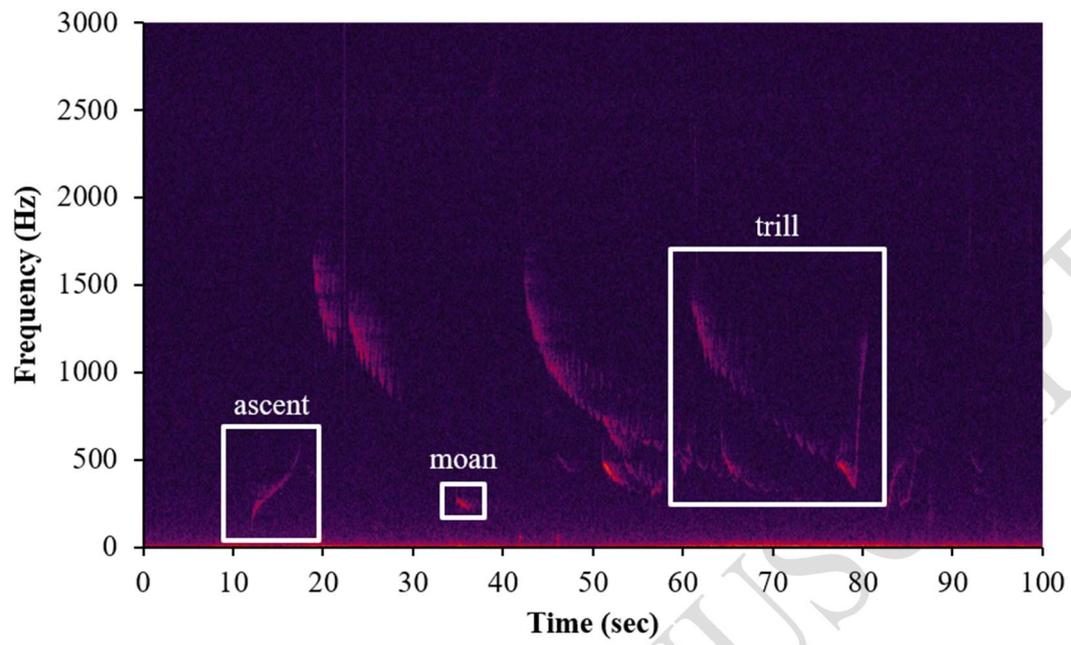


Fig. An example of a sound spectrogram of three major call types of bearded seals. X-axis represent time, Y-axis represent frequency, and color represent amplitude.