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ORIGINAL PAPER

Seasonal detections of bearded seal (*Erignathus barbatus*) vocalizations in Baffin Bay and Davis Strait in relation to sea ice concentration

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Abstract

There is limited information about the biology and seasonal distribution of bearded seals (*Erignathus barbatus*) in Greenland. The species is highly ice-associated and depends on sea ice for hauling out and giving birth, making it vulnerable to climate change. We investigated the seasonality and distribution of bearded seal vocalizations at seven different locations across southern Baffin Bay and Davis Strait, West Greenland. Aural M2 and HARUphone recorders were deployed on the sea bottom during 2006–2007 and 2011–2013. Recordings were analyzed for presence/absence of bearded seal calls relative to location (including distance to shore and depth), mean sea ice concentration and diel patterns. Calling occurred between November and late June with most intense calling during the mating season at all sites. There was a clear effect of depth and distance to shore on the number of detections, and the Greenland shelf (< 300 m) appeared to be the preferred habitat for bearded seals during the mating season. These results suggest that bearded seals may retreat with the receding sea ice to Canada during summer or possibly spend the summer along the West Greenland coast. It is also possible that, due to seasonal changes in bearded seal vocal behavior, animals may have been present in our study area in summer, but silent. The number of detections was affected by the timing of sea ice formation but not sea ice concentration. Diel patterns were consistent with patterns found in other parts of the Arctic, with a peak during early morning (0400 local) and a minimum during late afternoon (1600 local). While vocalization studies have been conducted on bearded seals in Norwegian, Canadian, northwest Greenland, and Alaskan territories, this study fills the gap between these areas.

Keywords Bearded seals · *Erignathus barbatus* · Baffin Bay · Greenland · Passive acoustic monitoring · Sea ice · Diel pattern

Introduction

The bearded seal (*Erignathus barbatus*) is an ice-associated marine mammal with a circumpolar distribution (Burns 1981; Laidre et al. 2008). Highly dependent on sea ice for hauling out, breeding, and molting, bearded seals are found mainly over the shallow waters of the continental shelf in areas with drift ice or near shore leads off both East and West Greenland with highest numbers in areas where sea ice is present (Laidre et al. 2008). The species is hunted for subsistence in Greenland with no quota restrictions as a valuable resource for local hunters who use the hides for clothing and tools. The meat is used for sled dog food. In West Greenland the hunters catch close to 1000 bearded seals year-round with most catches during April and May (Greenland Government 2015).

Little is known about the behavior, distribution and habitat use of bearded seals in Greenland. Tagging studies of bearded seals in Greenland and Norway have shown that some bearded seals are stationary while others, probably younger males, roam larger areas (Van Parijs et al. 2003; Rosing-Asvid et al. 2012). Aerial surveys in Greenland aimed at other marine mammal species have given some insights into bearded seal distribution along predefined

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transects in some regions. Heide-Jørgensen et al. (2013) found that bearded seals hauled out on ice floes or along the ice edge over shallow waters in the eastern part of the North Water Polynya. The same study found that more seals were seen during a year with more ice floes in contrast to a year with little ice, as seals in the water were hard to detect. Hence, bearded seals are a species that is difficult to monitor due to its widespread, undefined distribution in a harsh and remote environment.

Increasing temperatures around Greenland and the Arctic in general are causing a rapid shift in environmental stability and the bearded seals' critical reliance on sea ice is threatened by a reduction in annual sea ice cover (Walsh 2008; Laidre et al. 2008, 2015). Furthermore, human activities in terms of shipping, tourism and oil and gas exploration are rapidly increasing in Greenland as previously ice-covered areas become accessible and ice-free periods are prolonged (Huntington 2009). Thus, anthropogenic disturbance in the territories of bearded seals is increasing. From a management and conservation perspective it is important to gain a better understanding of their ecology, movements and habitat use.

Passive acoustic monitoring (PAM) has proven to be an efficient tool to monitor vocalizing animals that inhabit remote and inaccessible habitats (Mellinger et al. 2007; Ahonen et al. 2017). Bearded seals are highly vocal, especially in winter and spring, and they rely on sound for keeping territories and finding mates (Van Parijs et al. 2003). Most underwater vocal activity is made by males which produce a variety of long narrowband frequency-modulated underwater trills (Terhune 1999; Davies et al. 2006). These sounds have a frequency range of 20–6000 Hz (Richardson 1995), can last up to 3 min and may disseminate as far as 25 km (Cleator et al. 1989). Although most trills disseminate only 5–10 km (Cleator et al. 1989), the long-distance propagation of some calls presents the opportunity to be heard by a larger number of conspecifics. Here we use the terms 'trills' and 'calls' interchangeably.

In this study, we present data on bearded seal calls collected from acoustic recorders attached on a mooring network spread across Baffin Bay and Davis Strait for up to 2 years. We analyze the temporal and spatial distribution of vocalizing bearded seals in relation to time of day and sea ice cover along with an analysis of diel patterns. Most acoustic studies conducted in Greenland waters are directed at cetaceans, especially the larger baleen whales (Stafford et al. 2008; Simon et al. 2010; Tervo et al. 2011). Frouin-Mouy et al. (2017) studied marine mammal seasonality, in the northernmost Baffin Bay and Melville Bay, West Greenland, based on acoustics. While these studies have addressed bearded seal presence/absence in this northern region, they have not reported it in the same detail presented here. Hence, these are among the first data available on bearded seal seasonality and calling behavior in Greenland and provide a basis for which circumpolar comparisons can be made.

Materials and methods

Acoustic sampling

Nine recorders were moored in seven different locations (Fig. 1 and Table 1) in Baffin Bay and Davis Strait, over the periods from 2006–2007 and 2011–2013. At all locations, the recorder was deployed for 1 year except location C1 and C6 where the recorders were deployed continuously for 2 years (2011–2013). All moorings were part of three larger mooring programs with different objectives, and therefore the recording timing, settings and instruments differed among positions (Table 1). The recorders were moored to the ocean bottom with ~ 600 kg iron weights, linked to the mooring line with an acoustic release (Edgetech PORT) and connected to subsurface floats. The acoustic recorders were attached to the mooring lines at water depths between 150 and 300 m. Two different sound recording instruments were used; HARUphone (Fox et al. 2001) and Aural M2 (Multi-Electronique, Rimouski, Canada) recorders (Table 1). Only C4 (HARUphone) was set to record continuously for 1 year. The four recorders in Baffin Bay (Aural M2 at B1, B2, D1 and D3) and the two other recorders in Davis Strait (HARUphone at C1 and C6) were set to record for 1 year with duty cycles and sample rates as described in Table 1. Sample rate varied between recording sites, however, this did not alter the possibilities of detection as all recorders covered the frequency range of bearded seals (Richardson 1995; C4 only in the bottom third of their frequency range). C1 and C6 were recovered after sampling two consecutive years at those positions. The hydrophones were pre-calibrated at the factory and the Aural M2s had sensitivities of − 164.1 dB re 1 V/μPa (16-bit resolution) and the HARUphone had a recording sensitivity of − 160 dB re 1 V/μPa (16-bit resolution).

Acoustic and diel pattern analysis

After downloading the acoustic data files, recordings were inspected visually to identify bearded seal calls, using the program Ishmael 2.4 (Mellinger 2001). Bearded seal calls are quite distinctive (see description above) and can be identified by their frequency-modulated downsweeping trills (Cleator et al. 1989). The frequency range was set at 0–4000 Hz for analysis for the Baffin and Disko Bay moorings (B1, B2, D1, D3) and 0–2000 Hz for the Davis Strait moorings (C1, C4, C6). When bearded seal calls were identified in the first 15 min of each file, the sound file was marked for acoustic presence and the analyst moved to the next

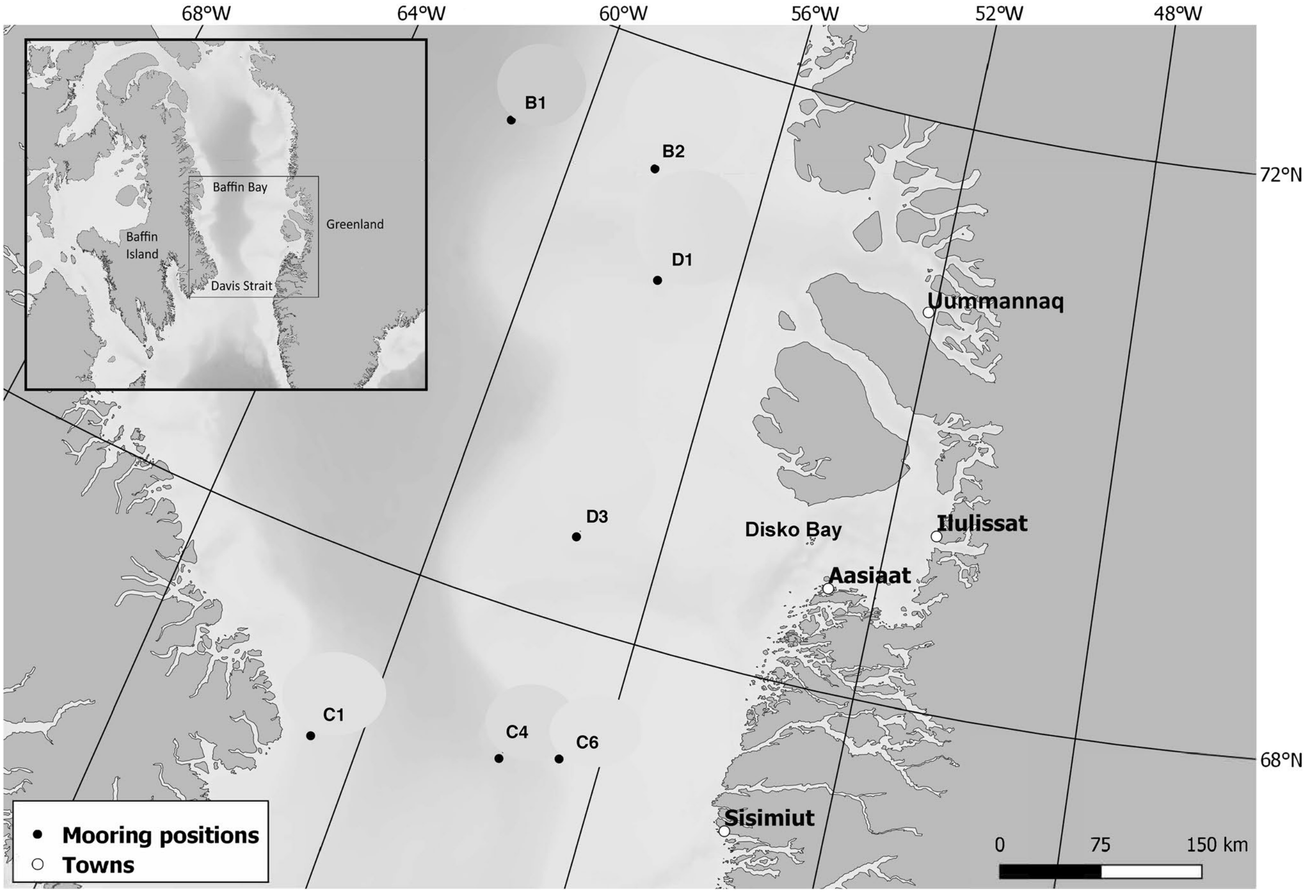


Fig. 1 Study area in Baffin Bay and Davis Strait with mooring deployment locations (black circles)

Table 1 Deployment and recording parameters for each mooring position

	Location	Recorder type	Sample rate (Hz)	Duty cycle	Bottom depth (m)	Distance to land (km)	Recording start	Recording end	Days of recording
Baffin 1 (B1)	71.15° N, 61.44° W	AURAL M2	16,384	35 min/2 h	1705	207.4	15-10-2011	13-09-2012	335
Baffin 2 (B2)	71.17° N, 58.30° W	AURAL M2	8192	45 min/2 h	332.6	105.5	15-10-2011	17-09-2012	339
Disko 1 (D1)	70.45° N, 57.55° W	AURAL M2	8192	45 min/2 h	421.2	93.7	15-10-2011	12-09-2012	334
Disko 3 (D3)	68.60° N, 57.55° W	AURAL M2	8192	45 min/2 h	336	158.8	15-10-2011	10-09-2012	332
Davis C1 (C1)	66.70° N, 60.80° W	HARU	5000	12 min/1 h	350	21.5	22-10-2011	15-09-2013	695
Davis C4 (C4)	66.98° N, 57.68° W	HARU	2000	Continuous	870	162	22-10-2006	04-10-2007	347
Davis C6 (C6)	67.10° N, 56.70° W	HARU	5000	12 min/1 h	400	119	22-10-2011	15-09-2013	695

sound file. Because there were different duty cycles for many of the locations and/or years, we report the percentage of hours available for each site and year by day that contained bearded seal calls. In this way, bearded seal presence was calculated as percentage of daily recordings by hour with the detection of at least one bearded seal call.

Diel patterns were analyzed on recorders B1, B2, D1 and D3, which had similar duty cycles (35 min/120 min or 45 min/120 min). The period of April through June was chosen for this analysis as calls were detected on all recordings during a day in this period. Analyses were done by counting all bearded seal calls recorded on each file from a subset of every other hour every fourth day from April to June. To account for the different general levels of calls among recorders, the normalized number of calls was calculated by dividing the mean number of calls by hour for each recorder by the total number of hours of data available for each recorder. In this way the results among recorders were comparable despite the shorter duty cycle for B1 (7 h total per day) as compared to B2, D1, and D3 (9 h total per day). Diel curves were fitted to the mean number of calls per hour for each recorder (Fig. 3). The diel data for calling rate were then analyzed by circular statistics using the cosinor analysis (Cornelissen 2014). Rao's spacing test of uniformity were applied to test of a diurnal pattern were significant. The phase angle (cosinor) of the diurnal data is fitted and a test is performed that represent the compactness of the data and whether the phase angles are the same. We assumed that the 24-h day represented a single diel period. The cosinor analysis fit a cosine wave to the hour of the day. The analyses including testing of the significance of diel variation was performed using the libraries *psych* and *circular* in R (R Core Team 2017).

Sea ice data

Sea ice concentration data (AMSR-E Aqua 12.5 km resolution) were obtained from the National Snow and Ice Data Center (Cavalieri et al. 2004). Following MacIntyre et al. (2013) we calculated the mean daily sea ice concentration as the average at each location with a radius of 20 km using Zonal statistics toolbox in ArcMap 10.0 (ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute). The 20-km radius was chosen on the basis that we expect that recorded bearded seals to be 20 km or less away from the mooring (Cleator et al. 1989).

Results

Bearded seals were detected in all areas and on all hydrophones and calling was restricted to the period from late November to late June (Table 2, Fig. 2). At all sites, calling within the mating season (from at least mid-April to the start of June) was intense with daily detections and calling on nearly all recordings during each day. Also, at all sites calling stopped more or less abruptly during June. However, the date for first and last detection along with intensity of calling prior to the mating season varied somewhat between sites. Three clusters were identified based on water depth, distance to land, and seasonal detection of signals. At mooring B1, which was the deepest (1705 m) and northernmost positioned mooring, there were essentially no detections of seals up until mid-April when calling started. Calling ended abruptly by late June. At moorings B2, C6 and C1, all of which were in similar water depth (332–400 m), there was a steady and continuous increase in calling starting in January and peaking during breeding season until immediate cessation by mid-June. At moorings D1, D3 and C4, and C1 from 2011 to 2012, there was sporadic calling from January onward until the start of April when calling became intense. D1 and D3 resembled each other in relation to both sea ice cover and depth (336–421 m). C4, on the other hand, was much deeper (870 m) than D1 and D3 and sea ice was present at that site nearly 1 month longer. The calling patterns at the three sites were similar.

The seasonal detection of bearded seals was not related to latitude, longitude or sea ice concentration. However, qualitatively, depth and distance to land may have an influence, as the deepest positioned moorings (B1 and C4), which were

Table 2 Hours of total recordings and recordings with bearded seal calls in the nine recording sessions, from seven different positions

	Total (h)	With calls (h)	With calls (%)	First detection	Last detection
Baffin 1 (B1) 2011–2012	2344	475	20.3	29/01/2012	27/06/2012
Baffin 2 (B2) 2011–2012	3051	993	32.5	03/01/2012	18/06/2012
Disko 1 (D1) 2011–2012	2999	729	24.3	27/11/2011	18/06/2012
Disko 3 (D3) 2011–2012	2986	771	25.8	11/12/2011	25/06/2012
Davis C1 (C1) 2011–2012	1756.8	422.8	24.0	04/01/2012	24/06/2012
Davis C1 (C1) 2012–2013	1579.2	466.6	29.5	01/01/2013	22/06/2013
Davis C4 (C4) 2006–2007	8322	1781	21.4	31/12/2006	29/06/2007
Davis C6 (C6) 2011–2012	1756.8	412.8	23.5	01/01/2012	13/06/2012
Davis C6 (C6) 2012–2013	1579.2	509.6	32.3	28/12/2013	19/06/2013
Total	26,374	6561	24.9		

Date of first and last detected bearded seal call is noted also the furthest offshore, had the fewest detections overall with 20.3% and 21.4%, respectively, of the total analyzed hours containing calls (Table 2).

Diel curves were fitted to the mean number of calls per hour for each of the four recorders used in the diel analysis (Fig. 3). A circadian pattern was apparent although not significant for any of the recorders individually (Rao's spacing test, $p > 0.05$). Further circular statistics shows that the phases were significantly different ($p > 0.05$, Table 3). For all, the diel rhythm was similar with more calls during nighttime and fewer during the daytime. The number of calls detected on B1 from April to June was reduced compared to the three other recorders used in this analysis (Fig. 3).

When the mean number of calls in each hour of each recorder was adjusted by total recording time for each recorder, and data from all four recorders were included, a significant diel pattern was evident. There were significantly more calls during the early morning between 0200 and 0400 followed by a decrease in calls, which reached minimum levels during the afternoon between 1400 and 1600 (Rao's spacing test, $p < 0.05$, Fig. 4).

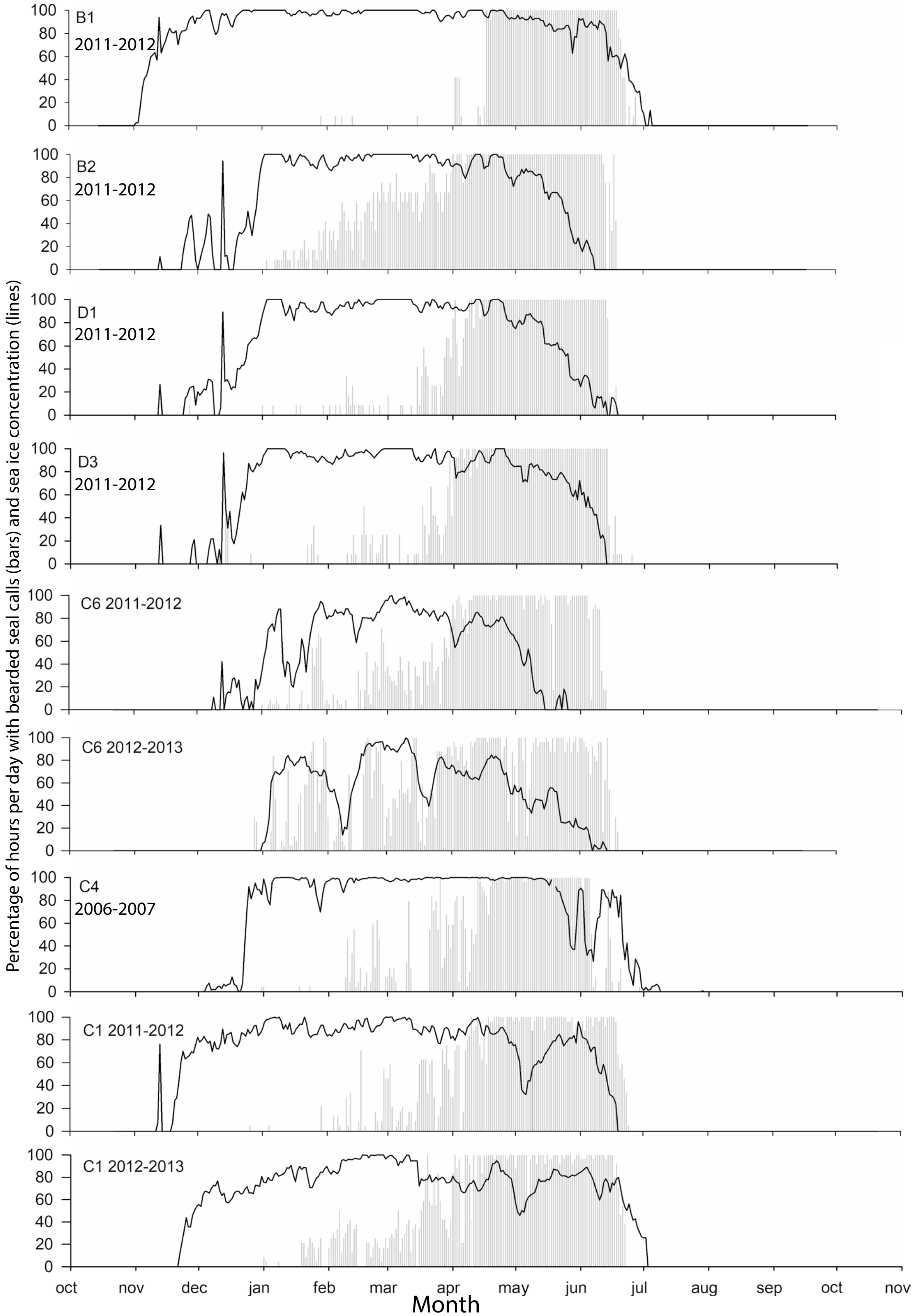
The sea ice expands seasonally across Baffin Bay and Davis Strait from the northwest in a southeast direction and the extent of sea ice at the seven mooring locations throughout a year was not the same. B1 (the northwestern most mooring) and C1 (the western most mooring) experienced the longest periods and most extensive sea ice cover (Fig. 2) whereas C6, the south easternmost mooring, had a highly variable sea ice extent during winter and spring due to its position in the warm West Greenland Current. For the two moorings C1 and C6 which were deployed for two consecutive years, the period with sea ice was slightly different between years. Hence, during 2011–2012, the sea ice formed and retreated 2–3 weeks earlier compared to 2012–2013. The difference in the timing of sea ice formation and retreat between the 2 years of recording did not seem to have any influence on the bearded seal calling period (Table 2). The dates of first and last detections were more or less the same for both years. However, there was a difference in the overall numbers of recordings with bearded seal detections between the 2 years for both C1 and C6. A higher percentage of bearded seal detections (6–8% higher) were found on C1 and C6 during 2012–2013, however, only significant for C1 (*t*-test, $p < 0.001$ and $p = 0.06$) covering the period February to June, the period with later freeze-up and retreat (Table 2) compared to 2011–2012.

Discussion

This study presents year-round recordings of bearded seals in the Baffin Bay and Davis Strait in the Atlantic Arctic. From November through June, bearded seals were detected at all sites. Bearded seals were not the target species for mooring deployments, therefore with regards to recorder placement, no bearded seal-specific considerations were done in relation to the extent of sea ice cover or water depth.

Bearded seal detections for the Baffin Bay and Davis Strait all had a limited period of calling that started in winter, peaked in spring, and ceased during the second half of June. MacIntyre et al. (2015) studied the spatio-temporal distribution of vocalizing bearded seals in the Bering, Chukchi, and Beaufort Seas in relation to sea ice concentration. They recorded vocalizing bearded seals nearly year-round in the Chukchi and Beaufort Seas with a seasonal peak in spring, whereas calling activity of seals in the Bering Sea was restricted to a 5-month period between January and May and was closely linked to the presence of sea ice. Bearded seals in Kongsfjord, Svalbard, had a restricted period of calling from early April to mid-July (Van Parijs et al. 2001), which was similar to the detections of bearded seals by Frouin-Mouy et al. (2017) in northern Baffin Bay. Bearded seal detections in the present study largely shared the same pattern as those found in the Bering Sea, Kongsfjord and northern Baffin Bay with a clearly delimited calling period. Differences include calling in the Davis Strait/Baffin Bay region commenced somewhat earlier than in Kongsfjord and the northern Baffin Bay, and ceased later than in the Bering Sea. B1, the deepest and northernmost site, however, had the same calling pattern as Kongsfjord and northern Baffin Bay.

Bearded seals prefer medium-coverage sea ice to heavy sea ice because they require some open water near ice on which they haul out (Burns 1981; Van Parijs et al. 2004). If the ice becomes too extensive, particularly early in the season, bearded seals may move to areas with less heavy ice (Van Parijs et al. 2004). The Baffin Bay sea ice thickness has been found to vary on an east–west gradient more than on a north to south gradient (Landy et al. 2017). Landy et al. (2017) found the sea ice thickness in the West Baffin Bay to exceed that on the East and based on their study, the recording sites in present study are likely to have more or less same conditions in relation to sea ice thickness. Still it is clear that the position of the recorder does influence the amount of calling recorded (which may represent the number of seals present). At some sites, vocal behavior was detected prior to the mating season. In particular, coastal sites B2 and C6 had many detections of calls during January, February and early March where males were likely starting to claim and defend territories prior to and during breeding season (e.g., Burns 1981; Stirling et al. 1983; Cleator et al. 1989; Cleator and Stirling 1990; Cleator 1996; Terhune 1999). This is similar to other studies where recordings were made in relatively shallow water (MacIntyre et al. 2015; Jimbo et al. 2019). B1 and C4, the two recorders in deep water (1705 m and 870 m, respectively), recorded very few bearded seal trills prior to the mating season. This was particularly true at B1, where


B1
2011-2012
B2
2011-2012
D1
2011-2012
D3
2011-2012
C6 2011-2012
C6 2012-2013
C4
2006-2007
C1 2011-2012
C1 2012-2013
Percentage of hours per day with bearded seal calls (bars) and sea ice concentration (lines)
100
80
60
40
20
0
oct
nov
dec
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
Month

◂**Fig. 2** Bearded seal (*Erignathus barbatus*) detections (gray bars) as percentage of recordings per day with detections and mean sea ice concentration around each mooring location (black lines) by deployment year

calling started very abruptly in mid-April. This pattern was similar to the findings in Frouin-Mouy et al. (2017) in which instruments were also located in deep water (575–1000 m depth).

The difference in call detection became more evident when counting the actual numbers of calls for the diel pattern analysis and not just recording presence/absence. There were many fewer calls detected at B1 compared to B2, which was only 61 nm away but closer to the coast. Reduced or absent calling prior to the mating season in some areas could indicate that these areas constitute less attractive habitats for the seals. According to Kingsley et al. (1985) the preferred habitat of bearded seals in the Canadian High Arctic was in waters not exceeding 100 m in depth. The recorders in this study were not deployed in what would be considered as optimal bearded seal habitat: shallow water with access to benthic prey (Burns 1970; Laidre et al. 2008). Bearded seals can feed on more pelagic species if benthic prey becomes inaccessible (Vibe 1950) and it is possible that species such as polar cod (*Boreogadus saida*) are available in the vicinity of the recorders (Kjellerup et al. 2015). Further, bearded seals have been documented to dive up to 600 m (Rosing-Asvid et al. 2012). Nevertheless, it appears that depth may influence bearded seal detections as the deeper sites had fewer call detections overall. It is clear from the present study that vocal behavior is most common at all sites during the mating season from March through June (McLaren 1958; Burns 1981; Cleator et al. 1989). This corresponds to the findings by Frouin-Mouy et al. (2016). They studied the variance in calling activity of bearded seals in the Chukchi Sea and found that time of year had the greatest influence on vocal activity and that the mating season likely was the strongest explanation for the presence or absence of vocalizing bearded seals. According to that study, sea ice coverage and location of the recorder also explained the variation in detection of vocalizations. Several recent studies of bearded seal vocalizations have found that call activity was significantly correlated with higher sea ice concentrations (MacIntyre et al. 2015; Frouin-Mouy et al. 2017; Halliday et al. 2019; de Vincenzi et al. 2019). In this study, like that of De Vincenzi et al. (2019) from a Spitsbergen fjord, there was some calling at locations that did not have sea ice coverage during mating season, indicating that time of year has a strong influence on calling. Intense calling persisted at C6 and C1 during late May and June in 2012 even though the sea ice in 2012 retreated around 3 weeks earlier than during 2013. Very few calls were detected on any recorder before the formation of sea ice. At C6, which had most variable ice conditions, there was a tendency for more calls when ice concentrations increased. Covering the period from January to April a significant positive correlation between ice and number of calls was found (correlation, $\tau = 0.24$, $p < 0.01$). The timing of sea ice coverage seems to influence the onset of calling. At C1 and C6 in 2012–2013, sea ice formed and retreated later, and more recordings had bearded seal detections on them as compared to 2011–2012. The increased number of recordings with bearded seal calls was especially pronounced in the period leading up to the mating season. How much a difference in the timing of freeze-up and sea ice retreat matters should be further studied with multiple years of recordings at a single site.

To what extent the bearded seals in West Greenland and East Canada constitute different subpopulations is unknown and population dynamics of bearded seals have not been thoroughly studied in Greenland. Genetic studies are rare, however Davis et al. (2008) did not find significant genetic differentiation between seals from northwest Greenland and the Labrador Sea. Hunting patterns along West Greenland and East Baffin Island, along with tagging studies in South Greenland, suggest that some bearded seals in Baffin Bay and Davis Strait likely follow the pulse of the ice while others are resident along the coast of Greenland. Tagged bearded seal individuals in South Greenland showed a large degree of site fidelity, residing in the same general area throughout a year (Rosing-Asvid et al. 2012), and bearded seals in Greenland are hunted along the coast year-round. In Nunavut, on the other hand, the hunt of bearded seals is limited to April and May. Instead, the hunt increases in the period July through October from the communities on the east of Baffin Island (Priest and Usher 2004). The increase in the hunt is likely a result of seals retreating towards Canada with the ice.

No calls were detected on the recorders from July until November in Davis Strait or Baffin Bay. It is possible that the seals are present in the open water without vocalizing (e.g., Frouin-Mouy et al. 2016). In the Chukchi Sea, bearded seals have been found to occupy nearly ice-free waters from August through October, although calls were only recorded beginning in late September (Boveng and Cameron 2013; MacIntyre et al. 2015; Jimbo et al. 2019). However, these waters are by far shallower than the Baffin Bay (e.g., Tang et al. 2004; Weingartner et al. 2005) making benthic prey more accessible. Yet, Frouin-Mouy et al. (2017) found bearded seals to be present in the Northern Baffin Bay during summer and fall at depths of 1000 m. Bearded seals have also been observed during summer in the area of the present study, although observations are few (Johansen et al. 2015; Greenland Institute of Natural Resources and Danish Centre for Environment and Energy 2018) and we believe that generally this open water area is not of importance to bearded seals during summer and fall. The data presented

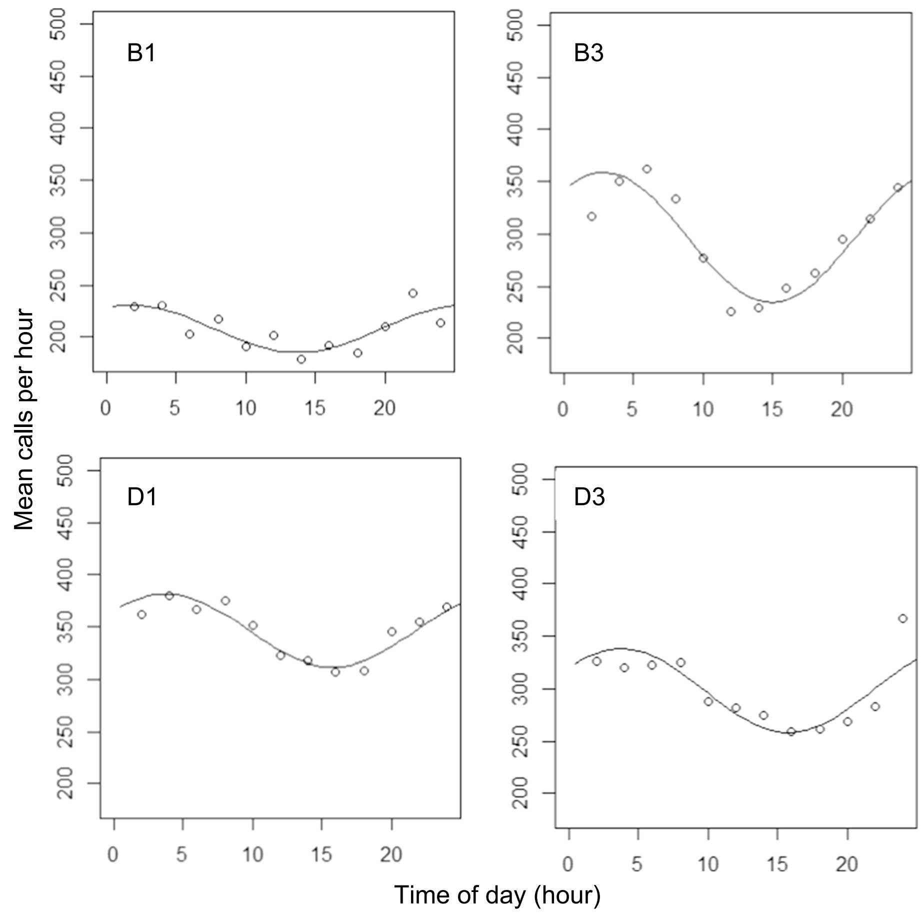


Fig. 3 Mean numbers of bearded seal (*Erignathus barbatus*) calls in relation to hour of day detected for B1, B2, D1 and D3. The solid lines represent fitted diel curves. Fewer calls were detected on B1 compared to the other positions

Table 3 Basic statistics of the circular analyses

Location	Phase	Fit	Mean	SD	Intercept
Baffin 1 (B1)	1.74	0.80	207.7	19.8	222
Baffin 2 (B2)	2.90	0.92	296.4	47.7	328
Disko 1 (D1)	3.76	0.94	346.8	26.4	360
Disko 3 (D3)	3.77	0.85	298.1	33.3	314
All	3.04	0.83	1	0.1	1.1

Phase is the hour where the curve peaks, fit is the value of the correlation of the fit. Mean, standard deviation (SD) and intercept are the appropriate circular statistic values

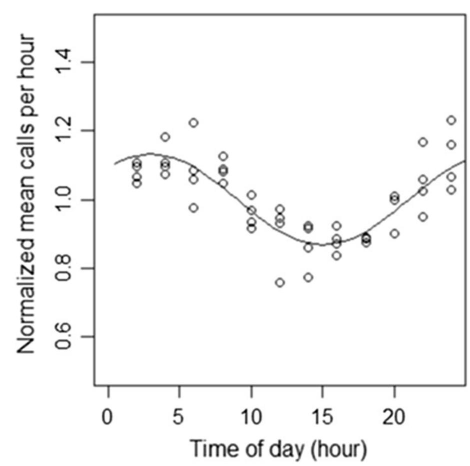


Fig. 4 Normalized numbers of bearded seal (*Erignathus barbatus*) calls for each recorder in relation to hour of day

here combined with the marine mammal observer data noted above, suggest that the seals either retreat westwards towards Canada with the sea ice, or eastwards towards more coastal waters with presence of ice along the West Greenland coast. However, as with all passive acoustic monitoring studies, we cannot completely exclude the possibility of silent animals present in the region.

The numbers of calls in this study showed a significant diel pattern for the four locations analyzed when standardized. Calling peaked around 0400 local and reached a minimum around 1600 local. This temporal pattern is entirely consistent with diel patterns found in both Alaska (Frouin-Mouy et al. 2016), the Northwest Territories of Canada (Halliday et al. 2019) and Svalbard (Van Parijs et al. 2001). Both Van Parijs et al. (2001) and Frouin-Mouy et al. (2016) argue that the peak in calling activity coincides with the time most females are in the water. No dive data are available for female bearded seals in Greenland but from a cost–benefit point of view it makes sense for males to produce underwater mating calls during the period when chances for a female receiver are greatest. What is interesting is that at the latitudes of our mooring locations the months used for the diel analysis (April and May) had 24 h of daylight suggesting that light levels were not directly influencing calling behavior.

This study provides insight into the calling behavior and distribution of bearded seals in Baffin Bay and Davis Strait throughout the annual cycle. PAM studies have been conducted on bearded seal vocalizations in Norwegian, Canadian, northwest Greenland and Alaskan territories and this study fills the gap in between the different areas. The shelf areas in Baffin Bay and Davis Strait appear to be the best habitat for the bearded seals during the mating season whereas the deeper waters are less attractive. Some bearded seals most likely retreat with the ice towards Canada during summer while others reside along the West Greenland coast. As ice concentrations change in Baffin Bay in future years, passive acoustic monitoring will be a valuable tool to monitor how environmental changes may affect the distribution and mating behavior of the ice-dependent bearded seals in this area.

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Author contributions TB, KS and MS conceived and designed research. KL and FR undertook statistical analysis. TB, FR, KL and KS analyzed data. All authors wrote and approved the manuscript.

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