Spring 2023

Investigating the relationship between sea ice extent and Erignathus barbatus breeding phenology in the Alaskan Arctic

Rachel E. Lewis
University of New Hampshire, Durham

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Abstract:

As sea ice decreases in Arctic ecosystems due to climate change, it is imperative to understand how culturally and ecologically relevant species like bearded seals (*Erignathus barbatus; 'ugruk'*) will be affected both by changes in physical habitat and the associated soundscape. Passive acoustic monitoring data from two historic breeding seasons (April-May 2010 and 2011) off the coast of Utqiaġvik, AK were used in conjunction with historical sea ice data to assess the relationship between advertisement behavior, sea ice extent, and ambient noise. We investigated peak calling onset and call density to assess how breeding phenology related to sea ice conditions. Additionally, call duration and peak frequency were compared to ambient noise conditions to assess vocal plasticity and compensation of bearded seals during periods of elevated ambient noise associated with conspecifics. Peak calling onset occurred on April 28th in 2011 and on April 7th in 2010 during the observed timeframe. Calling increased by 362% in 2011, a year with high sea ice concentration variation (2011 min.=0.03, median=0.95, max.=1.00 [100% cover in the study area]) compared to 2010 which had minimal variation (2010 min.=0.79, median=0.99, max.=0.99). Analyses indicate that peak frequency of bearded seal advertisement calls is not related to ambient noise, which is consistent with what is known about the vocal plasticity of phocids, and bearded seals specifically. Call duration may be related to ambient noise, with initial evidence suggesting that longer duration calls may be more common in higher ambient noise conditions than shorter duration calls. However, this study cannot fully

explain this relationship. The lack of compensation observed in bearded seal calls to increasing ambient noise suggests minimal resilience in a changing Arctic soundscape. Interpreting the relationships, or lack thereof, between shifting ecological conditions, changing soundscapes, and advertisement behavior is vital for understanding this bearded seal population, in order to establish effective management and conservation efforts in a changing Arctic Ocean.

Introduction:

Arctic ecosystems are changing (Comiso et. al, 2008) (Huntington et. al, 2020), and climate change induced losses of sea ice threaten species that rely on this ecosystem feature for survival. Established Arctic summer sea ice trends show that the ice is getting younger, thinner, and there is less of it (Rigor & Wallace, 2004) (Comiso et. al, 2008). Not only is the habitat structure changing rapidly, but anthropogenic use and stressors are also predicted to increase as commercial shipping, fishing, and tourism become more accessible in an Arctic with less ice (Hauser et. al, 2018) (Moore et. al, 2012). This will lead to an increase in ambient noise due to anthropogenic sources previously unseen in this ecosystem as well as shifts in ice habitat location and use by ice obligate species (Moulton et. al, 2003). One ecologically and culturally relevant species that will be affected by these changes is the bearded seal, *Erignathus barbatus*.

Bearded seals are ecologically relevant as prey and predator. They are also culturally important to indigenous communities in the Arctic. This species among others has been used in subsistence hunts by Indigenous peoples in the Arctic for many generations (Gryba et. al, 2021) (Lafrance, 2017). Subsistence harvests have been utilized for nutritional, social, and ceremonial purposes throughout the history of these cultures. The harvest of marine mammals in the Arctic, such as the bowhead whale specifically, has enabled Iñupiat cultural growth and expansion due to its value as a cultural and nutritional resource (Mason, 2009). As bearded seals are also a culturally significant resource, it is vitally important to understand their behavior in relation to shifts in the environment.

Bearded seals depend on sea ice for their reproductive strategy. These animals migrate north to the Arctic for the breeding season (April-July), mate underwater, then use the ice for resting, pupping, and nursing (Kovacs, 2018). In an Arctic with less ice, these seals will have to adapt to new conditions for both ice and sound. Other ice-obligate seals, while known to abandon breathing holes and pupping lairs due to anthropogenic stressors, are not easily displaced by high levels of human activity (Moulton et. al, 2003). This implies that as the Arctic changes, these species will experience all the effects of that change rather than simply adjust their range. As such, it is important to understand how bearded seal populations will be affected by a changing Arctic for species conservation, human health, and management decisions.

As industrial activities and the sound associated with them increase in a less icy Arctic, the soundscape will get louder in ways previously unobserved (Hauser et. al, 2018, Moore et. al, 2012). Historically these animals have evolved in noisy conditions and as such have methods of compensating for periods of increased loudness. One method called the Lombard effect refers to animals increasing call frequency, duration, or loudness in order to be heard over elevated ambient noise levels (Erbe et. al, 2016). Species-specific underwater vocalizations are used to attract mates, defend territories, and guide social encounters in many phocids including bearded seals (Van Parijs & Clark, 2006) (Stirling & Thomas, 2003). Previous research has established that there is a threshold above which bearded seals cannot or will not continue to increase call amplitude (Fournet et. al, 2021). In order to meaningfully manage access to an Arctic with less ice, it is essential to establish how increasing noise levels will affect marine mammals such as bearded seals.

Acoustic methods like passive acoustic monitoring (PAM) are an established tool for studying marine mammal populations where it might be too difficult to use more visual or hands-on methods (Risch et. al, 2007). Due to the increased speed at which sound propagates underwater as opposed to in air, many marine animals rely on hearing for survival. Sound is an especially useful ecosystem parameter in the Arctic, where darkness prevails for a large part of the year and primary production affects water visibility when light is abundant (Ji et. al, 2012). The distinct underwater vocalizations that bearded seals emit can thus be used to study various aspects of their life strategy including breeding phenology.

PAM has been used specifically to study bearded seals in this region in the past (Van Parijs & Clark, 2006). Recent research has established that bearded seals display limited noise compensation and are thus vulnerable to acoustic masking in louder soundscapes (Fournet et. al, 2021). It has also been shown that vocal activity peaks in spring in correlation with ice and the mating season (MacIntyre et. al, 2013).

The above demonstrates the need to understand how bearded seal populations will respond to climate change as a function of their ice-reliant reproductive strategy. The stressors induced by less sea ice availability (decreased overall area, earlier break-up, later formation, etc.) and increased anthropogenic noise could strongly affect these populations whose mating process relies on ice availability and accessibility as well as sound propagation. Thus, the objective of this study is to assess how the breeding phenology of bearded seals changes in response to changing sea ice extent, in order to assess what the future of these animals in the Arctic might look like. Specifically, this study investigated peak calling onset and call density during historic breeding seasons to assess when bearded seals call in relation to sea ice. Call parameters like peak frequency and duration, which have been shown to influence mate choice in phocids (Matthews et. al, 2018), were also investigated as a function of increasing ambient noise due to conspecifics.

Methods:

This study aimed to establish various characteristics of bearded seal calling during the breeding period in relation to sea ice concentration. The first question concerned how peak calling changed in years with differing sea ice conditions. To answer this, day of calling onset and call density was evaluated. The second approach was to look at specific call characteristics in relation to ambient noise levels. This was done to evaluate how calling behavior changes in a varying soundscape. An Arctic Ocean with less ice is expected to experience an increase in ambient noise from a multitude of sources as stated above. To answer this inquiry, peak frequency and 90% duration of the recorded calls were evaluated. Peak frequency was chosen as, due to the nature of the data (which was originally calibrated to record bowhead whale vocalizations), the full bandwidth of the bearded seal call is not captured. Duration was chosen as a characteristic, along with frequency, that has been established as influencing mate choice in phocids (Matthews et. al, 2018).

Acoustic data from the census for Bering-Chukchi-Beaufort bowhead whales (Charif et. al, 2013) was used from the first of April through the end of May in 2010, a year with low sea-ice concentration variation during this period, and 2011, a normal ice year. This census used arrays of Marine Autonomous Recording Units (MARUs) deployed along ice edge adjacent to Utqiaġvik, Alaska (Fig. 1), recording continuously at a 2000 Hz sampling rate with an effective bandwidth of 10-900 Hz after accounting for high and low pass filters, and a flat sensitivity of −145.5 dB re 1 V μPa−1 (Fournet et. al, 2021). Recordings were time aligned and merged into single multi-channel files with all continuously recording channels used for analysis.

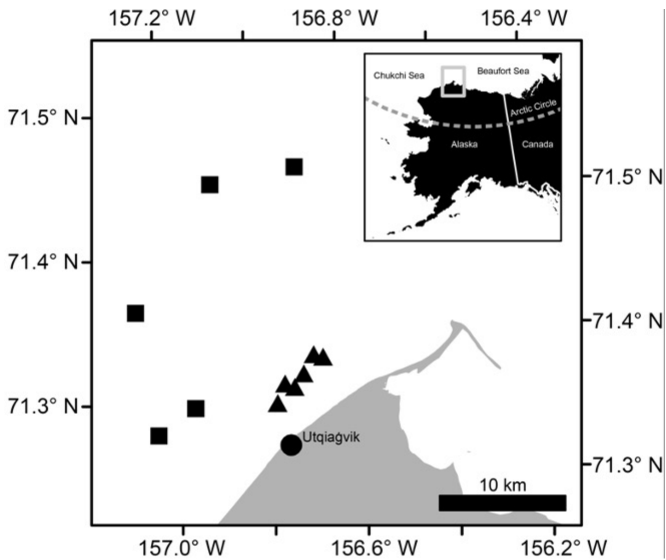

Figure 1: Map of hydrophone deployments. 2010 is displayed in triangles and 2011 in squares. (Fournet et. al, 2021)

The first five minutes of sunrise, solar noon, sunset, and solar midnight for each day in the chosen sampling period were analyzed for bearded seal call density and characteristic analysis. For days with 24-hour sunlight, the first five minutes of each quarter of the day were analyzed. These times were chosen as a sample of ecological relevance, as seals tend to be crepuscular in foraging (Krause et. al, 2016), but spend a decent amount of time in the water. Solar noon and midnight were used to ensure that a range of ambient noise values were recorded and so that periods of non-overlapping calls could be observed.

For each time, bearded seal calls were manually annotated in Raven Pro 1.6.4 (*K. Lisa Yang Center for Bioacoustics*). The maximum frequency of bearded seal calls exceeded the Nyquist frequency of these MARUs, so annotations were limited to sound below 1000 Hz. For 2010 channels 1-5 were used. For 2011, channels 2-6 were used. Channels were chosen based on whether they had data for the time periods being analyzed. Every call in every channel during the sampling period was annotated. To avoid pseudo replication, one channel of annotations was used for analysis in each year. Once all annotations were made, time of peak calling was found by plotting the number of calls annotated per day.

Sea ice extent was gathered from the Aqua/Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) data provided by NASA and accessed using the Worldview tool (NASA Worldview). This spatial sea ice concentration data was taken at a resolution of 12 km daily and measurements were recorded for the latitude and longitude of deployed hydrophones for each year on a scale of 0%-100% coverage.

Ambient noise levels were taken from the one second period before each annotated call. This ensured that the ambient sound environment a seal was experiencing directly before vocalizing was captured.

PAMGuide was utilized to conduct power spectral density (PSD) analyses and broadband noise analyses in the 10 Hz – 1000 Hz range using a Hann window for the study period each year. Long-term spectral analyses (LTSAs) were formed using the PSD analyses. All channels continuously recording during this time were used (channels 1-5 in 2010 and 2-5 in 2011).

A generalized liner model with a Poisson distribution was used to test for the relationship between the number of bearded seal calls and sea ice concentration as a function of ice and year. The Akaike Information Criterion (AIC) model selection method was used to test multiple models containing every combination of possible explanatory variables. The Kruskal-Wallis test was used to account for variation in the sea ice concentration by year as the data were not normally distributed.

To assess if bearded seals in the area were altering call frequency, ambient noise was compared to peak frequency using a linear regression model. Calls with peak frequencies below 250 Hz were considered outliers as they could possibly be misidentified bowhead whales and excluded to make the data approach a normal distribution. Similarly, to assess if bearded seals were altering call duration as a function of ambient noise a linear regression model was used. Duration data was log transformed in order to approach a normal distribution.

Results:

The early breeding season in 2010 displayed significantly less variation in daily sea ice concentration than in 2011, when the median was higher (Fig. 2, 4) (Kruskal-Wallis, p=0.001).

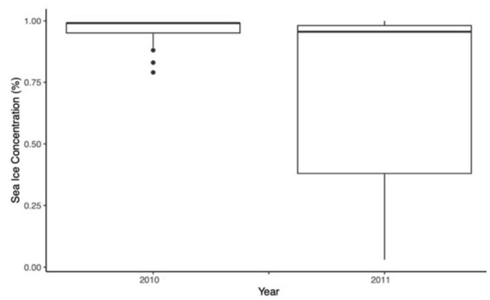

Figure 2: Displaying the variation in daily sea ice concentration from April-May in 2010 and 2011. 2010 was a year with low sea ice variation during this period, whereas 2011 displayed high levels of variation. (2010 min. = 0.79, median = 0.99, max. = 0.99) (2011 min. = 0.03, median = 0.95, max. = 1.00).

A 362% increase in calls was observed in 2011 (95% CI 330%-399%, p<0.0001) (Fig. 3, 7). On average, sound levels in 2011 were 10 dB louder than in 2010 (95% CI 9.7-10.2 dB, p<0.001) (Fig. 4). From mid-April through the end of May in 2010, the soundscape was generally quiet, with ice being the largest contributor of sound. 2011 was distinctly louder, with the increase in sound attributed to chorusing bearded seals (Fig. 3, 6). The relationship between bearded seal calling and daily sea ice concentration was such that for every one unit decrease in sea ice, calling increased by 25% (95% CI 18%-31%, p<0.0001).

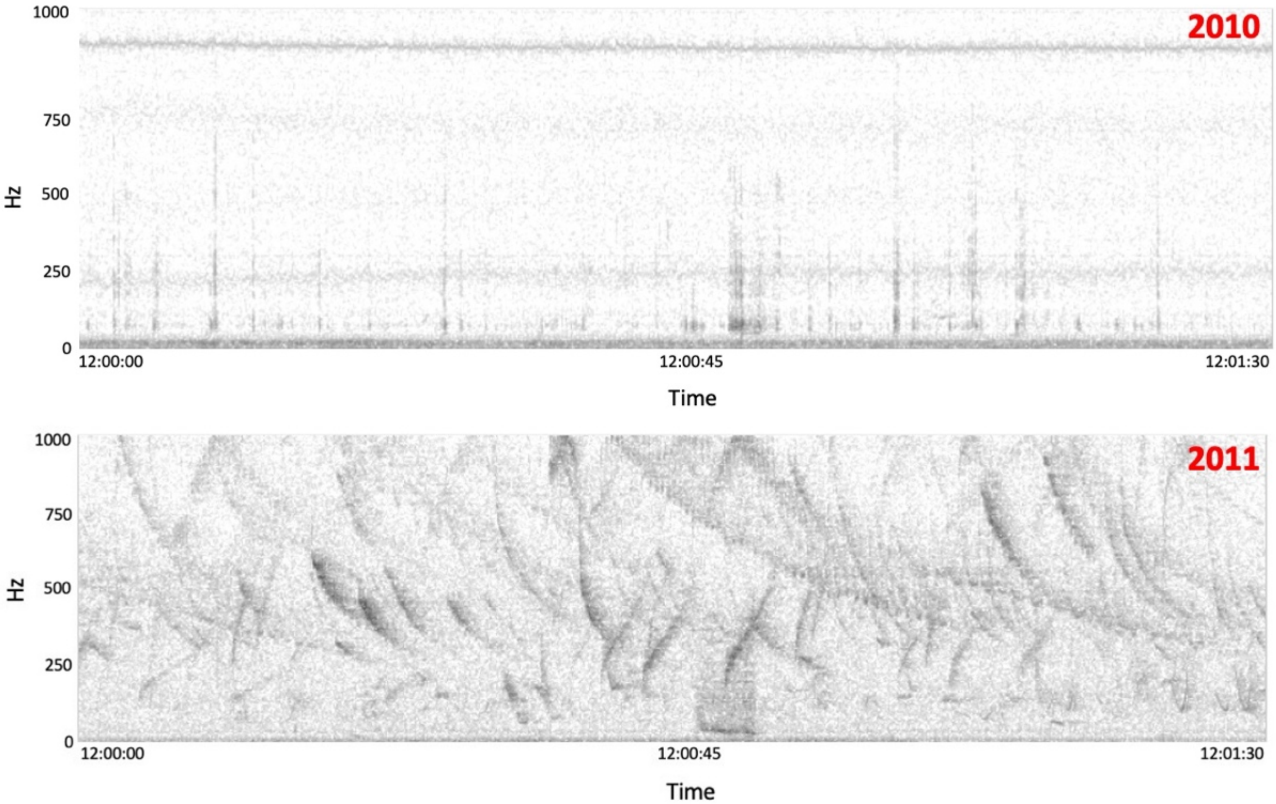

Figure 3: Spectrograms from both years on April 28th at 12:00:00 noon (Hann window, FFT = 512). The 2011 spectrogram is dominated by bearded seal calls compared to 2010, where the dominant noise source is ice.

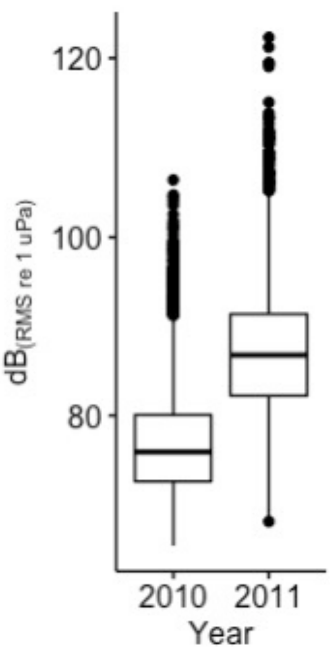

Figure 4: A boxplot displays ambient noise values, which on average were 10 dB louder in 2011 than in 2010. Due to the logarithmic nature of the decibel scale, this is over a sextupling in the general loudness of the soundscape, attributed to bearded seal chorusing.

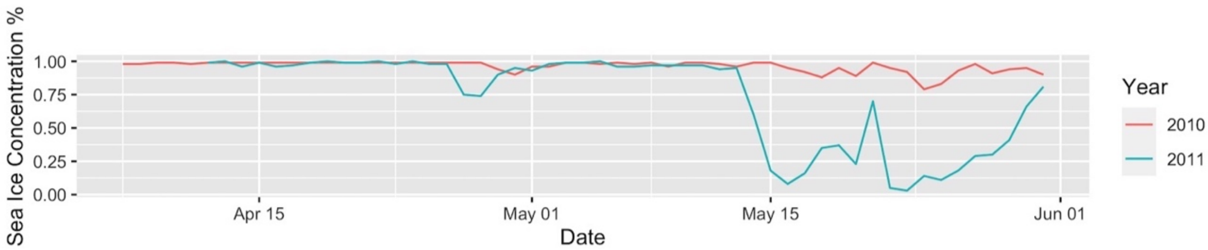

Figure 5: A display of the daily sea ice concentration over deployed hydrophones by year.

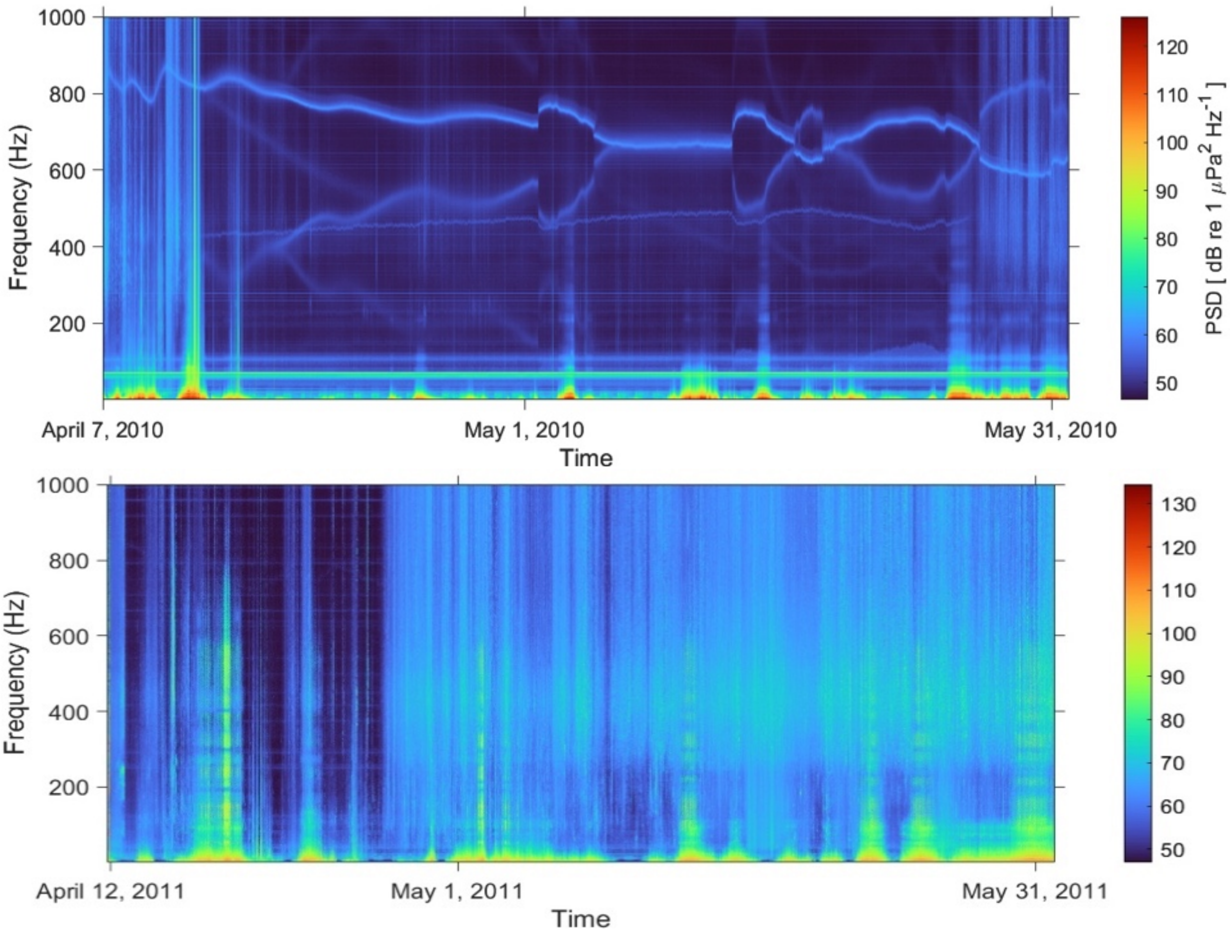

Figure 6: LTSAs (long term spectral averages) from beginning of MARU deployment in April through the end of May for each year. 2010 (top) lacks the noise from chorusing bearded seals seen in 2011 (bottom).

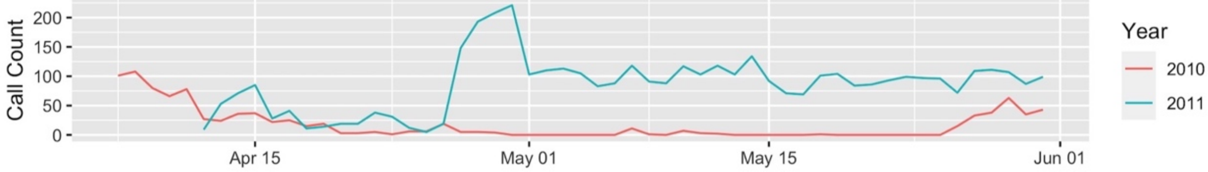

Figure 7: Bearded seal calls counted in one hydrophone per sample of every day in deployment from April – May.

There was no relationship between the peak frequency of annotated bearded seal calls and ambient noise (Fig. 8). There was also no clear relationship between 90% call duration and ambient noise. However, for every one decibel increase in noise levels, duration increased by 1.73 seconds, and 90% call duration was on average 0.18 seconds longer in 2011 than 2010 ($p<0.0001$) (Fig. 9). Due to the non-normal distribution of this data, further analysis is required to determine the full relationship between ambient noise and call duration.

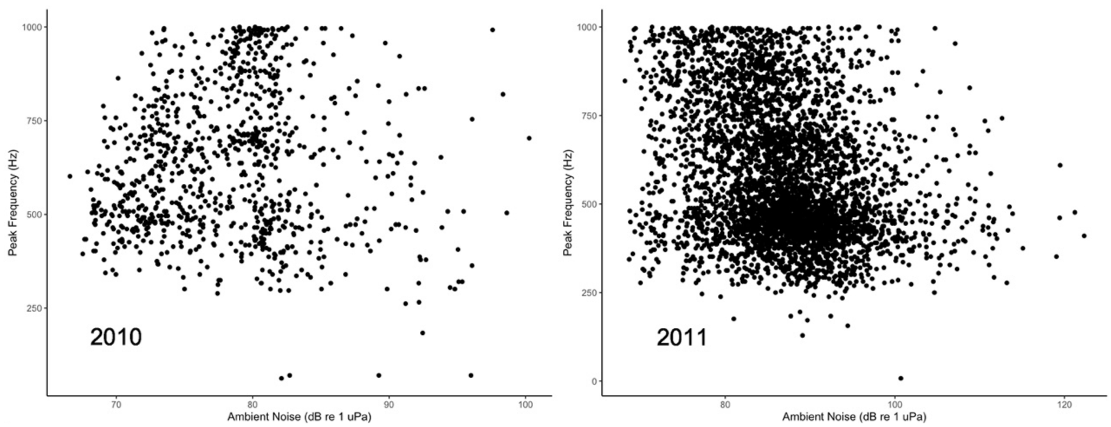

Figure 8: Comparing ambient noise values to the peak frequencies of annotated bearded seal calls.

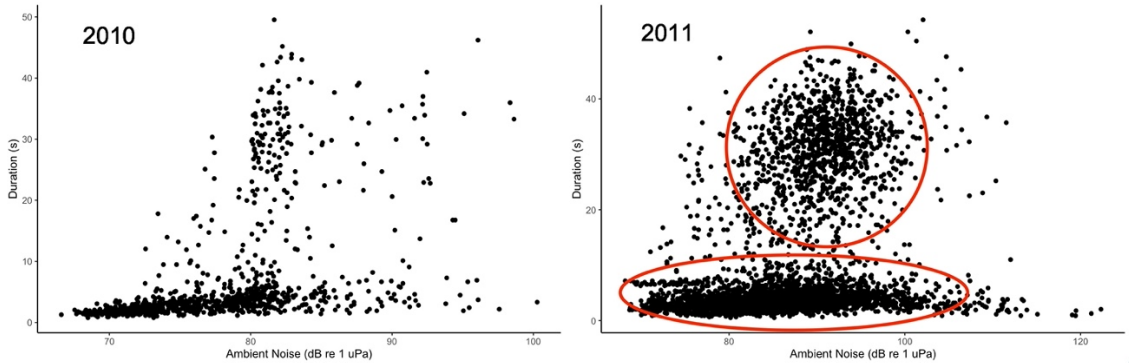

Figure 9: Comparing ambient noise values to 90% call duration of annotated bearded seal calls.

Discussion:

When ice breaks up earlier, bearded seals call more often and for longer throughout the breeding season, altering the ambient soundscape. In 2010, a year with low sea ice variation, bearded seals called less, resulting in a shorter breeding season. This year also had nearly 100% sea ice cover in the study area during the study period. It is possible that such complete ice cover decreased the usable habitat for bearded seals, as there was less ice edge and thus access to the water compared to 2011. In 2011, earlier ice breakup and significantly more ice variation led to an observed increase in *E. barbatus* calling. This increase meant a longer breeding season with significantly more biological noise.

Due to the logarithmic nature of the decibel scale, the average of a 10 dB increase in the biological soundscape from 2010 to 2011 means it was over six times as loud. Based on the annotation of this historic PAM data, this sextupling of loudness can be attributed almost entirely to bearded seal chorusing. While other Arctic marine mammal species known to be in the same Chukchi and Beaufort seas like ringed seals (*Pusa hispida*) and bowhead whales (*Balaena mysticetus*) were also present in the data, they did not chorus as the bearded seals did. This shift in *E. barbatus* calling behavior in relation to sea ice increases acoustic competition between conspecifics vying for the same acoustic space, and heterospecifics like bowhead whales migrating through. Such intense conspecific competition for a finite amount of acoustic space relates to increased competition for both territory and a mate, as these are the functions of the bearded seal call (Van Parijs & Clark, 2006) (Stirling & Thomas, 2003).

Since the breeding *E. barbatus* chorus is already so loud, these animals are at risk of masking from anthropogenic sound sources as human use is expected to increase in more accessible, less icy Arctic waters. Acoustic masking refers to when the perception of one sound is hindered by the presence of another sound. Past studies have demonstrated a threshold in bearded seal call amplitude in relation to ambient noise levels above which the animals could not or would not call louder (Fournet et. al, 2021). This study demonstrated that similarly, bearded seals do not adjust call frequency in response to ambient noise. This aligns with what is known about phocid calling behavior. These animals, which have evolved in an acoustically competitive environment, are presumably already calling at their biological maximum. So, as ambient noise levels are expected to increase in a future Arctic, *E. barbatus* will be unable to adjust their calling, which has implications for breeding and population success and on the long-term scale.

The last call parameter this study looked at in relation to ambient noise was duration. While there was no clear linear relationship between call duration and increasing ambient noise, there did seem to be two clusters displayed in the data. One cluster was calls of shorter duration spread over all levels of ambient noise, and the other was calls of longer duration occurring between 80 dB re 1 μPa and 100 dB re 1 μPa (Fig. 9). This may indicate call switching in response to the ambient soundscape and have implications for breeding strategy, as these seals have been shown to have multiple territorial strategies (Van Parijs & Clark, 2006). This result requires further investigation to uncover exactly what the relationship between ambient noise and bearded seal call duration is, as well as how it relates to breeding behavior.

This knowledge of *E. barbartus* calling behavior, coupled with decreasing Arctic ice and the expected increase in anthropogenic sound sources, puts bearded seals at severe risk for both physical and acoustic habitat degradation. For the indigenous peoples that rely on these mammals as a food source, this loss would be significantly harmful. Further, for the sake of conservation and preservation of this ecosystem, elucidating the full relationships between sea ice, ambient noise, and *E. barbatus* calling behavior is critical.

Conclusions:

Looking at the relationship between sea ice extent and bearded seal calling in historic breeding seasons established that these animals depend on ice and ice breakup for successful breeding. It is likely bearded seals use ice breakup as a cue for the breeding season (Gryba et. al, 2021). As ice extent lessens and ice breakup occurs earlier in a changing Arctic, the habitat these animals get cues from for when to exhibit breeding behaviors and do so successfully will no longer be a reliable indicator. Further research into exactly what sea ice parameters *E. barbatus* is relying on and how they affect the length and timing of the breeding season is essential for understanding population trajectory and creating effective management plans.

In the two breeding seasons this study observed, increasing sea ice variation was correlated with substantial increases in calling. In order to determine how sea ice variation relates to *E. barbatus* habitat use and mating strategy, future research must look at whether the increase in recorded calls in 2011 was due to a similar number of seals as were in the area in 2010 calling more often, or more seals coming to the area. Should the result be the latter, then decreasing sea ice would show a clear relationship to increasing territorial competition. Understanding this cause and effect is again important for modeling the populations of bearded seals in this area. Without this understanding, management efforts will be unable to effectively conserve this population.

The question of ambient noise and its relationship to bearded seal calling behavior in the Alaskan Arctic can be summed by saying there is a lack of vocal plasticity displayed by *E. barbatus*. Bearded seals cannot call much louder (Fournet et. al, 2021) or at higher frequencies, and they don't appear to be calling for longer durations as the soundscape they exist within intensifies. These animals are already performing at their biological maximum, which must be kept in mind as the Arctic opens for human use and management decisions are made. Regulating anthropogenic use, and thus noise, is critical for ensuring that human involvement within this system does not significantly hinder bearded seal breeding through acoustic masking.

Continued investigation of the above parameters associated with breeding phenology and calling behavior is critical for interpreting *E. barbatus* resilience in a changing Arctic. In order to effectively manage and conserve this population, it must first be understood how habitat factors known to be shifting affect this population's behavior and growth. Bearded seals in the Alaskan Arctic have survived and coexisted with humans for a multitude of generations. It is imperative that as climate conditions and human use of the area changes, such coexisting continues. Elucidating the relationships between sea ice and *E. barbatus* breeding phenology is the first step in understanding how these seals interpret their environment and being able to use that knowledge in order to make meaningful and well-informed management and conservation decisions.

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