ARCTIC
VOL. 75, NO. 4 (DECEMBER 2022) P. 462–479
https://doi.org/10.14430/arctic76400

The Underwater Soundscape of Minto Inlet, Northwest Territories, Canada

William D. Halliday,[1,2,3] Sarah A. Brittain,[3] Andrea Niemi,[4] Andrew R. Majewski,[4] Xavier Mouy[3,5]
and Stephen J. Insley[1,6]

(Received 20 February 2022; accepted in revised form 6 June 2022)

ABSTRACT. Passive acoustic monitoring is a powerful tool for observing soniferous species in remote marine environments over long periods of time, which can inform conservation planning and wildlife management. In this study, we collected seven months of passive acoustic data from early February to early September 2019 in Minto Inlet, Northwest Territories, Canada, to examine the seasonal presence of four species of marine mammals and unidentified fish species, examine drivers of underwater sound levels, and quantify underwater noise from vessel traffic. Bearded seals were vocally present from mid-March to early July. Ringed seals were present in every month. Beluga whales were present from early July until September. Bowhead whales were detected from April to August, and fish were detected from February to July. Underwater sound levels were dampened by the presence of landfast sea ice and increased with wind speed. Increased bearded seal calls also caused increased sound levels. The only vessel detected was the research vessel that recovered the acoustic recorder. Underwater sound levels were much lower in Minto Inlet compared to other areas in the region, and it appears to be an important site for many marine mammals where forage fish species, primarily Arctic cod, are abundant at depth. These results are in line with Minto Inlet being identified as an important area by the community of Ulukhaktok. At present, anthropogenic impact on this area appears to be very low, but further monitoring is required to determine if any management measures are necessary to maintain these low levels.

Key words: Arctic; ambient sound; bioacoustics; cetaceans; fish; passive acoustic monitoring; pinnipeds; sea ice; underwater noise; underwater sound levels

RÉSUMÉ. La surveillance acoustique passive est un outil puissant pour observer les espèces sonifères des milieux marins éloignés sur de longues périodes, ce qui permet d'éclairer la gestion de la faune et la planification de la conservation. Dans le cadre de cette étude, nous avons recueilli des données acoustiques passives échelonnées sur sept mois, du début de février au début de septembre 2019 à l'inlet Minto, dans les Territoires du Nord-Ouest, au Canada, dans le but d'examiner la présence saisonnière de quatre espèces de mammifères marins et d'espèces de poissons non identifiées, de nous pencher sur les facteurs à la base des niveaux sonores sous-marins et de quantifier le bruit sous-marin émanant de la circulation des navires. Le son des phoques barbus s'est fait entendre de la mi-mars au début de juillet. Les phoques annelés étaient présents pendant chacun des mois. Les bélugas étaient présents du début de juillet jusqu'en septembre. Des baleines boréales ont été détectées d'avril à août, et des poissons ont été décelés de février à juillet. Les niveaux sonores sous-marins ont été étouffés par la présence de glace de rive rapide et se sont accrus avec la vitesse du vent. L'intensification des vocalises du phoque barbu a également eu pour effet d'accroître les niveaux sonores. Le seul navire détecté a été le navire de recherche qui a récupéré l'enregistreur acoustique. Les niveaux sonores sous-marins étaient nettement inférieurs dans l'inlet Minto comparativement aux autres zones de la région. Il semble qu'il s'agisse d'un lieu privilégié par de nombreux mammifères marins et où les espèces de poissons à fourrage, principalement la morue polaire, abondent en profondeur. Ces résultats concordent avec la grande importance qu'accorde la communauté d'Ulukhaktok à l'inlet Minto. En ce moment, l'incidence anthropique sur cet endroit semble très faible, mais d'autres travaux de surveillance s'imposent afin de déterminer s'il y a lieu d'adopter des mesures de gestion pour maintenir ces faibles niveaux.

Mots clés : Arctique; son ambiant; bioacoustique; cétacés; poissons; surveillance acoustique passive; pinnipèdes; glace de mer; bruit sous-marin; niveaux sonores sous-marins

Traduit pour la revue *Arctic* par Nicole Giguère.

---

[1] Wildlife Conservation Society Canada, 169 Titanium Way, Whitehorse, Yukon Y1A 0E9, Canada
[2] Corresponding author: whalliday@wcs.org
[3] School of Earth and Ocean Sciences, University of Victoria, 3800 Finnerty Road, Victoria, British Columbia V8P 5C2, Canada
[4] Freshwater Institute, Fisheries and Oceans Canada, 501 University Crescent, Winnipeg, Manitoba R3T 2N6, Canada
[5] JASCO Applied Sciences Ltd., 4464 Markham Street, Victoria, British Columbia V8Z 7X8, Canada
[6] Department of Biology, University of Victoria, 3800 Finnerty Road, Victoria, British Columbia V8P 5C2, Canada

INTRODUCTION

The Arctic marine environment is facing several concurrent threats caused directly and indirectly by climate change (Laidre et al., 2008; Meredith et al., 2019; Niemi et al., 2019). These threats include sea ice loss, increasing water temperatures, a shifting food web, and increased anthropogenic stressors (Niemi et al., 2019). For example, sea ice is important habitat for many Arctic marine species yet changing ice conditions have potentially led to shifted migration timing of whales (Hauser et al., 2014; Stafford et al., 2021), changed haul-out behaviour of ice seals (Hamilton et al., 2018), and a shifted distribution of Arctic cod (*Boreogadus saida*) (Huntington et al., 2020). Increased oil and gas activity and vessel traffic have led to higher levels of underwater noise in certain parts of the Arctic (Roth et al., 2012; Halliday et al., 2021), which can cause significant disturbance to marine mammals and other marine species (PAME, 2019; Halliday et al., 2020a). Given these emerging threats, it is imperative to understand the distributions and movement patterns of species, their important habitats, and to evaluate the impacts of exposure to these different threats.

Passive acoustic monitoring is a powerful tool for studying soniferous marine species (organisms that make sounds), as well as for understanding underwater sound levels, including any sources of underwater noise (Mellinger et al., 2007; Van Parijs et al., 2009; Moore et al., 2012). Given that a large proportion of marine mammals and fish are soniferous (Au and Hastings, 2008; Looby et al., 2022), passive acoustic monitoring is an ideal tool to study both the distribution of marine animals and their exposure to underwater noise in the Arctic. Soundscape analysis is a holistic approach to analyzing passive acoustic data, which identifies different signals of interest and examines the contributions of different sound sources to underwater sound levels (Pijanowski et al., 2011; Halliday et al., 2020b; McKenna et al., 2021). The main contributors to the soundscape can be grouped into three general categories: 1) natural non-biological sounds (often called geophony: e.g., waves crashing and ice sounds), 2) biological sounds (biophony: e.g., whale moans and fish grunts), and 3) anthropogenic sounds (anthrophony or anthropophony: e.g., vessel noise and naval sonar) (Pijanowski et al., 2011). Previous analyses of the Arctic soundscape have identified that wind, sea ice, and glaciers are the dominant sources of natural non-biological sounds (Roth et al., 2012; Kinda et al., 2013; Deane et al., 2014; Halliday et al., 2020b, c, 2021; Bonnel et al., 2021; McKenna et al., 2021; Podolskiy et al., 2022). Biological sounds are often locally specific in the Arctic, although bearded seals (*Erignathus barbatus*) seem to be an important driver of sound levels at many locations (Clark et al., 2015; Heimrich et al., 2021). Other studies have identified high sound source levels of bowhead whale (*Balaena mysticetus*) singing (Tervo et al., 2012) and high acoustic energy from beluga whales (*Delphinapterus leucas*) in an estuary with large congregations of individuals (Halliday et al., 2020c). Anthropogenic noise is also quite variable, but the main sources identified in the Arctic are from vessel traffic (Halliday et al., 2020b, 2021; McKenna et al., 2021), seismic airguns (Guerra et al., 2011; Roth et al., 2012; Han et al., 2021), and drilling for oil and gas (Blackwell and Greene, 2006; Quijano et al., 2018). Local community boats and snowmobiles may also be consistent contributors of underwater noise close to communities (Bedard, 2019; Halliday et al., 2020b).

In this study, we use passive acoustic monitoring to study the soundscape of Minto Inlet, Northwest Territories (NWT). Minto Inlet is a small inlet on the west side of Victoria Island, located roughly 40 km north of Ulukhaktok (previously Holman, also called Olokhaktomiut), NWT (Fig. 1). The inlet is roughly 115 km long and 35 km wide at its mouth. Multiple streams and rivers run into Minto Inlet, but the largest of these is the Kuujjua River, which flows into the southern side of the inlet. Minto Inlet has been identified as an important site to the community of Ulukhaktok for several reasons, including its significance as a summer habitat for beluga whales (Fisheries Joint Management Committee, 2013), haul-out and reproductive habitat for ringed seals (*Pusa hispida*), place where polar bears (*Ursus maritimus*) hunt for ringed seals, and good habitat for Arctic char (*Salvelinus alpinus*) (Olokhaktomiut Hunters and Trappers Committee et al., 2016). Minto Inlet is also a popular site for subsistence hunting and fishing by the people of Ulukhaktok (Olokhaktomiut Hunters and Trappers Committee et al., 2016). Like most Inuit and Inuvialuit communities in the Canadian Arctic, the people of Ulukhaktok rely on these and many more species for subsistence. The conservation of these species is therefore not just of biological importance, but also of cultural importance as well as important for food security. There were two goals for our study: first, to establish a baseline of how different soniferous species use Minto Inlet and second, to establish a baseline of underwater sound levels in Minto Inlet, including how different acoustic sources contribute to underwater sound levels.

METHODS

Data Collection

We deployed an oceanographic mooring through the sea ice in Minto Inlet on 7 February 2019 (coordinates: 71.3045˚ N, 116.8437˚ W WGS84) at a water depth of 319 m (Fig. 1). The oceanographic mooring was recovered during the open water period (8 September 2019) by RV *Frosti*, as part of the Canadian Beaufort Sea Marine Ecosystem Assessment (CBS-MEA). This site is only 2.5 km from shore but is at the bottom of the deepest channel that runs through Minto Inlet. The mooring consisted of an anchor weight tied to an acoustic release with a 1 m length of rope, a 3 m length of rope connecting the top of the release to subsurface floats, and three scientific instruments attached to the rope between the floats and the release. The

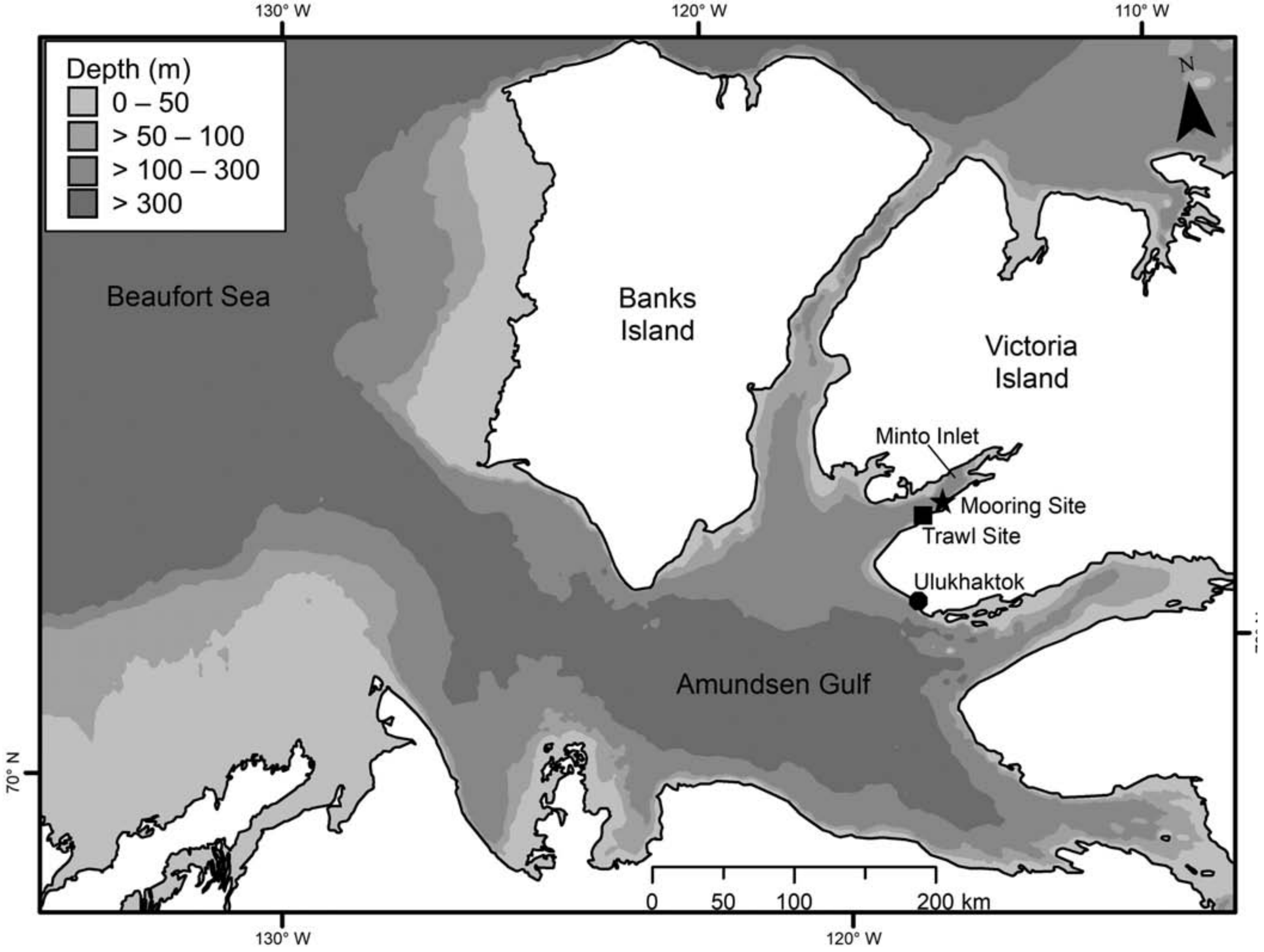

FIG. 1. Study area map showing the location of the oceanographic mooring used to collect data for this study within Minto Inlet and an approximate location where fish trawls were conducted. A CTD cast was taken the day after the mooring was deployed directly adjacent to the point for the mooring, and another CTD cast was taken in September, the day that the mooring was recovered near the point for the trawls.

instruments included a SoundTrap ST500 acoustic recorder (Ocean Instruments, Auckland, New Zealand), a Sea-Bird MicroCAT conductivity-temperature-depth (CTD) recorder (model 37SM; Sea-Bird Scientific, Bellevue, Washington, USA), and a VEMCO acoustic receiver. The latter instrument was attached for another local project and is not discussed further in this study. The acoustic recorder was set to record 5 min of audio data every hour at a 48 kHz sample rate and had a sensitivity of 175.4 dB re 1 V/µPa; this model of acoustic recorder does not have a gain setting. The noise floor of the acoustic recorder is at roughly 62 dB re 1 µPa^2/Hz at 20 Hz and decreases steadily to roughly 38 dB re 1 µPa^2/Hz at 10 kHz. The CTD recorder was set to record data once every 2.5 h.

CTD casts were also collected the day after the mooring was deployed (8 February 2019) and the day before the mooring was recovered (7 September 2019). The cast taken in February was taken roughly 5 m adjacent to the mooring through a hole in the sea ice, and the CTD recorder (model RBR Concerto[3]; RBR Ltd, Ottawa, Ontario, Canada) was lowered through the ice by hand at a rate of roughly 1 m/s with the recorder sampling at a rate of 8 Hz. A reference CTD cast (model SBE-25; Sea-Bird Scientific, Bellevue, Washington, USA) was also taken by the RV *Frosti* on 8 September 2019 roughly 17 km west of the mooring (71.236˚ N, 117.269˚ W) at a water depth of 272 m.

Marine fish were assessed in Minto Inlet as part of the CBS-MEA on 4 September 2017, 16 August 2018, and 7 September 2019. We include data on fish catches to provide context for fish present during the recorder deployment, which is especially important given that the vocalizations made by most Arctic marine fish are unknown to science, except for Arctic cod (Riera et al., 2018). A modified Atlantic Western IIA otter trawl was deployed in the deep trough of Minto Inlet (71.230˚ N, 117.27˚ W; 280 m depth; Fig. 1) to identify the community composition of demersal fishes (Majewski et al., unpubl. data). Descriptions of trawling gear and deployment methods are described in Atchison et al. (2022) and Majewski et al. (2017). Fish from the trawl were identified to the lowest taxonomic level possible and catch-per-unit-effort (CPUE; number of fish/km^2) was calculated as per Atchison et al. (2022).

Bioacoustic Analysis

We used the software Raven Pro (K. Lisa Yang Center for Conservation Bioacoustics, 2019) to manually analyse every 10th acoustic data file (i.e., one 5 min file every 10 h), which meant that two or three files were analyzed for every day of data collection. We set the spectrogram parameters in Raven Pro to a window size of 7000 samples, 50% overlap, Hann window, time scale to 10 s, and frequency scale to 3000 Hz for a first pass of each file, then 6000 Hz for the second pass through the file. We used these two different frequency ranges to better aid in detection of low frequency vocalizations (bowhead whales, fish, and ringed seals), which would be difficult to detect at the 6000 Hz scale, and then again for high frequency vocalizations (beluga whales) that would be partially missed at the 3000 Hz scale. All of the species that we identified in the acoustic data are easily differentiated (Fig. 2). Bowhead whales produce low frequency (50–400 Hz) moans that last between 0.5 and 2 s (Cummings and Holliday, 1987; Stafford and Clark, 2021). Beluga whales produce a wide range of higher frequency (0.5–16 kHz) whistles and pulsed calls (Chmelnitsky and Ferguson, 2012; Panova et al., 2019), as well as echolocation clicks that can be seen below 20 kHz (Jones et al., 2022a); note that although echolocation clicks would be detectable for very close belugas in our data, we focused on social calls (whistles and pulsed calls). Bearded seals make long (> 10 s, sometimes > 60 s) trills, sweeps, ascents, and moans that range from 50 Hz to > 6 kHz (Cleator et al., 1989; Risch et al., 2007; Frouin-Mouy et al., 2016; Heimrich et al., 2021). Ringed seals produce short (0.2–1 s), low frequency (50–400 Hz) barks and short mid frequency (500–2500 Hz) yelps (Stirling, 1973; Mizuguchi et al., 2016). Arctic cod make short (0.5–1 s) low frequency (50–200 Hz) grunts (Riera et al., 2018). Other fish in the region also likely make vocalizations, but these have not yet been described in a scientific study, which currently makes it impossible to identify fish calls to the species level (Pine et al., 2020). However, a large proportion of fish are likely soniferous (Looby et al., 2022), so there are several other candidate species in the region that might vocalize. For example, other gadids in the region, including polar cod (*Arctogadus glacialis*) and Greenland cod (*Gadus ogac*), likely vocalize. Sculpins, such as Arctic sculpin (*Myoxocephalus scorpioides*), also likely vocalize.

We also processed the acoustic data with an automated detector and classifier for signals by bowhead whales, beluga whales, and bearded seals (Spectro Detector, JASCO Applied Sciences Ltd., Victoria, British Columbia, Canada; Mouy et al., 2013). This detector has been extensively used in studies of these species in the Beaufort, Chukchi, and Labrador Seas (Hannay et al., 2013; Halliday et al., 2018a, 2019, 2020b; Booy et al., 2021). We did not use results from the detector as a final metric of species presence, but rather used the detector to guide our manual analysis. We compared seasonal trends between the detector and manual analysis of 10% of the data, and if there were any obvious anomalies in the detector results (e.g., species present that the manual results missed), we completed additional manual analysis of individual files where the detector found a species of interest. For example, based on our manual analysis of 10% of the data, bowhead whales were not present in the data after June, yet the detector found bowhead whales on 17 days in July and 2 days in August. We therefore investigated files during July and August where the detector noted bowhead whales. When investigating files noted by the detector that we had not previously analyzed, we also annotated all species present in that file. Our final manual results are therefore the combination of a systematic analysis of 10% of the data plus other files identified by the detector that were missed by the systematic analysis. We only present the results from the manual analysis for this study. However, we still quantified the performance of the detector by calculating precision and recall of the detector by comparing detector results to manual analysis results. Precision is defined as:

$$\text{Precision} = \frac{\text{True Positives}}{(\text{True Positives} + \text{False Positives})}$$

and recall is defined as:

$$\text{Recall} = \frac{\text{True Positives}}{(\text{True Positives} + \text{False Negatives})}$$

where the number of true positives, false positives, and false negatives is based on the presence or absence of the target species for each 5 min file, and by only considering detections with a confidence of classification above 70%.

Vessel Noise Analysis

We manually reviewed every file between 1 July 2019 and the last day of the deployment (8 September 2019), which is the ice-free period and a few days before ice breakup, for the presence of vessel noise. We identified vessel noise based on the presence of long, continuous flat tonal signals below 1 kHz, as well as increased sound pressure level (SPL) and broadband signals, which are indicative of close approaching vessels (Fig. 2). This type of analysis has been used previously and is effective at detecting both small community vessels and larger vessels such as cruise ships, tugboats, and research vessels (Halliday et al., 2020b). Spectrogram settings were identical to the bioacoustic analysis, except frequency scale was set to 3000 Hz and time scale was set to 300 s (the length of the file). We also examined satellite automatic identification system (AIS) vessel tracking data (exactEarth Ltd., Cambridge, Ontario, Canada) to determine which vessels with AIS signals were within Minto Inlet during the deployment and confirmed that those vessels correlated with an acoustic detection of vessel noise.

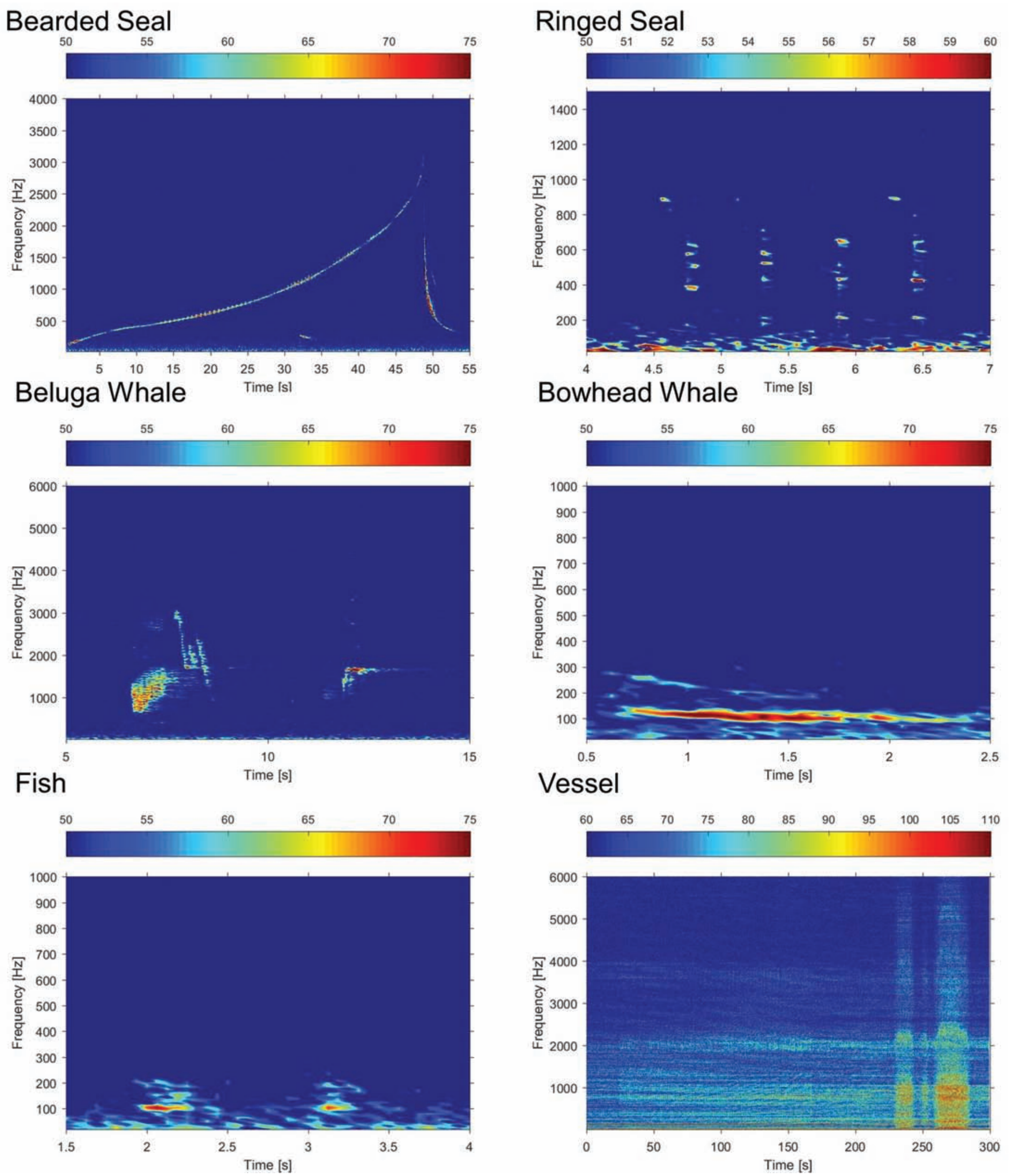

FIG. 2. Example spectrograms showing vocalizations of bearded seals (*Erignathus barbatus*), ringed seals (*Pusa hispida*), beluga whales (*Delphinapterus leucas*), bowhead whales (*Balaena mysticetus*), and fish. The bottom right panel shows one of the few examples of vessel noise in this dataset. Spectrograms were built using a Hann window with 50% overlap and a window size with 3000 samples for all marine animal vocalizations and with 12,000 samples for vessel noise. Note that the scales of the frequency and time axes and colour bar vary between panels. The colour bar represents power spectral density (dB re 1 μPa^2/Hz).

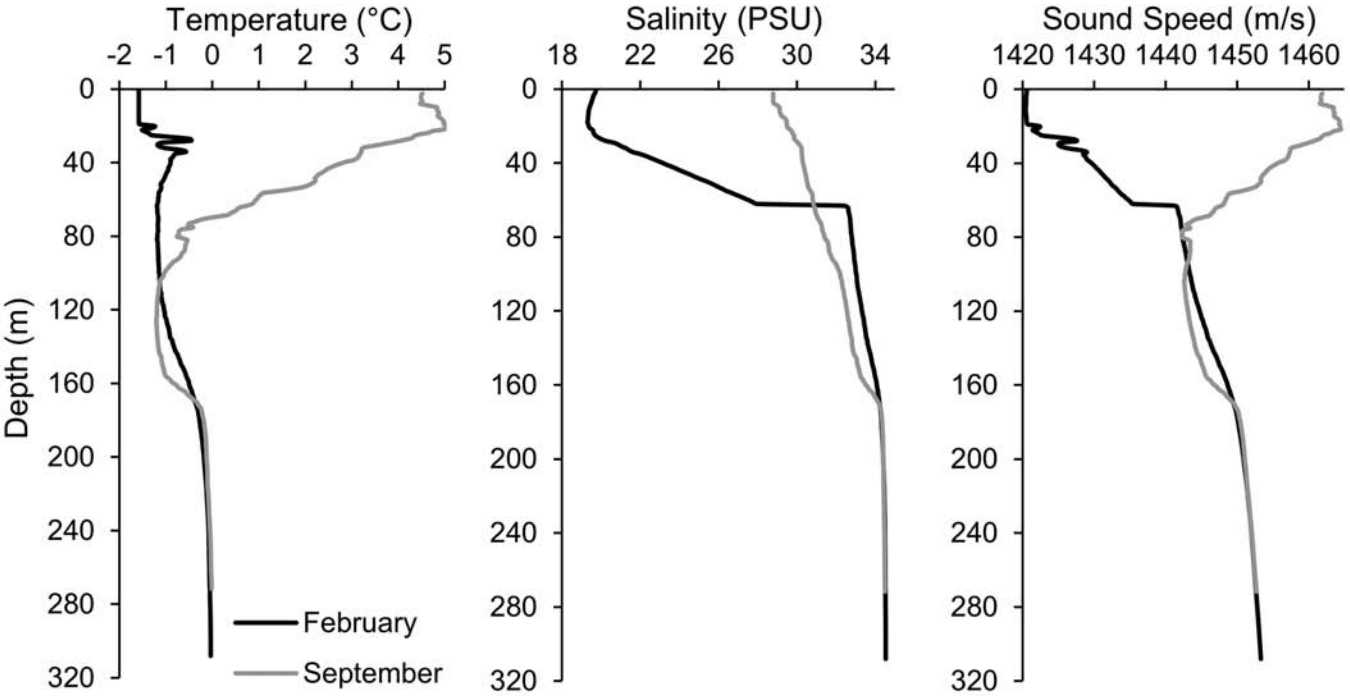

FIG. 3. Temperature and salinity CTD measurements taken near the mooring location in February and September 2019 and the estimated sound speed profile based on these measurements.

Acoustic Data Processing

We measured underwater sound levels by calculating SPL and power spectral densities (PSD) in the acoustic data using the PAMGuide package (Merchant et al., 2015) in Matlab (version 2017a; MathWorks, Natick, Massachusetts, USA) and calibrated the measurements based on the end-to-end sensitivity of the recording unit provided by the manufacturer. For PSD, we processed data in 1 Hz by 1 s windows using a Hann window with 50% overlap and calculated 60 s averages (5 measurements per file). We measured SPL in three separate frequency bands: low (20 – 1000 Hz), mid (1 – 10 kHz), and high (10 – 24 kHz). We similarly used a Hann window with 1 s windows and 50% overlap to calculate SPL, but calculated a 5 min average for each acoustic file.

Statistical Analyses

To examine monthly trends in occurrence for each species, we used linear models in R (R Core Team, 2019), with the proportion of files examined per day (based on the manual bioacoustic analysis) and with a species present as the dependent variable and with month as the independent, categorical variable. The month of September was not included in any of these analyses because there were only eight days of data from that month. All assumptions of linear models (e.g., normality of variance, homoscedasticity of residuals) were examined, and the models met all assumptions.

We assessed the influence of environmental variables (wind speed, air temperature, and sea ice) and biological signals on SPL in all three frequency bands (with separate models for each band) using linear mixed-effects models in R (Bates et al., 2015). SPL was the dependent variable. Wind speed, air temperature, ice concentration (categorical: solid ice, broken ice, open water), and the two-way interactions between ice concentration and both temperature and wind speed were fixed effects, and day was a random effect. We built additional models that added in the counts of bearded seal, bowhead whale, and beluga whale vocalizations from the automated detector as fixed effects. Hourly wind speed and air temperature data were obtained from the weather station at the Ulukhaktok Airport (ECCC, 2018). We examined ice conditions in Minto Inlet on NASA Worldview (NASA, 2021) to determine the date that ice began to break up and the day that all ice was gone from the inlet. We compared different candidate models using Akaike's information criterion (AIC) and selected the model with the lowest AIC score as the best model. Our SPL and bioacoustic data are available at the Polar Data Catalogue (Halliday et al., 2022).

RESULTS

Oceanographic Patterns

CTD profiles identify that the moored equipment (sitting near the bottom at ~315 m depth) was situated within the Atlantic water layer of the Amundsen Gulf with temperature and salinity varying little between February and September (Fig. 3). In February there was a distinct surface layer suggesting the accumulation of river water under the sea ice. The freshened layer overlies warmed summer surface waters and the Pacific halocline extending downward to 170 m. The moored CTD data from the Atlantic layer show a distinct warming of –0.04 and 0.01 variability in salinity, which began before the ice broke up in Minto Inlet (Fig. 4).

The seasonal differences in temperature and salinity between February and September led to nearly opposite sound speed profiles, with lower sound speed at shallow depths in February versus higher sound speeds in shallow depths in September (Fig. 3). What remains consistent between these two periods is that between 20 and 60 m, sound speed transitioned quickly towards the more stable profile seen in deeper waters. This zone of quick transition between 20 and 60 m likely leads to large amounts of refraction of acoustic signals around that depth.

Seasonal Trends in Bioacoustic Signals

All four species of marine mammals (bearded seal, ringed seal, beluga whale, and bowhead whale) and unknown fish species (likely Arctic cod or other gadids) were detected in the passive acoustic data, although fish were rare (Fig. 5). Bearded seals showed a very strong seasonal trend, with vocalizations beginning in mid-March, peaking between mid-May and late June, and then completely disappearing as the ice broke up just after 4 July 2019. Ringed seals were detected very consistently, although at low levels, throughout the recording period, with multiple detections every month. Beluga whales were detected once in late May, two times in late June, but then showed a very strong and sudden appearance in early July as the ice broke up and remained present on every day in July after that. Beluga whales were also present throughout August, although at lower levels than during July; belugas were completely absent on 7 days in August but were only absent on one day in July. Fish were detected on 21 days throughout the deployment, spread between February and July. Bowhead whales were detected on 52 days in April through August, although the majority of these were in May to July. For comparison, bearded seals were detected on 75 days, ringed seals on 95 days, and beluga whales on 55 days.

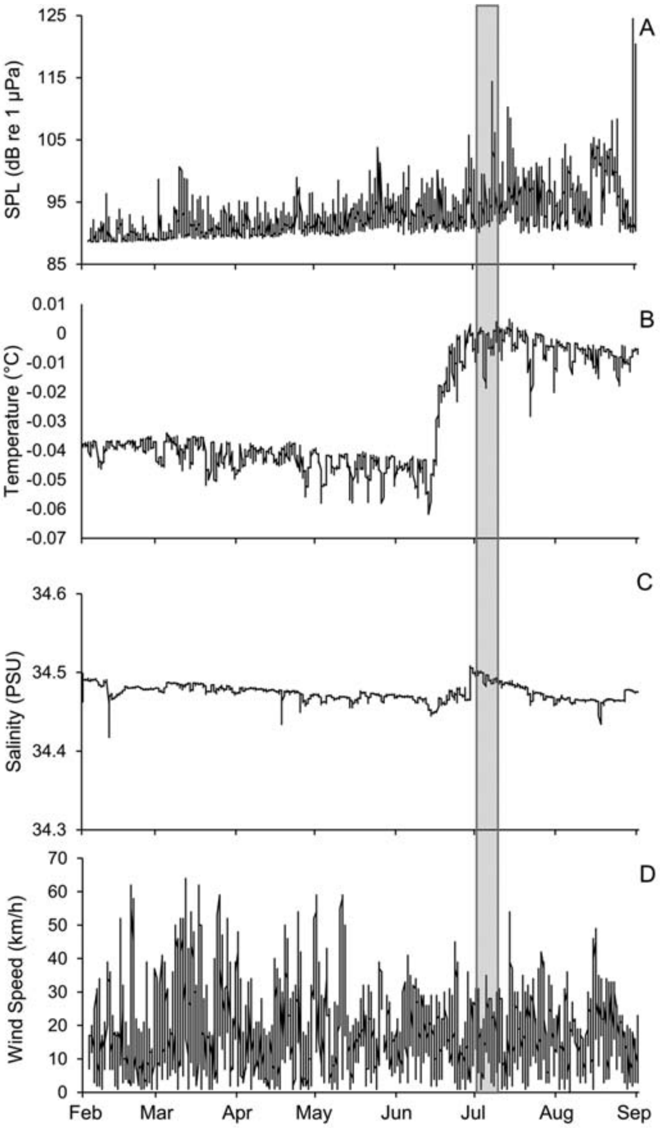

FIG. 4. Time series of sound pressure level (A: SPL; 20 Hz to 24 kHz; one 5 min average/h), temperature (B: one measurement per 2.5 h), and salinity (C: one measurement per 2.5 h) measured in situ at the oceanographic mooring, and hourly wind speed measured at the Ulukhaktok airport (D). The period of ice breakup in Minto Inlet is shown as the vertical grey box across all panels.

The statistical analysis demonstrated that peak bearded seal acoustic occurrence was in June (t_{148} = 15.06, $p > 0.0001$), followed by May (t_{148} = 3.77, $p > 0.001$), then April (t_{148} = 7.11, $p > 0.0001$), and with low levels of occurrence in July (t_{148} = 8.41, $p > 0.0001$) and March (t_{148} = 10.59, $p > 0.0001$; model R^2_{adj} = 0.47, $p < 0.0001$). No bearded seals were present in February and August, so these months were excluded from the analysis. Beluga whales had peak occurrence in July (t_{89} = 12.73, $p > 0.0001$), followed closely by August (t_{89} = 3.91, $p > 0.001$), with nearly no occurrence in June (t_{89} = 8.81, $p > 0.0001$, model R^2_{adj} = 0.45, $p < 0.0001$). February to April were not included in this analysis because no belugas were present in those months, and because May only had a single day where belugas were detected. Ringed seal presence was highest in May to August (t_{202} = 6.06, $p > 0.0001$), low in March (t_{202} = 2.30, p = 0.02) and April (t_{202} = 2.62, $p > 0.01$), and nearly absent in February (t_{202} = 3.79, $p > 0.001$; model R^2_{adj} = 0.09, $p < 0.001$). Bowhead whale daily occurrence peaked in June (t_{148} = 9.36, $p < 0.0001$), was intermediate in May (t_{148} = 3.16, $p < 0.01$) and July (t_{148} = 4.29, $p < 0.0001$), and was low in April (t_{148} = 5.94, $p < 0.0001$) and August (t_{148} = 5.71, $p < 0.0001$; model R^2_{adj} = 0.22, $p < 0.0001$). February and March were excluded from the bowhead analysis since bowheads were absent from these months. Fish occurrence peaked in May (t_{172} = 4.75, $p < 0.0001$) and June (t_{172} = 2.48, p = 0.01), and was low in February (t_{172} = 2.00, p = 0.047), March (t_{172} = 2.60, p = 0.01), April (t_{172} = 2.82, $p < 0.01$),

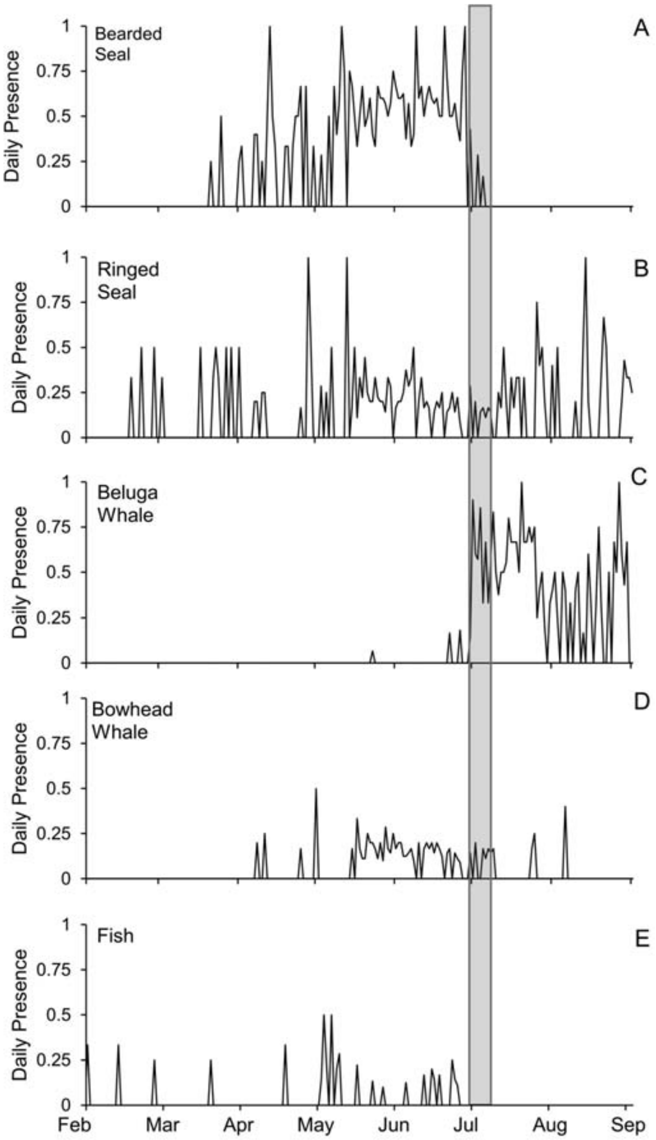

FIG. 5. Time series of species detections based on the presence of vocalizations in the acoustic data. Daily presence is measured as the proportion of files manually analyzed per day with at least one vocalization present for a species. (A) Bearded seal (*Erignathus barbatus*), (B) ringed seal (*Pusa hispida*), (C) beluga whale (*Delphinapterus leucas*), (D) bowhead whale (*Balaena mysticetus*), and (E) fish. The period of ice breakup in Minto Inlet is shown as the vertical grey box across all panels. Tick marks correspond to the 8th day of the month.

and July ($t_{172} = 2.97$, $p < 0.01$; model $R^2_{adj} = 0.04$, $p = 0.03$). August was excluded from this analysis because no fish were detected.

The automated detector had a precision of 0.77 and recall of 0.89 for bowheads, precision of 0.50 and recall of 0.77 for beluga, and precision of 0.90 and recall of 0.83 for bearded seals.

Trawl Catches

TABLE 1. Catch-per-unit-effort (CPUE; number fish/km^2) of species caught during trawls in Minto Inlet during 2017, 2018, and 2019.

Family	Species	2017	2018	2019
Agonidae	*Aspidophoroides olrikii*	6.9	12.7	0
	Leptagonus decagonus	13.8	57.3	27.7
Cottidae	*Artediellus atlanticus*	41.4	0	9.2
	Gymnocanthus tricuspis	0	0	9.2
	Icelus bicornis	6.9	31.8	0
	Triglops sp.	0	0	9.2
	Triglops nybelini	151.7	6.4	46.2
	Triglops pingelii	0	0	9.2
Gadidae	*Boreogadus saida*	28,455.2	10,242.8	3843.8
Liparidae	*Careproctus reinhardti*	27.6	70.1	110.9
	Liparidae sp.	6.9	0	0
	Liparis bathyarcticus	27.6	0	0
	Liparis fabricii	41.4	6.4	0
	Liparis tunicatus	0	0	18.5
Rajidae	*Amblyraja hyperborea*	13.8	0	0
Stichaeidae	*Anisarchus medius*	13.8	0	0
	Leptoclinus maculatus	117.2	127.4	9.2
Zoarcidae	*Lycodes marisalbi*	68.9	12.7	55.4
	Lycodes seminudus	55.2	19.1	18.5

Trawl catches from 2019 indicated that Arctic cod was the most abundant fish (CPUE = 3843.8) in the habitat surrounding the mooring and was the only gadid captured (Table 1). Other prevalent species in 2019 included sea tadpole (*Careproctus reinhardti*, CPUE = 110.9), White Sea eelpout (*Lycodes marisalbi*, CPUE = 55.4), and bigeye sculpin (*Triglops nybelini*, CPUE = 46.2). The CPUE of Arctic cod was relatively low in 2019 compared to the two previous summers, and fish community structure also varied among year (Table 1).

Boat Noise Detections

Only a single vessel with an AIS signal came into Minto Inlet during the deployment, and this was RV *Frosti* that recovered the mooring. The only vessel noise signals detected in the dataset were during the last three days of the deployment, and all likely belonged to the research vessel; no signals from small community boats were detected before this point. This vessel was also responsible for the largest spike in broadband (20 Hz to 24 kHz) SPL throughout the deployment (124.5 dB re 1 μPa), and this was on the day before recovery when the vessel was conducting research in Minto Inlet.

Seasonal Trends in Underwater Sound Levels

PSD (measured in dB re 1 μPa^2/Hz) did not vary in the 1st or 5th percentiles across any season, which were all at or near the noise floor of the recorder (Fig. 6). The median PSD was just above the noise floor in winter (February–March) and spring (April–June) but was 5–10 dB re 1 μPa^2/Hz above the noise floor in summer (July–September) at between 100 Hz and 20 kHz. The root mean squared (RMS) PSD and 95th and 99th percentiles were all well above the median values in each season, but with different patterns in each season. In winter, RMS and the upper percentiles stayed relatively flat between 200 Hz and 20 kHz and remained around roughly 50, 55, and 60 dB re 1 μPa^2/Hz,

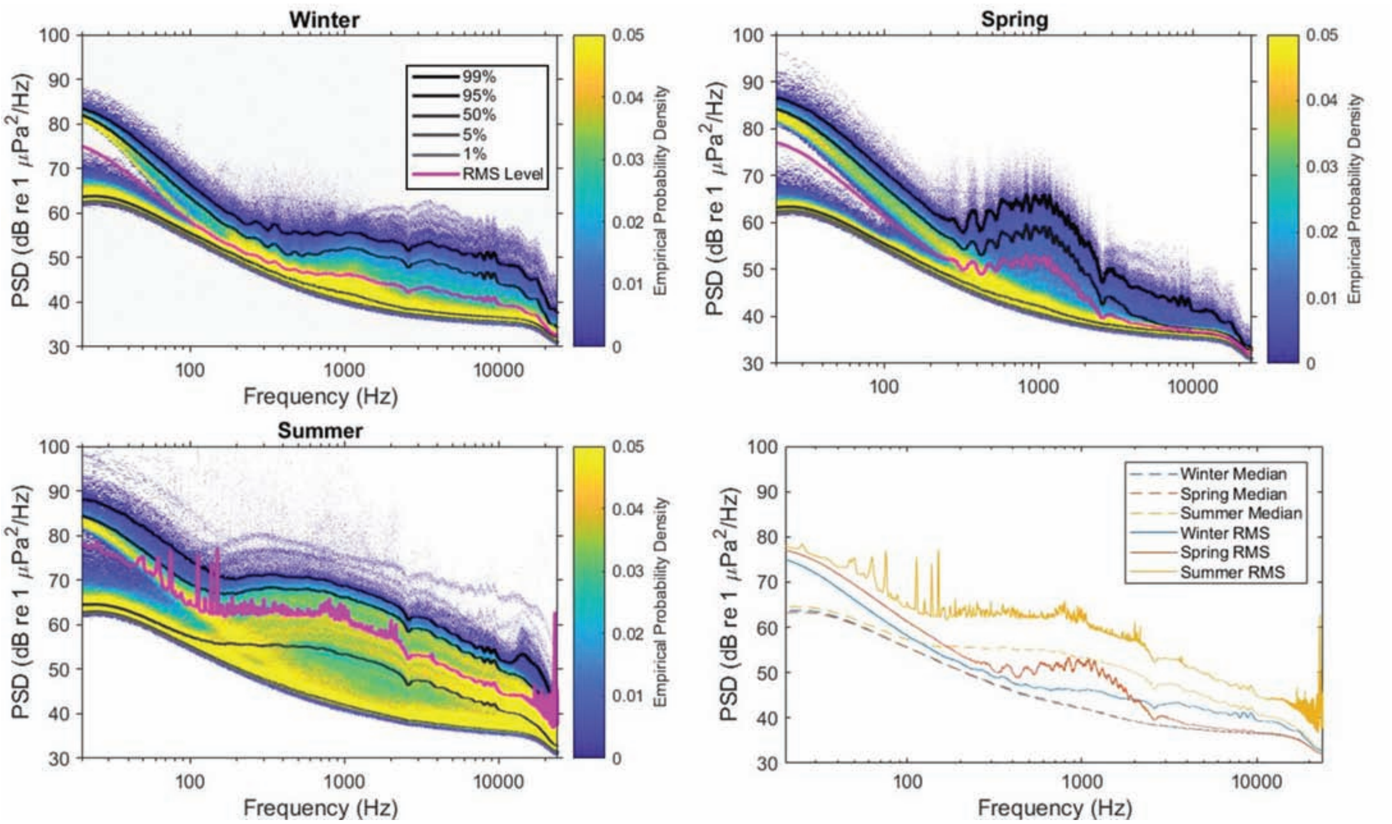

FIG. 6. Power spectral densities (PSD) for winter (February–March), spring (April–June), summer (July–September), and a comparison of median and root mean squared (RMS) PSD for each season. The colours in the winter, spring, and summer panels are the empirical probability density.

respectively. In spring, there was a clear hump in RMS and the upper percentiles between 300 and 1200 Hz, raising levels to a maximum of 55 dB re 1 μPa²/Hz for RMS, 60 dB re 1 μPa²/Hz for the 95th percentile, and 65 dB re 1 μPa²/Hz for the 99th percentile within this range. This hump in PSD in the spring seems related to bearded seal vocalizations. In the summer, the RMS and upper percentiles remained relatively flat between 100 and 1100 Hz, with the RMS at 65 dB re 1 μPa²/Hz, 95th percentile at 70 dB re 1 μPa²/Hz, and the 99th percentile at around 73 dB re 1 μPa²/Hz. The RMS also contained multiple spikes between 40 and 1200 Hz, which were caused by the few files with vessel noise (see *Boat Noise Detections*).

SPL (measured in dB re 1 μPa) in the 20 Hz to 24 kHz band varied between 87 and 100 dB re 1 μPa in February through June, but during ice breakup in July and through the rest of the deployment into early September, SPL began varying much more, ranging between 87 and 115 dB re 1 μPa in the absence of vessel noise, but up to 124 dB re 1 μPa when vessel noise was present (Fig. 4).

Drivers of Underwater Sound Levels

Ice cover was an important driver of underwater sound levels. Landfast ice covered Minto Inlet from our deployment date in February until 4 July 2019, then broke up over the following 18 days, and the inlet was completely free of ice from 22 July 2019 until recovery of the mooring in September. When comparing the solid ice, broken ice, and open water periods, while accounting for variation in wind speed, the solid ice period had the lowest SPL in all three frequency bands (Tables 2,3), whereas the broken ice and open water periods both had significantly higher SPL than the solid ice period but were not significantly different than each other in all three frequency bands.

Wind speed had a significant, positive effect on SPL during the open water period in all three frequency bands (low frequency: slope ± SE = 0.03 ± 0.01 dB re 1 μPa/km/h; mid frequency: 0.08 ± 0.02 dB re 1 μPa/km/h; high frequency: 0.03 ± 0.01 dB re 1 μPa/km/h; Table 2), whereas during the solid ice period, there was only a significant, positive effect in the high frequency band (Table 2). During the broken ice period, wind speed had a negative effect on SPL in the low frequency band, no significant effect in the mid frequency band, and a positive effect in the high frequency band (Table 2).

Air temperature was positively correlated with SPL in the low (slope = 0.04 ± 0.01 dB re 1 μPa/°C, $t_{1539} = 4.38$, $p < 0.0001$) and mid frequency bands (0.06 ± 0.02 dB re 1 μPa/°C, $t_{1834} = 4.59$, $p < 0.0001$) but not in the high frequency band ($p < 0.05$; Table 2).

Bioacoustic signals only had one significant, positive effect on SPL; in the mid frequency band, the automated count of bearded seal vocalizations was positively correlated with SPL (slope = 0.14 ± 0.02 dB re 1 μPa/bearded seal call, $t_{4954} = 6.23$, $p < 0.0001$). This result

TABLE 2. Final model outputs of linear mixed-effect models examining the effects of wind speed, temperature, ice category, and counts of marine mammal vocalizations on sound pressure level (SPL) in the low (20–1000 Hz), mid (1–10 kHz), and high frequency bands (10–24 kHz). The “broken ice” category for the variable “ice” is included in the intercept and in the wind space coefficient in models where the interaction between ice and wind is included.

Parameter	Estimate ± SE	*t*	*p*
Low frequency (20–1000 Hz)			
Intercept	93.65 ± 0.47	200.45	< 0.0001
Ice: Open water	0.05 ± 0.54	0.10	0.92
Ice: Solid	−3.06 ± 0.51	5.99	< 0.0001
Wind speed	0.03 ± 0.01	2.14	0.03
Temperature	0.04 ± 0.01	4.38	< 0.0001
Ice (open water): Wind speed	0.05 ± 0.01	3.41	< 0.001
Ice (solid): Wind speed	0.03 ± 0.01	2.34	0.02
Mid frequency (1–10 kHz)			
Intercept	86.28 ± 0.89	96.67	< 0.0001
Ice: Open water	1.73 ± 1.04	1.66	0.10
Ice: Solid	−5.26 ± 0.97	5.39	< 0.0001
Wind speed	0.005 ± 0.02	0.23	0.82
Temperature	0.08 ± 0.02	3.79	< 0.001
Beluga whale count	−0.04 ± 0.01	3.98	< 0.0001
Bearded seal count	0.14 ± 0.02	6.23	< 0.0001
Ice (open water): Wind speed	0.07 ± 0.02	3.02	< 0.01
Ice (solid): Wind speed	0.02 ± 0.02	1.12	0.26
High frequency (10–24 kHz)			
Intercept	82.15 ± 0.45	184.46	< 0.0001
Ice: Open water	0.12 ± 0.51	0.24	0.81
Ice: Solid	−3.91 ± 0.47	8.37	< 0.0001
Wind speed	0.03 ± 0.01	7.50	< 0.0001
Beluga whale count	−0.04 ± 0.01	5.89	< 0.0001

TABLE 3. Predictive equations for sound pressure level in each frequency band and ice category built from the statistical model outputs in Table 2.

Frequency	Ice category	Predictive equation
20 – 1000 Hz	Broken	SPL = 93.65 – 0.02 × Wind Speed + 0.04 × Temperature
	Open	SPL = 93.60 + 0.03 × Wind Speed + 0.04 × Temperature
	Solid	SPL = 90.59 + 0.01 × Wind Speed + 0.04 × Temperature
1 – 10 kHz	Broken	SPL = 86.28 + 0.005 × Wind Speed + 0.06 × Temperature – 0.04 × Beluga Count + 0.14 × Bearded Seal Count
	Open	SPL = 88.01 + 0.075 x Wind Speed + 0.06 × Temperature – 0.04 × Beluga Count + 0.14 × Bearded Seal Count
	Solid	SPL = 81.02 + 0.025 × Wind Speed + 0.06 × Temperature – 0.04 × Beluga Count + 0.14 × Bearded Seal Count
10 – 24 kHz	Broken	SPL = 82.15 + 0.03 × Wind Speed – 0.04 × Beluga Count
	Open	SPL = 82.27 + 0.03 × Wind Speed – 0.04 × Beluga Count
	Solid	SPL = 78.24 + 0.03 × Wind Speed – 0.04 × Beluga Count

corroborates our interpretation of the PSD plot (Fig. 6), where during the spring season, there was a strong peak in PSD that we assumed was related to bearded seal vocalizations. Adding bioacoustic signals into the low frequency model resulted in a poorer-fitting model based on AIC, and beluga vocalizations were included in both the mid and high frequency model, but they had a negative correlation with SPL, which is indicative of a masking effect rather than cause and effect. In other words, beluga signals were more likely to be detected when SPL was low because it is easier to detect these signals under low background sound levels.

DISCUSSION

Our study demonstrates that Minto Inlet is occupied by ringed seals at least from February through September, bearded seals are vocally active between March and early July, and beluga whales use the inlet frequently during the ice-free season. We also identified several fish vocalizations, and trawl results demonstrate that Arctic cod are the main fish species found at this site. These results corroborate the importance of this site for all of these species, as laid out in the *Beaufort Sea Beluga Management Plan* (Fisheries Joint Management Committee, 2013) and in the *Olokhaktomiut Community Conservation Plan* (Olokhaktomiut Hunters and Trappers Committee et al., 2016). Our results also demonstrate that Minto Inlet has underwater sound levels that are lower, on average, than any that we have previously recorded in the Inuvialuit Settlement Region (ISR; Kinda et al., 2013; Insley et al., 2017; Halliday et al., 2020b, c) and among the lowest measured across the entire Canadian Arctic based on a recent analysis of archived data, particularly during the open water season (Halliday et al., 2021). These low underwater sound levels are related to at least two factors: first, there was almost no anthropogenic noise recorded at this site other than by the vessel recovering the mooring; and second, the effects of wind and wave action are limited because of the deep water (> 300 m), the relatively long period that landfast ice remains intact, and isolation from the open, exposed waters of the Amundsen Gulf. These low sound levels make Minto Inlet a nearly pristine soundscape for the soniferous animals that live there or pass through. It also makes for better detection of biological signals such as the pronounced effect of bearded seal vocalizations on PSDs (Fig. 6). Presumably other narrow inlets and fjords across the Canadian Arctic have similarly low underwater sound levels if they are rarely visited by vessel traffic. Although sound levels were very low in our study, including only minimal anthropogenic noise, sound levels did rise very quickly when the research vessel was present to recover the mooring, which means that increased anthropogenic activity will lead to higher underwater sound levels, and consequently, a potentially greater relative impact. Keeping unnecessary anthropogenic activity out of Minto Inlet will help to preserve this soundscape for the many species that inhabit it.

Our study used only seven months of data from a single site in Minto Inlet. Given that sounds travel efficiently underwater and many types of signals can be detected from far away, such as marine mammal vocalizations and underwater noise from vessels, we are confident that sampling at a different site within the inlet would have yielded similar results for these types of signals. More locally specific signals like fish vocalizations might have varied more by site. However, we did miss sampling within the September to January portion of the year, which means that we missed the migration of whales away from this site and any changes that might have happened with seals and fish during this period, such as the onset of bearded seal vocalizations in the autumn. The addition of more years of data would also help establish a better baseline in terms of the seasonality of different signals. As with many Arctic studies during this time frame, we were limited by a combination of resources and the COVID-19 pandemic to continue monitoring at this site. However, we still believe that this seven-month dataset is valuable in highlighting the importance of Minto Inlet, and our results show multiple unique characteristics that have not been thoroughly described in the literature. One example is the influence of bearded seal vocalizations on underwater sound levels, which is very clearly shown in the spring power spectral density plot (Fig. 6). Another example is the clear onset of belugas using Minto Inlet as the ice started to break up in July. Finally, possibly the most unique aspect of our study is being able to link the presence of fish vocalizations with the abundance of different fish species using Minto Inlet, which has never been done for studies of fish vocalizations in the Arctic.

Biological Patterns

Ringed seals were present in Minto Inlet throughout our entire data collection period, from February to September. This finding is similar to other passive acoustic studies from near Ulukhaktok and elsewhere in the region, where ringed seals can generally be detected year round (Halliday et al., 2018a, 2019, 2020b). The *Olokhaktomiut Community Conservation Plan* outlined that Minto Inlet was good habitat for ringed seals when ice was present, at which time they were seen hauling out on the ice and where lairs were observed (Olokhaktomiut Hunters and Trappers Committee et al., 2016). However, our data also suggest that ringed seals continue to use Minto Inlet during open water, which further supports it as an important site for this species. The year-round detections indicate that ringed seals are well adapted to the observed seasonal changes in water column structure.

We detected bearded seals vocalizations between March and early July, with peak vocalizations in May and June. These patterns of peak vocalizations match other studies (MacIntyre et al., 2013; Halliday et al., 2018a) and generally reflect the timing of the mating season for this species. Two patterns stand out with the bearded seal results from our study. First, we did not detect any bearded seals in February, which suggests that male bearded seals did not set up territories and vocalize from then until March in Minto Inlet. This finding stands out because other datasets with bearded seals show vocalizations occurring much earlier, typically right after ice formation in the autumn (MacIntyre et al., 2013; Jones et al., 2014; Halliday et al., 2018a, 2019, 2020b). Bearded seals also vocalized much earlier near Ulukhaktok, just 40 km south, that same year (Halliday, unpubl. data). Second, bearded seals vocalized in Minto Inlet right up until the ice broke up in early July but stopped immediately afterward. Studies in other sites in the Pacific Arctic have shown bearded seals continuing to vocalize after ice breakup (MacIntyre et al., 2015; Halliday et al., 2018a). However, those sites were all exposed to open waters such as the Amundsen Gulf and Beaufort Sea, where ice breakup occurred much earlier (April–May) and pack ice continued to persist in the area for many weeks afterwards. Conversely, Minto Inlet maintained its landfast ice until early July, and when breakup occurred, all ice disappeared over a two-week period; the neighbouring Amundsen Gulf was already ice-free at that point. Some studies have hypothesized that bearded seals follow the pack ice in the summer and only vocalize when around ice (MacIntyre et al., 2015). The sudden loss of ice in Minto Inlet in early July is therefore a likely candidate for why bearded seals stopped vocalizing so abruptly and is suggestive but not conclusive evidence that they were then absent from the inlet for the remainder of the deployment.

Bowhead whales were only detected sporadically between April and August, and none of these detections were particularly close based on the low signal-to-noise ratio (roughly < 6 dB) of the calls. This suggests that bowhead whales were not really entering Minto Inlet, but we were likely detecting their vocalizations from the adjacent Amundsen Gulf when their calls managed to propagate into the inlet, for example, such as when a bowhead was near the mouth of the inlet. A quick propagation loss calculation using spherical spreading ($20\log_{10}R$) and accounting for frequency-dependent absorption (Ainslie and McColm, 1998), using a bowhead whale call source level of 150 dB re 1 μPa at 1 m (Thode et al., 2020) at a frequency of 150 Hz, and based on median PSD value at 150 Hz being roughly 60 dB re 1 $\mu Pa^2/Hz$ in summer and 55 dB re 1 $\mu Pa^2/Hz$ in spring (Fig. 6), shows bowhead whales could be detected from 31 km away from the acoustic recorder in summer and 55 km away in spring. However, this simple calculation does not take the impacts of sea ice into consideration, and a recent modeling study suggests that sea ice causes increased propagation loss for bowhead whale calls (Jones et al., 2022b). Therefore, the spring estimate is likely an overestimate. Even still, the estimated distances would mean that bowheads vocalizing from the mouth of Minto Inlet during the spring and summer could be detected by the recorder. Bowhead whales were detected in the Amundsen Gulf for the first time throughout the winter during 2018–19 at acoustic recorders near Ulukhaktok and in the southern Amundsen Gulf, and visually by community members near Ulukhaktok (Insley et al., 2021). Despite bowhead whales being present in the middle of winter near Ulukhaktok, we did not record any in Minto Inlet until April, which again suggests that bowhead whales were not entering the inlet and were likely spatially limited to areas with leads in the sea ice.

Beluga whales were almost constantly present in Minto Inlet between July and September. Minto Inlet is highlighted as an important site for belugas by the *Beaufort Sea Beluga Management Plan* (Fisheries Joint Management Committee, 2013), and our results confirm that belugas seem to use it regularly during the open water season. Before ice breakup in July, belugas were only detected three times, and these were all faint calls, suggesting that the belugas were farther from the acoustic recorder and closer to the entrance to Minto Inlet. Using the same calculation as above, but with a source level of beluga calls at 144 dB re 1 µPa at 1 m (Le Bot et al., 2016) and a whistle frequency of 2 kHz and the median summer and spring PSDs at roughly 55 dB re 1 μPa^2/Hz and 45 dB re 1 μPa^2/Hz respectively, belugas could be detected from 20 km away in summer and 45 km in spring. Again, the spring estimate is likely an overestimate due to the negative effects of sea ice on sound propagation (Jones et al., 2022b). Minto Inlet was covered in landfast ice until ice breakup, which would have made it largely inaccessible to belugas because of their need to reach the surface to breathe. Belugas have arrived in the Amundsen Gulf as early as April in recent years (Halliday et al., 2018a), so if ice breakup had occurred earlier in Minto Inlet, presumably belugas would have started using this site earlier.

Fish sounds were detected between February and July. These sounds can be attributed to Arctic cod given their numerical dominance in nearby trawl catches and the similarity in calls to Arctic cod sounds previously recorded (Riera et al., 2018). Other gadids that are common to the Beaufort Sea include Greenland cod and saffron cod (*Eleginus gracilis*), both of which are typically found in warmer coastal waters, and neither of which were captured during offshore trawl surveys near the mooring. However, vocalizations have not been described for any other species of Arctic marine fish, so it could also be some other unknown species producing these sounds. Other species that were prevalent in trawl catches near the mooring in 2019 included sea tadpole, White Sea eelpout, and bigeye sculpin, though none of these species are known to make vocalizations. The specific site where we deployed our recorder had a large aggregation of Arctic cod during the previous summer (Table 1), so it is quite possible that Arctic cod were also present under the ice through the winter, but had shifted their distribution prior to the mooring deployment. Arctic cod catches were lower in September 2019 relative to the previous two years, reflecting substantial year-to-year variability in the fish community at the mooring location. As far as we know, this is only the third study to publish detections of marine fish sounds in passive acoustic data from the Arctic (Halliday et al., 2020b; Pine et al., 2020), so much more work is required to identify patterns in fish sound detections and identify the sounds made by different species of Arctic fish. Fish also produce very low amplitude vocalizations that can only be detected over 10s or 100s of meters (Biggs and Erisman, 2021), therefore only fish vocalizing near the hydrophone would be detected. Thus, we would only expect to detect many fish vocalizations if the acoustic recorder was placed directly in a site with high fish density and if those fish were vocally active. Fish vocalizations are an important yet poorly studied component of the marine soundscape, particularly in the Arctic, and we encourage other researchers collecting passive acoustic data to start reporting on fish vocalizations identified in their data.

The occurrence of adult Arctic cod at mesopelagic depths in Minto Inlet, as occurs elsewhere in the Beaufort Sea (Geoffroy et al., 2016; Majewski et al., 2017), likely attracts predators including seals and beluga detected in this study. The CPUEs of Arctic cod in Minto Inlet are considerably higher than those reported at comparable depths on the Mackenzie Shelf slope (Majewski et al., 2017), indicating that in addition to a pristine soundscape, Minto Inlet has an abundant forage base for marine mammal predators. The deep Atlantic Ocean layer is important habitat for the larger adult Arctic cod in Amundsen Gulf and is accessed by diving marine mammals for feeding (Storrie et al., 2022). The observed water mass exchange in the Atlantic layer of Minto Inlet prior to ice-off identifies habitat connectivity between Amundsen Gulf and the deep trough of Minto Inlet. In addition to sea ice, the deep trough habitat is also a key feature of this important area for Ulukhaktok.

Soundscape Patterns

Previous studies have identified wind speed and ice concentration as the main drivers of natural underwater sound levels in the Arctic. Wind speed tends to have a positive effect on SPL, but solid ice tends to reduce the impact of wind speed on SPL, thus the ice-covered season tends to have lower SPL than the open water season (Roth et al., 2012; Insley et al., 2017; Halliday et al., 2020b, c, 2021; McKenna et al., 2021). Our results do demonstrate that both wind speed and sea ice are important drivers of sound levels in Minto Inlet, although the overall effect size for wind speed was much lower in our study compared to others, with positive statistically significant values ranging between 0.01 and 0.08 dB re 1 µPa/km/h, whereas previous studies have documented effect size above 0.40 dB re 1 µPa/km/h (Insley et al., 2017). The lower effect size for wind speed in our study might be caused by a combination of the deep water and the isolation of Minto Inlet (e.g., reduced fetch, nearby high elevation).

Air temperature had a positive correlation with underwater sound levels in the low (20 – 1000 Hz) and mid frequency (1 – 10 kHz) bands. The increased sound levels as temperatures increased might be related to sounds made by sea ice as it melts and cracks (Ganton and Milne, 1965). This trend was opposite of a recent study examining underwater sound levels across the Canadian Arctic, which found a negative correlation with air temperature (Halliday et al., 2021). The causal link between air temperature and underwater sound levels in the Arctic is under-studied, and more work needs to be done to examine the causes of these changes in sound level that correlate with changes in temperature.

An interesting result from our study was the pronounced impact of bearded seal vocalizations on underwater sound levels, as demonstrated by both the peaks in the spring PSD plot (Fig. 6) and the statistically significant effect in the mid frequency band. Although we have previously demonstrated that bearded seal vocalizations can cause increased underwater sound levels (Heimrich et al., 2021), this is the first time that we have noticed such a strong trend in PSDs. This pattern identified in our spring PSD plot can be useful for future studies for quickly examining patterns in PSDs and identifying the potential causes of those patterns.

Minto Inlet had very low levels of anthropogenic noise during our deployment, with the only noise detected being from the research vessel that recovered our mooring. The lack of other vessel noise is not due to bias in data processing. We manually viewed all of the spectrograms during the July to September open water period when other vessels would be present and found no other evidence of vessel noise. Minto Inlet is a popular site for subsistence hunting and fishing for the people of Ulukhaktok, and the main ways to access the site are by boat or all-terrain vehicle in the summer and by snow machine in the winter. We did not actively look for snow machine noise in the winter, but snow machine noise does not propagate very far through the ice and underwater (W. Halliday, pers. obs.), so snow machines would likely have to drive nearly right over top of the mooring site to cause spikes in underwater sound levels. Figure 6 does not show any spikes in RMS levels, so we assume that no snow machines were nearby during our recordings. One possibility for both snow machines and small local boats is that due to the low duty cycle of our acoustic recorder (5 min recording every hour), these vehicles could have traveled by our recording site during the 55 min that it was off every hour. Although Minto Inlet is a popular site, it is difficult to get to, so it is unlikely that there would have been many snow machines and small boats traveling close enough to our recorder to be detected even if the recorder was on when they passed by. To better assess the level of noise from snow machines and small boats, acoustic recorders could be set at multiple points throughout the inlet and could record continuously or at least more frequently than our recorder.

Oceanographic Patterns

There was little change in the oceanographic conditions of the deep water at our mooring site during our study. Salinity stayed consistent around 34.5 PSU, whereas temperature ranged from −0.06 to −0.04˚C between February and June, and then about two weeks before ice breakup, showed a sharp increase from −0.03 to 0˚C from July through September. These trends also match the CTD casts in February and September, which showed very little difference in both temperature and salinity at depth, especially when compared with much larger changes through time at the surface. This increase in deep water temperature before ice breakup in Minto Inlet is likely related to water entering the inlet from Amundsen Gulf. The CTD casts in February and September showed significant stratification in both temperature and salinity, leading to a sharp change in the sound speed profile between 20 and 60 m. This sharp change in sound speed may also lead to increased refraction of acoustic signals generated near the surface, therefore limiting their propagation to our recorder on the bottom. Given that we only have sound speed profiles for the start and end of our study, it is currently unknown what the sound speed profile was like throughout the deployment, which may be considerably different at times of transition such as during ice breakup.

CONCLUSIONS

Our study, which took place between February and September 2019, documented many vocalizations by bearded seals, ringed seals, and beluga whales, which suggest that this site is used frequently by these species possibly in response to an abundant forage base. Bowhead whales likely did not come into the inlet, and Arctic cod were also only sporadically detected, although the most abundant fish in the area. Minto Inlet had very low underwater sound levels throughout the deployment, and the only anthropogenic noise detected was from the research vessel that recovered the mooring. Since this area is of conservation value to the community of Ulukhaktok (Olokhaktomiut Hunters and Trappers Committee et al., 2016), continued monitoring should be conducted to track species presence and anthropogenic stressors. Year-round monitoring would allow for an estimation of the time that migratory belugas stop using the inlet in the autumn, and an expanded monitoring network would allow for a more complete assessment of the underwater noise created by community boats and snow machines traveling in the inlet, as well as detection of any vessels that are not tracked by AIS. For example, a recent study in the ISR showed that a small fraction of pleasure craft was broadcasting AIS signals (Halliday et al., 2018b). Based on the data collected in our study (seven months during a single year), there seems to be very little anthropogenic impact on Minto Inlet. Continued monitoring would allow detection of increased noise levels associated with more activity, and should that occur, appropriate management measures could be considered. Currently, however, there does not seem to be a need for further management of Minto Inlet.

ACKNOWLEDGEMENTS

Logistical support and funding were provided by the Polar Continental Shelf Program, and additional logistical support was provided by Fisheries and Oceans Canada, specifically Krystal Woodard and the Aurora Research Institute. We are extremely grateful to the captain and crew of the RV *Frosti* for recovering our mooring. Funding was provided by Fisheries and Oceans Canada, the Canada Nature Fund for Aquatic Species at Risk, and the Weston Family Foundation. Satellite AIS data were provided by MERIDIAN (Dalhousie University) through a partnership with exactEarth Ltd. (Cambridge, Ontario). This research was conducted under Aurora Research Institute License 16330 and was formally supported by the Inuvialuit Game Council and the Olokhaktomiut Hunters and Trappers Committee. We are also grateful to two anonymous reviewers and Michael Ladegaard for providing constructive reviews that strengthened this study. Lastly, our work would not have been possible, or even as pleasant, without the wonderful support of our hosts in Ulukhaktok, Robert and Agnes Kuptana, and our wildlife monitor, Ron Kallak, who joined us on the sea ice.

REFERENCES

Ainslie, M.A., and McColm, J.G. 1998. A simplified formula for viscous and chemical absorption in sea water. The Journal of the Acoustical Society of America 103(3):1671–1672.
https://doi.org/10.1121/1.421258

Atchison, S., Majewski, A.R., Morrison, C., Ouellette, M., Woodard, K., and Reist, J.D. 2022. Basic biological data from fish caught during the Beaufort Sea Marine Fishes Project (BSMFP), August and September 2012. Canadian Data Report of Fisheries and Aquatic Sciences 1303. Winnipeg: Freshwater Institute, Fisheries and Oceans Canada.
https://waves-vagues.dfo-mpo.gc.ca/Library/41028983.pdf

Au, W.W.L., and Hastings, M.C. 2008. Principles of marine bioacoustics. New York: Springer Science+Business Media, LLC.

Bates, D., Mächler, M., Bolker, B., and Walker, S. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67(1):1–48.
https://doi.org/10.18637/jss.v067.i01

Bedard, J. 2019. The role of variable oceanographic and environmental conditions on acoustic tracking effectiveness. PhD thesis, University of Victoria, Victoria, British Columbia.
http://hdl.handle.net/1828/11357

Biggs, C.R., and Erisman, B.E. 2021. Transmission loss of fish spawning vocalizations and the detection range of passive acoustic sampling in very shallow estuarine environments. Estuaries and Coasts 44:2026–2038.
https://doi.org/10.1007/s12237-021-00914-5

Blackwell, S.B., and Greene, C.R., Jr. 2006. Sounds from an oil production island in the Beaufort Sea in summer: Characteristics and contribution of vessels. The Journal of the Acoustical Society of America 119(1):182–196.
https://doi.org/10.1121/1.2140907

Bonnel, J., Kinda, G.B., and Zitterbart, D.P. 2021. Low-frequency ocean ambient noise on the Chukchi Shelf in the changing Arctic. The Journal of the Acoustical Society of America 149(6):4061–4072.
https://doi.org/10.1121/10.0005135

Booy, K.V., Mouy, X., Ferguson, S.H., and Marcoux, M. 2021. Spatio-temporal summer distribution of Cumberland Sound beluga whales (*Delphinapterus leucas*) in Clearwater Fiord, Nunavut, Canada. Arctic Science 7:394–412.
https://doi.org/10.1139/as-2019-0031

Chmelnitsky, E.G., and Ferguson, S.H. 2012. Beluga whale, *Delphinapterus leucas*, vocalizations from the Churchill River, Manitoba, Canada. Journal of the Acoustical Society of America 131(6):4821–4835.
https://doi.org/10.1121/1.4707501

Clark, C.W., Berchok, C.L., Blackwell, S.B., Hannay, D.E., Jones, J., Ponirakis, D., and Stafford, K.M. 2015. A year in the acoustic world of bowhead whales in the Bering, Chukchi and Beaufort Seas. Progress in Oceanography 136:223–240.
https://doi.org/10.1016/j.pocean.2015.05.007

Cleator, H.J., Stirling, I., and Smith, T.G. 1989. Underwater vocalizations of the bearded seal (*Erignathus barbatus*). Canadian Journal of Zoology 67:1900–1910.
https://doi.org/10.1139/z89-272

Cummings, W.C., and Holliday, D.V. 1987. Sounds and source levels from bowhead whales off Pt. Barrow, Alaska. The Journal of the Acoustical Society of America 82(3):814–821.
https://doi.org/10.1121/1.395279

Deane, G.B., Glowacki, O., Tegowski, J., Moskalik, M., and Blondel, P. 2014. Directionality of the ambient noise field in an Arctic, glacial bay. The Journal of the Acoustical Society of America 136(5):EL350–EL356.
https://doi.org/10.1121/1.4897354

ECCC (Environment and Climate Change Canada). 2018. Historical climate data.
https://climate.weather.gc.ca/index_e.html

Fisheries Joint Management Committee. 2013. Beaufort Sea beluga management plan, 4th amended printing. Inuvik, Northwest Territories.
https://www.beaufortseapartnership.ca/wp-content/uploads/2015/04/Beaufort-Sea-Beluga-Management-Plan-2013.pdf

Frouin-Mouy, H., Mouy, X., Martin, B., and Hannay, D. 2016. Underwater acoustic behavior of bearded seals (*Erignathus barbatus*) in the northeastern Chukchi Sea, 2007–2010. Marine Mammal Science 32(1):141–160.
https://doi.org/10.1111/mms.12246

Ganton, J.H., and Milne, A.R. 1965. Temperature- and wind-dependent ambient noise under midwinter pack ice. The Journal of the Acoustical Society of America 38(3):406–411.
https://doi.org/10.1121/1.1909697

Geoffroy, M., Majewski, A., LeBlanc, M., Gauthier, S., Walkusz, W., Reist, J.D., and Fortier, L. 2016. Vertical segregation of age-0 and age-1+ polar cod (*Boreogadus saida*) over the annual cycle in the Canadian Beaufort Sea. Polar Biology 39:1023–1037.
https://doi.org/10.1007/s00300-015-1811-z

Guerra, M., Thode, A.M., Blackwell, S.B., and Macrander, A.M. 2011. Quantifying seismic survey reverberation off the Alaskan North Slope. The Journal of the Acoustical Society of America 130(5):3046–3058.
https://doi.org/10.1121/1.3628326

Halliday, W.D., Insley, S.J., de Jong, T., and Mouy, X. 2018a. Seasonal patterns in acoustic detections of marine mammals near Sachs Harbour, Northwest Territories. Arctic Science 4:259–278.
https://doi.org/10.1139/AS-2017-0021

Halliday, W.D., Têtu, P.-L., Dawson, J., Insley, S.J., and Hilliard, R.C. 2018b. Tourist vessel traffic in important whale areas in the western Canadian Arctic: Risks and possible management solutions. Marine Policy 97:72–81.
https://doi.org/10.1016/j.marpol.2018.08.035

Halliday, W.D., Pine, M.K., Insley, S.J., Soares, R.N., Kortsalo, P., and Mouy, X. 2019. Acoustic detections of Arctic marine mammals near Ulukhaktok, Northwest Territories, Canada. Canadian Journal of Zoology 97(1):72–80.
https://doi.org/10.1139/cjz-2018-0077

Halliday, W.D., Pine, M.K., and Insley, S.J. 2020a. Underwater noise and Arctic marine mammals: Review and policy recommendations. Environmental Reviews 28(4):438–448.
https://doi.org/10.1139/er-2019-0033

Halliday, W.D., Pine, M.K., Mouy, X., Kortsalo, P., Hilliard, R.C., and Insley, S.J. 2020b. The coastal Arctic marine soundscape near Ulukhaktok, Northwest Territories, Canada. Polar Biology 43:623–636.
https://doi.org/10.1007/s00300-020-02665-8

Halliday, W.D., Scharffenberg, K., Whalen, D., MacPhee, S.A., Loseto, L.L., and Insley, S.J. 2020c. The summer soundscape of a shallow-water estuary used by beluga whales in the western Canadian Arctic. Arctic Science 6(4):361–383.
https://doi.org/10.1139/as-2019-0022

Halliday, W.D., Barclay, D., Barkley, A.N., Cook, E., Dawson, J., Hilliard, R.C., Hussey, N.E., et al. 2021. Underwater sound levels in the Canadian Arctic, 2014–2019. Marine Pollution Bulletin 168: 112437.
https://doi.org/10.1016/j.marpolbul.2021.112437

Halliday, W., Brittain, S., Niemi, A., Majewski, A., Mouy, X., and Insley, S. 2022. Minto Inlet 2019 passive acoustic monitoring data. Waterloo, Ontario: Canadian Cryospheric Information Network.
https://doi.org/10.21963/13276

Hamilton, C.D., Kovacs, K.M., Ims, R.A., and Lydersen, C. 2018. Haul-out behaviour of Arctic ringed seals (*Pusa hispida*): Inter-annual patterns and impacts of current environmental change. Polar Biology 41:1063–1082.
https://doi.org/10.1007/s00300-018-2260-2

Han, D.-G., Joo, J., Son, W., Cho, K.H., Choi, J.W., Yang, E.J., Kim, J.-H., Kang, S.-H., and La, H.S. 2021. Effects of geophony and anthrophony on the underwater acoustic environment in the East Siberian Sea, Arctic Ocean. Geophysical Research Letters 48(12): e2021GL093097.
https://doi.org/10.1029/2021GL093097

Hannay, D.E., Delarue, J., Mouy, X., Martin, B.S., Leary, D., Oswald, J.N., and Vallarta, J. 2013. Marine mammal acoustic detections in the northeastern Chukchi Sea, September 2007–July 2011. Continental Shelf Research 67:127–146.
https://doi.org/10.1016/j.csr.2013.07.009

Hauser, D.D.W., Laidre, K.L., Suydam, R.S., and Richard, P.R. 2014. Population-specific home ranges and migration timing of Pacific Arctic beluga whales (*Delphinapterus leucas*). Polar Biology 37:1171–1183.
https://doi.org/10.1007/s00300-014-1510-1

Heimrich, A.F., Halliday, W.D., Frouin-Mouy, H., Pine, M.K., Juanes, F., and Insley, S.J. 2021. Vocalizations of bearded seals (*Erignathus barbatus*) and their influence on the soundscape of the western Canadian Arctic. Marine Mammal Science 37(1):173–192.
https://doi.org/10.1111/mms.12732

Huntington, H.P., Danielson, S.L., Wiese, F.K., Baker, M., Boveng, P., Citta, J.J., De Robertis, A., et al. 2020. Evidence suggests potential transformation of the Pacific Arctic ecosystem is underway. Nature Climate Change 10:342–348.
https://doi.org/10.1038/s41558-020-0695-2

Insley, S.J., Halliday, W.D., and de Jong, T. 2017. Seasonal patterns in ocean ambient noise near Sachs Harbour, Northwest Territories. Arctic 70(3):239–248.
https://doi.org/10.14430/arctic4662

Insley, S.J., Halliday, W.D., Mouy, X., and Diogou, N. 2021. Bowhead whales overwinter in the Amundsen Gulf and eastern Beaufort Sea. Royal Society Open Science 8: 202268.
https://doi.org/10.1098/rsos.202268

Jones, J.M., Thayre, B.J., Roth, E.H., Mahoney, M., Sia, I., Merculief, K., Jackson, C., et al. 2014. Ringed, bearded, and ribbon seal vocalizations north of Barrow, Alaska: Seasonal presence and relationship with sea ice. Arctic 67(2):203–222.
https://doi.org/10.14430/arctic4388

Jones, J.M., Frasier, K.E., Westdal, K.H., Ootoowak, A.J., Wiggins, S.M., and Hildebrand, J.A. 2022a. Beluga (*Delphinapterus leucas*) and narwhal (*Monodon monoceros*) echolocation click detection and differentiation from long-term Arctic acoustic recordings. Polar Biology 45:449–463.
https://doi.org/10.1007/s00300-022-03008-5

Jones, J.M., Hildebrand, J.A., Thayre, B.J., Jameson, E., Small, R.J., and Wiggins, S.M. 2022b. The influence of sea ice on the detection of bowhead whale calls. Scientific Reports 12: 8553.
https://doi.org/10.1038/s41598-022-12186-5

K. Lisa Yang Center for Conservation Bioacoustics. 2019. Raven Pro: Interactive sound analysis software. Version 1.6.1. Ithaca, New York: The Cornell Lab of Ornithology.
https://ravensoundsoftware.com/

Kinda, G.B., Simard, Y., Gervaise, C., Mars, J.I., and Fortier, L. 2013. Under-ice ambient noise in eastern Beaufort Sea, Canadian Arctic, and its relation to environmental forcing. The Journal of the Acoustical Society of America 134(1):77–87.
https://doi.org/10.1121/1.4808330

Laidre, K.L., Stirling, I., Lowry, L.F., Wiig, Ø., Heide-Jørgensen, M.P., and Ferguson, S.H. 2008. Quantifying the sensitivity of Arctic marine mammals to climate-induced habitat change. Ecological Applications 18(2):S97–S125.
https://doi.org/10.1890/06-0546.1

Le Bot, O., Simard, Y., Roy, N., Mars, J.I., and Gervaise, C. 2016. Whistle source levels of free-ranging beluga whales in Saguenay-St. Lawrence marine park. The Journal of the Acoustical Society of America 140(1):EL89–EL93.
https://doi.org/10.1121/1.4955115

Looby, A., Cox, K., Bravo, S., Rountree, R., Juanes, F., Reynolds, L.K., and Martin, C.W. 2022. A quantitative inventory of global soniferous fish diversity. Reviews in Fish Biology and Fisheries 32:581–595.
https://doi.org/10.1007/s11160-022-09702-1

MacIntyre, K.Q., Stafford, K.M., Berchok, C.L., and Boveng, P.L. 2013. Year-round acoustic detection of bearded seals (*Erignathus barbatus*) in the Beaufort Sea relative to changing environmental conditions, 2008–2010. Polar Biology 36:1161–1173.
https://doi.org/10.1007/s00300-013-1337-1

MacIntyre, K.Q., Stafford, K.M., Conn, P.B., Laidre, K.L., and Boveng, P.L. 2015. The relationship between sea ice concentration and the spatio-temporal distribution of vocalizing bearded seals (*Erignathus barbatus*) in the Bering, Chukchi, and Beaufort Seas from 2008 to 2011. Progress in Oceanography 136:241–249.
https://doi.org/10.1016/j.pocean.2015.05.008

Majewski, A.R., Atchison, S., MacPhee, S., Eert, J., Niemi, A., Michel, C., and Reist, J.D. 2017. Marine fish community structure and habitat associations on the Canadian Beaufort shelf and slope. Deep Sea Research Part I: Oceanographic Research Papers 121:169–182.
https://doi.org/10.1016/j.dsr.2017.01.009

McKenna, M.F., Southall, B.L., Chou, E., Robards, M., and Rosenbaum, H.C. 2021. An integrated underwater soundscape analysis in the Bering Strait region. The Journal of the Acoustical Society of America 150(3):1883–1896.
https://doi.org/10.1121/10.0006099

Mellinger, D.K., Stafford, K.M., Moore, S.E., Dziak, R.P., and Matsumoto, H. 2007. An overview of fixed passive acoustic observation methods for cetaceans. Oceanography 20(4):36–45.
https://doi.org/10.5670/oceanog.2007.03

Merchant, N.D., Fristrup, K.M., Johnson, M.P., Tyack, P.L., Witt, M.J., Blondel, P., and Parks, S.E. 2015. Measuring acoustic habitats. Methods in Ecology and Evolution 6(3):257–265.
https://doi.org/10.1111/2041-210X.12330

Meredith, M., Sommerkorn, M., Cassotta, S., Derksen, C., Ekaykin, A., Hollowed, A., Kofinas, G., et al. 2019. Polar regions. In: Pörtner, H.-O., Roberts, D.C., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., Mintenbeck, K., et al., eds. IPCC Special report on the ocean and cryosphere in a changing climate. Cambridge: Cambridge University Press. 203–320.
https://doi.org/10.1017/9781009157964.005

Mizuguchi, D., Tsunokawa, M., Kawamoto, M., and Kohshima, S. 2016. Underwater vocalizations and associated behavior in captive ringed seals (*Pusa hispida*). Polar Biology 39:659–669. https://doi.org/10.1007/s00300-015-1821-x

Moore, S.E., Reeves, R.R., Southall, B.L., Ragen, T.J., Suydam, R.S., and Clark, C.W. 2012. A new framework for assessing the effects of anthropogenic sound on marine mammals in a rapidly changing Arctic. BioScience 62(3):289–295. https://doi.org/10.1525/bio.2012.62.3.10

Mouy, X., Oswald, J., Leary, D., Delarue, J., Vallarta, J., Rideout, B., Mellinger, D.K., Erbe, C., Hannay, D., and Martin, B. 2013. Passive acoustic monitoring of marine mammals in the Arctic. In: Adam, O., and Samaran, F., eds. Detection, classification, localization of marine mammals using passive acoustics: 2003-2013 10 years of international research. Paris: Dirac NGO. 185–224.

NASA (National Aeronautics and Space Administration). 2021. NASA Worldview. https://worldview.earthdata.nasa.gov/

Niemi, A., Ferguson, S., Hedges, K., Melling, H., Michel, C., Ayles, B., Azetsu-Scott, K., et al. 2019. State of Canada's Arctic seas. Canadian Technical Report of Fisheries and Aquatic Sciences 3344. Winnipeg: Freshwater Institute, Fisheries and Oceans Canada. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40838973.pdf

Olokhaktomiut Hunters and Trappers Committee, Ulukhaktok Community Corporation, Wildlife Management Advisory Council (NWT), Fisheries Joint Management Committee, and Joint Secretariat. 2016. Olokhaktomiut community conservation plan Ulukhaqtuum Angalatchivingit Niryutinik: A plan for the conservation and management of renewable resources and lands within the Inuvialuit Settlement Region in the vicinity of Ulukhaktok, Northwest Territories. https://static1.squarespace.com/static/5e2093a7fd6f455447254aff/t/5e262b83e3c0a94c0a904bf2/1579559867490/2016-Uluhaktok-Community-Conservation-Plan-R.pdf

PAME (Protection of the Arctic Marine Environment). 2019. Underwater noise in the Arctic: A state of knowledge report. Rovaniemi, May 2019. Akureyri: Arctic Council Secretariat. http://hdl.handle.net/11374/2394

Panova, E., Agafonov, A., Belikov, R., and Melnikova, F. 2019. Characteristics and microgeographic variation of whistles from the vocal repertoire of beluga whales (*Delphinapterus leucas*) from the White Sea. The Journal of the Acoustical Society of America 146(1):681–692. https://doi.org/10.1121/1.5119249

Pijanowski, B.C., Villanueva-Rivera, L.J., Dumyahn, S.L., Farina, A., Krause, B.L., Napoletano, B.M., Gage, S.H., and Pieretti, N. 2011. Soundscape ecology: The science of sound in the landscape. BioScience 61(3):203–216. https://doi.org/10.1525/bio.2011.61.3.6

Pine, M.K., Halliday, W.D., Insley, S.J., and Juanes, F. 2020. Fish sounds near Sachs Harbour and Ulukhaktok in Canada's western Arctic. Polar Biology 43:1207–1216. https://doi.org/10.1007/s00300-020-02701-7

Podolskiy, E.A., Murai, Y., Kanna, N., and Sugiyama, S. 2022. Glacial earthquake-generating iceberg calving in a narwhal summering ground: The loudest underwater sound in the Arctic? The Journal of the Acoustical Society of America 151(1):6–16. https://doi.org/10.1121/10.0009166

Quijano, J.E., Hannay, D.E., and Austin, M.E. 2018. Composite underwater noise footprint of a shallow Arctic exploration drilling project. IEEE Journal of Oceanic Engineering 44(4):1228–1239. https://doi.org/10.1109/JOE.2018.2858606

R Core Team. 2019. R: A language and environment for statistical computing, Version 3.6.1. Vienna: R Foundation for Statistical Computing. https://www.r-project.org/

Riera, A., Rountree, R.A., Pine, M.K., and Juanes, F. 2018. Sounds of Arctic cod (*Boreogadus saida*) in captivity: A preliminary description. The Journal of the Acoustical Society of America 143(5):EL317–EL321. https://doi.org/10.1121/1.5035162

Risch, D., Clark, C.W., Corkeron, P.J., Elepfandt, A., Kovacs, K.M., Lydersen, C., Stirling, I., and Van Parijs, S.M. 2007. Vocalizations of male bearded seals, *Erignathus barbatus*: Classification and geographical variation. Animal Behaviour 73(5):747–762. https://doi.org/10.1016/j.anbehav.2006.06.012

Roth, E.H., Hildebrand, J.A., Wiggins, S.M., and Ross, D. 2012. Underwater ambient noise on the Chukchi Sea continental slope from 2006–2009. The Journal of the Acoustical Society of America 131(1):104–110. https://doi.org/10.1121/1.3664096

Stafford, K.M., and Clark, C.W. 2021. Chapter 22 – Acoustic behavior. In: George, J.C., and Thewissen, J.G.M., eds. The bowhead whale: *Balaena mysticetus*: Biology and human interactions. London: Academic Press. 323–338. https://doi.org/10.1016/b978-0-12-818969-6.00022-4

Stafford, K.M., Citta, J.J., Okkonen, S.R., and Zhang, J. 2021. Bowhead and beluga whale acoustic detections in the western Beaufort Sea 2008–2018. PLoS ONE 16(6): e0253929. https://doi.org/10.1371/journal.pone.0253929

Stirling, I. 1973. Vocalization in the ringed seal (*Phoca hispida*). Journal of the Fisheries Research Board of Canada 30(10):1592–1594. https://doi.org/10.1139/f73-253

Storrie, L., Hussey, N.E., MacPhee, S.A., O'Corry-Crowe, G., Iacozza, J., Barber, D.G., Nunes, A., and Loseto, L.L. 2022. Year-round dive characteristics of male beluga whales from the eastern Beaufort Sea population indicate seasonal shifts in foraging strategies. Frontiers in Marine Science 8: 715412. https://doi.org/10.3389/fmars.2021.715412

Tervo, O.M., Christoffersen, M.F., Simon, M., Miller, L.A., Jensen, F.H., Parks, S.E., and Madsen, P.T. 2012. High source levels and small active space of high-pitched song in bowhead whales (*Balaena mysticetus*). PLoS ONE 7(12): e52072. https://doi.org/10.1371/journal.pone.0052072

Thode, A.M., Blackwell, S.B., Conrad, A.S., Kim, K.H., Marques, T., Thomas, L., Oedekoven, C.S., Harris, D., and Bröker, K. 2020. Roaring and repetition: How bowhead whales adjust their call density and source level (Lombard effect) in the presence of natural and seismic airgun survey noise. The Journal of the Acoustical Society of America 147(3):2061–2080. https://doi.org/10.1121/10.0000935

Van Parijs, S.M., Clark, C.W., Sousa-Lima, R.S., Parks, S.E., Rankin, S., Risch, D., and Van Opzeeland, I.C. 2009. Management and research applications of real-time and archival passive acoustic sensors over varying temporal and spatial scales. Marine Ecology Progress Series 395:21–36. https://doi.org/10.3354/meps08123