Baffinland Iron Mines Corporation – Mary River Project

2020 Underwater Acoustic Monitoring Program

JASCO Applied Sciences (Canada) Ltd

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Executive Summary

The Mary River Project (the Project) is an operating open-pit iron ore mine owned by Baffinland Iron Mines Corporation (Baffinland). The Project is located in the Qikiqtani Region of North Baffin Island, Nunavut. The operating mine site is connected to a port at Milne Inlet (Milne Port) via the 100 km long Milne Inlet Tote Road, for shipping along the Northern Shipping Route using chartered ore carrier vessels. Daily shipping activity related to the Project overlaps with established summering grounds for the Eclipse Sound narwhal summer stock.

Shipping noise has the potential to elicit disturbance effects on narwhal, and it is important to evaluate whether such effects could lead to changes in narwhal distribution, abundance, or migration patterns that could then affect their availability for harvesting by local communities. In accordance with existing terms and conditions of Project Certificate No. 005, Baffinland is responsible for establishing and implementing environmental effects monitoring (EEM) studies that can identify unforeseen adverse effects, providing early warnings of undesirable changes in the environment, and improving understanding of local environmental processes and potential Project-related cause-and-effect relationships. This report details the methods and results of a passive acoustic monitoring study conducted to fulfill part of these environmental effects monitoring requirements.

The 2020 Passive Acoustic Monitoring Program was developed by JASCO Applied Sciences (JASCO), in collaboration with Golder Associates Ltd. (Golder) and Baffinland, to evaluate potential Project-related effects to marine mammals from shipping noise. The main objective of this program was to document and characterize ambient and anthropogenic underwater noise levels recorded in 2020 at three acoustic monitoring stations located along the Northern Shipping Route in Tasiujaq (Eclipse Sound) and Milne Inlet. A secondary objective was to acoustically identify marine mammal species (notably narwhal) present along the Northern Shipping Route in 2020. A third objective was to evaluate Project-shipping noise levels in relation to established marine mammal acoustic thresholds for injury and disturbance and to compare measured sound levels from shipping activities to modelled estimates used for environmental effects assessment. A final objective was to estimate the extent of listening range reduction (LRR) associated with Project vessel transits along the Northern Shipping Route relative to ambient noise levels.

Underwater sound recorders (Autonomous Multichannel Acoustic Recorders, AMARs) were deployed at three locations in 2020 including near Bylot Island, Imilik (Ragged Island), and Iluvilik (Bruce Head). The Ragged Island and Bylot Island recorders collected underwater acoustic data from 12 Jul 2020, through to their retrieval on 5 Sep 2020 (the Ragged Island recorder batteries were depleted on 3 Sep 2020). The Bruce Head recorder was deployed 1 Aug 2020 and recorded continuously until retrieved on 6 Sep 2020.

The results of the ambient noise analysis for the early shoulder season recording period (12 Jul to 1 Aug 2020) for the Bylot Island and Ragged Island recording stations showed an increase at frequencies below 1000 Hz over the 20 days of recording for both stations. This increase is largely attributed to the increase in vessel traffic (both Project and non-Project vessels) and also to weather- and wave-induced noise at these locations due to decreasing ice presence. The Ragged Island recorder had overall higher sound levels than were recorded at the Bylot Island recorder, likely due to it being closer to the nominal shipping lane and because of its shallower deployment location (91 m at Ragged Island compared to 297 m at Bylot Island); noting the Ragged Island station would have been exposed to a greater amount of vessel, flow, and surface sounds. Sound exposure levels never exceeded thresholds for acoustic injury (temporary or permanent hearing loss) at either recording location, based on criterion from the US National Oceanic and Atmospheric Administration (NOAA) guidance for assessing acoustic injury of marine mammals, for the species that occur in the Project Area. The sound pressure level (SPL) occasionally exceeded 120 dB re 1 µPa (a threshold recommended by NOAA for assessing disturbance

of marine mammals) throughout the recording period; only for 7.6% of the 20 day early shoulder season recording period at Ragged Island and for 1.8% of the same recording period (20 days) at Bylot Island.

During the open-water recording period (1 Aug to 5 Sep 2020), the recorder at Bruce Head had elevated percentile levels near 20 kHz that are attributed to the presence of narwhal echolocation clicks (the other recording locations did not show equivalent elevated percentile levels near 20 kHz). Sound exposure levels never exceeded thresholds for acoustic injury (temporary or permanent hearing loss) at any recording location. The one-minute averaged SPL occasionally exceeded the 120 dB re 1 µPa marine mammal disturbance threshold at any station; 4.6 % of the 33 days of recording at Ragged Island, 1.3 % of the 35 days of recording at Bylot Island, and 2.3 % of the 35 days of recording at Bruce Head.

Sounds from five marine mammal species (bowhead, killer whale, beluga, narwhal, and sperm whales) were identified in the acoustic data, as well as sounds that were suspected to be from bearded seals and ringed seals. Narwhal vocalizations were recorded at all three recording stations. For the Ragged Island and Bylot Island recorders, narwhal calls were more prevalent in July than in August or September. For the Bruce Head recorder, narwhal calls were prevalent in both August and September. Bowhead whale vocalizations were detected (and manually validated) on the Bylot Island and Ragged Island recorders in July and were detected through manual analysis in two instances at Bruce Head in August, which is consistent with visual observations made during the 2020 Bruce Head shore-based monitoring program (Golder 2021a). Several killer whale vocalizations were detected (and manually validated) at all stations during the latter half of August. This short period of killer whale vocalizations is consistent with the migratory behaviour of this species in the study area. Some acoustic signals consistent with those produced by bearded seals and ringed seals were detected throughout the recordings. Sperm whales were detected regularly at the Bylot Island recorder and once at the Ragged Island recorder in mid-August.

During the early shoulder season, vessels were acoustically detected on 21% and 18% of the total recordings at Bylot Island and Ragged Island, respectively. During the open-water season, vessels were acoustically detected on 42%, 33% and 28% of the total recordings at Bylot Island, Ragged Island and Bruce Head, respectively. Listening range reduction (LRR)—the fractional decrease in the available listening range for marine animals—was computed at each recording station for three frequencies, each representative of different narwhal vocalization types: 1 khz (representative of narwhal burst pulses), 5 kHz (representative of whistles and knock trains) and 25 kHz (representative of clicks and high-frequency buzzes). The LRR results for each of the three frequencies are summarized as follows:

1 kHz (burst pulses):

During the early shoulder season, vessel noise resulted in >50% LRR for sound at 1 kHz for 0.8% and 1.3% of the total recording period at Bylot Island and Ragged Island, respectively. During the open-water season, vessel noise resulted in >50% LRR for sound at 1 kHz for 0.2%, 0.9%, and 1.2% of the total recording period at the Bylot Island, Ragged Island, and Bruce Head recorders, respectively. During both early shoulder and open-water seasons, ambient noise did not cause appreciable LRR at 1 kHz at any recording station, given the hearing threshold for a narwhal at 1 kHz is higher than the median ambient sound level at this specific frequency.

5 kHz (whistles/knock trains):

During the early shoulder season, vessel noise resulted in >50% LRR for sound at 5 kHz for 8% and 7% of the total recording period at Bylot Island and Ragged Island, respectively. During this same period, ambient noise resulted in >50% LRR for sound at 5 kHz for 22% and 16% of the total recording period at Bylot Island and Ragged Island, respectively.

During the open-water season, vessel noise resulted in >50% LRR for sound at 5 kHz for 13%, 8% and 7% of the total recording period at Bylot Island, Ragged Island and Bruce Head recorders, respectively. During this same period, ambient noise resulted in >50% LRR for sound at 5 kHz for 17%, 18% and 18% of the total recording period at Bylot Island, Ragged Island and Bruce Head recorders, respectively.

25 kHz (clicks / high frequency buzzes):

During the early shoulder season, vessel noise resulted in >50% LRR for sound at 25 kHz for 9% and 11% of the total recording period at Bylot Island and Ragged Island recorders, respectively. During this same period, ambient noise resulted in >50% LRR for sound at 25 kHz for 31% and 28% of the total recording period at Bylot Island and Ragged Island, respectively.

During the open-water season, vessel noise resulted in >50% LRR for sound at 25 kHz for 15%, 10% and 8% of the total recording period at Bylot Island, Ragged Island and Bruce Head recorders, respectively. During this same period, ambient noise resulted in >50% LRR for sound at 25 kHz for 20%, 27% and 26% of the total recording period at Bylot Island, Ragged Island and Bruce Head recorders, respectively.

1. Introduction

Underwater sound level measurements were collected at locations in Milne Inlet and Tasiujaq (Eclipse Sound) during JASCO Applied Sciences' (JASCO) 2020 Passive Acoustic Monitoring (PAM) program conducted for Baffinland Iron Mine Corporation's (Baffinland's) Mary River Project. The data were analyzed to document the spatial and temporal variability of recorded underwater sounds, to document marine mammal vocalization occurrence (primarily focused on narwhal), and to quantify the degree to which noise from Project vessels contributed to the underwater sound field. This report presents the results of the 2020 PAM Program, developed in collaboration with Golder Associates Ltd. (Golder) and Baffinland, to evaluate potential Project-related effects to marine mammals from shipping noise.

Acoustic data were recorded using Autonomous Multichannel Acoustic Records (AMARs; JASCO Applied Sciences) between 12 Jul and 5 Sep 2020. This period encompassed the 2020 early shoulder season (21 Jul through 01 Aug) and a portion of the 2020 open-water season. The open-water season is the ice-free period along the Northern Shipping Route when no Project icebreaking activities occurred; in 2020 the last day requiring icebreaker escorts occurred on 01 Aug.

1.1. Project Context

The Mary River Project (the Project) is an operating open-pit iron ore mine located in the Qikiqtani Region of North Baffin Island, Nunavut. Baffinland is the owner and operator of the Project. The operating mine site is connected to a port at Milne Inlet (Milne Port) via the 100 km long Milne Inlet Tote Road. Future, but yet undeveloped, components of the Project include a South Railway connecting the mine site to a future port at Steensby Inlet (Steensby Port).

Project Certificate No. 005, amended by the Nunavut Impact Review Board (NIRB) on 27 May 2014, authorizes Baffinland to mine up to 22.2 million tonnes per annum (Mtpa) of iron ore from Deposit No. 1. Of this 22.2 Mtpa, Baffinland is currently authorized to transport 18 Mtpa of ore by rail to Steensby Port for year-round shipping through the Southern Shipping Route (via Foxe Basin and Hudson Strait), and 4.2 Mtpa of ore by truck to Milne Port for open-water shipping through the Northern Shipping Route using chartered ore carrier vessels. A production increase to ship 6.0 Mtpa from Milne Port was approved for 2018–2019 and renewed for 2020–2021.

In accordance with existing terms and conditions of Project Certificate No. 005, Baffinland is responsible for establishing and implementing environmental effects monitoring (EEM) studies conducted over a defined time period with the following objectives:

- Assess the accuracy of effects predictions in the Final Environmental Impact Statement (FEIS; BIM 2012) and Addendum 1 (BIM 2013).
- Assess the effectiveness of Project mitigation measures.
- Verify the Project's compliance with regulatory requirements, Project permits, standards, and policies.
- Identify unforeseen adverse effects.
- Improve understanding of local environmental processes and potential Project-related cause-and-effect relationships.
- Provide feedback to the applicable regulators (e.g., NIRB) and advisory bodies (e.g., Marine Environmental Working Group (MEWG)) with respect to:
    - Potential adjustments to existing monitoring protocols or monitoring framework to allow for scientifically defensible synthesis, analysis, and interpretation of data.

  - Project management decisions requiring modifying operational practices where and when necessary.

The PAM Program was designed to help verify the following predictions made in the FEIS (2012) and (2013) addendums.

- *Narwhal are expected to exhibit temporary and localized avoidance behaviour when encountering Project vessels along the shipping route, and*
- *No abandonment or long-term displacement effects are expected.*

The PAM Program also specifically aimed to address monitoring requirements outlined in the following Project Certificate No. 005 terms and conditions:

- *Condition No. 109: "The Proponent shall conduct a monitoring program to confirm the predictions in the FEIS with respect to disturbance effects from ships noise on the distribution and occurrence of marine mammals. The survey shall be designed to address effects during the shipping seasons, and include locations in Hudson Strait and Foxe Basin, Milne Inlet, Eclipse Sound and Pond Inlet. The survey shall continue over a sufficiently lengthy period to determine the extent to which habituation occurs for narwhal, beluga, bowhead and walrus".*
- *Condition No. 110: "The Proponent shall immediately develop a monitoring protocol that includes, but is not limited to, acoustical monitoring, to facilitate assessment of the potential short term, long term, and cumulative effects of vessel noise on marine mammals and marine mammal populations".*
- *Condition No. 112: "Prior to commercial shipping of iron ore, the Proponent, in conjunction with the Marine Environment Working Group, shall develop a monitoring protocol that includes, but is not limited to, acoustical monitoring that provided an assessment of the negative effects (short and long term cumulative) of vessel noise on marine mammals. Monitoring protocols will need to carefully consider the early warning indicator(s) that will be best examined to ensure rapid identification of negative impacts. Thresholds be developed to determine if negative impacts as a result of vessel noise are occurring. Mitigation and adaptive management practices shall be developed to restrict negative impacts as a results of vessel noise. Thus, shall include, but not be limited to:*
  1. *Identification of zones where noise could be mitigated due to biophysical features (e.g., water depth, distance from migration routes, distance from overwintering areas etc.)*
  2. *Vessel transit planning, for all seasons*
  3. *A monitoring and mitigation plan is to be developed, and approved by Fisheries and Oceans Canada prior to the commencement of blasting in marine areas".*

1.2. Study Objectives

The objectives of the 2020 Open-Water Season PAM Program were the following:

- Measure and report the ambient noise levels in representative areas along the Northern Shipping Route, including Milne Inlet (North and South) and Eclipse Sound (Figure 1),
- Compare in-situ (i.e. measured) sound levels relative to modelled sound levels used in the environmental assessment review of the Project,
- Acoustically identify marine mammal species (notably narwhal) presence along the Northern Shipping Route,
- Evaluate Project shipping noise levels in relation to established marine mammal acoustic thresholds for injury and onset of disturbance,
- Estimate the extent of listening range reduction (LRR) associated with Project vessel transits along the Northern Shipping Route relative to ambient noise levels.

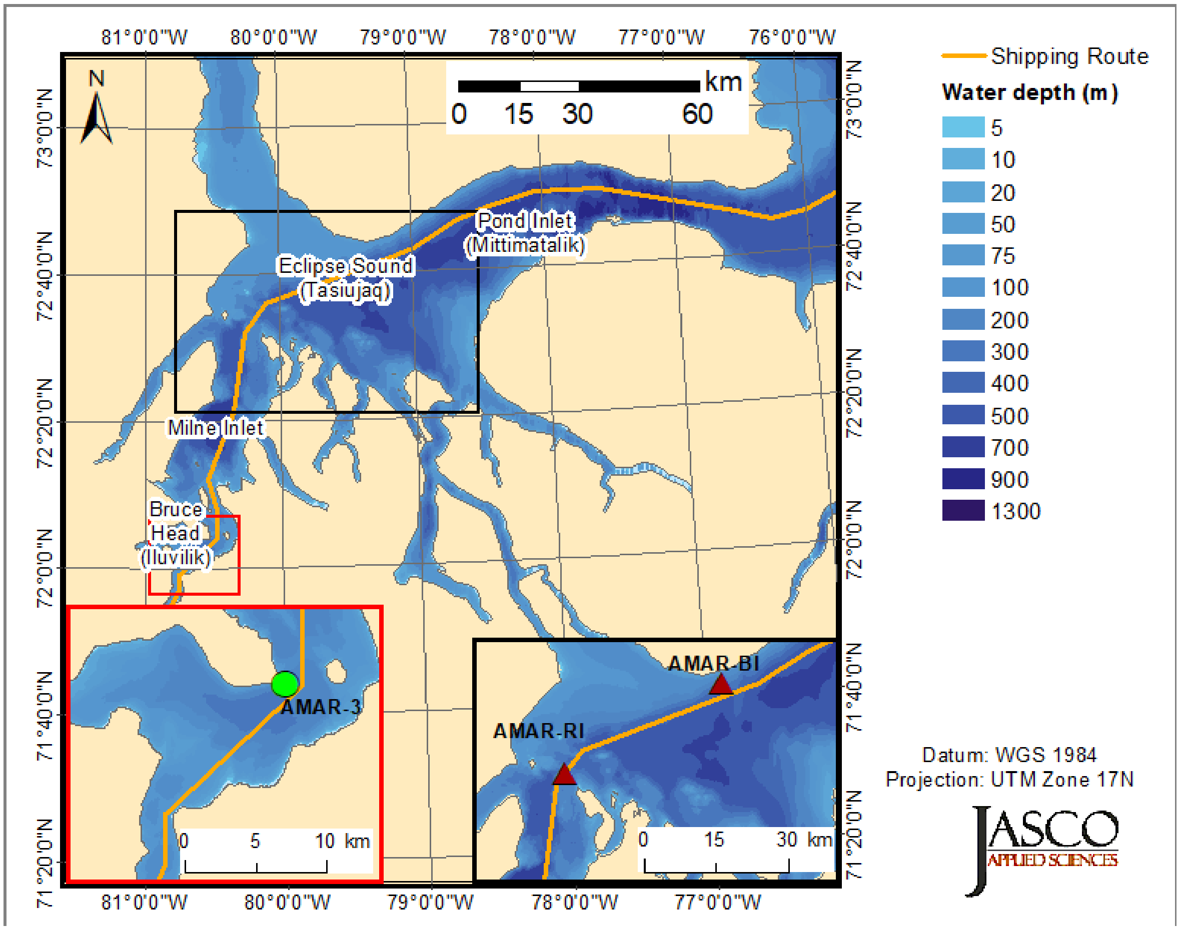

Figure 1. Acoustic monitoring area and locations of recorder stations along the Northern Shipping Route, including Milne Inlet South (red insert: AMAR–1, –2, and –3), Milne Inlet North (black insert: AMAR–RI), and Eclipse Sound (black insert: AMAR–BI).

1.3. Ambient Sound Levels

Ambient sound is defined as any sound that is present in the absence of human activities. It is also temporally and spatially specific (ISO 2017a). The typical frequencies and spectral levels of natural and human-produced noise are shown on Wenz curves (Wenz 1962) (Figure 2), which illustrate the variability of ambient spectral levels off the US Pacific coast as a function of frequency of measurements for a range of weather, vessel traffic, and geologic conditions. The Wenz curve levels are generalized and are used for approximate comparisons only. The main environmental sources of sound are wind, precipitation, and sea ice movement/cracking sounds. Wind-generated noise in the ocean is well-described (e.g., Wenz 1962, Ross 1976), and surf noise is known to be an important contributor to near-shore soundscapes (Deane 2000). In polar regions, sea ice can produce loud sounds that are often the main contributor of acoustic energy in the local soundscape, particularly during ice formation, temperature changes, and break up (Milne and Ganton 1964). Precipitation is a frequent source of sound, with contributions typically concentrated at frequencies above 500 Hz. At low frequencies (<100 Hz), earthquakes and other geological events contribute to the soundscape (Figure 2). Kim and Conrad (2016) reported that in the Project area, below 1000 Hz, moderate winds (~6 m/s) typical of the site contributed to average measured ambient sound levels of ~94 dB re 1 µPa.

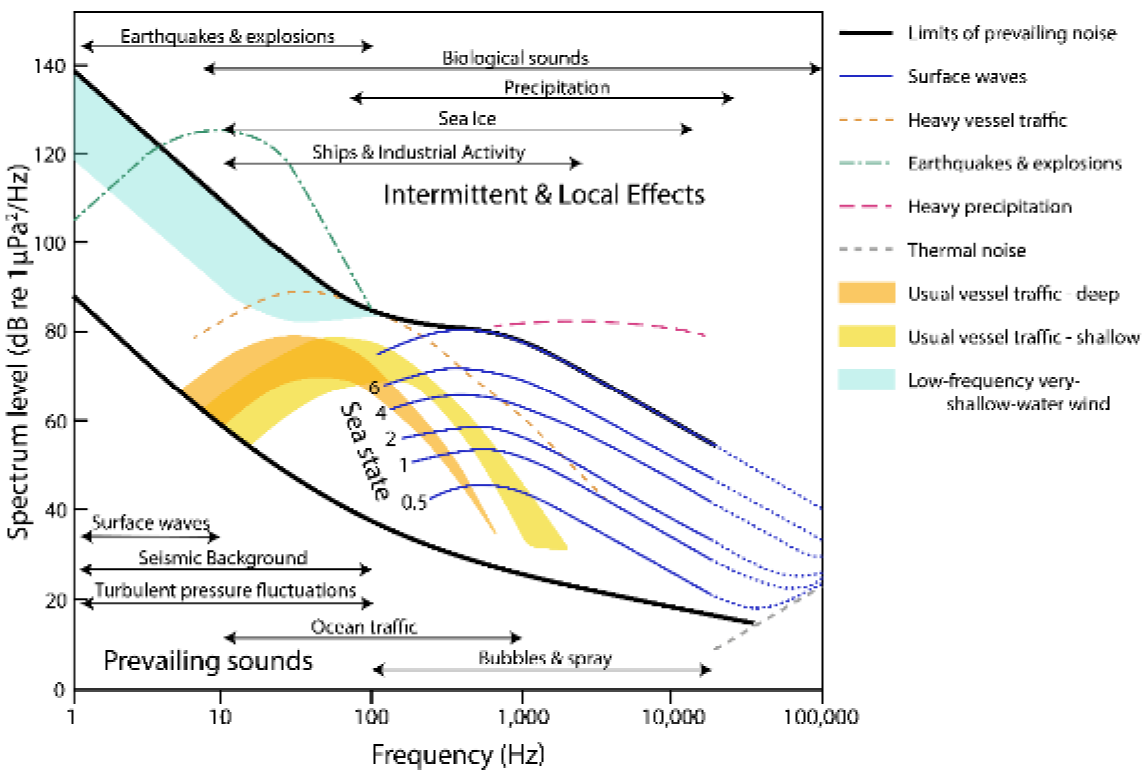

Figure 2. Wenz curves. While the often cited Wenz curves show sea state dependent spectra only above 200 Hz, with a peak at ~500 Hz, Wenz showed measurements at lower frequencies (Wenz 1962). Spectrum levels exhibit a local minimum at ~100–200 Hz and rise for frequencies less than 100 Hz.

1.4. Biological Contributors to the Marine Soundscape

Five cetacean (bowhead whales, narwhal, beluga whales, killer whales, and sperm whales) and five pinniped (ringed seals, bearded seals, harp seals, hooded seals, and walrus) species may be found in or near the Project area (Table 1). Current knowledge on marine mammal presence and distribution in Milne Inlet is largely derived from traditional knowledge (Jason Prno Consulting Services Ltd. 2017) and scientific survey data (Golder Thomas et al. 2015, 2016, 2018, 2019) as reported in the 2010 Arctic Marine Workshop (Stephenson and Hartwig 2010) and from research activities (Yurkowski et al. 2018).

The presence of cetaceans (bowhead whales, beluga whales, narwhal, and killer whales) and pinnipeds (ringed seals, bearded seals, harp seals, and walrus) has been previously reported in at least part of the Project area (Ford et al. 1986, Campbell et al. 1988, COSEWIC 2004a, COSEWIC 2004b, COSEWIC 2008, COSEWIC 2009, Marcoux et al. 2009, Stephenson and Hartwig 2010, Thomas et al. 2014, Smith et al. 2015, COSEWIC 2017, Sportelli 2019).

Table 1. List of cetacean and pinniped species known to occur (or possibly occur) in or near the Project area and their Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and Species at Risk Act (SARA) status.

Species	Scientific name	COSEWIC status	SARA status
Cetaceans			
Bowhead whales	*Balaena mysticetus*	Special concern[1]	Not listed[1]
Beluga whales	*Delphinapterus leucas*	Special concern[2]	Not listed[2]
Narwhal	*Monodon monoceros*	Special concern	Not listed
Killer whales	*Orcinus orca*	Special concern[3]	Not listed[3]
Sperm whales	*Physeter macrocephalus*	Not at risk	Not listed
Pinnipeds			
Ringed seals	*Phoca hispida*	Special concern	Not listed
Bearded seals	*Erignathus barbatus*	Data deficient	Not listed
Harp seals	*Pagophilus groenlandicus*	Not assessed	Not listed
Hooded seals	*Cystophora cristata*	Not at risk	Not listed
Atlantic walrus	*Odobenus rosmarus rosmarus*	Special concern[4]	No status[4,5]

[1] Status of the Eastern Canada-West Greenland population
[2] Status of the Eastern High Arctic-Baffin Bay population
[3] Status of the Northwest Atlantic/Eastern Arctic population
[4] Status of the High Arctic population
[5] Under consideration for addition

Marine mammals are the primary biological contributors to the underwater soundscape in the Project area. Marine mammals, and cetaceans in particular, rely almost exclusively on sound for navigating, foraging, breeding, and communicating (Clark 1990, Edds-Walton 1997, Tyack and Clark 2000). Although species differ widely in their vocal behaviour, most can be reasonably expected to produce sounds on a regular basis. Passive acoustic monitoring (listening) with long-duration recorders is therefore an efficient survey method. However, this approach produces huge data sets that must be analyzed, either manually or with computer programs that can automatically detect and classify sounds produced by different species. Seasonal and sex- or age-biased differences in sound production, as well as signal frequency, source level, and directionality all influence the applicability and success rate of acoustic monitoring, and its effectiveness must be considered separately for each species and season.

Understanding of the acoustic signals produced by the marine mammals expected in the Project area varies by species. The produced sounds can be divided into two broad categories: narrow-band signals including baleen whale moans, odontocete whistles and pinniped vocalizations, and echolocation clicks produced by all odontocetes mainly for foraging and navigating. While the signals of most species in the Project area have been described to some extent, descriptions are not always sufficient for reliable, systematic identification or for designing automated acoustic signal detectors to process large data sets (Table 2).

Table 2. Acoustic signals used for identification and automated detection of the species expected in Milne Inlet and supporting references.

Species	Identification signal	Automated detection signal	Reference
Bowhead whales	Moan	Moan	Clark and Johnson (1984) Delarue et al. (2009)
Beluga whales	Whistle	Whistle	Karlsen et al. (2002) Garland et al. (2015)
Narwhal	Whistle, click, buzz, knock	Whistle, click, buzz knock	Stafford et al. (2012) Ford and Fisher (1978) Walmsley et al. (2020)
Killer whales	Whistle, pulsed vocalization	Tonal signal <6 kHz	Ford (1989) Deecke et al. (2005)
Sperm whales	Click	Click	Watkins (1980)
Ringed seals	Grunt, yelp, bark	Grunt	Stirling et al. (1987) Jones et al. (2011)
Bearded seals	Trill	Trill	Risch et al. (2007)
Harp seals	Grunt, yelp, bark	Grunt	Terhune (1994)
Walrus	Grunt, knock, bells	Grunt, bells	Stirling et al. (1987) Mouy et al. (2011)

1.5. Anthropogenic Contributors to the Soundscape

Anthropogenic (human-generated) sound can be a by-product of vessel operations, such as engine sound radiating through vessel hulls and cavitating propellers. The main anthropogenic contributor to the total sound field in the study was vessel traffic associated with the transport of iron ore. Project vessels, both those associated with transporting the iron ore (i.e., ore carriers) and support vessels (tugs, icebreakers, fuel tankers, and cargo vessels.), contribute to the soundscape. These vessels generally follow the nominal shipping lane (the Northern Shipping Route) that passes through the Project area (Figure 3). The icebreaker MSV *Botnica* escorted vessels along the Northern Shipping Route between 21 Jul and 01 Aug; they transited through ice concentrations between 2/10 and 9/10 at the locations of the Bylot Island and Ragged Island recorders for the first 5 of those days (21 through 26 Jul) and transited in open water on the other days. Sounds recorded from these icebreaker transits were analysed and reported separately (Austin and Dofher 2021).

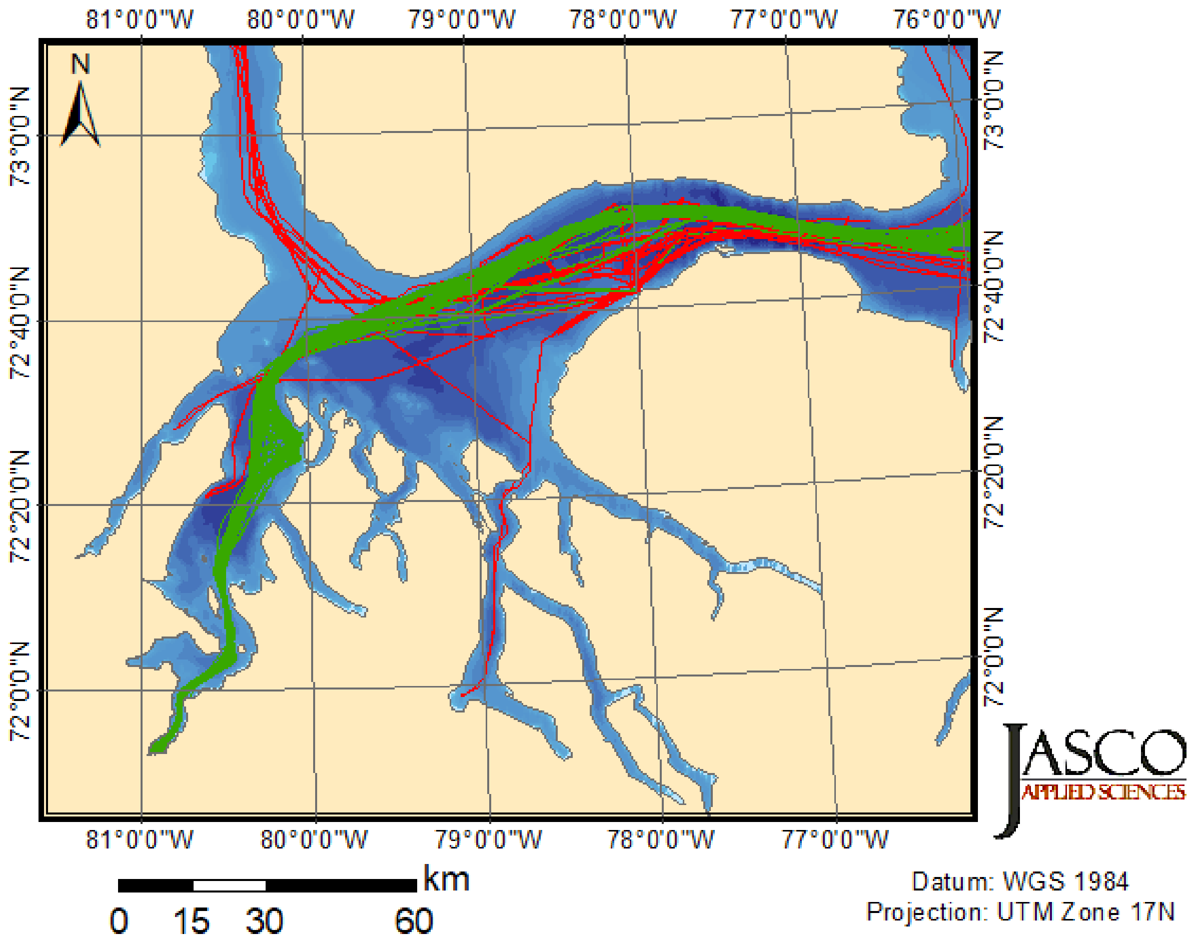

Figure 3. Vessel traffic travelling along the Northern Shipping Route during the 2020 recording period; both Project-related vessels (green) and non-Project related vessels (red) are displayed. Automatic Identification System (AIS) vessel tracking data was acquired from ground-based stations at Bruce Head and Pond Inlet, as well as AIS data collected by satellites (exactEarth 2020).

2. Methods

2.1. Acoustic Data Acquisition

Underwater sound was recorded with AMARs (Figure 4) commencing during the 2020 early shoulder season and concluding in early September of the 2020 open-water season. AMARs were each fitted with a M36 omnidirectional hydrophone (GeoSpectrum Technologies Inc., −165 ± 3 dB re 1 V/µPa sensitivity). All devices were calibrated to within 1 dB using a pistonphone calibrator. The AMAR hydrophones were protected by a hydrophone cage, which was covered with a shroud to minimize noise artifacts from water flow. Recorders at Imilik (Ragged Island) and Bylot Island were both single channel hydrophones sampling continuously at 64 kHz, whereas the recorder at Iluvilik (Bruce Head) had a duty cycle, sampling alternately at 64 kHz for 14 minutes and a 637.5 kHz for 1 minute.

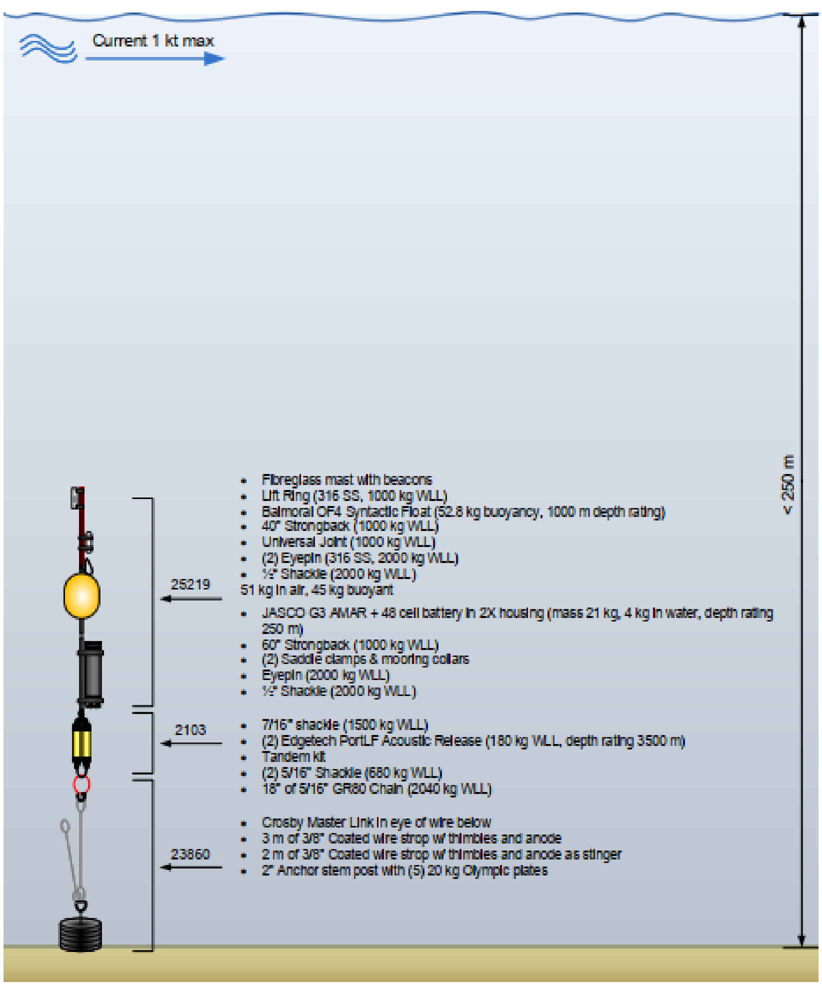

Figure 4. The Autonomous Multichannel Acoustic Recorder used to measure underwater sound in and near Milne Inlet and in Eclipse Sound.

2.1.1. Deployment Locations

AMARs were deployed at three locations (Table 3, Figure 1) near Bylot Island, Ragged Island, and Bruce Head. The Ragged Island and Bylot Island recorders began recording on 12 Jul 2020 and sampled continuously until their retrieval on 5 Sep 2020 (the Ragged Island recorder batteries were depleted on 3 Sep 2020. The Bruce Head recorder was deployed 1 Aug 2020 and was retrieved early September at the same time as the other two recorders. Full details of deployment locations and cycles appear in Table 3. The Bylot Island and Ragged Island recorders were deployed from the *MSV Botnica* (Figure 5) and the Bruce Head recorder from Baffinland's Research Vessel (Figure 6). All recorders were retrieved from the Research Vessel.

Table 3. Operation period and location of the Autonomous Multichannel Acoustic Recorders (AMARs) deployed for the 2020 Passive Acoustic Monitoring (PAM) program.

Station	Latitude	Longitude	Water depth (m)	Start date/ Time	Stop date/ Time	Recording duration (days)
Ragged Island	72.55742°N	–80.2071°W	91	2020 Jul 12 00:00:00	2020 Sep 3 1:00:00	53 (20 shoulder, 33 open water)
Bylot Island	72.72408°N	–79.2139°W	297	2020 Jul 12 00:00:00	2020 Sep 5 15:38:00	55 (20 shoulder, 35 open water)
Bruce Head	72.06727°N	–80.5182°W	225	2020 Aug 1 02:40:31	2020 Sep 6 18:42:00	35

Figure 5. Vessel *MSV Botnica* used for deployment of Bylot Island and Ragged Island recorders.

Figure 6. BIM Research Vessel used for Bruce Head AMAR deployments and retrievals, and Bylot Island and Ragged Island retrievals.

2.1.2. Analysis of Total Ocean Sound Levels

The data collected in Milne Inlet and Eclipse Sound span 1–2 months at each of the three stations at 10–32,000 Hz (at Bylot Island and Ragged Island) or 10–343,750 Hz (at Bruce Head). The goal of the total ocean sound analysis is to present this expansive data in a manner that documents the baseline underwater sound conditions surrounding Baffinland's Mary River Project to make comparisons between stations, over time, and with external factors that change sound levels such as weather and human activities.

The first stage of the total sound level analysis involves computing the peak pressure level (PK) and sound pressure level (SPL) for each minute of data. This reduces the data to a manageable size without compromising the value for characterizing the soundscape (ISO 2017b, Ainslie et al. 2018, Martin et al. 2019). The SPL analysis was performed by averaging 120 fast-Fourier transforms (FFTs) that each include 1 s of data with a 50% overlap and that use the Hann window to reduce spectral leakage. The 1 minute average data were stored as power spectral densities (1 Hz resolution) and summed over frequency to calculate decidecade band SPL levels. Decidecade band levels are very similar to 1/3-octave-band levels. Appendix A.2 lists the decidecade band and decade-band frequencies. The decidecade analysis sums the frequency range from the 180,000 frequencies (representing the frequency range 1 Hz to 180 kHz) in the power spectral density data to a manageable set of 43 bands that approximate the critical bandwidths of mammal hearing. The decade bands further summarize the sound levels into four frequency bands for manageability. Detailed descriptions of the acoustic metrics and decidecade analysis can be found in Appendix A.

2.1.3. Vessel Noise Detection

Vessels were detected in two steps:

1. Constant, narrowband tones (also referred to as tonals) produced by a vessel's propulsion system and other rotating machinery (Arveson and Vendittis 2000) were detected as frequency peaks in a 0.125 Hz resolution spectrogram of the data.
2. SPL was assessed for each minute in the 40–315 Hz frequency band, which commonly contains most sound energy produced by mid- to large-sized vessels. Background estimates of the shipping band SPL and broadband SPL are then compared to their median values over the 12 h window, centred on the current time.

Vessel detections were defined by three criteria:

- The SPL in the shipping band was at least 3 dB above the median.
- At least five shipping tonals (0.125 Hz bandwidth) were present.
- The SPL in the shipping band was within 8 dB of the broadband SPL (Figure 7).

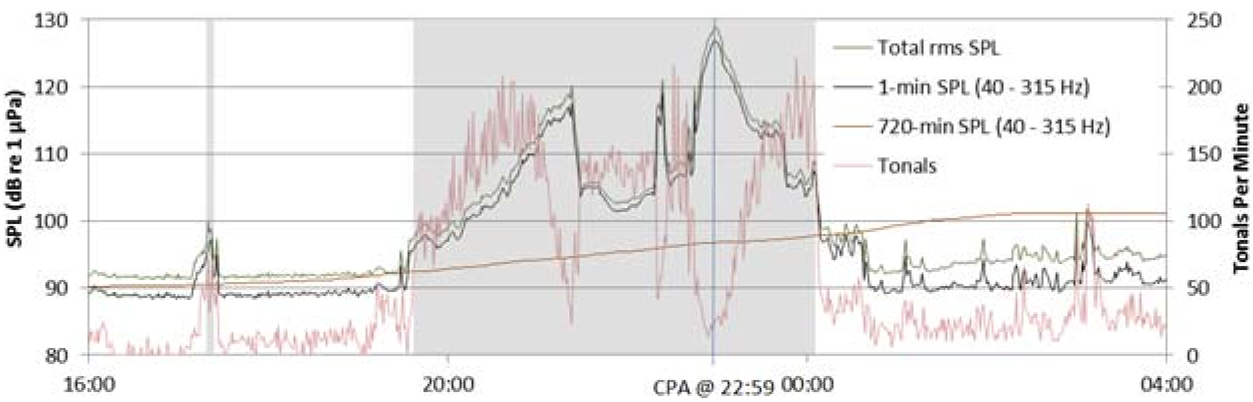

Figure 7. Example of broadband and 40–315 Hz band sound pressure level (SPL), as well as the number of tonals detected per minute as a ship approached a recorder, stopped, and then departed. The shaded area is the period of shipping detection. Fewer tonals are detected at the ship's closest point of approach (CPA) at 22:59 because of masking by broadband cavitation noise and due to Doppler shift that affects the tone frequencies and causes the detector to lose track of them.

2.2. Listening Range Reduction Calculations

The term "listening space" refers to the area over which sources of sound can be detected by an animal at the centre of the space. Listening range reduction (LRR) is the fractional decrease in the available listening range for marine animals (similar to listening space reduction (Pine et al. 2018b), however, the more intuitive range instead of the area is computed). LRR is computed in specific critical hearing bands (Equation 1, Equation 7 from Pine et al. (2018a), modified to remove the factor of 2). In Equation 1, NL_2 is SPL with the masking noise present, NL_1 is SPL without the masking present, and N is the geometric spreading coefficient for the acoustic propagation environment. The sound pressure levels are computed for decidecade bands (previously called 1/3-octave-bands) that are representative of the important listening frequencies for animals of interest.

$$\mathrm{LRR} = 100 * (1 - 10^{\frac{-(NL_2 - NL_1)}{N}}) \quad (1)$$

LRR for narwhal were calculated to evaluate the effects of shipping noise on their listening space during the early shoulder and open-water seasons. LRR calculates a fractional reduction in an animal's listening range when exposed to a combination of anthropogenic and natural ambient noise sources compared to that range under natural ambient conditions (i.e., representing the proportional reduction in distance at which a signal of interest can be heard, in the presence of noise). LRR does not provide absolute areas or volumes of space. However, a benefit of the LRR method is that it does not rely on source levels of the sounds of interest, which is often unknown. Instead, the method depends only on the transmission loss.

LRR was calculated for three frequencies representative of five types of narwhal vocalizations, for all AMAR locations. At each location, LRR was determined for narwhal low-frequency buzzes (or burst pulses) using 1 kHz as the representative frequency, for whistles and knock trains using 5 kHz as a representative frequency (mean frequency; Marcoux et al. 2012), and for clicks and high-frequency buzzes using 25 kHz as a representative frequency (25 kHz is the maximum 1/3-octave available for data sampled at 64 kHz; narwhal mid-frequency clicks have a mean frequency of ~10 kHz (Stafford et al. 2012); high-frequency clicks have a centre frequency of 53 kHz; (Rasmussen et al. 2015)). It is thought that low-frequency buzzes, whistles and knocks are call types used for communication and that clicks and high frequency buzzes and clicks are associated with feeding and orientation.

The data were divided into periods with and without vessel detections. The normal listening range was determined using the maximum of the mid-frequency cetacean audiogram (see Table A-9 in Finneran 2015) or the median 1-minute SPL without vessels in each of the 1/3-octave-bands of interest as the baseline hearing threshold (Table 4). The geometric spreading coefficient was set to a nominal value of 15. The analysis was performed for each 1 dB of increased 1/3-octave-band SPL above the normal condition.

Table 4. Parameters used to determine the normal condition, NL_1, in calculations of Listening Range Reduction (LRR).

Band center frequency (kHz)	Decidecade band baseline ambient level (dB re 1 µPa)					Hearing threshold for mid-frequency cetaceans * (dB re 1 µPa)
	Early shoulder season		Open-water season			
	Bylot Island	Ragged Island	Bylot Island	Ragged Island	Bruce Head	
1	81.0	74.4	78.0	79.1	83.8	96.7
5	81.6	75.4	76.9	78.1	82.0	74.1
25	75.8	71.0	71.9	73.5	75.4	57.2

* From Finneran 2016, Equation A-9 and Table A-3.

2.3. Marine Mammal Detection Overview

We used a combination of automated detector-classifiers (referred to as automated detectors) and manual review by experienced analysts to determine the presence of sounds produced by marine mammals in the acoustic data. First, a suite of automated detectors was applied to the full data set (see Appendices B.1 and B.2). Second, a subset (3%) of acoustic data was selected for manual analysis of marine mammal acoustic occurrence. The subset was selected based on automated detector results via our Automatic Data Selection for Validation (ADSV) algorithm (Kowarski et al. 2021) (see Appendix B.3). Third, manual analysis results were compared to automated detector results to determine automated detector performance (see Appendix B.4). Finally, hourly marine mammal occurrence plots were created that incorporated both manual and automated detections (see Section 3.3) and automated detector performance metrics were provided (see Appendix C) to present a reliable representation of marine mammal presence in the acoustic data. These marine mammal analysis steps are summarised here and described in detail in Appendix A.

2.3.1. Automated Click Detection

Odontocete clicks are high-frequency impulses ranging from 5 to over 150 kHz (Au et al. 1999, Møhl et al. 2000). We applied an automated click detector to the acoustic data to identify clicks from sperm whales, delphinids, beaked whales, and *Monodontidae* sp. This automated detector is based on zero-crossings in the acoustic time series. Zero-crossings are the rapid oscillations of a click's pressure waveform above and below the signal's normal level (e.g., Figure B-1). Zero-crossing-based features of automatically detected events are then compared to templates of known clicks for classification (see Appendix B.1 for details).

2.3.2. Automated Tonal Signal Detection

Tonal signals are narrowband, often frequency-modulated, signals produced by many species across a range of taxa (e.g., baleen whale moans, odontocete whistles, and pinniped moans). They range predominantly between 15 Hz and 20 kHz (Steiner 1981, Berchok et al. 2006, Risch et al. 2007). The automated tonal signal detector identified continuous contours of elevated energy and classified them against a library of marine mammal signals (see Appendix B.2 for details).

2.3.3. Evaluating Automated Detector Performance

JASCO's suite of automated detectors are developed, trained, and tested to be as reliable and broadly applicable as possible. However, the performance of marine mammal automated detectors varies across acoustic environments (e.g., Hodge et al. 2015, Širović et al. 2015, Erbs et al. 2017, Delarue et al. 2018). Therefore, automated detector results must always be supplemented by some level of manual review to evaluate automated detector performance. Here, we manually analysed a subset of acoustic files for the presence/absence of marine mammal acoustic signals via spectrogram review in JASCO's PAMlab software. A subset (3%) of acoustic data from each station and sampling rate was selected via ADSV for manual review (see Appendix B.3).

To determine the performance of the automated detectors at each station per acoustic file (30 min files sampled at 64 kHz at Bylot Island and Ragged Island; 14 min files sampled at 64 kHz and 1 min files sampled at 687.5 kHz at Bruce Head), the automated and manual results (excluding files where an analyst indicated uncertainty in species occurrence) were fed into an algorithm that calculates precision (*P*), recall (*R*), and Matthew's Correlation Coefficient (*MCC*) (see Appendix B.4 for formulas). *P* represents the proportion of files with detections that are true positives. A *P* value of 0.90 means that 90% of the files with automated detections truly contain the targeted signal, but it does not indicate whether all files containing acoustic signals from the species were identified. *R* represents the proportion of files containing the signal of interest that were identified by the automated detector. An *R* value of 0.90 means that 90% of files known to contain a target signal had automated detections, but it says nothing about how many files with automated detections were incorrect. An MCC is a combined measure of *P* and *R*, where an MCC of 1.00 indicates perfect performance–all events were correctly automatically detected. The algorithm determines a per file automated detector threshold (the number of automated detections per file at and above which automated detections were considered valid) that maximizes the MCC.

Only detections associated with a *P* greater than or equal to 0.75 were considered. When $P < 0.75$, only the validated results were used to describe the acoustic occurrence of a species.

The occurrence of each species (both validated and automated, or validated only where appropriate) was plotted using JASCO's Ark software as time series showing presence/absence by hour over each day of the recording period. Automated detector performance metrics are provided in Appendix C and should be considered when interpreting results. For example, where an automated detector has a Recall of 0.90, readers must take into account when interpreting the occurrence figure that it is an underestimate of vocalization occurrence as 10% of acoustic files containing the signal of interest were not captured by the automated detector.

3. Results

3.1. Ambient Noise Measurements

3.1.1. Total Ocean Sound Levels

Total ocean sound levels are presented as:

- **Band-level plots:** These strip charts show the averaged received sound pressure levels as a function of time within a given frequency band. We show the total sound levels (across the entire recorded bandwidth from 10 to 32,000 Hz or 343,750 Hz) and the levels in the decade bands of 10–100, 100–1000, 1000–10,000, 10,000–100,000 Hz, and 100–1000 kHz depending on the recording bandwidth. The 10–100 Hz band is associated with fin, sei, and blue whales, large shipping vessels, flow and mooring noise, and seismic survey pulses. Sounds within the 100–1000 Hz band are generally associated with the physical environment such as wind and wave conditions but can also include both biological and anthropogenic sources such as minke, right, and humpback whales, fish, nearby vessels, and pile driving. Sounds above 1000 Hz include high-frequency components of humpback whale sounds, odontocete whistles and echolocation signals, wind- and wave-generated sounds, and sounds from human sources at close range including pile driving, vessels, seismic surveys, and sonars.
- **Long-term Spectral Averages (LTSAs)**: These color plots show power spectral density levels as a function of time (*x*-axis) and frequency (*y*-axis). The frequency axis uses a logarithmic scale, which provides equal vertical space for each decade increase in frequency and allows the reader to equally see the contributions of low and high-frequency sound sources. The LTSAs are excellent summaries of the temporal and frequency variability in the data.
- **Decidecade box-and-whisker plots**: In these figures, the 'boxes' represent the middle 50% of the range of sound pressure levels measured, so that the bottom of the box is the sound level 25th percentile (L_{25}) of the recorded levels, the bar in the middle of the box is the median (L_{50}), and the top of the box is the level that exceeded 75% of the data (L_{75}). The whiskers indicate the maximum and minimum range of the data.
- **Spectral density level percentiles**: The decidecade box-and-whisker plots are representations of the histogram of each band's sound pressure levels. The power spectral density data have too many frequency bins for a similar presentation. Instead, colored lines are drawn to represent the L_{eq}, L_5, L_{25}, L_{50}, L_{75}, and L_{95} percentiles of the histograms. Shading is provided underneath these lines to provide an indication of the relative probability distribution. It is common to compare the power spectral densities to the results from Wenz (1962), which documented the variability of ambient spectral levels off the US Pacific coast as a function of frequency of measurements for a range of weather, vessel traffic, and geologic conditions. The Wenz levels are appropriate for approximate comparisons only since the data were collected in deep water, largely before an increase in low-frequency sound levels (Andrew et al. 2011).
- **Daily sound exposure levels (SEL; $L_{E,24h}$)**: The SEL represents the total sound energy received over a 24 h period, computed as the linear sum of all 1-minute values for each day. It has become the standard metric for evaluating the probability of temporary or permanent hearing threshold shift. Long-term exposure to sound impacts an animal more severely if the sounds are within its most sensitive hearing frequency range. Therefore, during SEL analysis recorded sounds are typically

filtered by the animal's auditory frequency weighting function before integrating to obtain SEL. For this analysis the 10 Hz and above SEL were computed as well as the SEL weighted by the marine mammal auditory filters (Appendix D) (NMFS 2018). The SEL thresholds for possible hearing impacts from sound on marine mammals are provided in Table AE-1 of NMFS (2018).

- **Cumulative Distribution Functions (CDFs):** Empirical distribution functions quantify the proportion of data that exceeded a given SPL. To obtain these, the broadband 1-minute SPL data were sorted from smallest to largest, and then the total number of minutes that were greater than a given sound pressure level were computed as a percentage of the recording duration. These plots can be interpreted in two ways: the y-axis on these plots give the percent of the data that were below the corresponding x-axis value, and the integral of the y-axis values for all data to the right of a given x-axis value provides the exceedance value for that SPL.

The spectrogram and band-level plots for all stations (left panels of Figures 8–10) provide an overview of the sound variability in time and frequency presenting an overview of presence and level of contribution from different sources. Short-term events appear as vertical stripes on the spectrograms and spikes on the band level plots. Long-term events affect (increasing or decreasing accordingly) the band level over the event period and appear in the spectrograms as horizontal bands of colour. The percentile figures (right panels of Figures 8–10) show boxplots by decidecade band (top panels) and power spectral density by percentile. Spikes in the percentiles can be indicative of longer-term trends or major events in specific frequency bands. Cumulative distribution functions for each recorder are plotted in Figure 11 for the early shoulder season recordings and Figure 12 for the open water season recordings.

The dominant anthropogenic contribution to the ambient soundscape at the Bylot Island and Ragged Island stations is from vessel noise. Due to its proximity to the shipping lane, the Ragged Island recording station is the most influenced by vessel noise, which is particularly evident in the recording period when the 10–100 Hz range demonstrated elevated sound levels. Vessel noise was reduced at Bruce Head in comparison to the other two stations; in 2020 the shipping lane through southern Milne Inlet was redirected farther east to minimize interference between shipping and hunting activities at the base of Bruce Head. This meant that the recorder at the Bruce Head location was farther from the shipping lane compared to acoustic recordings in previous years.

In the July to September recording period, both Bylot Island and Ragged Island demonstrate an increase across all decade bands around approximately 20 Jul 2020, which is attributed to the breakup of ice and the onset of the shipping season; the first transit occurred on 21 Jul 2020. Note that the Bruce Head recording began in August, following the start of the shipping season.

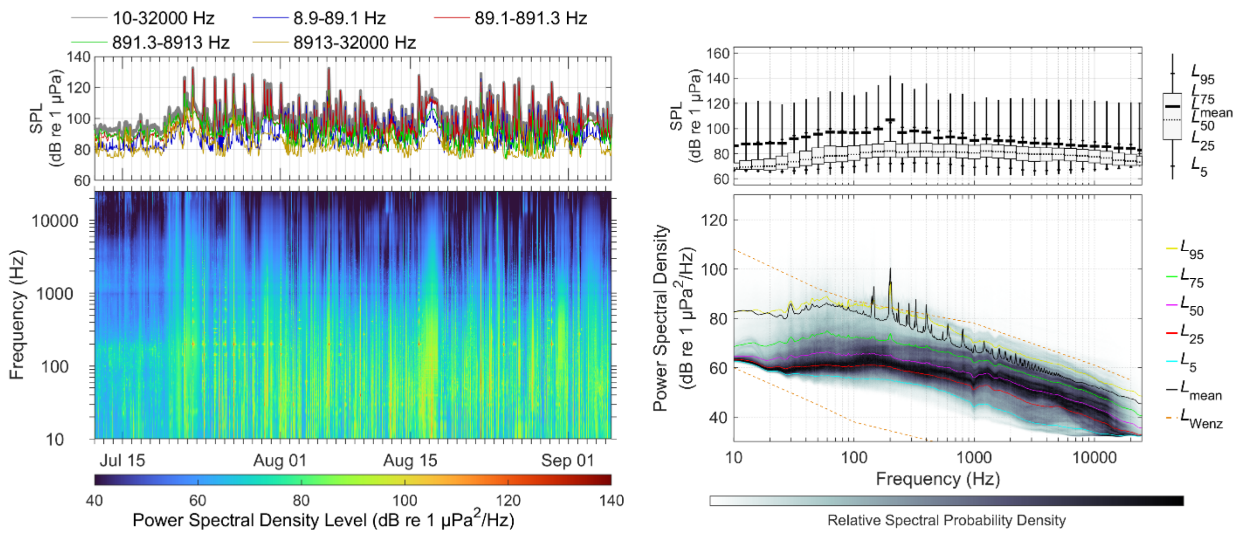

Figure 8. Bylot Island: (left) In-band sound pressure level (SPL) and spectrogram of underwater sound. (Right) Exceedance percentiles and mean of decidecade-band SPL and exceedance percentiles and probability density (grayscale) of 1-min power spectrum density (PSD) levels compared to the limits of prevailing noise (Wenz 1962).

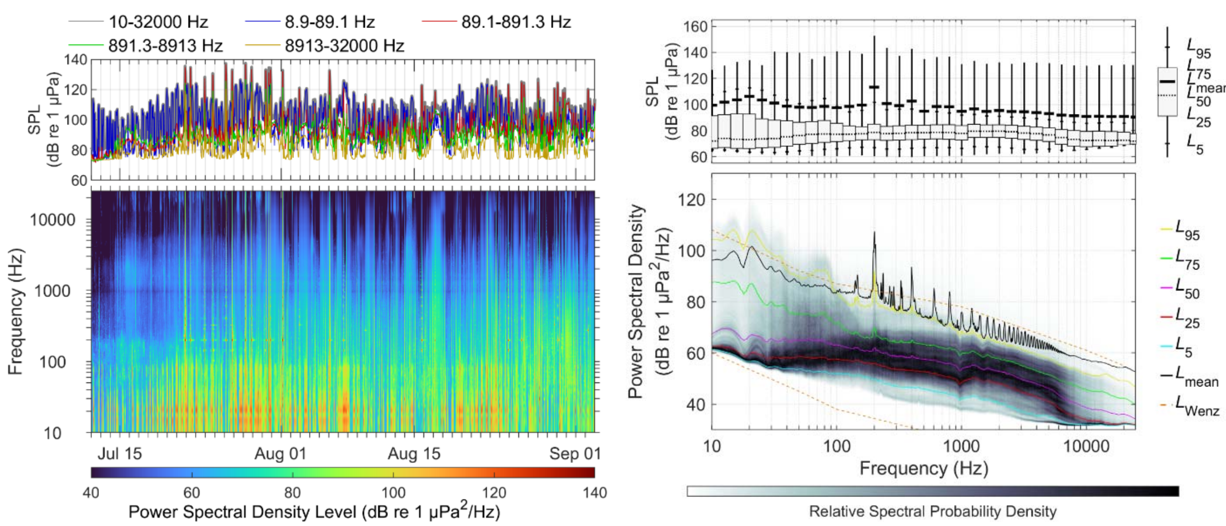

Figure 9. Ragged Island: (left) In-band sound pressure level (SPL) and spectrogram of underwater sound. (Right) Exceedance percentiles and mean of decidecade-band SPL and exceedance percentiles and probability density (grayscale) of 1-min power spectrum density (PSD) levels compared to the limits of prevailing noise (Wenz 1962).

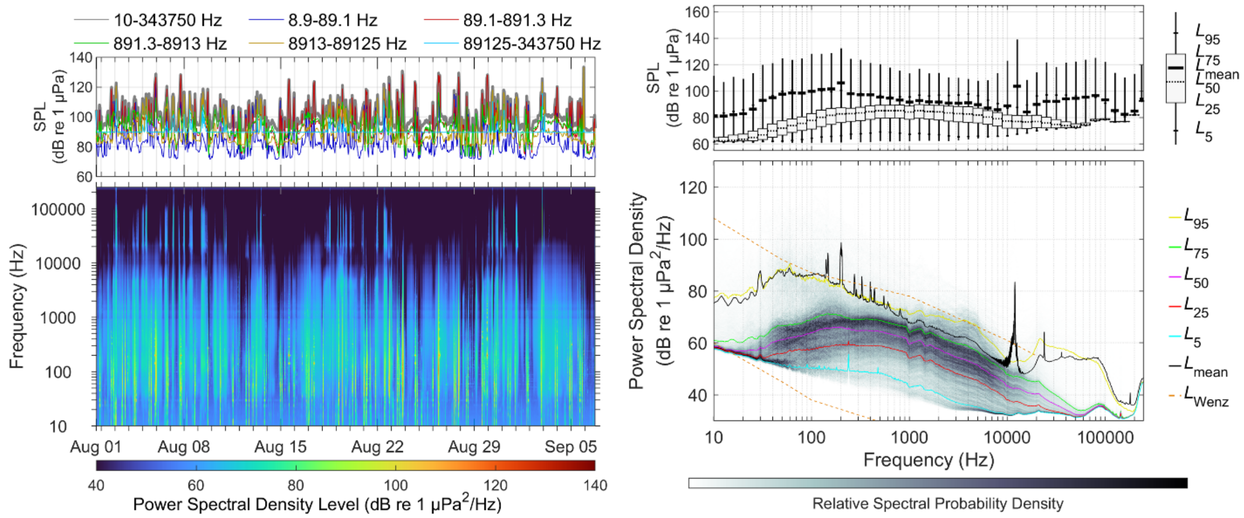

Figure 10. Bruce Head: (left) In-band sound pressure level (SPL) and spectrogram of underwater sound. (Right) Exceedance percentiles and mean of decidecade-band SPL and exceedance percentiles and probability density (grayscale) of 1-min power spectrum density (PSD) levels compared to the limits of prevailing noise (Wenz 1962). The recordings occurred from August to September 2020.

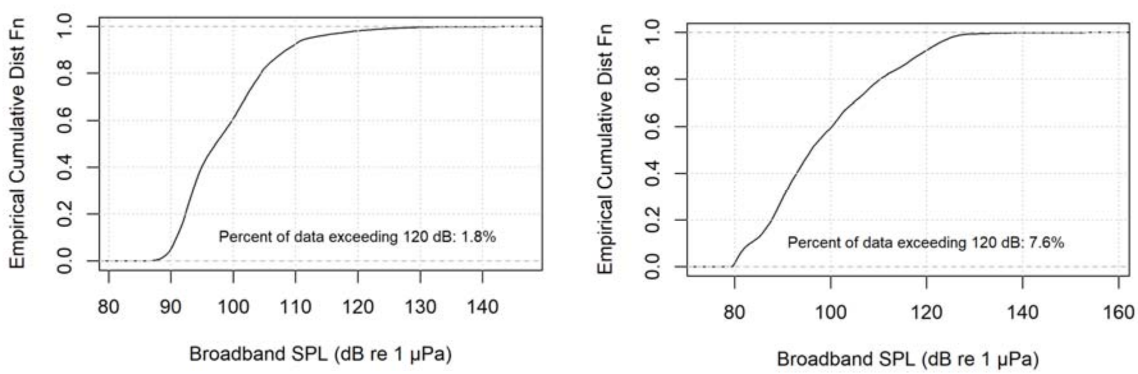

Figure 11. Empirical cumulative distribution functions for (left) Bylot Island and (right) Ragged Island during the 2020 early shoulder season recordings.

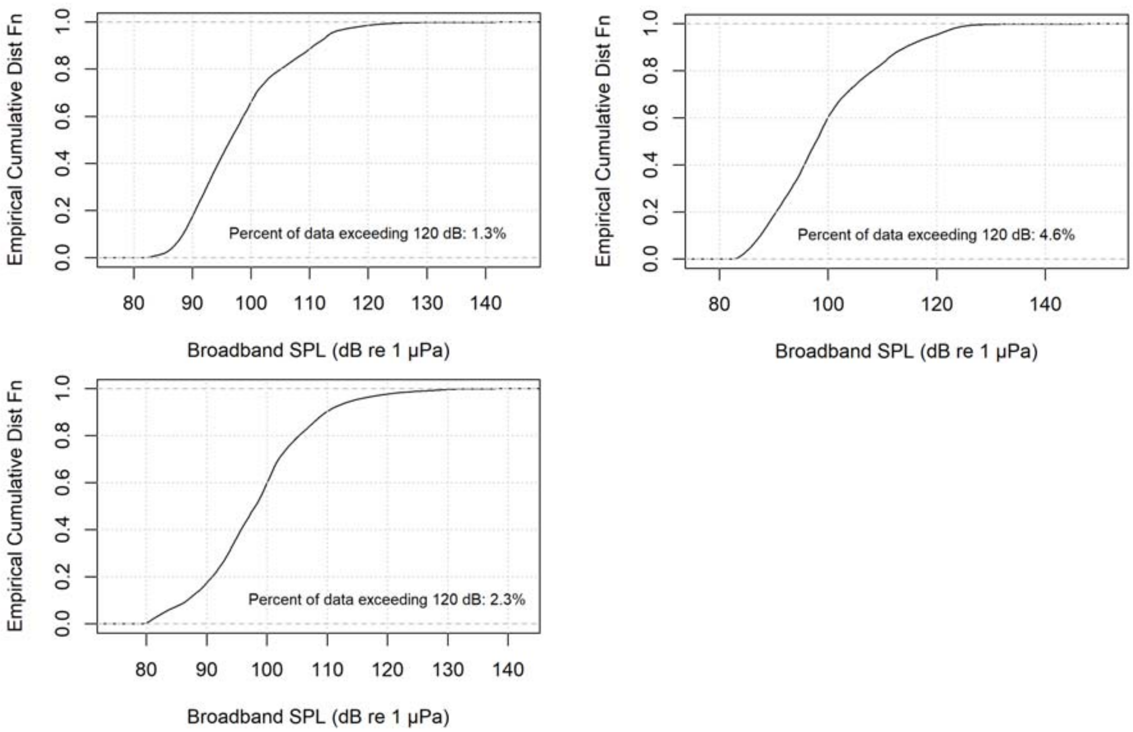

Figure 12. Empirical cumulative distribution functions for (top left) Bylot Island, (top right) Ragged Island, and (bottom left) Bruce Head during the 2020 open water season recordings.

3.1.2. Daily Sound Exposure Levels

The perception of underwater sound depends on the hearing sensitivity of the receiving animal in the frequency bands of the sound signal. Hearing sensitivity in animals varies with frequency, the hearing sensitivity curve (audiogram) usually follows a U-shaped curve (where there is a central frequency band of optimal hearing sensitivity and reduced hearing sensitivity at higher and lower frequencies). The hearing sensitivity frequency range differs between species, meaning that different species will perceive underwater sound differently, depending on the frequency content of the sound. Auditory frequency weighting functions for different functional hearing groups (see Appendix D) are applied to reflect an animal's ability to hear a sound and to de-emphasize frequencies animals do not hear well relative to the frequency band of best sensitivity. Figures 13–15 show the difference between perceived daily sound exposure by low-, mid-, and high-frequency cetaceans and pinnipeds (otariid and phocid). All daily sound exposure levels recorded during this study were below the thresholds for temporary or permanent hearing threshold shifts (i.e., hearing loss) for each functional hearing group (Southall et al. 2019).

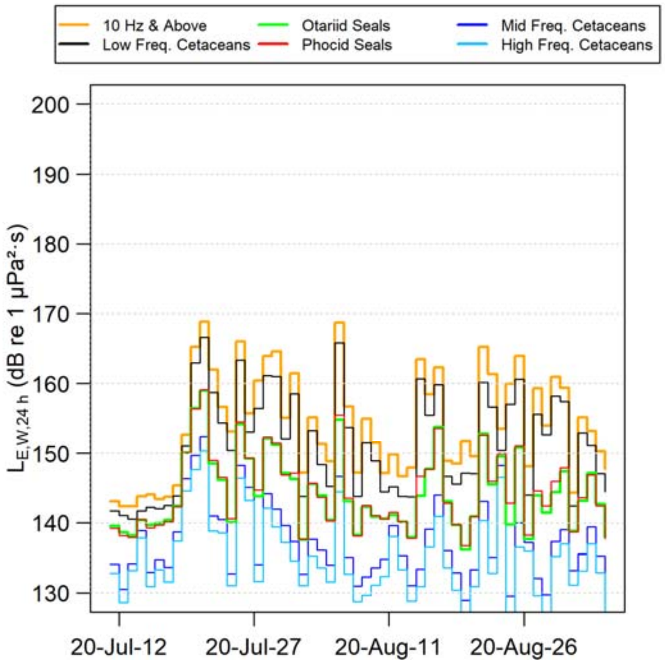

Figure 13. Bylot Island: Daily sound exposure level (SEL).

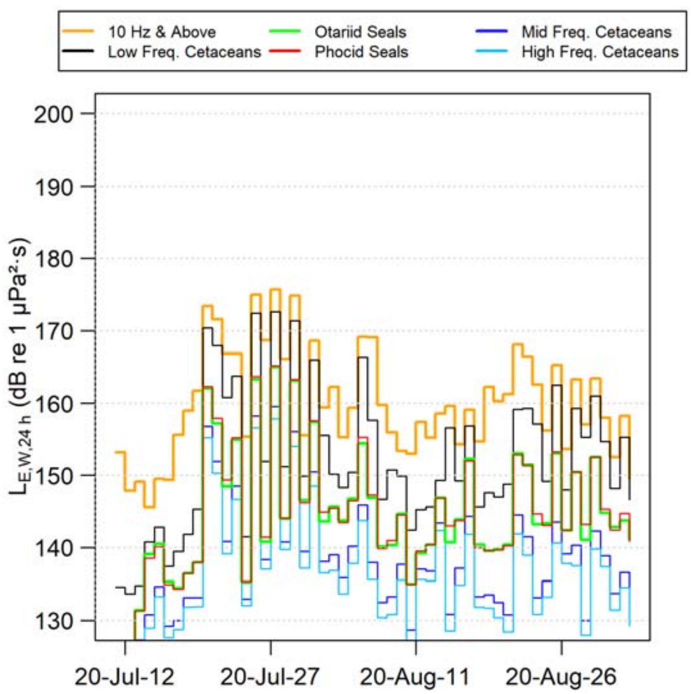

Figure 14. Ragged Island: Daily sound exposure level (SEL).

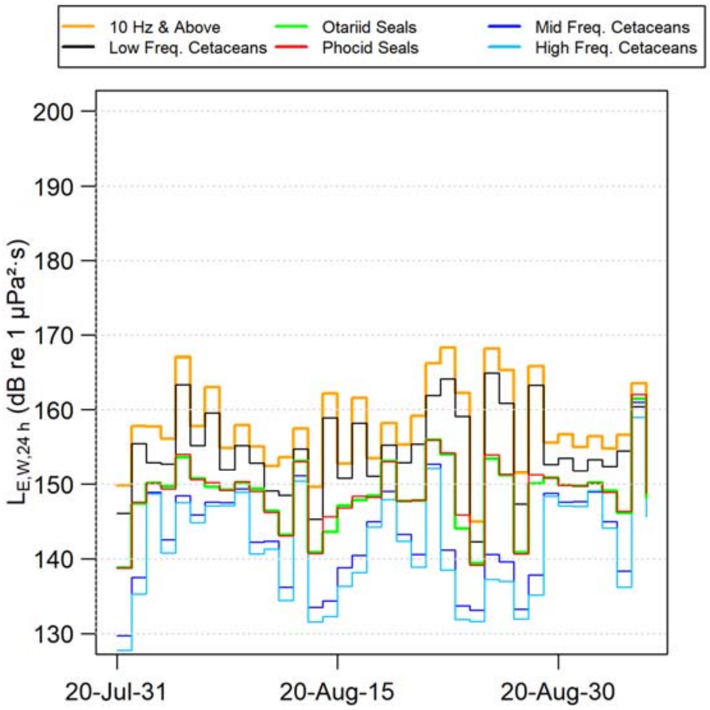

Figure 15. Bruce Head: Daily sound exposure level (SEL).

3.2. Vessel Detections

The bulk of vessel automated detections started on 21 Jul 2020 at Bylot Island and Ragged Island, which coincides with the first day of shipping in 2020. After that time, vessels were detected for several hours per day at both stations until the recorders were retrieved (see Section 4.2). When recordings started at Bruce Head on 1 Aug 2020, the shipping season was already underway. Vessels were also detected daily until the end of the deployment on 5 Sep 2020 (Figure 16).

Narwhal detections are plotted along vessel detections in Figure 16 (manual narwhal detections were chosen for display not to overlap the display of vessel detections; automated narwhal detections are presented in Section 3.3.3). Narwhal detections off Bylot Island stopped shortly after the beginning of the shipping season, while overlapping detections of vessels and narwhal vocalizations were identified throughout the recording period at both Ragged Island and Bruce Head. Thus, the decline in detections at Bylot Island is likely a result of the normal seasonal patterns in narwhal distribution in the Project Regional Study Area, which is corroborated by the 2020 aerial survey distribution data (Golder 2021b).

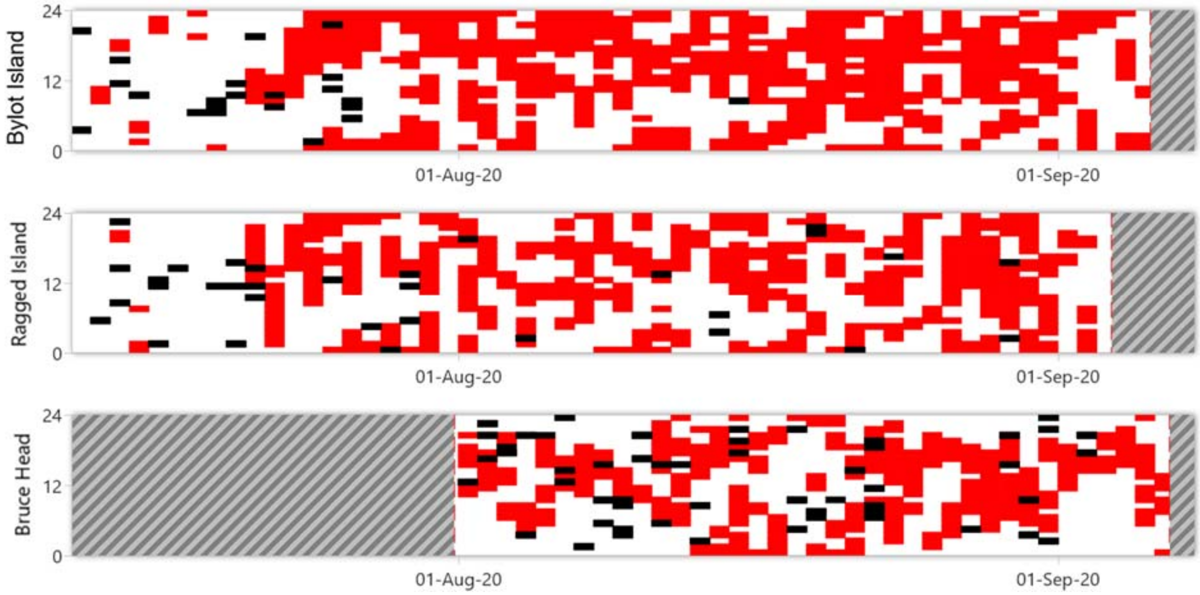

Figure 16. Vessel automatic detections (red) and narwhal manual detections (all call types, black) between 12 Jul and 10 Sep 2020. Hashed areas indicate times when there were no acoustic data.

3.3. Marine Mammal Detections

The acoustic presence of marine mammals was identified automatically by JASCO's detectors and validated via the manual review of 3% of the data (see Section 2.3), which represents 370 sound files, or ~106 h of data (1.75 h worth of 1-min 687.5 kHz sound files from Bruce Head, 24.73 h worth of 14-min 64 kHz sound files from Bruce Head, 41 h worth of 30-min 64 kHz sound files from Bylot Island, and 38.5 h worth of 30-min 64 kHz sound files from Ragged Island). Both the detectors and analysts found acoustic signals of bowhead, sperm, and killer whales as well as narwhal. In addition to these species, signals potentially produced by bearded seals, ringed seals, and beluga whales were identified. For each confirmed species, exemplar vocalizations and occurrence through the recording period are provided below along with the Precision and Recall values of automated detectors. Detailed automated detector results can be found in Appendix C. Where automated detectors were deemed to perform poorly (P>0.75), only manually validated results are presented.

3.3.1. Bowhead Whales

Bowhead whale moans (Figure 17) were present at a near hourly basis from 12–20 Jul 2020 at Bylot Island and Ragged Island, at which point the frequency of acoustic occurrence decreased through the remainder of July, and there were no detections in August or September 2020 (Figure 18). This is consistent with known patterns of bowhead migration through Eclipse Sound during the early shoulder season (JPCS 2017, QIA 2018). No acoustic data were available at Bruce Head during the period of peak bowhead whale occurrence at the other stations, but the species was identified during manual review in two instances in August (Figure 18).

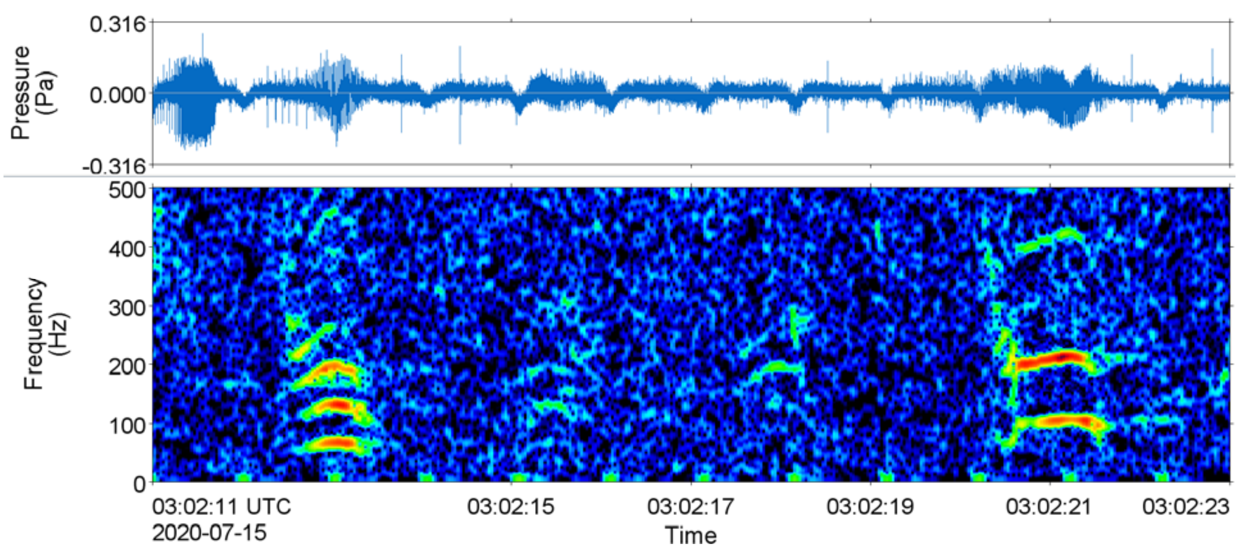

Figure 17. Spectrogram of bowhead whale vocalizations recorded on 15 Jul 2020 at the Ragged Island station (2 Hz frequency resolution, 0.128 s time window, 0.032 s time step, Hamming window, normalized across time, 12 s of data).

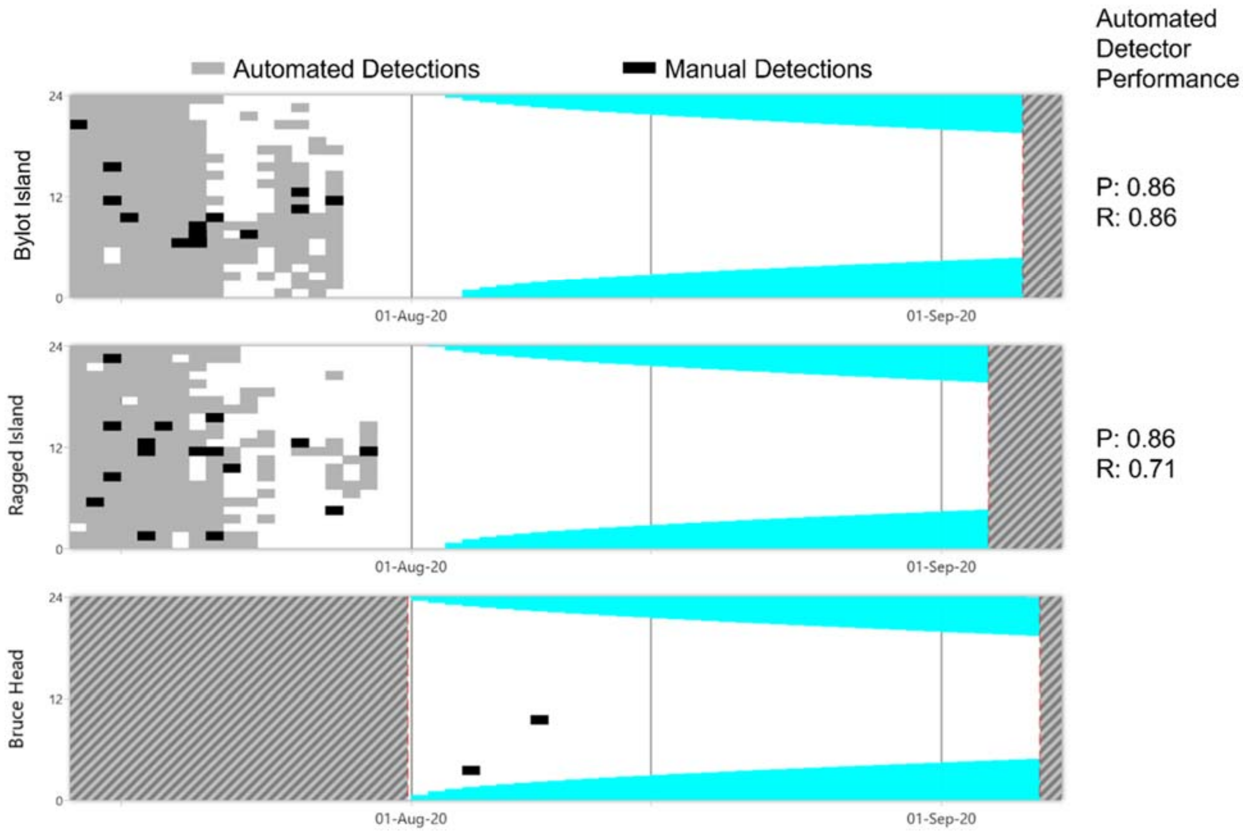

Figure 18. Hours per day with bowhead whale moan detections at each station through the recording period. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included along right side. The blue areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the MFMoanLow detector.

3.3.2. Killer Whales

Killer whale vocalizations (Figure 19) were rare in the data with the species only acoustically confirmed on 1–3 days in the latter half of August at all three stations (Figure 20).

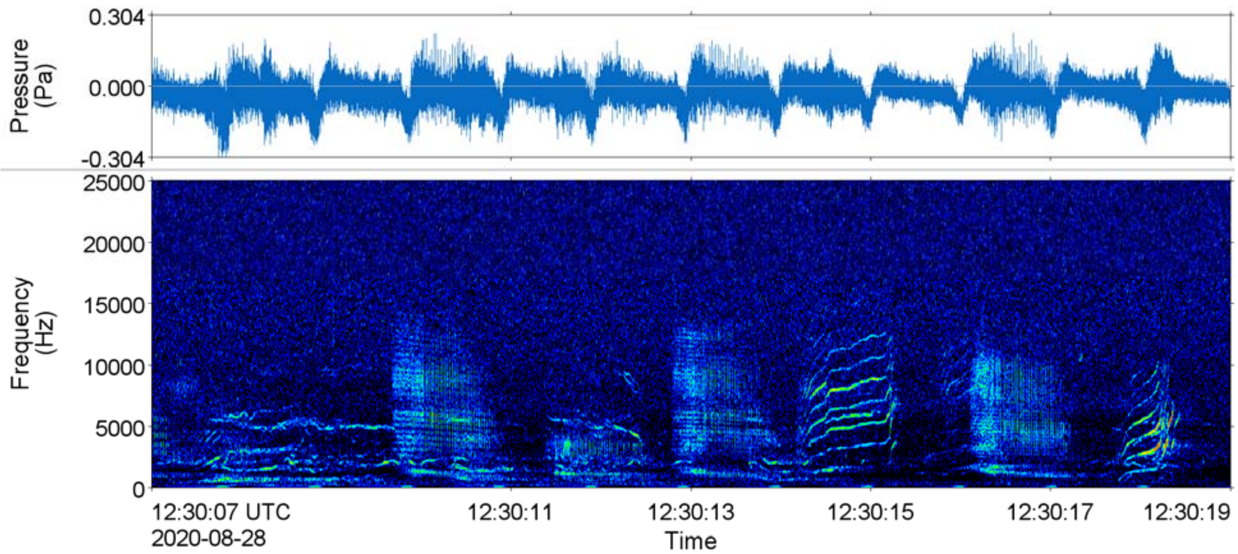

Figure 19. Waveform (top) and spectrogram (bottom) of killer whale whistles, buzzes, and clicks recorded on 28 Aug 2020 at the Bylot Island station (64 Hz frequency resolution, 0.01 s time window, 0.005 s time step, Hamming window, normalized across time, 10 s of data).

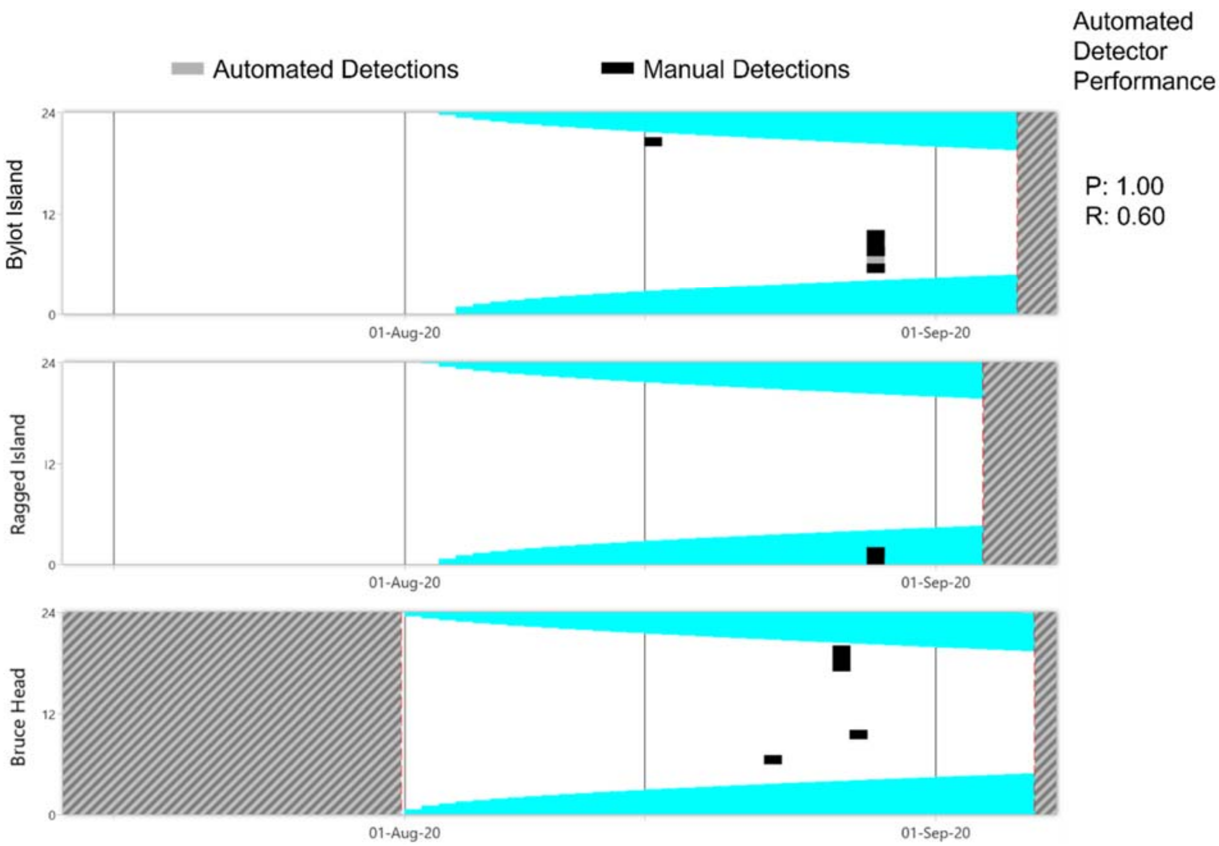

Figure 20. Hours per day with killer whale whistle detections at each station through the recording period. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included along right side. The blue areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the WhistleHigh detector.

3.3.3. Narwhal and Possible Beluga Whales

Narwhal vocalizations identified during manual analysis include clicks (and click trains), high-frequency buzzes, low-frequency buzzes, knock trains, and whistles (Figures 21 and 22). The co-occurrence of several signals attributed to narwhal allowed us to confidently identify this species. However, there is some overlap in the repertoire of beluga whales and narwhal, particularly in terms of clicks and whistles (e.g., Figure 23). Therefore, though there was never an instance where we could unequivicably confirm beluga whale presence, we cannot rule out that a subset of the narwhal detections presented here could be beluga whales or that beluga whales were not near or mingling with a group of narwhal. At Bylot Island, narwhal were acoustically present nearly hourly from 12–27 Jul 2020 but were not detected through August or September (Figures 24 to 29). At Ragged Island, narwhal occurred on a daily basis through most of July, before their acoustic occurrence decreased in August and September (Figures 24 to 29). In contrast, at Bruce Head, the species was common through August and September (Figures 24 to 29). These detections correspond with expected seasonal distribution and habitat use in the Regional Study Area for this species (QIA 2018).

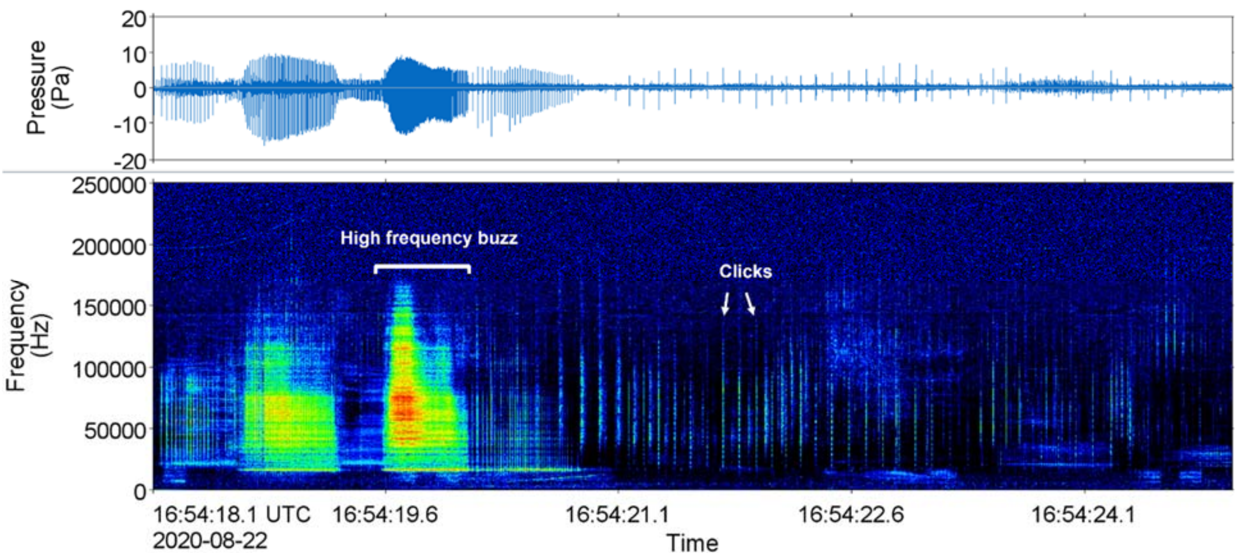

Figure 21. Waveform (top) and spectrogram (bottom) of narwhal clicks (including click trains) and high-frequency buzzes recorded on 22 Aug 2020 at Bylot Island (64 Hz frequency resolution, 0.01 s time window, 0.005 s time step, Hamming window, normalized across time, 6 s of data).

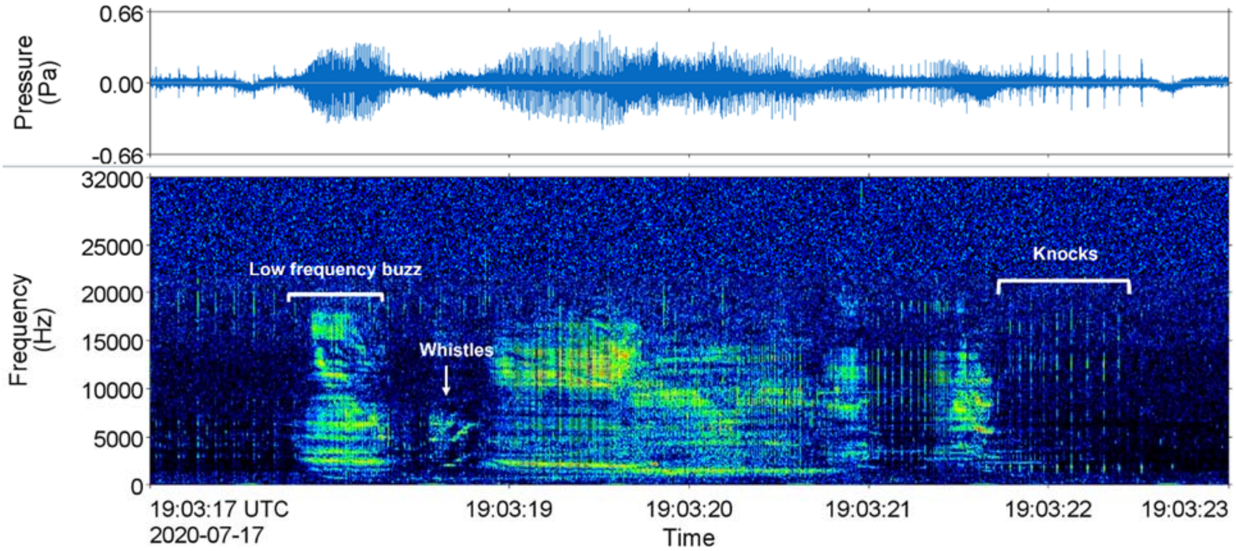

Figure 22. Waveform (top) and spectrogram (bottom) of narwhal knocks, whistles, and low-frequency buzzes recorded on 17 Jul 2020 at the Ragged Island station (64 Hz frequency resolution, 0.01 s time window, 0.005 s time step, Hamming window, normalized across time, 6 s of data).

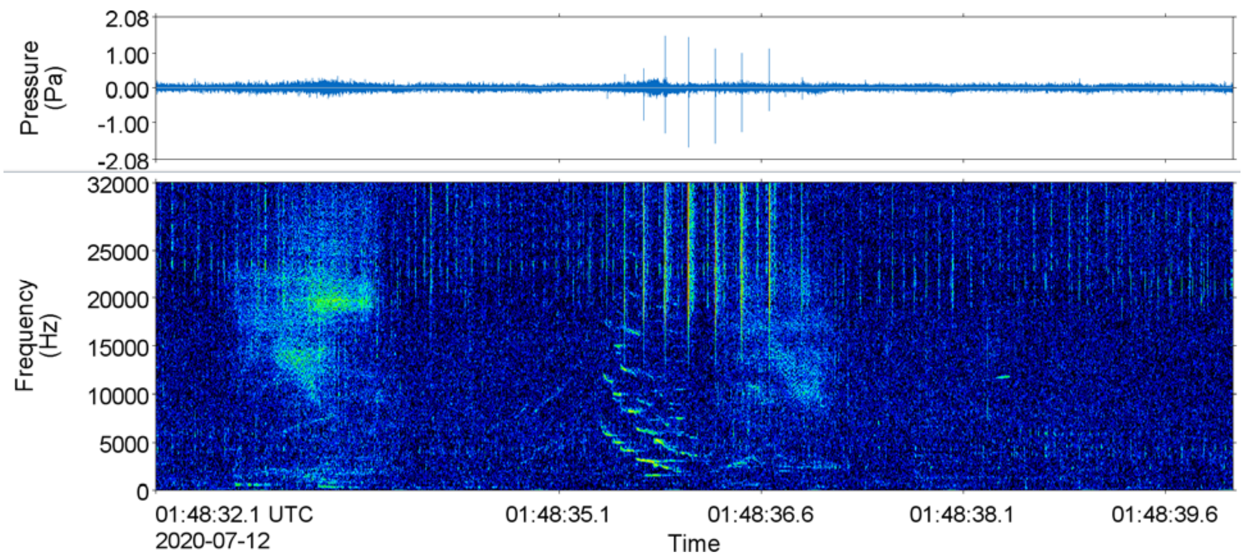

Figure 23. Waveform (top) and spectrogram (bottom) of whistles and clicks potentially produced by beluga whales recorded on 12 Jul 2020 at Bylot Island (64 Hz frequency resolution, 0.01 s time window, 0.005 s time step, Hamming window, normalized across time, 8 s of data).

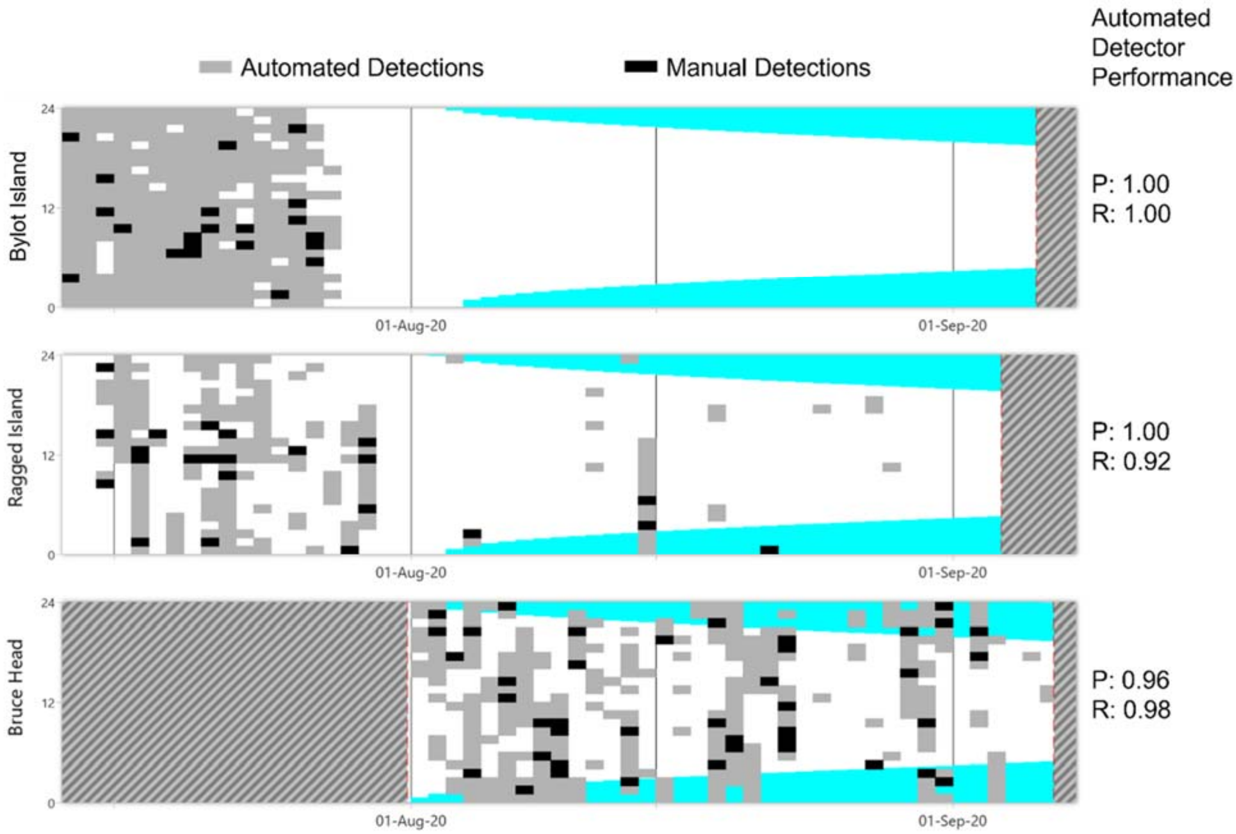

Figure 24. Hours per day with narwhal high-frequency buzz detections at each station through the recording period. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The blue areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the Narwhal HFbuzz detector.

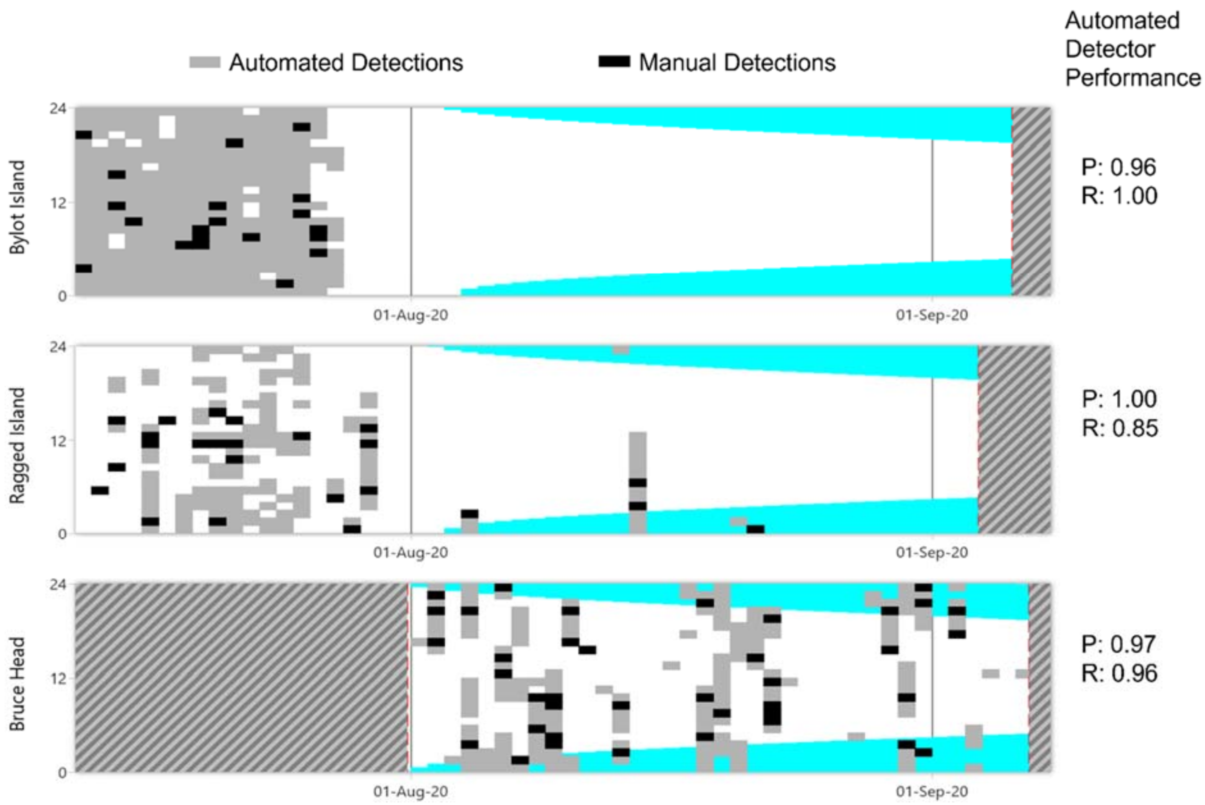

Figure 25. Hours per day with narwhal click detections at each station through the recording period. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The blue areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the narwhal click detector.

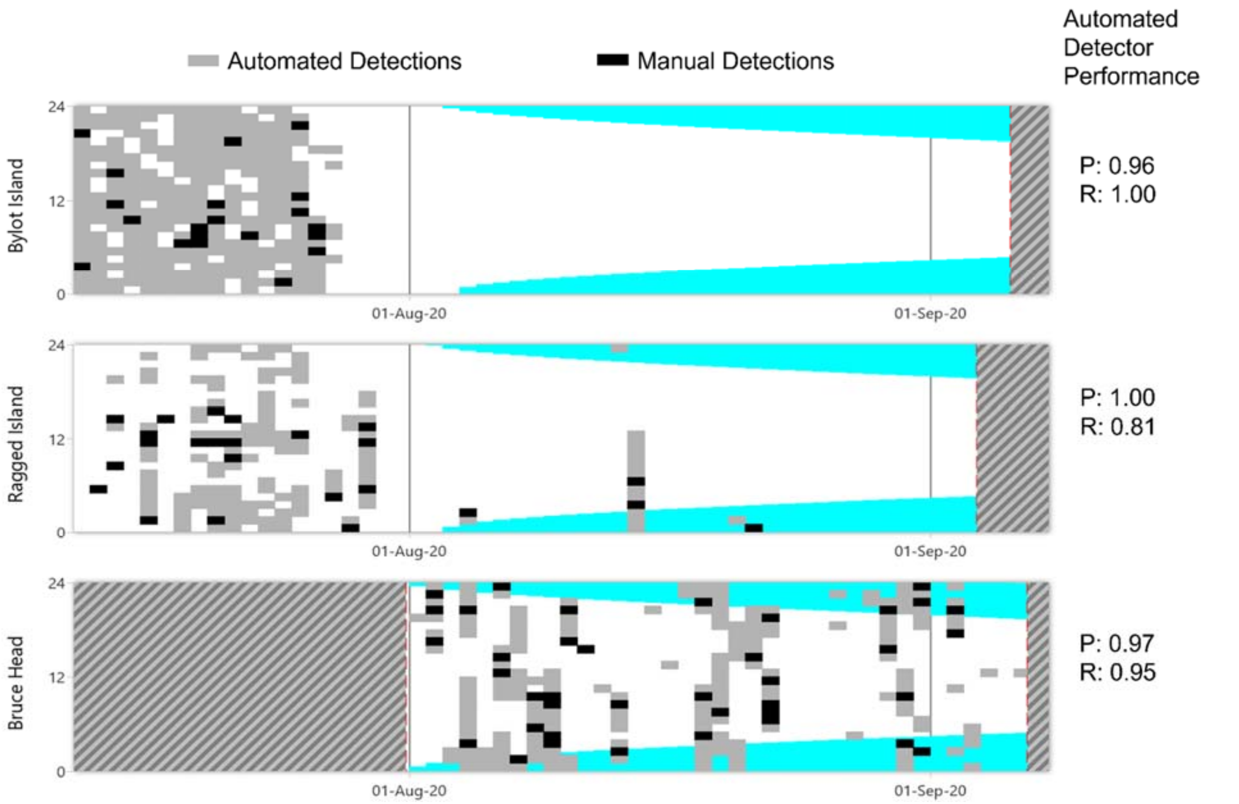

Figure 26. Hours per day with narwhal click train detections at each station through the recording period. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The blue areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the narwhal click train detector.

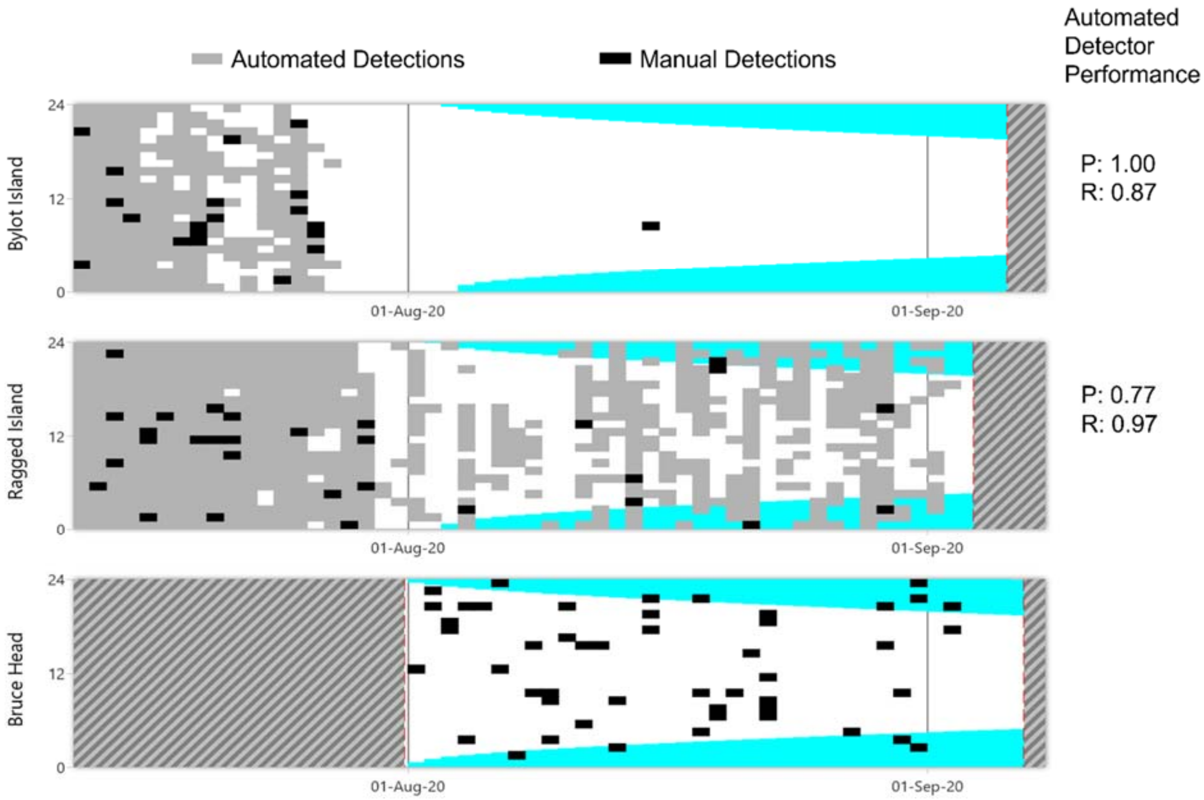

Figure 27. Hours per day with narwhal low-frequency buzz detections at each station through the recording period. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The blue areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the Narwhal_LFbuzz detector.

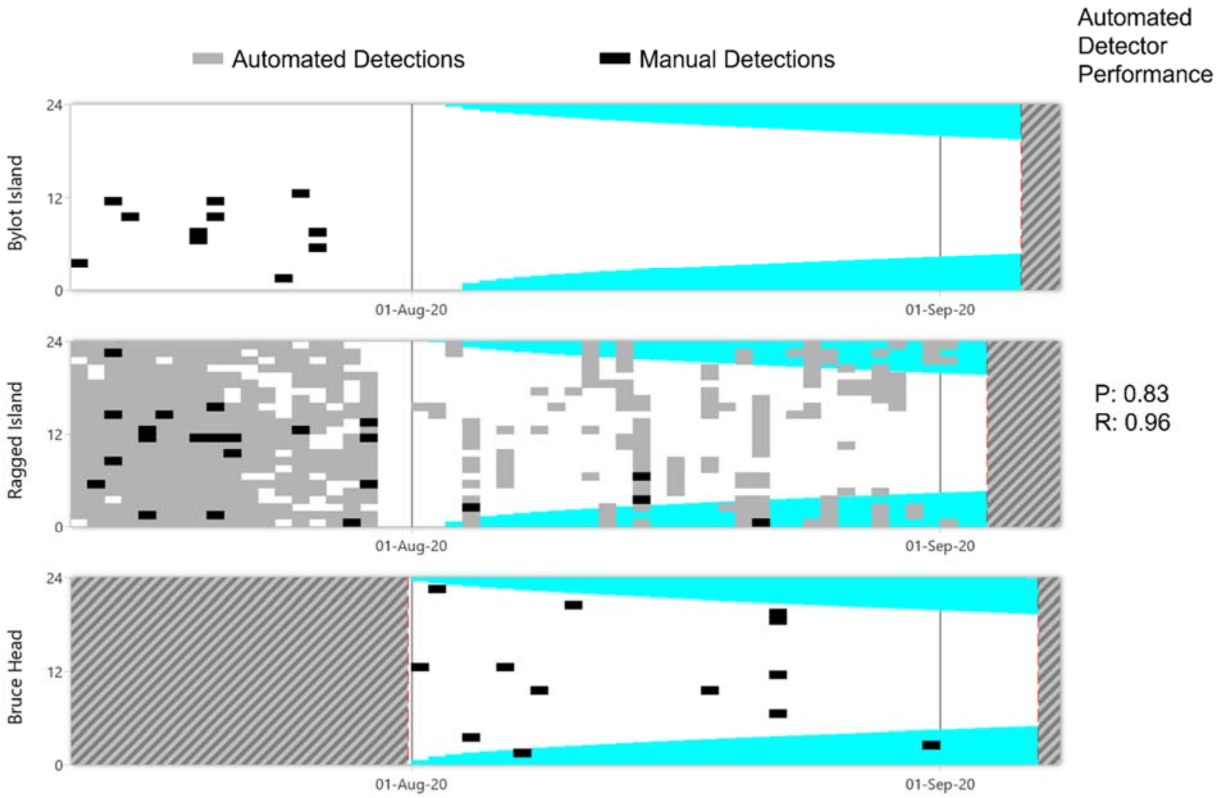

Figure 28. Hours per day with narwhal whistle detections at each station through the recording period. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The blue areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the Narwhal_Whistle detector.

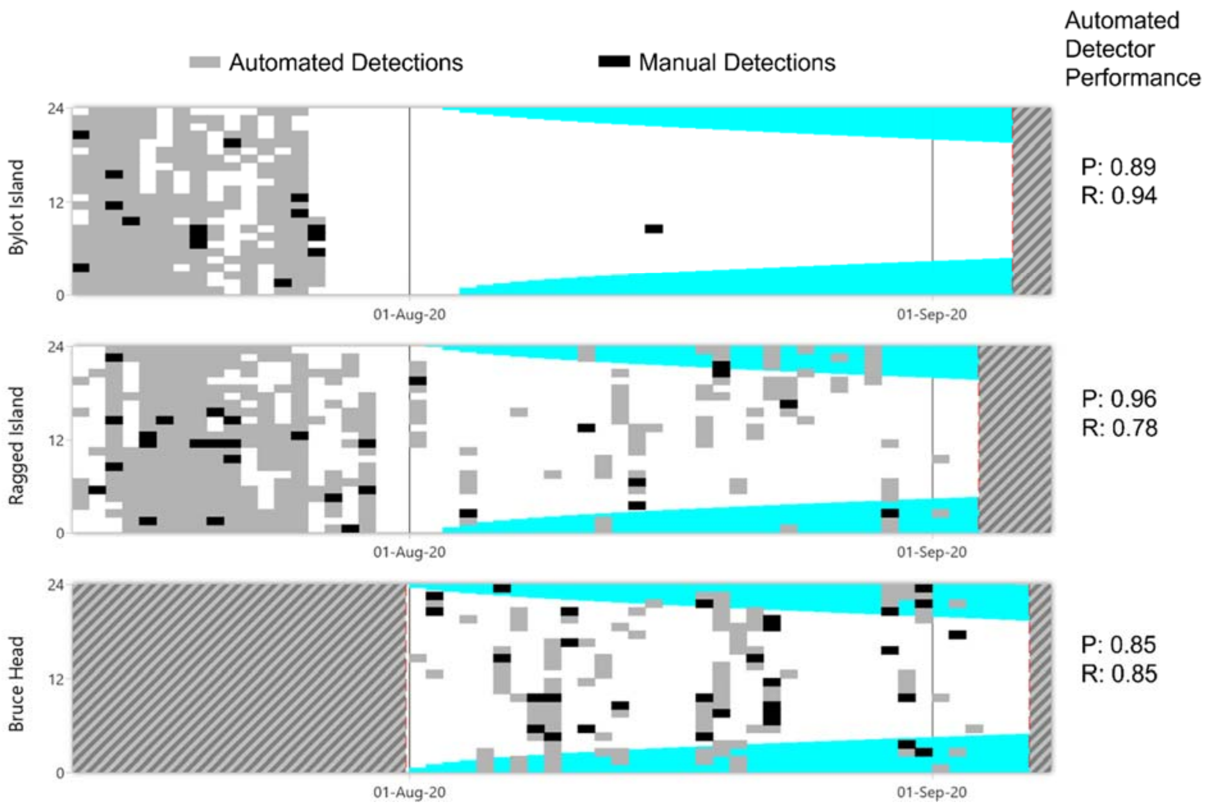

Figure 29 Hours per day with narwhal knock train detections at each station through the recording period. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The blue areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the NarwhalKnockTrain detector.

3.3.4. Pinnipeds

While pinniped vocalizations were never unequivocally confirmed in the acoustic data, on occasion analysts identified acoustic signals similar to those produced by bearded seals (Figure 30) and ringed seals (Figure 31). In these instances, analysts could never rule out that the sounds were produced by narwhal and/or bowhead whales, both of whose wide vocal repertoires span many frequencies and durations, overlapping with the properties of pinniped signals.

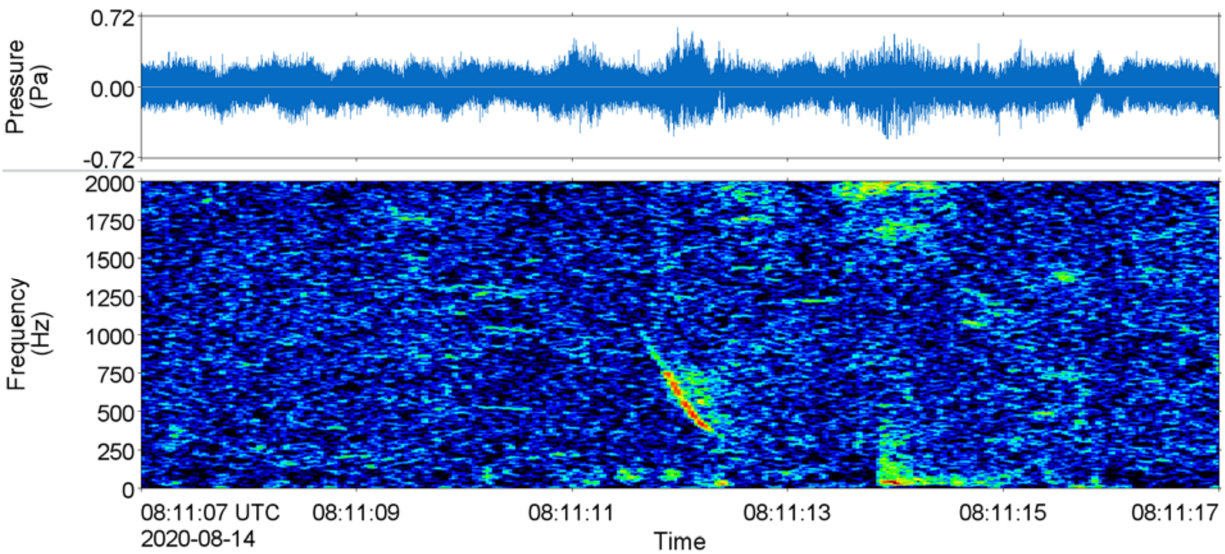

Figure 30. Waveform (top) and spectrogram (bottom) of a potential bearded seal trill recorded on 14 Aug 2020 at Ragged Island (2 Hz frequency resolution, 0.128 s time window, 0.032 s time step, Hamming window, normalized across time, 10 s of data).

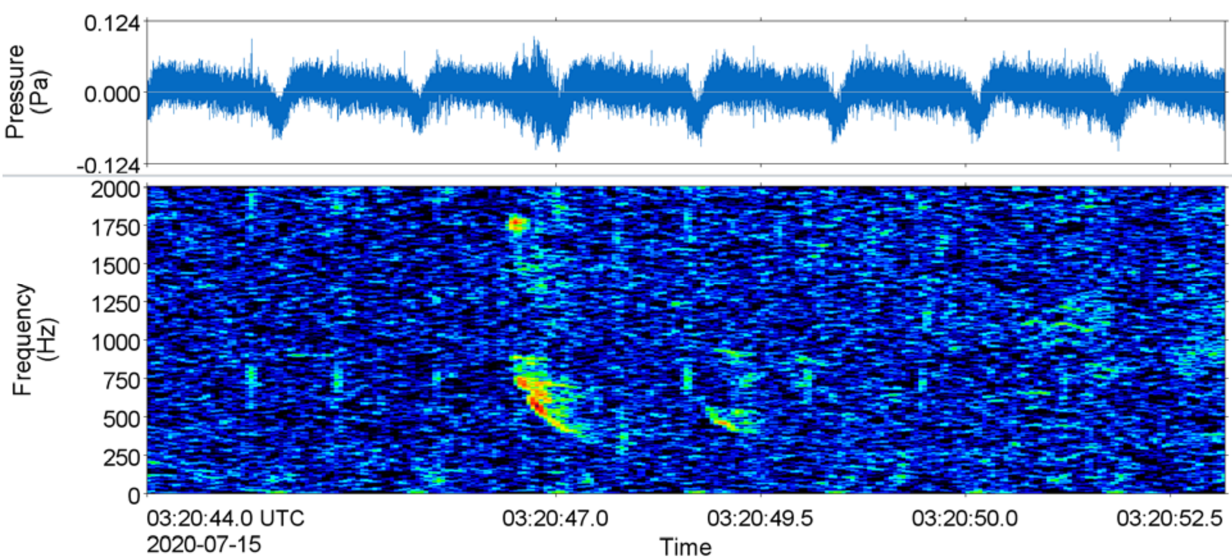

Figure 31. Waveform (top) and spectrogram (bottom) of a potential ringed seal vocalization recorded on 15 Jul 2020 at Ragged Island (2 Hz frequency resolution, 0.128 s time window, 0.032 s time step, Hamming window, normalized across time, 8 s of data).

3.3.5. Sperm Whales

Sperm whale clicks (Figure 32) were detected regularly from mid-August to the end of the recording period at Bylot Island, and on 22 Aug 2020 at Ragged Island. None were detected at Bruce Head (Figure 33).

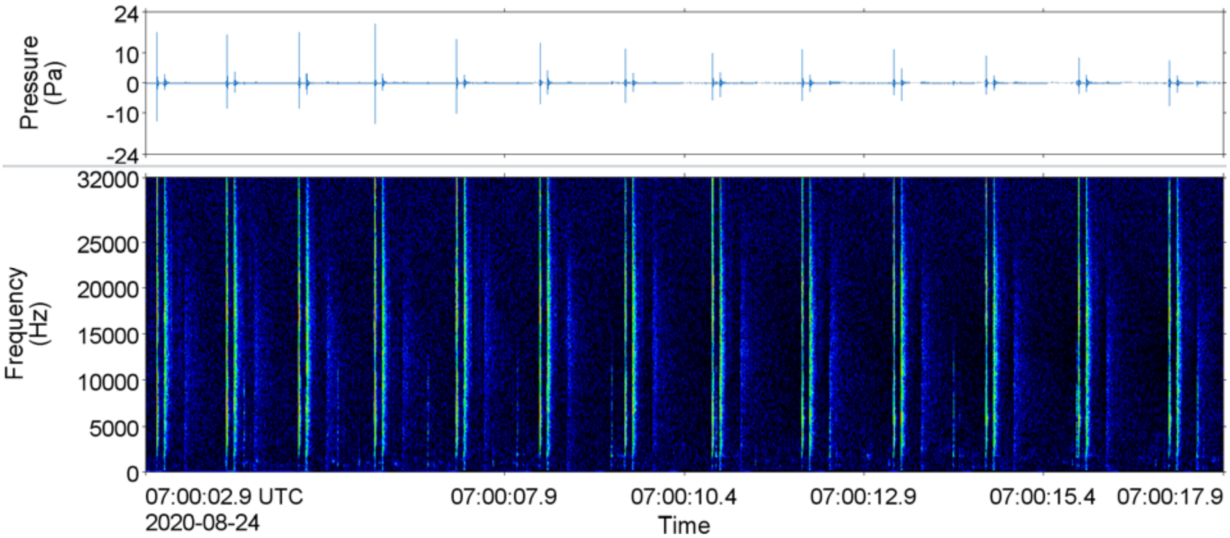

Figure 32. Waveform (top) and spectrogram (bottom) of sperm whale clicks recorded on 24 Aug 2020 at the Pond Inlet station (64 Hz frequency resolution, 0.01 s time window, 0.005 s time step, Hamming window, normalized across time, 15 s of data).

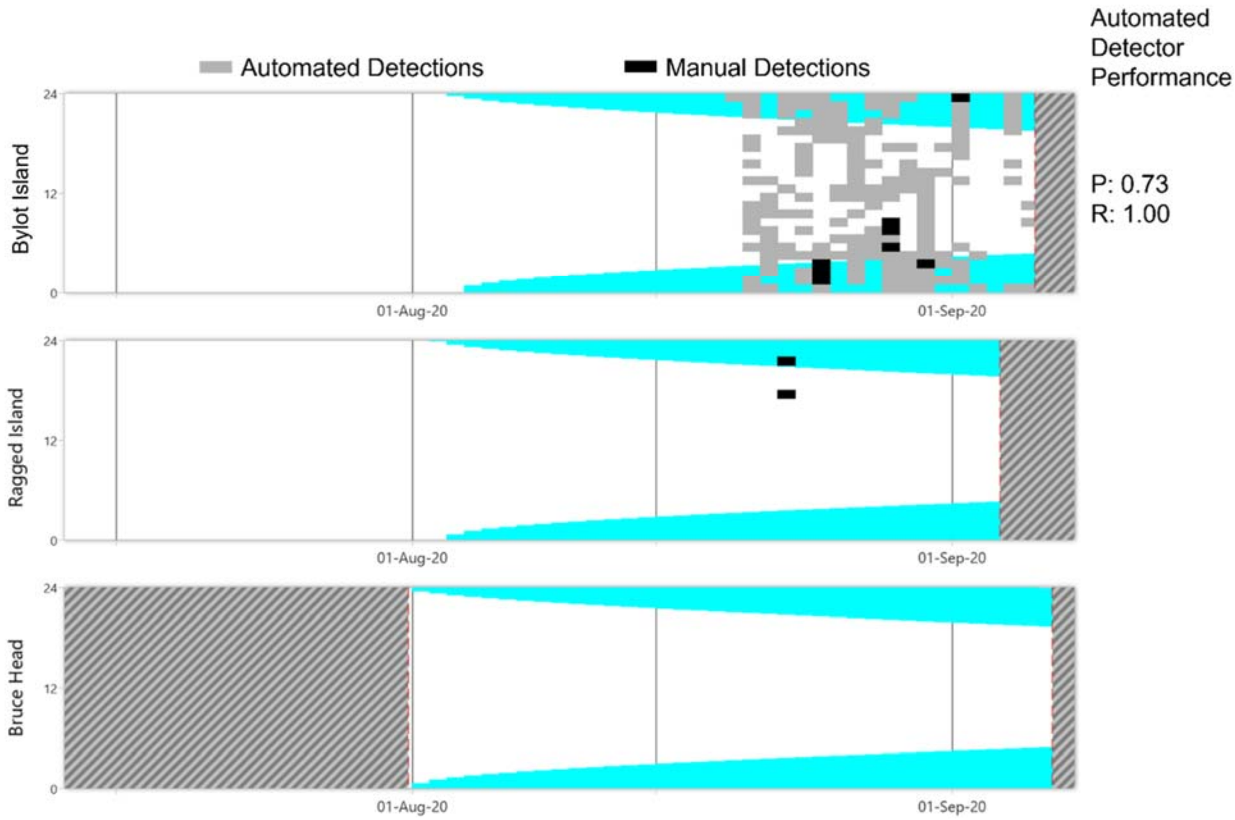

Figure 33. Hours per day with sperm whale click detections at each station through the recording period. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The blue areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the sperm whale click detector.

3.4. Impulsive Pile Driving Noise Detections

Impulsive noise events were detected on the Bylot Island recorder throughout July and August 2020. The spectral and temporal characteristics of the impulses were consistent with those typically recorded during impact pile driving activities; an example is shown in Figure 34. The impulses occurred at frequencies between approximately 100 Hz and 1 kHz.

At close range, impact pile driving impulses typically generate noise at frequencies lower than 100 Hz and extend in frequency to several kilohertz. This indicates that the pile driving likely occurred in shallow water (stripping out the low-frequency components of the impulses) and likely occurred far from the acoustic recorder (since the higher frequency components would attenuate with distance due to seawater absorption effects). The impulses arrived in pairs, indicating the presence of a reflected arrival that could have originated from a deep reflective layer in the sediment or from refraction from the steep walls of the channel between Mittimatalik (Pond Inlet) and the Bylot Island recorders.

A small-craft harbour construction project at Pond Inlet, approximately 40 km distant from the recorder, was occurring during this time and was the origin of these impulses. Table 5 summarizes the dates and times that impulses were detected in the recording at Bylot Island and summary statistics for the SPL of the recorded impulses. All these detections correlate exactly with the times when impact pile driving was occurring at the Pond Inlet Small Craft Harbour (Advisian 2021). These detected impulses encompass all, except 9 of the 39 pile driving events that were monitored by the small craft harbour construction monitors (Advisian 2021).

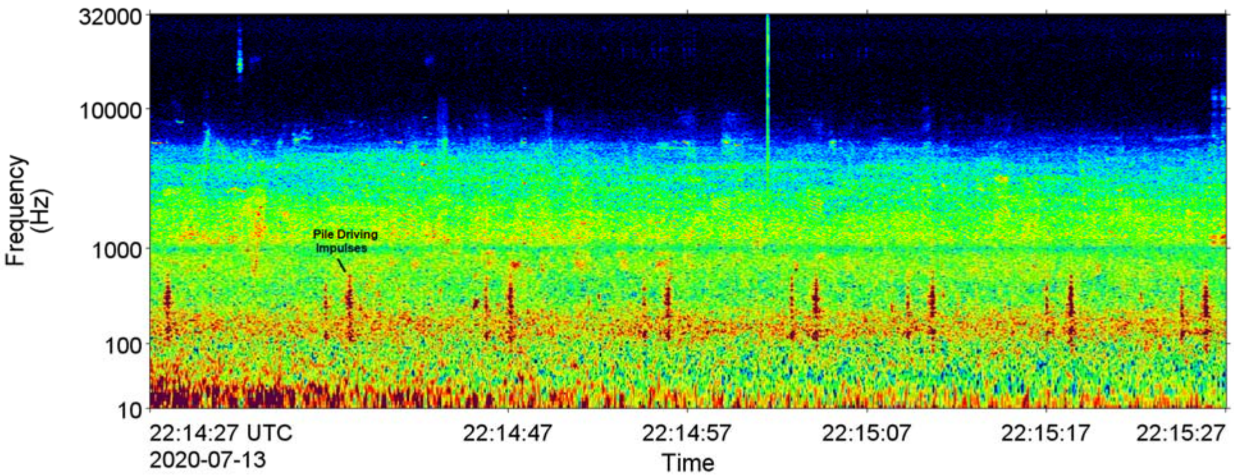

Figure 34. Example spectrogram of impact pile driving impulses recorded at Bylot Island on 13 Jul 2020.

Table 5. Summary statistics of pile driving impulses recorded on the Bylot Island recorder in July and August 2020.

Date	Time (UTC)	Number of impulses detected	SPL (dB re 1 µPa)			
			Minimum	Maximum	Median	Mean
13 Jul	22:07–22:28	82	97.2	105.5	101.7	101.6
24 Jul	14:14–14:19	66	92.8	97.0	94.6	94.8
	14:30–14:33	39	95.8	99.2	97.8	97.8
	17:08–17:11	96	102.4	100.5	100.1	96.2
	17:31–17:42	202	97.0	104.2	100.6	100.6
25 Aug	13:00–13:29	124	93.4	107.8	100.6	100.8
	14:01–14:10	103	89.3	101.1	94.7	94.6
	14:47–14:49	22	90.6	99.0	96.1	95.9
27 Aug	14:01–14:07	180	97.2	105.3	101.5	101.5
	15:20–15:22	85	93.3	103.0	99.9	100.0
	15:50–15:55	89	99.6	105.5	102.5	102.4
	17:30–18:00	308	95.6	111.3	102.4	102.5
	18:00–18:05	104	96.8	108.4	103.6	103.6
	21:27–21:30	90	96.8	101.3	99.6	99.6
	21:30–21:51	342	98.0	104.2	101.2	101.3
28 Aug	11:30–11:49	291	93.4	111.0	102.5	102.3
	12:23–12: 28	109	84.7	116.9	94.8	94.4
	12:30–12:38	122	91.9	100.9	96.0	96.0
	13:08–13:19	221	91.6	104.6	99.5	99.5
	13:47–13:55	128	102.2	108.0	104.8	104.7
	14:39–14:48	123	101.8	107.6	104.1	104.1

Date	Time (UTC)	Number of impulses detected	SPL (dB re 1 µPa)			
			Minimum	Maximum	Median	Mean
	15:31–15:38	134	102.2	110.0	107.3	107.1
	17:02–17:10	44	99.5	109.0	102.0	102.4
29 Aug	11:51–11:53	27	90.8	102.5	96.8	96.7
	12:25–12:28	39	86.3	101.1	93.8	94.2
	13:02–13:03	41	93.4	105.8	102.5	102.0
	14:56–14:58	27	93.1	104.2	98.9	98.7
	15:37–15:43	92	96.3	110.0	104.8	104.5
	17:12–17:18	159	99.2	108.3	104.4	104.2
	17:35–17:38	52	92.3	108.4	102.4	100.6
	17:36–17:38	16	102.4	106.6	104.7	104.5
	18:24–18:27	88	97.2	107.4	101.7	101.9
	19:44–19:45	27	98.2	102.4	100.0	100.1
30 Aug	11:21–11:24	52	92.7	104.1	97.1	97.9
	11:48–11:51	50	98.9	108.4	104.9	104.8
	12:12–12:15	103	91.2	103.8	98.4	98.1
	12:42–12:45	82	88.2	102.2	97.3	96.7
	13:18–13:24	94	95.2	101.8	99.2	99.0
	13:40–13:50	156	92.5	122.0	99.7	99.9
	14:25–14:30	148	95.4	107.0	99.9	100.1
	14:30–14:35	62	93.9	106.5	101.2	101.0

3.5. Noise from Aerial Surveys

At the request of the Marine Environmental Working Group (MEWG), JASCO also characterized noise generated by the DeHavilland Twin Otter aircraft used to conduct marine mammal aerial surveys for Baffinland (Golder 2021b). We analyzed a section of data during an overflight of the aerial survey aircraft from 27 Aug 2020 at 14:25 local time. At this time, the aircraft was flying at 50 kn at an altitude of 274 m (900 ft) and passed over top of the Bruce Head AMAR at a closest horizontal range of 74 m. This was the closest approach that occurred between the aircraft and the AMAR. Figure 35 is a spectrogram of the acoustic data recorded on the Bruce Head AMAR at this time. Tones were present at 80 and 160 Hz when the airplane passed at its nearest approach. The broadband SPL (1-second averaged) reached a maximum level of 105 dB re 1 µPa within a one-minute window around the time when the aircraft was nearest to the AMAR. As a comparison, the broadband SPL (1-second averaged) also reached a maximum level of 105 dB re 1 µPa during a one-minute window recorded 30 min after the aircraft had left the area and when no vessels were in the area, indicating that the aircraft noise was within the range of ambient sound levels.

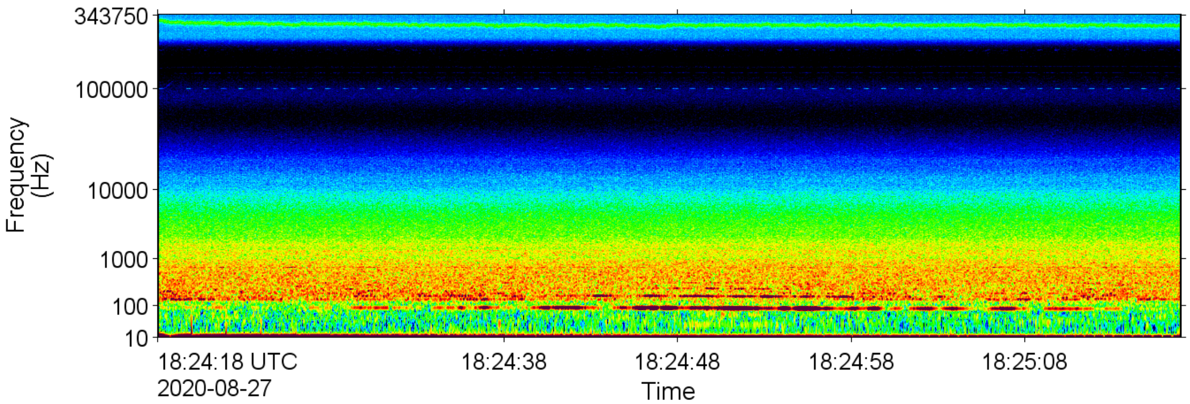

Figure 35 Spectrogram recorded when the aerial survey airplane flew over the AMAR at a closest horizontal range of 74 m. The airplane travelled at 50 kn at an altitude of 900 ft.

3.6. Listening Range Reduction

Listening Range Reduction (LRR) was calculated (Table 6 and Table 7) for reductions in listening range of at least 50% and 90% (>50% and >90% LRR), for each recorder location and for all narwhal vocalization types (clicks, high-frequency buzzes, whistles, knocks, and burst pulse or low-frequency buzzes). Figure 36 presents LRR results for the recordings at Bylot Island and Ragged Island in the early should season and Figure 37 for recordings at Bylot Island, Ragged Island, and Bruce Head during the open-water recording period.

For discussion purposes, a general overview is provided below relative to the 50% LRR metric. Corresponding values for 90% LRR are provided in Table 6 and Table 7.

Table 6. Percent of ambient or vessel minutes associated with >50% and >90% listening range reduction (LRR) at each acoustic recorder location during the 2020 early shoulder shipping season and part of the 2020 open-water shipping season.

Recorder		1 kHz (Burst Pulses)		5 kHz (Whistles and Knock Trains)		25 kHz (Clicks and High-Frequency Buzz)	
		>50 % LRR	>90 % LRR	>50 % LRR	>90 % LRR	>50 % LRR	>90 % LRR
Early shoulder season deployments (12 Jul to 1 Aug)							
Bylot Island	Ambient noise data	0.3	0	28.3	1.2	39.8	17.5
	Data with vessels detected	3.7	0.6	39.5	1.9	50.9	13.5
Ragged Island	Ambient noise data	0	0	19.6	0.1	34.6	16.0
	Data with vessels detected	6.4	1.9	39.4	8.8	50.8	28.4
Open-water season deployments (1 Aug to 5 Sep)							
Bruce Head	Ambient noise data	0.1	0	24.7	3.8	36.1	17.5
	Data with vessels detected	4.3	0.3	25.0	3.5	29.5	10.6
Bylot Island	Ambient noise data	0.4	0	28.5	2.8	34.3	5.9
	Data with vessels detected	0.5	0.1	29.7	2.4	34.8	7.9
Ragged Island	Ambient noise data	0.3	0.1	26.3	0.4	39.6	5.5
	Data with vessels detected	2.8	0.4	23.1	2.8	29.3	8.2

Table 7. Percent of total recording minutes associated with >50% and >90% listening range reduction (LRR) at each acoustic recorder location during the 2020 early shoulder shipping season and part of the 2020 open-water shipping season.

Recorder		1 kHz (Burst Pulses)		5 kHz (Whistles and Knock Trains)		25 kHz (Clicks and High-Frequency Buzz)	
		>50 % LRR	>90 % LRR	>50 % LRR	>90 % LRR	>50 % LRR	>90 % LRR
Early shoulder season deployments (12 Jul to 1 Aug)							
Bylot Island	Ambient noise data	0.2	0	22	0.9	31	14
	Data with vessels detected	0.8	0.1	8.3	0.4	11	2.8
Ragged Island	Ambient noise data	0	0	16	0.1	28	13
	Data with vessels detected	1.2	0.3	7.1	1.6	9.1	5.1
Open-water season deployments (1 Aug to 5 Sep)							
Bruce Head	Ambient noise data	0.1	0	18	2.7	26	13
	Data with vessels detected	1.2	0.1	7	1.0	8.3	3.0
Bylot Island	Ambient noise data	0.2	0	17	1.6	20	3.4
	Data with vessels detected	0.2	0	12.5	1.0	15	3.3
Ragged Island	Ambient noise data	0.2	0.1	18	0.3	27	3.7
	Data with vessels detected	0.9	0.1	7.6	0.9	10	2.7

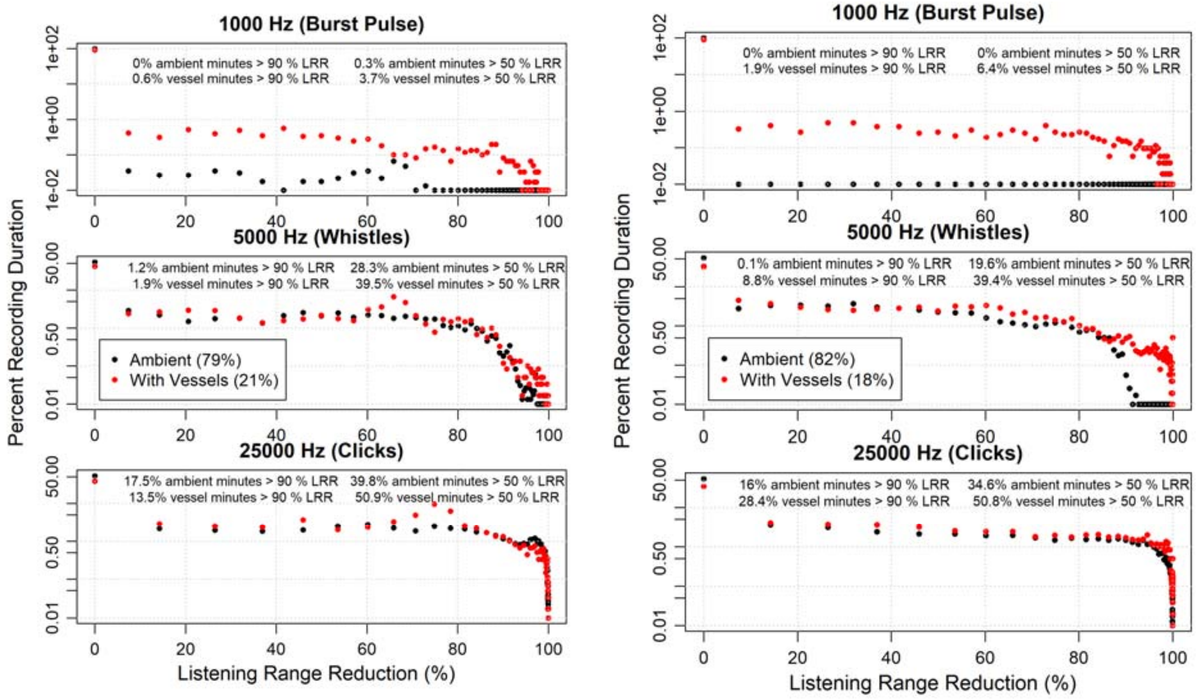

Figure 36. Listening range reduction (LRR) during the early shoulder season for the three considered frequencies at (left) Bylot Island and (right) Ragged Island. For each station, the top figure shows LRR for the 1 kHz 1/3-octave-band, which is representative of burst pulses, the middle figure shows LRR for the 5 kHz 1/3-octave-band, which is representative of listening for whistles and knocks, and the bottom figure shows LRR for 25 kHz which is representative of clicks and high-frequency buzzes. The black dots show the distribution of LRR for ambient noise data only (no vessels), while the red dots show the distribution of LRR for recordings with vessels detected (vessels + ambient noise). The y-axis is logarithmic to better illustrate the rare high LRR events.

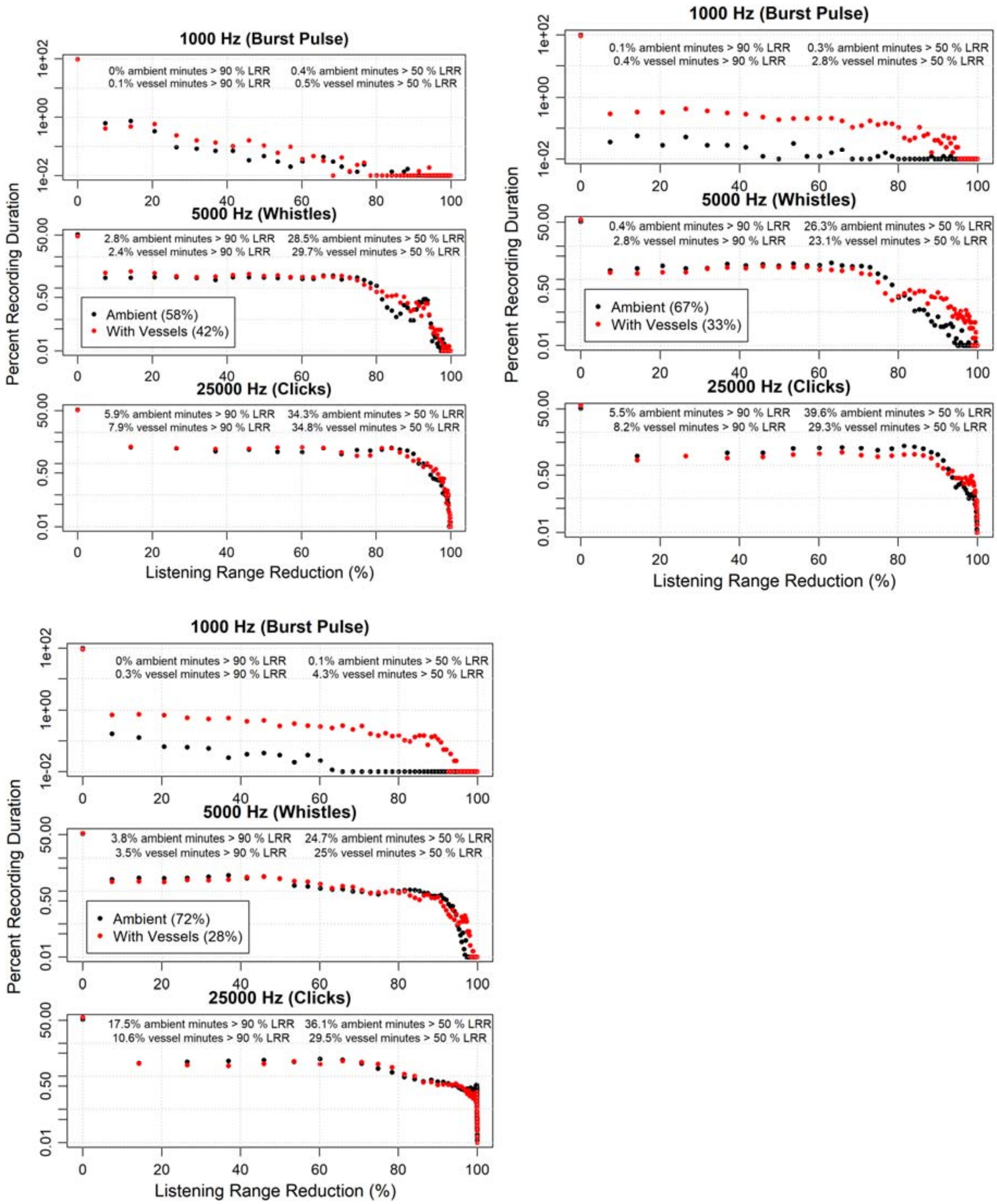

Figure 37. Listening range reduction (LRR) during the early shoulder season for the three considered frequencies at (left, top) Bylot Island, (right, top) Ragged Island, and Bruce Head (left, bottom). For each station, the top figure shows LRR for the 1 kHz 1/3-octave-band, which is representative of burst pulses, the middle figure shows LRR for the 5 kHz 1/3-octave-band, which is representative of listening for whistles and knocks, and the bottom figure shows LRR for 25 kHz which is representative of clicks and high-frequency buzzes. The black dots show the distribution of LRR for ambient noise data only (no vessels), while the red dots show the distribution of LRR for recordings with vessels detected (vessels + ambient noise). The y-axis is logarithmic to better illustrate the rare high LRR events.

3.6.1. Bylot Island

Vessel noise was acoustically detected on the Bylot Island recorder 21% of the early shoulder season recording at this location and on 42% of the open-water season recording. A summary of the LRR calculations for each of the three considered frequencies, with a relative comparison to ambient noise (i.e., data with no vessels present) follows.

3.6.1.1. 1 kHz (Burst Pulses)

During the early shoulder season, greater than 50% LRR for sound at 1 kHz (a frequency component of narwhal burst pulses) occurred during 3.7% of the time vessels were detected acoustically on the recording. This means that 96.3% of the time when vessel noise was detectable in the shoulder season at the Bylot Island recorder, a stationary narwhal would be able to detect a sound at 1 kHz to distances over half of its full detection range, and 3.7% of the time when vessel noise was detectable in the shoulder season at this location, its detection range at this frequency would be reduced by at least half. Because the hearing threshold for a narwhal at 1 kHz is higher than the median ambient sound level at this frequency, ambient noise did not cause appreciable LRR for this vocalization type during any of the early shoulder season recording (0.3% of the recording). Overall, vessel noise and ambient resulted in greater than 50% LRR for sound at 1 kHz for 0.8% and 0.2%, respectively, of the total recording period during the early shoulder season.

During the open-water season, greater than 50% LRR occurred for sound at 1 kHz during 0.5% of the time vessels were detected on the recording. Ambient noise caused greater than 50% LRR for sound at 1 kHz during 0.4% of the recordings when no vessels were detected acoustically. Overall, ambient noise and vessel noise each caused greater than 50% LRR for sound at 1 kHz for 0.2% of the total open-water recording period.

3.6.1.2. 5 kHz (Whistles and Knock Trains)

During the early shoulder season, greater than 50% LRR occurred for sound at 5 kHz (a frequency component of narwhal whistles and knock trains) during 39.5% of the time vessels were detected acoustically on the recording at the Bylot Island recorder. In comparison, ambient noise during the early shoulder season resulted in greater than 50% LRR for sound at 5 kHz during 28.3% of the recordings when no vessels were detected. Overall, vessel noise resulted in greater than 50% LRR for sound at 5 kHz for 8.3% of the total shoulder season recording period and ambient noise for 22% of the total shoulder season recording period.

During the open-water season, greater than 50% LRR occurred for sound at 5 kHz during 29.7% of the time vessels were detected on the recording at the Bylot Island recorder. Ambient noise resulted in greater than 50% LRR for sound at 5 kHz during 28.5% of the recordings when no vessels were detected acoustically. Overall, ambient noise resulted in greater than 50% LRR for sound at 5 kHz for 16.5% of the total open-water recording period, while vessel noise resulted in greater than 50% LRR for sound at 5 kHz for 12.5% of the total open-water recording period.

3.6.1.3. 25 kHz (Clicks and High-frequency Buzzes)

During the early shoulder season, greater than 50% LRR occurred for sound at 25 kHz (a frequency component of narwhal clicks and high-frequency buzzes) during 50.9% of the time vessels were detected acoustically on the recording at the Bylot Island recording station. During this same period, ambient noise resulted in greater than 50% LRR for sound at 25 kHz during 39.8% of the recordings when no vessels were detected. Overall, greater than 50% LRR occurred for sound at 25 kHz for 42% of the total recording period during the early shoulder season; 31% of this was related to ambient noise and 11% of this was related to vessel noise.

During the open-water season, greater than 50% LRR occurred for sound at 25 kHz during 34.8% of the time vessels were detected on the recording. Ambient noise resulted in greater than 50% LRR for sound at 25 kHz during 34.3% of the recordings when no vessels were detected acoustically. Overall, greater than 50% LRR occurred for sound at 25 kHz for 34% of the total recording period during the open-water season; 20% of this was related to ambient noise and 15% of this was related to vessel noise.

3.6.2. Ragged Island

The Ragged Island recorder was located directly on the nominal shipping route in Milne Inlet North adjacent to the Ragged Island anchorage locations. Vessel noise was acoustically detected on 18% of the early shoulder season recording at this location and on 33% of the open-water season recording. A summary of the LRR calculations for each of the three considered frequencies, with a relative comparison to ambient noise (i.e., data with no vessels present) follows.

3.6.2.1. 1 kHz (Burst Pulses)

During the early shoulder season, greater than 50% LRR for sound at 1 kHz (a frequency component of narwhal burst pulses) occurred during 6.4% of the time vessels were detected acoustically on the recording. This means that 93.6% of the time when vessel noise was detectable in the shoulder season at the Raged Island recorder, a stationary narwhal would be able to detect a sound at 1 kHz to distances over half of its full detection range, and 6.4% of the time when vessel noise was detectable in the shoulder season at this location, its detection range at this frequency would be reduced by at least half. Because the hearing threshold for a narwhal at 1 kHz is higher than the median ambient sound level at this frequency, ambient noise did not cause appreciable LRR for this vocalization type during any of the early shoulder season recording (0% of the recording). Overall, vessel noise resulted in greater than 50% LRR for sound at 1 kHz for 1.3% of the total recording period during the early shoulder season.

During the open-water season, greater than 50% LRR occurred for sound at 1 kHz during 2.8% of the time vessels were detected on the recording. Ambient noise caused greater than 50% LRR for sound at 1 kHz during 0.3% of the recordings when no vessels were detected acoustically. Overall, ambient noise caused greater than 50% LRR for sound at 1 kHz for 0.2% of the total open-water recording period, while vessel noise caused greater than 50% LRR for sound at 1 kHz for 0.9% of the open-water recording period.

3.6.2.2. 5 kHz (Whistles and Knock Trains)

During the early shoulder season, greater than 50% LRR occurred for sound at 5 kHz (a frequency component of narwhal whistles and knock trains) during 39.4% of the time vessels were detected acoustically on the recording at the Ragged Island recorder. In comparison, ambient noise during the early shoulder season resulted in greater than 50% LRR for sound at 5 kHz during 19.6% of the recordings when no vessels were detected. Overall, vessels resulted in greater than 50% LRR for sound at 5 kHz for 7% of the total shoulder season recording period and ambient noise for 16% of the total shoulder season recording period.

During the open-water season, greater than 50% LRR occurred for sound at 5 kHz during 23.1% of the time vessels were detected on the recording at the Ragged Island recorder. Ambient noise resulted in greater than 50% LRR for sound at 5 kHz during 26.3% of the recordings when no vessels were detected acoustically. Overall, ambient noise resulted in greater than 50% LRR for sound at 5 kHz for 17% of the total open-water recording period, while vessel noise resulted in greater than 50% LRR for sound at 5 kHz for 7.6% of the total open-water recording period.

3.6.2.3. 25 kHz (Clicks and High-frequency Buzzes)

During the early shoulder season, greater than 50% LRR occurred for sound at 25 kHz (a frequency component of narwhal clicks and high-frequency buzzes) during 50.8% of the time vessels were detected acoustically on the recording at the Ragged Island recording station. During this same period, ambient noise resulted in greater than 50% LRR for sound at 25 kHz during 34.6% of the recordings when no vessels were detected. Overall, greater than 50% LRR occurred for sound at 25 kHz for 37% of the total recording period during the early shoulder season; 28% of this was related to ambient noise and 9% of this was related to vessel noise.

During the open-water season, greater than 50% LRR occurred for sound at 25 kHz during 29.3% of the time vessels were detected on the recording. Ambient noise resulted in greater than 50% LRR for sound at 25 kHz during 39.6% of the recordings when no vessels were detected acoustically. Overall, greater than 50% LRR occurred for sound at 25 kHz for 37% of the total recording period during the open-water season; 27% of this was related to ambient noise and 10% of this was related to vessel noise.

3.6.3. Bruce Head

Vessel noise was acoustically detected on the Bruce Head recorder 28% of the open-water season recording at this location. A summary of the LRR calculations for each of the three considered frequencies, with a relative comparison to ambient noise (i.e., data with no vessels present) follows.

3.6.3.1. 1 kHz (Burst Pulses)

During the open-water season, greater than 50% LRR occurred for sound at 1 kHz during 4.3% of the time vessels were detected on the recording. Ambient noise caused greater than 50% LRR for sound at 1 kHz during 0.1% of the recordings when no vessels were detected acoustically. Overall, vessel noise and ambient noise caused greater than 50% LRR for sound at 1 kHz for 1.2% and 0.1%, respectively, of the open-water recording period.

3.6.3.2. 5 kHz (Whistles and Knock Trains)

During the open-water season, greater than 50% LRR occurred for sound at 5 kHz during 25% of the time vessels were detected on the recording at the Bylot Island recorder. Ambient noise resulted in greater than 50% LRR for sound at 5 kHz during 24.7% of the recordings when no vessels were detected acoustically. Overall, ambient noise resulted in greater than 50% LRR for sound at 5 kHz for 18% of the total open-water recording period, while vessel noise resulted in greater than 50% LRR for sound at 5 kHz for 7% of the total open-water recording period.

3.6.3.3. 25 kHz (Clicks and High-frequency Buzzes)

During the open-water season, greater than 50% LRR occurred for sound at 25 kHz during 29.5% of the time vessels were detected on the recording. Ambient noise resulted in greater than 50% LRR for sound at 25 kHz during 36.1% of the recordings when no vessels were detected acoustically. Overall, greater than 50% LRR occurred for sound at 25 kHz for 34% of the total recording period during the open-water season; 26% of this was related to ambient noise and 8% of this was related to vessel noise.

4. Discussion

4.1. Listening Range Reduction

To evaluate the potential for effects of acoustic masking, we applied an alternate metric referred to as *listening range reduction* (LRR). This metric assesses the percentage decrease in the maximum distance an animal can acoustically detect an important sound producer, such as prey or other vocalizing animals, due to increased masking noise. Specifically, we calculated the percentage of time that narwhal experienced listening range reductions of 90% or more and 50% or more due to the presence of masking vessel noise. We also computed the percentage of time that narwhal experienced listening range reductions when ambient sounds exceeded the median ambient sound level, in the absence of vessel noise.

Results demonstrate that both ambient and vessel noise sources can result in LRR, at different contributing levels depending on the vocalization type of interest. The listening range for sound at 25 kHz (representative of narwhal clicks and high-frequency buzzes) was more affected, by both vessel noise and ambient noise, than sound at 1 kHz (a representation frequency for burst pulses) where narwhal have decreased hearing sensitivity. The potential consequence is a reduced range at which the listener (narwhal) can detect potential prey. At frequencies consistent with narwhal clicks, knocks, and whistles, vessel noise resulted in LRR similar to what narwhal experience from ambient noise sources (e.g., wind, waves, rain). A small seasonal effect is present for both narwhal vocalization types, with vessel noise slightly more influential than ambient noise sources during the early shoulder season and ambient noise sources have comparable influence as vessel noise during the open-water season. Burst pulses were the least susceptible vocalization type to LRR due to vessel noise, with a 90% LRR occurring ≤1% of the time. As aforementioned, ambient noise did not result in any appreciable level of LRR for burst pulses because the hearing threshold for narwhal at 1 kHz is higher than the median ambient sound level at this frequency.

It is well known that currently there are no established regulatory thresholds under any jurisdiction that would aid in the determination of significance of acoustic masking effects on narwhal. As described in Hemmera (2019), Erbe et al. (2016) characterize acoustic masking as a complex phenomenon. Masking levels can be variable and dependent on the physiological and anatomical characteristics, and activity, of the sender and receiver, the levels of ambient noise and the degree of habituation of the individuals, as well as any anti-masking strategies employed. There is no vocalization masking model developed in the literature that is narwhal-specific and no research is available on the hearing ability (i.e., audiogram) of narwhal (Erbe et al. 2016). More research is needed to understand the process and biological significance of masking, as well as the risk of masking by various anthropogenic activities, before masking can be incorporated into regulation strategies or approaches for mitigation (Erbe et al. 2016).

4.2. Vessel Contributions to Ambient Noise

All sound levels measured in this study were below the thresholds for auditory injury for all marine mammals species that occur in the study area. Nevertheless, vessel noise has the potential to result in disturbance or acoustic masking effects on marine mammals. We investigated potential acoustic disturbance using the criterion of NOAA (1998), which is based on minimum sound levels observed to produce deflections of migrating bowhead whales near industrial activities in the arctic (Richardson et al. 1985). This criterion, defined as when broadband SPL exceeds 120 dB re 1 µPa, is the current disturbance threshold used by NOAA for assessing disturbance to marine mammals by continuous-type sounds such as vessel noise. New guidance on methods for assessing behavioural disturbance to marine mammals from underwater noise (Southall et al. 2021) were published following completion of the analysis for this report that may, in future, change the way that marine mammal behavioural responses are assessed, but no new thresholds or species-specific thresholds have been defined. Subsequently, to facilitate comparison with effects predictions for this Project, and in keeping with established assessment methods at the time of this analysis, for this report we have applied an analysis of the exceedances of the 120 dB SPL threshold.

Measured underwater sound levels from the recording stations were analyzed to determine the amount of time that broadband sound levels exceeded the disturbance onset threshold of 120 dB re 1 μPa over the early shoulder and open-water seasons (Table 8; Figure 38). Icebreaker transits at the Bylot Island and Ragged Island locations between 21 and 26 Jul occurred when ice concentrations were between 2/10 and 9/10. Transits occurred in open water on the remaining days of the early shoulder season. Comparing these times, icebreaker transits through ice did not noticeably increase the durations of exceedance of 120 dB at either location (Figure 38).

As shown in Section 3.1, during the early shoulder season, the SPL exceeded 120 dB re 1 μPa for 7.6% of the total recording duration (28 days) at Ragged Island and 1.8% of the same total recording duration (28 days) at Bylot Island. During the open-water season, underwater sound levels exceeded the 120 dB threshold for 1.3%, 4.6%, and 2.3% of the recording durations for the Bylot Island, Ragged Island, and Bruce Head locations, respectively. On average, received sound levels at the AMAR locations exceeded the disturbance threshold of 120 dB re 1 μPa for less than one hour per day (averaged over acoustic recording days during the shipping season). Corresponding values from 2019 are included in Appendix E for reference. The values in Appendix E were updated from those in the 2019 Passive Acoustic Monitoring Report (Frouin-Mouy et al. 2020), to be averaged over acoustic recording days during the shipping season days rather than averaged over the full recording period (as was computed in 2019). Table 8 also shows the maximum number of hours in a day during which the SPL exceeded the 120 dB re 1 μPa threshold; less than 2.5 hours per day at all locations other than Ragged Island. At Ragged Island, periods with elevated flow noise and mooring noise also contributed to this value.

Table 8. Average and maximum daily exposure durations for disturbance (120 dB re 1 µPa) for each recorder during the 2020 acoustic monitoring program.

Recorder		2020: Time per shipping season day with SPL > 120 dB (hours [minutes])	
		Average	Maximum
Bylot Island (Shoulder Season)	All recorded data	0.1 [7.2]	1.9 [114.0]
	Only data with vessels detected	0.1 [6.6]	1.9 [114.0]
Ragged Island (Shoulder Season)	All recorded data	0.5 [28.5]	7.2 [430.0]*
	Only data with vessels detected	0.3 [15.5]	6.1 [367.0]
Bruce Head (Open Water)	All recorded data	0.3 [18.1]	2.5 [153.0]
	Only data with vessels detected	0.3 [17.7]	2.5 [153.0]
Bylot Island (Open Water)	All recorded data	0.2 [9.6]	1.9 [112.0]
	Only data with vessels detected	0.1 [5.2]	1.3 [75.0]
Ragged Island (Open Water)	All recorded data	0.4 [23.9]	7.4 [447.0]
	Only data with vessels detected	0.2 [12.7]	6.3 [376.0]*

*Influenced by periods with elevated flow and mooring noise in the recordings.

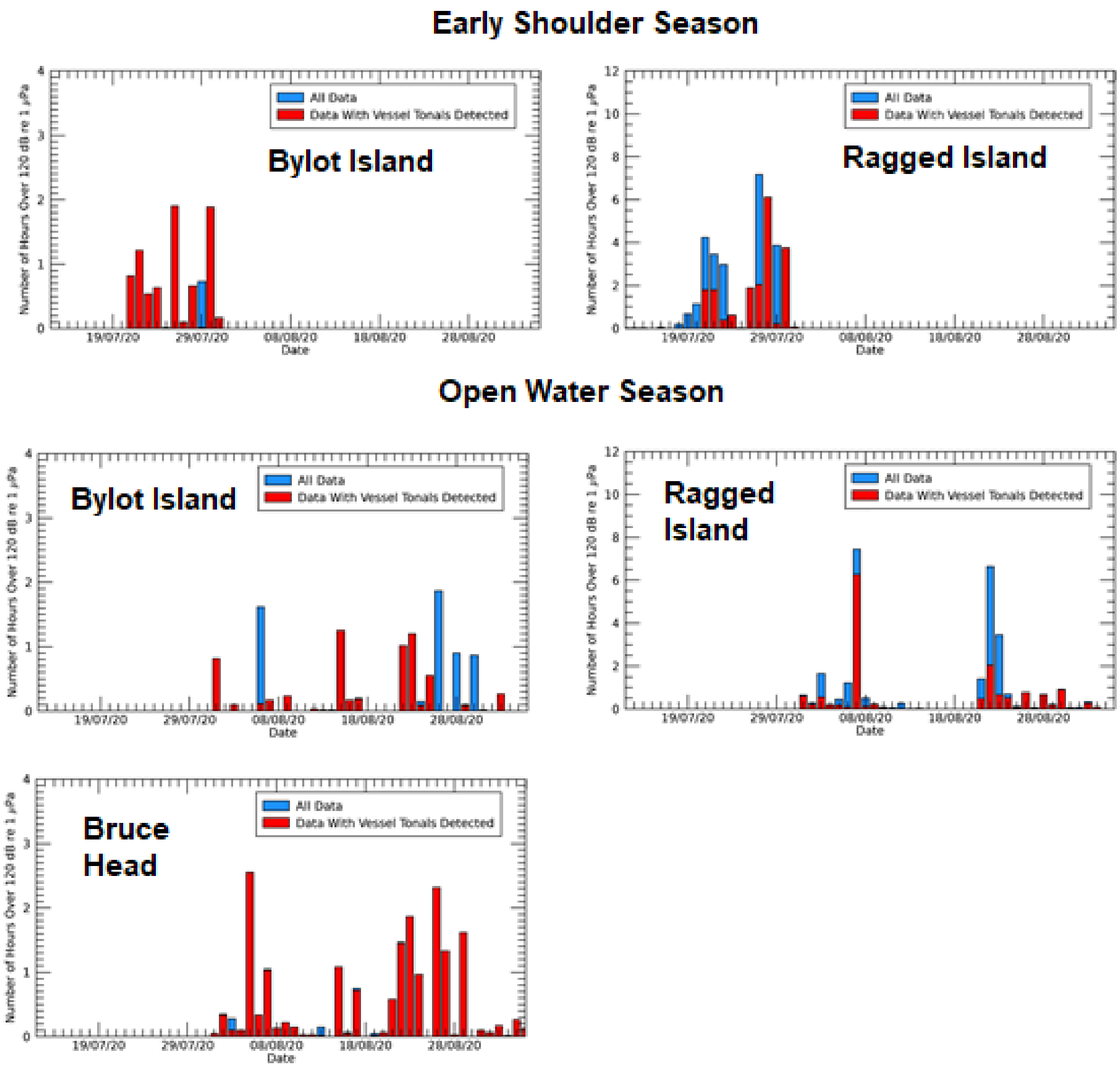

Figure 38. Hours per day with recorded sound pressure level (SPL) exceeding 120 dB re 1 µPa during shoulder season ((top left) Bylot Island and (top right) Ragged Island) and during the open-water season ((center left) Bylot Island, (center right) Ragged Island, and (bottom left) Bruce Head.

4.3. Marine Mammal Presence

The marine mammal acoustic detection results presented in this report provide an index of acoustic occurrence for each species. Although these results can be used to describe the relative abundance of a species across the study area, several factors influence the detectability of the targeted signals. Although acoustic detection does indicate presence, an absence of detections does not necessarily indicate absence of animals. For example, an animal may be present but not detected if no individuals were vocalizing near the recorder, their signals were masked environmental and/or anthropogenic noise sources, or a combination of these factors. Different sound propagation environments and different seasonal effects will impact the detection range of a given signal over time and, therefore, influence the number of detectable signals. Seasonal variations in vocalizing behaviour may also falsely suggest changes in occurrence. Therefore, the acoustic occurrence of each species across stations is discussed considering any environmental, anthropogenic, and biological factors that may influence the detectability of the targeted acoustic signals. The discussion emphasizes those species confirmed to be acoustically present in the data (bowhead, killer, and sperm whales and narwhal), but there is some evidence suggesting that beluga whales, bearded seals, and ringed seals may have also been present.

4.3.1. Bowhead Whales

The acoustic occurrence of bowhead whales in the data is unsurprising given that the range of the Eastern Canada-West Greenland (ECWG) bowhead whale population (COSEWIC 2009) overlaps with the present monitoring area (Heide-Jørgensen et al. 2008, Wiig et al. 2010). Although bowhead whales do not leave Arctic waters, they do follow annual migration patterns. The ECWG population aggregates in several areas in winter: in Hudson Strait, in the Davis Strait-southern Baffin Bay, and in and near Disko Bay. Whales tagged in Cumberland Sound in spring were found to circumnavigate Baffin Island. Both Inuit observations and tag data indicates that from May to July bowhead whales move northward from the Cumberland Sound to Pond Inlet (COSEWIC 2009). The animals then summer in northern Baffin Island and the northeast coast which includes the present study area from May to August (COSEWIC 2009). The acoustic occurrence of bowhead whales at the Bylot Island and Ragged Island recorders through July is consistent with these patterns. The lack of bowhead whale detections in August and September is likely a true reflection of the animals leaving the area as part of their annual migration cycle, a conclusion strengthened by the fact that bowhead whales are vocally active year-round (Clark et al. 2015). These acoustic detections are also consistent with Baffinland's aerial survey and Bruce Head monitoring programs (Golder 2021b, 2021a). As no recordings were collected at Bruce Head in July, it is difficult to know if the animals regularly frequent that area as they did the other stations, but animals certainly make their way into that region of the channel at least on occasion given the few detections in August. Recorded whales likely included juveniles and mother-calf pairs, which were the predominant age and sex groups found in Pond Inlet early in the summer along the ice floe edge (COSEWIC 2009).

4.3.2. Killer Whales

Killer whales are found in all the world's oceans and share the sperm whale's distinction of having the largest range of any non-human mammal (Whitehead 2002a). Killer whale sightings in the eastern Canadian Arctic are widely distributed, with the highest reported numbers in Lancaster Sound, which includes the Project area (Higdon et al. 2012). The killer whale population size in the eastern Canadian Arctic is unknown but believed to be small. Group sizes of up to 100 animals have been observed, although typical group sizes are lower and vary according to prey type, which include bowhead whales, monodontids, and seals (Higdon et al. 2012, Lefort et al. 2020). Prey preferences of killer whales in eastern Canada is unknown, and whether prey specialization even exists here is unclear (Lawson and Stevens 2013). Mammal-eating killer whales in the north Pacific tend to be more acoustically cryptic than their fish-eating counterparts (Barrett-Lennard et al. 1996). As a result, the acoustic foraging behaviour of killer whales in the Arctic should be considered when assessing the acoustic occurrence of that species. The limited acoustic detections of killer whales in the present data set are consistent with the presumably small (although likely increasing) population size and its potentially vocally cryptic behavior. Killer whales satellite-tagged in the Gulf of Boothia in summer avoided areas covered by ice but did not leave the area until forced out by sea ice in early October (Matthews et al. 2011).

4.3.3. Narwhal and Beluga Whales

The acoustic occurrence of narwhal in the data was expected, as this Arctic species is hunted in the monitoring region and is known to spend the summer aggregated in bays and fjords around Baffin Island, Hudson Bay, Lancaster Sound, and the northeast coast of Greenland. In winter, they aggregate in dense pack ice in the middle of Baffin Bay and Davis Strait as well as in Disko Bay and near the entrance of the Hudson Strait, with relatively short migratory movements between summer and winter grounds (COSEWIC 2004b). Corrected estimates put the Eclipse Sounds stock at 10,489 (coefficient of variation = 24%) individuals (Doniol-Valcroze et al. 2015).

Narwhal acoustic occurrence across recording stations indicates that animals occur in Eclipse Sound through summer, remaining later in the summer in areas farther into the Sound. Indeed, the species was acoustically absent at Bylot Island after late July, sporadic at Ragged Island after 1 Aug, and common at Bruce Head through August and September. Hunters have observed that since the 1960's narwhal have become less common near Pond Inlet, instead preferentially travelling down the middle of the inlet, potentially to avoid hunters, motorboats, and snowmobiles near the community (COSEWIC 2004b). As noted in Section 3.3.3, there were no obvious effects of the presence of vessels on the acoustic detections of narwhal.

Beluga whales are generally associated with Subarctic and Arctic waters. They often occur in inshore and shallow waters (Richard et al. 2001). While not as common as narwhal, beluga whales are known to occur in the monitoring area and given their overlapping whistle and click repertoire with narwhal, we cannot completely rule out the acoustic occurrence of this species. Beluga whales generally vocalize abundantly, whistles representing a large portion of their vocal repertoire (Garland et al. 2015). In contrast, while the narwhal repertoire includes whistles, they are less common than their other sounds such as buzzes and knock trains (Ford and Fisher 1978). We never observed a recording filled with many whistles typical of beluga whales and lacking signals typical of narwhal. We were unable to confidently identify beluga whales, but there were several instances where the species was noted as being possibly present.

4.3.4. Pinnipeds

Vocalizations from pinnipeds were never confirmed in the acoustic data, but there were several instances where signals potentially produced by bearded or ringed seals were identified. These signals also overlapped with the repertoire of narwhal and bowhead whales, making it difficult to confirm any pinnipeds. Both bearded seals and ringed seals are likely to have occurred in the area. Bearded seals are found throughout Arctic and Subarctic waters and are an ice-associated species. They are predominantly benthic feeders and thus, feed in shallow, often coastal, areas and are not deep divers (Gjertz et al. 2000). Like many pinnipeds, bearded seals display a pronounced seasonality in vocalizing rates. Vocalizations are rare in summer, limiting opportunities to confirm their presence in the data (MacIntyre et al. 2013). Ringed seals are probably the most abundant northern phocid, with an aggregate population numbering at least several million (Kingsley and Reeves 1998). It is also one of the more widely distributed species, having a continuous circumpolar distribution throughout the Arctic basin, Hudson Bay, Hudson Strait, and the Bering Sea. Ringed seals are an ice-obligate species. Their distribution is strongly related to pack ice and shore-fast ice, and to areas covered at least seasonally by ice (McLaren 1958). On occasion, faint moans and grunts were observed in the data which JASCO analysts identified as potentially being produced by a ringed seal or other pinniped.

4.3.5. Sperm Whales

Sperm whales are the largest toothed whales and the largest toothed predator, with an extensive worldwide distribution. They are usually found in deep, offshore waters, but may be seen closer to shore, for instance near oceanic islands. The global population is currently estimated at 360,000 individuals (Whitehead 2002b). Sperm whales in eastern Canadian and Arctic waters appear to be exclusively males (Reeves and Whitehead 1997). Females remain at lower latitudes year-round, while males migrate between higher latitudes feeding grounds in the summer and lower latitude to breed in winter (Whitehead 2002a).

Our monitoring area was once believed to be beyond the northern extent of the sperm whale range, but this species has been sited there in recent years (CBC News 2018, Baffinland 2021), potentially in response to climatic changes in the Arctic . The regular sperm whale detections at Bylot Island through late August and into September and sporadic detections at Ragged Island, combined with previous reports, suggests that this species may now be frequenting this area more regularly. Sperm whale acoustic signals can be heard at great distances (Madsen et al. 2002) making them ideal species for passive acoustic monitoring.

4.4. Summary

The results of 2020 passive acoustic monitoring program contained in this report are consistent with results from similar programs conducted by JASCO since 2018. A novel source of noise that was detected during the 2020 acoustic monitoring recordings at Bylot Island included impulsive sound from impact pile driving from the small craft harbour construction site in Pond Inlet. These sounds were clearly identifiable in the acoustic data measured at a distance of 42 km from Pond Inlet, throughout the impact pile driving activities.

Marine mammal vocalizations were detected throughout the recordings from five marine mammal species: bowhead whales, killer whales, sperm whales, pinnipeds, and narwhal/beluga. Though results from the 2020 aerial survey and Bruce Head programs indicated a decrease in narwhal presence in

Eclipse Sound and Milne Inlet in 2020, patterns in the general timing of acoustic detections and the types of sounds detected were consistent with prior acoustic monitoring results (Frouin-Mouy et al. 2020).

The results in this report demonstrate that while noise from Project vessels is detectable in the underwater soundscape, vessel noise exposure is temporary in nature and below sound levels that could cause acoustic injury. Assessed relative to a broadband SPL of 120 dB re 1 µPa, sound exposure durations averaged less than 1 hour per day. This is consistent with effects predictions that acoustic impacts would be localized and temporary and that there are substantial periods in each day when marine mammals are not disturbed by Project vessel noise.

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Glossary

Unless otherwise stated in an entry, these definitions are consistent with ISO 80000-3 (2017a).

1/3-octave

One third of an octave. *Note*: A one-third octave is approximately equal to one decidecade (1/3 oct ≈ 1.003 ddec).

1/3-octave-band

Frequency band whose bandwidth is one one-third octave. *Note*: The bandwidth of a one-third octave-band increases with increasing centre frequency.

ambient sound

Sound that would be present in the absence of a specified activity, usually a composite of sound from many sources near and far, e.g., shipping vessels, seismic activity, precipitation, sea ice movement, wave action, and biological activity.

audiogram

A graph or table of hearing threshold as a function of frequency that describes the hearing sensitivity of an animal over its hearing range.

auditory frequency weighting

The process of applying an auditory frequency weighting function. In human audiometry, C-weighting is the most commonly used function, an example for marine mammals are the auditory frequency weighting functions published by Southall et al. (2007).

auditory frequency weighting function

Frequency weighting function describing a compensatory approach accounting for a species' (or functional hearing group's) frequency-specific hearing sensitivity. Example hearing groups are low-, mid-, and high-frequency cetaceans, phocid and otariid pinnipeds.

background noise

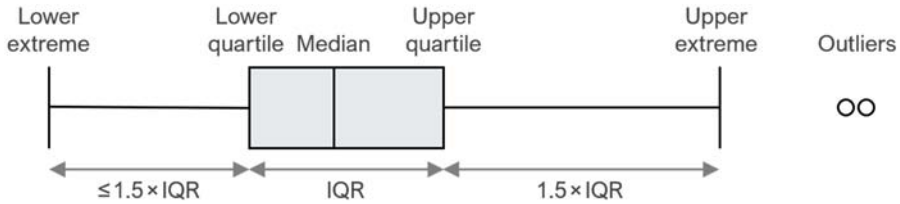
Combination of ambient sound, acoustic self-noise*,* and sonar reverberation*.* Ambient sound detected, measured, or recorded with a signal is part of the background noise.

bandwidth

The range of frequencies over which a sound occurs. Broadband refers to a source that produces sound over a broad range of frequencies (e.g., seismic airguns, vessels) whereas narrowband sources produce sounds over a narrow frequency range (e.g., sonar) (ANSI S1.13-2005 (R2010)).

box-and-whisker plot

A plot that illustrates the centre, spread, and overall range of data from a visual 5-number summary. The box is the interquartile range (IQR), which shows the middle 50% of the data—from the lower quartile (25th percentile) to the upper quartile (75th percentiles). The line inside the box is the median (50th percentile). The whiskers show the lower and upper extremes excluding outliers, which are data points that fall more than 1.5 × IQR beyond the upper and lower quartiles.



broadband level

The total level measured over a specified frequency range.

cetacean

Any animal in the order Cetacea. These are aquatic species and include whales, dolphins, and porpoises.

continuous sound

A sound whose sound pressure level remains above ambient sound during the observation period. A sound that gradually varies in intensity with time, for example, sound from a marine vessel.

critical band

The auditory bandwidth within which background noise strongly contributes to masking of a single tone. Unit: hertz (Hz).

decade

Logarithmic frequency interval whose upper bound is ten times larger than its lower bound (ISO 80000-3:2006).

decidecade

One tenth of a decade. *Note*: An alternative name for decidecade (symbol ddec) is “one-tenth decade”. A decidecade is approximately equal to one third of an octave (1 ddec ≈ 0.3322 oct) and for this reason is sometimes referred to as a “one-third octave”.

decidecade band

Frequency band whose bandwidth is one decidecade. *Note*: The bandwidth of a decidecade band increases with increasing centre frequency.

decibel (dB)

Unit of level used to express the ratio of one value of a power quantity to another on a logarithmic scale. Unit: dB.

delphinid

Family of oceanic dolphins, or Delphinidae, composed of approximately thirty extant species, including dolphins, porpoises, and killer whales.

duty cycle

The time when sound is periodically recorded by an acoustic recording system.

Fourier transform (or Fourier synthesis)

A mathematical technique which, although it has varied applications, is referenced in the context of this report as a method used in the process of deriving a spectrum estimate from time-series data (or the reverse process, termed the inverse Fourier transform). A computationally efficient numerical algorithm for computing the Fourier transform is known as fast Fourier transform (FFT).

frequency

The rate of oscillation of a periodic function measured in cycles-per-unit-time. The reciprocal of the period. Unit: hertz (Hz). Symbol: *f*. 1 Hz is equal to 1 cycle per second.

hearing group

Category of animal species when classified according to their hearing sensitivity and to the susceptibility to sound. Examples for marine mammals include very low-frequency (VLF) cetaceans, low-frequency (LF) cetaceans, mid-frequency (MF) cetaceans, high-frequency (HF) cetaceans, very high-frequency (VHF) cetaceans, otariid pinnipeds in water (OPW), phocid pinnipeds in water (PPW), sirenians (SI), other marine carnivores in air (OCA), and other marine carnivores in water (OCW) (NMFS 2018, Southall et al. 2019). See auditory frequency weighting functions, which are often applied to these groups. Examples for fish include species for which the swim bladder is involved in hearing, species for which the swim bladder is not involved in hearing, and species without a swim bladder (Popper et al. 2014).

hearing threshold

The sound pressure level for any frequency of the hearing group that is barely audible for a given individual for specified background noise during a specific percentage of experimental trials.

hertz (Hz)

A unit of frequency defined as one cycle per second.

high-frequency (HF) cetacean

See hearing group.

hydrophone

An underwater sound pressure transducer. A passive electronic device for recording or listening to underwater sound.

impulsive sound

Qualitative term meaning sounds that are typically transient, brief (less than 1 second), broadband, with rapid rise time and rapid decay. They can occur in repetition or as a single event. Examples of impulsive sound sources include explosives, seismic airguns, and impact pile drivers.

low-frequency (LF) cetacean

See hearing group.

masking

Obscuring of sounds of interest by sounds at similar frequencies.

median

The 50th percentile of a statistical distribution.

mid-frequency (MF) cetacean

See hearing group.

mysticete

A suborder of cetaceans that use baleen plates to filter food from water. Members of this group include rorquals (Balaenopteridae), right whales (Balaenidae), and grey whales (*Eschrichtius robustus*).

octave

The interval between a sound and another sound with double or half the frequency. For example, one octave above 200 Hz is 400 Hz, and one octave below 200 Hz is 100 Hz.

odontocete

The presence of teeth, rather than baleen, characterizes these whales. Members of the Odontoceti are a suborder of cetaceans, a group comprised of whales, dolphins, and porpoises. The skulls of toothed whales are mostly asymmetric, an adaptation for their echolocation. This group includes sperm whales, killer whales, belugas, narwhal, dolphins, and porpoises.

otariid

A common term used to describe members of the Otariidae, eared seals, commonly called sea lions and fur seals. Otariids are adapted to a semi-aquatic life; they use their large fore flippers for propulsion. Their ears distinguish them from phocids. Otariids are one of the three main groups in the superfamily Pinnipedia; the other two groups are phocids and walrus.

peak sound pressure level (zero-to-peak sound pressure level)

The level ($L_{p,pk}$ or L_{pk}) of the squared maximum magnitude of the sound pressure (p_{pk}^2). Unit: decibel (dB). Reference value (p_0^2) for sound in water: 1 µPa^2.

$$L_{p,\mathrm{pk}} := 10\log_{10}\left(p_{\mathrm{pk}}^2/p_0^2\right)\,\mathrm{dB} \ = 20\log_{10}\left(p_{\mathrm{pk}}/p_0\right)\,\mathrm{dB}$$

The frequency band and time window should be specified. Abbreviation: PK or Lpk.

peak-to-peak pressure

The difference between the maximum and minimum sound pressure over a specified frequency band and time window. Unit: pascal (Pa).

percentile level

The sound level not exceeded *N*% of the time during a specified time interval. The *N*th percentile level is equal to the (100−*N*)% exceedance level. Also see *N* percent exceedance level.

permanent threshold shift (PTS)

An irreversible loss of hearing sensitivity caused by excessive noise exposure. PTS is considered auditory injury.

phocid

A common term used to describe all members of the family Phocidae. These true/earless seals are more adapted to in-water life than are otariids, which have more terrestrial adaptations. Phocids use their hind flippers to propel themselves. Phocids are one of the three main groups in the superfamily Pinnipedia; the other two groups are otariids and walrus.

phocid pinnipeds in water (PPW)

See hearing group.

pinniped

A common term used to describe all three groups that form the superfamily Pinnipedia: phocids (true seals or earless seals), otariids (eared seals or fur seals and sea lions), and walrus.

pressure, acoustic

The deviation from the ambient pressure caused by a sound wave. Also called sound pressure. Unit: pascal (Pa).

pressure, hydrostatic

The pressure at any given depth in a static liquid that is the result of the weight of the liquid acting on a unit area at that depth, plus any pressure acting on the surface of the liquid. Unit: pascal (Pa).

received level

The level measured (or that would be measured) at a defined location. The type of level should be specified.

reference values

standard underwater references values used for calculating sound, e.g., the reference value for expressing sound pressure level in decibels is 1 µPa.

Quantity	Reference value
Sound pressure	1 µPa
Sound exposure	1 µPa^2 s
Sound particle displacement	1 pm
Sound particle velocity	1 nm/s
Sound particle acceleration	1 µm/s^2

rms

abbreviation for root-mean-square.

sound

A time-varying disturbance in the pressure, stress, or material displacement of a medium propagated by local compression and expansion of the medium.

sound exposure

Time integral of squared sound pressure over a stated time interval. The time interval can be a specified time duration (e.g., 24 hours) or from start to end of a specified event (e.g., a pile strike, an airgun pulse, a construction operation). Unit: Pa^2 s.

sound exposure level

The level (L_E) of the sound exposure (E). Unit: decibel (dB). Reference value (E_0) for sound in water: 1 µPa^2 s.

$$L_E := 10\log_{10}(E/E_0)\ \mathrm{dB}\ = 20\log_{10}\left(E^{1/2}/E_0^{1/2}\right)\ \mathrm{dB}$$

The frequency band and integration time should be specified. Abbreviation: SEL.

sound field

Region containing sound waves.

sound pressure level (rms sound pressure level)

The level ($L_{p,\mathrm{rms}}$) of the time-mean-square sound pressure (p_{rms}^2). Unit: decibel (dB). Reference value (p_0^2) for sound in water: 1 µPa^2.

$$L_{p,\mathrm{rms}} := 10\log_{10}(p_{\mathrm{rms}}^2/p_0^2)\ \mathrm{dB}\ = 20\log_{10}(p_{\mathrm{rms}}/p_0)\ \mathrm{dB}$$

The frequency band and averaging time should be specified. Abbreviation: SPL or Lrms.

source level (SL)

A property of a sound source obtained by adding to the sound pressure level measured in the far field the propagation loss from the acoustic centre of the source to the receiver position. Unit: decibel (dB). Reference value: 1 µPa^{2}m^2.

spectrogram

A visual representation of acoustic amplitude compared with time and frequency.

spectrum

An acoustic signal represented in terms of its power, energy, mean-square sound pressure, or sound exposure distribution with frequency.

temporary threshold shift (TTS)

Reversible loss of hearing sensitivity. TTS can be caused by noise exposure.

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Appendix A. Acoustic Data Analysis Methods

The data sampled at 64 or 675 kHz was processed for ambient sound analysis, vessel noise detection, and detection of all marine mammal vocalizations. This section describes the ambient, vessel, and marine mammal detection algorithms employed (Figure A-1).

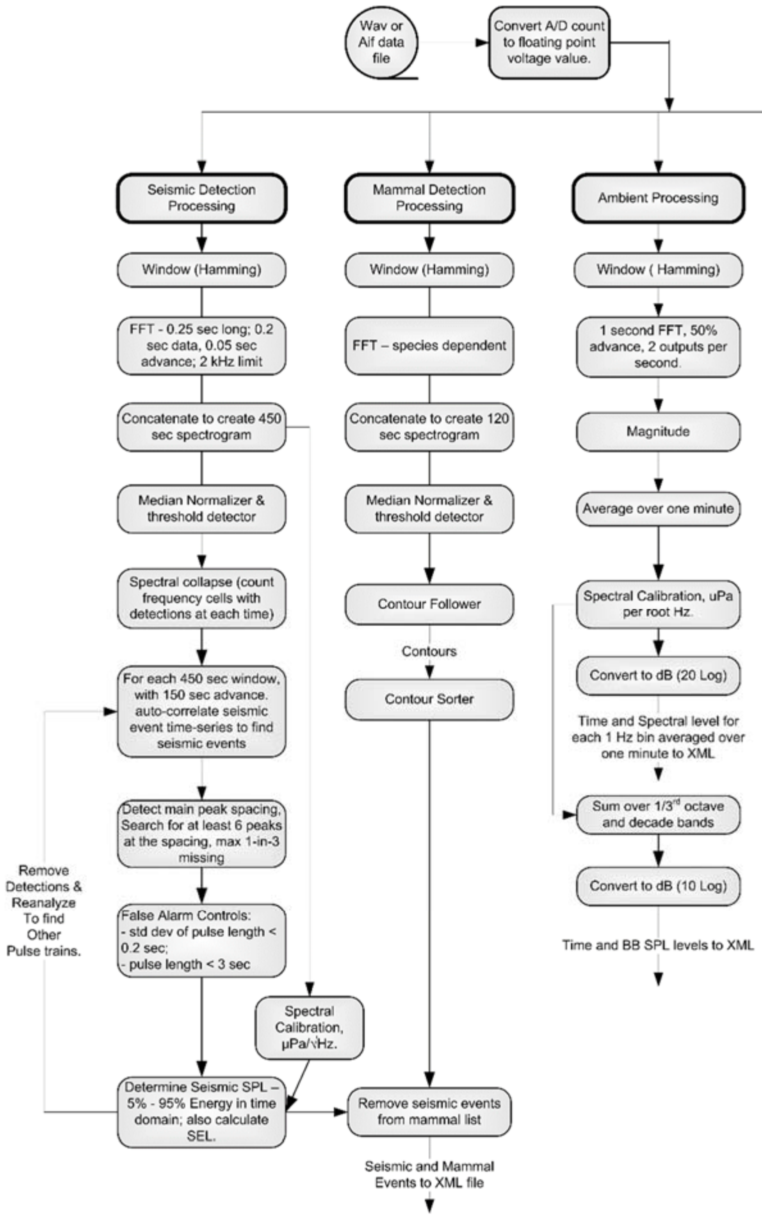

Figure A-1. Major stages of the automated acoustic analysis process performed with JASCO's custom software suite.

A.1. Total Ambient Sound Levels

Underwater sound pressure amplitude is measured in decibels (dB) relative to a fixed reference pressure of p_0 = 1 μPa. Because the perceived loudness of sound, especially impulsive noise such as from seismic airguns, pile driving, and sonar, is not generally proportional to the instantaneous acoustic pressure, several sound level metrics are commonly used to evaluate noise and its effects on marine life. We provide specific definitions of relevant metrics used in this report. Where possible we follow the ANSI and ISO standard definitions and symbols for sound metrics, but these standards are not always consistent.

The zero-to-peak pressure level, or peak pressure level (PK or $L_{p,pk}$; dB re 1 μPa), is the decibel level of the maximum instantaneous sound pressure level in a stated frequency band attained by an acoustic pressure signal, $p(t)$:

$$\mathrm{PK} = L_{p,\mathrm{pk}} = 10\log_{10}\frac{\max|p^2(t)|}{p_0^2} \tag{A-2}$$

PK is often included as criterion for assessing whether a sound is potentially injurious; however, because it does not account for the duration of a noise event, it is generally a poor indicator of perceived loudness.

The sound pressure level (SPL or L_p; dB re 1 μPa) is the decibel level of the root-mean-square (rms) pressure in a stated frequency band over a specified time window (T; s) containing the acoustic event of interest. It is important to note that SPL always refers to an rms pressure level and therefore not instantaneous pressure:

$$\mathrm{SPL} = L_p = 10\log_{10}\left[\frac{1}{T}\int_T p^2(t)\,dt \Big/ p_0^2\right] \tag{A-3}$$

The SPL represents a nominal effective continuous sound over the duration of an acoustic event, such as the emission of one acoustic pulse, a marine mammal vocalization, the passage of a vessel, or over a fixed duration. Because the window length, *T*, is the divisor, events with similar sound exposure level (SEL), but more spread out in time have a lower SPL.

The sound exposure level (SEL or L_E, dB re 1 μPa^2 s) is a measure related to the acoustic energy contained in one or more acoustic events (N). The SEL for a single event is computed from the time-integral of the squared pressure over the full event duration (T):

$$\mathrm{SEL} = L_E = 10\log_{10}\left[\int_T p^2(t)\,dt \Big/ T_0 p_0^2\right] \tag{A-4}$$

where T_0 is a reference time interval of 1 s. The SEL continues to increase with time when non-zero pressure signals are present. It therefore can be construed as a dose-type measurement, so the integration time used must be carefully considered in terms of relevance for impact to the exposed recipients.

SEL can be calculated over periods with multiple events or over a fixed duration. For a fixed duration, the square pressure is integrated over the duration of interest. For multiple events, the SEL can be computed by summing (in linear units) the SEL of the N individual events:

$$L_{E,N} = 10\log_{10}\sum_{i=1}^{N}10^{\frac{L_{E,i}}{10}} \tag{A-5}$$

To compute the SPL(T_{90}) and SEL of acoustic events in the presence of high levels of background noise, equations A-2 and A-3 are modified to subtract the background noise contribution:

$$\mathrm{SPL}(T_{90}) = L_{p90} = 10\log_{10}\left[\frac{1}{T_{90}}\int_{T_{90}}\left(p^2(t)-\overline{n^2}\right)dt \Big/ p_0^2\right] \tag{A-6}$$

$$L_E = 10\log_{10}\left[\int_{T}\left(p^2(t)-\overline{n^2}\right)dt \Big/ T_0 p_0^2\right] \tag{A-7}$$

where $\overline{\mathrm{n}^2}$ is the mean square pressure of the background noise, generally computed by averaging the squared pressure of a temporally-proximal segment of the acoustic recording during which acoustic events are absent (e.g., between pulses).

Because the SPL(T_{90}) and SEL are both computed from the integral of square pressure, these metrics are related numerically by the following expression, which depends only on the duration of the time window T:

$$L_p = L_E - 10\log_{10}(T) \tag{A-8}$$

$$L_{p90} = L_E - 10\log_{10}(T_{90}) - 0.458 \tag{A-9}$$

where the 0.458 dB factor accounts for the 10% of SEL missing from the SPL(T_{90}) integration time window.

Energy equivalent SPL (dB re 1 µPa) denotes the SPL of a stationary (constant amplitude) sound that generates the same SEL as the signal being examined, $\mathrm{p(t)}$, over the same period of time, T:

$$L_{\mathrm{eq}} = 10\log_{10}\left[\frac{1}{T}\int_{T} p^2(t)\,dt \Big/ p_0^2\right] \tag{A–10}$$

The equations for SPL and the energy-equivalent SPL are numerically identical; conceptually, the difference between the two metrics is that the former is typically computed over short periods (typically of 1 s or less) and tracks the fluctuations of a non-steady acoustic signal, whereas the latter reflects the average SPL of an acoustic signal over times typically of one minute to several hours.

A.2. Decidecade Band Analysis

The distribution of a sound's power with frequency is described by the sound's spectrum. The sound spectrum can be split into a series of adjacent frequency bands. Splitting a spectrum into 1 Hz wide bands, called passbands, yields the power spectral density of the sound. These values directly compare to the Wenz curves, which represent typical deep ocean sound levels (Figure 2) (Wenz 1962). This splitting of the spectrum into passbands of a constant width of 1 Hz, however, does not represent how animals perceive sound.

Because animals perceive exponential increases in frequency rather than linear increases, analyzing a sound spectrum with passbands that increase exponentially in size better approximates real-world scenarios. In underwater acoustics, a spectrum is commonly split into decidecade bands, which are one tenth of a decade wide. A decidecade is sometimes referred to as a "1/3-octave" because one tenth of a decade is approximately equal to one third of an octave. Each decade represents a factor 10 in sound frequency. Each octave represents a factor 2 in sound frequency. The centre frequency of the ith band, $f_c(i)$, is defined as:

$$f_c(i) = 10^{\frac{i}{10}}\,\text{kHz} \tag{A-1}$$

and the low (f_{lo}) and high (f_{hi}) frequency limits of the ith decade band are defined as:

$$f_{lo,i} = 10^{\frac{-1}{20}} f_c(i) \text{ and } f_{hi,i} = 10^{\frac{1}{20}} f_c(i) \tag{A-2}$$

The decidecade bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced (Figure A-2).

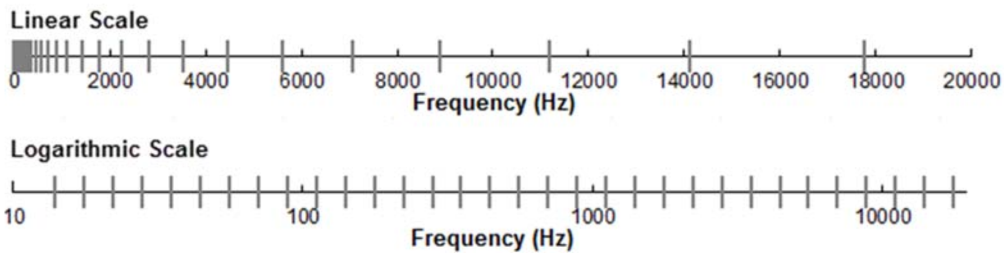

Figure A-2. Decidecade frequency bands (vertical lines) shown on a linear frequency scale and a logarithmic scale.

The sound pressure level in the ith band ($L_{p,i}$) is computed from the spectrum $S(f)$ between $f_{lo,i}$ and $f_{hi,i}$:

$$L_{p,i} = 10 \log_{10} \int_{f_{lo,i}}^{f_{hi,i}} S(f)\, df \text{ dB} \tag{A-3}$$

Summing the sound pressure level of all the bands yields the broadband sound pressure level:

$$\text{Broadband SPL} = 10 \log_{10} \sum_i 10^{\frac{L_{p,i}}{10}} \text{ dB} \tag{A-4}$$

Figure A-3 shows an example of how the decidecade band sound pressure levels compare to the sound pressure spectral density levels of an ambient sound signal. Because the decidecade bands are wider than 1 Hz, the decidecade band SPL is higher than the spectral levels at higher frequencies. Decidecade band analysis is applied to continuous and impulsive noise sources. For impulsive sources, the decidecade band SEL is typically reported.

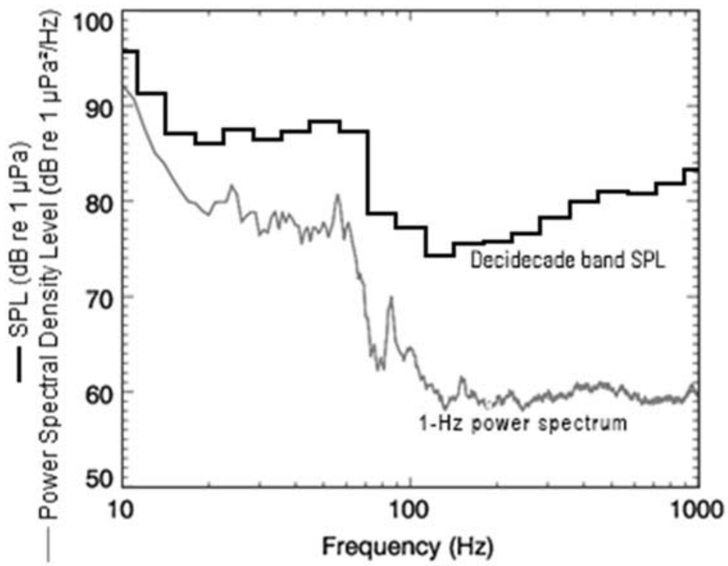

Figure A-3. Sound pressure spectral density levels and the corresponding decidecade band sound pressure levels of example ambient sound shown on a logarithmic frequency scale. Because the decidecade bands are wider with increasing frequency, the 1/3-octave-band SPL is higher than the power spectrum.

Table A-1. Decidecade-band frequencies (Hz).

Band	Lower frequency	Nominal centre frequency	Upper frequency
10	8.9	10.0	11.2
11	11.2	12.6	14.1
12	14.1	15.8	17.8
13	17.8	20.0	22.4
14	22.4	25.1	28.2
15	28.2	31.6	35.5
16	35.5	39.8	44.7
17	44.7	50.1	56.2
18	56.2	63.1	70.8
19	70.8	79.4	89.1
20	89.1	100.0	112.2
21	112	126	141
22	141	158	178
23	178	200	224
24	224	251	282
25	282	316	355
26	355	398	447
27	447	501	562
28	562	631	708
29	708	794	891

30	891	1000	1122
31	1122	1259	1413
32	1413	1585	1778
33	1778	1995	2239
34	2239	2512	2818
35	2818	3162	3548
36	3548	3981	4467
37	4467	5012	5623
38	5623	6310	7079
39	7079	7943	8913
40	8913	10000	11220
41	11220	12589	14125

Band	Lower frequency	Nominal centre frequency	Upper frequency
10	8.9	10.0	11.2
11	11.2	12.6	14.1
12	14.1	15.8	17.8
13	17.8	20.0	22.4
14	22.4	25.1	28.2
15	28.2	31.6	35.5
16	35.5	39.8	44.7
17	44.7	50.1	56.2
18	56.2	63.1	70.8
19	70.8	79.4	89.1
20	89.1	100.0	112.2
21	112	126	141
22	141	158	178
23	178	200	224
24	224	251	282
25	282	316	355

Band	Lower frequency	Nominal centre frequency	Upper frequency
26	355	398	447
27	447	501	562
28	562	631	708
29	708	794	891
30	891	1000	1122
31	1122	1259	1413
32	1413	1585	1778
33	1778	1995	2239
34	2239	2512	2818
35	2818	3162	3548
36	3548	3981	4467
37	4467	5012	5623
38	5623	6310	7079
39	7079	7943	8913
40	8913	10000	11220
41	11220	12589	14125

Table A-2. Decade-band frequencies (Hz).

Decade band	Lower frequency	Nominal centre frequency	Upper frequency
2	8.9	50	56234
3	8.9	500	89.1
4	89.1	5,000	891
5	891	50,000	8913
6	8913	500,000	89125
7	89125	5,000,000	N/A – above Nyquist

Appendix B. Marine Mammal Detection Methodology

B.1. Automated Click Detector for Odontocetes

We applied an automated click detector/classifier to the data to detect clicks from odontocetes (Figure B-1.). This detector/classifier is based on the zero-crossings in the acoustic time series. Zero-crossings are the rapid oscillations of a click's pressure waveform above and below the signal's normal level (e.g., Figure B-1.). Clicks are detected by the following steps (Figure B-1.):

1. The raw data is high-pass filtered to remove all energy below 5 kHz. This removes most energy from other sources such as shrimp, vessels, wind, and cetacean tonal calls, yet allows the energy from all marine mammal click types to pass.
2. The filtered samples are summed to create a 0.334 ms rms time series. Most marine mammal clicks have a 0.1–1 ms duration.
3. Possible click events are identified with a split-window normaliser that divides the 'test' bin of the time series by the mean of the 6 'window' bins on either side of the test bin, leaving a 1-bin wide 'notch'.
4. A Teager-Kaiser energy detector identifies possible click events.
5. The high-pass filtered data is searched to find the maximum peak signal within 1 ms of the detected peak.
6. The high-pass filtered data is searched backwards and forwards to find the time span where the local data maxima are within 9 dB of the maximum peak. The algorithm allows for two zero-crossings to occur where the local peak is not within 9 dB of the maximum before stopping the search. This defines the time window of the detected click.
7. The classification parameters are extracted. The number of zero crossings within the click, the median time separation between zero crossings, and the slope of the change in time separation between zero crossings are computed. The slope parameter helps to identify beaked whale clicks, as beaked whales can be identified by the increase in frequency (upsweep) of their clicks.
8. The Mahalanobis distance between the extracted classification parameters and the templates of known click types is computed. The covariance matrices for the known click types, computed from thousands of manually identified clicks for each species, are stored in an external file. Each click is classified as a type with the minimum Mahalanobis distance unless none of them are less than the specified distance threshold.

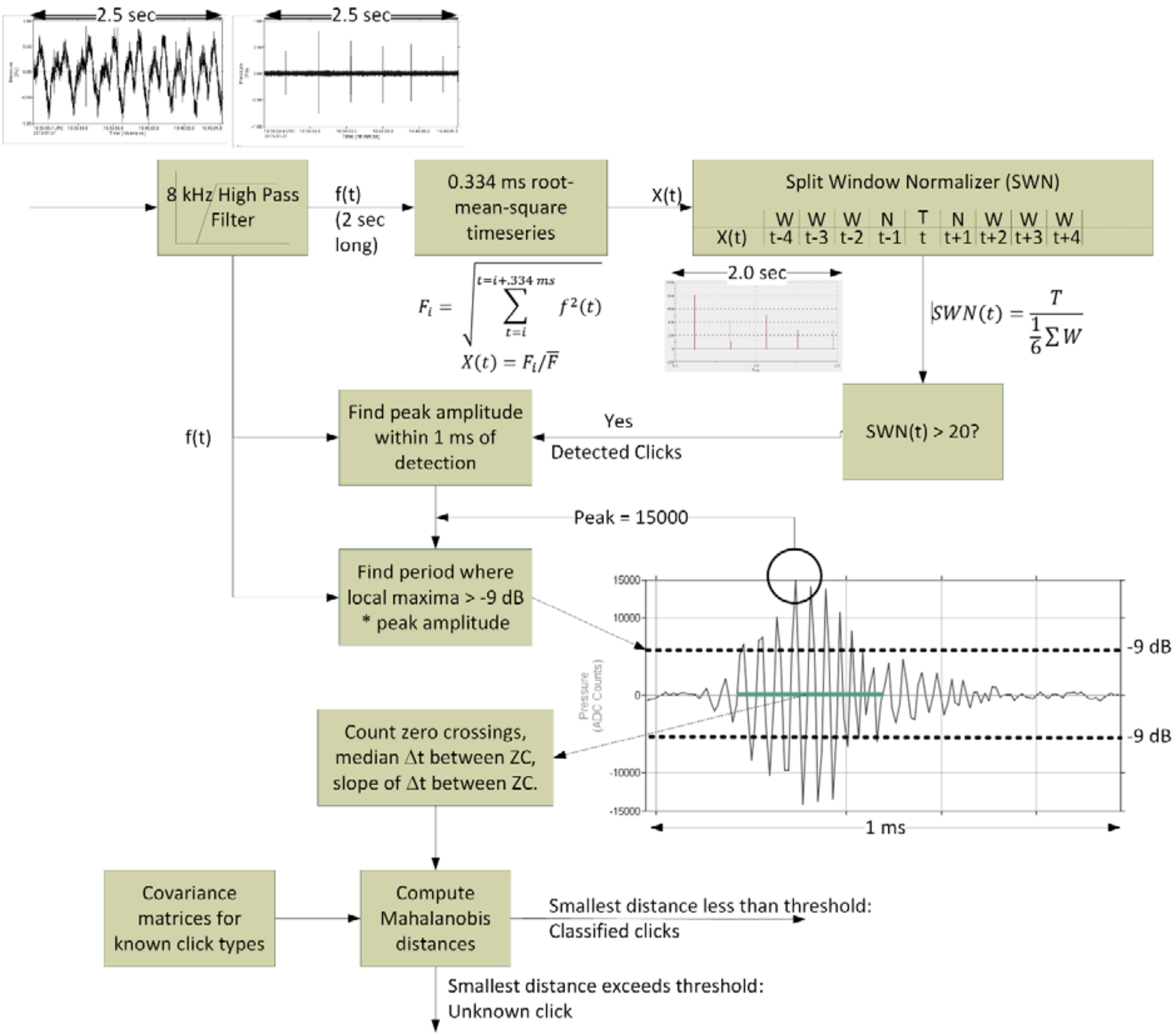

Figure B-1. The automated click detector/classifier block diagram.

Odontocete clicks occur in groups called click trains. Each species has a characteristic inter-click-interval (ICI) and number of clicks per train. The automated click detector includes a second stage that associates individual clicks into trains (Figure B-2). The steps of the click train associator algorithm are:

1. Queue clicks for N seconds, where N is twice the maximum number of clicks per train times the maximum ICI.
2. Search for all clicks within the window that have Mahalanobis distances less than 11 for the species of interest (this gets 99% of all clicks for the species as defined by the template).
3. Create a candidate click train if:
    a. The number of clicks is greater or equal to the minimum number of clicks in a train;
    b. The maximum time between any two clicks is less than twice the maximum ICI, and
    c. The smallest Mahalanobis distance for all clicks in the candidate train is less than 4.1.
4. Create a new 'time-series' that has a value of 1 at the time of arrival of each clicks and zeroes everywhere else.

5. Apply a Hann window to the timeseries then compute the cepstrum.
6. A click train is classified if a peak in the cepstrum with amplitude > 5 times the standard deviation of the cepstrum occurs at a quefrency between the minimum maximum ICI.
7. Queue clicks for N seconds
8. Search for all clicks within the window that have Mahalanobis distances less than 10 (equal to the extent of the variance in the training data set).
9. If the number of clicks is greater than or equal to 3 and dT is less than 2 * max ICI, make a new time-series at the 0.333 ms rate; where the value is 1 when the clicks occurred and 0 for all other time bins. Perform the following processing on this time series:
    a. Compute cepstrum
    b. ICI is the peak of the cepstrum with amplitude > 5 * stdev and searching for quefrency between minICI and maxICI.
    c. For each click related to the previous Ncepstrum, create a new time series and compute ICI; if we get a good match, extend the click train; find a mean ICI and variance.
10. If the click features, total clicks and mean ICI match the species, output a species_click_train detection.

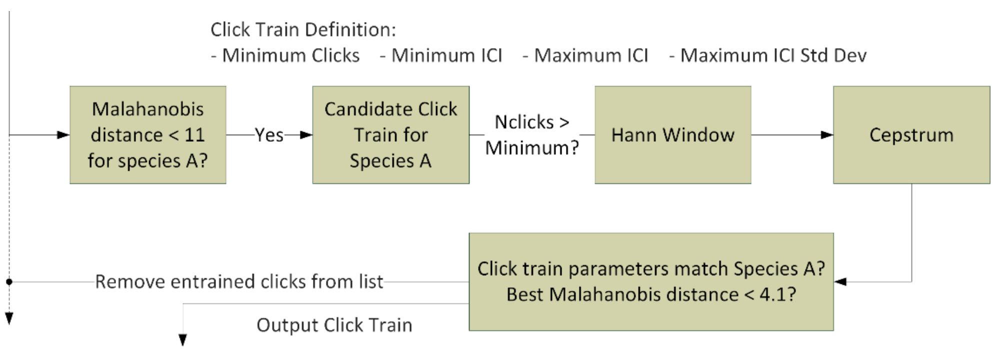

Figure B-2. The click train automated detector/classifier block diagram.

B.2. Automated Tonal Signal Detection

Marine mammal tonal acoustic signals are automatically detected by the following steps:

1. Spectrograms of the appropriate resolution for each mammal vocalisation type that were normalised by the median value in each frequency bin for each detection window Table B-1 were created.
2. Adjacent bins were joined, and contours were created via a contour-following algorithm (Figure B-3).
3. A sorting algorithm determined if the contours match the definition of a marine mammal vocalization (Table B-2).

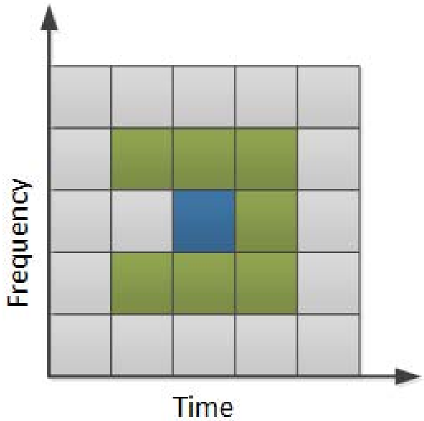

Figure B-3. Illustration of the search area used to connect spectrogram bins. The blue square represents a bin of the binary spectrogram equalling 1 and the green squares represent the potential bins it could be connected to. The algorithm advances from left to right so grey cells left of the test cell need not be checked.

The tonal signal detector is expanded into a pulse train detector through the following steps:

1. Detect and classify contours as described in steps 1 and 2 above.
2. A sorting algorithm determines if any series of contours can be assembled into trains that match a pulse train template (Table B-3).

Table B-1. Fast Fourier Transform (FFT) and detection window settings for all automated contour-based detectors used to detect tonal vocalizations of marine mammal species expected in the data. Values are based on JASCO's experience and empirical evaluation on a variety of data sets.

Automated detector	FFT			Detection window (s)	Detection threshold
	Resolution (Hz)	Frame length (s)	Timestep (s)		
Ringedseal_LFdoublethump	20	0.05	0.025	5	4
Narwhal_HFbuzz	64	0.01	0.005	5	2.5
Narwhal_LFbuzz	16	0.03	0.015	5	2
Narwhal_Whistle	4	0.05	0.01	5	3.5
NarwhalKnockTrain	64	0.01	0.005	40	2
Beardedseal_downsweep	2	0.2	0.05	10	3
Beardedseal_upsweep	2	0.2	0.05	10	3
Beardedseal_fulltrill	4	0.25	0.125	10	3
VLFMoan	2	0.2	0.05	15	4
LFMoan	2	0.25	0.05	10	3
ShortLow	7	0.17	0.025	10	3
MFMoanLow	4	0.2	0.05	5	3
MFMoanHigh	8	0.125	0.05	5	3
WhistleLow	16	0.03	0.015	5	3
WhistleHigh	64	0.015	0.005	5	3

Table B-2. A sample of vocalization sorter definitions for the tonal vocalizations of cetacean species expected in the area.

Automated detector	Target species	Frequency (Hz)	Duration (s)	Bandwidth (B; Hz)	Other detection parameters
Ringedseal_LFdoublethump	Ringed seal	10–250	0.2–1.0	>20	minF<50 Hz
Narwhal_HFbuzz	Narwhal	14,000–100,000	0.1–10	>3000	n/a
Narwhal_LFbuzz	Narwhal	1000–10,000	0.5–5	>1000	minF<5000 Hz
Narwhal_Whistle	Narwhal	1000–20,000	0.5–5	20–1000	minF<9000 Hz
Beardedseal_downsweep	Bearded seal	200–1500	1–10	>100	Sweep rate: −30-−500 Hz/s
Beardedseal_upsweep	Bearded seal	150–2000	1–6	>100	Sweep rate: 100-1000 Hz/s
Beardedseal_fulltrill	Bearded seal	125–8200	10–90	>500	Sweep rate: −5-−150 Hz/s
VLFMoan	Blue/fin whale	10–100	0.30–10.00	>10	minF<40 Hz
LFMoan	Bowhead whale	40–250	0.50–10.00	>15	InstantaneousBandwidth<50 Hz
ShortLow	Baleen whale, pinniped	30–400	0.08–0.60	>25	n/a
MFMoanLow	Bowhead whale	100–700	0.50–5.00	>50	minF<450 Hz InstantaneousBandwidth<200 Hz
MFMoanHigh	Bowhead whale	500–2500	0.50–5.00	>150	minF<1500 Hz InstantaneousBandwidth<300 Hz
WhistleLow	Narwhal, beluga, killer whale	1000–10000	0.50–5.00	>300	Max Instantaneous Bandwidth = 1000 Hz minF<5000 Hz
WhistleHigh	beluga, killer whale	4000–20000	0.30–3.00	>700	Max Instantaneous Bandwidth = 5000 Hz

Table B-3. A sample of vocalization sorter definitions for the tonal pulse train vocalizations of cetacean species expected in the area.

Automated detector	Target species	Frequency (Hz)	Pulse duration (s)	Inter-pulse interval (s)	Train duration (s)	Train length (# pulses)
NarwhalKnockTrain	Narwhal	1000–8000	0.005–0.04	0.03–0.5	0.5–30	6–100

B.3. Automatic Data Selection for Validation (ADSV)

To standardise the file selection process for the selection of data for manual analysis, we applied our Automated Data Selection for Validation (ADSV) algorithm. Details of the ADSV algorithm are described in Kowarski et al. (2021) and a schematic of the process is provided in Figure B-4. ADSV computes the distribution of three descriptors that describe the automated detections in the full data set: the Diversity (number of automated detectors triggered per file), the Counts (number of automated detections per file for each automated detector), and the Temporal Distribution (spread of detections for each automated detector across the recording period). The algorithm removes files from the temporary data set that have the least impact on the distribution of the three descriptors in the full data set. Files are removed until a pre-determined data set size (N) is reached, at which point the temporary data set becomes the subset to be manually reviewed.

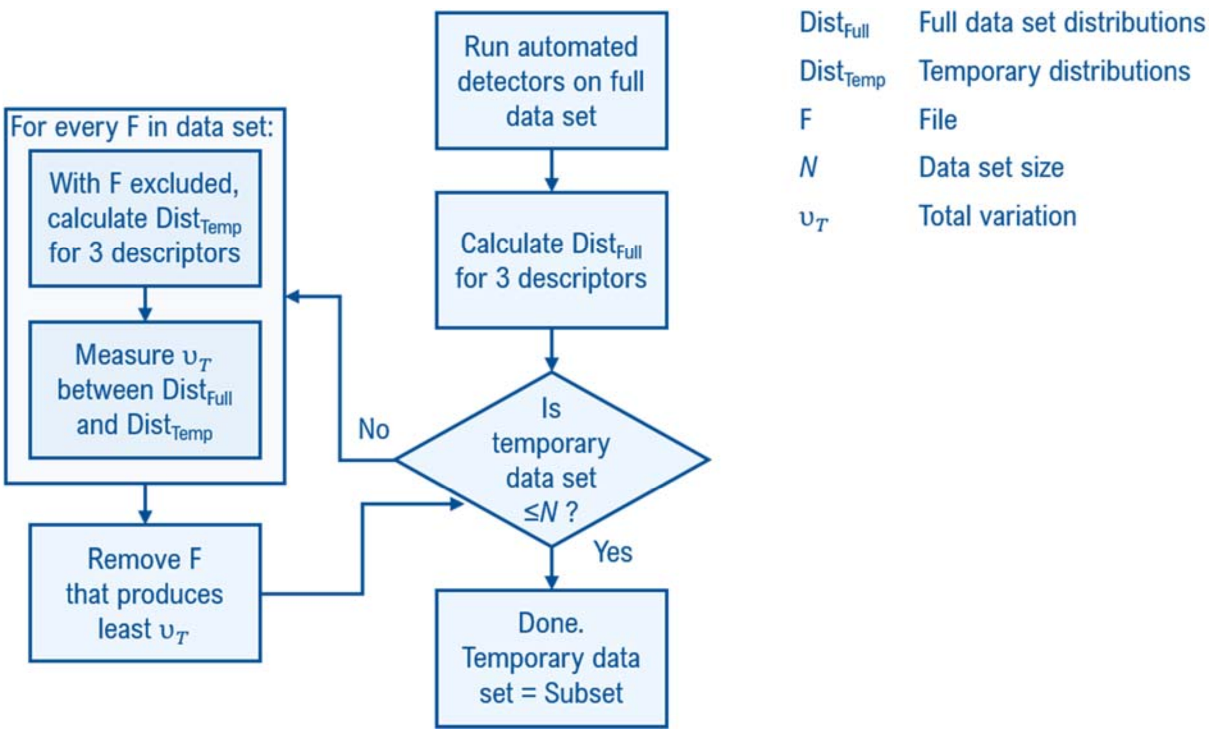

Figure B-4. Automated Data Selection for Validation (ADSV) process based on Figure 1 from Kowarski et al. (2021).

For the present work, an N of 3% was selected. Even with only a subset of data manually reviewed, the results presented here can be considered reliable, but some caveats should be considered. It is important to note that with only a subset of data manually reviewed, very rare species may have been missed or their occurrence underestimated. If the 3% subset of data manually analysed was not sufficiently large to capture the full range of acoustic environments in the full data set, the resulting automated detector performance metrics may be inaccurate and therefore should be taken as an estimate.

B.4. Automated Detector Performance Calculation and Optimization

All files selected for manual validation were reviewed by an experienced analyst using JASCO's PAMlab software to determine the presence or absence of every species, regardless of whether a species was automatically detected in the file. Although the automated detectors classify specific signals, we validated the presence/absence of species at the file level, not the detection level. Acoustic signals were only assigned to a species if the analyst was confident in their assessment. When unsure, analysts would consult one another, peer reviewed literature, and other experts in the field. If certainty could not be reached, the file of concern would be classified as possibly containing the species in question or containing an unknown acoustic signal. Next, the validated results were compared to the automated detector results in three phases to refine the results and ensure they accurately represent the occurrence of each species in the study area.

In phase 1, the human validated versus automated detector results were plotted as time series and critically reviewed to determine when and where automated detections should be excluded. Questionable detections that overlap with the detection period of other species were scrutinized. By restricting detections spatially and/or temporally where appropriate, we can maximize the reliability of the results.

In phase 2, the performance of the automated detectors was calculated and optimized for each species using a threshold, defined as the number of automated detections per file at and above which detections of species were considered valid.

To determine the performance of each automated detector and any necessary thresholds, the automated and validated results (excluding files where an analyst indicated uncertainty in species occurrence) were fed to a maximum likelihood estimation algorithm that maximizes the probability of detection and minimizes the number of false alarms using the Matthews Correlation Coefficient (MCC):

$$MCC = \frac{TPxTN - FPxFN}{\sqrt{(\mathrm{TP}+\mathrm{FP})(\mathrm{TP}+\mathrm{FN})(\mathrm{TN}+\mathrm{FP})(\mathrm{TN}+\mathrm{FN})}}$$

$$P = \frac{TP}{TP+FP}; R = \frac{TP}{TP+FN}$$

where *TP* (true positive) is the number of correctly detected files, *FP* (false positive) is the number of files that are false detections, and *FN* (false negatives) is the number of files with missed detections.

In phase 3, detections were further restricted to include only those where *P* was greater than or equal to 0.75. When *P* was less than 0.75, only validated results were used to describe the acoustic occurrence of a species. The occurrence of each species was plotted using JASCO's Ark software as time series showing presence/absence by hour over each day.

Appendix C. Marine Mammal Automated Detector Performance Results

Automated detectors that triggered on species' vocalizations confirmed to occur in the data during manual analysis are included in Table C-1. These detectors had performance metrics that varied across species, vocalization types, and stations (Table C-1). Automated detectors targeting stereotyped acoustic signals or those that are unique in spectral content, such as narwhal high-frequency buzzes, outperformed detectors aimed at finding acoustic signals with greater inter-specific overlap in spectral content, such as the moans of bowhead whales. Where there was sufficient data to calculate automated detector performance metrics, the precision and recall was generally high (Table C-1). Exceptions include narwhal tonal signals and killer whale whistles at Bruce Head where there were low annotations for these vocalization types. Automated detector results deemed reliable and refined to incorporate the classification threshold and exclusion periods are presented in Section 3.3.

Table C-1. The per-file performance of automated detectors by station including the detection-per-file threshold implemented, the resulting Precision (P) and Recall (R), the number of files in the validation sample (# Files), the number of files in the sample containing an annotation (# A) and automated detections (# D) of the relevant species. 'NA' denotes values that could not be calculated due to an insufficient number of TP, FN, and FP files to calculate the P and R, or a lack of validated signals. ND indicates that a species was never manually detected. LF and HF refer to the 64 and 687.5 kHz data recorded at Bruce Head, respectively. Stations where a detector had P < 0.75 are bolded.

Species signal (Detector)	Station	Threshold	P	R	MCC	# Files	# A	# D	Exclusion periods
Bowhead moans (MFMoanLow)	Bylot Island	1	0.86	0.75	0.76	82	16	14	28 Jul to end
	Ragged Island	5	0.86	0.71	0.72	77	17	20	30 Jul to end
	Bruce Head	NA	NA	NA	NA	106	2	9	10 Aug to end
Killer whale tonal calls (WhistleHigh)	Bylot Island	11	1.00	0.60	0.76	82	5	5	Start to 31 Jul
	Ragged Island	NA	NA	NA	NA	77	2	29	
	Bruce Head	**1**	**0.06**	**0.60**	**0.07**	**106**	**5**	**48**	
Sperm whale clicks (sperm whale click)	Bylot Island	**1**	**0.73***	**1.00**	**0.84**	**82**	**8**	**11**	**Start to 19 Aug**
	Ragged Island	NA	NA	NA	NA	77	1	51	
	Bruce Head	ND							
Narwhal Click (narwhal click)	Bylot Island	7	0.96	1.00	0.97	82	23	25	28 Jul to end
	Ragged Island	209	1.00	0.85	0.80	77	26	65	
	Bruce Head LF	83	0.98	0.95	0.93	106	42	58	
	Bruce Head HF	12	0.96	0.96	0.82	105	77	86	
Narwhal click trains (narwhal click train)	Bylot Island	1	0.96	1.00	0.97	82	23	24	28 Jul to end
	Ragged Island	14	1	0.81	0.85	77	26	37	
	Bruce Head LF	2	0.98	0.95	0.94	106	42	42	
	Bruce Head HF	1	0.96	0.94	0.81	105	77	75	
Narwhal low-frequency buzz (Narwhal_LFbuzz)	Bylot Island	1	1.00	0.87	0.91	82	23	20	28 Jul to end
	Ragged Island	1	0.77	0.97	0.76	77	32	39	
	Bruce Head	**1**	**0.74**	**0.87**	**0.58**	**106**	**52**	**61**	
Narwhal high-frequency buzz (Narwhal_HFbuzz)	Bylot Island	1	1.00	1.00	1.00	82	24	24	28 Jul to end
	Ragged Island	18	1.00	0.92	0.94	77	25	38	
	Bruce Head	2	0.96	0.98	0.94	106	46	48	
Narwhal knocks (NarwhalKnockTrain)	Bylot Island	1	0.89	0.94	0.90	82	18	19	28 Jul to end
	Ragged Island	7	0.96	0.78	0.78	77	32	34	
	Bruce Head	11	0.85	0.85	0.77	106	33	41	
Narwhal tonal calls (Narwhal_Whistle)	Bylot Island	**4**	**0.69**	**0.92**	**0.75**	**82**	**12**	**18**	28 Jul to end
	Ragged Island	3	0.83	0.96	0.83	77	25	34	
	Bruce Head	**12**	**0.64**	**0.64**	**0.56**	**106**	**14**	**50**	

* Although P was below the 0.75 threshold for sperm whales, the rarity of this species in the area warranted inclusion of the automated detections. Several detections outside of the validation sample have been confirmed.

Appendix D. Auditory Frequency Weighting Functions

The potential for anthropogenic sounds to impact marine mammals is largely dependent on whether the sound occurs at frequencies that an animal can hear well, unless the sound pressure level is so high that it can cause physical tissue damage regardless of frequency. Auditory (frequency) weighting functions reflect an animal's ability to hear a sound (Nedwell and Turnpenny 1998, Nedwell et al. 2007). Houser et al (2017) provide an example illustrating the effect of applying a weighting function to a (hypothetical) sound (Figure D-1).

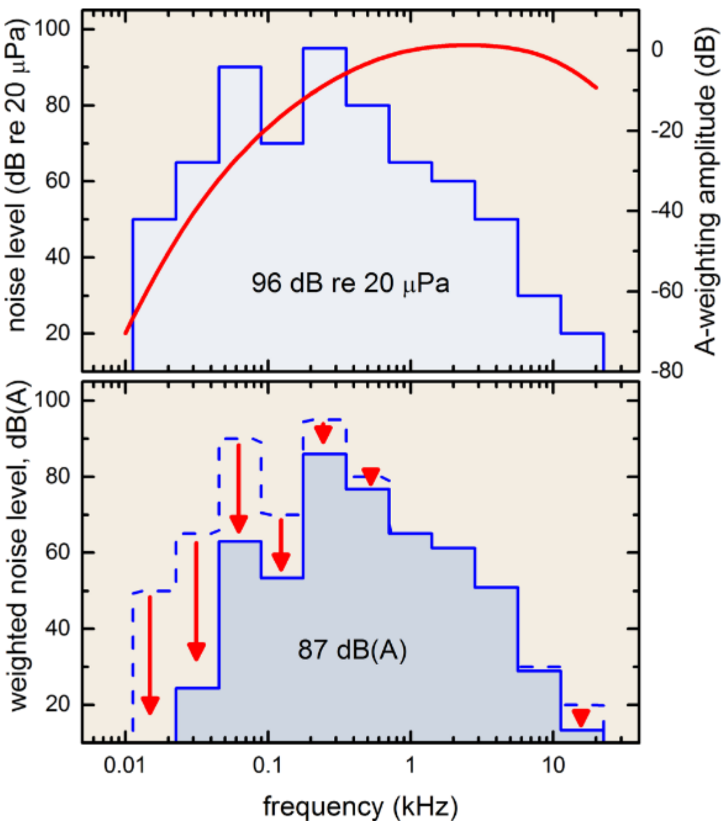

Figure D-1. Application of an auditory weighting function. Blue line shows a hypothetical, octave-band sound pressure spectrum in air, with a total sound pressure level (integrated over all octave-bands) of 96 dB re 20 µPa (This example uses in air-noise levels; therefore, a different reference pressure (20 µPa) applies. The principle is identical to underwater sound where a reference pressure of 1 µPa applies). (Top) Red line shows the human A-weighting function amplitude (A-weighting applies only to human hearing). (Bottom) To determine the weighted exposure level, the A-weighting amplitude at each frequency is added to the sound pressure level at each frequency (red arrows). The weighted spectrum has lower amplitude at the frequencies where the A-weighting function amplitudes are negative. The values from 1–4 kHz do not change substantially, because the weighting function is flat (i.e., the weights are near zero). The weighted SPL is calculated by integrating the weighted spectrum across all octave-bands; the result is 87 dBA, meaning a sound pressure level of 87 dB re 20 µPa after applying the human A-weighting function (Source: Houser et al. 2017).

To better reflect the auditory similarities between phylogenetically closely related species, but also significant differences between species groups among the marine mammals, the extant marine mammal species are assigned to functional hearing groups based on their hearing capabilities and sound production (NMFS 2018) (Table D-1). This division into broad categories is intended to provide a realistic number of categories for which individual noise exposure criteria were developed and the categorisation as such has proven to be a scientifically justified and useful approach in developing auditory frequency weighting functions and deriving noise exposure criteria for marine mammals.

Table D-1. Marine mammal hearing groups (NMFS 2018).

Hearing group	Generalised hearing range*
Low-frequency (LF) cetaceans (mysticetes or baleen whales)	7 Hz to 35 kHz
Mid-frequency (MF) cetaceans (odontocetes: delphinids, beaked whales)	150 Hz to 160 kHz
High-frequency (HF) cetaceans (other odontocetes)	275 Hz to 160 kHz
Phocid pinnipeds (PW) (underwater)	50 Hz to 86 kHz
Otariid pinnipeds (OW) (underwater)	60 Hz to 39 kHz

* The generalized hearing range for all species within a group. Individual hearing will vary.

The potential for noise to affect animals depends on how well the animals can hear it. Noises are less likely to disturb or injure an animal if they are at frequencies that the animal cannot hear well. An exception occurs when the sound pressure is so high that it can physically injure an animal by non-auditory means (i.e., barotrauma). For sound levels below such extremes, the importance of sound components at particular frequencies can be scaled by frequency weighting relevant to an animal's sensitivity to those frequencies (Nedwell and Turnpenny 1998, Nedwell et al. 2007).

In 2015, a US Navy technical report by Finneran (2015) recommended new auditory weighting functions. The overall shape of the auditory weighting functions is similar to human A-weighting functions, which follows the sensitivity of the human ear at low sound levels. The new frequency-weighting function is expressed as:

$$G(f) = K + 10\log_{10}\left[\left(\frac{(f/f_{10})^{2a}}{[1+(f/f_{lo})^2]^a[1+(f/f_{hi})^2]^b}\right)\right]. \tag{D-1}$$

Finneran (2015) proposed five functional hearing groups for marine mammals in water: low-, mid-, and high-frequency cetaceans, phocid pinnipeds, and otariid pinnipeds. The parameters for these frequency-weighting functions were further modified the following year (Finneran 2016) and were adopted in NOAA's technical guidance that assesses noise impacts on marine mammals (NMFS 2016, NMFS 2018). Table D-2 lists the frequency-weighting parameters for each hearing group; Figure D-2 shows the resulting frequency-weighting curves.

Table D-2. Parameters for the auditory weighting functions used in this project as recommended by NMFS (2018).

Hearing group	a	b	f_{lo} (Hz)	f_{hi} (kHz)	K (dB)
Low-frequency cetaceans (baleen whales)	1.0	2	200	19,000	0.13
Mid-frequency cetaceans (dolphins, plus toothed, beaked, and bottlenose whales)	1.6	2	8,800	110,000	1.20
High-frequency cetaceans (true porpoises, *Kogia*, river dolphins, cephalorhynchid, *Lagenorhynchus cruciger* and *L. australis*)	1.8	2	12,000	140,000	1.36
Phocid seals in water	1.0	2	1,900	30,000	0.75
Otariid seals in water	2.0	2	940	25,000	0.64

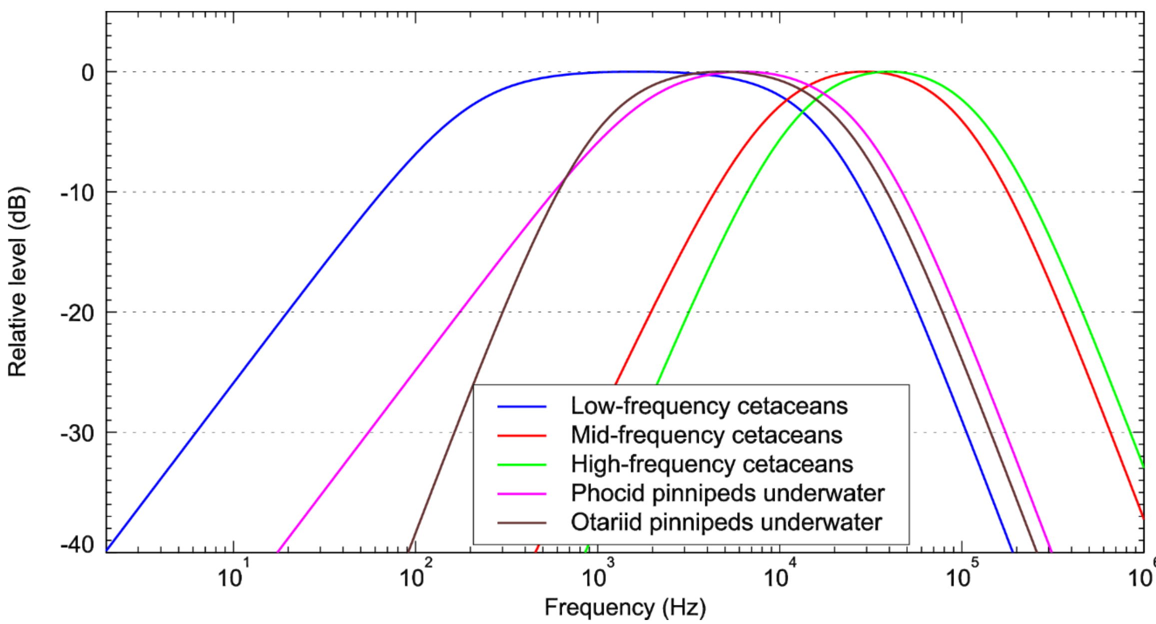

Figure D-2. Auditory weighting functions for functional marine mammal hearing groups as recommended by NMFS (2018).

The latest National Oceanic and Atmospheric Administration (NOAA) criteria for auditory injury (NMFS 2018) and its earlier iterations (NOAA 2013, 2015, NMFS 2016) have been scrutinized by the public, industrial proponents, and academics. This study applies the specific methods and thresholds for auditory injury summarized by NMFS (2018). Figure D-3 lists the applicable marine mammal auditory injury thresholds.

Figure D-3. Marine mammal auditory injury (permanent threshold shift, PTS and temporary threshold shift, TTS) sound exposure level (SEL) thresholds based on NMFS (2018) for non-impulsive sound sources, in dB re 1 $\mu Pa^2 \cdot s$.

Hearing group	PTS threshold	TTS threshold
Low-frequency (LF) cetaceans	199	179
Mid-frequency (MF) cetaceans	198	178
High-frequency (HF) cetaceans	173	153
Phocid pinnipeds in water	201	181
Otariid pinnipeds in water	219	199

Appendix E. Updated Calculations of 120 dB Exceedances for 2019

Recorder		Average time per shipping season day with SPL > 120 dB (hours [minutes])	Maximum time per shipping season day with SPL > 120 dB (hours [minutes])
AMAR–BI	All recorded data	0.3 [15.2]	8.6 [516.0]
	Only data with vessels detected	0.3 [15.1]	8.6 [516.0]
AMAR–RI (first deployment)	All recorded data	1.1 [67.4]	10.6 [637.0]
	Only data with vessels detected	0.8 [47.8]	7.1 [427.0]
AMAR–1	All recorded data	0.6 [38.1]	2.3 [136.0]
	Only data with vessels detected	0.2 [13.1]	0.8 [47.0]
AMAR–2	All recorded data	0.2 [10.1]	1.4 [82.0]
	Only data with vessels detected	0.1 [3.4]	0.5 [28.0]
AMAR–3	All recorded data	0.5 [31.3]	2.4 [145.0]
	Only data with vessels detected	0.2 [11.0]	0.9 [52.0]
AMAR–RI (second deployment)	All recorded data	0.3 [17.3]	3.1 [184.0]
	Only data with vessels detected	0.1 [4.8]	0.7 [43.0]

Appendix F. Marine Environment Working Group Comments

F.1. Qikiqtani Inuit Association

Name: Jeff W. Higdon, D. Bruce Stewart

Agency / Organization: Qikiqtani Inuit Association

Date of Comment Submission: 14 March 2022

#	Document Name	Section Reference	Comment	Baffinland Response
1	Austin, M.E., C.C. Wilson, K.A. Kowarski, J.J-Y. Delarue, and E.E. Maxner. 2022. Baffinland Iron Mines Corporation – Mary River Project: 2020 Underwater Acoustic Monitoring Program (Open-Water Season). Document 02514, Version 1.0. Technical report by JASCO Applied Sciences for Golder Associates Ltd. (File "Baffinland 2020 Open Water Acoustic Monitoring Report_Draft for MEWG.pdf")	General	How can these results be linked to other monitoring programs, and how can they inform mitigation? For example, what are the behavioural implications for listening range reduction (LRR) reductions in narwhal, and how can these implications be monitored? Table 8 (p. 52) shows the maximum number of hours in a day during which the sound pressure level (SPL) exceeded the 120 dB re 1 µPa threshold, with the daily maximum higher at Ragged Island (up to 7+ hours) than the other two sites. Are there certain periods in the season when such days occur, or any particular shipping conditions? Only 1-2 days per year have these extended periods with SPL > 120 dB (Figure 38), but similar patterns were reported in 2019 (Appendix E), suggesting that this situation occurs annually. Are days with high SPL exceedances predictable based on shipping schedules, and are there short-term mitigation opportunities? At Ragged Island, "periods with elevated flow noise and mooring noise also contributed to this value". Can this contribution be quantified?	More research within the field of underwater acoustics is needed to understand the biological significance and behavioural implications of masking before a link can be made between LRR and behavioural responses. Regarding the maximum number of hours in a day in which sound levels exceeded 120 dB at the Ragged Island recorder - There was one day (July 28) when the SPL exceeded 120 dB for 6.1 hours. On that day there was one outbound transit of the icebreaker escorting 2 ore carries, and one inbound transit of the icebreaker escorting 2 ore carriers. However, low-frequency flow noise and mooring noise dominated the recordings at Ragged Island on that day and caused the extended duration of 120 dB exceedance. This was not a result of shipping noise or a factor of specific shipping conditions. The same vessel conditions (an outbound and an inbound transit of the icebreaker with 2 ore carriers) also occurred on 26 July, but the SPL exceeded 120 dB for less than 2 hours on that day. The same was true in the open water season. On August 7, the SPL exceeded 120 dB during 6.3 hours when vessels were detected, and

#	Document Name	Section Reference	Comment	Baffinland Response
				7.4 hours in total. This noise was again attributed to low frequency flow and mooring noise. Three Project vessels passed the Ragged Island recorder that day - a cargo vessel, the icebreaker, and an ore carrier.
2	Austin et al. 2022	General	Are LRR calculations additive? For example, for 25 kHz (clicks / high frequency buzzes) in the early shoulder season, vessel noise resulted in >50% LRR for 11% of the total recording period at Ragged Island, and ambient noise resulted in >50% LRR for 28% of the total recording period. Does this mean that when both these sources of LRR are considered, narwhal experienced a 11%+28% = 39% LRR for the total recording period at Ragged Island? Or is there overlap such that some periods see both vessel traffic and ambient noise contributing to >50% LRR?	Periods identified as containing vessels do not overlap with the times characterized as ambient. So, yes, the calculations are additive. Recall that the LRR calculation is computed relative to the median ambient sound level. This means that 50% of the time there is 0% reduction of the listening range relative to listening range at the median ambient sound level. This also means narwhal would experience LRR (from any noise source) for at most 50% of the day, relative to the median ambient sound level.
3	Austin et al. 2022	General	Is it possible to calculate LRR for ringed seal given community observations of impacts and declines? Are there sufficient data on hearing capabilities?	It is possible to calculate LRR for ringed seal, however at the time year when shipping occurs ringed seals tend to be solitary and do not depend on communication to carry out life functions. They also do not echolocate to find food. For these reasons, LRR has not been calculated for ringed seal because this is not expected to be an important pathway of effect.

#	Document Name	Section Reference	Comment	Baffinland Response
4	Austin et al. 2022	Executive Summary, p. 2	Draft says five species detected acoustically, should be six (as listed)? Or seven as per the detection figures (bowhead, killer whale, narwhal, beluga, sperm whale, ringed seal, bearded seal)?	Five species were detected and confirmed (bowhead, killer whale, beluga, narwhal, and sperm whale), in addition sounds from ringed seal and bearded seal were suspected but not confirmed. This has been clarified in the text.
5	Austin et al. 2022	1.3. Ambient Sound Levels, p. 7	"Kim and Conrad (2016) reported that in the Project area, below 1000 Hz, moderate winds (~6 m/s) typical of the site contributed to average measured ambient sound levels of ~94 dB re 1 µPa." How do more recent data, including these 2020 recordings, compare?	A year over-year comparison of the data recorded since 2018 is included in the forthcoming 2021 Passive Acoustic Monitoring report.
6	Austin et al. 2022	1.4. Biological Contributors to the Marine Soundscape, Table 2, p. 9	Any relevant info in Sportelli's MSc thesis re: killer whale calls? Why are some references in parentheses? ("(Walmsley et al. 2020)" for narwhal, "(Watkins 1980)" for sperm whale)	A reference to Sportelli 2019 has been added to Section 1.4 of the report, however at this time these results have not enhanced our ability to detect or classify killer whale vocalizations.
7	Austin et al. 2022	2.1.2. Analysis of Total Ocean Sound Levels, p. 13 (and s. 2.2 Listening Range Reduction Calculations)	"Decidecade band levels are very similar to 1/3-octave-band levels." How similar is "very similar"? Can this be quantified? Also, s. 2.2 says "… decidecade bands (previously called 1/3-octave-bands)…", suggesting that they are the same thing, not similar?	For the purposes of this report, 1/3-octave band and decidecade band levels are equivalent. The difference between the two relates to the precise bandwidth of the frequency band. The bandwidth of decidecade band is one tenth of a decade, which is approximately equal to 1/3 of an octave. For this reason decidecade bands have historically often been called 1/3-ocatve bands. JASCO has always computed decidecade bands, so the results in the PAM reports between 2018 and

#	Document Name	Section Reference	Comment	Baffinland Response
				2020 are directly comparable. We have just changed the terminology to reflect more accurately what was actually computed, and to be consistent with ANSI standards.
8	Austin et al. 2022	2.3. Marine Mammal Detection Overview, p. 17	"Automated detector performance metrics are provided in Appendix C and should be considered wen interpreting results." Considered how? Also note typo in quoted text- "wen".	Please refer to the earlier paragraphs in Section 2.3.3 for details around how to interpret the detector performance metrics. The following text has been added to improve clarity: "For example, where an automated detector has a Recall of 0.90, readers must take into account when interpreting the occurrence figure that it is an underestimate of vocalization occurrence as 10% of acoustic files containing the signal of interest were not captured by the automated detector.". The typo has also been corrected.
9	Austin et al. 2022	3. Results, p. 18	… in 2020 the shipping lane through southern Milne Inlet was redirected farther east… meant that the recorder at the Bruce Head location was farther from the shipping lane compared to acoustic recordings in previous years." How does this influence comparability with results from previous years? Can data be standardized, etc?	The data cannot be standardized to account for this change of the shipping lane. The received vessel sound levels at the recorder location would be expected to be lower than in years prior due to the increased separation between the recorder and the vessels.

#	Document Name	Section Reference	Comment	Baffinland Response
10		3. Results, p. 22, Figure 12	Figure 12 caption should refer to open water, not early shoulder season?	The caption has been updated accordingly.
11		3.2. Vessel Detections, p. 25, Figure 16	Figure 16 - does black shading for manual narwhal detections cover up and obscure vessel detection, i.e., are there red cells underneath the black cells on occasion? If so, an alternate display should be used for cases where both narwhal and vessels were detected.	Yes, in some instances narwhal detections overlap with and obscure vessel detections. Alternate presentation formats will be considered in future; presently the plotting software does not provide flexibility for this level of control.
12		3.3.3. Narwhal and Possible Beluga Whales, p. 35, Figures 27 and 28	Figures 27 and 28 - all narwhal low-frequency buzz and whistle detections at Bruce Head were manual? Was automatic detection not used here, or was it not effective?	Please reference Table C-1; the automated detectors did not perform sufficiently well to be included in the Figure. As stated in Section 2.3.3 3 “Only detections associated with a P greater than or equal to 0.75 were considered. When P < 0.75, only the validated results were used to describe the acoustic occurrence of a species.” And B.4 “were further restricted to include only those where P was greater than or equal to 0.75. When P was less than 0.75, only validated results were used to describe the acoustic occurrence of a species.” The following text has been added to Section 3.3 “Where automated detectors were deemed to perform poorly (P>0.75), only manually validated results are presented.”

#	Document Name	Section Reference	Comment	Baffinland Response
13		4.3.3. Narwhal and Beluga Whales, p. 55	The narwhal population estimate used here is quite dated, see DFO surveys from 2013.	The following text has been added: "Corrected estimates put the Eclipse Sounds stock at 10,489 (coefficient of variation = 24%) individuals (Doniol-Valcroze et al. 2015)."
14		4.4. Summary, p. 56	"Though results from the 2020 aerial survey and Bruce Head programs indicated a decrease in narwhal presence in Eclipse Sound and Milne Inlet in 2020, patterns in their acoustic detections were consistent with prior acoustic monitoring results." Consistent how? The report doesn't include any comparison with prior results.	A reference to the 2019 Acoustic Monitoring report has been added and some clarifying text has been added. A year-over-year comparison has added to the forthcoming 2021 Acoustic Monitoring Report.

F.3. Fisheries and Oceans Canada

Name: Marianne Marcoux

Agency / Organization: Fisheries and Oceans Canada

Date of Comment Submission:

#	Document Name	Section Reference	Comment	Baffinland Response
1	2020 Underwater Acoustic Monitoring Program (Open-Water Season)	1. Introduction	There was only a mention of icebreaking in the introduction. What was the ice conditions in 2020? Was there no ice breaking? How does it related to the sound level results?	Text has now been added to the report (in Section 1.5 and the Executive Summary) to explicitly identify the dates (5 days) during which icebreaking was recorded. Consideration of this activity has also been added to the Discussion Section 4.2. Specific analysis of sound levels from icebreaking in 2020, recorded on the Bylot Island and Ragged Island recorders, were reported separately (Austin and Dofher, 2020). Based on feedback on that report (requesting LRR analysis of the icebreaker recordings), we included the 2020 early shoulder season recordings in the analysis for this report as well. *Note: DFO has previously provided comments on Austin and Dofher, 2020. Austin, M.E. and T.S. Dofher. 2021. *Underwater Acoustic Monitoring: Baffinland Iron Mines Shoulder Season Shipping 2019–2020*. Document Number 02330, Version 1.0. Technical report by JASCO Applied Sciences for Golder Associates, Ltd.

#	Document Name	Section Reference	Comment	Baffinland Response
	2020 Underwater Acoustic Monitoring Program (Open-Water Season)	3.5. Noise from Aerial Surveys	This section is interesting! Could you produce more figures (SPL, PSD) to illustrate the noise from twin otter? This is important as it relates to monitoring activities that the MEWG is involved with.	When interpreting these results it should be noted that we did not have any data recorded when the twin otter passed directly over the AMAR location. As such, these data are not suitable to characterize a source sound signature for aircraft overflight. This was an opportunistic measurement and was analyzed in an attempt to provide information based on a concern received from the MEWG. If more detailed analysis is desired, it would be best to collect dedicated measurements of an aircraft passing directly over the recorder. While this analysis was undertaken opportunistically, it is worth noting that it is out of scope for effects monitoring for the Project.
	2020 Underwater Acoustic Monitoring Program (Open-Water Season)	3.6. Listening Range Reduction	The sections after the table are helpful to put the results from the table in context. Could you add the information about the overall time there is exceedance above the 50% and 90% listening range in the table, similar to what is in the text?	Table 7 contains the percentage of the overall recording period for which there is greater than 50% and 90% listening range reduction.
		4.2. Vessel Contributions to Ambient Noise. Table 8	Are the data from this table from 2020 only or an average of 2019 and 2020. The table caption seems to contradict the table header.	The Table Caption has been corrected; Table 8 contains results for 2020 only. The revised 2019 results were moved into Appendix E.

#	Document Name	Section Reference	Comment	Baffinland Response

F.4. Parks Canada

Name: Jordan Hoffman, Chantal Vis, Allison Stoddart

Agency / Organization: Parks Canada Agency

Date of Comment Submission: March 16, 2022

#	Document Name	Section Reference	Comment	Baffinland Response
1	2020 Underwater Acoustic Monitoring Program (Open-water Season)	2.2, 4.1	JASCO presents the metric of 'listening range reduction (LRR)' to evaluate for the potential effects of acoustic masking. JASCO calculated the LRR for three frequencies representative of five sounds produced by narwhal that are used for orientation, communication, and feeding. Results from the 2020 monitoring program suggest that both ambient vessel sounds contribute to LRR. In the discussion on page 51, JASCO states that "It is well known that currently there are no established regulatory thresholds under any jurisdiction that would aid in the determination of significance of acoustic masking effects on narwhal… There is no	1. Baffinland will continue to analyze LRR and to consider the results in combination with other metrics, such as exposure duration, to understand the acoustic environment in relation to project shipping. LRR calculation results are one piece of information, that

#	Document Name	Section Reference	Comment	Baffinland Response
			vocalization masking model developed in the literature that is narwhal-specific and no research is available on the hearing ability (i.e., audiogram) of narwhal (Erbe et al. 2016). More research is needed to understand the process and biological significance of masking, as well as the risk of masking by various anthropogenic activities, before masking can be incorporated into regulation strategies or approaches for mitigation (Erbe et al. 2016)." 1. Given that there are data and knowledge gaps to determine the significance of measures of acoustic masking such as LRR how will Baffinland use this metric as a part of its acoustic monitoring program? 2. Will a threshold be developed where approaches for mitigation will be developed if vessel noise contributions to LRR exceed a certain threshold compared to the contributions to LRR from ambient noise? 3. Similarly, will a threshold be developed where approaches for mitigation be developed if there are inter-annual increases in the LRR? 4. Is LRR expected to be highly variable across years? 5. What level of increase in the LRR for vessels present compared to ambient noise be considered significant to further explore potential impacts or cumulative impacts?	provides supporting context to any potential changes in the metrics that can be more easily tied to a threshold such as changes in calving rates or density estimates. But it is not a metric that can presently be interpreted in isolation and linked directly to a potential impact. 2. Due to the lack of regulatory guidance around the significance of measures of acoustic masking, Baffinland is unable to incorporate LRR as a threshold for mitigation purposes at this time. Baffinland will continue to investigate the relevance and applicability of this metric and developments of this emerging science. But it is premature at this time to develop thresholds related to this metric or its change over time. 3. See the response to Question 2. 4. The degree of expected interannual variability is not well known, however the results should likely not be highly variable across years. 5. Further exploration of potential impacts as a result of LRR would be warranted if the LRR when vessels

#	Document Name	Section Reference	Comment	Baffinland Response
				were present was much higher than the LRR due to ambient noise. That is not the case in the results computed to date.
2	2020 Underwater Acoustic Monitoring Program (Open-water Season)	2.2	There is some evidence of the sounds produced by narwhal calves to maintain communication in mother-calf pairs (Ames et al. 2021, https://doi.org/10.1371/journal.pone.0254393). Will these frequencies be considered when determining the LRR for biologically significant frequencies?	Baffinland will consider the frequencies at which these data suggest evidence of mother-calf communication in future analyses of LRR. MEWG members with relevant expertise should consider providing input on this topic during future meetings.