Baffinland Iron Mines Corporation – Mary River Project

2022 Underwater Acoustic Monitoring Program (Open-Water Season)

JASCO Applied Sciences (Canada) Ltd

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Phil Rouget
WSP Canada
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Authors:

Melanie E. Austin
Katie A. Kowarski
Colleen C. Wilson

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Contents

Figures

Tables

Acronyms and Abbreviations

ADSV	Automatic Data Selection for Validation
AIS	Automatic Identification Systems
AMAR	Autonmous Multichannel Acoustic Recorder
AMAR-EFE	eastern floe edge acoustic recorder
AMAR-MI	Milne Inlet acoustic recorder
AMAR-WFE	western floe edge acoustic recorder
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CPA	closest point of approach
DFT	discrete Fourier Transform
ECWG	Eastern Canada-West Greenland
EEM	environmental effects monitoring
ERP	Early Revenue Phase
FEIS	Final Environmental Impact Statement
FFTs	fast-Fourier transforms
FN	false negatives
FP	false positive
HF	high-frequency (cetaceans)
ICI	inter-click-interval
IQR	interquartile range
JASCO	JASCO Applied Sciences
LF	low-frequency (cetaceans)
LRR	Listening Range Reduction
LTSA	Long-term Spectral Average
MCC	Matthew's Correlation Coefficient
MEWG	Marine Environmental Working Group
MF	mid-frequency (cetaceans)
NOAA	National Oceanic and Atmospheric Administration
OCA	other marine carnivores in air
OCW	other marine carnivores in water
OPW	otariid pinnipeds in water
P	Precision
PK	peak sound pressure level
PPW	phocid pinnipeds in water
PSD	power spectrum density
PTS	permanent threshold shift
R	Recall
RSA	Regional Study Area
SARA	Species at Risk Act
SEL	Sound exposure level
SI	sirenians
SL	source level
SPL	Sound pressure level
TOW	temporal observation window
TP	true positive
TTS	temporary threshold shift
UTC	Coordinated Universal Time
VHF	very high-frequency (cetaceans)
VLF	very low-frequency (cetaceans)

Executive Summary

The 2022 Underwater Acoustic Monitoring Program was developed by JASCO Applied Sciences (JASCO), in collaboration with WSP Canada 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 2022 at three acoustic monitoring stations: one in Milne Inlet (Milne Inlet recorder, AMAR-MI) located along Baffinland's Northern Shipping Route approximately 4 km south-south-west of Iluvilik (Bruce Head), one at a western floe edge location (western floe edge recorder, AMAR-WFE) 25 km west of Mittimatalik (Pond Inlet), and one at an eastern floe edge location (eastern floe edge recorder, AMAR-EFE) 55 km east of Pond Inlet. The Milne Inlet recorder was deployed on 13 Aug 2022 and retrieved on 1 Oct 2022, and recorded continuously. The western and eastern floe edge recorders were deployed on 15 Sep 2021, recorded continuously for one month then powered off until 7 Jul 2022, when they recorded continuously for one additional month before retrieval between 14 and 15 Aug 2022. The 2021 floe edge data are considered part of the 2022 underwater acoustic monitoring program dataset for the purposes of this report.

Additional objectives of the program were: to acoustically identify marine mammal species (notably narwhal) present along the Northern Shipping Route in 2022; 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; to characterize the noise footprints for vessel convoys involving transits of two or more Project vessels spaced less than 10 km from each other; and to estimate the extent of Listening Range Reduction (LRR) associated with Project vessels relative to ambient noise levels. Year over year comparisons of the LRR calculations since 2018 were made.

Overall, the results of the 2022 acoustic monitoring program are consistent with results from previous annual acoustic monitoring programs conducted by JASCO in the regional study area since 2018 (Frouin-Mouy et al. 2020, Austin et al. 2022a, Austin et al. 2022b). The results demonstrate that while noise from Project vessels is detectable in the underwater soundscape, vessel noise exposure is temporary in nature (detectable in 32 % of the recordings at most) and below sound levels that could cause acoustic injury. Assessed relative to a broadband SPL of 120 dB re 1 µPa (i.e., the current noise disturbance threshold standard used by industry and government for assessing disturbance to marine mammals by continuous-type sounds such as vessel noise, and the threshold against which this Project was assessed and approved), 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.

All underwater recordings were made during open-water shipping periods with no icebreaking activities. Mean broadband sound levels in 2022 (one-minute averaged) were 115.9, 105.2, and 105.4 decibel relative to 1 micropascal (dB re 1 µPa) at the Milne Inlet, western floe edge, and eastern floe edge recorders, respectively (median levels were 100.3, 95.1, and 93.5 dB re 1 µPa). In late 2021, mean broadband sound levels were 112.3 and 109.3 dB re 1 µPa the western and eastern floe edge locations, respectively (median levels were 96.1 and 100.3 dB re 1 µPa). Sound exposure levels (SEL) never exceeded thresholds for acoustic injury to marine mammals (i.e., temporary or permanent hearing loss) at any of the three recording locations. The one-minute averaged sound pressure level (SPL) occasionally exceeded the 120 dB re 1 µPa marine mammal disturbance threshold at each station; for 2.8 % of the 49 days of recording at Milne Inlet, 0.5 % of the 29 days of recording at the western floe edge recorder in 2022 (1.3 % of the 30 days of recording there in late 2021), and 0.4 % of the 29 days of recording at the eastern floe edge recorder in 2022 (1.0 % of the 30 days of recording there in late 2021).

Sounds from four marine mammal species (bowhead, beluga, sperm whale, and narwhal) were identified in the acoustic data, in addition to suspected sounds from pinnipeds and possibly killer whales. Though the timing for narwhal acoustic detections at Bruce Head was consistent with recordings since 2018, there were fewer acoustic detections compared to an apparent peak of detections in 2019 (Austin et al. 2022a). This is consistent with the results of Baffinland's marine mammal aerial survey program (WSP Canada Inc. 2023a), which recorded lower numbers of narwhal in the Regional Study Area in 2021 and 2022 compared to 2019. Based on this, it is not likely that the decreased number of acoustic detections is a result of changed acoustic behaviour in 2021–2022 compared to 2019, but rather a product of there being fewer narwhal in the area. Beluga whale acoustic detections were confidently identified in the 2021 and 2022 recordings following the methodology of Zahn et al. (2021), indicating that beluga were occasionally present in the region amongst or near narwhal. Bowhead whale vocalizations were acoustically detected (and manually validated) occasionally at all stations and sperm whale clicks were detected at the eastern floe edge recorder between 26 and 28 Sep 2021. Analysts detected whistles that could have been from killer whales, but no validated killer whale calls were confirmed. Some acoustic signals consistent with those produced by bearded seals and ringed seals were also detected throughout the recordings. All of the detected cetacean species were acoustically present at the eastern and western floe edge recorders at the start of the 2022 recording period, in early July. Calls were detected first at the eastern floe edge recorder and later at the western floe edge recorder, indicating that the animals were likely travelling from east to west, consistent with their expected behaviour. Call detections decreased at the western floe edge recorder prior to the start of the Baffinland shipping season, likely indicating that the animals had continued their migrations past that location before shipping began.

Vessels were acoustically detected in 32 % and 23 % of the 2021 acoustic recordings (between 15 Sep and 15 Oct) at the western and eastern floe edge recorders, respectively, and in 20 %, 11 %, and 14 % of the total recordings at the Milne Inlet, western floe edge, and eastern floe edge recorders, respectively, in the 2022 recording periods. 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 kilohertz (kHz; representative of narwhal burst pulses), 5 kHz (representative of whistles and knock trains) and 25 kHz (representative of clicks and high-frequency buzzes). In response to requests from the Marine Environment Working Group, JASCO compiled a year-over-year comparison of LRR calculations. The LRR results for each of the three frequencies are summarized as follows:

1 kHz (burst pulses):

In the recordings from Sep-Oct 2021, greater than 50 % LRR for sound at 1 kHz occurred during 1.1 and 1.7 % of the time when vessels were detected (i.e., 0.35 and 0.39 % of the respective recording periods) at the western and eastern floe edge recorders, respectively. Greater than 50 % LRR for sound at 1 kHz occurred during 5.9, 3.2, and 3.6 % of the time when vessels were detected (i.e., 1.2, 0.4, and 0.5 % of the recording period) at the Milne Inlet, western floe edge, and eastern floe edge recorders, respectively in 2022. 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. These LRR values at Milne Inlet are consistent with values computed in the same area between 2019 and 2021, when vessel noise resulted in greater than 50 % LRR for sound at 1 kHz during between 1.2 and 1.9 % of the total recording durations for those years.

5 kHz (whistles/knock trains):

In the recordings from Sep-Oct 2021, greater than 50 % LRR for sound at 5 kHz occurred during 20.7 % and 20.6 % of the time when vessels were detected (i.e., 6.6 and 4.7 % of the recording period) at the western and eastern floe edge recorders, respectively. Greater than 50 % LRR for sound at 5 kHz occurred during 18.1, 26.1, and 48.2 % of the time when vessels were detected (i.e., 3.6, 2.9, and 6.7 % of the recording periods) at the Milne Inlet, western floe edge, and eastern floe edge recorders, respectively in 2022. Ambient noise resulted in greater than 50 % LRR for sound at 5 kHz during 22.6 and 22.8 % of the recording period without vessel noise (i.e., 15.4 and 17.6 % of the recording period) at western and eastern floe edge recorders in late 2021, and in 20.8, 28.9, and 29.6 % of the recording period without vessel noise (i.e., 16.6, 25.7, and 25.5 % of the recording period) at the Milne Inlet, western floe edge, and eastern floe edge recorders, respectively in 2022. These vessel-attributed LRR values at Milne Inlet are lower than the values computed in the same area between 2019 and 2021, when vessel noise resulted in greater than 50 % LRR for sound at 5 kHz during between 7 and 8 % of the total recording durations in those years. Ambient noise at Milne Inlet resulted in greater than 50 % LRR for sound at 5 kHz during between 8 and 18 % of the total recording durations in those years, with the results for 2022 falling within that range.

25 kHz (clicks / high frequency buzzes):

In the recordings from Sep-Oct 2021, greater than 50 % LRR for sound at 25 kHz occurred during 14.2 and 2.1 % of the time when vessels were detected (i.e., 4.5 and 0.5 % of the recording period) at the western and eastern floe edge recorders, respectively. Greater than 50 % LRR for sound at 25 kHz occurred during 24.2, 7.3, and 13.5 % of the time when vessels were detected (i.e., 4.8, 0.8, and 1.9 % of the recording periods) at the Milne Inlet, western floe edge, and eastern floe edge recorders, respectively in 2022. Ambient noise resulted in greater than 50 % LRR for sound at 25 kHz during 19.5 and 1.2 % of the recording period without vessel noise (i.e., 13.3 and 0.9 % of the recording period) at western and eastern Eclipse Sound in later 2021, and in 28.6, 20.0, and 11.8 % of the recording period without vessel noise (i.e., 22.9, 17.8, and 10.1 % of the recording period) at the Milne Inlet, western floe edge, and eastern floe edge recorders, respectively in 2022. These vessel-attributed LRR values at Milne Inlet are consistent with results in the area from 2021 and are lower than the values computed in 2019 and 2020 (with greater than 50 % LRR at 25 kHz occurring for 8–9 % of the total recording durations in those years). Ambient noise at Milne Inlet resulted in greater than 50 % LRR for sound at 25 kHz during between 10 and 26 % of the total recording durations between 2019 and 2021, with the results for 2022 falling within that range.

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2022 ᐃᒫᓂ ᓂᐱᓂᒃ ᖃᐅᔨᓴᖅᐸᓪᓕᐊᖏᓐᓇᕐᓂᕐᒧᑦ ᐱᓕᕆᐊᖅ ᐱᕙᓪᓕᐊᑎᑕᐅᓚᐅᖅᑐᑦ ᔫᔅᑯ ᑭᓪᓕᓯᓂᐊᖅᑎᒃᑯᓐᓂ, ᐱᓕᕆᖃᑎᖃᖅᖢᑎᒃ WSP ᑲᓇᑕ ᐊᒻᒪᓗ ᐹᕙᓛᓐᑯᓐᓂᑦ, ᖃᐅᔨᓴᖅᑕᐅᖁᓪᓗᒋᑦ ᐱᓕᕆᐊᒥᖔᑐᐃᓐᓇᕆᐊᓖᑦ ᐊᒃᑐᐃᓃᑦ ᑕᕆᐅᒥ ᐳᐃᔨᓂᒃ ᐅᒥᐊᕐᔪᐊᖅᑲᒃᑲᑦᑕᕐᓂᕐᒧᑦ ᓂᐱᓂᑦ. ᑎᑭᑕᐅᓇᓱᑦᑐᐊᑦᑕᖅᑐᖅ ᑕᒪᑐᒥᙵ ᐱᓕᕆᐊᒥᑦ ᑎᑎᕋᖅᑕᐅᖁᓪᓗᒋᑦ ᐊᒻᒪᓗ ᐊᕙᒃᑐᖅᑕᐅᖁᓪᓗᒋᑦ ᓂᓪᓕᐊᖏᓐᓇᖅᑐᑦ ᐊᒻᒪᓗ ᐆᒪᔪᓂᖔᖅᑐᑦ ᐃᒫᓂ ᓂᐲᑦ ᓂᐱᖅᑯᖅᑐᓕᓈᑦ ᓂᐱᓕᐅᖅᑕᐅᔪᑦ 2022-ᒥ ᐱᙵᓯᓂ ᓂᐱᓄᑦ ᖃᐅᔨᓴᐃᓐᓇᕝᕕᐅᔪᓂ: ᐊᑕᐅᓯᖅ ᕿᙳᐊᓂ (ᕿᙳᐊᓂ ᓂᐱᓕᐅᕈᑎ AMAR-MI) ᐃᓂᖃᖅᑐᑦ ᑕᐅᕗᓇ ᐹᕙᓛᓐᑯᑦ ᐅᑭᐅᖅᑕᖅᑐᒥ ᐅᒥᐊᕐᔪᐊᖅ ᐊᖅᑯᑖᒍᑦ 4 ᑭᓛᒥᑕᐸᓗᖕᓂᒃ ᓂᐱᖅᐸᓯᐊᓂ-ᐱᓇᖕᓇᔾᔮᒥ ᐃᓗᕕᓕᖕᒥ (ᐃᓗᕕᓕᒃ), ᐊᑕᐅᓯᖅ ᐱᓇᖕᓇᔮᖕᒐᓂ ᓯᓈᓂ (ᐱᓇᖕᓇᖕᒐᓂ ᓯᓈᓂ ᓂᐱᓕᐅᕈᑎ AMAR-WFE) 25 ᑭᓛᒥᒃᑦ ᐱᓇᖕᓇᖕᒐᓂ ᒥᑦᑎᒪᑕᓕᐅᑉ (ᒥᑦᑎᒪᑕᓕᒃ), ᕿᙳᐊᓃᑦᑐᖅ ᓂᐱᓕᐅᕈᑎ ᐋᖅᑭᒃᑕᐅᓚᐅᖅᑐᑦ 13 ᐋᒡᒋᓯ 2022-ᒥ ᐊᒻᒪᓗ ᐲᖅᑕᐅᓪᓗᓂ 1 ᐅᑐᐱᕆ 2022-ᒥ, ᓂᐱᓕᐅᕆᓐᓇᓚᐅᖅᓱᓂᓗ. ᐱᓇᖕᓇᖕᒐᓂ ᐊᒻᒪᓗ ᑲᓇᖕᓇᖕᒐᓂ ᓯᓈᓂ ᓂᐱᓕᐅᕈᑏᑦ ᐋᖅᑭᒃᑕᐅᓚᐅᖅᑐᑦ 15 ᓯᑎᐱᕆ 2022-ᒥ, ᓂᐱᓕᐅᕆᓐᓇᓚᐅᖅᓱᑎᓪᓗ ᑕᖅᑭᓕᒪᑦ ᖃᒥᑕᐅᓪᓗᓂ ᑭᓯᐊᓂ 7 ᔪᓚᐃ 2022-ᒥ, ᓂᐱᓕᐅᕆᓐᓇᓕᓚᐅᕐᒥᔪᑦ ᑕᖅᑭᒃᑲᓐᓂᕐᒧᑦ ᐲᖅᑕᐅᖅᑳᖅᑎᓐᓇᒋᑦ ᐊᑯᓐᓂᖓᓂ 14 ᐊᒻᒪᓗ 15 ᐋᒡᒋᓯ 2022-ᒥ. 2021-ᒥ ᓯᓈᓂ ᖃᐅᔨᓴᕈᑎᕕᖏᑦ ᐃᓕᒋᔭᐅᔪᑦ 2022-ᒧᑦ ᐃᒫᓂ ᓂᐱᓂᒃ ᖃᐅᔨᓴᖅᐸᔾᓕᐊᖏᓐᓇᕐᓂᕐᒧᑦ ᐱᓕᕆᐊᑦ ᑎᑎᖅᑲᖁᑎᖏᓐᓄᑦ ᐱᔾᔪᑎᒋᓪᓗᒍ ᑖᓐᓇ ᐅᓂᒃᑳᖅ.

ᑎᑭᑕᐅᓇᓱᐊᒃᑲᓐᓂᖅᑐᑦ ᐱᓕᕆᐊᒥ ᐃᒪᐃᑦᑑᓚᐅᖅᑐᑦ: ᓂᐲᑦ ᓇᓗᓇᐃᖅᑕᐅᓗᑎᒃ ᓇᓕᐊᒃ ᑕᕆᐅᒥ ᐳᐃᔩᑦ ᓂᕐᔪᑏᑦ ᐊᔾᔨᒌᙱᐊᕐᔪᒃᑐᑦ (ᓇᓗᓇᐃᑦᓗᐊᑦᑕᕐᓗᒍ ᑑᓖᓕᑦ) ᐱᑕᖃᖅᑐᑦ ᑕᐅᕗᓇ ᐅᑭᐅᖅᑕᖅᑐᒥ ᐅᒥᐊᕐᔪᐊᑦ ᐊᖅᑯᑖᒍᑦ 2022-ᒥ; ᖃᐅᔨᓴᖅᑕᐅᖁᓪᓗᒋᑦ ᐱᓕᕆᐊᒥ-ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖏᑕ ᓂᐱᖅᑯᖅᑐᓕᕿᖏᑦ ᐊᒃᑐᐊᔪᑦ ᓴᖅᑭᑕᐅᓇᓱᐊᕐᓂᖏᓐᓄᑦ ᑕᕆᐅᒥ ᐳᐃᔩᑦ ᓂᐱᓄᑦ ᖃᓄᐃᓪᓕᔪᖃᖅᑳᖅᑎᓐᓇᒍ ᑭᓪᓕᐅᔪᑦ ᐋᓐᓂᕐᓂᕐᒧᑦ ᐊᒻᒪᓗ ᐸᕝᕕᓴᐃᓂᕐᒧᑦ ᐊᒻᒪᓗᑦᑕᐅᖅ ᖃᓄᐃᓐᓂᖅᓴᐅᕐᒪᖔᑕ ᖃᐅᔨᓴᖅᑕᐅᓯᒪᔪᑦ ᓂᐲᑦ ᓂᐱᖅᑯᖅᑐᓕᕿᑦ ᐅᒥᐊᕐᔪᐊᓂ ᐱᓕᕆᐊᖑᔪᓂ ᐋᖅᑭᙳᐊᖅᑕᐅᖁᓪᓗᒋᑦ ᒥᒃᓴᐅᓴᒃᑕᐅᓯᒪᔪᑦ ᐊᑐᖅᑕᐅᔪᑦ ᐊᕙᑎᒧᑦ ᐊᒃᑐᐃᓂᕐᓄᑦ ᖃᐅᔨᓴᕈᑎᓂ; ᐊᕕᒃᑐᕐᓗᒋᑦ ᓂᐱᖃᕐᕕᐅᔪᑦ ᐊᑐᓂ ᐅᒥᐊᕐᔪᐊᑦ ᑭᙳᓕᓂᑦᑎᐊᙳᓪᓗᑎᒃ ᐊᑕᐅᑦᑎᒃᑰᖅᑐᑦ ᐱᖃᓯᐅᔾᔨᔪᑦ ᒪᕐᕉᖕᓂᒃ ᐅᖓᑖᓂᓪᓘᓐᓂᑦ ᐱᓕᕆᐊᒥ ᐅᒥᐊᕐᔪᐊᑦ ᐊᑯᓐᓂᖃᖅᑐᑦ ᑐᖕᒐᓂ 10 ᑭᓛᒥᑕᑦ ᐃᒻᒥᖕᓄᑦ; ᐊᒻᒪᓗ ᒥᒃᓴᐅᓴᒃᑕᐅᖁᓪᓗᖏᑦ ᐊᑯᓂᐅᓂᖏᑦ ᑑᓴᔭᐅᔭᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᓯᕆᐊᕐᓂᑦ ᐊᒃᑐᐊᔪᑦ ᐱᓕᕆᐊᑉ ᐅᒥᐊᕐᔪᐊᖏᓐᓄᑦ ᐊᒃᑐᐊᓪᓗᑎᒃ ᓂᐱᖃᐃᓐᓇᖅᑐᑦ ᓂᐱᖅᑯᖅᑐᓕᓐᓄᑦ. ᐊᕐᖁᒍᓂ ᐊᓂᒍᖅᑐᓂ ᖃᓄᐃᓐᓂᖅᓴᐅᕐᒪᖔᑕ ᑖᒃᑯᐊ ᑑᓴᔭᐅᔭᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᓯᕆᐊᕐᓂᕐᓄᑦ ᓈᓴᐅᓯᖅᓯᓃᑦ ᑕᐃᑲᙵᓂᑦ 2018-ᒥᓂᑦ ᐋᖅᑭᒃᑕᐅᓚᐅᖅᑐᑦ.

ᑕᒪᐃᓐᓄᑦ, ᖃᐅᔨᔭᐅᔪᑦ 2022-ᒥ ᓂᐱᓂᒃ ᖃᐅᔨᓴᖅᐸᓪᓕᐊᖏᓐᓇᕐᓂᕐᒧᑦ ᐱᓕᕆᐊᑦ ᒪᓕᒃᑐᑦ ᖃᐅᔨᔭᐅᔪᓂᒃ ᑯᖕᓂᙵᑦᑎᓐᓂ ᐊᕐᖁᒍᑕᓖᑦ ᓂᐱᓂᒃ ᖃᐅᔨᓴᖅᐸᓪᓕᐊᖏᓐᓇᕐᓂᕐᒧᑦ ᐱᓕᕆᐊᓄᑦ ᐱᓕᕆᐊᖑᓯᒪᔪᑦ ᔫᔅᑰᒃᑯᓐᓂ ᓄᓇᓂ ᐊᕕᒃᑐᖅᓯᒪᔪᓂ ᖃᐅᔨᓴᕐᕕᐅᔪᓂ ᑕᐃᑲᙵᓂᑦ 2018 (ᕘᐊᐃᓐ–ᒧᐃ ᐊᑕᖏᖅᓱᑎᒃ 2020, ᐋᔅᑎᓐ ᐊᑕᖏᖅᓱᑎᒃ 2022ᐃ, ᐋᔅᑎᓐ ᐊᑕᖏᖅᓱᑎᒃ 2022ᒥᐱ). ᖃᐅᔨᓴᔭᐅᔪᑦ ᓴᖅᑮᔭᖅᑎᑦᑎᔪᑦ ᓂᐲᑦ ᐱᓕᕆᐊᒥ ᐅᒥᐊᕐᔪᐊᓂ ᑑᓴᔭᐅᔪᓐᓇᖅᓴᓗᐊᖅᑎᓪᓗᖏᑦ ᐃᒫᓂ ᓂᐱᖃᕐᕕᐅᔪᒥ, ᐅᒥᐊᕐᔪᐊᓂ ᓂᐲᑦ ᓂᐱᖃᖅᑎᑦᑎᓂᖓ ᕿᓚᒻᒥᐅᔫᖅ ᖃᓄᐃᓕᖓᓂᖓ (ᑑᓴᔭᐅᔭᓐᓇᖅᑐᑦ 32% ᓂᐱᓕᐅᖅᑕᐅᓯᒪᔪᓂ ᑕᐃᒪᐃᙵᓕᒫᐸᓗᒃ) ᐊᒻᒪᓗ ᑐᖔᓂᑦᑐᑦ ᓂᐲᑦ ᓂᐱᖅᑯᖅᑐᓕᕆᓂ ᓂᐱᓂᑦ ᐋᓐᓂᕈᑕᐅᔪᓐᓇᖅᑐᑦ. ᖃᐅᔨᓴᖅᑕᐅᓯᒪᔪᑦ ᐊᒃᑐᐊᔪᑦ ᖃᓄᐃᑦᑑᓂᖏᓐᓄᑦ SPL of 120 dB re 1 µPa (ᓲᕐᓗ ᒫᓐᓇ ᓂᐲᑦ ᐸᕝᕕᓴᐃᔪᑦ ᖃᓄᐃᓪᓕᔪᖃᖅᑳᖅᑎᓐᓇᒍ ᑭᓪᓕᐅᔪᑦ ᒪᓕᒃᑕᐅᕙᒃᑐᑦ ᐊᑐᖅᑕᐅᕙᒃᓱᑎᓪᓗ ᓴᓇᕝᕕᐅᔪᓂ ᒐᕙᒪᒃᑯᓐᓂᓪᓗ ᖃᐅᔨᓴᖅᓯᓂᕐᒧᑦ ᐸᕝᕕᓴᐃᓂᕐᓂᒃ ᑕᕆᐅᒥ ᐳᐃᔨᓂᒃ ᑲᔪᓲᓐᓇᖅᑐᑎᒍᑦ–ᖃᓄᐃᑦᑑᓂᖏᑦ ᓂᐲᑦ ᓲᕐᓗ ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖏᑦ, ᐊᒻᒪᓗ ᖃᓄᐃᓪᓕᔪᖃᖅᑳᖅᑎᓐᓇᒍ ᑭᓪᓕᐅᔪᑦ ᑕᒪᒃᑯᓄᖓ ᐱᓕᕆᐊᒥ ᖃᐅᔨᓴᖅᑕᐅᓚᐳᖅᑐᑦ ᓈᒻᒪᒋᔭᐅᓪᓗᑎᓪᓗ), ᓂᐱᖃᕐᕕᐅᔪᑦ ᐊᑯᓂᐅᓂᖏᑦ ᑑᒐᓂᒐᔪᓚᐅᖅᑐᑦ 1 ᐃᑲᕐᕋᖅ ᐊᑐᓂ ᐅᓪᓗᒧᑦ. ᑖᓐᓇ ᒪᓕᒃᑐᖅ ᐊᒃᑐᐃᓃᑦ ᓇᓚᐅᖅᑖᖅᑕᐅᓯᒪᒧᑦ ᑕᒪᓐᓇ ᓂᐱᒧᑦ ᐊᒃᑐᐃᓂᖅ

ᓄᓇᖓᓂᑐᐊᖑᓇᔭᕐᓂᖓᓂᒃ ᐊᒻᒪᓗ ᕿᓚᒻᒥᐅᓗᓂ ᐱᑕᖅᑲᙱᓗᓂᓗ ᐊᑭᓂᐅᕐᔪᐊᑐᓂᒃ ᐅᑦᑐᑕᒫᑦ ᑕᕆᐅᒥ ᐳᐃᔫᑦ ᐸᒡᕕᓴᒃᑕᐅᙱᑦᑐᑦ ᐱᓕᕆᐊᒥ ᐅᒥᐊᕐᔪᐊᑦ ᓂᐃᖏᓐᓄᑦ.

ᐊᑕᖅᑭᖅᒍᑦ ᐃᒫᓂ ᓂᐱᓕᐅᖅᑕᐅᔪᑦ ᓂᐱᓕᐅᖅᑕᐅᓚᐅᖅᑐᑦ ᓯᑯᖅᑲᙱᑎᑦᑐᒍ ᐅᒥᐊᕐᓇᐊᖅᑲᕐᓇᖅᑎᑦᑐᖑ ᐊᒻᒪᓗ ᓯᑯᓂᒃ ᐊᔭᐅᖅᑐᐃᓂᖅᑕᖅᑲᓚᐅᙱᑦᑐᖅ. ᓈᓴᐅᑕᐅᓚᐅᖅᑐᑦ ᓂᐲᑦ ᓂᐱᖅᑯᖅᑐᓕᓐᓄᑦ 2022-ᒥ (1-ᒥᓇᑦ ᐊᑐᖅᑕᐅᒐᔪᒃᑯᓂ) ᐃᒪᐃᑦᑑᓚᐅᖅᑐᑦ 115.9, 105.2, ᐊᒻᒪᓗ 105.4 ᑕᓯᐳ ᐊᒃᑐᐊᔪᑦ 1 ᒪᐃᑯᕈᐹᔅᑭᐅᑦᒧᑦ (dB re 1 μPa) ᕿᙳᐊᓂ, ᐱᓇᖕᓇᖕᖓᓂ ᓯᓈᓂ ᐊᒻᒪᓗ ᑲᓇᖕᓇᖕᖓᓂ ᓯᓈᓂ ᓂᐱᓕᐅᖅᑕᐅᔪᑦ, ᐃᓱᒪᒋᑦᓗᒋᑦ (ᓂᐱᖅᑯᖅᑐᓂᐅᓚᐅᖅᑯᑦ ᐃᒪᐃᑦᑑᓚᐅᖅᑐᑦ 100.3, 95.1, ᐊᒻᒪᓗ 93.5 dB re 1 μPa). ᓄᙳᐊᓂ 2021-ᒥ, ᓂᐲᑦ ᓂᐱᖅᑯᖅᑐᓕᓐᖑᓂᐅᓚᔪᓚᐅᖅᑐᑦ ᐃᒪᐃᑦᑑᓚᐅᖅᑐᑦ 112.3 and 109.3 dB re 1 μPa ᐱᓇᖕᓇᖕᖓᓂ ᐊᒻᒪᓗ ᑲᓇᖕᓇᖕᖓᓂ ᓯᓈᓃᑦᑐᓂ, ᐃᓱᒪᒋᑦᓗᒋᑦ (ᓂᐱᖅᑯᖅᑐᓂᐅᓚᐅᖅᑯᑦ ᐃᒪᐃᑦᑑᓚᐅᖅᑐᑦ 96.1 and 100.3 dB re 1 μPa). ᓂᐱᐅᔪᑦ ᓂᐱᖅᑯᖅᑐᓕᕐᑮᑦ (SEL) ᐅᖓᑕᐅᔾᔨᖅᑲᑦᑕᓚᐅᙱᑦᑐᑦ ᖃᓄᐃᑦᓕᔪᖅᑲᖅᑳᖅᑎᓐᓇᒍ ᑭᒡᓕᐅᔪᓂᒃ ᓂᐱᓂᑦ ᐋᓐᓂᖅᑐᖅᑲᕐᓂᕐᒧᑦ ᑕᕆᐅᒥ ᐳᐃᔫᓄᑦ (ᓲᕐᓗ ᒫᓐᓇᓚᐅᑲᒃ ᐅᕝᕙᓘᓐᓃᑦ ᑐᓵᔪᓐᓃᑦᑎᐊᒻᒪᕆᒡᓗᑎᒃ) ᓇᓕᐊᖕᓂᑐᐃᓐᓇᖅ ᐱᖓᓱᓂ ᓂᐱᓕᐅᕐᕕᐅᔪᓂ. 1-ᒥᓇᑦᒧᑦ ᐊᑐᖅᑕᐅᒐᔪᒃᑐᑦ ᓂᐱᖅᑯᖅᑐᓕᓐᓄᑦ (SPL) ᐃᑖᓐᓂᒃᑯᑦ ᐅᖓᑕᐅᔾᔨᖅᑲᑦᑕᓚᐅᖅᑐᑦ 120 ᑕᓯᐳ re 1 μPa ᑕᕆᐅᒥ ᐳᐃᔪᓂᒃ ᐸᒡᕕᓴᐃᓂᕐᒧᑦ ᖃᓄᐃᑦᓕᔪᖅᑲᖅᑳᖅᑎᓐᓇᒍ ᑭᒡᓕᐅᔪᖅ ᐊᑐᓂ ᖃᐅᔨᓴᕐᕕᐅᔪᒥ; ᑖᒃᑯᓄᖓ 2.8% 49-ᓂ ᐅᓪᓗᓂ ᓂᐱᓕᐅᕐᕕᐅᔪᓂ ᕿᙳᐊᓂ, 0.5% ᑖᒃᑯᓇᓂ 29-ᓂ ᐅᓪᓗᓂ ᓂᐱᓕᐅᕐᕕᐅᔪᓂ ᐱᓇᖕᓇᖕᖓᓂ ᓯᓈᓂ ᓂᐱᓕᐅᕆᔪᓂ 2022-ᒥ (1.3 % 30-ᓂ ᐅᓪᓗᓂ ᓂᐱᓕᐅᕆᓂᕐᓂᒃ ᑕᐅᕙᓂ ᓂᙳᐊᓂ 2021), ᐊᒻᒪᓗ 0.4% ᑖᒃᑯᓇᓂ 29-ᓂ ᐅᓪᓗᓂ ᓂᐱᓕᕆᓂᐅᔪᓂ ᐱᓇᖕᓇᖕᖓᓂ ᓯᓈᓂ ᓂᐱᓕᐅᕆᔪᓂ 2022-ᒥ (0.1% ᑖᒃᑯᓇᓂ 30-ᓂ ᐅᓪᓗᓂ ᓂᐱᓕᐅᕆᓂᐅᔪᓂ ᑕᐅᕙᓂ ᓄᙳᐊᓂ 2021-ᒥ).

ᓂᐲᑦ ᑖᒃᑯᓈᙵᑦ ᑎᓴᒪᓂ ᑕᕆᐅᒥ ᐳᐃᔪᓂᒃ ᓂᕐᔪᑏᑦ ᐊᔾᔨᒌᙱᐊᕐᔪᒃᑐᑦ (ᐊᕐᕕᖅ, ᕿᓚᓗᒐᖅ, ᕿᓚᓗᒑᔭᖅ, ᐊᒻᒪᓗ ᑑᒑᓖᑦ) ᓇᓗᓇᐃᖅᑕᐅᓚᐅᖅᑐᑦ ᓂᐱᓄᑦ ᖃᐅᔨᓴᕈᑎᕕᓂᕐᓂᒃ, ᖄᒃᑲᓐᓂᐊᒍᑦ ᑲᖕᑮᕆᔭᐅᔪᑦ ᓂᐲᑦ ᑖᒃᑯᓇᖕᖒᖅᓯᒪᔪᑦ ᓇᑦᑎᐅᔭᑦ ᐊᒻᒪᓗ ᐊᕐᔫᑐᐃᓐᓇᑎᐊᓛᑦ. ᖃᖓᒃᑰᓂᖏᑦ ᑑᒑᓖᑦ ᓂᐱᖅᑲᕐᓂᖏᑦ ᑐᓵᔭᐅᔪᑦ ᐃᓗᕕᓕᖕᒥ ᒪᓕᒃᑐᑦ ᓂᐱᓕᐅᖅᑕᐅᓯᒪᓚᐅᖅᑐᓄᑦ 2018-ᒥ, ᐅᓄᙱᓐᓂᖅᓴᑦ ᓂᐲᑦ ᑐᓵᔭᐅᔪᓐᓇᖅᑐᑦ ᖃᓄᐃᓐᓂᖅᓴᐅᓂᖕᒋᑦ ᕿᒥᕐᕈᓪᓗᖕᒋᑦ ᓇᓗᓇᖅᑰᙱᑦᑐᑦ ᑐᓴᖅᑕᐅᓃᑦ ᑐᓵᔭᐅᓯᒪᔪᑦ 2019-ᒥ (ᐋᔅᑎᓐ ᐊᑕᖅᑭᖅᒍᑎᒃ 2022ᐃ). ᑕᒪᓐᓇ ᓕᒃᑐᖅ ᖃᐅᔨᔭᐅᔪᓂᒃ ᐹᕙᓐᓛᓐᑯᑦ ᑕᕆᐅᒥ ᐳᐃᔪᓂᒃ ᖃᖓᑕᓲᒃᑯᑦ ᖃᐅᔨᓴᕈᑎᓄᑦ ᐱᓕᕆᐊᒥ (WSP ᑲᓇᑕ 2023ᐃ), ᓂᐱᓕᐅᕆᓯᒪᔪᑦ ᐅᓄᙱᓐᓂᖅᓴᕐᓂᒃ ᑑᖕᒑᓕᖕᓂᒃ ᓄᓇᓂ ᐊᕕᒃᑐᖅᓯᒪᔪᓂ ᖃᐅᔨᓴᕐᕕᐅᔪᓂ 2021-ᒥ ᐊᒻᒪᓗ 2022-ᒥ ᖃᓄᐃᓐᓂᖅᓴᐅᓂᖕᒋᑦ ᑕᑯᓪᓗᒋᑦ 2019-ᒥ. ᑐᙵᕕᒋᓪᓗᒍ ᑕᒪᓐᓇ, ᐅᓄᕈᓐᓃᖅᓯᒪᔪᑦ ᓂᐲᑦ ᑐᓵᔭᐅᔪᑦ ᓴᖅᐲᓯᒪᙱᑦᑐᒃᓴᐅᔪᑦ ᐊᓯᔾᔨᖅᑐᒃ ᓂᐲᑦ ᐃᓕᖅᑯᓯᓇᓕᖅᐊᒃᑕᖅᑭᓐᓂᒃ 2021-2022 ᖃᓄᐃᓐᓂᖅᓴᐅᓂᖕᒋᓐᓄᑦ 2019-ᒥᓂᑦ, ᑭᓯᐊᓂᓕ ᑕᐃᒪᐃᑦᑐᒃᓴᐅᔪᑦ ᐅᓄᙱᓐᓂᖅᓴᐅᓂᖕᒋᓐᓄᑦ ᑑᒑᓖᑦ ᑕᐅᕙᓂ. ᕿᓚᓗᖕᒑᑦ ᓂᐃᖕᒋᑦ ᑐᓴᐅᖅᓴᐅᔪᑦ ᓇᓗᓇᙱᑎᑦᑎᐊᖅᑐᒥᒃ ᓇᓗᓇᐃᖅᑕᐅᓚᐅᖅᑐᑦ 2021-ᒥ ᐊᒻᒪᓗ 2022 ᓂᐱᓕᐅᖅᓯᓂᕐᓂ ᒪᓕᒃᑯᑎᒃ ᐱᓕᕆᔾᔪᓯᖕᒋᓐᓂᒃ ᔫᓐ ᐊᑕᖅᑭᖅᒍᑎᒃ (2021), ᓇᓗᓇᐃᖅᓯᑦᓗᑎᒃ ᑖᒃᑯᐊ ᕿᓚᓗᖕᒑᑦ ᐃᑖᓐᓂᒃᑯᑦ ᑕᐅᕙᓐᓂᖅᑲᑦᑕᕐᓂᖕᒋᓐᓄᑦ ᖃᓂᒋᔭᓂ ᑑᖕᒑᓕᑦ. ᐊᕐᕕᑦ ᓂᐱᖅᑲᕐᓂᖕᒋᑦ ᓂᐱᑎᖑᑦ ᑐᓵᔭᐅᔪᓐᓇᓚᐅᖅᑐᑦ (ᐊᒻᒪᓗ ᐱᓕᕆᓂᒃᑯᑦ ᓇᓗᓇᕈᓐᓃᖅᑎᑕᐅᓪᓗᑎᒃ) ᐃᑖᓐᓂᒃᑯᑦ ᐊᑕᖅᑭᖅᑐᓂ ᖃᐅᔨᓴᕐᕕᐅᔪᓂ ᐊᒻᒪᓗ ᐊᕐᕕᐅᔭᑦ ᑲᓯᒃᑐᖅᑰᔨᓂᖕᒋᑦ ᑐᓵᔭᐅᔪᓐᓇᓚᐅᖅᑐᑦ ᐱᓇᖕᓇᖕᖓᓂ ᓯᓈᓂ ᓂᐱᓕᐅᕈᑎᓂ ᐊᑯᓐᓂᖓᓂ 26 ᐊᒻᒪᓗ 28 ᓯᑎᐱᕆ 2021-ᒥ. ᖃᐅᔨᓴᖅᑏᑦ ᑐᓴᓚᐅᖅᑐᑦ ᐅᕙᖕᓂᐊᖅᑕᖅᑭᓐᓂᒃ ᑖᒃᑯᓇᖕᖑᑐᐃᓐᓇᑎᐊᓛᑦ ᐊᕐᓗᖕᓂᒃ, ᑭᓯᐊᓂᓕ ᓇᓗᓇᕈᓐᓃᖅᑎᓯᒪᙱᑦᑐᓂᒃ ᐊᕐᓘᓂᖕᒋᓐᓂᒃ ᓇᓗᓇᐃᖅᑕᐅᔪᑎᖅᑲᓚᐅᙱᑦᑐᑦ. ᐃᓚᖕᒋᑦ ᓂᐲᑦ ᑐᓴᖅᑎᑦᑎᓇᓱᐊᕈᑏᑦ ᒪᓕᒃᑐᑦ ᑖᒃᑯᓄᖓ ᓂᐱᖅᑲᖅᑎᑕᐅᔪᓂᑦ ᐅᒡᔪᕐᓂᒃ ᐊᒻᒪᓗ ᓇᑦᑎᕐᓂᒃ ᑐᓴᖅᑕᐅᔪᓐᓇᓚᐅᖅᑐᕐᒥᔪᑦ ᓂᐱᓕᐅᕆᓂᓗᒃᑖᖅᑭᓐᓂ. ᐊᑕᖅᑭᖅᒍᑦ ᑐᓴᖅᑕᐅᔪᓐᓇᖅᑐᑦ ᕿᒥᕐᓗᖅᑲᙱᑦᑐᑦ ᓂᕐᔪᑏᑦ ᐊᔾᔨᒌᙱᐊᕐᔪᒃᑐᑦ ᓂᐱᖅᑲᓚᐅᕐᒥᔪᑦ ᑲᓇᖕᓇᖕᖓᓂ ᐊᒻᒪᓗ ᐱᓇᖕᓇᖕᖓᓂ ᓯᓈᓂ ᓂᐱᓕᐅᕈᑎᓂ ᐱᒋᐊᕐᓂᖓᓂ 2022 ᓂᐱᓕᐅᕆᓐᓇᒥ, ᔪᓚᐃᖑᓕᕋᖅᑎᓪᓗᒍ. ᑐᓴᖅᑕᐅᔪᑦ ᑐᓵᔭᐅᖅᑲᓚᐅᖅᑐᑦ ᓯᕗᓪᓕᖅᐹᒥ ᑲᓇᖕᓇᖕᖓᓂ ᓯᓈᓂ ᓂᐱᓕᐅᕈᑎᓂ ᐊᒻᒪᓗ ᑭᖑᓂᖓᐳᑦ ᐱᓇᖕᓇᖕᖓᓂ ᓯᓈᓂ ᓂᐱᓕᐅᕈᑎᓂ, ᓇᓗᓇᐃᖅᓯᑦᓗᑎᒃ ᐆᒪᔪᑦ ᐃᖕᒋᕐᕋᕝᕕᓕᐊᓂᖕᒋᓐᓂᒃ ᑲᓇᖕᒥ

ᐱᓇᓐᓇᒧᑦ, ᒪᓕᒃᑲᑎᒃ ᓂᕿᐅᑦᓯᐅᔪᑦ ᐃᓕᖅᑯᓯᕆᕚᒃᑖᕐᑦ. ᑐᓵᔭᐅᓇᓱᒃᑯᑦ ᑐᓴᖅᑕᐅᔪᑦ ᐱᓇᓐᓇᓐᓂ ᓯᓈᓂ ᐱᒋᐊᖅᑕᐅᖅᑳᖅᑎᓐᓇᒋᑦ ᐹᕗᓐᓛᓐᑯᑦ ᐅᒥᐊᕐᔪᐊᕐᑲᕐᓇᓐᖓ, ᓇᑐᓇᐃᖅᓯᖅᑰᔾᔪᖅ ᑖᒃᑯᐊ ᓂᕐᔪᑏᑦ ᐃᓐᒋᕐᕋᕚᓪᓕᐊᓐᒋᓐᓇᓚᐅᖅᑐᑦ ᐅᓐᖓᑖᓄᑦ ᑕᐃᒃᑯᐊ ᐃᓃᑦ ᐅᒥᐊᕐᔪᐊᖅᑲᓯᒋᐊᖅᑳᖅᑎᓐᓇᒍ.

ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᑎᙶᑦ ᑑᓵᔭᐅᔪᓐᓇᓚᐅᖅᑐᑦ 32% ᐊᒻᒪᓗ 23% ᑖᒃᑯᓇᓂ 2021-ᒥ ᓂᐱᓂᒃ ᓂᐱᓕᐅᕆᓂᕐᓂ (ᐊᑯᓐᓂᖓᓂ 15 ᓯᑎᐱᕆ ᐊᒻᒪᓗ 15 ᐅᑐᐱᕆ) ᐱᓇᓐᓇᖓᓂ ᐊᒻᒪᓗ ᑲᓇᓐᓇᖓᓂ ᓯᓈᓂ ᓂᐱᓕᐅᕈᑎᓂ, ᑕᒪᐃᓐᓄᑦ, ᐊᒻᒪᓗ ᑖᒃᑯᓇᓂ 20%, 11%, ᐊᒻᒪᓗ 14% ᑖᒃᑯᓇᓂ ᑲᑎᑐᒃᑖᖅᑲᒋᑦ ᓂᐱᓕᐅᕆᓂᕐᓂ ᕿᙳᐊᓂ, ᐱᓇᓐᓇᖓᓂ ᓯᓈᓂ, ᐊᒻᒪᓗ ᑲᓇᓐᓇᖓᓂ ᓯᓈᓂ ᓂᐱᓕᐅᕈᑎᓂ, ᑕᒪᐃᓐᓄᑦ, 2022-ᒥ ᓂᐱᓕᐅᕆᓐᓇᒥ. ᑑᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᑖᕆᐊᕐᓃᑦ – ᓂᐱᒃᑖᕆᐊᕐᕌᕐᔪᒃᓯᒪᔪᑦ ᐊᑐᐃᓐᓇᐅᔪᓂ ᑑᓵᐅᔪᓐᓇᖅᑐᒥ ᑕᕆᐅᒥ ᓂᕐᔪᑎᓂᑦ - ᓇᐃᓴᐅᑎᖅᓱᖅᑕᐅᓚᐅᖅᑐᑦ ᐊᑐᓂ ᓂᐱᓕᐅᕐᕙᓐᓂ ᐱᓐᖓᓱᕗᑦ ᖃᑕᐃᓕᓅᓄᑦ, ᐊᑐᓂ ᑮᓚᖅᐃᑐᑦᑐᑎᒃ ᐊᔾᔨᒌᖅᑭᑦᑐᓂᒃ ᑑᓖᑦ ᓕᐃᖃᖅᑎᑦᑎᓂᖅᑭᓐᓄᑦ ᖃᓄᐃᑦᑑᓂᖅᑭᓐᓄᑦ: 1 ᑭᓗᕼᐅᑦ (ᑭᓗᕼᐅᑦ; ᑮᓚᖅᑐᐃᔪᖅ ᑑᓖᑦ ᓂᐱᖃᓛᖑᓂᖅᑭᓐᓂᒃ), 5 ᑭᓚᕼᐅᑦ (ᑮᓚᖅᑐᐃᔪᖅ ᐅᕙᓐᓂᐊᕐᓂᕐᓂᒃ ᐊᒻᒪᓗ ᑎᒃᑯᖅᑐᖅᐸᓚᑦᑎᔪᓂᒃ) ᐊᒻᒪᓗ 25 ᑭᓚᕼᐅᑦ (ᑮᓚᖅᑐᐃᔪᖅ ᑲᓱᒃᑐᖅᐸᓚᑦᑎᔪᓂᒃ ᐊᒻᒪᓗ ᖃᑕᐃᑦᑐᓂᒃ ᓂᑦᓕᐊᔪᓂᒃ). ᑭᐅᔾᔪᑕᐅᓇᓱᐊᖅᑲᑎᒃ ᑐᒃᓯᕋᐅᑕᐅᔪᓄᑦ ᑖᒃᑯᓈᙵᑦ ᑕᕆᐅᑉ ᐊᕙᑎᖓᓄᑦ ᐱᓕᕆᖃᑎᒌᓄᑦ, ᔮᓐᑯᒃᑯᑦ ᐋᖅᑭᒃᓱᐃᓯᒪᔪᑦ ᐊᕐᕌᒍᒥᑦ-ᐊᕐᕌᒍᒧᑦ ᐋᖅᑭᒃᓱᖅᓯᒪᔪᑦ ᖃᓄᐃᓐᓂᖅᓴᐅᓚᖓᓚ ᑑᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᑖᕆᐊᕐᓂᕐᓄᑦ ᓈᓴᐅᓯᕆᔭᐅᓯᒪᔪᑦ. ᑑᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᑖᕆᐊᕐᓃᑦ ᖃᐅᔨᔭᐅᔪᑦ ᐊᑐᓂ ᑖᒃᑯᓇᓂ ᐱᖓᓱᓂ ᖃᑕᐃᓕᓅᓂᑦ ᓇᐃᓈᖅᓯᒪᔪᑦ ᐃᒪᓐᓇ:

1 ᑭᓗᕼᐅᑦ (ᓂᑦᓕᑳᑦᓚᒃᑕᖅᑐᑦ):

ᓂᐱᓕᐅᖅᓯᒪᔪᓂ ᓯᑎᐱᕆᒥᑦ-ᐅᑐᐱᕆᒧᑦ 2021-ᒥ, ᐅᓄᕐᓂᖅᓴᑦ 50%-ᒥᑦ ᑑᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᑖᕆᐊᕐᓃᑦ ᓂᐱᓄᑦ 1 ᑭᓚᑕᐅᑦᓄᑦ ᐊᑐᖅᑕᐅᓚᐅᖅᑐᑦ ᐊᑐᖅᑎᑦᑐᒋᑦ 1.1 ᐊᒻᒪᓗ 1.7%-ᒥ ᐅᒥᐊᕐᔪᐊᑦ ᑐᓴᖅᓴᐅᔪᓐᓇᖅᑎᑦᑐᕐᒋᑦ (ᓱᕐᓗ 0.35 ᐊᒻᒪᓗ 0.39% ᓂᐱᓕᐅᖅᑕᐅᓇᐅᑎᑦᑐᒍ) ᐱᓇᓐᓇᖓᓂ ᐊᒻᒪᓗ ᑲᓇᓐᓇᖓᓂ ᓯᓈᓂ ᓂᐱᓕᐅᕐᕙᓐᓂ, ᑕᒪᐃᓐᓄᑦ. ᐅᓄᕐᓂᖅᓴᑦ 50% ᑑᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᑖᕆᐊᕐᓃᑦ ᓂᐱᓄᑦ 1 ᑭᓗᕼᐅᑦᓄᑦ ᐱᑕᕐᑲᓚᐅᖅᑐᑦ 5.9, 3.2 ᐊᒻᒪᓗ 3.6% ᐅᒥᐊᕐᔪᐊᑦ ᑑᓵᔭᐅᔪᓐᓇᖅᑎᑦᑐᒋᑦ (ᓱᕐᓗ 1.2, 0.4 ᐊᒻᒪᓗ 0.5% ᓂᐱᓕᐅᕆᓐᓇᒥ) ᕿᙳᐊᓂ, ᐱᓇᓐᓇᖓᓂ ᓯᓈᓂ ᐊᒻᒪᓗ ᑲᓇᓐᓇᖓᓂ ᓯᓈᓂ ᓂᐱᓕᐅᕈᑎᓂ, ᑕᒪᐃᓐᓄᑦ 2022-ᒥ. ᓂᐱᖃᐃᓐᓇᖅᑐᑦ ᓴᖅᑮᓚᐅᙱᑦᑐᑦ ᓈᒻᒪᒃᑐᓂᒃ ᑑᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᑖᕆᐊᕐᓃᑦ 1 ᑭᓗᕼᐅᑦ ᓇᓕᐊᓐᓂᑐᐃᓐᓇᖅ ᓂᐱᓕᐅᕆᙴᓐᓂ, ᐱᔾᔪᑎᒋᑦᓗᒍ ᑖᓯᓂᕐᒧᑦ ᖃᓄᐃᑦᓕᔪᖅᑳᖅᑳᖅᑎᓐᓇᒍ ᑮᓕᐅᔪᑦ ᑑᓕᓐᓄᑦ 1 ᑭᓗᕼᐅᑦ ᖁᑦᑎᖕᓂᖅᓴᐅᓂᖓᓄᑦ ᓈᓴᐅᑕᐅᒐᔪᒃᑐᓂ ᑐᓴᖅᓴᐅᕆᓐᓇᖅᑐᓂ ᑖᒃᑯᓇᓂᑦᓚᑦᑖᖅ ᖃᑕᐃᓕᓅᓂ. ᑖᒃᑯᐊ ᑑᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᑖᕆᐊᕐᓃᑦ ᓈᓴᐅᑎᖕᒋᑦ ᕿᙳᐊᓂ ᒪᓕᒃᑐᑦ ᓈᓴᐅᑎᓂᒃ ᓈᓴᐅᓯᖅᑐᖅᑕᐅᓯᒪᔪᓂ ᑕᐃᑲᓂᔅᓴᐃᓐᓇᖅ ᐊᑯᓐᓂᖓᓂ 2019 ᐊᒻᒪᓗ 2021, ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖕᒋᑦ ᓴᖅᑮᖅᑲᑦᑕᖅᑎᑦᑐᖕᒋᑦ ᐅᓄᕐᓂᖅᓴᓂ 50% ᑑᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᑖᕆᐊᕐᓃᑦ ᓂᐱᖁᑦ 1 ᑭᓗᕼᐅᑦ ᐊᑐᖅᑎᑦᑐᖕᒋᑦ ᐊᑯᓐᓂᖓᓂ 1.2 ᐊᒻᒪᓗ 1.9% ᑲᑎᑐᒃᑖᖅᑲᒋᑦ ᑖᒃᑯᓐᖓ ᐊᕐᕌᒍᓄᑦ.

5 ᑭᓗᕼᐅᑦ (ᐅᕕᖕᓂᐊᖅᑐᑦ/ᑎᒡᓗᖅᑐᖅᐸᓚᕐᑎᔪᓂᒃ):

ᓂᐱᓕᐅᕆᔭᐅᔪᓂᑦ ᓯᑎᐱᕆ-ᐅᑐᐱᓂ 2021-ᒥ, ᐅᓄᕐᓂᖅᓴᑦ 50% ᑐᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᓵᕆᐊᕐᓃᑦ ᓂᐱᓄᑦ 5 ᑭᓗᕼᐅᑦ ᑐᓴᖅᓴᐅᔪᑦ 20.7% ᐊᒻᒪᓗ 20.6% ᐅᒥᐊᕐᔪᐊᑦ ᑐᓴᖅᑕᐅᔪᓐᓇᖅᑎᓪᓗᒋᑦ (ᓲᕐᓗ 6.6 ᐊᒻᒪᓗ 4.6% ᓂᐱᓕᐅᕆᓐᓇᒥ) ᐱᓇᖕᓇᖕᒐᓂ ᑲᓇᖕᓇᖕᒐᓂᓗ ᓯᓈᓂ ᓂᐱᓕᐅᕈᑎᓂ, ᑕᒪᐃᓐᓄᑦ. ᐅᓄᕐᓂᖅᓴᑦ 50% ᑐᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᓵᕆᐊᕐᓃᑦ ᓂᐱᓄᑦ 5 ᑭᓗᕼᐅᑦ ᐊᑐᖅᑕᐅᓚᐅᖅᑐᑦ 18.1, 26.1 ᐊᒻᒪᓗ 48.2% ᐅᒥᐊᕐᔪᐊᑦ ᑐᓴᖅᑕᐅᔪᓐᓇᖅᑎᓪᓗᒋᑦ (ᓲᕐᓗ 3.6, 2.9, ᐊᒻᒪᓗ 6.7 % ᓂᐱᓕᐅᕆᓐᓇᒥ(ᕿᙵᐊᓂ, ᐱᓇᖕᓇᖕᒐᓂ ᓯᓈᓂ ᐊᒻᒪᓗ ᑲᓇᖕᓇᖕᒐᓂ ᓯᓈᓂ ᓂᐱᓕᐅᕈᑎᓂ, ᑕᒪᐃᓐᓄᑦ 2022-ᒥ. ᓂᐱᖃᐃᓐᓇᖅᑐᑦ ᓴᖅᑭᑦᑐᑦ ᐅᓄᕐᓂᖅᓴᐅᓪᓗᑎᒃ 50% ᑐᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᓵᕆᐊᕐᓃᑦ 5 ᑭᓗᕼᐅᑦ ᐊᑐᖅᑎᓪᓗᒍ 22.6 ᐊᒻᒪᓗ 22.8 % ᓂᐱᓕᐅᕆᓐᓇᒥ ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖃᙱᑎᓪᓗᒋᑦ (ᓲᕐᓗ 15.4 ᐊᒻᒪᓗ 17.6% ᓂᐱᓕᐅᕆᓐᓇᒥ) ᐃᓇᖕᓇᖕᒐᓂ ᐊᒻᒪᓗ ᑲᓇᖕᓇᖕᒐᓂ ᓯᓈᓂ ᓂᐱᓕᐅᕆᕝᕕᖕᓂ ᐅᙵᐊᓂ 2021, ᐊᒻᒪᓗ ᑖᒃᑯᓇᓂ 20.8, 28.9, ᐊᒻᒪᓗ 29.6 % ᓂᐱᓕᐅᕆᓐᓇᒥ ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖃᙱᑎᓪᓗᒋᑦ (ᓲᕐᓗ 16.6, 25.7, ᐊᒻᒪᓗ 25.5 % ᓂᐱᓕᐅᕆᓐᓇᒥ) ᕿᙵᐊᓂ, ᐱᓇᖕᓇᖕᒐᓂ ᓯᓈᓂ, ᐊᒻᒪᓗ ᑲᓇᖕᓇᖕᒐᓂ ᓯᓈᓂ ᓂᐱᓕᐅᕆᕝᕕᖕᓂ, ᑕᒪᐃᓐᓄᑦ 2022-ᒥ. ᑖᒃᑯᐊ ᐅᒥᐊᕐᔪᐊᒥᖕᒎᖅᑕᐅᔪᑦ ᑐᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᓵᕆᐊᕐᓃᑦ ᓈᓴᐅᑎᖕᒋᑦ ᕿᙵᐊᓂ ᐊᒃᐸᓯᖕᓂᖅᓴᐅᒧᑦ ᓈᓴᐅᑎᓂᒃ ᓈᓴᐅᓯᓇᔭᐅᓯᒪᔪᓂ ᑖᒻᓴᐃᓐᓇᖅ ᐊᑯᓐᓂᖕᒐᓂ 2019 ᐊᒻᒪᓗ 2021, ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖕᒋᑦ ᓴᖅᑮᓯᒪᓪᓗᑎᒃ ᐅᓄᕐᓂᖅᓴᓂᒃ 50 % ᑐᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᓵᕆᐊᕐᓃᑦ ᓂᐱᓄᑦ 5 ᑭᓗᕼᐅᑦ ᐊᑐᖅᑎᓪᓗᒋᑦ ᐊᑯᓐᓂᖕᒋᓐᓂᒃ 7 ᐊᒻᒪᓗ 8 % ᑲᑎᓗᒃᑖᖅᓱᒋᑦ ᓂᐱᓕᐅᖅᑕᐅᔪᑦ ᑖᒃᑯᐊ ᐊᑐᖅᑎᓪᓗᖕᒋᑦ ᐊᕐᕌᒍᐱᑦ. ᓂᐱᖃᐃᓐᓇᖅᑐᑦ ᕿᙵᐊᓂ ᓴᖅᑮᓯᒪᓪᓗᑎᒃ ᐅᓄᕐᓂᖅᓴᓂᒃ 50 % ᑐᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᓵᕆᐊᕐᓃᑦ ᓂᐱᓄᑦ 5 ᑭᓗᕼᐅᑦ ᐊᑐᖅᑎᓪᓗᖕᒋᑦ ᐊᑯᓐᓂᖕᒐᓂ 8 ᐊᒻᒪᓗ 18 % ᑲᑎᓗᒃᑖᖅᓱᖕᒋᑦ ᓂᐱᓕᐅᕆᓂ ᑖᒃᑯᓇᓂ ᐊᕐᕌᒍᓂ, ᖃᐅᔨᓴᐅᔪᑦ 2022-ᒥ ᐃᓗᐊᓃᓱᑎᒃ ᑖᒃᑯᐊ ᖃᓄᐃᓕᖕᒐᓂᖕᒋᓐᓂ.

25 ᑭᓗᕼᐅᑦ (ᖃᓯᒃᑐᖅᐸᓚᕐᑎᔪᓂᒃ ᐊᒻᒪᓗ ᖃᑕᐃᑦᑐᓂᒃ ᓂᓪᓕᐊᔪᓂᒃ):

ᓂᐱᓕᐅᖅᑕᐅᔪᑦ ᓯᑎᐱᕆ-ᐅᑐᐃᕆ 2021-ᒥ, ᐅᓄᕐᓂᖅᓴᑦ 50% ᑐᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᓵᕆᐊᕐᓃᑦ (LRR) ᓂᐱᓄᑦ 25 ᑭᓗᕼᐅᑦ ᐊᑐᖅᑎᓪᓗᖕᒋᑦ 14.2 ᐊᒻᒪᓗ 2.1% ᐅᒥᐊᕐᒧᐊᑦ ᑐᓴᖅᓴᐅᑎᓪᓗᒋᑦ (ᓲᕐᓗ 4.5 ᐊᒻᒪᓗ 0.5 % ᓂᐱᓕᐅᕆᓐᓇᒥ) ᐱᓇᖕᓇᖕᒐᓂ ᐊᒻᒪᓗ ᑲᓇᖕᓇᖕᒐᓂ ᓯᓈᓂ ᓂᐱᓕᐅᕈᑎᓂ, ᑕᒪᐃᓐᓄᑦ. ᐅᓄᕐᓂᖅᓴᑦ 50% ᑐᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᓵᕆᐊᕐᓃᑦ (LRR) ᓂᐱᓄᑦ 25 ᑭᓗᕼᐅᑦ ᓂᐱᖃᓚᐅᖅᑐᑦ 24.2, 7.3 ᐊᒻᒪᓗ 13.5% ᐅᒥᐊᕐᔪᐊᑦ ᑐᓴᖅᓴᐅᑎᓪᓗᒋᑦ (ᓲᕐᓗ 4.8, 0.8 ᐊᒻᒪᓗ 1.9% ᓂᐱᓕᐅᕆᓐᓇᒥ) ᕿᙵᐊᓂ, ᐱᓇᖕᓇᖕᒐᓂ ᓯᓈᓂ, ᐊᒻᒪᓗ ᑲᓇᖕᓇᖕᒐᓂ ᓯᓈᓂ ᓂᐱᓕᐅᕈᑎᓂ, ᑕᒪᐃᓐᓄᑦ 2022-ᒥ. ᓂᐱᖃᐃᓐᓇᖅᑐᑦ ᓴᖅᑮᓯᒪᔪᑦ ᐅᓄᕐᓂᖅᓴᓂ 50% ᑐᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᓵᕆᐊᕐᓃᑦ (LRR) ᓂᐱᓄᑦ 25 ᑭᓗᕼᐅᑦ ᐊᑐᖅᑎᓪᓗᖕᒋᑦ 19.5 ᐊᒻᒪᓗ 1.2% ᓂᐱᓕᐅᕆᓐᓇᒥ ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖃᙱᑎᓪᓗᒋᑦ (ᓲᕐᓗ 13.3 ᐊᒻᒪᓗ 0.9% ᓂᐱᓕᐅᕆᓐᓇᒥ) ᐱᓇᖕᓇᖕᒐᓂ ᐊᒻᒪᓗ ᑲᓇᖕᓇᖕᒐᓂ ᑕᓯᐅᔭᒥ ᓄᙵᐊᓂ 2021-ᒥ, ᐊᒻᒪᓗ 28.6, 20.0 ᐊᒻᒪᓗ 11.8% ᓂᐱᓕᐅᕆᓐᓇᒥ ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖃᙱᑎᓪᓗᒋᑦ (ᓲᕐᓗ 22.9, 17.8 ᐊᒻᒪᓗ 10.1% ᓂᐱᓕᐅᕆᓐᓇᒥᒃ) ᕿᙵᐊᓂ, ᐱᓇᖕᓇᖕᒐᓂ ᓯᓈᓂ ᐊᒻᒪᓗ ᑲᓇᖕᓇᖕᒐᓂ ᓯᓈᓂ ᓂᐱᓕᐅᕆᕝᕕᖕᓂ, ᑕᒪᐃᓐᓄᑦ 2022-ᒥ. ᑕᒪᒃᑯᐊ ᐅᒥᐊᕐᔪᐊᓂᖕᒎᖅᑐᑦ ᑐᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᓵᕆᐊᕐᓃᑦ (LRR) ᓈᓴᐅᑎᖕᒋᑦ ᕿᙵᐊᓂ ᒪᓕᒃᑐᑦ ᖃᐅᔨᓴᐅᔪᓂ ᑕᐅᕙᓂ 2021-ᒥ ᐊᒻᒪᓗ ᐊᒃᐸᓯᖕᓂᖅᓴᐅᓪᓗᑎᒃ ᓈᓴᐅᑎᖕᒋᑦ ᓈᓴᐅᓯᓇᔭᐅᓯᒪᔪᓂᑦ 2019-ᒥ ᐊᒻᒪᓗ 202-ᒥ (ᐅᓄᕐᓂᖅᓴᑦ 50% ᑐᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᓵᕆᐊᕐᓃᑦ (LRR) 25 ᑭᓗᕼᐅᑦ ᐊᑐᖅᑐᑦ 8-9% ᑲᑎᓗᒃᑖᖅᓱᖕᒋᑦ ᓂᐱᓕᐅᕆᓂᕐᓂ ᑖᒃᑯᓄᖕᒐ ᐊᕐᕌᒍᓄᑦ). ᓂᐱᖃᐃᓐᓇᖅᑐᑦ ᕿᙵᐊᓂ ᓴᖅᑭᓯᒪᔪᑦ ᐅᓄᕐᓂᖅᓴᐅᓪᓗᑎᒃ 50% ᑐᓵᔭᐅᔪᓐᓇᕐᓂᕐᒧᑦ ᓂᐱᒃᓵᕆᐊᕐᓃᑦ (LRR) ᓂᐱᓄᑦ 25 ᑭᓗᕼᐅᑦ ᐊᑐᖅᑎᓪᓗᖕᒋᑦ ᐊᑯᓐᓂᖕᒐᓂ 10 ᐊᒻᒪᓗ 26% ᑲᑎᓗᒃᑖᖅᓱᒋᑦ ᓂᐱᓕᐅᕆᓂᕐᓂ ᐊᑯᓐᓂᖕᒋᓐᓂ 2019 ᐊᒻᒪᓗ 2021, ᖃᐅᔨᓴᐅᔪᓪᓗ 2022-ᒧᑦ ᐃᓗᐊᓃᓱᑎᒃ ᑖᒃᑯᓇᓂ.

1. Introduction

Underwater sound level measurements were collected at locations in Milne Inlet and Eclipse Sound during JASCO Applied Sciences' (JASCO) 2022 Acoustic Monitoring program, developed in collaboration with WSP Canada (WSP, formerly Golder Associates Ltd.) and Baffinland Iron Mines Corporation (Baffinland), to evaluate potential Project-related effects to marine mammals from shipping noise associated with 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.

Underwater sound level measurements were collected at two floe edge locations (eastern and western) and one location in Milne Inlet. One acoustic recorder (referred to as the eastern floe edge location) was deployed 55 km east (in the direction of the floe edge, ataggaq) of Mittimatalik (Pond Inlet), one (referred to as the western floe edge location) was deployed 25 km west of Pond Inlet (in the inland direction, kangivak), and one (the Milne Inlet recorder) was deployed approximately 5 km from the mouth of Koluktoo Bay and approximately 4 km south-southwest from Iluvilik (Bruce Head), as shown in Figure 1. Underwater acoustic data were collected using Autonomous Multichannel Acoustic Recorders (AMARs; JASCO). The Milne Inlet recorder was deployed on 13 Aug 2022 and was retrieved on 1 Oct 2022, and it recorded continuously during this period. The western and eastern floe edge recorders were deployed on 15 Sep 2021, and they recorded continuously for one month then powered off until 7 Jul 2022 when they recorded continuously for one additional month before retrieval between 14–15 Aug 2022. The 2021 floe edge data are considered part of the 2022 underwater acoustic monitoring program data set for the purposes of this report.

When feasible, Baffinland implemented vessel convoys in 2022 to investigate their effectiveness as a mitigation measure intended to reduce the total amount of noise exposure from shipping within the Regional Study Area (RSA). In this context, a convoy is defined as a transit involving two or more Project vessels, transiting in the same direction, within 10 km of each other. It was predicted that the noise footprint (i.e., the area affected by vessel noise) for a vessel convoy would be slightly larger than the individual footprint of the loudest vessel in the convoy, but smaller than total footprint for all the convoy vessels individually, and that the noise footprint for a convoy of two similar vessels would be less than the sum of the individual vessel noise footprints. Thus, the use of convoys as a mitigation measure was implemented based on the hypothesis that there would be a reduction of the total amount of sound exposure throughout the shipping season. JASCO performed an analysis specific to the sound levels associated with vessel convoys; those results are presented in a separate report (Austin 2023).

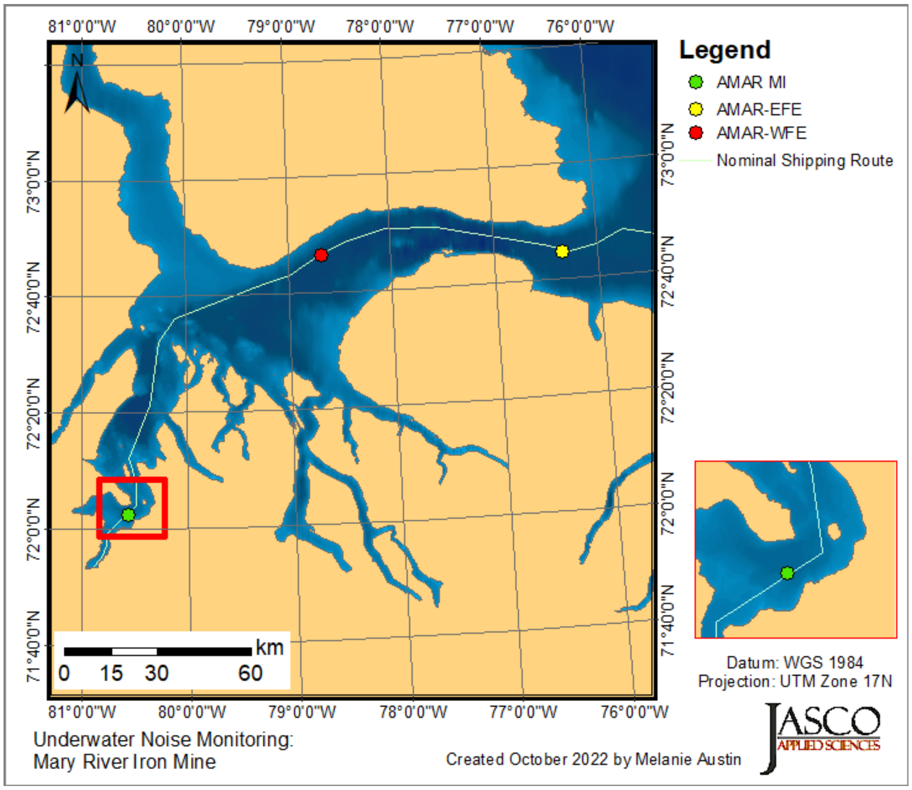


Figure 1. Acoustic monitoring area and locations of recorder stations along the Northern Shipping Route, in Milne Inlet (red insert: AMAR–MI) and in Eclipse Sound (AMAR-WFE and AMAR-EFE).

1.1. Project Context

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

To date, Baffinland has been operating in the Early Revenue Phase (ERP) of the Project and is authorized to transport 4.2 Mtpa of ore by truck to Milne Port for 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 2018–2022 and shipping is expected to continue for the life of the Project (20+ years). During the first year of ERP operations in 2015, Baffinland shipped ~918,000 tonnes of iron ore from Milne Port involving 13 return ore carrier voyages. In 2016, the total volume of ore shipped out of Milne Port reached 2.6 million tonnes involving 37 return ore carrier voyages. In 2017, the total volume of ore shipped out of Milne Port reached 4.1 million tonnes involving 58 return ore carrier voyages. Following approval to increase production to 6.0 Mtpa, a total of 5.1 Mtpa of ore was shipped via 71 return voyages in 2018, 5.9 Mtpa of ore was shipped via 81 return voyages in 2019, 5.5 Mtpa was shipped via 72 return voyages in 2020, and 5.6 Mtpa via 73 return voyages in 2021. In 2022, a total of 4.7 Mtpa of iron ore was shipped via 62 return voyages with the first inbound transit of the season occurring on 31 Jul 2022 (UTC) and the last outbound transit of the season occurring on 13 Oct 2022.

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 2022 Acoustic Monitoring 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 2022 Acoustic Monitoring 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 2022 Open-Water Season Acoustic Program were the following:

- Measure and report ambient noise levels at locations along the Northern Shipping Route (Figure 1);
- Compare in-situ sound levels relative to modelled sound levels;
- Determine marine mammal species (notably narwhal) acoustic 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;
- Compare LRR calculations with results from prior years (a Baffinland commitment in response to requests from the Marine Environment Working Group); and
- Characterize noise from vessel convoys transiting along the Northern Shipping Route.

1.3. Ambient Sound Levels

The ambient, or background, sound levels that create the ocean soundscape are comprised of many natural and anthropogenic sources (Figure 2). The main environmental sources of sound are wind, precipitation, and sea ice. Wind-generated noise in the ocean is well-described (e.g., Wenz 1962, Ross 1976), and surf sound 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 and break up. Precipitation is a frequent noise source, with contributions typically concentrated at frequencies above 500 Hz. At low frequencies (<100 Hz), earthquakes and other geological events contribute to the soundscape. Biological sound sources, including marine mammals and fish, are another natural source of sound (Section 1.4).

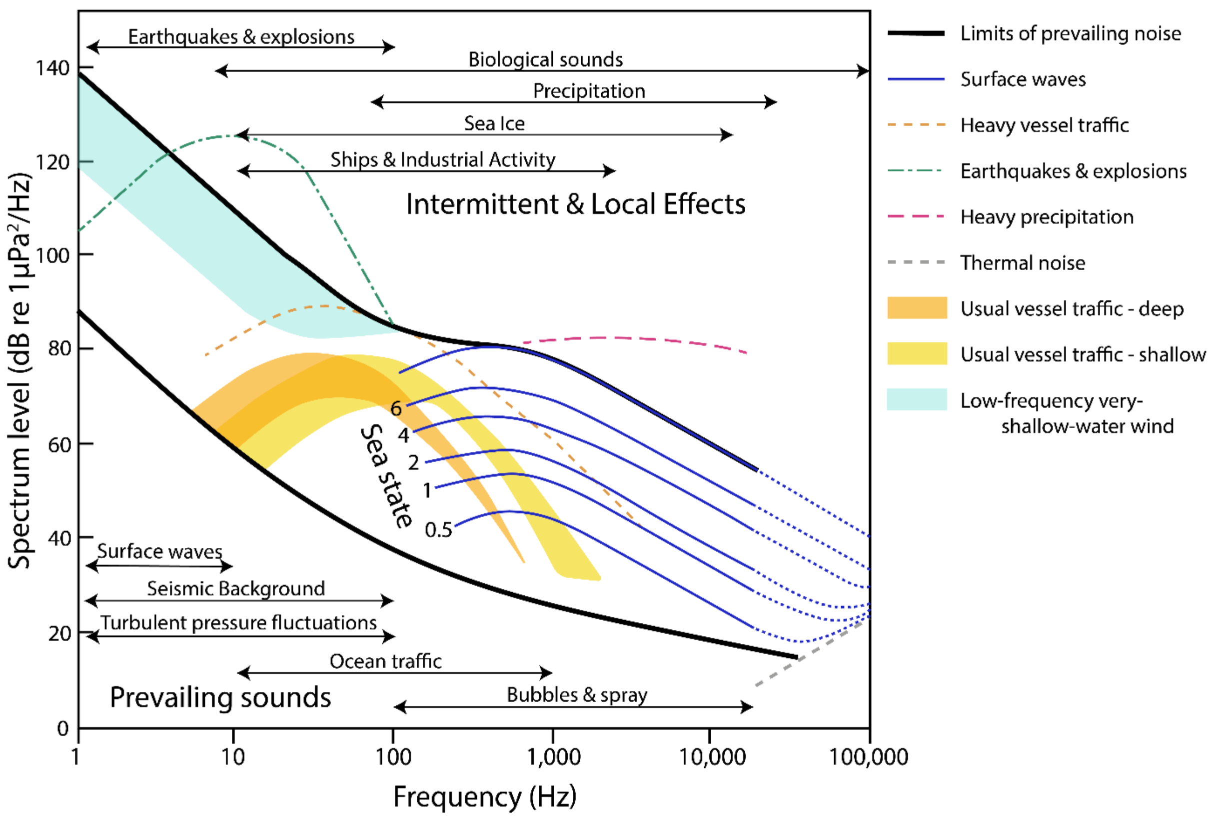


Figure 2. Wenz curves describing pressure spectral density levels of marine ambient sound from weather, wind, geologic activity, and commercial shipping (adapted from NRC 2003, based on Wenz 1962). The thick lines are the limits of prevailing ambient sound, which are included in some of the results plots to provide context.

1.4. Biological Contributors to the Marine Soundscape

Five cetacean (beluga whales, bowhead whales, killer whales, narwhals, 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 (Thomas et al. 2015, 2016, Golder Associates Ltd. 2018, 2019, 2020) 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, narwhals, killer whales, and sperm 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 2004b, COSEWIC 2004a, COSEWIC 2008, COSEWIC 2009, Marcoux et al. 2009, Stephenson and Hartwig 2010, Thomas et al. 2014, Smith et al. 2015, COSEWIC 2017, Austin et al. 2021, Posdaljian et al. 2022, Austin et al. 2023).

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 [f]
Cetaceans			
Beluga whales	*Delphinapterus leucas*	Special concern [b] (COSEWIC 2020)	Not listed [b,e]
Bowhead whales	*Balaena mysticetus*	Special concern [a] (COSEWIC 2009)	Not listed [a,e]
Killer whales	*Orcinus orca*	Special concern [c] (COSEWIC 2008)	Not listed [c,e]
Narwhal	*Monodon monoceros*	Special concern (COSEWIC 2004a)	Not listed [e]
Sperm whales	*Physeter macrocephalus*	Not at risk	Not listed
Pinnipeds			
Ringed seals	*Phoca hispida*	Special concern (COSEWIC 2019)	Not listed [e]
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*	Special concern [d] (COSEWIC 2017)	No status [d,e]

[a] Status of the Eastern Canada-West Greenland population
[b] Status of the Eastern High Arctic-Baffin Bay population
[c] Status of the Northwest Atlantic/Eastern Arctic population
[d] Status of the High Arctic population
[e] Under consideration for addition
[f] The SARA establishes Schedule 1. Schedule 1 is the official wildlife species at risk list in Canada. Species on schedule 1 are classified as being either extirpated, endangered, threatened, or a special concern. Measures to protect and recover listed species are implemented.

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	Sound production frequency range (kHz) [a]	Identification signal	Automated detection signal	Reference
Beluga whales	0.1 to 21 (whistle, pulsed call) 40 to 20 (echolocation)	Whistle	Whistle	Karlsen et al. (2002) Garland et al. (2015)
Bowhead whales	0.02 (moan) to 6 (warble)	Moan	Moan	Clark and Johnson (1984) Delarue et al. (2009)
Killer whales	0.1 (click burst) to 75 (ultrasonic whistles) 22 to 80 (echolocation)	Whistle, pulsed vocalization	Tonal signal <6 kHz	Ford (1989) Deecke et al. (2005)
Narwhal	0.3 (whistle, pulsed call) to 24 (pulsed call) 53 (echolocation mean)	Whistle, click, buzz, knock	Whistle, click, buzz knock	Stafford et al. (2012) Ford and Fisher (1978) Walmsley et al. (2020)
Sperm whales	0.4 (squeal) to 9 (coda) 3 to 26 (echolocation)	Click	Click	Watkins (1980)
Ringed seals	0.4 (howl) to 0.7 (howl)	Grunt, yelp, bark	Grunt	Stirling et al. (1987) Jones et al. (2011)
Bearded seals	0.08 (groan) to 22 (moan)	Trill	Trill	Risch et al. (2007)
Harp seals	0.1 to 10	Grunt, yelp, bark	Grunt	Terhune (1994)
Hooded seals	0.01 to 6.11	Trill, groan, howl, moo, etc.,	Howl	Frouin-Mouy and Hammill (2021)
Walrus	0.02 (grunt) to 20 (knock)	Grunt, knock, bells	Grunt, bells	Stirling et al. (1987) Mouy et al. (2011)

[a] Southall et al. (2019)

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 propulsion systems, or it can be a product of active acoustic data collection with seismic surveys (not a Baffinland activity), military sonar (not a Baffinland activity), and depth sounding as the main contributors. Marine construction projects often involve nearshore blasting and pile driving that can produce high levels of impulsive-type noise thus mitigation measures tailored to activities are typically implemented (e.g., bubble curtains). The contribution of anthropogenic sources to the ocean soundscape has increased from the 1950s to 2010, largely driven by greater maritime shipping traffic (Ross 1976, Andrew et al. 2011). Recent trends suggest that global sound levels are leveling off or potentially decreasing in some areas (Andrew et al. 2011, Miksis-Olds and Nichols 2016). Oil and gas exploration (not a Baffinland activity) with seismic airguns, marine pile driving and oil and gas production platforms elevate sound levels over radii of 10 to 1000 km when present (Bailey et al. 2010, Miksis-Olds and Nichols 2016, Delarue et al. 2018).The extent of seismic survey sounds has increased substantially following the expansion of oil and gas exploration into deep water, and seismic sounds can now be detected across ocean basins (Nieukirk et al. 2004). Vessel-generated noise is the anthropogenic source of noise associated with the Project that contributes to the local soundscape.

1.5.1. Vessel Traffic

The main anthropogenic (human-generated) contributor to the total sound field in the RSA is vessel traffic from both Baffinland (Project vessels) and non-Baffinland vessels (non-Project vessels). This sound is a by-product of vessel operations, including engine sound radiating through vessel hulls and cavitating propellers. Project vessels, both those associated with transporting the iron ore (i.e., ore carriers) and support vessels (tugs, icebreaker, fuel tankers, and cargo vessels), contribute to the soundscape. Project vessels are to follow the nominal shipping lane (the Northern Shipping Route) that passes through the Project area (Figure 3). Other non-Project vessels that transited through the area in 2022 included cargo, fishing, passenger, and search and rescue vessels as well as service ships, tankers, and tugs but do not follow a defined shipping lane. Small boats are also frequently in the RSA and are a relevant source of anthropogenic noise (Hermannsen et al. 2019, Wilson et al. 2022), which has not been well characterized in the RSA because these boats typically do not have Automatic Identification Systems (AIS) installed for remote tracking of their vessel movements.

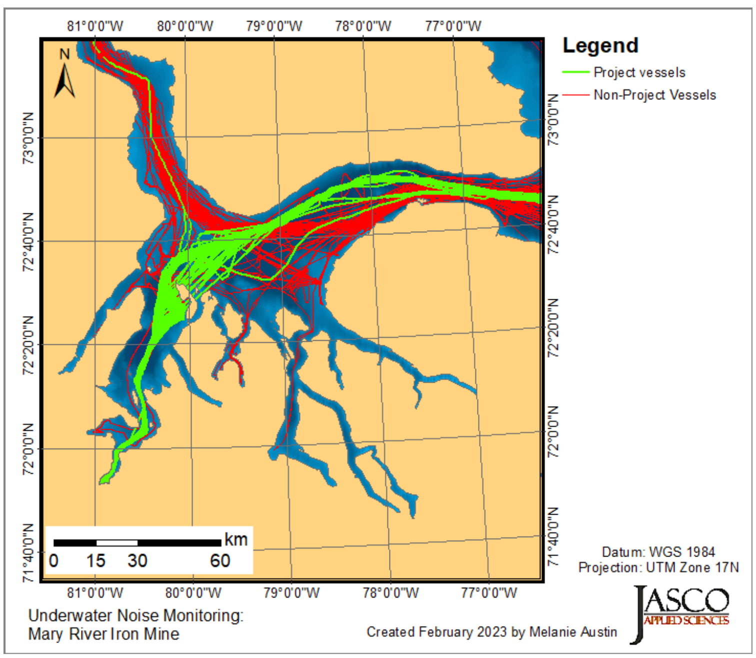


Figure 3. Vessel traffic travelling through the Regional Study Area during the 2022 season; both Project-related vessels (green) and non-Project related vessels (red) are displayed. Automatic Identification System (AIS) vessel tracking data was acquired from ground-based stations at Bruce Head and Pond Inlet, as well as AIS data collected by satellites (exactEarth 2020, Spire 2023).

2. Methods

2.1. Acoustic Data Acquisition

2.1.1. Underwater Acoustic Recorders

Underwater sound was recorded with two Autonomous Multichannel Acoustic Recorders (AMAR) Generation 3-A Deep (AMAR-WFE and AMAR-EFE) and one Autonomous Multichannel Acoustic Recorder Generation 4 ACE (AMAR-MI). AMAR-WFE and AMAR-EFE were fitted in anodized aluminum housings and AMAR-MI was fitted in an acetal housing. Each AMAR was fitted with an M36 omnidirectional hydrophone (GeoSpectrum Technologies Inc., −165 ± 3 dB re 1 V/µPa sensitivity). The AMAR hydrophones were protected by a hydrophone cage which was covered with an open-cell foam shroud to minimize noise artifacts from water flow over the hydrophone. These are passive instruments that do not emit any sound. The moorings (Figures 4 and 6) do not contain any chain and all metal components are isolated from each other and/or coated in rubber to avoid making any noise.

AMAR-WFE and AMAR-EFE recorded continuously on a duty cycle of 14 minutes at 64,000 samples per second and one minute at 512,000 samples per second for a recording bandwidths of 10 Hz to 32 kHz and 256 kHz respectively. The recording channel had 24-bit resolution with a spectral noise floor of 6 dB re 1 μPa^2/Hz and a nominal ceiling of 171 dB re 1 µPa. Acoustic data were stored on 256 GB of internal solid-state flash memory. AMAR-MI recorded continuously at 128,000 samples per second for a recording bandwidth of 10 Hz to 64 kHz. The recording channel had 24-bit resolution with a spectral noise floor of 6 dB. Acoustic data were stored on 10 TB of internal solid-state flash memory.

The calibration procedures are described in Appendix A.

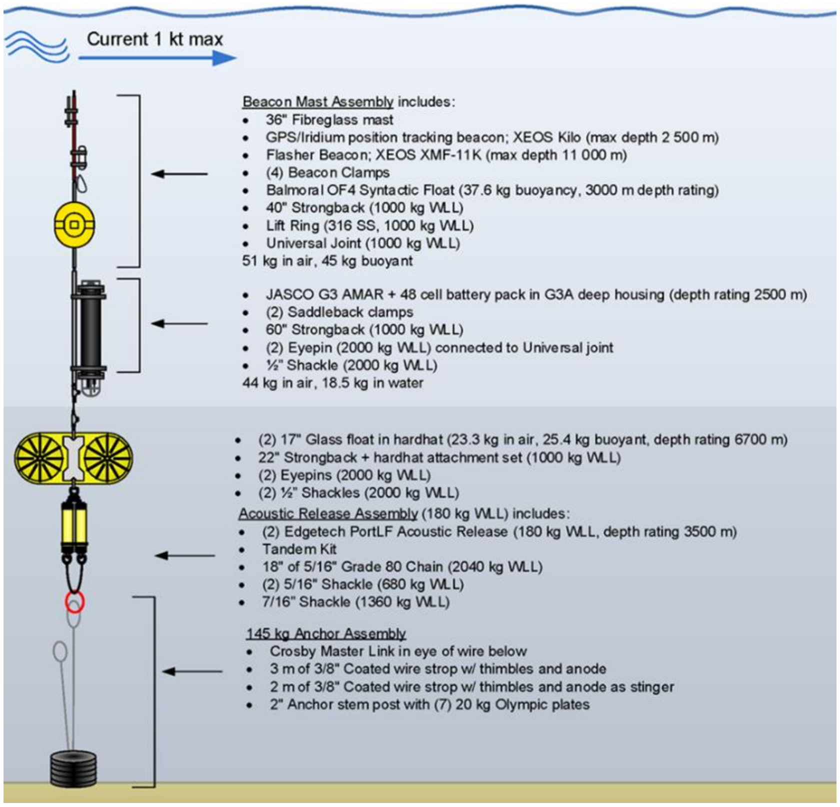


Figure 4. Mooring design: Kilo beacon on mast, OF4 float assembly, AMAR-G4, and tandem PortLF.

Figure 5.Configuration of AMAR-WFE and AMAR-EFE showing hydrophone location.

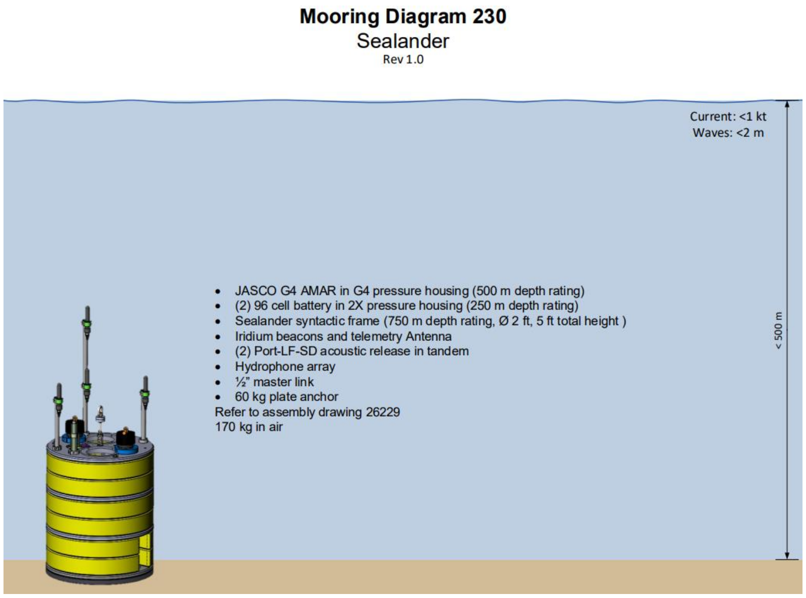


Figure 6. Mooring design 230: C-Lander with orthogonal array

2.1.2. Deployment Locations

The AMARs were deployed at three locations (Figure 1; Table 3) using the icebreaker *MSV Botnica*). AMAR-WFE an AMAR-EFE were deployed on 15 Sep 2021 and were retrieved on 14 Aug 2022. Both recorders had a period of overwintering between 16 Oct 2021 and 6 Jul 2022 where no data was recorded. AMAR-MI was deployed on 13 Aug 2022 and retrieved on 1 Oct 2022. All three AMARS were retrieved as planned using acoustic releases. All retrieved AMARs recorded as planned from deployment until retrieval, for an average gross recording duration of 49–60 days each.

Figure 7. *MSV Botnica*, used to deploy and retrieve the acoustic recorders.

Table 3. Operation period and location of the Autonomous Multichannel Acoustic Recorders (AMARs) deployed for the 2022 Acoustic Monitoring program.

2022 stations	Latitude	Longitude	Water depth (m)	Start date	Overwintering duration	Stop date	Recording duration (days)
AMAR-WFE	72° 46.400' N	-78° 40.223' W	674	14 Sep 2021	16 Oct 2021 7 Jul 2022	14 Aug 2022	30 (2021) 30 (2022)
AMAR-EFE	72° 44.455' N	-76° 19.730' W	629	15 Sep 2021	16 Oct 2021- 7 Jul 2022	14 Aug 2022	30 (2021) 30 (2022)
AMAR-MI	72° 02.187' N	-080° 33.366' W	277	13 Aug 2022	n/a	1 Oct 2022	49

Figure 8. The fast rescue craft from the *MVS Botnica* towing the AMAR mooring to the vessel post retrieval.

2.2. Automated Data Analysis

The AMARs collected approximately 12 TB of acoustic data during this study. All acoustic data was processed with JASCO's PAMlab software suite, which processes acoustic data hundreds of times faster than real time. PAMlab performed automated analysis of total ocean noise and sounds from vessels and (possible) marine mammal vocalizations. The following sections describe each type of analysis, and Appendix B provides an overview of the processing algorithms.

2.2.1. Total Ocean Sound Levels

The data collected spans one year at three locations, over the frequency band of 10–256 000 Hz. The goal of the total ocean sound analysis is to present this expansive data in a manner that documents the baseline underwater sound conditions and allows us to compare them between stations, over time, and with external factors that affect sound levels such as weather and human activities.

The first stage of the total sound level analysis involves computing the peak sound pressure level (PK) and sound pressure level (SPL) for each minute of data. This reduces the data to a manageable size without compromising its value for characterizing the soundscape (ISO 2017a, Ainslie et al. 2018, Martin et al. 2019). The SPL analysis is 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-min 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 similar to 1/3-octave-band levels, and their frequencies are listed in Appendix B.2. The decidecade analysis sums the frequency range from the 256,000 frequencies (representing the frequency range 1 Hz to 256 kHz) in the power spectral density data to a manageable set of 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 Appendices B.1 and B.2.

Weather conditions throughout the recording periods were gathered to inform the discussion on the factors driving noise levels and influencing marine mammal detections. Figure 9 shows wind data obtained from Pond Inlet (https://climate.weather.gc.ca).

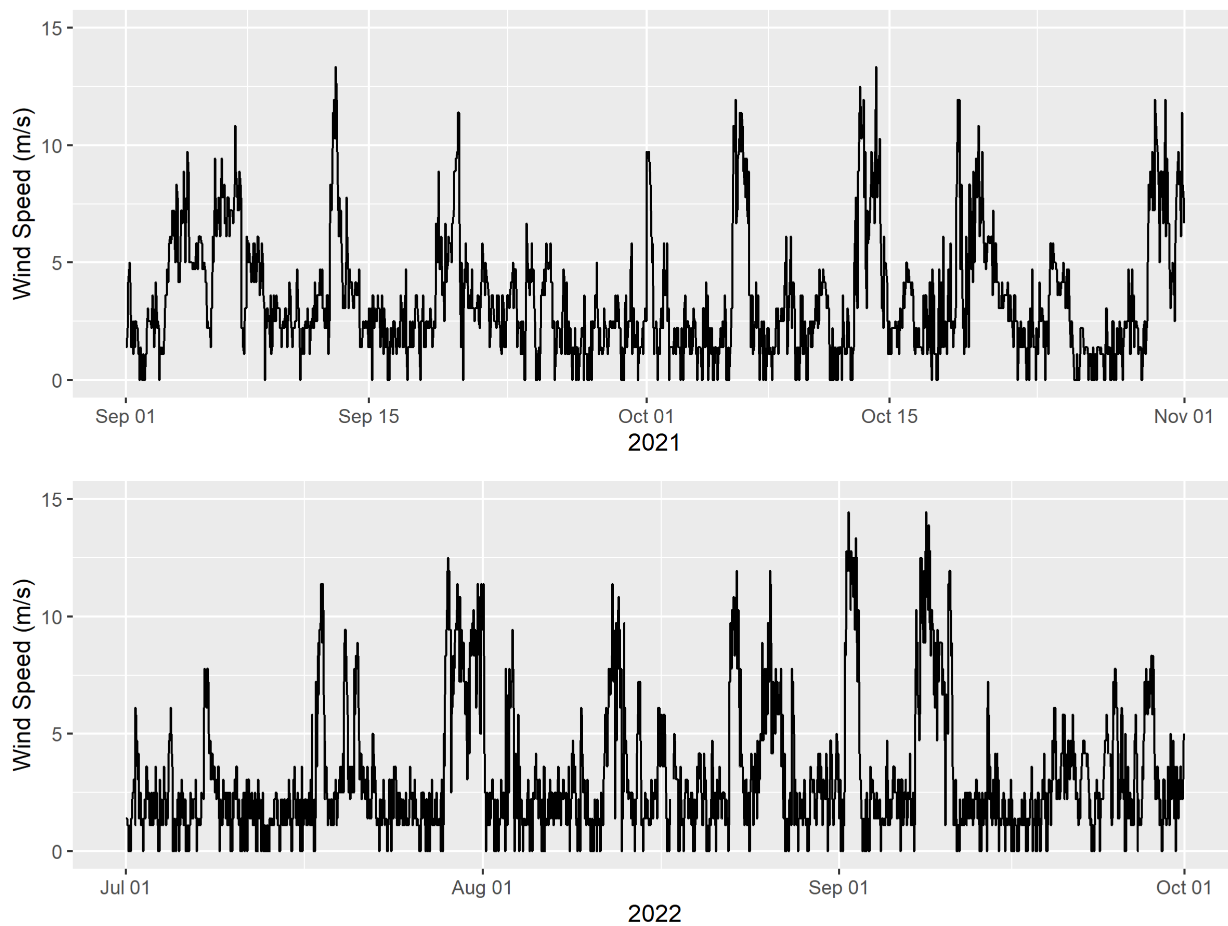


Figure 9. Wind speeds at Pond Inlet in September to October 2021 and July to September 2022.

In Section 3.1, the total sound levels are presented as:

- **Band-level plots**: These strip charts show the averaged received SPL as a function of time within a given frequency band. We show the total sound levels (across the entire recorded bandwidth from 10 to 256,000 Hz) and the levels in the decade bands of 10–100, 100–1000, 1000–10,000, and 10,000–100,000 Hz, depending on the recording bandwidth. The 10–100 Hz band is associated with fin, sei, and blue whale vocalizations, noise from 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 whale vocalizations, sounds produced by fish and invertebrates, nearby vessel noise, and pile driving noise. Sounds above 1000 Hz include high-frequency components of humpback whale vocalizations, odontocete (i.e., toothed whale) whistles and echolocation signals, wind- and wave-generated sounds, and sounds from human sources at close range including sounds generated by pile driving (not a Baffinland activity in 2021 or 2022), vessels, seismic surveys (not a Baffinland activity), 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 level measurements, 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 ranges 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 has 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-min 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 (see Appendix C) (NMFS 2018). The SEL thresholds for possible hearing impacts from sound on marine mammals are from Table AE-1 of NMFS (2018).

2.2.2. Vessel Noise Detection

The boat/vessel detector compares sound levels in an established frequency range to criteria values. If all criteria are met, a 'shippingFlag' value of either 1 (boat/vessel is present) or 4 (boat/vessel is nearby) is set. The highest sound level within the minutes flagged as having a boat/vessel present is assigned as the closest point of approach (CPA). The detector is executed twice, once for vessels and once for boats, with different parameter and criteria values; parameter/criteria values are provided for vessels in the description below with values for boats shown in parenthesis. The detector was originally designed to detect larger vessels, so the second set of parameters/criteria allow it to detect boats, which are quieter and emit more sound at higher frequencies. The vessel (or boat) detector performs the following operations for each minute of data, within the frequency range of 40–315 Hz (315–2000 Hz):

- The background SPL is calculated as the long-term average over the 12 h centred on the current time.
- The 1-min SPL must be:
  - 3 dB above the background SPL,
  - 12 dB (15 dB) above the total broadband SPL, and
  - Greater than 105 dB (95 dB).

Durations over which the above is true are then checked for the following:

- The average number of tonals detected per minute over a 5 min (3 min) window must be greater than 3 (0.49).
- The duration of the shipping detection must be between 5 and 360 min (3 and 60 min) long.

If all criteria are met, the 'shippingFlag' is set to 1, indicating that a boat or vessel is present in that minute of data. We then assume that the 15 min of data before and after the shipping detection flag '1' values have energy from the vessel/boat that did not meet the criteria but should not be considered as 'ambient'. These windows are given a value of 4 for the shipping detection flag. This system of 1 and 4 attempts to distinguish between vessels/boats that are nearer and farther from the AMAR, i.e., for large vessels the sequence is typically a series of flags of 4 (approach), then 1 (over/nearest), and then 4 (departure).

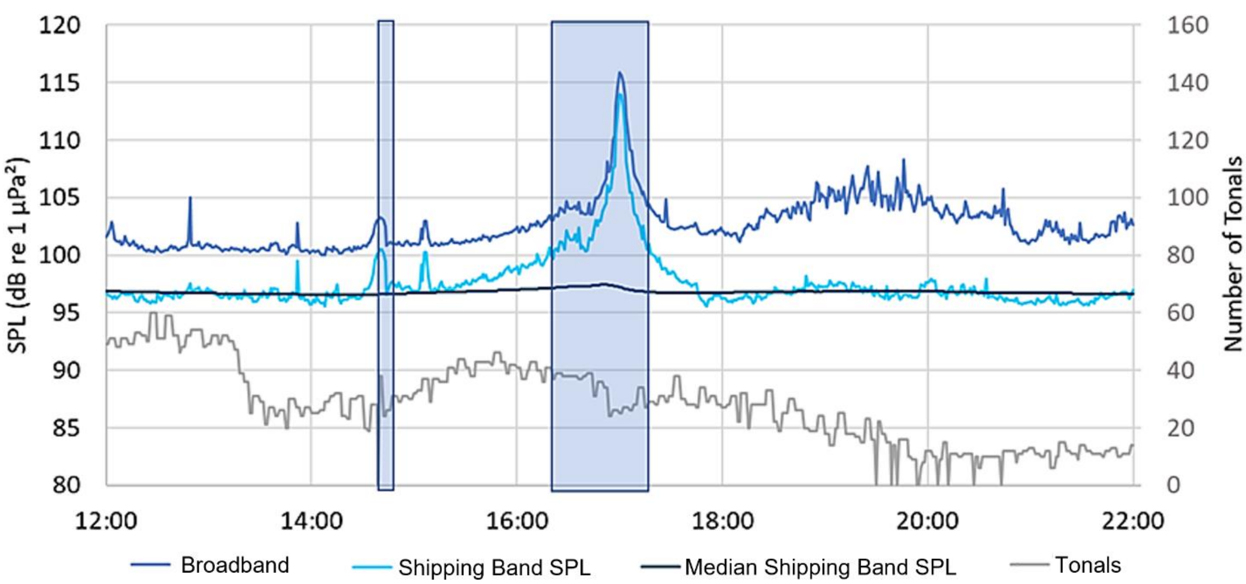


Figure 10. Generic example (not recorded during this project) of broadband and 40–315 Hz band sound pressure level (SPL), and the number of tonals detected per minute as a vessel approached a recorder, stopped, and then departed. The shaded area is the period of shipping detection. Fewer tonals are detected at the vessel's closest point of approach (CPA) at 17:00 because of masking by broadband cavitation noise and due to Doppler shift that changes the tone frequencies and makes them more difficult to identify.

2.3. 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. 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 ranges. 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 focuses only on the transmission loss.

LRR was calculated for three frequencies representative of five types of narwhal vocalizations, for all three AMAR locations in the regional study area. LRR was calculated at each AMAR station using the same methodology outlined in the 2018 Bruce Head Passive Acoustic Monitoring report (Frouin-Mouy et al. 2019), as follows. 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 decidecade band 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)). 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 decidecade 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 decidecade 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)
	AMAR-EFE (2021)	AMAR-WFE (2021)	AMAR-EFE (2022)	AMAR-WFE (2022)	AMAR-MI (2022)	
1	87.7	81.0	75.5	80.7	87.0	96.7
5	81.7	81.8	74.6	80.9	85.1	74.1
25	74.1	74.5	70.9	73.5	78.1	57.2

* From Finneran 2016, Equation A-9 and Table C-2.

2.4. Marine Mammal Detection Overview

A combination of automated detector-classifiers (referred to as automated detectors) and manual review by experienced analysts were used 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 D.1 and D.2). Second, a subset (2 %) of acoustic data was selected for manual analysis of marine mammal acoustic occurrence. The subset was selected based on automated detector results via an Automatic Data Selection for Validation (ADSV) algorithm (Kowarski et al. 2021) (see Appendix D.3). Third, manual analysis results were compared to automated detector results to determine automated detector performance (see Appendix D.4). Finally, hourly marine mammal occurrence plots were created that incorporated both manual and automated detections (see Section 3.5) and automated detector performance metrics were provided (see Appendix E) to present a reliable representation of marine mammal presence in the acoustic data. These marine mammal analysis steps are summarized here and described in detail in Appendix D.

2.4.1. Automated Click Detection

Odontocete clicks are high-frequency impulses ranging from 5 to over 150 kHz (Au et al. 1999, Møhl et al. 2000). An automated click detector was applied to the acoustic data to identify clicks from sperm whales, delphinids, beaked whales, and *Monodontidae* sp in the data sampled at 512 kHz. The 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., Appendix D.1). Zero-crossing-based features of automatically detected events are then compared to templates of known clicks for classification (see Appendix D.1 for details).

2.4.2. 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 D.2 for details).

2.4.3. 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. For this report, a subset of acoustic files was manually analysed for the presence/absence of marine mammal acoustic signals via spectrogram review in JASCO's PAMlab software. A subset (2 %) of acoustic data from each station and sampling rate was selected via ADSV for manual review (see Appendix D.3).

To determine the performance of the automated detectors at each station per acoustic file (14 min files sampled at 64 kHz and 1 min files sampled at 512 kHz), 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 D.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 where automated detections were considered valid) that maximizes the MCC.

Only automated detectors associated with a *P* greater than or equal to 0.75 were considered. When $P < 0.75$, only the manually 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 E and should be considered when interpreting results.

2.4.4. Differentiating Between Narwhal and Beluga Vocalizations

The acoustic repertoire of narwhal and beluga is diverse with both species producing clicks, whistles, and buzzes with such variety that consistently classifying their signals or differentiating between the species is challenging. Given the location of the acoustic recorders and the rarity of beluga visual sightings, signals were preferentially assigned to narwhal. Narwhal vocalizations were categorized as high-frequency buzz, low-frequency buzz, knocks, whistles, and echolocation clicks following the definition in Table 5. These call types and their definitions do not cover the full extent of the narwhal repertoire but identify relatively stereotyped signals that can be separated for detection and classification purposes. While we have set limits for each category, these signals occur on a spectrum where the line between them is arbitrarily chosen (e.g., knock vs click, buzz vs tonal, click vs buzz).

Table 5. Definitions used during manual analysis to annotate different narwhal call types.

Call type	Definition
Echolocation click	Inter-click-interval > 0.05 s, −3 dB frequency maximum < 55 kHz
High-frequency buzz	>14 kHz, Inter-click-interval reaches <0.01 s
Low-frequency buzz	<10 kHz Minimum frequency is equal or less than 5 kHz, Inter-click-interval reaches <0.01 s
Knock	1–8 kHz, Minimum frequency < 5 kHz, Inter-click-interval > 0.03 s
Whistle	<20 kHz tonal

There are some differences between the narwhal and beluga vocal repertoire that can help in determining when beluga were possibly present. First, it seems that beluga produce tonal whistles more prolifically than narwhal, given the name 'canaries of the sea'. Indeed, whistles have been described as the most common vocalization type of belugas (Garland et al. 2015). Whereas pure tonal whistles from narwhal are less common (Stafford et al. 2012). Therefore, when an acoustic file contained many whistles, analysts noted that beluga may be present, either instead of, or in addition to narwhal.

Differentiating species based on tonal sounds is inherently limited, particularly given that these animals commonly produce only clicks, without any tonal calls to allow for species identification. Zahn et al. (2021) produced a valuable article entitled '*Acoustic differentiation and classification of wild belugas and narwhals using echolocation clicks'*. Based on these findings, and subsequent JASCO internal review of archived data, the following protocols were applied for differentiating between the clicks of narwhal and beluga in the present data during manual analysis. If the average −3 dB frequency maximum of a click train is:

- Greater than 80 kHz, annotate as beluga click,
- Less than 55 kHz, annotate as narwhal click, and
- Between 55 and 80 kHz, annotated as unknown, either beluga or narwhal click.

These methods were applied to the AMAR-EFE and AMAR-WFE data sampled at 512 kHz where odontocete clicks (determined not to be sperm whale based on frequency characteristics and inter-pulse-interval) were identified. Killer whale clicks could have been mis-classified as narwhal using this methodology, but based on tonal signals, killer whale sounds were never confirmed present in 2022 and therefore such misclassification is expected to be rare. These techniques used to differentiate between species based on clicks should continue to be tested and refined as new information becomes available, such as the newly published work by Jones et al. (2022).

3. Results

3.1. Ambient Sound by Station

Ambient sound results and detailed discussions are presented here for two deep stations (AMAR-WFE; AMAR-EFE) and one shallow station (AMAR-MI) distributed over the study area. The spectrogram and band-level plots for all stations (see top/left panels of Figures 11-13) 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 (bottom/right panels of Figures 11–13) 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. The recorded broadband sound levels are summarized in Table 6. Cumulative distribution functions for each recorder are plotted in Figures 14 through 16.

The 2021 recording periods of AMAR-WFE and AMAR-EFE covered a time when open water was still present (14 Sep to 16 Oct 2021 and 15 Sep to 16 Oct 2021, respectively). The 2022 recording period of these two AMARs (7 Jul to 8 Aug 2022) began when ice was still present in July 2022, and captured the breakup period and onset of vessel traffic. Baffinland vessels entered the RSA on 31 Jul (UTC), whereas non-Project vessels were in the area as early as 21 Jul. AMAR-MI began recording after the breakup in August 2022 (recording from 13 Aug to 1 Oct 2022) when the area was ice-free and Baffinland's shipping season was underway. The dominant anthropogenic contribution to the ambient soundscape was from vessel noise (Project-related and non Project-related). The highest mean sound levels occurred at AMAR-MI. The second highest was at AMAR-WFE during July 2022 due to vessel traffic to Pond Inlet, and through traffic to Milne Inlet and Navy Board Inlet (predominantly non-Project vessels, as Project vessels did not enter the Regional Study Area until the last day of July).

As shown in Figure 3, all recording sites received a high volume of vessel traffic. AMAR-WFE and AMAR-EFE received soundscape contributions from both Project (green tracks in Figure 3) and Non-Project (red) vessels, whereas AMAR-MI was subject to predominantly Project vessel traffic only. Vessel detections by hour are shown in Figures 17-19, with an example spectrum of a vessel passing in Figure 20. The sound levels in vessel bands were higher at AMAR-MI than the other two stations, which may be related both to the specific recording periods selected, as well as the shallower depth of AMAR-MI.

There were also many natural contributions to the ambient soundscape including ice movement, weather, and mammal activity. At AMAR-WFE, the breakup of ice in 2022 and thus associated sounds began distinctly on 18 Jul and caused an immediate increase in broadband levels of approximately 10 dB. In contrast, the breakup of ice at AMAR-EFE in 2022 appeared to more gradually impact the soundscape in the initial stages. AMAR-EFE recorded ice-related sounds approximately four days before AMAR-WFE in July 2022, which aligns with AMAR-WFE being located further west in Eclipse Sound than AMAR-EFE. For both stations, there was a subsequent second increase in sound levels approximately one week following ice breakup which would be associated with increased vessel traffic (non-Project) in the now-accessible channel. AMAR-MI was deployed during open water conditions in August 2022 and thus ice movement was not a contributing sound source during the recording period.

Both AMAR-WFE and AMAR-EFE demonstrate fluctuations of sound levels between approximately 1000–2000 Hz. These fluctuations show up as horizontal lines on the spectrograms, and a zigzag in the percentiles. The cause of these fluctuations is due to the proximity of the hydrophone to the sphere above which causes shielding and constructive/destructive interference patterns and is not a real acoustic signal. This does not affect the results in this report because all analyses consider sound levels integrated over frequency bands that are wide enough to average out this mooring effect.

At AMAR-MI, sound levels in the frequency range of ~5–20 kHz decreased in early September 2022 relative to levels recorded earlier in the recording period (August 2022). This decrease accurately represents the local soundscape because this frequency band lies above that associated with vessel noise and below that associated with narwhal clicks. In early September 2022, the high frequency contribution by narwhals decreased as the animals departed the area, as shown in Section 3.5.4.

Wind conditions do not appear to be a dominant sound source at any of the recorders during the recording periods, although there was indication of a slight increase in broadband levels during some times of elevated wind speeds. For example, at AMAR-WFE, the increase in sound levels around 6 Oct 2021 corresponded with a period of higher wind speeds (approximately 12 m/s), as also observed at AMAR-EFE around 13 Oct 2021. However, not every period of increased wind speed in Figure 9 is reflected in the sound data. AMAR-WFE and AMAR-EFE are deeper stations, which may explain why they do not acoustically detect every storm event. AMAR-MI, the shallower station, appears more consistently sensitive to wind speeds. This is reflected in the broadband and lowest decade band increases in late August and early September 2022 on a few occasions which corresponded with periods of increased wind speeds. Although AMAR-MI appears more sensitive to wind conditions than the other two AMARs, wind was still not a dominant sound source at this station.

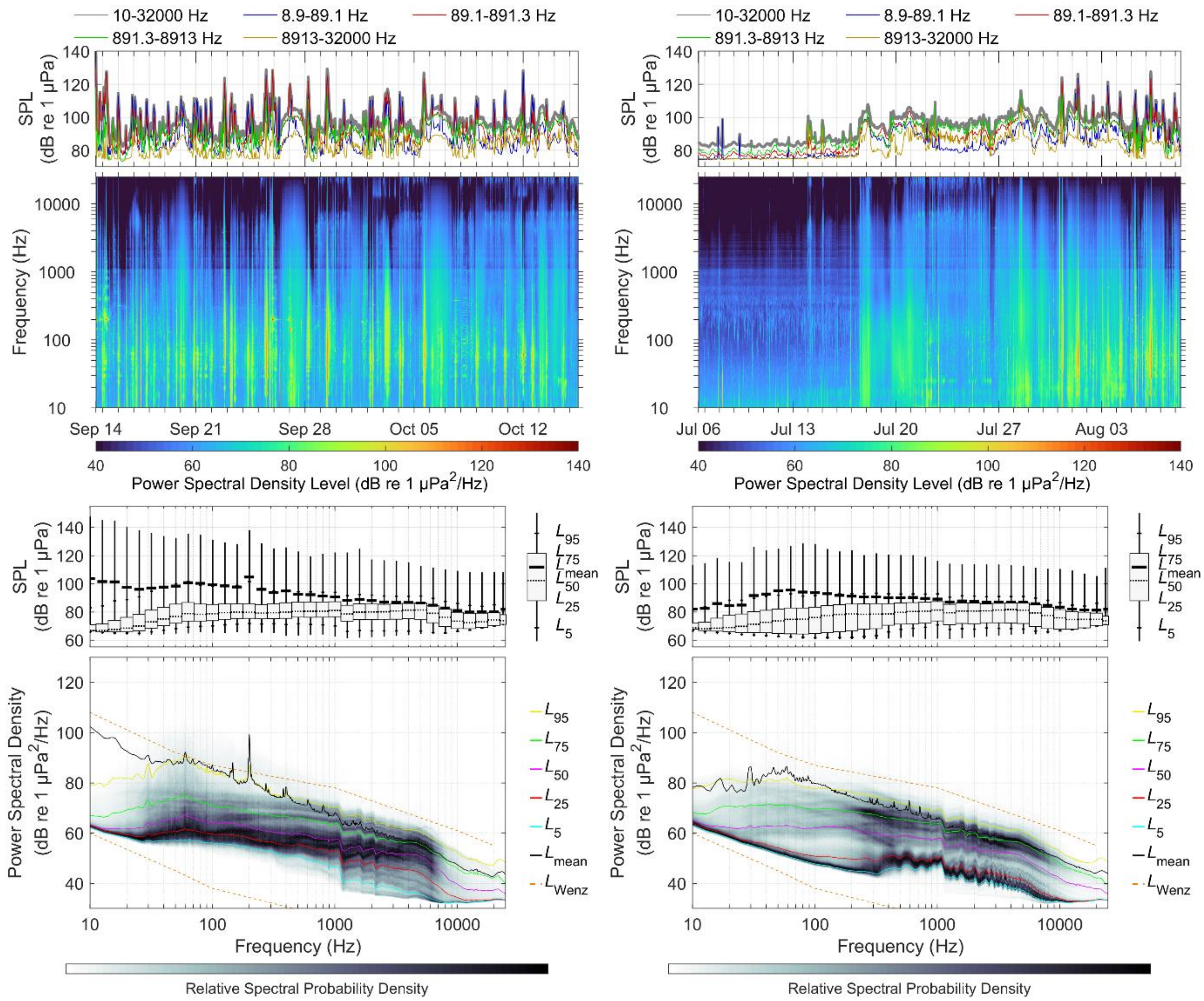


Figure 11. AMAR-WFE: (Top) In-band sound pressure level (SPL) and spectrogram of underwater sound. (Bottom) Exceedance percentiles and mean of decidecade-band SPL and exceedance percentiles and probability density (grayscale) of 1-min power spectrum density (PSD) levels compared to the typical range of sound levels (Wenz 1962). Figures for 2021 appear on the left side and figures for 2022 on the right.

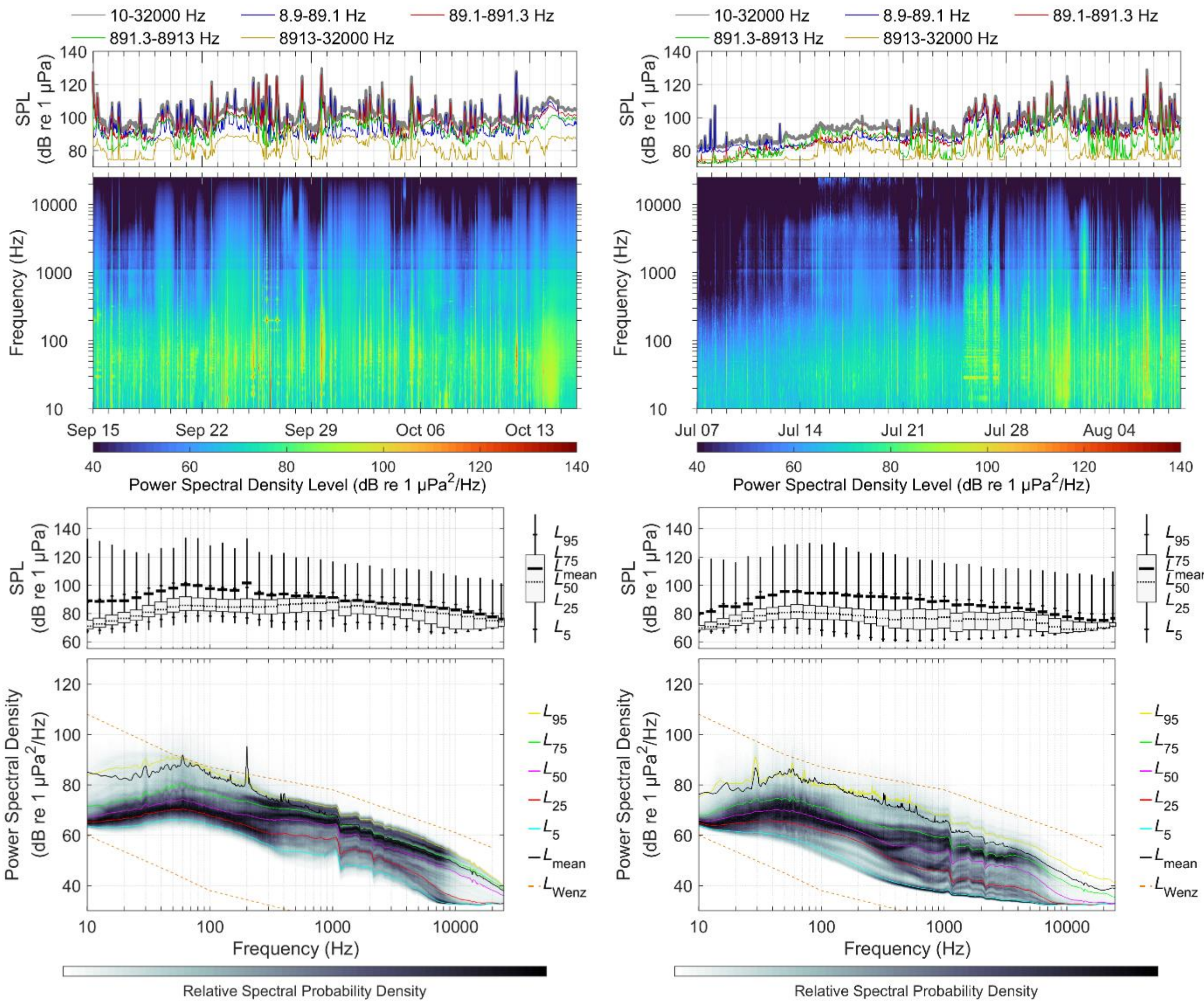


Figure 12. AMAR-EFE: (Top) In-band sound pressure level (SPL) and spectrogram of underwater sound. (Bottom) Exceedance percentiles and mean of decidecade-band SPL and exceedance percentiles and probability density (grayscale) of 1-min power spectrum density (PSD) levels compared to the typical range of sound levels (Wenz 1962). Figures for 2021 appear on the left side and figures for 2022 on the right.

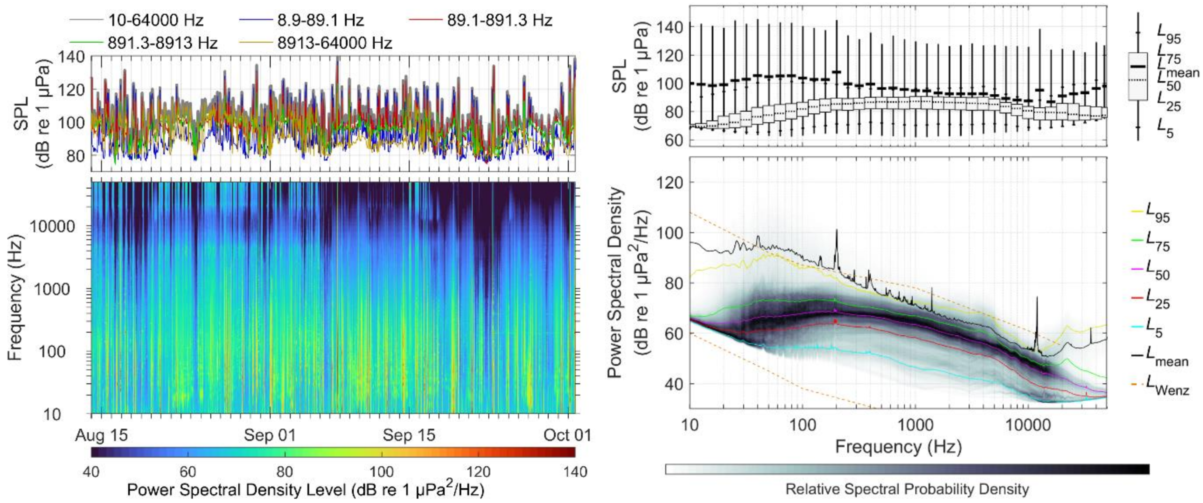


Figure 13. AMAR-MI: (Left) In-band sound pressure level (SPL) and spectrogram of underwater sound. (Right) Exceedance percentiles and mean of decidecade-band SPL and exceedance percentiles and probability density (grayscale) of 1-min power spectrum density (PSD) levels compared to the typical range of sound levels(Wenz 1962).

Table 6. Broadband, unweighted, sound pressure level (SPL; dB re 1 µPa) values at each recorder station.

Station	Minimum	Maximum	Mean	Median
AMAR-WFE 2021	81.4	151.7	112.3	96.1
AMAR-WFE 2022	81.2	135.4	105.2	95.1
AMAR-EFE 2021	86.7	137.1	109.3	100.3
AMAR-EFE 2022	80.5	137.4	105.4	93.5
AMAR-MI 2022	83.6	150.1	115.9	100.3

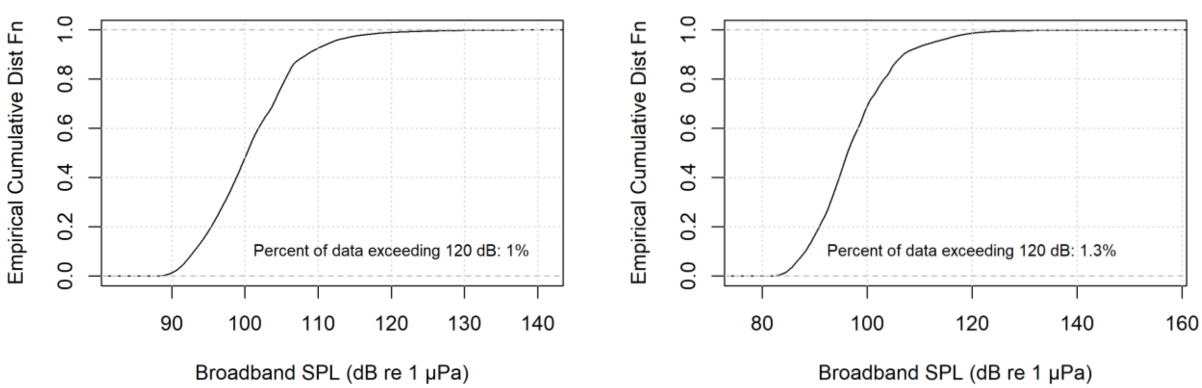
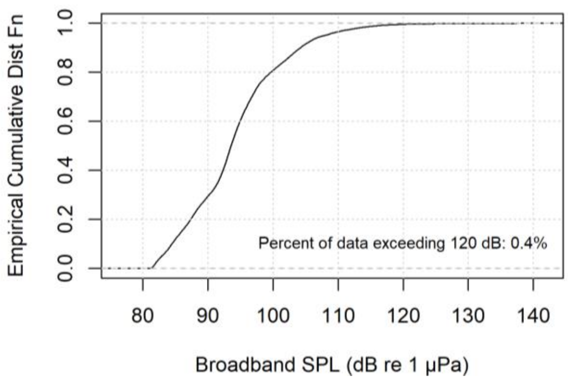


Figure 14. 2021: Empirical cumulative distribution functions for broadband sound pressure level (SPL) recorded at (left) AMAE-EFE and (right) AMAR-WFE in Sep-Oct 2021.



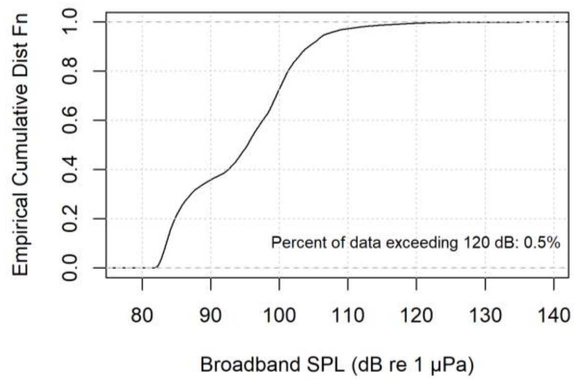


Figure 15. 2022: Empirical cumulative distribution functions for broadband sound pressure level (SPL) recorded at (left) AMAE-EFE and (right) AMAR-WFE in Jul-Aug 2022.

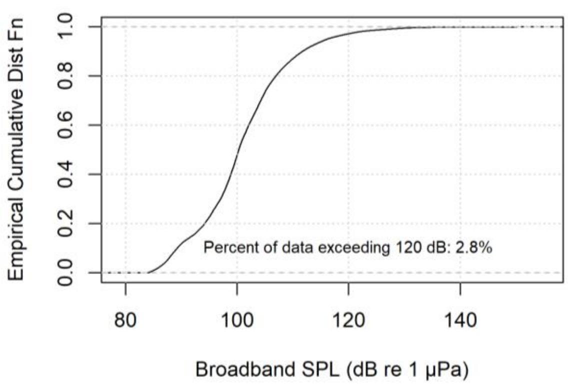


Figure 16. 2022: Empirical cumulative distribution functions for broadband sound pressure level (SPL) recorded at AMAR-MI in Aug-Sep 2022.

3.2. Vessel Detections

Vessels were detected using the automated detection algorithm described in Section 2.2.2. Vessel detections denote the closest points of approach (CPA) to a recorder by hour. Both AMAR-WFE and AMAR-EFE recorded daily vessel presence in advance of the over-winter period in 2021. When the recording period resumed in July 2022, there was a delay before vessels were detected, which corresponded with the ice breakup period. Large vessels first entered the area on 21 Jul 2022; these were non-Project vessels. Project vessels did not enter the RSA until 31 Jul so all detections prior to that are unrelated to the Project. It is important to note for the summer detections at AMAR-WFE and AMAR-EFE that ice breakup and vessel traffic occurred in similar frequency bands, and it could be possible that some ice movement were misrepresented as vessel detections in mid/late July. AMAR-MI recorded near-daily vessel presence for the entirety of its recording period. An example spectrum during a vessel pass for AMAR-WFE is shown in Figure 20.

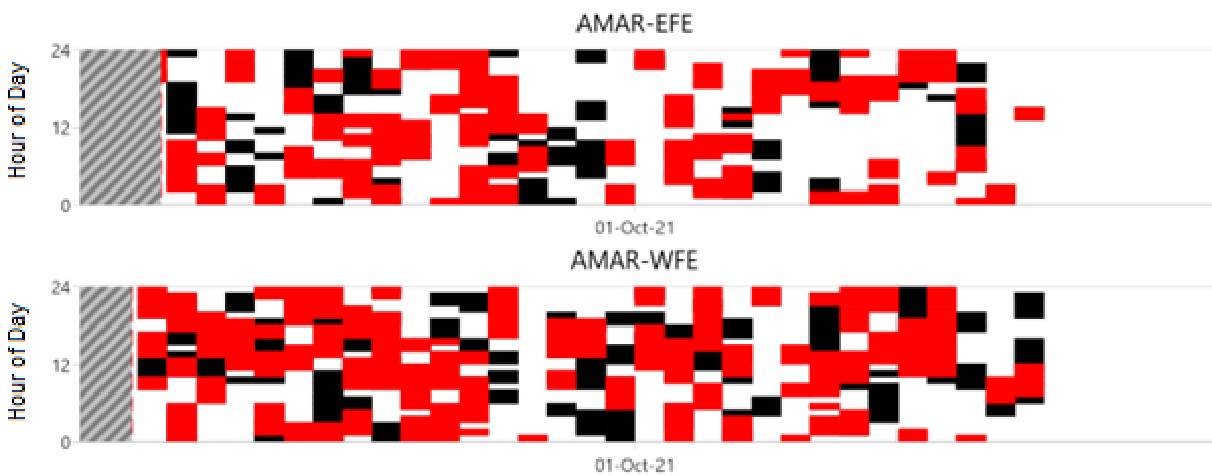


Figure 17. Vessel detections at AMAR-WFE and AMAR-EFE in fall 2021. Large vessels are in red and smaller boats in black. Grey stripes indicated time prior to deployment; AMAR-WFE was deployed 14 Sep 2021 and AMAR-EFE was deployed 15 Sep 2021. Both recorders turned off on 16 Oct 2021.

Figure 18. Vessel detections at AMAR-WFE and AMAR-EFE in summer 2022. Large vessels are in red and smaller boats in black. Grey stripes indicated time after retrieval. Both recorders started recording on 7 Jul and turned off on 8 Aug 2022. All vessels detected prior to 31 Jul 2022 were non-Project vessels.

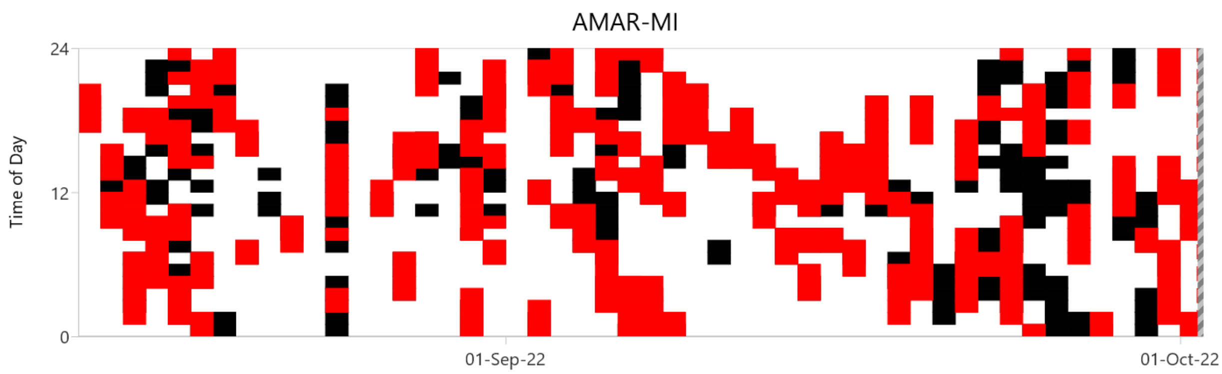


Figure 19. Vessel detections at AMAR-MI in 2022. Large vessels are in red and smaller boats in black. AMAR-MI recorded data between 13 Aug and 1 Oct 2022.

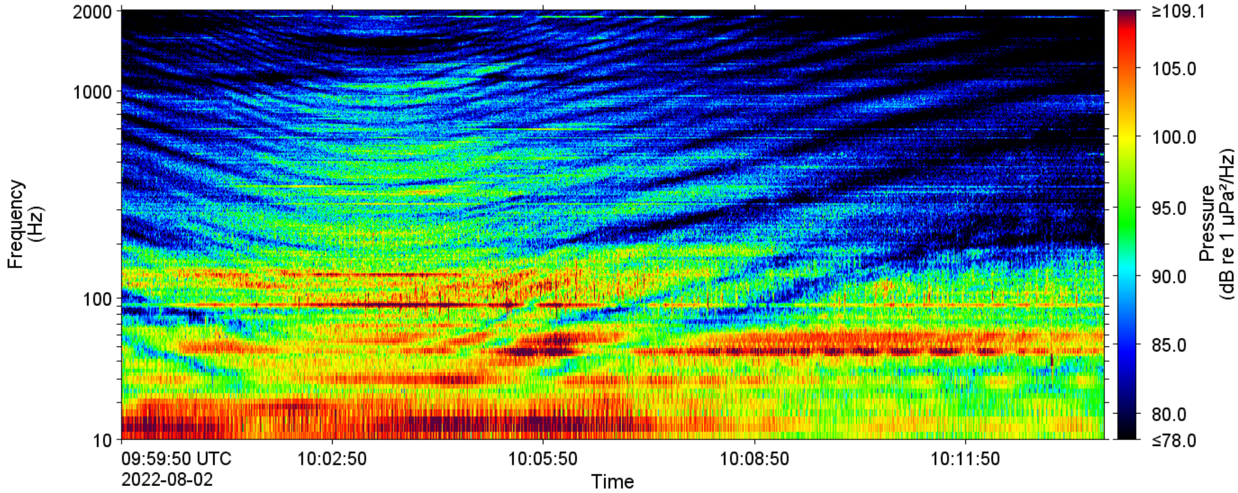


Figure 20. Example of vessel passing AMAR-WFE, recorded while the *Nordic Olympic* transited outbound at approximately 7.5 knots on 2 Aug 2022.

3.3. 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. 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 C) 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 21 through 23 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). There were no threshold exceedances at any of the three stations during the deployment period. The sound level increases occurring after ice breakup and during the onset of vessel traffic is also reflected in these figures.

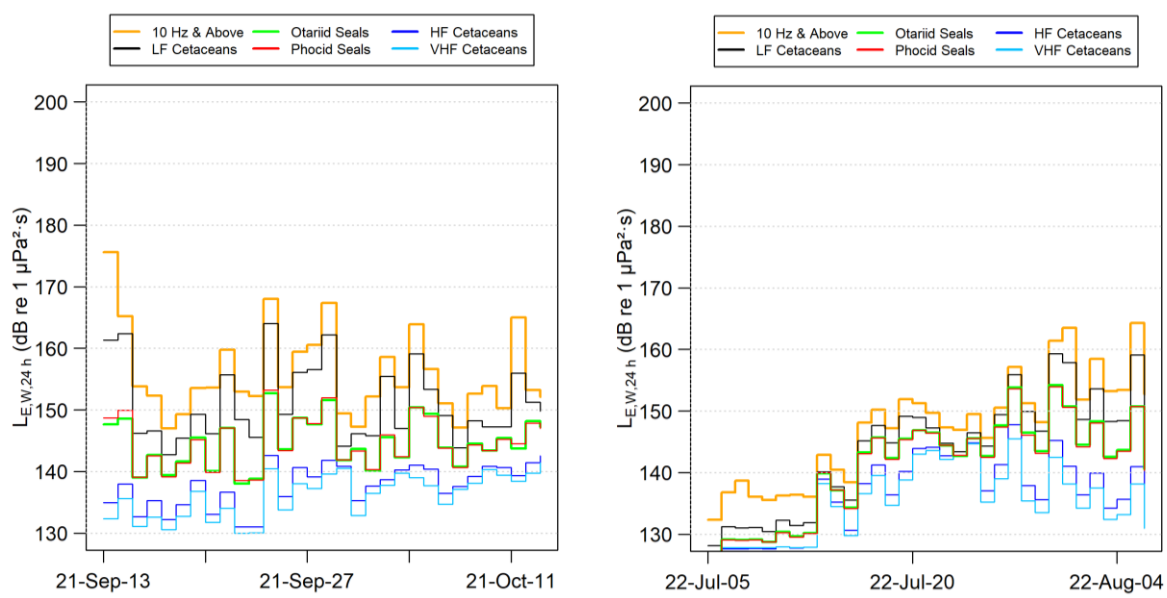


Figure 21. Daily sound exposure level (SEL) at AMAR-WFE.

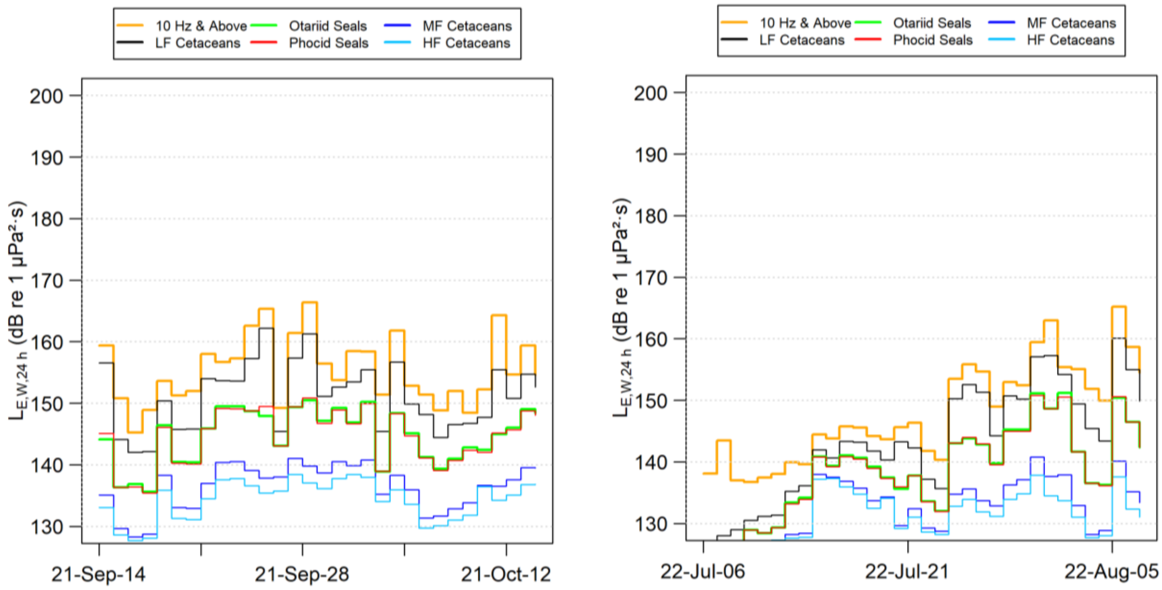


Figure 22. Daily sound exposure level (SEL) at AMAR-EFE.

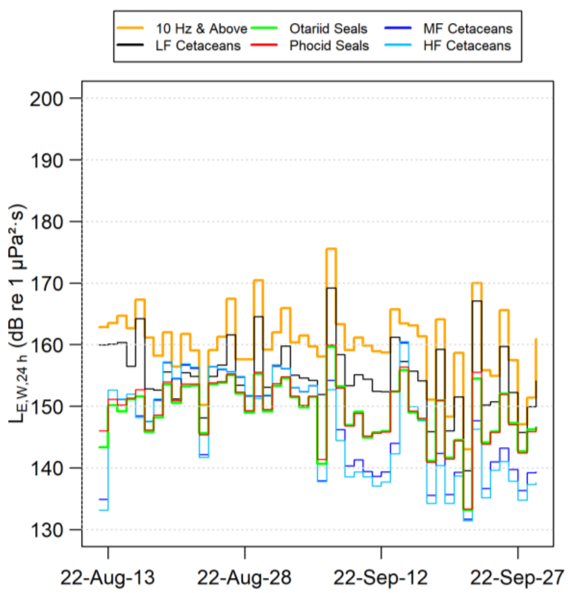


Figure 23. Daily sound exposure level (SEL) at AMAR-MI.

3.4. Listening Range Reduction

Listening Range Reduction (LRR) was calculated (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). Figures 24 through 26 present LRR results for recordings during the 2021 (Sep/Oct) and 2022 recording periods, showing the amount of LRR at each location during times with and without vessel noise detections, computed relative to the median ambient noise level from the recording period. Figures 27 through 29 show the % LRR at each location as a function of time. The time scale presented in these figures gives the impression that high percentages of LRR occur frequently throughout the recordings, however examining the data over the course of a single day, we see that high percentages of LRR occur for at most a few hours each day. As examples, plots of % LRR from AMAR-MI are provided for a day with low ambient sound levels during which a convoy of two ore carriers transited past the recorder (17 Sep 2022, Figure 30), and a day with some periods of elevated ambient sound levels when two ore carriers transited past the recorder separately at different times of the day (12 Sep 2022, Figure 31).

Table 7. Percent of recording minutes associated with >50 and >90 % listening range reduction (LRR) at each acoustic recorder location during the 2021 and 2022 acoustic monitoring periods.

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
2021	AMAR-EFE (Sep-Oct)	Ambient noise data	0.3	0.1	22.8	0.2	1.2	0.1
		Data with vessels detected	1.7	0.1	20.6	0.9	2.1	0.4
	AMAR-WFE (Sep-Oct)	Ambient noise data	0.7	0.1	22.6	0.4	19.5	2.5
		Data with vessels detected	1.1	0.1	20.7	0.9	14.2	1.9
2022	AMAR-MI (Aug-Sept)	Ambient noise data	0.2	0.0	20.8	0.7	28.6	14.9
		Data with vessels detected	5.9	1.1	18.1	2.4	24.2	9.6
	AMAR-EFE (July-Aug)	Ambient noise data	0.3	0.0	29.6	1.3	11.8	0.9
		Data with vessels detected	3.6	0.4	48.2	7.8	13.5	1.0
	AMAR-WFE (July-Aug)	Ambient noise data	0.2	0.0	28.9	0.9	20.0	3.3
		Data with vessels detected	3.2	0.5	26.1	3.1	7.3	1.3

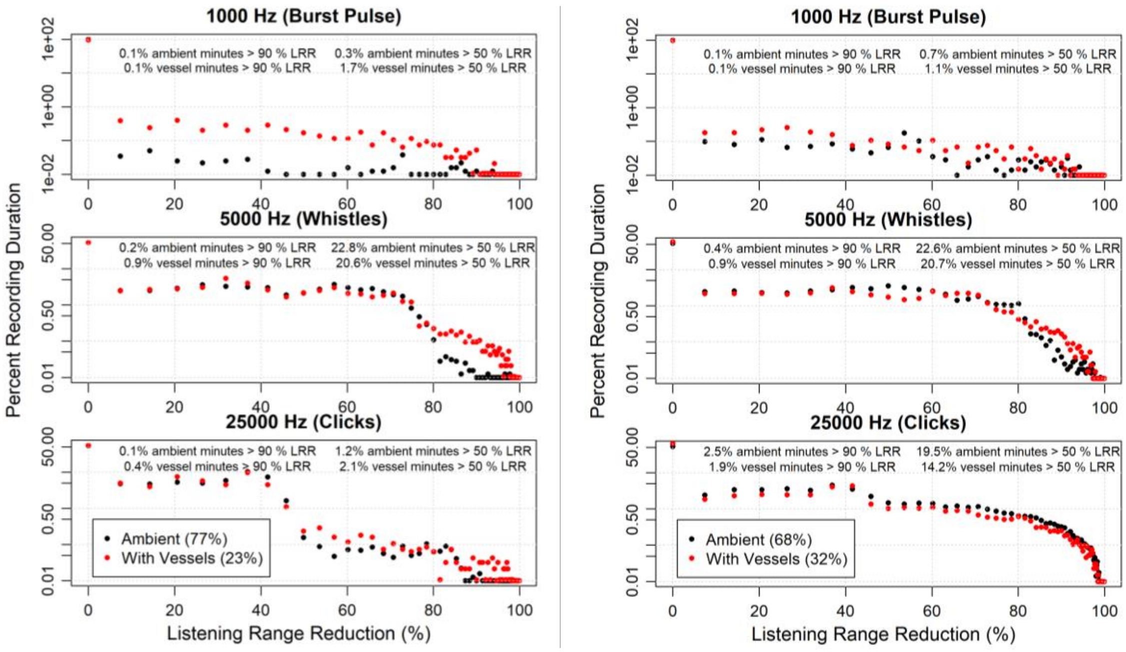


Figure 24. Sep-Oct 2021: Listening range reduction (LRR) for the three considered frequencies at (left) AMAR-EFE and (right) AMAR-WFE. For each station, the top figure shows LRR for the 1 kHz decidecade band, which is representative of burst pulses, the middle figure shows LRR for the 5 kHz decidecade 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.

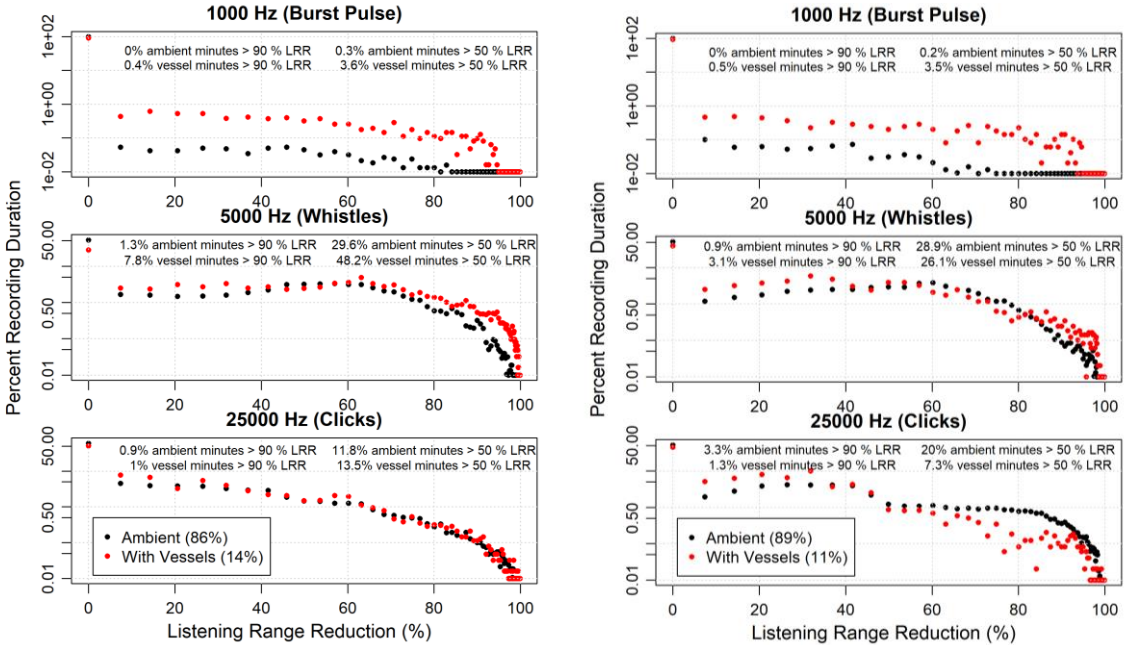


Figure 25. Jul-Aug 2022: Listening range reduction (LRR) for the three considered frequencies at (left) AMAR-EFE and (right) AMAR-WFE. For each station, the top figure shows LRR for the 1 kHz decidecade band, which is representative of burst pulses, the middle figure shows LRR for the 5 kHz decidecade 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.

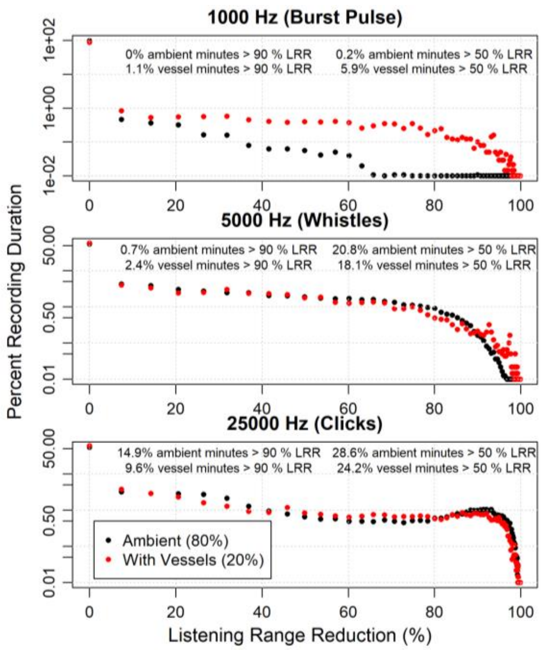


Figure 26. Aug-Sep 2022: Listening range reduction (LRR) for the three considered frequencies at AMAR-MI. The top figure shows LRR for the 1 kHz decidecade band, which is representative of burst pulses, the middle figure shows LRR for the 5 kHz decidecade band, which is representative of listening for 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.

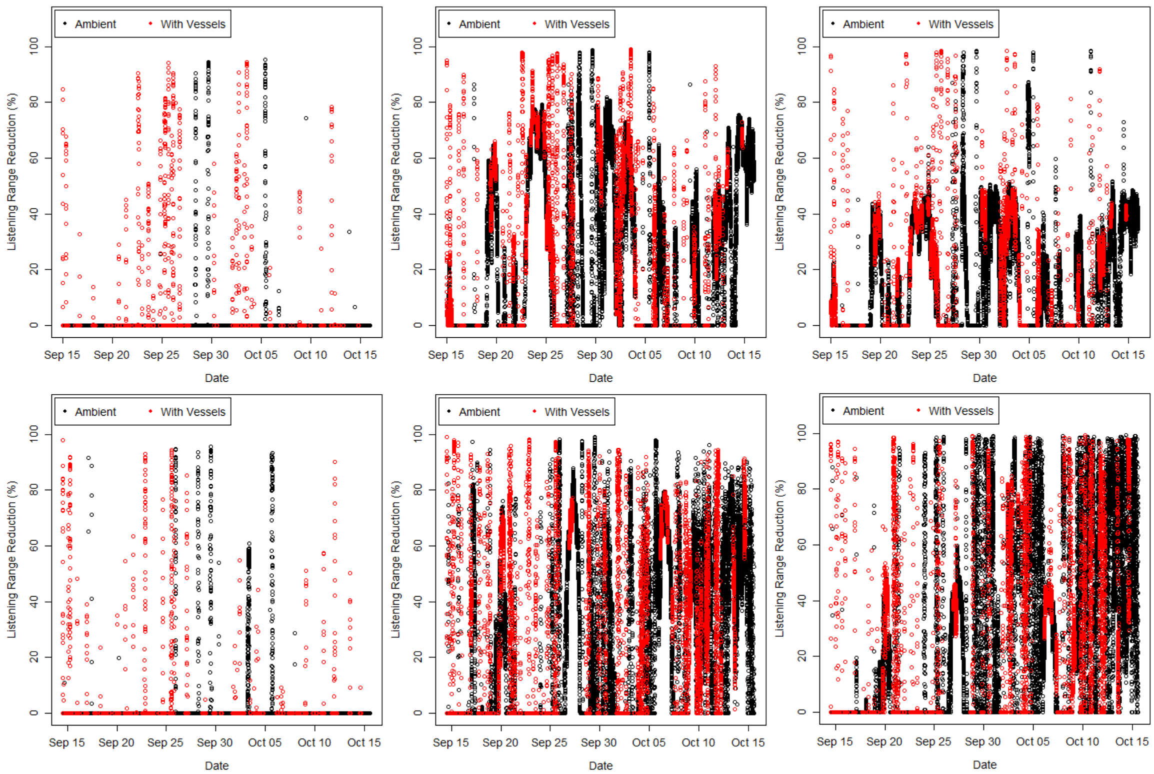


Figure 27. Sep-Oct 2021: Listening Range Reduction over time for the three considered frequencies at (top row) AMAR-EFE and (bottom row) AMAR-WFE. For each station, the left figure shows LRR for the 1 kHz decidecade band, which is representative of burst pulses, the middle figure shows LRR for the 5 kHz decidecade band, which is representative of listening for whistles and knocks, and the right 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).

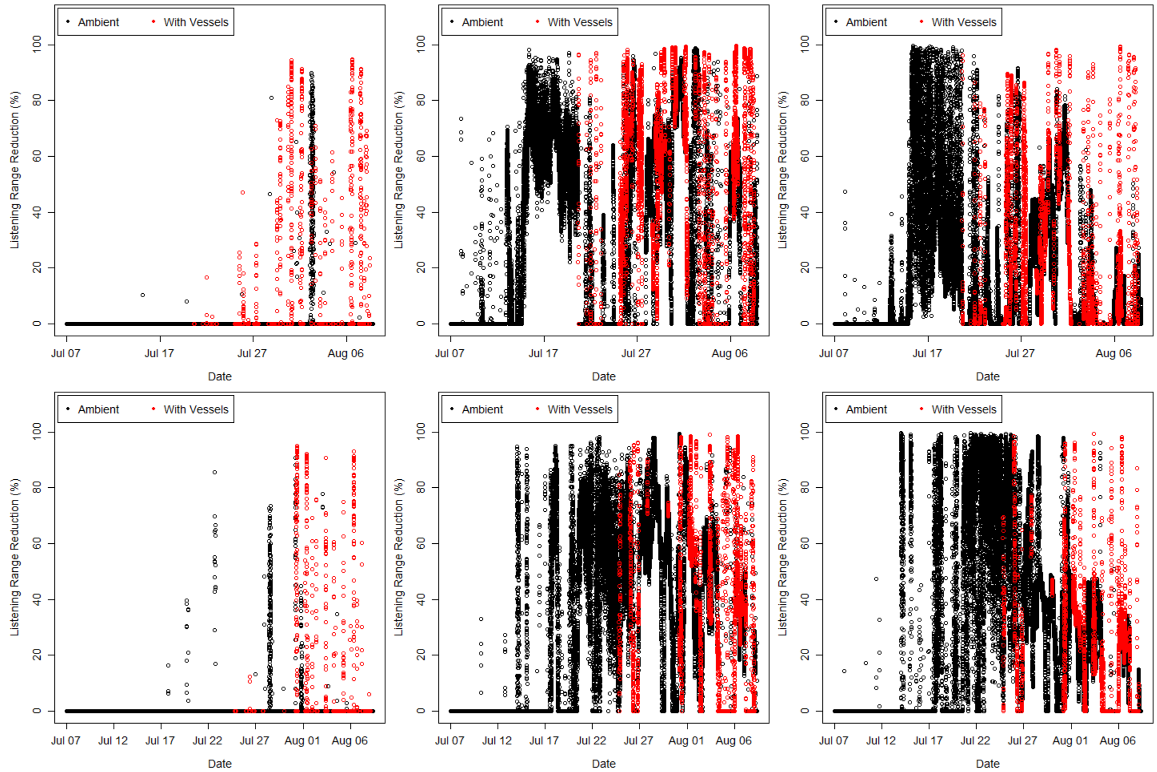


Figure 28. Jul-Aug 2022: Listening Range Reduction over time for the three considered frequencies at (top row) AMAR-EFE and (bottom row) AMAR-WFE. For each station, the left figure shows LRR for the 1 kHz decidecade band, which is representative of burst pulses, the middle figure shows LRR for the 5 kHz decidecade band, which is representative of listening for whistles and knocks, and the right 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). Non-Project vessels entered the Regional Study Area on 21 Jul and Baffinland vessels entered on 31 Jul 2022.

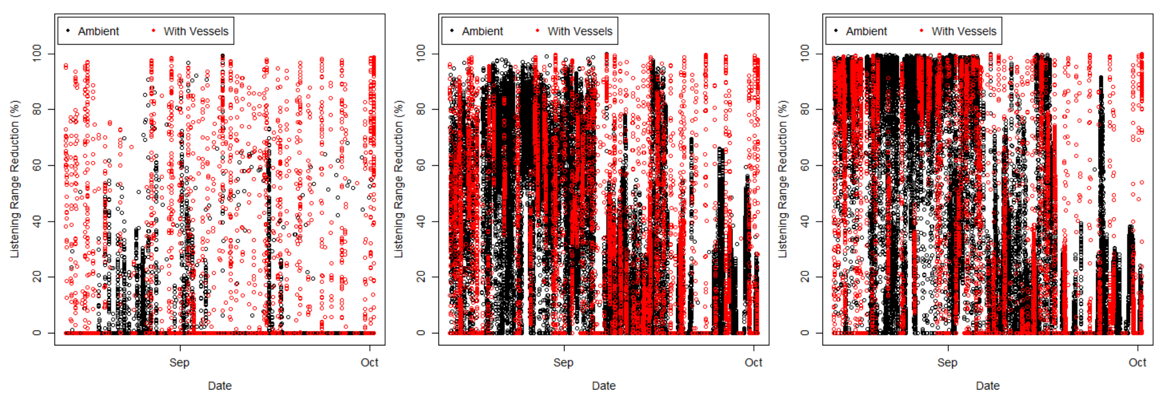


Figure 29. Aug-Sep 2022: Listening Range Reduction over time for the three considered frequencies at AMAR-MI. For each station, the left figure shows LRR for the 1 kHz decidecade band, which is representative of burst pulses, the middle figure shows LRR for the 5 kHz decidecade band, which is representative of listening for whistles and knocks, and the right 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). Recordings began on 13 Aug 2022.

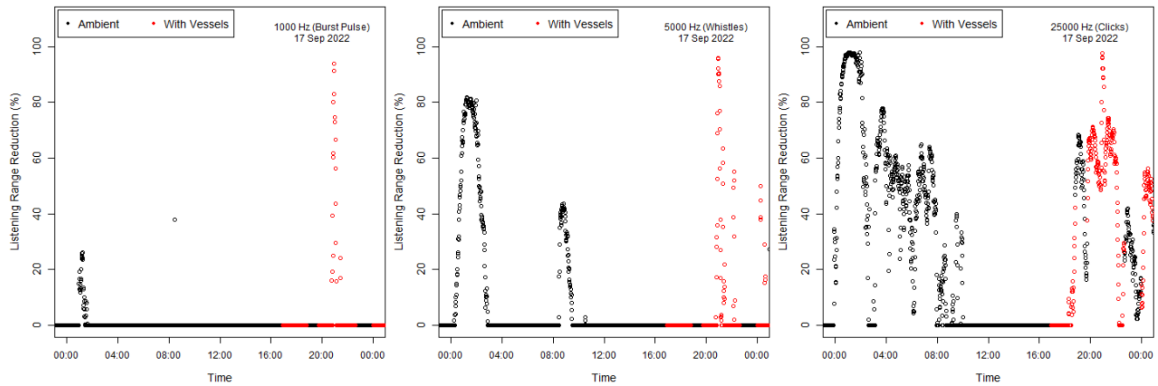


Figure 30. 17 Sep 2022: Listening Range Reduction over time for the three considered frequencies at AMAR-MI on a day when a convoy of the ore carrier *Golden Diamond* and cargo vessel *Rosaire A. Desgagnes* transited outbound past the recorder, closest point of approach to the recorder at 21:00 UTC. The left figure shows LRR for the 1 kHz decidecade band, which is representative of burst pulses, the middle figure shows LRR for the 5 kHz decidecade band, which is representative of listening for whistles and knocks, and the right 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).

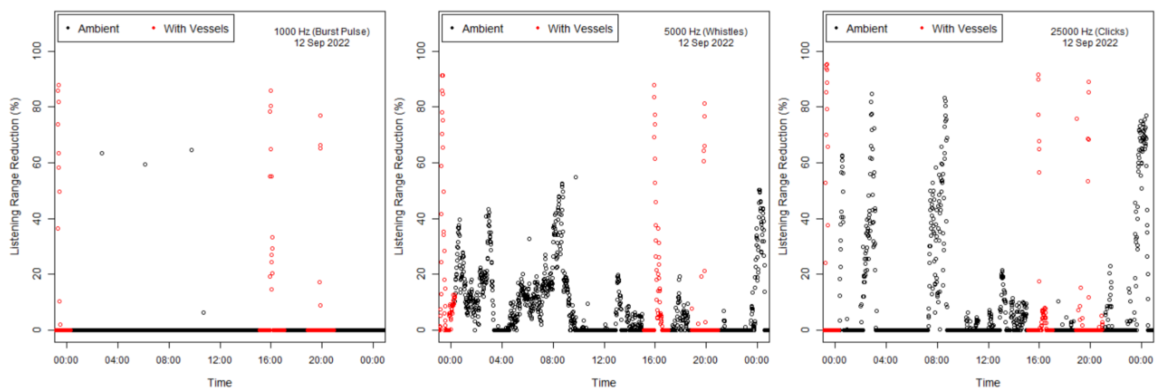


Figure 31. 12 Sep 2022: Listening Range Reduction over time for the three considered frequencies at AMAR-MI on a day when two ore carriers transited past the recorder, with closest points of approach to the recorder at 15:40 (*Nordic Oshima* transiting outbound) and 19:30 (*Nordic Qinngua* transiting inbound) UTC (a third ore carrier, the *Nordic Odyssey*, had passed the recorder going inbound at 23:00 UTC the night prior resulting in a small amount of LRR around 00:00 on 12 Sep as well). The left figure shows LRR for the 1 kHz decidecade band, which is representative of burst pulses, the middle figure shows LRR for the 5 kHz decidecade band, which is representative of listening for whistles and knocks, and the right 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).

3.5. Marine Mammals

The acoustic presence of marine mammals was identified automatically by JASCO's detectors and validated via the manual review of 2 % of the data (see Section 2.3), which represented 635 sound files, or ~85 h of data (4.1 h worth of 1-min 512 kHz sound files, 57.2 h worth of 14-min 64 kHz sound files, and 23.7 h worth of 10-min 128 kHz sound files). Both the automated detectors and analysts found acoustic signals of beluga, bowhead whale, narwhal, sperm whale, and bearded seal. In addition to these species, signals potentially produced by killer whales and ringed seals were detected. 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 E. Where automated detectors did not perform well ($P < 0.75$) or there were too few manual detections to calculate automated detector performance metrics, only manual detections are presented below.

3.5.1. Beluga Whales

Using the methods described in Section 2.4.4 to differentiate between narwhal and beluga during manual analysis, beluga acoustic signals were suspected on several occasions in the data. The methodology for detecting beluga clicks amongst narwhal (for example, Figure 32, where beluga clicks are higher frequency) is believed to be more robust and consistent, whereas the detection of whistles (see for example, Figure 33) should be considered less reliable. For this reason, we describe beluga whistle occurrence both as manual detections considered possible beluga whistles (purple in results figures), which occurred throughout the data, and as manual detections considered confirmed beluga whistles (black in results figures), where analysts were more confident in their classification. Possible whistle detections were instances where a file contained whistles that resembled both those of narwhal and beluga. These are included in the narwhal results section as true whistle detections, while here they are possible beluga. Manual whistle detections are instances where the whistles in a file were suspected of being from beluga, rather than narwhal, due to their pure tone, bird-like sound, and prolific occurrence.

Beluga clicks were detected in 2021 on one day at AMAR-EFE (11 Oct) and sporadically through October at WFE (Figure 34). Beluga whistles followed this trend somewhat and were not detected at AMAR-EFE in 2021 but were present at AMAR-WFE (Figure 35). In 2022, Beluga clicks were detected in mid-July at AMAR-EFE (manual detections 16–18 Jul) and in late July at AMAR-WFE (manual detections 22–25 Jul) (Figure 36). These pulses in detections at AMAR-EFE and AMAR-WFE may have recorded animals enroute to Milne Inlet. Indeed, over 100 beluga whales were counted in Milne Inlet (specifically, Assomption Harbour) in late July 2022 via aerial surveys) with visual detections on 26–27 Jul 2022 (WSP Canada Inc. 2023a, 2023b). Whistles were suspected (manual detections) at AMAR-EFE on 12 Jul and AMAR-WFE on 23 Jul, somewhat following the occurrence pattern of beluga clicks (Figure 37). At AMAR-MI, beluga whistles were suspected throughout much of the recording period until mid September (Figure 38). Though, being unable to detect clicks at AMAR-MI (given the sampling rate) our ability to detect beluga here was limited. Beluga whales were known to remain present in the region, at least until mid-August 2022 as they were observed around 9-11 Aug (WSP Canada Inc. 2023b).

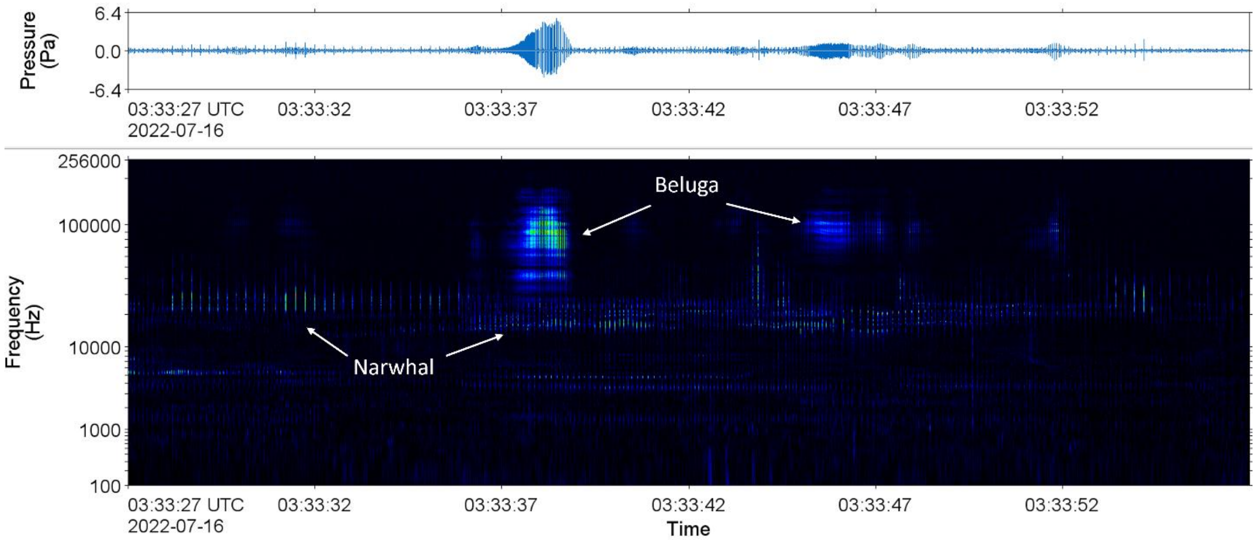


Figure 32. (Top) Waveform and (bottom) spectrogram of clicks believed to be produced by narwhal and beluga, as labelled. Data were recorded on 16 Jul 2022 at AMAR-EFE (64 Hz discrete Fourier Transform (DFT) frequency step, 0.01 s DFT temporal observation window (TOW), 0.005 s DFT time advance, and Hamming window resulting in a 50 % overlap and DFT size (N_{DFT}) of 2048, normalized across time, 30 s of data).

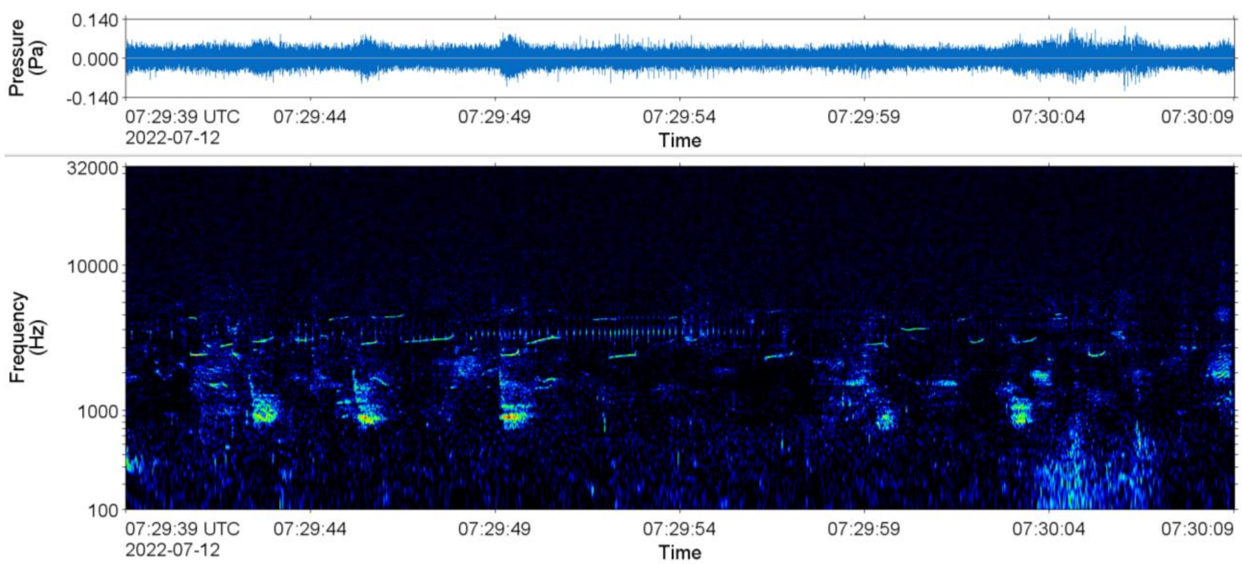


Figure 33. (Top) Waveform and (bottom) spectrogram depicting tonal whistles that occurred so frequently that beluga whales were possibly present. Data were recorded on 7 Jul 2022 at AMAR-EFE (64 Hz discrete Fourier Transform (DFT) frequency step, 0.01 s DFT temporal observation window (TOW), 0.005 s DFT time advance, and Hamming window resulting in a 50 % overlap and DFT size (N_{DFT}) of 2048, normalized across time, 30 s of data).

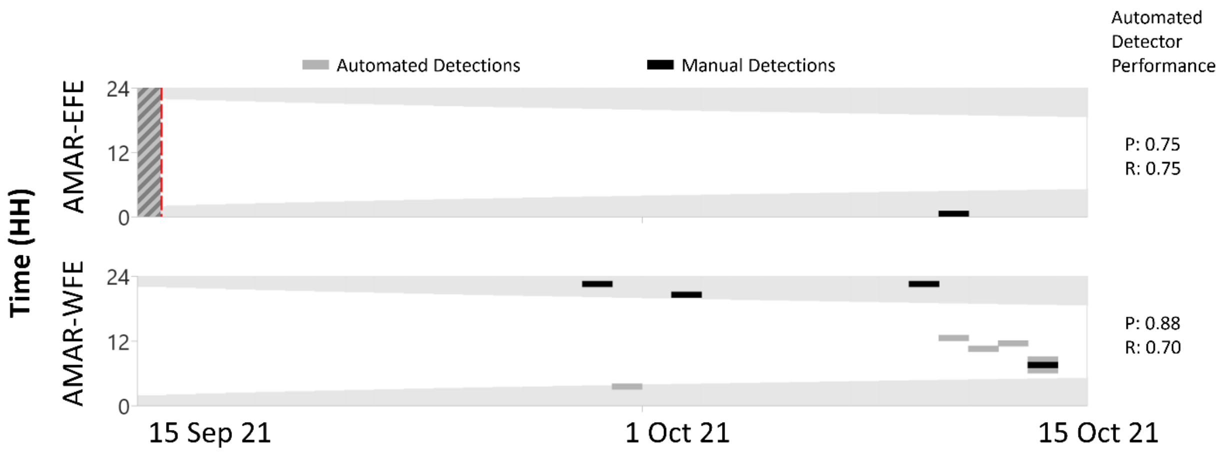


Figure 34. Hours per day with beluga click detections from 14 Sep to 15 Oct 2021. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. Performance metrics were calculated per-station and represent a detector's performance across both September to October 2021 and July to August 2022. The light grey 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 Beluga click detector.

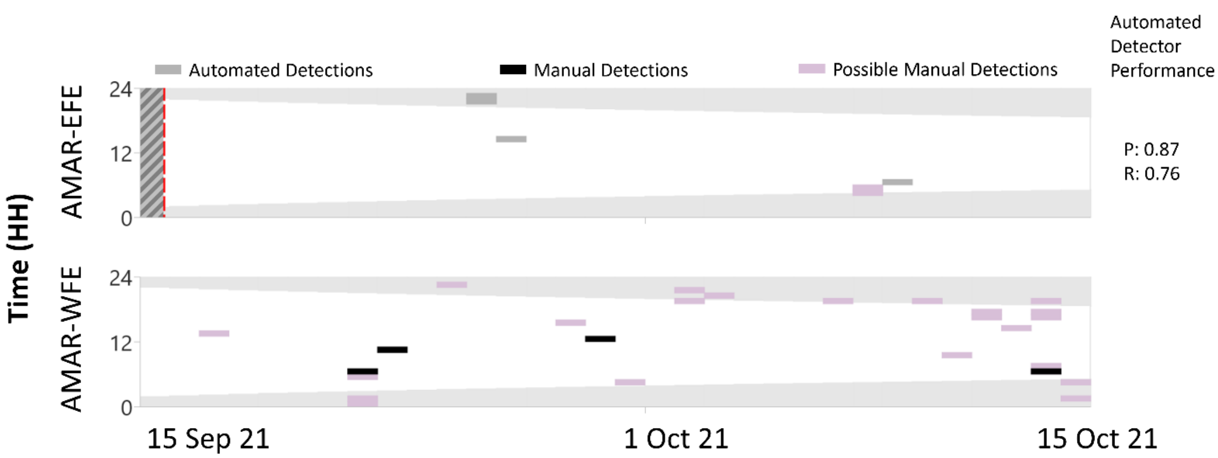


Figure 35. Hours per day with beluga whistle detections from 14 Sep to 15 Oct 2021. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. Performance metrics were calculated per-station and represent a detector's performance across both September to October 2021 and July to August 2022. The light grey 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 LowWhistleSupp detector.

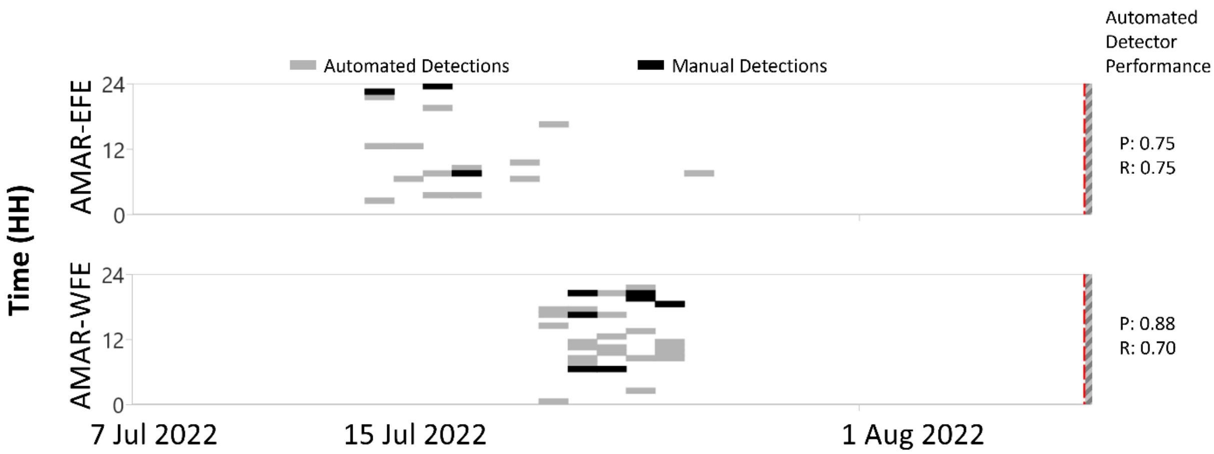


Figure 36. Hours per day with beluga click detections from 7 Jul to 8 Aug 2022. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. Performance metrics were calculated per-station and represent a detector's performance across both September to October 2021 and July to August 2022. There were no hours of darkness (sunset to sunrise) during this timeframe (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the Beluga click detector.

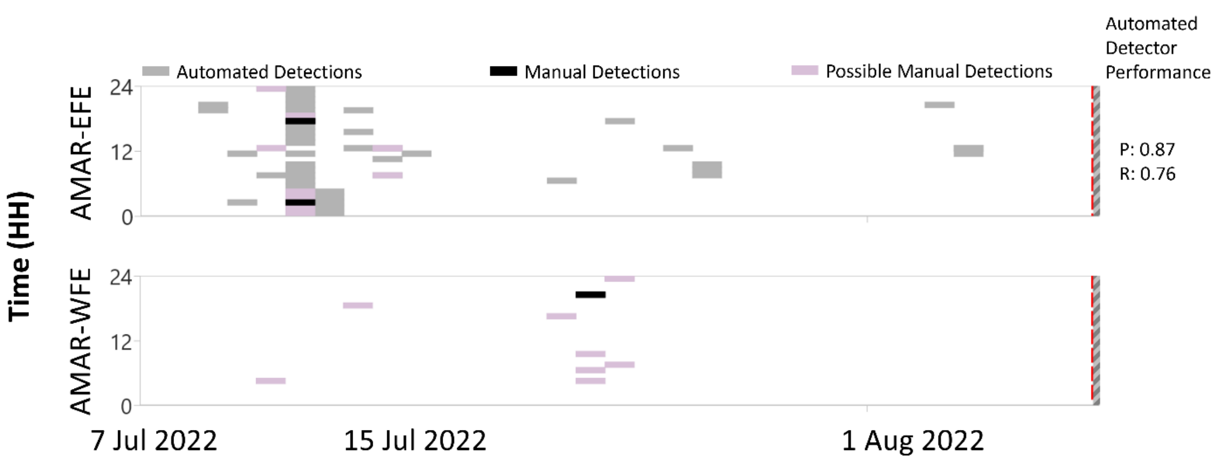


Figure 37. Hours per day with beluga whistle detections from 7 Jul to 8 Aug 2022. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. Performance metrics were calculated per-station and represent a detector's performance across both September to October 2021 and July to August 2022. There were no hours of darkness (sunset to sunrise) during this timeframe (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the LowWhistleSupp detector.

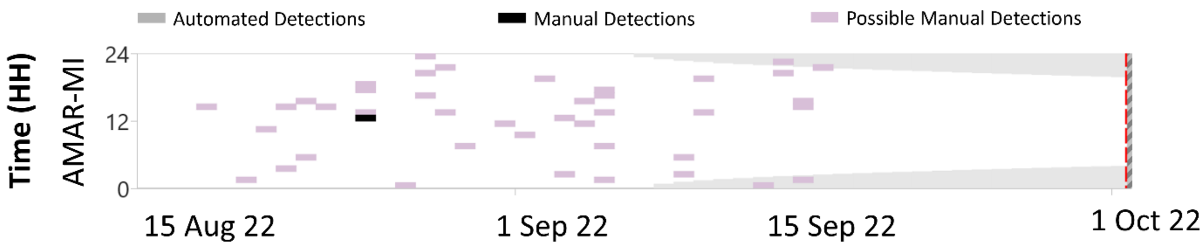


Figure 38. Hours per day with beluga whistle detections from 13 Aug to 1 Oct 2022. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The light grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the LowWhistleSupp detector.

3.5.2. Bowhead Whales

Bowhead whale moans (Figure 39) were present in the acoustic data and an automated detector performed sufficiently well at AMAR-WFE to include the results here. Detections were of non-song moans. In addition, some 'gunshot' sounds were identified that may have been produced by bowhead whales (Figure 39). In Sep/Oct 2021, bowhead whale vocalizations were only detected on one day (15 Oct) at AMAR-EFE but were common at AMAR-WFE (Figure 40; present on 18 days between 14 Sep and 15 Oct). In summer 2022, signals were detected on seven days at AMAR-EFE between 15 and 23 Jul, while at AMAR-WFE detections occurred over four days from 21 to 24 Jul (Figure 41). At AMAR-MI, bowhead whale vocalizations were manually detected from 13 Aug to 14 Sep (Figure 42). These acoustic detections are supported by visual sightings at the nearby Bruce Head between 7 and 20 Aug 2022 (WSP Canada Inc. 2023b).

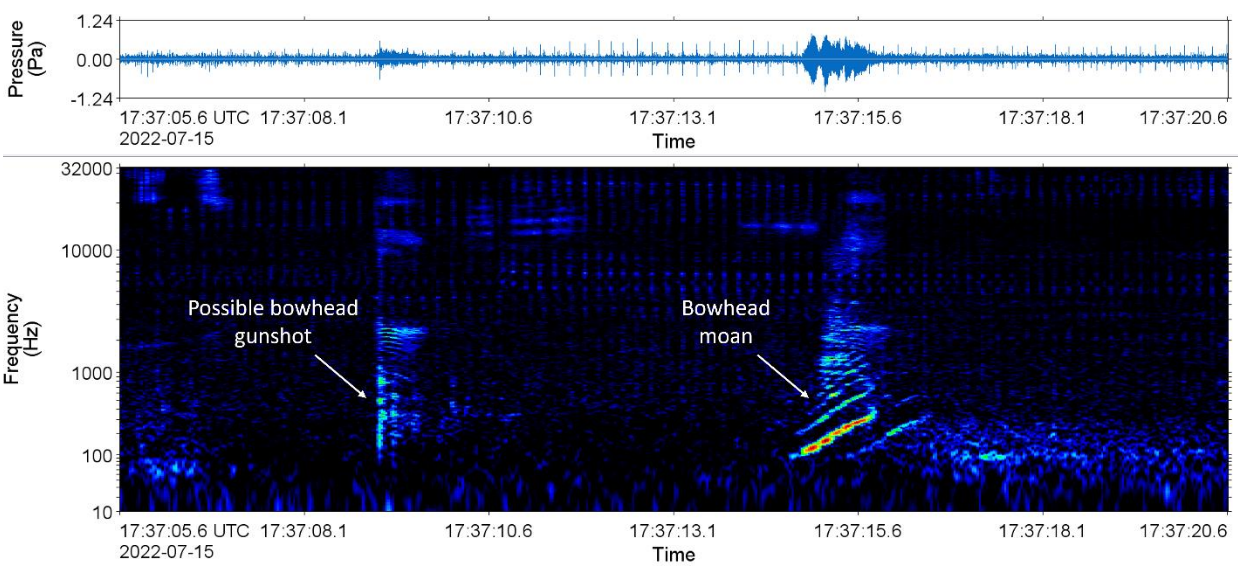


Figure 39. (Top) Waveform and (bottom) spectrogram of a bowhead whale moan recorded on 15 Jul 2022 at AMAR-EFE (2 Hz discrete Fourier Transform (DFT) frequency step, 0.2 s DFT temporal observation window (TOW), 0.02 s DFT time advance, and Hamming window resulting in a 75 % overlap and DFT size (N_{DFT}) of 65536, normalized across time, 30 s of data).

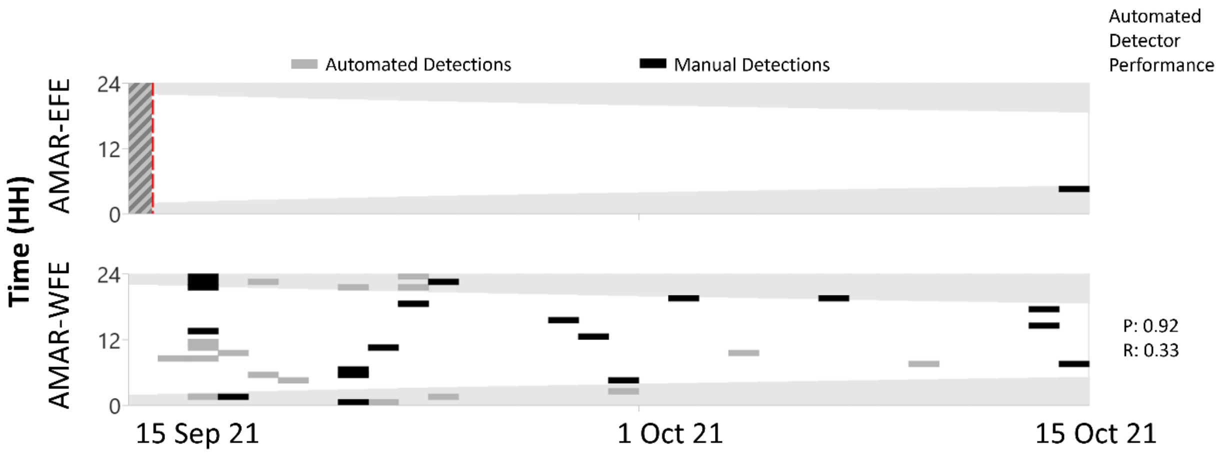


Figure 40. Hours per day with bowhead whale moan detections at each station through the recording period from 14 Sep to 15 Oct 2021. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included along right side. Performance metrics were calculated per-station and represent a detector's performance across both September to October 2021 and July to August 2022. The light grey 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 HighThreshold detector.

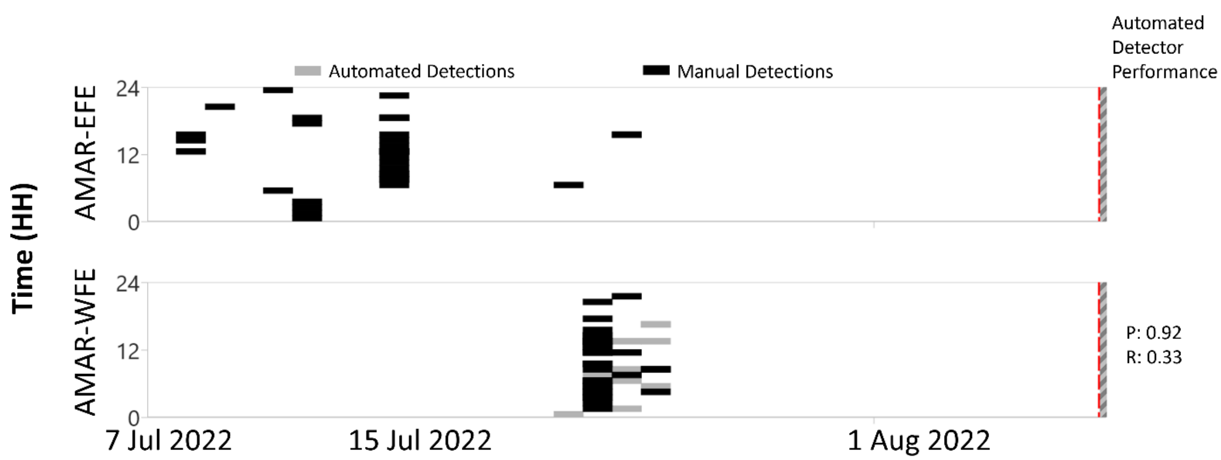


Figure 41. Hours per day with bowhead whale moan detections at each station through the recording period from 7 Jul to 8 Aug 2022. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included along right side. Performance metrics were calculated per-station and represent a detector's performance across both September to October 2021 and July to August 2022. There were no hours of darkness (sunset to sunrise) during this timeframe (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the MFMoanLow HighThreshold detector.

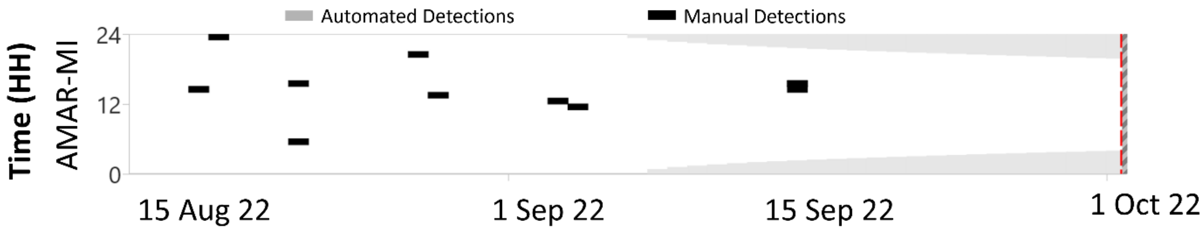


Figure 42. Hours per day with bowhead whale moan detections at each station through the recording period from 13 Aug to 1 Oct 2022. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included along right side. The light grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data.

3.5.3. Killer Whales

During manual analysis, a few whistles were highlighted that may have been produced by killer whales, but their presence could not be confirmed in the acoustic data. We do not have a systematic way to differentiate killer whale clicks from those of narwhal; therefore, killer whale clicks may have occasionally been misclassified as narwhal during analysis of the 512 kHz data. Nevertheless, this species was rare or absent in the present acoustic data set. Possible killer whale whistle detections were made at AMAR-WFE on 15 Oct 2021 and 23 Jul 2022 and at AMAR-EFE on 12 and 15 Jul 2022. The species was visually sighted near Pond Inlet (between AMAR-WFE and AMAR-EFE) on 26 Jul and 8 Aug 2022 (Genevieve Morinville, personal communication, March 2023).

3.5.4. Narwhal

Five call types were detected for narwhal as defined in Section 2.3: echolocation click (Section 3.5.4.1; Figure 32), high-frequency buzz (Section 3.5.4.2; Figure 43), low-frequency buzz (Section 3.5.4.3; Figure 44), knock (Section 3.5.4.4; Figure 45), and whistle (Section 3.5.4.5; Figure 44). The data sampled at 512 kHz at AMAR-EFE and AMAR-WFE were used to detect echolocation clicks, while the data sampled at 64 kHz at AMAR-EFE and AMAR-WFE and the data sampled at 128 kHz at AMAR-MI were used to identify the remaining call types. At AMAR-MI, all clicks above 10 kHz were assumed to be narwhal clicks as the sampling rate did not allow for the more detailed click analysis performed on the 512 kHz data.

Narwhal acoustic occurrence was generally the same across call types. In fall 2021, narwhal were present (manually confirmed) at AMAR-EFE from 11 to 15 Oct and at AMAR-WFE throughout the recording period, with the first manual detection on 21 Sep. In summer 2022, narwhal acoustic occurrence at the floe edge stations occurred in pulses with the animals most common at AMAR-EFE (manual detections 8 to 21 Jul) a few days prior to AMAR-WFE (manual detections 14 to 26 Jul). At AMAR-MI, narwhal were acoustically common from the start of the recording (14 Aug 2022) through to 17 Sep 2022, after which narwhal were not manually verified (Section 3.5.4.1 to 3.5.4.5).

When interpretting these results, we consider that beluga can produce many of these call types. Given the known predominance of narwhal in the region, most are assumed to be narwhal. Our differentiation of these two species based on click characteristics further supports the assertion that narwhal were much more common.

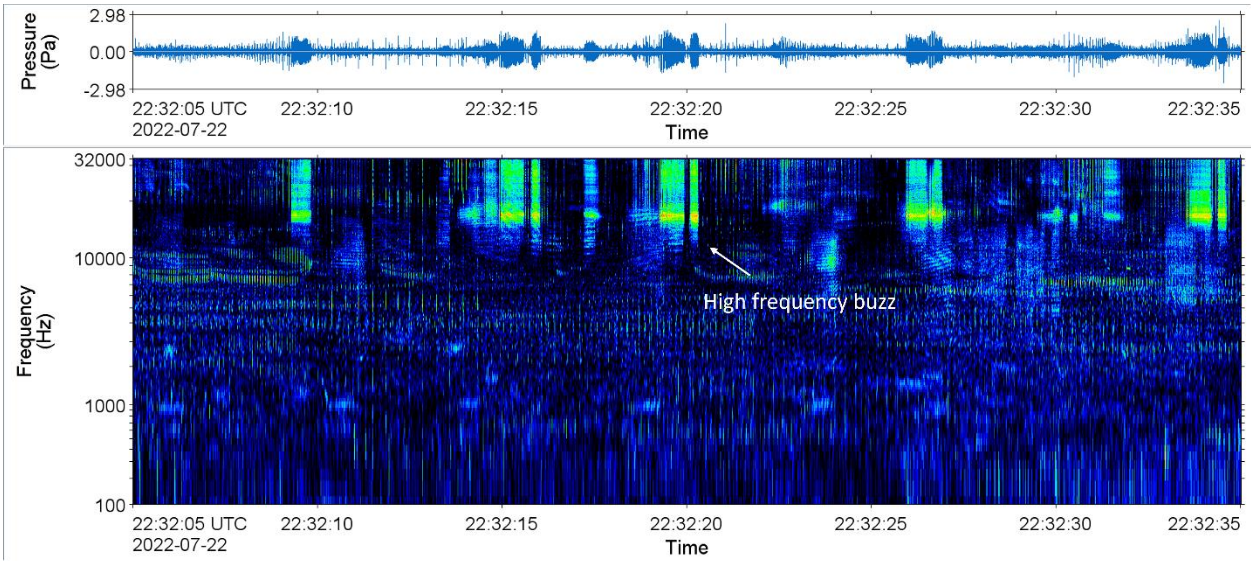


Figure 43. (Top) Waveform and (bottom) spectrogram of narwhal high-frequency buzzes, above 10 kHz, recorded on 22 Jul 2022 at AMAR-WFE (64 Hz discrete Fourier Transform (DFT) frequency step, 0.01 s DFT temporal observation window (TOW), 0.005 s DFT time advance, and Hamming window resulting in a 50 % overlap and DFT size (N_{DFT}) of 2048, normalized across time, 30 s of data).

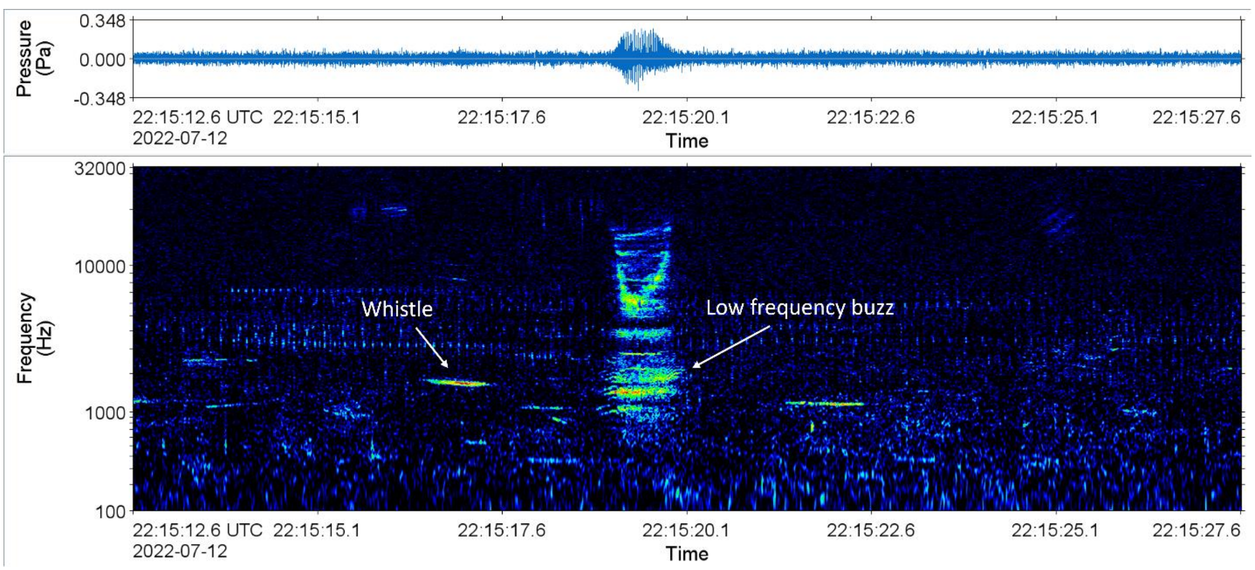


Figure 44. (Top) Waveform and (bottom) spectrogram of a narwhal low-frequency buzz along with tonal whistles recorded on 12 Jul 2022 at AMAR-WFE (64 Hz discrete Fourier Transform (DFT) frequency step, 0.01 s DFT temporal observation window (TOW), 0.005 s DFT time advance, and Hamming window resulting in a 50 % overlap and DFT size (N_{DFT}) of 2048, normalized across time, 15 s of data).

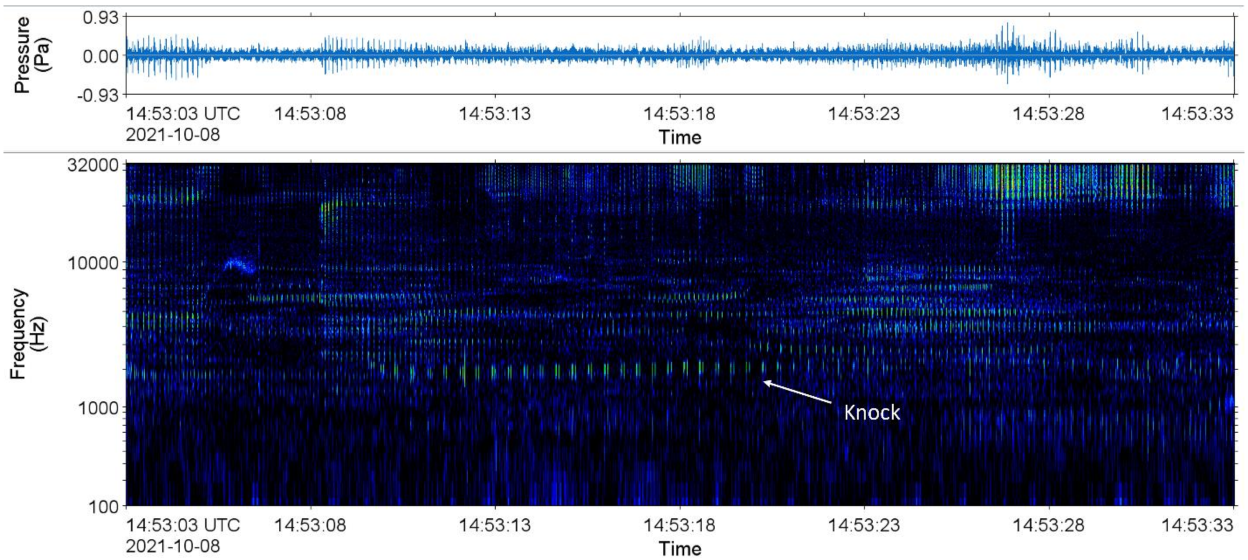


Figure 45. (Top) Waveform and (bottom) spectrogram of narwhal knocks, centered at 2 kHz, recorded on 8 Oct 2021 at AMAR-WFE (64 Hz discrete Fourier Transform (DFT) frequency step, 0.01 s DFT temporal observation window (TOW), 0.005 s DFT time advance, and Hamming window resulting in a 50 % overlap and DFT size (N_{DFT}) of 2048, normalized across time, 30 s of data).

3.5.4.1. Echolocation Clicks

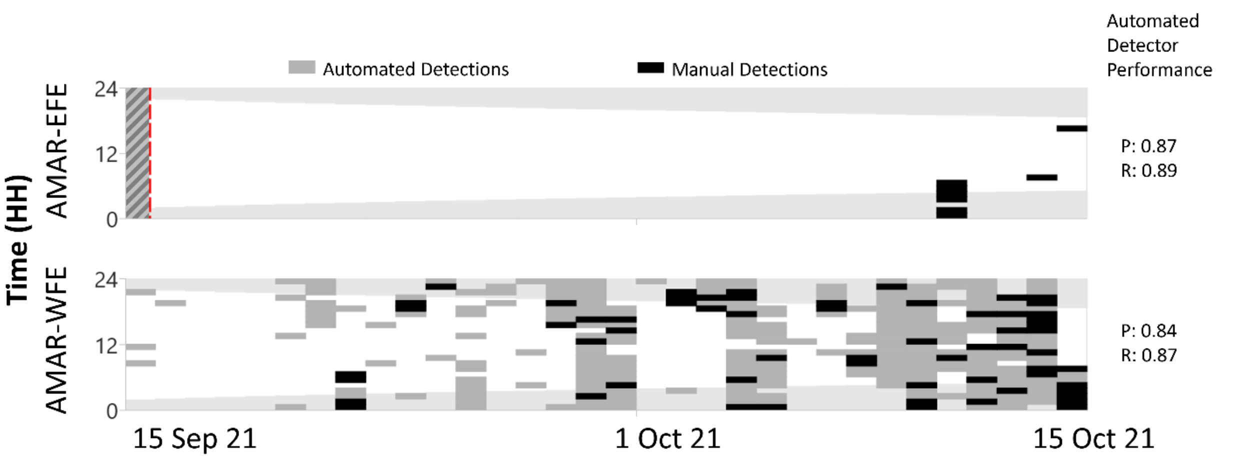


Figure 46. Hours per day with narwhal echolocation click detections at each station through the recording period from 14 Sep to 15 Oct 2021. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. Performance metrics were calculated per-station and represent a detector's performance across both September to October 2021 and July to August 2022. The light grey 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.

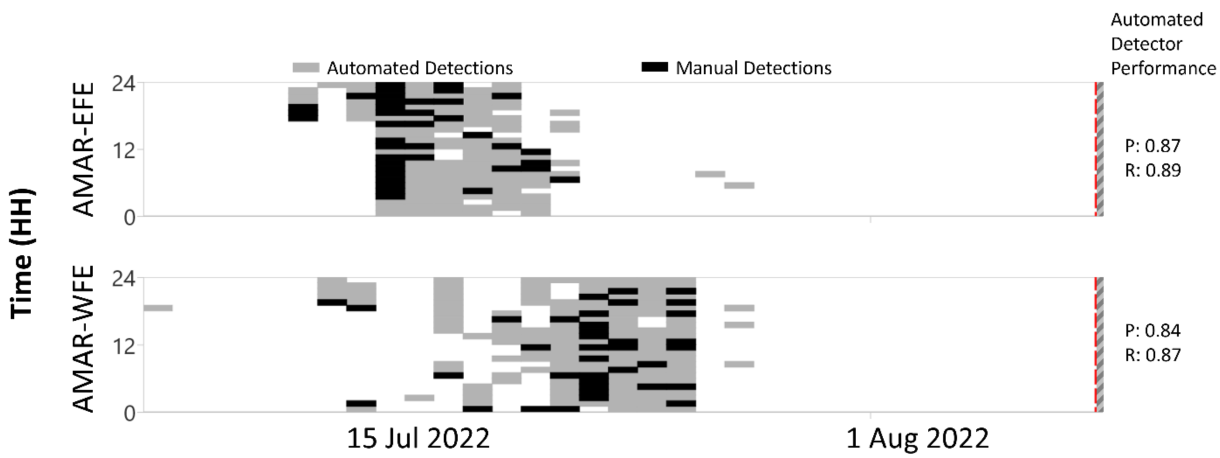


Figure 47. Hours per day with narwhal echolocation click detections at each station through the recording period from 7 Jul to 8 Aug 2022. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. Performance metrics were calculated per-station and represent a detector's performance across both September to October 2021 and July to August 2022. There were no hours of darkness (sunset to sunrise) during this timeframe (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the Narwhal Click detector.

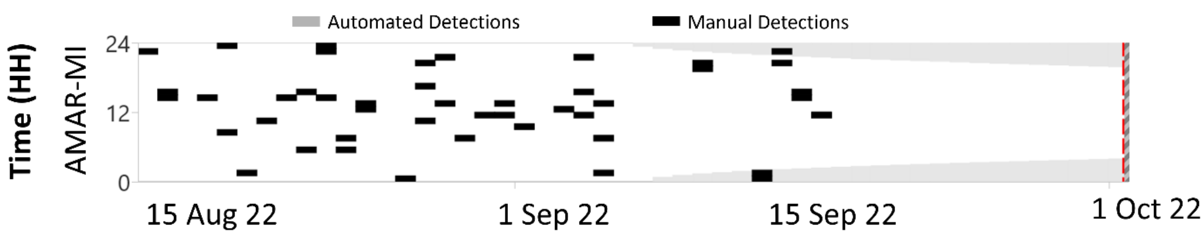


Figure 48. Hours per day with narwhal echolocation click detections at each station through the recording period from 13 Aug to 1 Oct 2022. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The light grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data.

3.5.4.2. High-frequency Buzzes

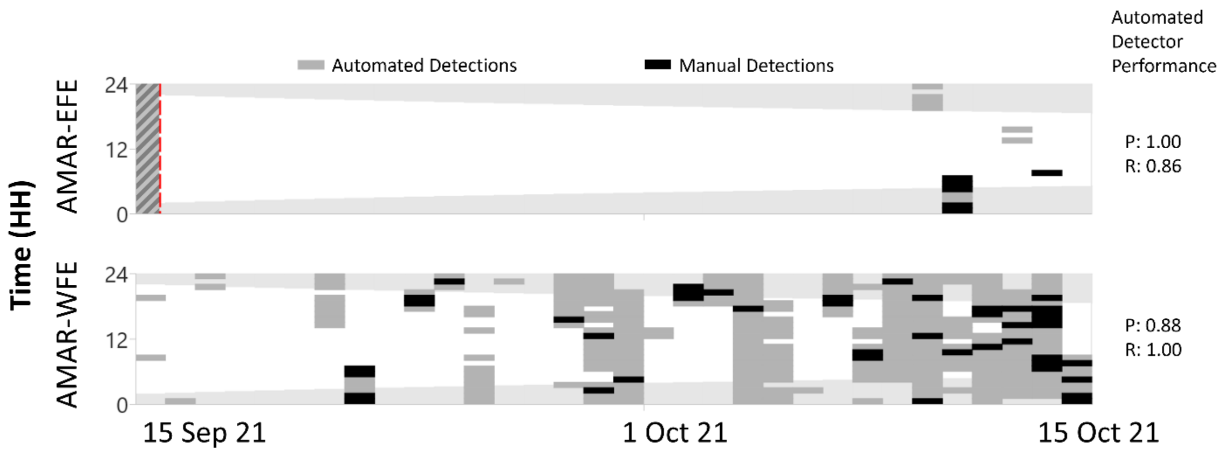


Figure 49. Hours per day with narwhal high-frequency buzz detections at each station through the recording period from 14 Sep to 15 Oct 2021. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. Performance metrics were calculated per-station and represent a detector's performance across both September to October 2021 and July to August 2022. The light grey 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 50. Hours per day with narwhal high-frequency buzz detections at each station through the recording period from 7 Jul to 8 Aug 2022. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. Performance metrics were calculated per-station and represent a detector's performance across both September to October 2021 and July to August 2022. There were no hours of darkness (sunset to sunrise) during this timeframe (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the Narwhal_HFbuzz detector.

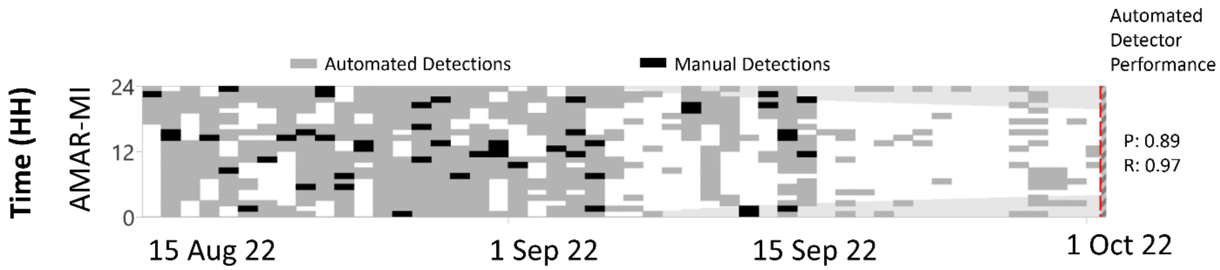


Figure 51. Hours per day with narwhal high-frequency buzz detections at each station through the recording period from 13 Aug to 1 Oct 2022. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. Performance metrics were calculated per-station and represent a detector's performance across both September to October 2021 and July to August 2022. The light grey 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.

3.5.4.3. Low-frequency Buzzes

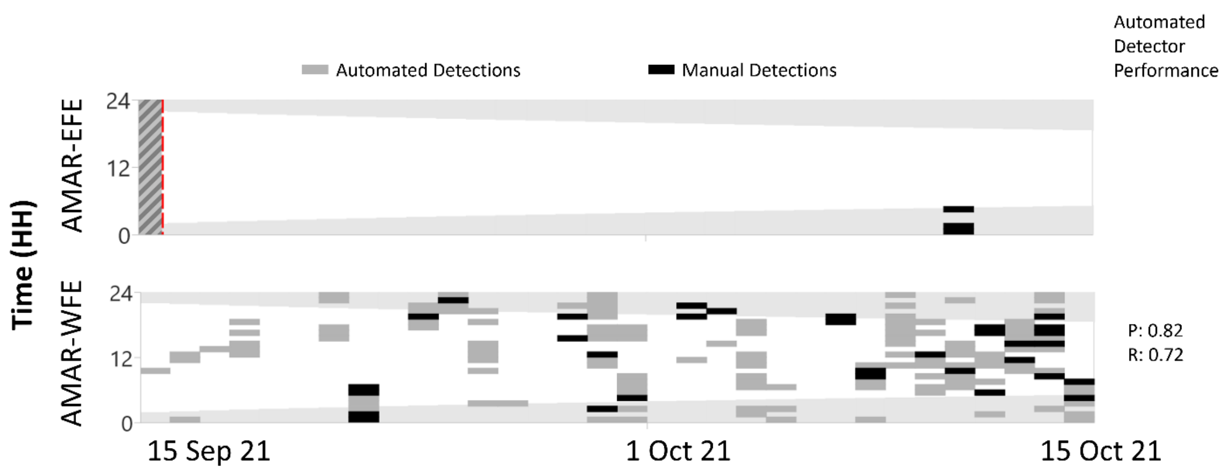


Figure 52. Hours per day with narwhal low- frequency buzz detections at each station through the recording period from 14 Sep to 15 Oct 2021. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. Performance metrics were calculated per-station and represent a detector's performance across both September to October 2021 and July to August 2022. The light grey 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.

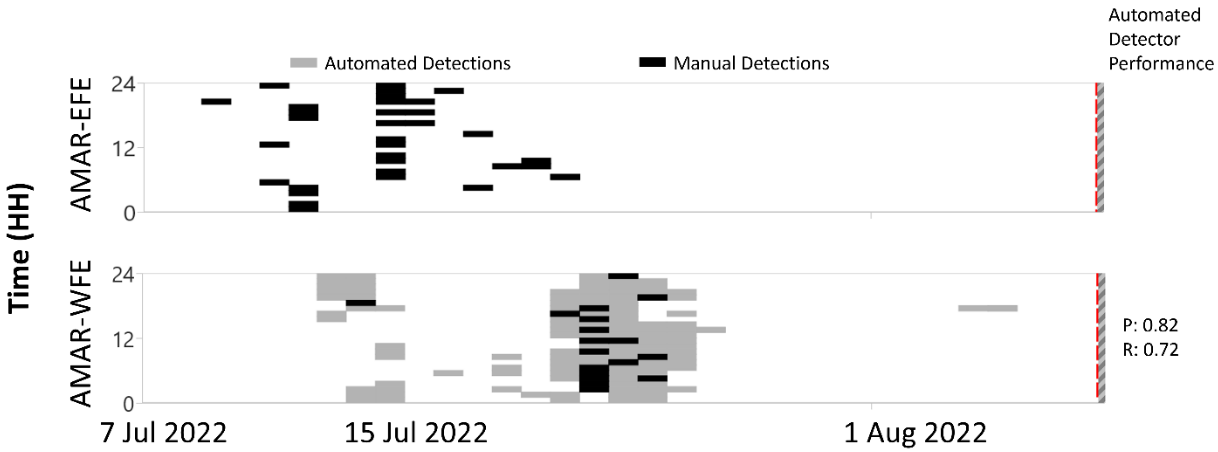


Figure 53. Hours per day with narwhal low-frequency buzz detections at each station through the recording period from 7 Jul to 8 Aug 2022. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. Performance metrics were calculated per-station and represent a detector's performance across both September to October 2021 and July to August 2022. There were no hours of darkness (sunset to sunrise) during this timeframe (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the Narwhal_LFbuzz detector.

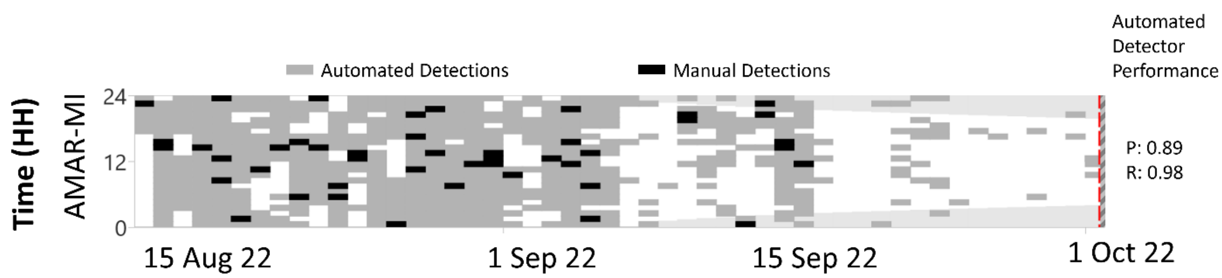


Figure 54. Hours per day with narwhal low-frequency buzz detections at each station through the recording period from 13 Aug to 1 Oct 2022. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. Performance metrics were calculated per-station and represent a detector's performance across both September to October 2021 and July to August 2022. The light grey 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.

3.5.4.4. Knocks

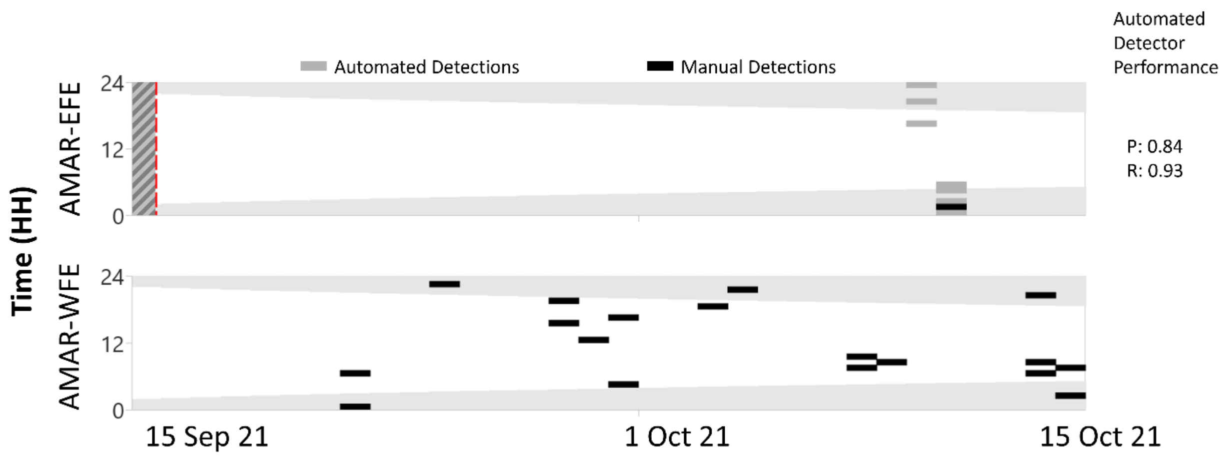


Figure 55. Hours per day with narwhal knock detections at each station through the recording period from 14 Sep to 15 Oct 2021. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. Performance metrics were calculated per-station and represent a detector's performance across both September to October 2021 and July to August 2022. The light grey 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.

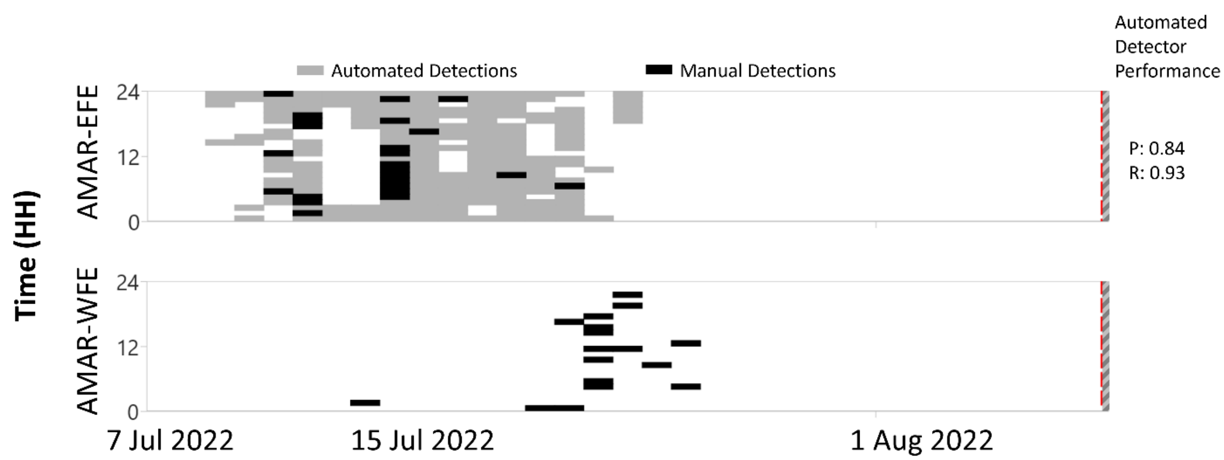


Figure 56. Hours per day with narwhal knock detections at each station through the recording period from 7 Jul to 8 Aug 2022. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. Performance metrics were calculated per-station and represent a detector's performance across both September to October 2021 and July to August 2022. There were no hours of darkness (sunset to sunrise) during this timeframe (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the NarwhalKnockTrain detector.

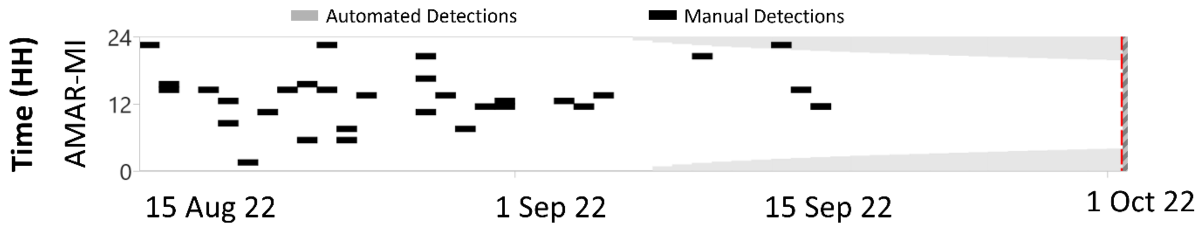


Figure 57. Hours per day with narwhal knock detections at each station through the recording period from 13 Aug to 1 Oct 2022. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The light grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data.

3.5.4.5. Whistles

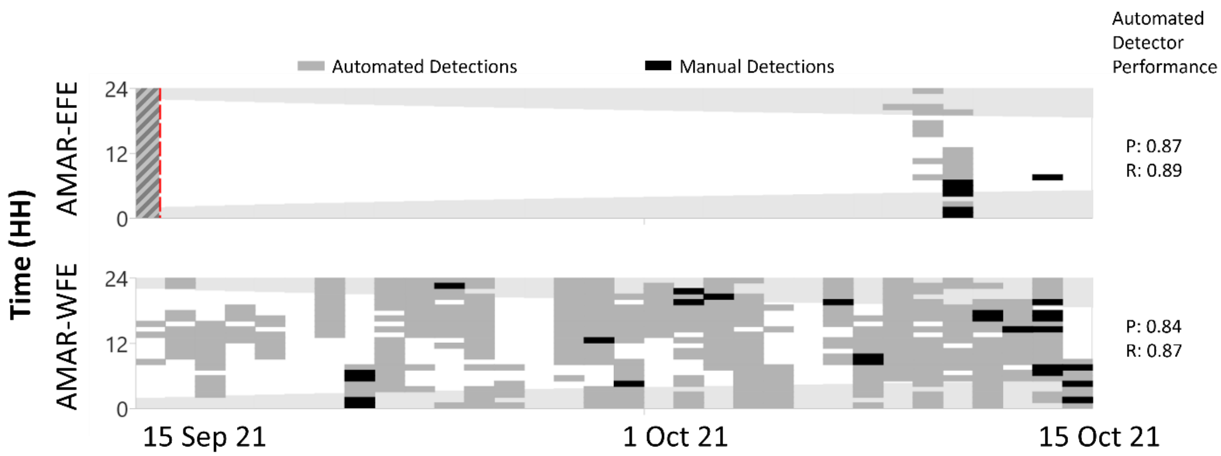


Figure 58. Hours per day with narwhal whistle detections at each station through the recording period from 14 Sep to 15 Oct 2021. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. Performance metrics were calculated per-station and represent a detector's performance across both September to October 2021 and July to August 2022. The light grey 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.

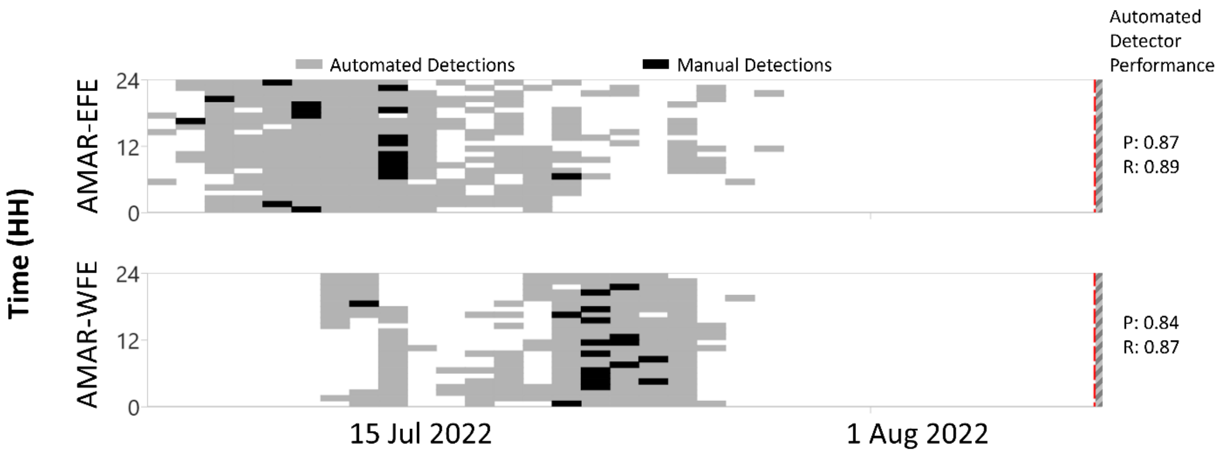


Figure 59. Hours per day with narwhal whistle detections at each station through the recording period from 7 Jul to 8 Aug 2022. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. Performance metrics were calculated per-station and represent a detector's performance across both September to October 2021 and July to August 2022. There were no hours of darkness (sunset to sunrise) during this timeframe (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data. Automated detector results are for the Narwhal_Whistle detector.

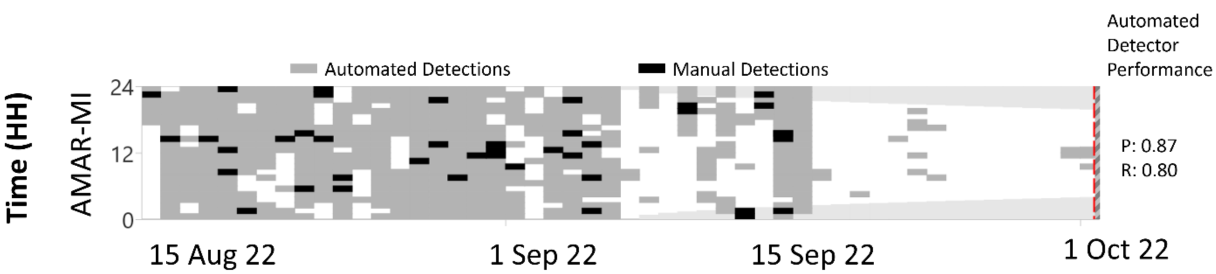


Figure 60. Hours per day with narwhal whistle detections at each station through the recording period from 13 Aug to 1 Oct 2022. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The light grey areas indicate 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.

3.5.5. Sperm Whales

Sperm whale clicks (Figure 61) were detected 26 to 28 Sep 2021 at AMAR-EFE (Figure 62). These signals were not manually confirmed at any other stations.

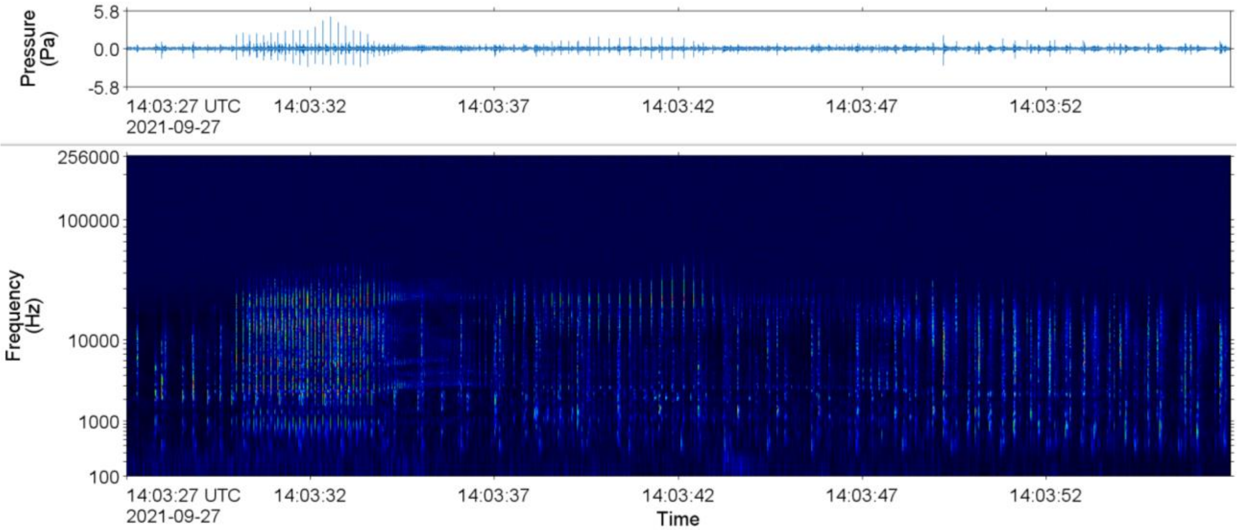


Figure 61. (Top) Waveform and (bottom) spectrogram sperm whale clicks. Data were recorded on 27 Sep 2021 at AMAR-EFE (64 Hz discrete Fourier Transform (DFT) frequency step, 0.01 s DFT temporal observation window (TOW), 0.005 s DFT time advance, and Hamming window resulting in a 50 % overlap and DFT size (N_{DFT}) of 2048, normalized across time, 30 s of data).

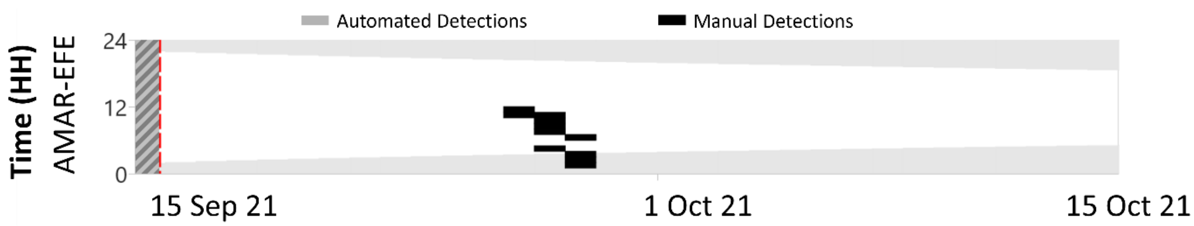


Figure 62. Hours per day with sperm whale click detections at AMAR-EFE which is the only station where the species was confirmed from 15 Sep to 15 Oct 2021. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The light grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data.

3.5.6. Pinnipeds

3.5.6.1. Bearded Seals

Bearded seal trills (Figure 63) were detected at AMAR-EFE from 7 to 10 Jul 2022 (Figure 64). These signals were not manually confirmed at any other stations.

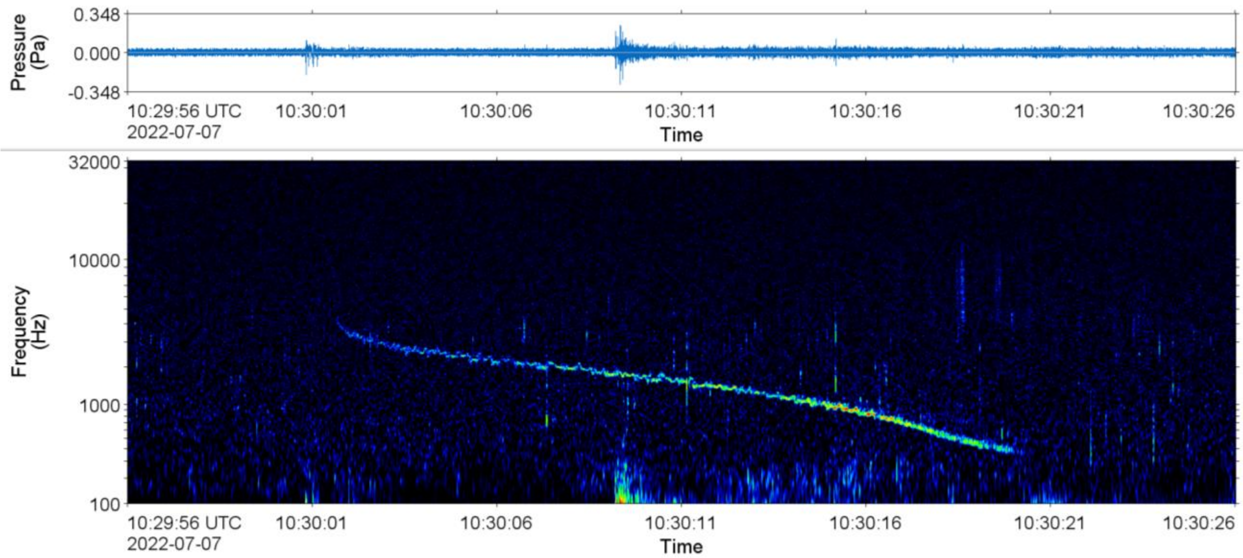


Figure 63. (Top) Waveform and (bottom) spectrogram of a bearded seal trill recorded on 7 Jul 2022 at AMAR-EFE (4 Hz discrete Fourier Transform (DFT) frequency step, 0.05 s DFT temporal observation window (TOW), 0.01 s DFT time advance, and Hamming window resulting in a 80 % overlap and DFT size (N_{DFT}) of 32768, normalized across time, 30 s of data).

Figure 64. Hours per day with bearded seal detections from 7 Jul to 8 Aug 2022 at AMAR-EFE which is the only station where the species was confirmed. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. There were no hours of darkness (sunset to sunrise) during this timeframe (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data.

3.5.6.2. Ringed Seals

Sounds similar to the bark/yelp/grunts produced by ringed seals were identified during manual analysis (Figure 65). These signals were detected 18 Sep 2021 at AMAR-EFE; 14 to 15 Oct 2021 and AMAR-WFE (Figure 66); 11 and 12 Jul 2022 at AMAR-EFE (Figure 67); and 3, 11, and 22 Sep 2022 at AMAR-MI (Figure 68).

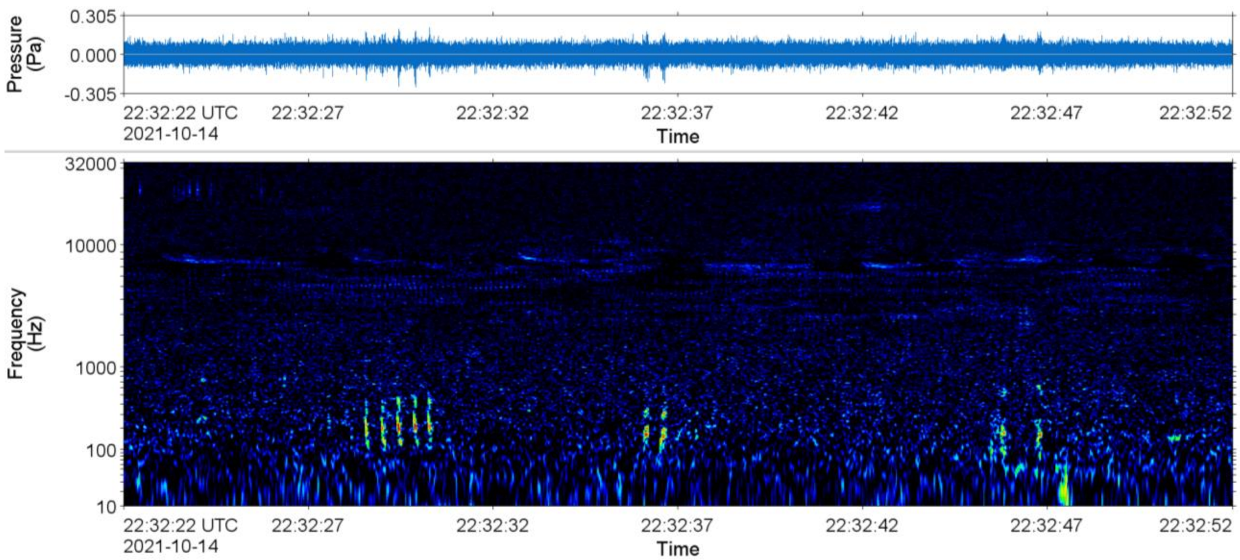


Figure 65. (Top) Waveform and (bottom) spectrogram of potential ringed seal bark-yelps recorded on 14 Oct 2021 at AMAR-WFE (2 Hz discrete Fourier Transform (DFT) frequency step, 0.125 s DFT temporal observation window (TOW), 0.03125 s DFT time advance, and Hamming window resulting in a 75 % overlap and DFT size (N_{DFT}) of 65536, normalized across time, 30 s of data).

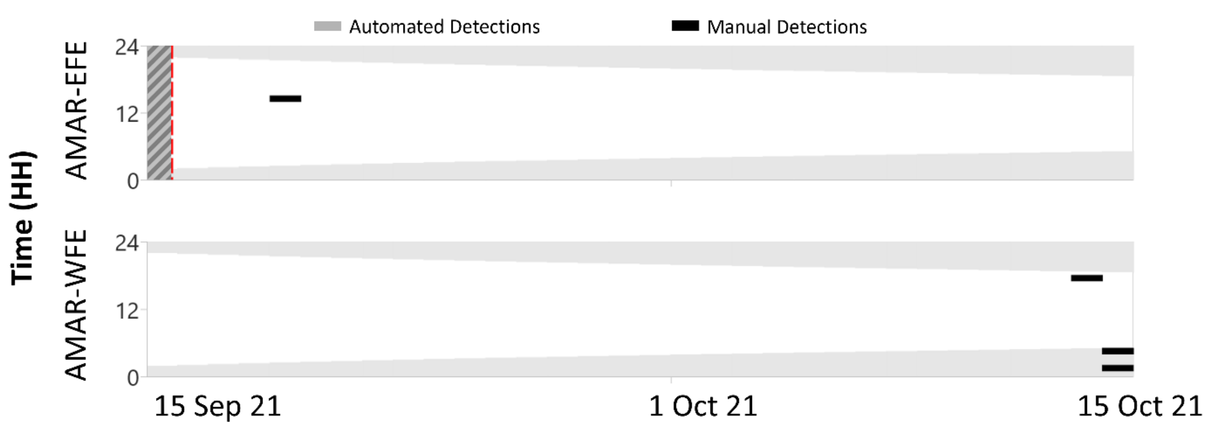


Figure 66. Hours per day with ringed seal detections at each station through the recording period from 14 Sep to 15 Oct 2021. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The light grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data.

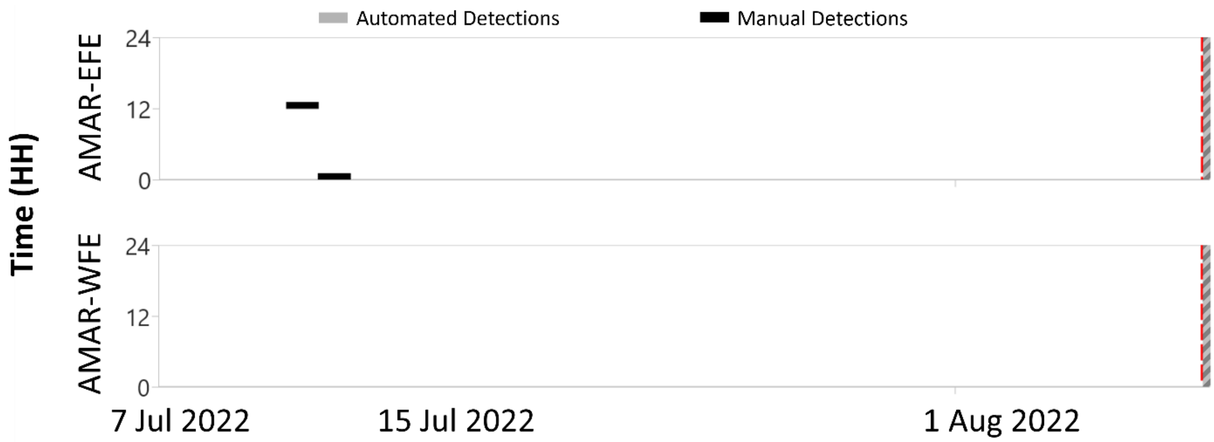


Figure 67. Hours per day with ringed seal detections at each station through the recording period from 7 Jul to 8 Aug 2022. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. There were no hours of darkness (sunset to sunrise) during this timeframe (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data.

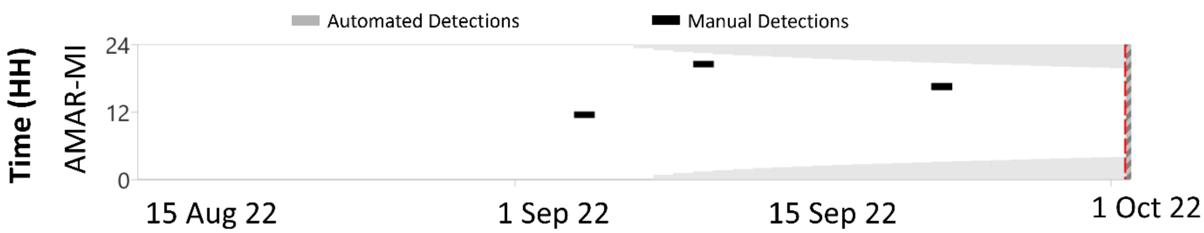


Figure 68. Hours per day with ringed seal detections at each station through the recording period from 13 Aug to 1 Oct 2022. Where an automated detector was deemed effective and automated detections were included, the performance metrics are included on the right side. The light grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data.

4. Discussion

4.1. Listening Range Reduction

To evaluate the potential for effects of acoustic masking, an alternate metric referred to as *Listening Range Reduction* (LRR) was applied. This metric assesses the percent 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, the percent of time that narwhal experienced listening range reductions of 90 % or more and 50 % or more due to the presence of masking vessel noise was calculated. The percent of time that narwhal experienced listening range reductions when ambient sounds exceeded the median ambient sound level, in the absence of vessel noise, was also calculated.

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). 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.

LRR results of this kind have been presented in Baffinland's acoustic monitoring reports since 2019 (Frouin-Mouy et al. 2020, Austin et al. 2022a, Austin et al. 2022b) and data has been collected consistently at a recording location in Milne Inlet, near Bruce Head, in each year. Although the exact location of this recorder was changed in 2022, it is still instructive to compare results for Milne Inlet across over time. Table 8 lists the percent of the total recording minutes during which there was >50 % LRR associated with either vessel noise or ambient conditions for the three decidecade bands of interest for each year between 2019 and 2022. The results for the decidecade band centered at 1 kHz are consistent across years, with vessel noise resulting in >50 % LRR in between 1.2 % (2020 and 2022) and 1.9 % (2019) of the total recording periods and ambient noise not resulting in LRR at this frequency band. The LRR attributed to vessel noise in the 5 kHz band decreased slightly over years with percent values ranging between 3.6 % (2022) and 7.8 % (2019) of the total recording periods. Similarly, the percent of time that >50 % LRR was attributed to vessel noise in the 25 kHz band decreased from 8.7 % of the recording period in 2019 to 4.4 % in 2021 (4.8 % in 2022). The percent of time in which ambient noise resulted in >50 % LRR in these bands fluctuated across years. Table 9 lists the parameters that were used for the LRR calculations in each year and Table 10 lists the percent of the recordings in which vessels were detected in each year.

Table 8. Percent of total recording minutes associated with >50 % Listening Range Reduction (LRR) for three considered frequencies based on acoustic recordings collected in Milne Inlet between 2019 and 2022.

Band center frequency (kHz)	>50 % LRR for data with vessels detected				>50 % LRR for ambient data			
	2019[1]	2020[2]	2021[3]	2022	2019[1]	2020[2]	2021[3]	2022
1 (burst pulse)	1.9	1.2	1.5	1.2	0.0	0.1	0.0	0.0
5 (whistles)	7.8	7.0	6.7	3.6	7.6	17.8	15.1	16.6
25 (clicks)	8.7	8.3	4.4	4.8	29.2	26.0	10.0	22.9

1 (Frouin-Mouy et al. 2020)
2 (Austin et al. 2022b)
3 (Austin et al. 2022a)

Table 9. Parameters used to determine the normal condition, NL_1, in calculations of Listening Range Reduction (LRR) for three considered frequencies based on acoustic recordings collected in Milne Inlet between 2019 and 2022.

Band center frequency (kHz)	Decidecade band baseline ambient level in Milne Inlet (dB re 1 µPa)				Hearing threshold for mid-frequency cetaceans* (dB re 1 µPa)
	2019[1]	2020[2]	2021[3]	2022	
1	87.5	83.8	84.6	87.0	96.7
5	86.0	82.0	83.2	85.1	74.1
25	79.8	75.4	77.6	78.1	57.2

* From Finneran 2016, Equation A-9 and Table C-2.
1 (Frouin-Mouy et al. 2020)
2 (Austin et al. 2022b)
3 (Austin et al. 2022a)

Table 10. Percent of recording periods during which vessel noise was detected in the acoustic data based on recordings in Milne Inlet between 2019 and 2022.

2019[1]	2020[2]	2021[3]	2022
23	28	30	20

1 (Frouin-Mouy et al. 2020)
2 (Austin et al. 2022b)
3 (Austin et al. 2022a)

4.2. Vessel Contribution to Soundscape

All sound levels measured in this study were below the thresholds (Appendix C) for auditory injury for all marine mammal species that occur in the study area. Nevertheless, vessel noise has the potential to result in disturbance or acoustic masking effects on marine mammals. 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) was investigated. 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 have been published (Southall et al. 2021) however no new thresholds or species-specific thresholds for acoustic disturbance have been defined. Subsequently, to facilitate comparison with effects predictions for this Project, and in keeping with established assessment methods, an analysis of the exceedances of the 120 dB SPL threshold was applied for this report.

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 (Table 11). This included exceedances due to all potential contributing noise sources in the study area (i.e., ship noise, small vessel noise, wind/wave/rain noise, etc.). As shown in Section 3.1, the broadband SPL exceeded 120 dB re 1 µPa for 1.0 and 1.3 % of the 30 day recording durations at AMAR-EFE and AMAR-WFE in Sep-Oct 2021, during 0.4 and 0.5 % of the 30 day recording durations at the same stations in Jul-Aug 2022, and during 2.8 % of the 49 day recording duration at AMAR-MI in Aug/Sep 2022. On average, received sound levels at the AMAR locations exceeded the disturbance threshold of 120 dB re 1 µPa for less than 35 minutes per day (averaged over acoustic recording days). Table 11 also shows the maximum number of hours in a day during which the SPL exceeded the 120 dB re 1 µPa threshold: 87 min (1.45 h) at AMAR-EFE and 43 minutes (0.72 h) at AMAR-WFE in Sep-Oct 2021, for 128 min (2.1 h) and 51 min (0.9 h) at the same locations in Jul-Aug 2022 and for 102 min (1.7 h) at AMAR-MI in Aug-Sep 2022.

Table 11. Average and maximum daily exposure durations for disturbance (120 dB re 1 µPa) for each recorder during the 2021 and 2022 acoustic monitoring periods.

Recorder		Time per shipping season day with SPL > 120 dB (min)	
		Average	Maximum
2021	AMAR-EFE	26	87
	AMAR-WFE	14	43
2022	AMAR-EFE	25	128
	AMAR-WFE	22	51
	AMAR-MI	35	102

In 2022, these maximum durations occurred on days with vessel convoys. While this indicates that there is a localized increase of the exposure duration for a vessel convoy, the use of convoys reduces the overall number of vessel transits and decreases the total sound exposure over the course of the shipping season. It was reported separately in Baffinland's Convoy Analysis Report (Austin 2023) that sound levels measured during vessel convoys in 2022 support the hypothesis that vessel convoys can be an effective means to reduce the overall sound exposure throughout the shipping season. Sound levels measured during vessel convoys were compared to previously measured noise footprints for transits of the corresponding vessels on their own. Specifically, JASCO compared the total 120 dB exceedance duration (i.e., the time when the sound pressure level exceeded 120 dB re 1 µPa) for each convoy with the total amount of time that the sound level would have exceeded 120 dB re 1 Pa had the vessels in the convoy transited individually (i.e., not in a convoy formation). For 7 of the 9 considered convoys, the 120 dB exceedance duration for the convoy was less than the sum of the average 120 dB exceedance durations for the individual vessels in the convoy. Indicating that, overall, the use of convoys is expected to result in a net reduction of sound exposure in the RSA throughout the shipping season.

4.3. Marine Mammals

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 individuals were not vocalizing near the recorder, if animals were in the study area but not in detection range for the recorders, if their signals were masked by 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.

4.3.1. Beluga Whales

Beluga whales are generally associated with Subarctic and Arctic waters. They often occur in inshore and shallow waters (Richard et al. 2001). Beluga whales are known to occur in the monitoring area, although not as regularly as narwhal. Beluga whales generally vocalize abundantly, with whistles representing a large portion of their vocal repertoire (Garland et al. 2015). In contrast, while the narwhal repertoire includes whistles, whistles are less common than their other sounds such as buzzes and knock trains (Ford and Fisher 1978). We attempted to identify beluga based on the frequency of tonal whistles and on the frequency of their clicks as described by Zahn et al. (2021). These analysis techniques indicate that beluga were occasionally present in the monitoring region among or near narwhal. Future collaboration between research groups that have classified the signals of narwhal and beluga would be beneficial, particularly if a standard for signal classification can be reached.

4.3.2. Bowhead Whales

The acoustic occurrence of bowhead whales in the data is expected 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. Inuit observations and tag data indicate that from May to July bowhead whales move northward from the Cumberland Sound to Pond Inlet (COSEWIC 2009). The animals then summer along northern Baffin Island on the northeast coast, which includes the present study area, from May to August (COSEWIC 2009).

The bowhead whale detections in the present data set suggested that some animals moved past AMAR-EFE in early to mid-July before passing AMAR-WFE in late July. Their signals continued farther in the Inlet, a known summer aggregation area, at AMAR-MI until mid-September. These results indicate a more prevalent acoustic occurrence of the species near Bruce Head in Milne Inlet than previous recordings years (Austin et al. 2021). Bowhead whales detected at AMAR-WFE through September and October 2021 likely represent animals on their southbound migration after summering farther north or in the Inlet.

4.3.3. 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 2002b). Killer whale sightings in the eastern Canadian Arctic are widely distributed, with the highest reported numbers in Lancaster Sound, which is located north of the study 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 smaller 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. Killer whale possible acoustic detections were made on four recording days, aligning with the few to no detections of the species in previous recording years in the region (Austin et al. 2021). Beyond acoustic detections, the species is known to occur in the monitoring area. Killer whales were sighted near Pond Inlet on 26 Jul and 8 Aug 2022, and one was hunted on 10 Oct 2022 (Genevieve Morinville, personal communication, March 2023).

4.3.4. Narwhal

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 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 2004a). Uncorrected estimates put the population between 45,000–50,000 in the Canadian Arctic (COSEWIC 2004a).

Narwhal seemed to move into the Inlet in July, first passing AMAR-EFE in mid-July before passing AMAR-WFE in late-July. Farther in the Inlet at AMAR-MI, narwhal were acoustically present through August and the first half of September, before they presumably began their fall migration out of the Inlet. Narwhal detected at AMAR-WFE through September and October, likely eventually moved out of the Inlet through AMAR-EFE in late October, as detections were just beginning to appear in at AMAR-EFE mid-October, before the recording ceased.

In many instances, low-frequency buzzes were identified as potentially being narwhal (or beluga) contact calls (Figure 69). These signals are of biological significance as they could indicate communications between individuals, such as mother-calf pairs. Future work to refine the definition of contact calls versus low-frequency buzzes would help to better systematically identify and characterize these signals. One excellent tool for this type of work is directional data where repeated signals from different individuals (different directions) can be observed (Figure 70).

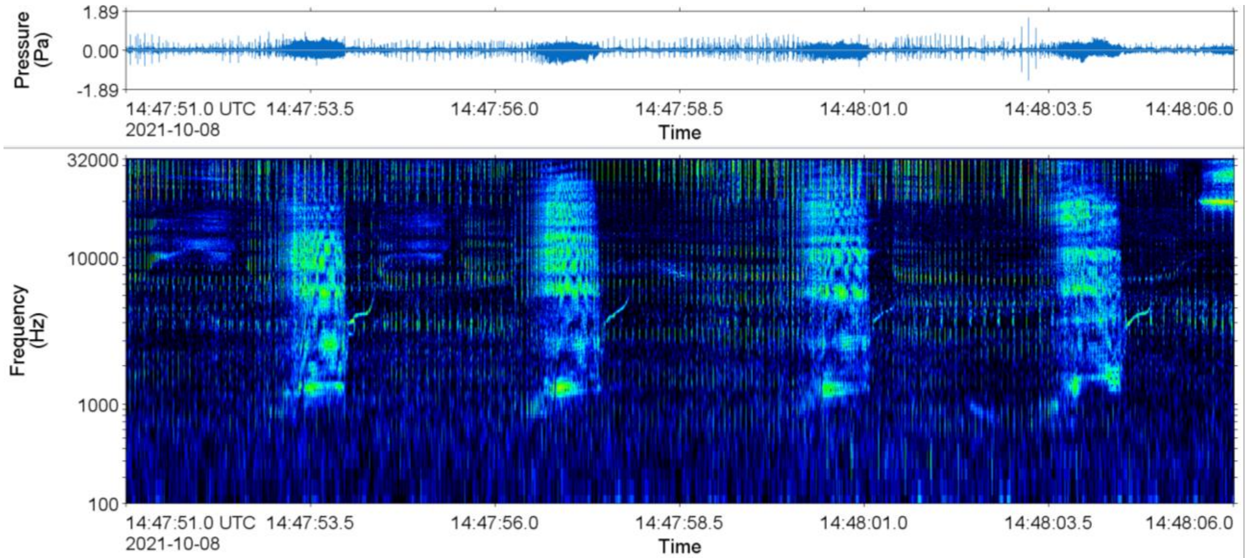


Figure 69. (Top) Waveform and (bottom) spectrogram of suspected narwhal contact calls. Data were recorded on 8 Oct 2021 at AMAR-WFE (64 Hz discrete Fourier Transform (DFT) frequency step, 0.01 s DFT temporal observation window (TOW), 0.005 s DFT time advance, and Hamming window resulting in a 50 % overlap and DFT size (N_{DFT}) of 2048, normalized across time, 15 s of data).

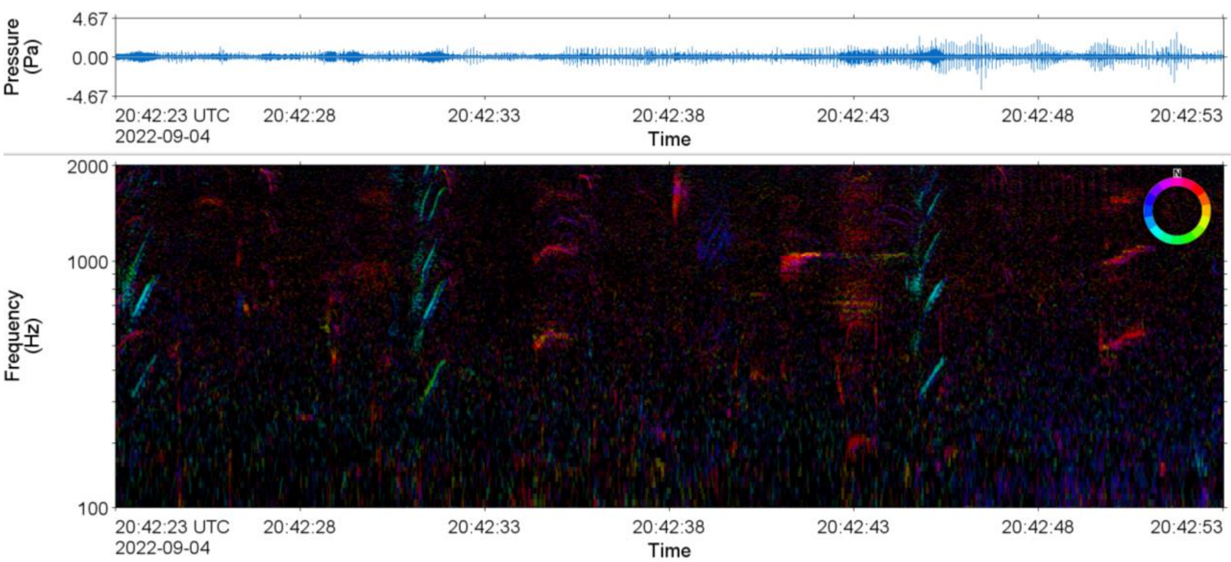


Figure 70. (Top) Waveform and (bottom) directogram of suspected narwhal contact calls. Data were recorded on 4 Sep 2022 at AMAR-MI (8 Hz discrete Fourier Transform (DFT) frequency step, 0.125 s DFT temporal observation window (TOW), 0.03125 s DFT time advance, and Hamming window resulting in a 50 % overlap and DFT size (N_{DFT}) of 2048, normalized across time, 30 s of data).

4.3.5. Sperm Whales

Sperm whales are the largest toothed whale and the largest toothed predator, with an extensive worldwide distribution. Their diet consists mainly of mesopelagic and benthic squids and fish (Martin and Clarke 1986, Smith and Whitehead 2000, Flinn et al. 2002). 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 2002a). 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 summer and lower latitude to breed in winter (Whitehead 2002b). Sperm whale acoustic signals can be heard over long distances (Madsen et al. 2002), making them ideal species for passive acoustic monitoring.

In the Canadian Arctic, the northernmost extent of sperm whales was once considered to be the Davis Strait (Breiwick 1984). However, in northeastern Baffin Bay sperm whales were sighted and/or acoustically detected from the months of June to November from 2012 to 2014, with detections increasing through the years (Frouin-Mouy et al. 2017). Starting in 2014, sperm whales have been detected (visually and/or acoustically) in late summer and fall in Eclipse Sound. The occurrence of sperm whales in northwestern areas of Baffin Bay was reported by Posdaljian et al. (2022) from 2014 to 2019, with the species becoming more common through the years. Sperm whales were detected on only 3 days in September 2016, whereas they were detected on 17 days in July and August 2019 (Posdaljian et al. 2022). Since 2019, the species was acoustically detected in the Eclipse Sound in August and September 2020 and September 2021 by Austin et al. (2021), (2023) and visually during 2020 aerial surveys (Golder 2021). It is clear the species now regularly occurs in northern Baffin Bay, a distribution shift attributed to changing sea ice conditions (Posdaljian et al. 2022). The few days of sperm whale detections at AMAR-EFE in fall 2021, combined with previous reports, suggests that this species may now be frequenting this area more regularly.

4.3.6. Pinnipeds

Ringed seals can occur in the recording area and were acoustically confirmed. 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).

5. Summary

In 2022, marine mammal vocalizations were detected throughout the recordings from four marine mammal species: bowhead whales, sperm whales, narwhal, and beluga, as well as likely detections of bearded seal and ringed seal and of sounds that could have been from killer whales. Patterns in marine mammal acoustic detections were consistent with JASCO's prior acoustic monitoring results and consistent with findings from Baffinland's other marine mammal monitoring programs. Marine mammals were noted to be present within the RSA when acoustic recording began in early July 2022 (7 Jul), before any large vessels had entered the RSA. Narwhal were detected acoustically first on the eastern floe edge recorder; acoustic detections began on the western floe edge recorder approximately one week later, indicating a westerly movement of the animals into the RSA in mid-July, consistent with findings from Baffinland's aerial surveys.

In 2022, large vessels were detected on the floe edge recorders in the second half of July, once ice had left the region. Vessel detections began on 21 Jul when non-Project vessels were detected, followed by detections of Baffinland vessels beginning early in the morning of 31 Jul 2022. Small boat traffic was also detected. Vessel noise was also prevalent in the Milne Inlet recordings between 13 Aug and 1 Oct 2022, including noise from both large Project vessels as well as small boats. The results in this report demonstrate that while noise from Project vessels is detectable in the underwater soundscape (vessels were detected in between 11 % and 30% of the data, depending on location and recording period), the vessel noise exposure is temporary in nature (i.e. occurring for short portions of the day) and below sound levels that could cause acoustic injury. Assessed relative to the established acoustic disturbance for marine mammals (broadband SPL of 120 dB re 1 µPa), sound exposure durations averaged less than one hour per day. Vessel convoys were implemented in 2022 and acoustic monitoring results support the hypothesis that vessel convoys can be an effective mitigation measure for reducing the overall noise exposure throughout the shipping season.

LRR was calculated for three frequencies representative of different narwhal vocalization types (1 kHz representing burst pulses, 5 kHz representing whistles and knock trains, and 25 kHz representing clicks and high-frequency buzzes). Both ambient and vessel noise sources can result in LRR, at different contributing levels depending on the vocalization type of interest. Given narwhals good hearing acuity at high frequencies, the listening range for sound at 25 kHz was more affected, by both vessel noise and ambient noise, than sound at 1 kHz where narwhal have decreased hearing sensitivity. The potential consequence is a reduced range at which the listener (narwhal) can detect potential prey when there are elevated sound levels due to vessel noise or increase ambient noise conditions. 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, and marine mammal calls themselves). Sound at 1 kHz was least susceptible to LRR due to vessel noise, with a 90 % LRR occurring ≤1 % of the time. Ambient noise did not result in any appreciable level of LRR at this frequency because the hearing threshold for narwhal at 1 kHz is higher than the median ambient sound level at this frequency. The LRR results have been consistent over the years of reporting (since 2019).

Overall, the results of the 2022 acoustic monitoring program contained in this report are consistent with results from previous acoustic monitoring programs conducted by JASCO in the RSA since 2018. The results are also consistent with effects predictions identified through the FEIS, and subsequent amendments to the ERP, 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.

Acknowledgements

The authors would like to acknowledge Emily Maxner, Laurel Mackinnon, Carmen Lawrence, and Jonathan Barrows of JASCO for their assistance deploying and retrieving the acoustic recorders, as well as the manual analysts, and the JASCO equipment team for their expert preparing and handling of the gear. The crew of MSV *Botnica* and Baffinland's Site Environment teams also contributed to the logistical and operational success of the deployment of the recorder at Pond Inlet and the retrievals of all recorders.

Glossary of Acoustics Terms

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

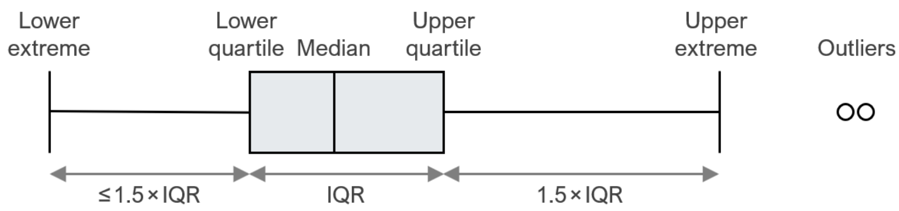
Combination of ambient sound, acoustic self-noise, and sonar reverberation. Ambient sound detected, measured, or recorded with a signal is part of the background noise.

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 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 percent 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^2_{pk}). Unit: decibel (dB). Reference value (p_0^2) for sound in water: 1 µPa^2.

$$L_{p,\text{pk}} := 10\log_{10}\left(p^2_{\text{pk}}/p^2_0\right)\text{ dB } = 20\log_{10}\left(p_{\text{pk}}/p_0\right)\text{ dB}$$

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 $\mu m/s^2$

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. Recorder Calibration

A.1. Recorder Calibrations

Each AMAR was calibrated before deployment and upon retrieval (battery life permitting) with a pistonphone type 42AC precision sound source (G.R.A.S. Sound & Vibration A/S; Figure A-1). The pistonphone calibrator produces a constant tone at 250 Hz at a fixed distance from the hydrophone sensor in an airtight space of known volume. The recorded level of the reference tone on the AMAR yields the system gain for the AMAR and hydrophone. To determine absolute sound pressure levels, this gain was applied during data analysis. Typical calibration variance using this method is less than 0.7 dB absolute pressure.

Figure A-1. Split view of a G.R.A.S. 42AC pistonphone calibrator with an M36 hydrophone.

Appendix B. Acoustic Data Analysis

The sampled data were processed for ambient sound analysis, vessel noise detection, and detection of all marine mammal vocalizations with JASCO's PAMlab acoustic analysis software suite. The major processing stages are outlined in Figure B-1.

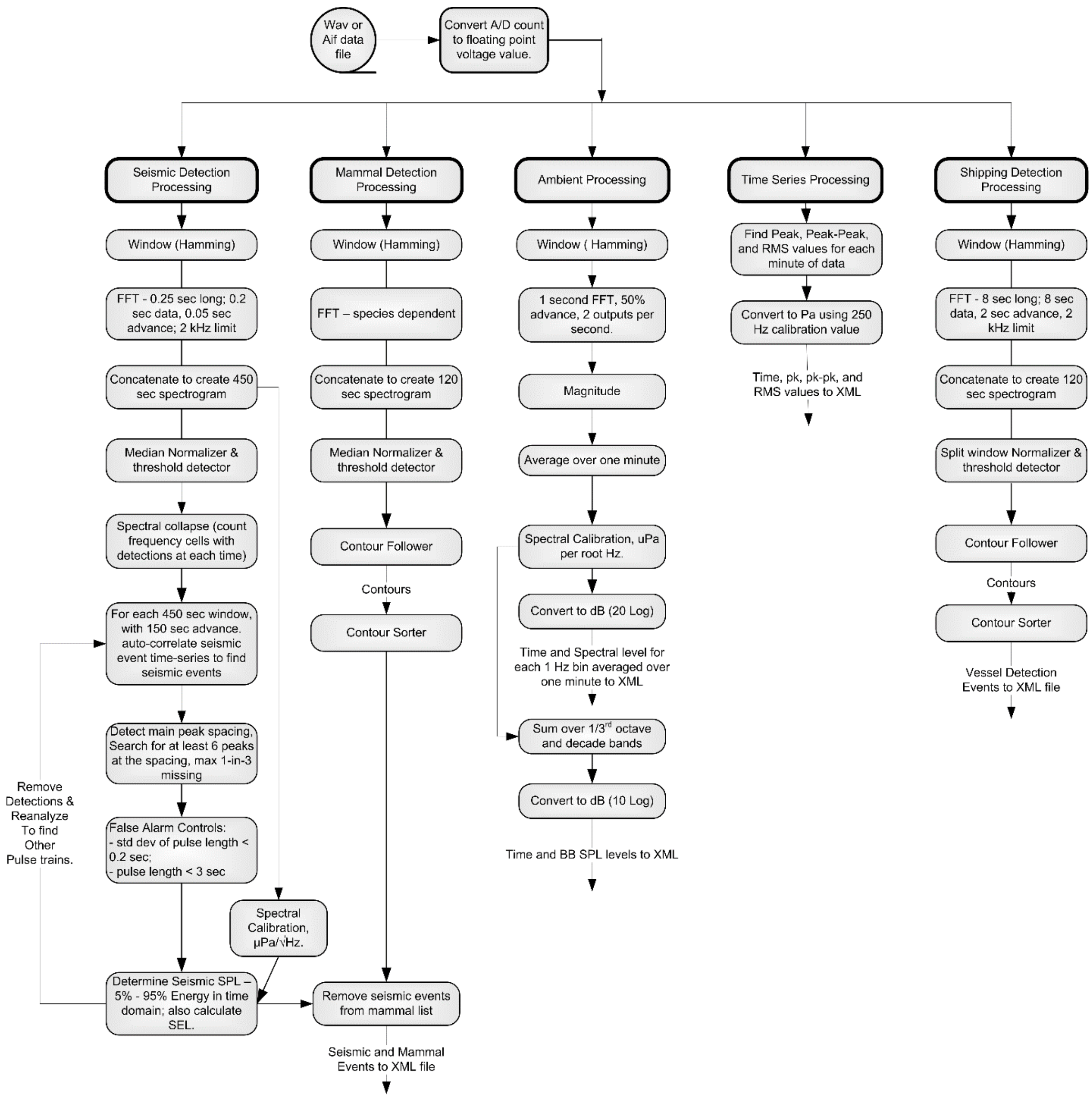

Figure B-1. Major stages of the automated acoustic analysis process performed with JASCO's PAMlab software suite.

B.1. Acoustic Metrics

Underwater sound pressure amplitude is quantified in decibels (dB) relative to a fixed reference pressure of p_0 = 1 μPa. Because the perceived loudness of sound, especially pulsed sound 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 sound and its effects on marine life. Here we provide specific definitions of relevant metrics used in the accompanying report. Where possible, we follow International Organization for Standardization definitions and symbols for sound metrics (e.g., ISO 18405:2017b, ANSI S1.1-2013).

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

$$L_{\text{pk}} = 10\log_{10}\frac{p_{\text{pk}}^2}{p_0^2} = 20\log_{10}\frac{p_{\text{pk}}}{p_0} = 20\log_{10}\frac{\max|p(t)|}{p_0} \quad \text{(B-1)}$$

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

The sound pressure level (SPL or L_p; dB re 1 µPa) is the root-mean-square (rms) pressure level in a stated frequency band over a specified time window (T; s):

$$L_p = 10\log_{10}\frac{p_{\text{rms}}^2}{p_0^2} = 10\log_{10}\left(\frac{1}{T}\int_T p^2(t)\,dt \Big/ p_0^2\right) \quad \text{(B-2)}$$

It is important to note that SPL always refers to an rms pressure level (i.e., a quadratic mean over a time interval) and therefore not instantaneous pressure at a fixed point in time. The SPL can also be defined as the *mean-square* pressure level, given in decibels relative to a reference value of 1 µPa^2 (i.e., in dB re 1 µPa^2). The two definitions of SPL are numerically equivalent, differing only in reference value.

The SPL can also be calculated using a time weighting function, $g(t)$:

$$L_p = 10\log_{10}\left(\frac{1}{T}\int_T g(t)\,p^2(t)\,dt \Big/ p_0^2\right)\ \text{dB} \quad \text{(B-3)}$$

In many cases, the start time of the integration is marched forward in small time steps to produce a time-varying SPL function. For short acoustic events, such as sonar pulses and marine mammal vocalizations, it is important to choose an appropriate time window that matches the duration of the signal. For in-air studies, when evaluating the perceived loudness of sounds with rapid amplitude variations in time, the time weighting function $g(t)$ is often set to a decaying exponential function that emphasizes more recent pressure signals. This function mimics the leaky integration nature of mammalian hearing. For example, human-based fast time-weighted SPL ($L_{p,\text{fast}}$) applies an exponential function with time constant 125 ms. A related simpler approach used in underwater acoustics sets $g(t)$ to a boxcar (unity amplitude) function of width 125 ms; the results can be referred to as $L_{p,\text{boxcar 125ms}}$.

Another approach, historically used to evaluate SPL of impulsive signals underwater (e.g., from pile driving or seismic airguns), defines $g(t)$ as a boxcar function with edges set to the times corresponding to 5 % and 95 % of the cumulative square pressure function encompassing the duration of an impulsive acoustic event. This calculation is applied individually to each impulse signal, and the results have been referred to as 90 % SPL ($L_{p,90}$).

The sound exposure level (SEL or L_E; dB re 1 µPa^2 s) is the time-integral of the squared acoustic pressure over a duration (T):

$$L_E = 10\log_{10}\left(\int_T p^2(t)\,dt \Big/ T_0 p_0^2\right)\,\mathrm{dB} \quad \text{(B-4)}$$

where T_0 is a reference time interval of 1 s. SEL continues to increase with time when non-zero pressure signals are present. It is a dose-type measurement, so the integration time applied must be carefully considered for its relevance to impact to the exposed recipients. SEL can be calculated over a fixed duration, such as the time of a single event or a period with multiple acoustic events.

When applied to pulsed sounds, SEL can be calculated by summing the SEL of the N individual pulses. 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:

$$L_{E,N} = 10\log_{10}\left(\sum_{i=1}^{N} 10^{\frac{L_{E,i}}{10}}\right) \quad \text{(B-5)}$$

Because the SPL 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:

$$L_p = L_E - 10\log_{10}(T) \quad \text{(B-6)}$$

Likewise, the SPL(T_{90}) and SEL metrics are related by:

$$L_{p,90} = L_E - 10\log_{10}(T_{90}) - 0.458 \quad \text{(B-7)}$$

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

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

$$L_{\mathrm{eq}} = 10\log_{10}\left(\frac{1}{T}\int_T p^2(t)\,dt \Big/ p_0^2\right) \quad \text{(B-8)}$$

The equations for SPL and the energy-equivalent SPL are numerically identical. Conceptually, the difference between the two metrics is that the SPL is typically computed over short periods (typically of 1 s or less) and tracks the fluctuations of a non-steady acoustic signal, whereas the L_{eq} reflects the average SPL of an acoustic signal over time periods typically of 1 min to several hours.

B.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 (see 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.

Animals perceive exponential increases in frequency rather than linear increases, so 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 of 10 in sound frequency. Each octave represents a factor of 2 in sound frequency. The centre frequency of the ith decidecade band, $f_c(i)$, is defined as:

$$f_{\mathrm{c}}(i) = 10^{\frac{i}{10}}\ \mathrm{kHz} \tag{B-9}$$

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

$$f_{\mathrm{lo},i} = 10^{\frac{-1}{20}} f_{\mathrm{c}}(i) \text{ and } f_{\mathrm{hi},i} = 10^{\frac{1}{20}} f_{\mathrm{c}}(i) \tag{B-10}$$

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

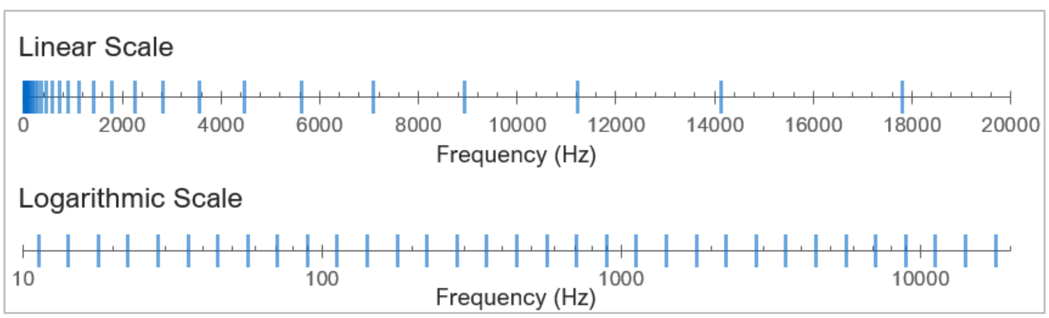

Figure B-2. Decidecade frequency bands (vertical lines) shown on (top) a linear frequency scale and (bottom) a logarithmic scale. On the logarithmic scale, the bands are equally spaced.

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

$$L_{p,i} = 10 \log_{10} \int_{f_{\mathrm{lo},i}}^{f_{\mathrm{hi},i}} S(f)\,\mathrm{d}f\ \mathrm{dB} \tag{B-11}$$

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

$$\text{Broadband SPL} = 10 \log_{10} \sum_i 10^{\frac{L_{p,i}}{10}}\ \mathrm{dB} \tag{B-12}$$

Figure B-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 can be applied to continuous and impulsive sound sources. For impulsive sources, the decidecade band SEL is typically reported.

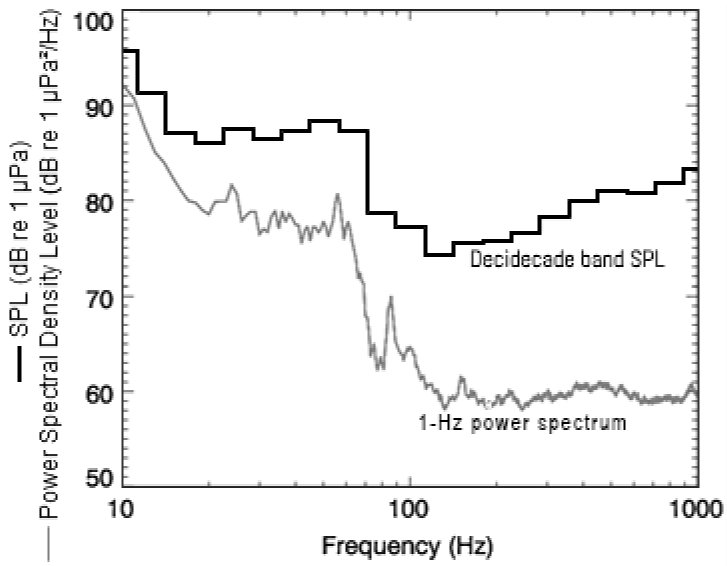

Figure B-3. Sound pressure spectral density levels and the corresponding decidecade band sound pressure levels (SPL) of example ambient sound shown on a logarithmic frequency scale. Because the decidecade bands are wider with increasing frequency, the decidecade band SPL is higher than the power spectrum, which is based on bands with a constant width of 1 Hz.

Table B-1. Decidecade band centre and limiting 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

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 B-2. Decade band centre and limiting frequencies (Hz).

Decade band	Lower frequency	Nominal centre frequency	Upper frequency
2	10	50	100
3	100	500	1,000
4	1,000	5,000	10,000

Appendix C. 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 C-1).

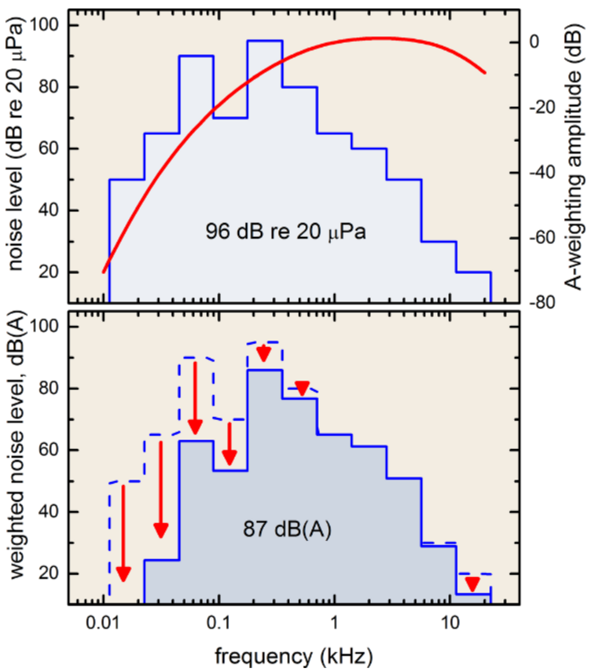

Figure C-1. Application of an auditory weighting function. Blue line shows a hypothetical, octave-band sound pressure spectrum in air, with a total sound pressure level (integrated over all octave-bands) of 96 dB re 20 µPa (This example uses in air-noise levels; therefore, a different reference pressure (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 C-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 C-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 United States 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:

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

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 C-2 lists the frequency-weighting parameters for each hearing group; Figure C-2 shows the resulting frequency-weighting curves.

Table C-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

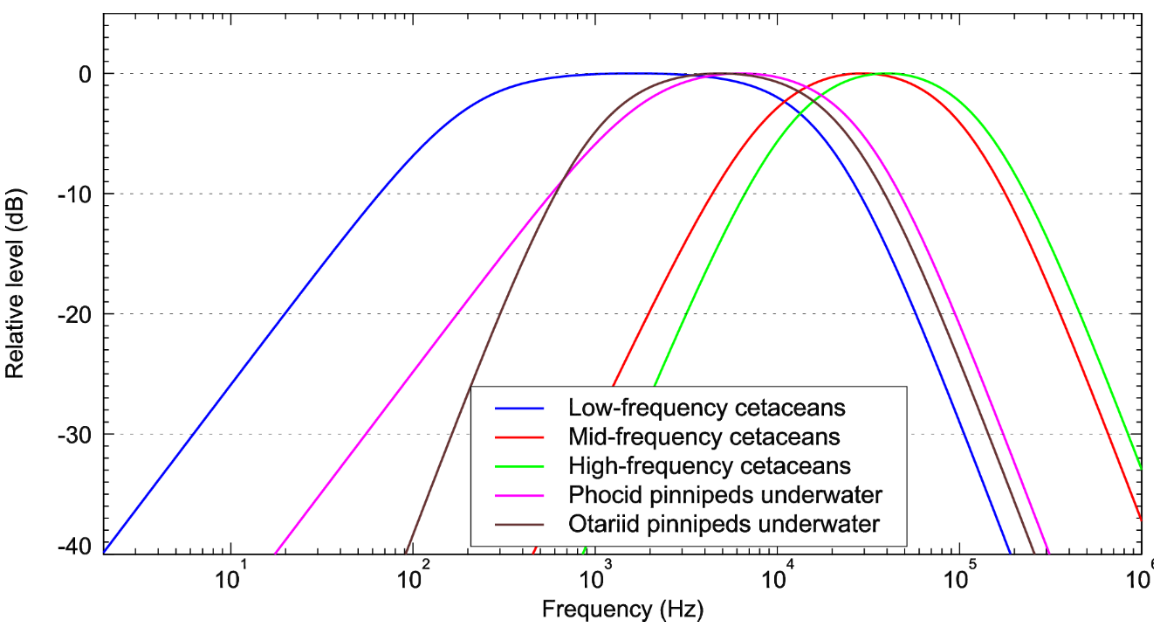

Figure C-2. Auditory weighting functions for functional marine mammal hearing groups as recommended by NMFS (2018).

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). Table C-3 lists the applicable marine mammal auditory injury thresholds.

Table C-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 D. Marine Mammal Detection Methodology

D.1. Automated Click Detector for Odontocetes

Figure D-1 shows how we apply an automated click detector/classifier to the data to detect clicks from odontocetes. 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. Clicks are detected by the following steps:

1. The raw data are high-pass filtered to remove all energy below 5 kHz. This removes most energy from sources other than odontocetes (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 normalizer 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 'notch' that is 1-bin wide.
4. A Teager-Kaiser energy detector identifies possible click events.
5. The high-pass filtered data are searched to find the maximum peak signal within 1 ms of the detected peak.
6. The high-pass filtered data are searched backwards and forwards to find the time span when 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 identify beaked whale clicks, because 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.

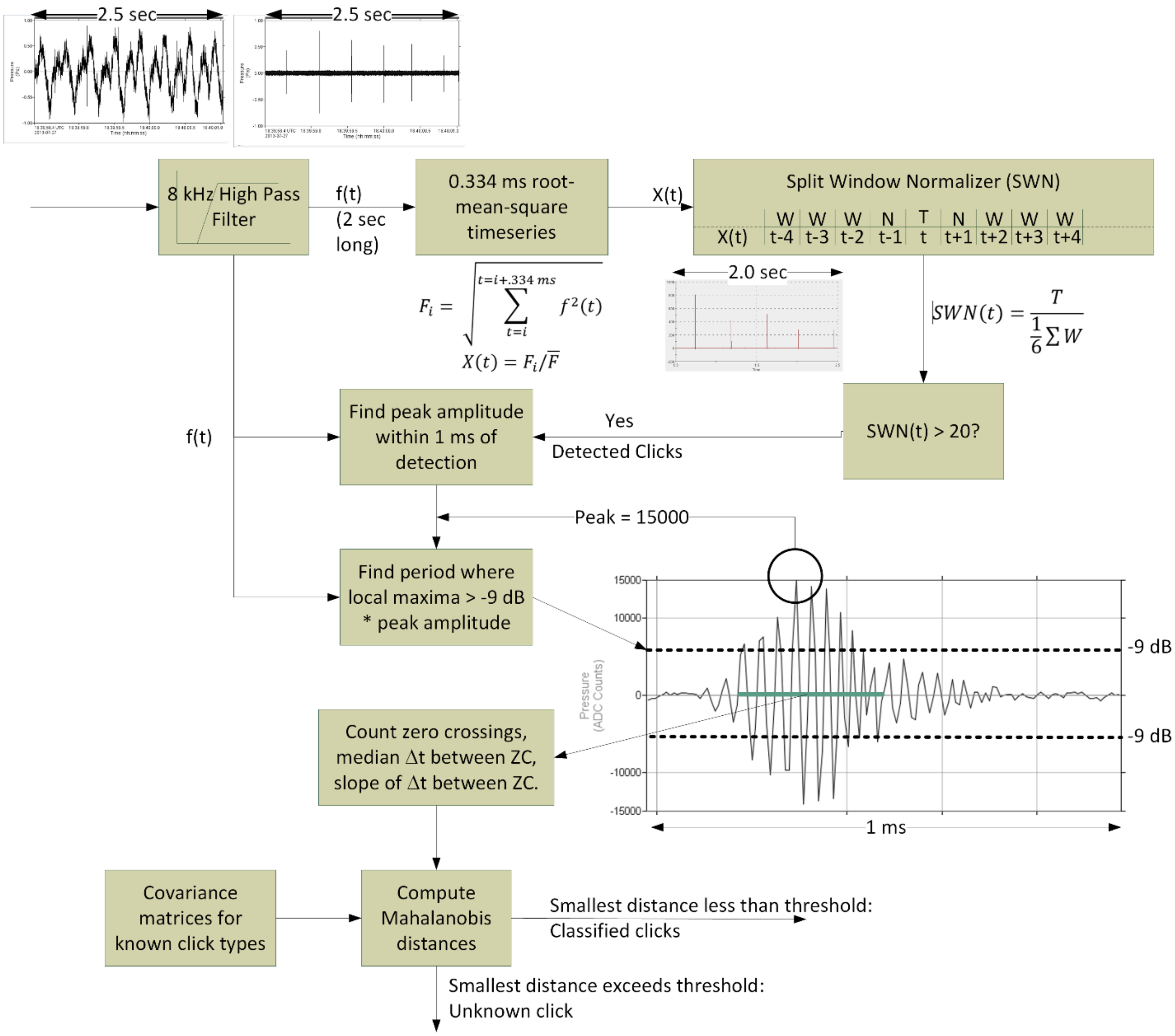

Figure D-1. Flowchart of the automated click detector/classifier process.

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 D-2). The click train associator algorithm performs the following steps:

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 a species of interest (this finds 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’ with a value of 1 at the time of arrival for each click and zero everywhere else.

5. Apply a Hann window to the time series, and then compute the cepstrum.
6. A click train is classified if a peak in the cepstrum with an amplitude greater than five 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 (i.e., 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 Delta Time (dT; i.e., the difference in time between clicks) is less than two times the maximum 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 the cepstrum.
    b. ICI is the peak of the cepstrum with an amplitude greater than five times the standard deviation, and search for a quefrency between the minimum ICI (minICI) and maximum ICI (maxICI).
    c. For each click related to the previous Ncepstrum, create a new time series and compute ICI. If there is a good match, then extend the click train. Next, find the mean ICI and variance.
10. Output a click train detection if the click features, total clicks, and mean ICI match the species.

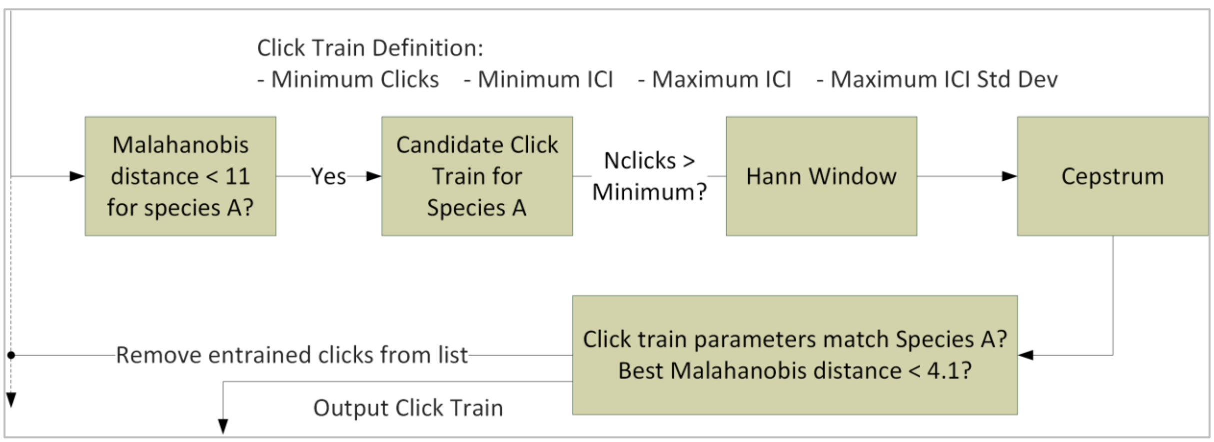

Figure D-2. Flowchart of the click train automated detector/classifier process.

D.2. Automated Tonal Signal Detection

Marine mammal tonal acoustic signals are automatically detected using a contour detection and following algorithm that is depicted in (Figure D-3). The algorithm has the following steps:

1. Create spectrograms of the appropriate resolution for each mammal vocalization type that were normalized by the median value in each frequency bin for each detection window (Table D-1).
2. Join adjacent bins and create contours via a contour-following algorithm (Figure D-4).
3. Apply a sorting algorithm to determine if the contours match the definition of a marine mammal vocalization (Table D-2).

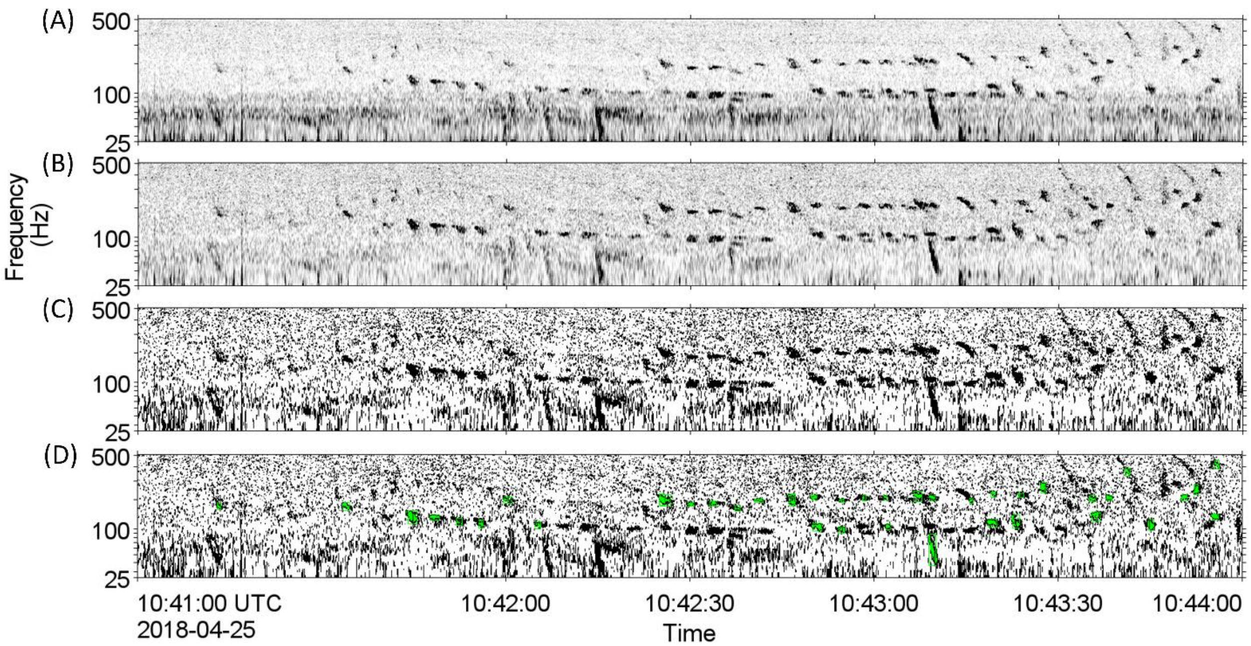

Figure D-3. Illustration of the contour detection process. (A) A spectrogram is generated at the frequency and time resolutions appropriate for the tonal calls of interest. (B) A median normalizer is applied at each frequency. (C) The data is turned into a binary representation by setting all normalized values less than the threshold to 0 and all values greater than the threshold to 1. (D) The regions that are ‘1’ in the binary spectrogram are connected to create contours, which are then sorted to detect signals of interest, shown here as green overlays.

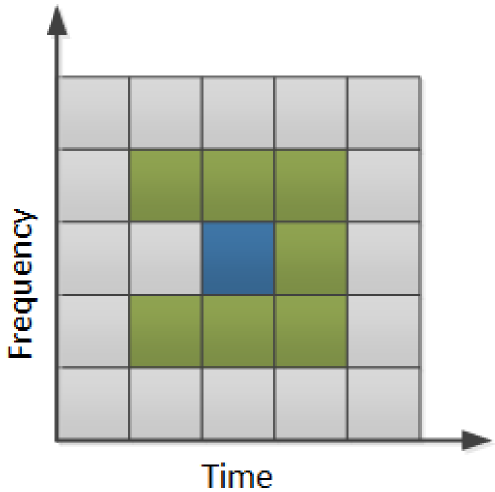

Figure D-4. Illustration of the search area used to connect spectrogram bins. The blue square represents a bin of the binary spectrogram equalling 1 and the green squares represent the potential bins it could be connected to. The algorithm advances from left to right, so grey cells left of the test cell 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 D-3).

Table D-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
MFMoanLowHighThreshold	4	0.2	0.05	5	5
MFMoanHigh	8	0.125	0.05	5	3
MFMoanHighHighThreshold	8	0.125	0.05	5	5
Low Whistle Supp	8	0.125	0.05	10	1.5
High Whistle Supp	64	0.015	0.005	10	1.5
Low Whistle Loud	8	0.125	0.05	10	4.5
Low Whistle Quiet	8	0.125	0.05	10	1.5
High Whistle Loud	64	0.015	0.005	10	4.5
High Whistle Quiet	64	0.015	0.005	10	1.5

Table D-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 to −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 to −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
MFMoanLowHighThreshold	Bowhead whale	100–700	0.5–5.0	>50	<450 Hz f_{min}; <200 MIB
MFMoanHigh	Bowhead whale	500–2500	0.50–5.00	>150	minF<1500 Hz InstantaneousBandwidth<300 Hz
MFMoanHighHighThreshold	Bowhead whale	500–2500	0.5–5.0	>150	<1500 Hz f_{min}; <300 MIB
LowWhistleSupp	Narwhal, beluga, and killer whale	1000–10000	0.8–5.0	>300	<5000 Hz f_{min}; <1000 MIB; 1 multi component; 50 min. component bandwidth; 0.4 min. component duration; suppress detections for high SPL (>125 dB) between 50–1000 Hz
HighWhistleSupp	Narwhal, beluga, and killer whale	4000–12000	0.3–5.0	>700	<2000 MIB; suppress detections for high SPL (>125 dB) between 50–1000 Hz
LowWhistleLoud	Narwhal, beluga, and killer whale	1000–10000	0.8–5.0	>300	<5000 Hz f_{min}; <1000 MIB; 1 multi component; 50 min. component bandwidth; 0.4 min. component duration
LowWhistleQuiet	Narwhal, beluga, and killer whale	1000–10000	0.8–5.0	>300	<5000 Hz f_{min}; MIB <1000 MIB; 1 multi component; 50 min. component bandwidth; 0.4 min. component duration
HighWhistleLoud	Narwhal, beluga, and killer whale	4000–12000	0.3–5.0	>700	<2000 MIB
HighWhistleQuiet	Narwhal, beluga, and killer whale	4000–12000	0.3–5.0	>700	<2000 MIB

Table D-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

D.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 D-5. 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.

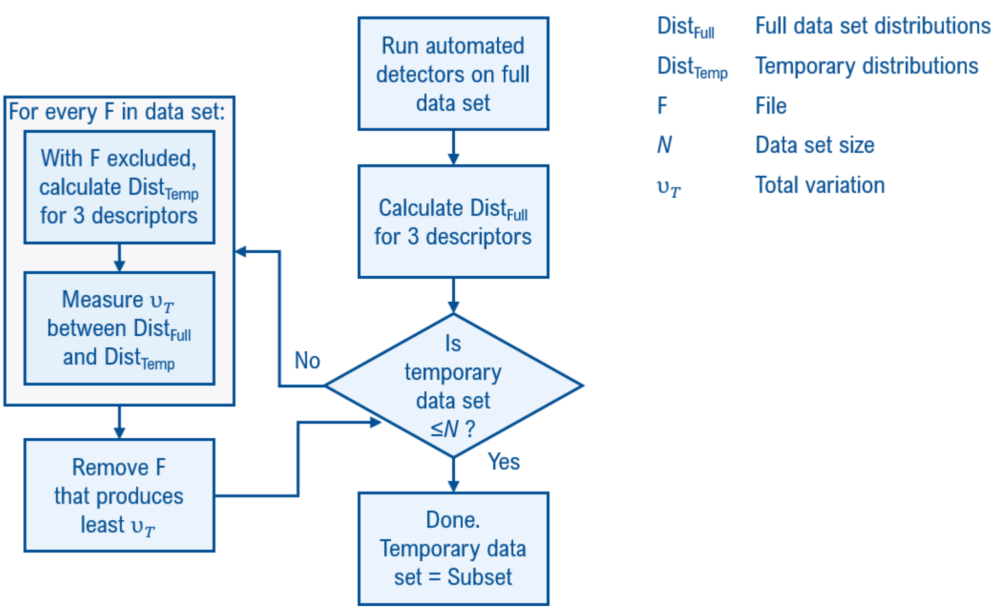

Figure D-5. Automated Data Selection for Validation (ADSV) process based on Figure 1 from Kowarski et al. (2021).

For the present work, an *N* of 2% 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 2% 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.

D.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 range of the number of automated detections per file within which detections of species were considered valid (bounded by a minimum and maximum).

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 E. Marine Mammal Automated Detector Performance Results

Table E-1 lists the automated detectors that triggered on species' vocalizations confirmed to occur in the data during manual analysis. The performance metrics of the detectors in Table E-1varied across species, vocalization types, and stations. 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 E-1). Automated detector results deemed reliable and refined to incorporate the classification threshold and exclusion periods are presented in Section 3.5. Beluga, narwhal, and sperm whale click detectors could only be evaluated for AMAR-EFE and AMAR-WFE where the sampling rate was sufficiently high to identify these signals.

Table E-1. Per-file performance of automated detectors by station including the detection-per-file threshold implemented, resulting Precision (P) and Recall (R), number of files in the validation sample (# Files), number of files in the sample containing an annotation (# A), and automated detections (# D) of the relevant species. The performance metrics are based on manual analysis of 2 % of the recording data. The threshold is a minimum number of automated detections required to consider the species present.

Species signal (Automated Detector)	Station	File length (min)	Temporal restriction	Threshold	P	R	MCC	TP	FP	FN	TN
Beluga click (Beluga Click)	AMAR-EFE	1	None	98	0.75	0.75	0.74	3	1	1	71
	AMAR-WFE	1	None	264	0.88	0.70	0.75	7	1	3	49
Beluga whistle (LowWhistleSupp)	AMAR-EFE	14	None	27	0.87	0.76	0.77	13	2	4	69
	AMAR-WFE	14	None	1	0.41	0.95	0.35	35	51	2	34
	AMAR-MI	10	None	2	0.53	0.79	0.41	37	33	10	60
Bowhead moans (MFMoanLow HighThreshold)	AMAR-EFE	14	None	2	0.53	0.26	0.22	8	7	23	69
	AMAR-WFE	14	Exclude 7–20 Jul 2022 and 1–8 Aug 2022	1	0.92	0.33	0.47	12	1	24	75
	AMAR-MI	10	None	6	0.36	0.40	0.32	4	7	6	101
Sperm whale click (SpermWhale ClickTrain)	AMAR-EFE	1	None	2	0.43	0.43	0.39	3	4	4	109
Bearded seal trill (Beardedseal_downsweep)	AMAR-EFE	14	None	3	0.38	0.75	0.50	3	5	1	90
Narwhal click (Narwhal Click)	AMAR-EFE	1	Exclude 14 Sep to 9 Oct 2021 and 30 Jul to 8 Aug 2022	3	1.00	0.95	0.96	40	0	2	71
	AMAR-WFE	1	Exclude 30 Jul to 8 Aug 2022	1	0.81	0.96	0.60	65	15	3	20
Narwhal click train (Narwhal ClickTrain)	AMAR-EFE	1	Exclude 14 Sep to9 Oct 2021 and 30 Jul to 8 Aug 2022	1	1.00	0.81	0.85	34	0	8	74
	AMAR-WFE	1	Exclude 30 Jul to 8 Aug 2022	1	0.86	0.81	0.54	55	9	13	26
Narwhal low-frequency buzz (Narwhal_LFbuzz)	AMAR-EFE	14	None	1	0.52	0.91	0.53	30	28	3	61
	AMAR-WFE	14	None	4	0.82	0.72	0.66	28	6	11	65
	AMAR-MI	10	None	1	0.89	0.98	0.89	55	7	1	79
Narwhal high-frequency buzz (Narwhal_HFbuzz)	AMAR-EFE	14	Exclude 14 Sep to 9 Oct 2021 and 30 Jul to 8 Aug 2022	1	1.00	0.86	0.91	24	0	4	94
	AMAR-WFE	14	None	1	0.88	1.00	0.89	52	7	0	64
	AMAR-MI	10	None	4	0.89	0.97	0.87	57	7	2	72
Narwhal knocks (NarwhalKnockTrain)	AMAR-EFE	14	Exclude 14 Sep to9 Oct 2021 and 30 Jul to 8 Aug 2022	25	0.84	0.93	0.84	26	5	2	82
	AMAR-WFE	14	None	123	0.36	0.94	0.43	17	30	1	46
	AMAR-MI	10	None	7	0.56	0.88	0.57	29	23	4	77
Narwhal tonal calls (Narwhal_Whistle)	AMAR-EFE	14	Exclude 14 Sep to 9 Oct 2021 and 30 Jul to 8 Aug 2022	1	0.87	0.89	0.83	33	5	4	80
	AMAR-WFE	14	Exclude 30 Jul to 8 Aug 2022	1	0.84	0.87	0.73	46	9	7	60
	AMAR-MI	10	None	1	0.87	0.80	0.69	55	8	14	65