Baffinland Iron Mines Corporation — Mary River Project

2023 Underwater Acoustic Monitoring Program (Open-Water Season)

JASCO Applied Sciences (Canada) Ltd

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Acronyms and Abbreviations

ADSV	Automatic Data Selection for Validation
AIS	Automatic Identification Systems
AMAR	Autonomous 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
DWT	Deadweight Tonnage
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
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)

ᐊᐅᓚᑦᑎᔨᓂᖕᒫᖅᑐᖅ ᓇᓄᓇᐃᖅᓯᔾᔪᑏᑦ

2023 ᐃᒫᓂ ᓂᐱᓂᒃ ᖃᐅᔨᓴᖅᐸᓪᓕᐊᖕᒋᓐᓇᕐᓂᕐᒧᑦ ᐱᓕᕆᐊᖅ ᓴᖅᑭᑕᐅᓚᐅᖅᑐᖅ ᔭᔅᑰ ᐊᑐᓕᖅᑎᑦᑎᓯᒪᔪᑦ ᑭᒡᓕᓯᓂᐊᕐᓂᕐᒥᒃ (JASCO), ᑲᑐᔾᔨᖃᑎᒌᒃᔪᑎᒃ WSP-ᑯᑦ ᐊᒻᒪᓗ ᐹᕙᓖᓐᑯᑦ, ᕿᒥᕐᕈᖁᓪᓗᒋᑦ ᐱᓕᕆᐊᕐᒨᑦ-ᐊᒃᑐᐊᑐᐃᓐᓇᕆᐊᓕᖕᓂᒃ ᐊᒃᑐᐃᓂᕐᓂᒃ ᑕᕆᐅᕐᒥ ᐳᐃᔨᓂᒃ ᐅᒥᐊᖅᔪᐊᑉ ᓂᐱᖏᓐᓂᑦ. ᑎᑭᓐᓇᓱᓪᓗᐊᑕᖅᑐᑦ ᑖᔅᓯᒪᙱᑦ ᐱᓕᕆᐊᕐᒥ ᑎᑎᕋᖅᑕᐅᖁᓪᓗᒋᑦ ᐊᒻᒪᓗ ᕿᒥᕐᕈᓗᒋᑦ ᖃᓂᒋᔭᖏᓐᓂᒃ ᐊᒻᒪᓗ ᐃᓄᖕᓂᖕᒫᖅᑐᑦ ᐃᒫᓂ ᓂᐱᖅᑯᖅᑐᓕᕇᑦ ᓂᐱᓕᐅᖅᑕᐅᓚᐅᖅᑐᑦ 2023-ᒥ ᒪᕐᕉᒃ ᓂᐱᓂᒃ ᖃᐅᔨᓴᖅᐸᓪᓕᐊᖕᒋᓐᓇᕐᓂᕐᒧᑦ ᖃᐅᔨᓴᕐᕕᖕᓂ. ᐊᑕᐅᓯᖅ ᖃᐅᔨᓴᕐᕕᒃ ᐃᓂᖃᓚᐅᖅᑐᖅ ᕿᖑᓂᐊᓂ (ᕿᖑᐊᓂ ᓂᐱᓕᐅᕈᑎ, AMAR-MI), ᑕᐃᑰᓇᓗ ᐹᕙᓖᓐᑯᑦ ᐅᐊᖕᓇᖕᒐᒨᑦ ᐅᒥᐊᕐᔪᐊᑦ ᐊᖅᑯᑖᒍᑦ 4 ᑭᓗᒦᑕᐸᓗᖕᓂᒃ ᑲᓇᖕᓈᔭᖅ−ᑲᓇᖕᓇ−ᐱᓇᖕᓇᖕᒐᓂ ᐃᓗᕕᓕᐅᑉ (ᐃᓗᕕᓕᒃ), ᐊᒻᒪᓗ ᐊᑕᐅᓯᖅ ᐃᓂᖃᓚᐅᖅᑐᖅ 2.5 ᑭᓗᒦᑕᐸᓗᖕᓂᒃ ᓯᒃᔭᖕᒐᓂ ᑕᐃᑲᓂ ᐃᓂᒥ (ᐃᓗᕕᓕᖕᒥ ᓂᐱᓕᐅᕈᑎ, AMAR-BH), ᐃᓗᐊᓂ ᐃᓂᐅᑉ ᐃᓗᕕᓕᖕᒥ ᓇᐅᑦᑎᖅᓱᕐᕕᖕᒥ ᐋᖅᑭᒃᓯᒪᓪᓗᑎᒃ ᖃᐅᔨᓴᐅᑎᒃᑯᑦ ᖃᐅᔨᓴᖅᐸᓪᓕᐊᖕᒋᓐᓇᕐᓃᑦ ᑑᒪᓖᑦ ᐃᓕᖅᑯᓯᖕᒋᓐᓂᒃ. ᓂᐱᓕᐅᕈᑏᑦ ᐋᖅᑭᒃᑕᐅᓚᐅᖅᑐᑦ ᐋᒡᒋᓯ 1-ᒥ ᐲᖅᑕᐅᓪᓗᑎᓪᓗ 9 ᐅᑐᐱᕆ 2023-ᒥ, ᐊᒻᒪᓗ ᓂᐱᓕᐅᕇᓐᓇᖅᓯᒪᔪᖅ ᑕᐃᔅᓱᒪᓇᐅᑎᓪᓗᒍ. ᓂᐲᑦ ᐹᕙᓖᓐᑯᑦ ᐅᒥᐊᕐᔪᐊᖃᖃᑦᑕᕐᓂᖕᒋᓐᓂᒃ 9 ᐅᑐᐱᕆ 2023-ᒥ ᓅᙳᐊᓄᑦ 2023 ᐅᒥᐊᕐᔪᐊᖃᕐᓇᒥ ᓂᐱᓕᐅᖅᑕᐅᓚᐅᖅᑐᑦ ᒪᕐᕉᖕᓂᒃ ᐃᓖᒃᑰᖅᑑᖕᓂᖅ ᐅᑮᓗᑎᒃ ᓂᐱᓕᐅᕈᑏᒃ, ᐲᖅᑕᐅᓛᖅᑐᑦ ᐋᒡᒋᓯ 2024-ᒥ.

ᕼᑲᓐᓂᐊᒍᑦ ᑎᑭᑕᐅᓇᓱᒃᑐᑦ ᐱᓕᕆᐊᒥ ᐃᒪᐃᑦᑑᓚᐅᖅᑐᑦ: ᓂᐱᑎᒍᑦ ᓇᓄᓇᐃᔭᖅᑕᐅᓗᑎᒃ ᑕᕆᐅᒥ ᐳᐃᔩᑦ ᐊᔾᔨᐤᒋᐊᕐᔫᑦ ᐆᒪᔪᑦ (ᓇᓄᓇᐃᕐᓗᒋᑦ ᑑᒪᓖᑦ) ᐱᑕᖅᑐᑦ ᑕᐅᕗᓇ ᐅᐊᖕᓇᖕᒐᒨᑦ ᐅᒥᐊᕐᔪᐊᑦ ᐊᖅᑯᑖᓂ 2023-ᒥ; ᕿᒥᕐᕈᔭᐅᖁᓪᓗᒋᑦ ᐱᓕᕆᐊᐸ-ᐅᒥᐊᕐᔪᐊᖕᒋᓐᓂᖕᒫᖅᑐᑦ ᓂᐱᖅᑯᖅᑐᓕᕇᑦ ᐊᒃᑐᐊᔪᑦ ᐱᑕᖅᑐᓂ ᑕᕆᐅᒥ ᐳᐃᔩᑦ ᓂᐱᖏᓐᓄᑦ ᖃᓄᐃᓪᓕᔪᖃᖅᑳᖅᑎᓐᓇᒍ ᑭᒡᓕᐅᔪᓄᑦ ᐋᓐᓂᕐᓂᕐᒧᑦ ᐊᒻᒪᓗ ᐸᕝᕙᓴᐃᓂᕐᒧᑦ ᖃᓄᐃᓐᓂᖅᓴᐅᓂᖕᒋᓐᓂᓪᓗ ᕿᒥᕐᕈᓂᖅ ᐆᒃᑐᕋᖅᑕᐅᓯᒪᔪᓂ ᓂᐱᖅᑯᖅᑐᓕᕇᓂ ᐅᒥᐊᕐᔪᐊᖃᖃᑦᑕᕐᓂᕐᒥ ᑕᐃᒃᑯᓄᖓ ᒥᒃᓴᐅᓴᒃᑕᐅᓯᒪᔪᑎᒍᑦ ᐊᑐᖅᐸᒋᑦ ᓂᐲᑦ ᐋᖅᑭᙳᐊᖅᑕᐅᓯᒪᔪᑦ ᐱᓕᕆᐊᖑᓚᐅᖅᑐᑦ ᐃᑲᔪᖅᑐᐃᖁᓪᓗᒋᑦ ᐊᕙᑎᒥ ᐊᕙᑎᒥᒃ ᐊᒃᑐᐃᓂᕐᓂᒃ ᖃᐃᔨᓴᕐᓂᕐᓄᑦ; ᓇᓄᓇᐃᔭᕐᓗᒋᑦ ᐱᕚᓪᓕᖅᑎᑕᐅᓯᒪᔪᑦ ᐊᖕᒋᔪᕐᔪᐊᓂ ᓴᕝᓴᓂᒃ ᐅᓯᔫᓴᓂᒃ ᓄᓇᖕᒐᓂ ᓂᐱᖃᕐᕕᐅᔪᓂ; ᒥᒃᓴᐅᓴᒃᑕᐅᖁᓪᓗᒋᑦ ᐊᖕᒋᓂᒋᑦ ᑐᓴᕝᕕᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓱᒋᐊᖅᓯᒪᓂᖕᒋᑦ (LRR) ᐊᒃᑐᐊᔪᑦ ᐱᓕᕆᐊᒥ ᐅᒥᐊᕐᔪᐊᓄᑦ ᐊᒃᑐᐊᓂᖃᖅᑐᓄᑦ ᓂᐱᖃᐃᓐᓇᖅᑐᓄᑦ. ᐊᕐᕌᒍᒥᑦ ᐊᕐᕌᒍᒧᑦ ᖃᓄᐃᓐᓂᖅᓴᐅᙱᓐᖓᑕ ᕿᒥᕐᕈᓃᑦ ᑖᒃᑯᓇᓂ ᑐᓴᕝᕕᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓱᒋᐊᖅᓯᒪᓂᖕᒋᑦ (LRR) ᓈᓴᐅᓯᕆᔾᔪᑏᑦ ᑕᐃᒪᙵᓂ 2018-ᒥ ᐋᖅᑭᒃᑕᐅᓚᐅᖅᑐᑦ.

ᑕᒪᐃᓐᓄ, ᖃᐅᔨᔭᐅᔪᑦ 2023 ᓂᐱᓂᒃ ᖃᐅᔨᓴᖅᐸᓪᓕᐊᖕᒋᓐᓇᕐᓂᒧᑦ ᐱᓕᕆᐊᒥ ᒪᓕᒃᑐᑦ ᖃᐅᔨᔭᐅᓯᒪᔪᓂᒃ ᐊᕐᕋᒎᓚᐅᖅᑐᓂ ᓂᐱᓂᒃ ᖃᐅᔨᓴᖅᐸᓪᓕᐊᖕᒋᓐᓇᕐᓂᕐᒧᑦ ᐱᓕᕆᐊᓂᑦ ᐱᓕᕆᐊᖑᓚᐅᖅᑐᖅ ᔭᐊᒃᑰᒃᑯᓐᓂ ᓄᓇᓂ ᐊᕕᒃᓯᒪᔪᓂ ᖃᐅᔨᓴᕝᕕᐅᔪᒥ ᑕᐃᒪᙵᓂ 2018-ᒥᓂᑦ (ᕗᕆᐃᓐ−ᒍᐃ ᐃᑦ ᐊᑕᖕᒋᖅᓱᑎᒃ 2019, ᕗᕆᐃᓐ−ᒍᐃ ᐊᑕᖕᒋᖅᓱᑎᒃ 2020, ᐊᒃᑕᓐ ᐊᑕᖕᒋᖅᓱᑎᒃ 2022ᐃ, ᐊᒃᑕᓐ ᐊᑕᖕᒋᖅᓱᑎᒃ 2022ᐱ, ᐊᒃᑕᓐ ᐊᑕᖕᒋᖅᓱᑎᒃ 2023). ᖃᐅᔨᔭᐅᔪᑦ ᓴᖅᑮᔭᖅᑎᑦᑎᔪᑦ ᓂᐲᑦ ᐱᓕᕆᐊᕐᒥ ᐅᒥᐊᕐᔪᐊᓂᑦ ᑐᓴᔭᐅᔪᓐᓇᖅᑐᑦ ᐃᒫᓂ ᓂᐱᖃᕐᕕᐅᔪᒥ, ᐅᒥᐊᖅᔪᐊᑦ ᓂᐱᖃᖅᑎᑦᑎᓂᖕᒐ ᑖᕙᓂᓚᐅᑲᐅᓗᓂ (ᑐᓴᖅᑕᐅᔪᓐᓇᖅᑐᑦ 21 %-ᒥ ᓂᐱᓕᐅᓂᕐᓂᑦ ᑕᐃᒪᙱᓕᒫᐸᓗᒃ) ᐊᒻᒪᓗ ᑐᖕᒐᓃᕗᑎᒃ ᓂᐱᖅᑯᖅᑐᓕᕇᑦ ᓂᐱᑎᒍᑦ ᓱᕋᐃᔪᓐᓇᖅᑐᑦ. ᕿᒥᕐᕈᔭᐅᔪᑦ ᐊᒃᑐᐊᓂᓖᑦ ᓂᐱᖃᕐᕕᐅᔪᒥ ᓂᐱᖅᑯᖅᑐᓕᕇᑦ (SPL) 120 ᑕᓯᐳᓪ (dB re 1 µPa) (ᓱᕐᓗ ᒦᓇ ᓂᐱᒃᑯᑦ ᐸᒡᕕᓴᐃᓃᑦ ᖃᓄᐃᓪᓕᔪᖃᖅᑳᖅᑎᓐᓇᒍ ᑭᒡᓕᐅᔪᑦ ᐊᑐᖅᑕᐅᕙᔾᔪᑦ ᓴᓇᕝᕙᐅᔪᓂ ᕚᕙᒪᒃᑯᓐᓂᓗ ᕿᒥᕐᕈᑎᓪᓗᒋᑦ ᐸᒡᕕᓴᐃᓂᕐᓂᒃ ᑕᕆᐅᒥ ᐳᐃᔨᓂᒃ ᓂᐱᖃᐃᓐᓇᖅᑐᓄᑦ ᓱᕐᓗ ᐅᒥᐊᕐᔪᐊᑦ ᓂᐃᖕᒋᑦ, ᐊᒻᒪᓗ ᖃᓄᐃᓪᓕᔪᖃᖅᑳᖅᑎᓐᓇᒍ ᐱᓕᕆᐊᒥ ᕿᒥᕐᕈᔭᐅᓯᒪᔪᑦ ᐊᒻᒪᓗ ᓈᒻᒪᒋᔭᐅᓪᓗᑎᒃ), ᓂᐱᖃᕐᕕᐅᔪᑦ ᐊᑯᓂᐅᓂᖕᒋᑦ ᑐᖕᒐᓃᕙᒃᓯᒪᔪᑦ 0.5 ᐅᓪᓗᑕᒦᑦ. ᑕᒪᓐᓇ ᒪᓕᒃᑐᖅ ᐊᒃᑐᐃᓂᕐᓄᑦ ᓇᓚᐅᑦᑖᖅᑕᐅᓯᒪᔪᓂᒃ ᑕᒪᓐᓇ ᓂᐱᓂᖕᒫᖅᑐᑦ ᐊᒃᑐᐃᓂᖅ ᓄᓇᖕᒐᓂᑐᐃᓐᓇᐅᔪᖅ ᐊᒻᒪᓗ ᒦᓇᓚᐅᑲᐅᓪᓗᓂ ᐱᕙᖅᑯᖅᑐᔪᒪᕆᐅᓪᓗᓂᓗ ᖃᐅᑖᒦᑦ ᑕᕆᐅᒥ ᐳᐃᔩᑦ ᐸᒡᕕᓴᒃᑕᐅᙱᓐᓂᖕᒋᑦ ᐱᓕᕆᐊᒥ ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖏᓐᓄᑦ.

ᐃᒫᓂ ᓂᐱᓕᐅᖅᑕᐅᔪᓘᒃᑖ ᐅᖃᐅᓯᐅᓯᒪᔪᑦ ᑕᕝᕙᓂ ᓂᐱᓕᐅᖅᑕᐅᓚᐅᖅᑐᑦ ᓯᑯᖃᙱᑎᓪᓗᒍ ᐅᒥᐊᕐᔪᐊᖃᕐᓇᒥ ᓯᑯᓂᒃ ᐊᔭᐅᖅᑐᐃᓂᖅᑕᖃᙱᓐᓂ. ᓂᐱᖅᑯᖅᑐᕐᔪᐊᖅᑐᑦ ᓂᐱᖅᑯᖅᑐᓕᕇᑦ 2023-ᒥ (ᐊᑕᐅᓯᖅ-ᑎᑦᑕᒥᒃ ᐊᑯᓂᐅᓂᖃᕆᐊᒃᑐᑦ) ᐃᒪᓐᓇᑎᑦᕆᐅᓚᐳᖅᑐᑦ 111.5 ᐊᒻᒪᓗ 108.1 ᑕᓯᐳᔅ, ᐊᒃᑐᐊᓂᖁᑦ 1 ᒪᐃᑯᐹᒃᑯᓪ (dB re 1 µPa) ᕿᙴᐊᓂ ᐃᓗᕕᓕᖕᒥᓗ ᓂᐱᓕᐅᕈᑎᓂ, ᐃᓱᒪᕆᓪᓗᒋᑦ (ᓂᐱᑯᖅᑐᕐᔪᐊᖅᑐᑦ ᓂᐃᖅᑯᖅᑐᓕᕇᑦ 97.9 ᐊᒻᒪᓗ 97.2 dB re 1 µPa). ᓂᐱᖅᑯᖅᑐᓕᕇᑦ (SEL) ᐅᖕᒐᑕᐅᔾᔨᓚᐅᖅᓯᒪᙱᑦᑐᑦ ᖃᓄᐃᓪᓕᔪᖃᖅᑳᖅᑎᓐᓇᒍ ᑭᒡᓕᐅᔪᓂ ᓂᐱᓂᑦ ᐋᓐᓂᕐᓂᕐᒨᑦ ᐊᒃᑐᐊᔪᑦ ᑕᕆᐅᒥ ᐳᐃᔨᓄᑦ (ᓱᕐᓗ ᒦᓇᓚᐅᑲᒃ ᐅᕙᓘᓐᓃᑦ ᑐᓴᑦᑎᐊᕈᓐᓃᓪᓚᑦᑖᖅᓱᑎᒃ) ᓇᓕᐊᖕᓂᑐᐃᓐᓇᖅ ᑖᒃᑯᓇᓂ ᐱᖕᒐᓱᓂ ᓂᐱᓕᐅᕐᕕᐅᔪᓂ. ᐊᑕᐅᓯᖅ-

ᑎᑦᑕᐅᒐᔪᒃᑐᑦ ᓂᐱᖃᕐᕕᐅᔪᒥ ᓂᐱᖅᑯᖅᑐᓕᕇᑦ (SPL) ᐃᓛᓐᓂᒃᑯᑦ ᐅᖓᑕᐅᔾᔨᓂᖅ 120 dB re 1 µPa ᑕᓇᐅᒥ ᐸᐃᔨᓂᒃ ᐸᒡᕕᓴᐃᓂᕐᓄᑦ ᖃᓄᐃᓪᓕᔪᖃᖅᑲᖅᑎᓐᓇᒍ ᑮᓪᓕᐅᔪᓂ ᐊᑐᓂ ᖃᐅᔨᓴᕐᕕᐅᔪᓂ; 1.9 % ᐊᒻᒪᓗ 1.2 % 69-ᓂ ᐅᓪᓗᓂ ᓂᐱᓕᐅᕆᓂᕐᓂ ᕿᙳᐊᓂ ᐊᒻᒪᓗ ᐃᓗᕕᓕᖕᒥ, ᐃᓱᒪᒋᓪᓗᒋᑦ.

ᓂᐲᑦ ᒪᕿᖕᓂ ᑐᓇᐅᒥ ᐳᐃᔨᓂᒃ ᐆᒪᔪᑦ ᐊᔾᔨᒌᙱᐊᕐᔪᒃᑐᓂ (ᐊᕐᕕᒃ ᐊᒻᒪᓗ ᑑᒑᓕᑦ) ᓇᓗᓇᐃᖅᑕᐅᓯᒪᔪᑦ ᓂᐱᓕᐅᖅᑕᐅᓯᒪᔪᓂ, ᖄᒃᑲᓐᓂᐊᒍᑦ ᑲᖏᓱᒃᑐᑦ ᓂᐱᑕᖃᕐᓂᖓᓂᒃ ᓇᑦᑎᐅᔭᓂᑦ ᖃᑯᖅᑕᓂ ᕿᓚᓗᒐᕐᓂᐅᔫᖅᓴᐅᔪᕐᓗ. ᖃᖓᒃᑰᓂᖏᑦ ᑑᒑᓖᑦ ᓂᐱᖏᑦ ᑐᓴᖅᑕᐅᔪᑦ ᕿᙳᐊᓂ ᒪᓕᑐᐃᓐᓇᓚᐅᖅᑐᑦ ᓂᐱᓕᐅᖅᑕᐅᓂᑯᓂᒃ ᑲᑎᑕᐅᓚᐅᖅᑐᑦ ᐊᕐᕋᒍᑕᒱᖅᓯᐅᑏᑦ ᖃᐅᔨᓴᖅᐸᓪᓕᐊᖏᓐᓇᕐᓂᕐᓂ ᐱᓕᕆᐊᓂ 2018-ᒥᓂᑦ. ᖃᑯᖅᑕᑦ ᕿᓚᓗᒐᑦ ᓂᐱᖏᑦ ᑐᓵᔭᐅᓇᓱᒋᓯᒪᔪᑦ ᐱᔾᔪᑕᐅᓪᓗᑎᒃ ᐱᓕᕆᔾᔪᔾᑦ ᐊᔾᔨᒌᙱᓕᖅᑎᑦᑎᔾᔪᑏᑦ ᕿᓚᓗᒐᑦ ᓂᐱᖏᑦ ᑐᓴᖅᓴᐅᓚᐅᕐᓂᖏᓐᓄᑦ ᑕᐃᑲᓂ (ᔫᓐ ᐊᑕᖏᖅᖠᑎᒃ 2021), ᓇᓗᓇᐃᖅᓯᓪᓗᑎᒃ ᖃᑯᖅᑕᑦ ᕿᓚᓗᒐᑦ ᑲᖏᑭᔭᐅᔪᑦ ᐃᓛᓐᓂᒃᑯᑦ ᑕᐅᕝᕕᓃᑉᐸᖕᓂᖏᓐᓄᑦ ᓄᓇᓂ ᐊᕕᒃᑐᖅᓯᒪᔪᓂ ᐃᓚᐅᓪᓗᑎᒃ ᖃᓂᒋᔭᓂᓘᓐᓃᑦ ᑑᒑᓖᑦ. ᐊᕐᕖᑦ ᓂᐱᖃᕐᓂᖏᑦ ᓂᐱᖃᕐᓂᖏᑦ ᑐᓵᔭᐅᔪᓐᓇᖅᓯᒪᔪᑦ (ᐊᒻᒪ ᐱᓕᕆᐊᖑᓪᓚᑦᑖᖅᓗᓂ ᖃᐅᔨᔭᐅᔪᖅ) ᐃᓛᓐᓂᒃᑯᑦ ᑕᒪᕐᒦᖕᓂᒃ ᖃᐅᔨᓴᕐᕕᖕᓂ. ᐃᓚᖏᑦ ᓂᐲᑦ ᓇᓗᓇᐃᖅᓯᔾᔪᑏᑦ ᒪᓕᒃᑐᑦ ᑕᐃᒃᑯᓄᖓ ᓂᐱᖃᖅᑎᑕᐅᔪᓂᒃ ᓇᑦᑎᕐᓂᒃ ᑐᓵᔭᐅᖃᑦᑕᓚᐅᕐᒥᔪᑦ ᓂᐱᓕᐅᕐᓂᓕᒫᖏᓐᓂ.

ᐅᒥᐊᕐᔪᐊᑦ ᑐᓵᔭᐅᔪᓐᓇᓚᐅᖅᑐᑦ 21 ᐊᒻᒪᓗ 20 %-ᒥᒃ ᑖᒃᑯᓇᓂ 2023 ᓂᐱᓕᐅᕆᓂᕐᓂ ᕿᙳᐊᓂ ᐊᒻᒪᓗ ᐃᓗᕕᖕᒥ ᓂᐱᓕᐅᕈᑎᓂ, ᐅᖃᐅᓯᑎᓪᓗᒋᑦ. ᑑᓵᕙᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓯᒋᐊᖅᓯᒪᓂᖏᑦ (LRR) - ᐃᓚᐅᓐᓇᖓᒍᑦ ᓂᐱᒃᓯᒋᐊᖅᓯᒪᔪᑦ ᑑᓵᕙᐅᔪᓐᓇᖅᑐᒥ ᑕᓇᐅᒥ ᓂᕐᔪᑎᓂᒃ - ᖃᓇᓴᐅᔭᒃᑯᓕᖅᑎᑕᐅᓪᓗᑎᒃ ᐊᑐᓂ ᓂᐱᓕᐅᕐᕖᑦ ᐱᖓᓱᓄᑦ ᖃᑕᐃᓕᓅᓄᑦ, ᐊᑐᓂ ᑭᒡᒐᖅᓯᐃᔪᑦ ᐊᔾᔨᒌᙱᑦᑐᓄᑦ ᑑᒑᓖᑦ ᓂᐱᖃᐅᓯᙱᑦᑎᒍᑦ: 1 ᑭᓗᕼᐉᑦ (ᑭᓗᕼᐉᑦ; ᑭᒡᒐᖅᓯᐃᔪᖅ ᑑᒑᓖᑦ ᓂᓪᓕᒃᑳᓪᓚᒃᑕᖅᑐᑦ), 5 ᑭᓗᕼᐉᑦ (ᑭᒡᒐᖅᑐᐃᔪᑦ ᐅᕙᖕᓂᐊᖅᑐᓂᒃ ᐊᒻᒪᓗ ᑲᓱᒃᑐᖅᐸᓪᓚᑦᑎᔪᓂᒃ) ᐊᒻᒪᓗ 25 ᑭᓗᕼᐉᑦ (ᑭᒡᒐᖅᑐᐃᔪᑦ ᑲᓱᒃᑐᖅᑑᔭᖅᑐᓂᒃ ᐊᒻᒪᓗ ᖃᑕᐃᓪᓚᓇᒃᑐᑦ ᓂᓪᓕᒃᑳᓪᓚᒃᑕᕐᓃᑦ). ᑭᐅᓇᓯᐊᖅᖢᒋᑦ ᑐᒃᓯᕋᖅᑕᐅᔪᑦ ᑕᓇᐅᒥ ᐊᕙᑎᖓᓄᑦ ᐱᓕᓇᖃᑎᒌᑦ, ᔮᒃᑯᑦᑐᑦ ᐋᖅᑭᒃᓱᐃᓯᒪᔪᑦ ᐊᕐᕋᒎᒥᑦ-ᐊᕐᕋᒎᒧᑦ ᖃᓄᐃᓐᓂᖅᓴᐅᖕᒪᖔᑕ ᕿᒥᕈᓂᕐᓂᒃ ᑑᓵᕙᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓯᒋᐊᖅᓯᒪᓂᖏᓐᓄᑦ (LRR) ᓈᓴᐅᓯᓇᔾᔪᑎᓂᒃ. ᑑᓵᕙᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓯᒋᐊᖅᓯᒪᓂᖏᓐᓂᑦ (LRR) ᖃᐅᔨᔭᐅᔪᑦ ᐊᑐᓂ ᐱᖓᓱᓄᑦ ᖃᑕᐃᓕᓅᓄᑦ ᓇᐃᓪᓕᑎᖅᑕᐅᓯᒪᔪᑦ ᐃᒪᓐᓇ:

1ᑭᓗᕼᐉᑦ (ᓂᓪᓕᒃᑳᓪᓚᑲᑕᖕᓃᑦ):

2023-ᒥ, ᐅᓄᕐᓂᖅᓴᑦ 50 % ᑑᓵᕙᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓯᒋᐊᖅᓯᒪᓂᖏᓐᓄᑦ (LRR) ᓂᐱᖃᖅᑐᓄᑦ 1 ᑭᓗᕼᐉᑦ ᑐᓴᖅᑕᐅᓃᑦ 4.4 ᐊᒻᒪᓗ 2.6 %-ᓂ ᐅᒥᐊᕐᔪᐊᑦ ᑐᓴᖅᓴᐅᑎᓪᓗᒋᑦ (ᓅᕐᓗ 0.9 ᐊᒻᒪᓗ 0.5 % ᓂᐱᓕᐅᕆᑎᓪᓗᒋᑦ) ᕿᙳᐊᓂ ᐊᒻᒪᓗ ᐃᓗᕕᓕᖕᒥ ᓂᐱᓕᐅᕈᑎᓂ, ᐅᖃᐅᓯᖃᖅᑎᓪᓗᑕ. ᓂᐱᖃᐃᓐᓇᖅᑐᑦ ᐱᕙᓪᓕᐊᑎᑦᑎᓂᕐᓂᒃ ᑑᓵᕙᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓯᒋᐊᖅᓯᒪᓂᖏᓐᓄᑦ (LRR) 1 ᑭᓗᕼᐅᑦᒥ ᓇᓕᐊᖕᓂᑐᐃᓐᓴᖅ ᓂᐱᓕᐅᕆᕝᕕᖕᓂ, ᐱᔾᔪᑎᒋᓪᓗᒋᑦ ᑑᓴᓂᕐᒧᑦ ᖃᓄᐃᓪᓕᔪᖃᖅᑲᖅᑎᓐᓇᒍ ᑮᓪᓕᐅᔪᑦ ᑑᒑᓖᖕᓄᑦ 1 ᑭᓗᕼᐅᑦᒥᒃ ᓂᐱᖅᑯᖅᑐᓂᖅᓵᕐᔪᒃ ᓂᐱᖃᐃᓐᓇᑦᑯᒃ ᓂᐱᖅᑯᖅᑐᓕᕇᓂᑦ ᓇᓕᐊᖕᓄᓪᓚᑦᑖᖅ ᖃᑕᐃᓐᓂᐅᔪᒥ. ᑕᒪᒃᑯᐊ ᑑᓵᕙᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓯᒋᐊᖅᓯᒪᓂᖏᓐᓄᑦ (LRR) ᓈᓴᐅᑏᑦ ᕿᙳᐊᓂ ᑐᖕᓕᓃᓐᓂᖅᓵᕐᔪᐃᑦ ᓈᓴᐅᑎᓂ ᖃᓇᓴᐅᔭᒧᐊᖅᑕᐅᔪᓂ ᑕᐅᕝᕕᓪᓴᐃᓐᓇᖅ ᐊᕐᕋᒎᓚᐅᖅᓯᒪᔪᓂ (2019 – 2022), ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖏᑦ ᓂᐱᖅᑯᖅᑎᓂᖅᓴᐅᑎᓪᓗᒋᑦ 50 %-ᒥᒃ ᓂᐱᓄᑦ 1 ᑭᓗᕼᐉᑦ ᐊᑯᓐᓂᖓᓂ 1.2 ᐊᒻᒪᓗ 1.9 % ᑲᑎᓗᒃᑖᖅᖢᒋᑦ ᓂᐱᓕᐅᕐᓂᐅᔪᓂ ᑲᑎᑕᐅᓯᒪᔪᑦ ᑖᒃᑯᓄᖓ ᐊᕐᕋᒍᓄᑦ.

5 ᑭᓗᕼᐃᐅᑦ (ᐅᕕᖕᓂᐊᖅᑐᑦ/ᑲᓱᒃᑐᖅᐸᓚᕐᑎᔪᑦ):

2023-ᒥ, ᐅᓄᕐᓂᖅᓴᖅ 50 %-ᒥᒃ ᑐᓵᕝᕕᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓰᕆᐊᖅᓯᒪᓂᖏᓐᓄᑦ (LRR) ᓂᐲᑦ 5 ᑭᓗᕼᐃᐅᑦᒥ 23.4 ᐊᒻᒪᓗ 28 %-ᓂ ᐅᒥᐊᕐᔪᐊᑦ ᑐᓵᔭᐅᔪᓐᓇᖅᑎᓪᓗᒋᑦ (ᓱᕐᓗ 4.9 % ᐊᒻᒪᓗ 5.6 % ᓂᐱᓕᐅᕐᓂᐅᔪᓂ) ᕿᙵᐊᓂ ᐊᒻᒪᓗ ᐃᓗᕖᓕᖕᒥ ᓂᐱᓕᐅᕈᑎᓂᒃ ᐅᖃᐅᓯᖃᖅᑎᓪᓗᑕ. ᓂᐱᖃᐃᓐᓇᖅᑐᑦ ᑐᓵᔭᐅᔪᑦ ᓂᐱᖅᑯᖅᑐᓂᖅᓴᐅᓪᓗᑎᒃ 50 % ᑐᓵᕝᕕᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓰᕆᐊᖅᓯᒪᓂᖏᓐᓄᑦ (LRR) ᓂᐱᓄᑦ 5 ᑭᓗᕼᐃᐅᑦ 22.1 ᐊᒻᒪᓗ 27.7 %-ᒥ ᓂᐱᓕᐅᖅᑎᓪᓗᒋᑦ ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖃᖅᑎᓐᓇᒋᑦ (ᓱᕐᓗ 17.5 % ᐊᒻᒪᓗ 22.2 % ᓂᐱᓕᐅᕆᓂᕐᓂ) ᕿᙵᐊᓂ ᐊᒻᒪᓗ ᐃᓗᕖᓕᖕᒥ ᓂᐱᓕᐅᕈᑎᓂ 2023-ᒥ. ᑕᒪᒃᑯᐊ ᐅᒥᐊᕐᔪᐊᑦ–ᐱᓪᓗᒋᑦ ᑐᓵᕝᕕᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓰᕆᐊᖅᓯᒪᓂᖏᓐᓄᑦ (LRR) ᓈᓴᐅᑎᖏᑦ ᕿᙵᐊᓂ ᑖᒃᑯᓇᓂ ᓈᓴᐅᑎᓂ ᖃᕆᓴᐅᔾᒃᑰᖅᑐᓂ ᑕᐅᕙᓂᓵᐃᓐᓇᖅ ᐊᑯᓐᓂᖓᓂ 2019 ᐊᒻᒪᓗ 2022, ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖃᕐᓂᖏᑦ ᓴᖅᑮᓯᒪᓪᓗᑎᒃ ᓂᐱᖅᑯᖅᑐᓂᖅᓴᓂ 50 % ᑐᓵᕝᕕᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓰᕆᐊᖅᓯᒪᓂᖏᓐᓄᑦ (LRR) ᓂᐱᓄᑦ 5 ᑭᓗᕼᐃᐅᑦᓄᑦ ᐅᓄᕐᓂᖅᓴᐅᓪᓗᑎᒃ 8 %-ᒥᒃ ᑲᑎᓗᒃᑖᖅᑯᒋᑦ ᓂᐱᓕᐅᕐᓂᐅᔪᓂ ᑖᒃᑯᓇᓂ ᐊᕐᕌᒍᓂ. ᓂᐱᖃᐃᓐᓇᖅᑐᑦ ᕿᙵᐊᓂ ᓴᖅᑮᓯᒪᔪᑦ ᓂᐱᖅᑯᖅᑐᓂᖅᓴᓂ 50 %-ᒥ ᑐᓵᕝᕕᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓰᕆᐊᖅᓯᒪᓂᖏᓐᓄᑦ (LRR) ᓂᐱᓄᑦ 5 ᑭᓗᕼᐃᐅᑦ ᐊᑯᓐᓂᖓᓂ 8 ᐊᒻᒪᓗ 18 % ᑲᑎᓗᒃᑖᖅᑯᖏᑦ ᓂᐱᓕᐅᕆᓂᕐᓂ ᑲᑎᑕᐅᓯᒪᔪᓂ ᑭᖑᓂᖓᑦᑎᓐᓂ ᐊᕐᕋᒍᓂ (2019-2022), ᒪᓕᒃᑐᑦ ᑕᒪᑐᒪᓂ ᐊᕐᕋᒎᒥ ᐆᒃᑐᕋᐅᑕᐅᔪᓂ 2023-ᒥ ᖃᐅᔨᓴᐅᔪᓂ.

25 ᑭᓗᕼᐃᐅᑦ ᑲᓱᒃᑐᖅᑑᔭᖅᑐᓂᒃ / ᖃᑕᐃᓪᓚᕆᒃᑐᑦ ᓂᓪᓕᑳᓪᓚᒃᑕᕐᓅᑦ).

2023-ᒥ, ᓂᐱᖅᑯᖅᑐᓂᖅᓴᖅ 50 %-ᒥᒃ ᑐᓵᕝᕕᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓰᕆᐊᖅᓯᒪᓂᖏᓐᓄᑦ (LRR) ᓂᐱᓄᑦ 25 ᑭᓗᕼᐃᐅᑦ ᑐᓴᖅᓴᐅᔪᑦ 20.4 ᐊᒻᒪᓗ 20.5 % ᐅᒥᐊᕐᔪᐊᑦ ᑐᓴᖅᓴᐅᑎᓪᓗᒋᑦ (ᓱᕐᓗ 4.3 ᐊᒻᒪᓗ 4.1 ᓂᐱᓕᐅᕐᓂᕐᓂ) ᕿᙵᐊᓂ ᐃᓗᕖᓕᖕᒥᓗ ᓂᐱᓕᐅᕈᑎᓂ, ᐅᖃᐅᓯᖃᖅᑎᓪᓗᑕ. ᓂᐱᖃᐃᓐᓇᖅᑐᑦ ᓴᖅᑮᔪᑦ ᐅᖓᑖᓂ 50 % ᑐᓵᕝᕕᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓰᕆᐊᖅᓯᒪᓂᖏᓐᓄᑦ (LRR) ᓂᐱᓄᑦ 25 ᑭᓗᕼᐃᐅᑦ 22 ᐊᒻᒪᓗ 24.6 %-ᒥ ᓂᐱᓕᐅᕐᓂᐅᔪᓂ ᐅᒥᐊᕐᔪᐊᑦ ᓂᐱᖃᖅᑎᓐᓇᒋᑦ (ᓱᕐᓗ 17.4 ᐊᒻᒪᓗ 19.7 % ᑐᓵᕝᕕᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓰᕆᐊᖅᓯᒪᓂᖏᓐᓄᑦ (LRR) ᓂᐱᓕᐅᕐᓂᐅᔪᓂ) ᕿᙵᐊᓂ ᐃᓗᕖᓕᖕᒥᓗ ᓂᐱᓕᐅᕈᑎᓂ, ᐅᖃᐅᓯᖃᖅᑎᓪᓗᑕ. ᑕᒪᒃᑯᐊ ᐅᒥᐊᕐᔪᐊᑦ-ᐱᓪᓗᒋᑦ ᑐᓵᕝᕕᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓰᕆᐊᖅᓯᒪᓂᖏᓐᓄᑦ (LRR) ᓈᓴᐅᑎᖏᑦ ᕿᙵᐊᓂ ᒪᓕᒃᑐᑦ ᖃᐅᔨᓴᐅᔪᓄᑦ ᑕᐅᕙᓂ ᐃᓂᒥ 2021-ᒥ 2022-ᒧᑦ ᐊᒻᒪᓗ ᐊᒃᐸᓯᖕᓂᖅᓴᐅᔪᑦ ᓈᓴᐅᑎᖏᑦ ᖃᓇᓴᐅᔭᒧᐊᖅᑕᐅᔪᑦ 2019-ᒥ ᐊᒻᒪᓗ 2020-ᒥ (ᓂᐱᖅᑯᖅᑐᓂᖅᓴᑦ 50 % ᑐᓵᕝᕕᐅᔪᓐᓇᖅᑐᑦ ᒥᒃᓰᕆᐊᖅᓯᒪᓂᖏᓐᓄᑦ (LRR) ᓂᐱᓄᑦ 25 ᑭᓗᕼᐃᐅᑦ ᐊᑯᓐᓂᖓᓂ 10 ᐊᒻᒪᓗ 26 % ᑲᑎᓗᒃᑖᖅᑯᒋᑦ ᓂᐱᓕᐅᕆᓂᐅᔪᓂᑦ ᑲᑎᑕᐅᕙᓪᓕᐊᑎᓪᓗᒋᑦ ᐊᕐᕌᒎᓚᐅᖅᓯᒪᔪᓂ (2019-2022), ᒪᓕᒃᑐᑦ 2023-ᒥ ᖃᐅᔨᓴᐅᔪᓂ.

Executive Summary

The 2023 Underwater Acoustic Monitoring Program was developed by JASCO Applied Sciences (JASCO), in collaboration with WSP 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 2023 at two acoustic monitoring stations. One station was located in Milne Inlet (Milne Inlet recorder, AMAR-MI) along Baffinland's Northern Shipping Route approximately 4 km south-south-west of Iluvilik (Bruce Head), and one was located approximately 2.5 km inshore from that location (Bruce Head recorder, AMAR-BH) within the area where the Bruce Head observation team monitors narwhal behaviour. The recorders were deployed on 1 Aug and retrieved on 9 Oct 2023, and recorded continuously during this period. Noise from Baffinland shipping activities from 9 Oct 2023 through the end of the 2023 shipping season were recorded on two separate over-winter acoustic recorders that will be retrieved in August 2024.

Additional objectives of the program were: to acoustically identify marine mammal species (notably narwhal) present along the Northern Shipping Route in 2023; 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 those predicted through acoustic modelling conducted in support of the environmental effects assessment; to characterize the contribution of Capesize ore carriers to the local underwater soundscape; 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 2023 acoustic monitoring program are consistent with results from previous annual acoustic monitoring programs conducted by JASCO in the Regional Study Area (RSA) since 2018 (Frouin-Mouy et al. 2019, Frouin-Mouy et al. 2020, Austin et al. 2022a, Austin et al. 2022b, Austin et al. 2023). The results demonstrate that while noise from Project vessels is detectable in the underwater soundscape, vessel noise exposure is temporary in nature (detectable in 21 % 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 0.5 hours 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 2023 (one-minute averaged) were 111.5 and 108.1 decibel, relative to 1 micropascal (dB re 1 µPa) at the Milne Inlet and Bruce Head recorders, respectively (median levels were 97.9 and 97.2 dB re 1 µPa). Sound exposure levels (SEL) never exceeded thresholds for acoustic injury to relevant 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 1.9 and 1.2 % of the 69 days of recording at Milne Inlet and Bruce Head, respectively.

Capesize ore carriers transited through the RSA for the first time in 2023. Underwater sounds from these vessels were measured and compared to sounds from smaller ore carriers. A detailed review of the source levels for these vessel classes is presented separately in (Austin et al. 2024), in which Capesize ore carriers were reported to have radiated noise levels as much as 4 dB greater than those for smaller ore carriers. However, on days when Capesize carrier transits occurred, sound levels did not exceed 120 dB re 1 µPa for extended durations, relative to other days of the shipping season. And, on days when Capesize carriers were being loaded at Port, there were no other Project vessels transiting through Milne Inlet and therefore no associated Project vessel noise generated in the RSA on those days. So, despite slightly elevated source levels for Capesize ore carriers, the overall noise exposure in the RSA was not significantly increased by the addition of these vessels to Baffinland's fleet in 2023.

Sounds from two marine mammal species (bowhead and narwhal) were identified in the acoustic data, in addition to suspected sounds from pinnipeds and possibly beluga. The timing (i.e., seasonal occurrence) for narwhal acoustic detections in Milne Inlet was consistent with previous annual recordings collected since 2018. Suspected beluga whale sounds were detected in the recordings following the methodology presented in Zahn et al. (2021), indicating that beluga were likely occasionally present in the region amongst or near narwhal. Bowhead whale vocalizations were acoustically detected (and manually validated) occasionally at both stations. Some acoustic signals consistent with those produced by ringed seals were also detected throughout the recordings.

Vessels were acoustically detected in 21 and 20 % of the 2023 acoustic recordings at the Milne Inlet and Bruce Head recorders, respectively. Listening range reduction (LRR)—the fractional decrease in the available listening range for marine animals—was computed at each recording station for three frequencies, each representative of different narwhal vocalization types: 1 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 (MEWG), 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 2023, greater than 50 % LRR for sound at 1 kHz occurred during 4.4 and 2.6 % of the time when vessels were detected (i.e., 0.9 and 0.5 % of the recording period) at the Milne Inlet and Bruce Head recorders, respectively. Ambient noise did not cause appreciable LRR at 1 kHz at either 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 slightly less than values computed in the same area in prior years (2019-2022), 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 conducted in those years.

5 kHz (whistles/knock trains):

In 2023, greater than 50 % LRR for sound at 5 kHz occurred during 23.4 and 28 % of the time when vessels were detected (i.e., 4.9 % and 5.6 % of the recording periods) at the Milne Inlet and Bruce Head recorders, respectively. Ambient noise resulted in greater than 50 % LRR for sound at 5 kHz during 22.1 and 27.7 % of the recording period without vessel noise (i.e., 17.5 % and 22.2 % of the recording period) at the Milne Inlet and Bruce Head recorders in 2023. These vessel-attributed LRR values at Milne Inlet are lower than the values computed in the same area between 2019 and 2022, when vessel noise resulted in greater than 50 % LRR for sound at 5 kHz during as much as 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 conducted in prior years (2019-2022), consistent with 2023 results.

25 kHz (clicks / high frequency buzzes):

In 2023, greater than 50 % LRR for sound at 25 kHz occurred during 20.4 and 20.5 % of the time when vessels were detected (i.e., 4.3 and 4.1 % of the recording period) at the Milne Inlet and Bruce Head recorders, respectively. Ambient noise resulted in greater than 50 % LRR for sound at 25 kHz during 22 and 24.6 % of the recording period without vessel noise (i.e., 17.4 and 19.7 % of the recording period) at the Milne Inlet and Bruce Head recorders, respectively. These vessel-attributed LRR values at Milne Inlet are consistent with results in the area from 2021–2022 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 conducted in prior years (2019-2022), consistent with 2023 results.

1. Introduction

JASCO Applied Sciences' (JASCO) collected underwater sound level measurements for the 2023 Acoustic Monitoring Program, developed in collaboration with WSP Canada Inc. (WSP, formerly Golder Associates Ltd.) and Baffinland Iron Mines Corporation (Baffinland), to evaluate potential Project-related effects on 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 acoustic recorder locations in Milne Inlet. The first recorder (AMAR-MI) was located on the Northern Shipping Route, approximately 5 km from the mouth of Koluktoo Bay and approximately 4 km south-south-west of Iluvilik (Bruce Head). The second recorder (AMAR-BH) was located approximately 2.5 km inshore from AMAR-MI as shown in Figure 1. Underwater acoustic data were collected using Autonomous Multichannel Acoustic Recorders (AMARs; JASCO). The Milne Inlet recorders were deployed on 1 Aug 2023 and retrieved on 9 Oct 2023. Both AMARs recorded continuously during this period. Two additional acoustic recorders were deployed (one in Milne Inlet and one in Eclipse Sound) on 9 Oct 2023 to record underwater sounds during the end of the 2023 shipping season and through winter. Those recorders will record noise during the start of the 2024 shipping season and will be retrieved in August 2024, for analysis and inclusion in 2024 annual reporting.

When feasible, Baffinland implemented vessel convoys in 2023 as a mitigation measure intended to reduce the total amount of noise exposure from shipping within the Regional Study Area (RSA), inclusive of Milne Inlet and Eclipse Sound marine waters. 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. Three vessel convoys between Ragged Island and Milne Port occurred during the 2023 underwater acoustic monitoring period. Baffinland also chartered two Capesize ore carriers (*Heide Oldendorff*, 207,629 DWT and *Hauke Oldendorff*, 207,694 DWT) for the first time in 2023, and this report contains a comparative analysis of the noise from these vessels as compared to the smaller ore carriers that called at Milne Port during the monitoring period.

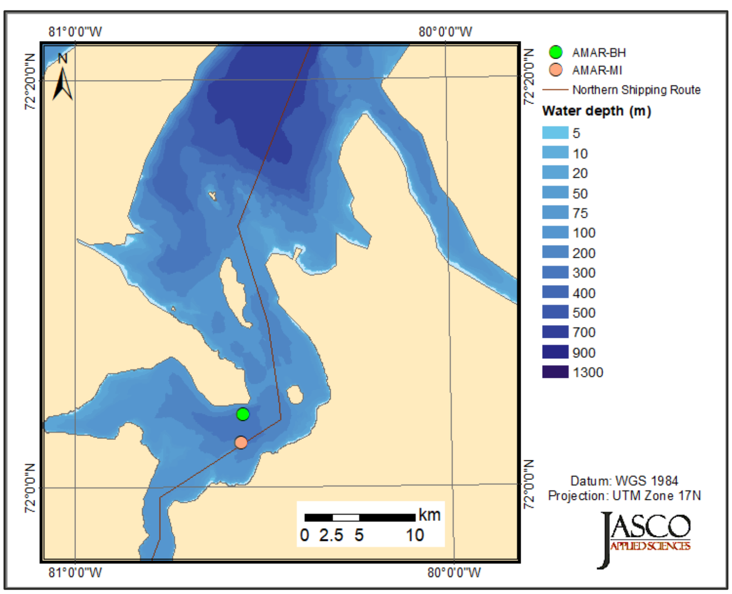

Figure 1. 2023 acoustic monitoring locations in Milne Inlet.

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).

Baffinland currently operates its Sustaining Operations Proposal (SOP), which involves open pit mining and transporting the ore by long-haul trucks to a port facility at Milne Inlet (Milne Port) for shipment to overseas markets. Mining operations started in 2014 with the first iron ore shipped to Europe via Milne Port in 2015. During the first year of shipping operations in 2015, Baffinland shipped ~918,000 t (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, 5.6 Mtpa via 73 return voyages in 2021, and a total of 4.7 Mtpa of iron ore was shipped via 62 return voyages in 2022. In 2023, a total of 6.1 Mtpa iron ore was shipped via 75 return ore carrier voyages, with the first inbound transit of the season commencing on 9 Aug 2023 and the last outbound transit of the season occurring on 30 Oct 2023.

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 frameworks to allow for scientifically defensible synthesis, analysis, and interpretation of data.
    - Project management decisions requiring modifying operational practices, where and when necessary.

The 2023 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 2023 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 2023 Acoustic Monitoring 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 (([NMFS] National Marine Fisheries Service 2013, 2018));
- Estimate the extent of listening range reduction (LRR, defined in Section 2.3) associated with Project vessel transits along the Northern Shipping Route, relative to ambient noise levels;
- Compare LRR calculations with results from previous monitoring years (a Baffinland commitment in response to requests from the Marine Environment Working Group); and
- Characterize noise from Capesize vessels 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).

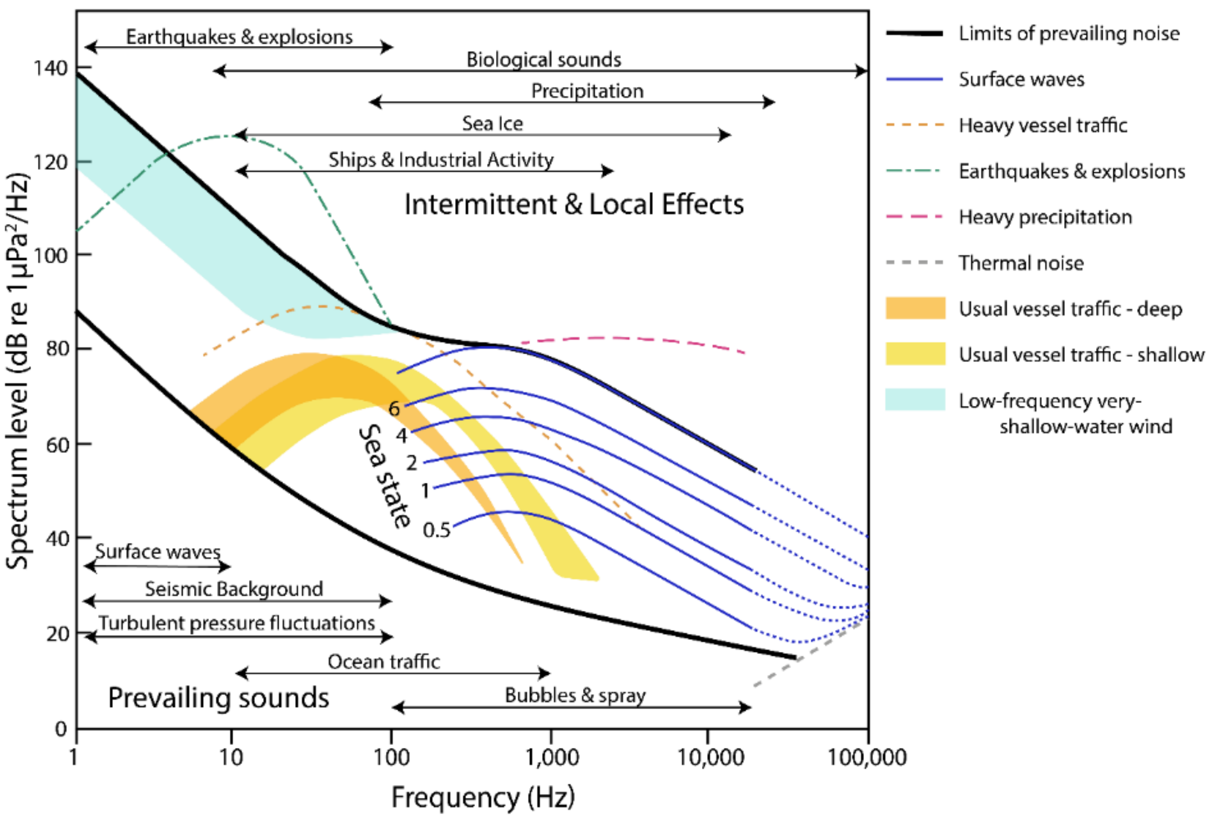

Figure 2. Wenz curves describing pressure spectral density levels of marine ambient sound from weather, wind, geologic activity, and commercial shipping (adapted from NRC 2003, based on Wenz 1962). The thick lines are the limits of prevailing ambient sound, which are included in some of the results plots 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 the RSA (Table 1). Current knowledge on marine mammal presence and distribution in Milne Inlet is largely derived from traditional knowledge ([JPCS] Jason Prno Consulting Services 2017, [QIA] Qikiqtani Inuit Association 2018, 2019, 2021) and scientific survey data (Thomas et al. 2015, Thomas et al. 2016, Golder Associates Ltd. 2018, 2019, 2020), as reported in the 2010 Arctic Marine Workshop (Stephenson and Hartwig 2010) and from regional research activities (Yurkowski et al. 2018).

Additional information on the presence, relative abundance and distribution of marine mammals in the RSA is available in the existing literature (Ford et al. 1986, Campbell et al. 1988, COSEWIC 2004a, COSEWIC 2004b, COSEWIC 2008, COSEWIC 2009, Marcoux et al. 2009, Stephenson and Hartwig 2010, Thomas et al. 2014, Smith et al. 2015, COSEWIC 2017, 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 the Regional Study Area (RSA) 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 2004b)	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 RSA. Marine mammals, and cetaceans in particular, rely 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 (PAM) 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 RSA varies by species. The produced sounds can be divided into two broad categories: narrow-band tonal 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 RSA 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). Further, signal characteristics can overlap across species, making species differentiation challenging.

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 these 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 10–1000 km when present (Bailey et al. 2010, Miksis-Olds and Nichols 2016, Delarue et al. 2018). 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 RSA (Figure 3). Other non-Project vessels that transited through the RSA in 2023 included cargo, fishing, passenger, and search and rescue vessels as well as service ships, tankers, and tugs, but these 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.

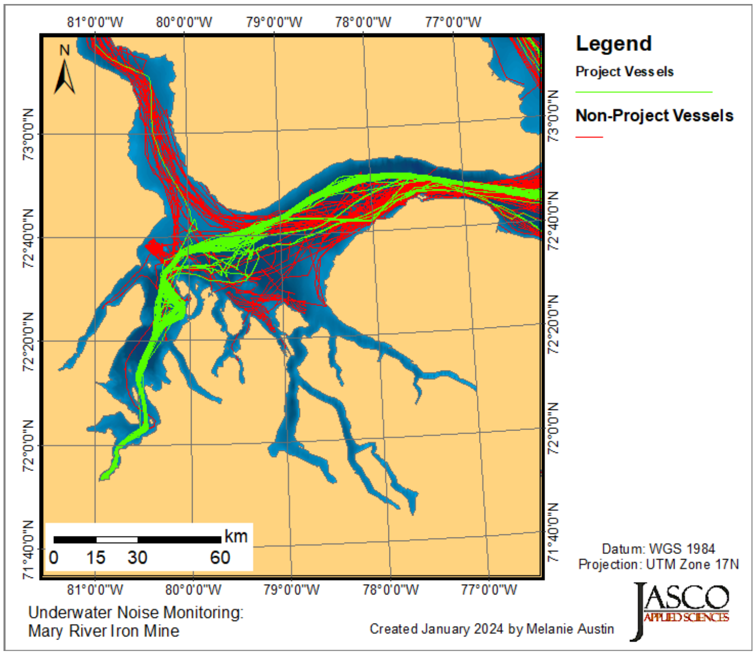

Figure 3. Vessel traffic travelling through the Regional Study Area during the 2023 season; both Project-related vessels (green) and non-Project related vessels (red) are displayed. Automatic Identification System (AIS) vessel tracking data was acquired from ground-based stations at Bruce Head and Pond 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 4 (AMAR-WFE and AMAR-EFE). 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 (Figure 4) do not contain any chain and all metal components are isolated from each other and/or coated in rubber to avoid making any noise.

Both AMARs 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 3 TB of internal solid-state flash memory.

The calibration procedures are described in Appendix A.

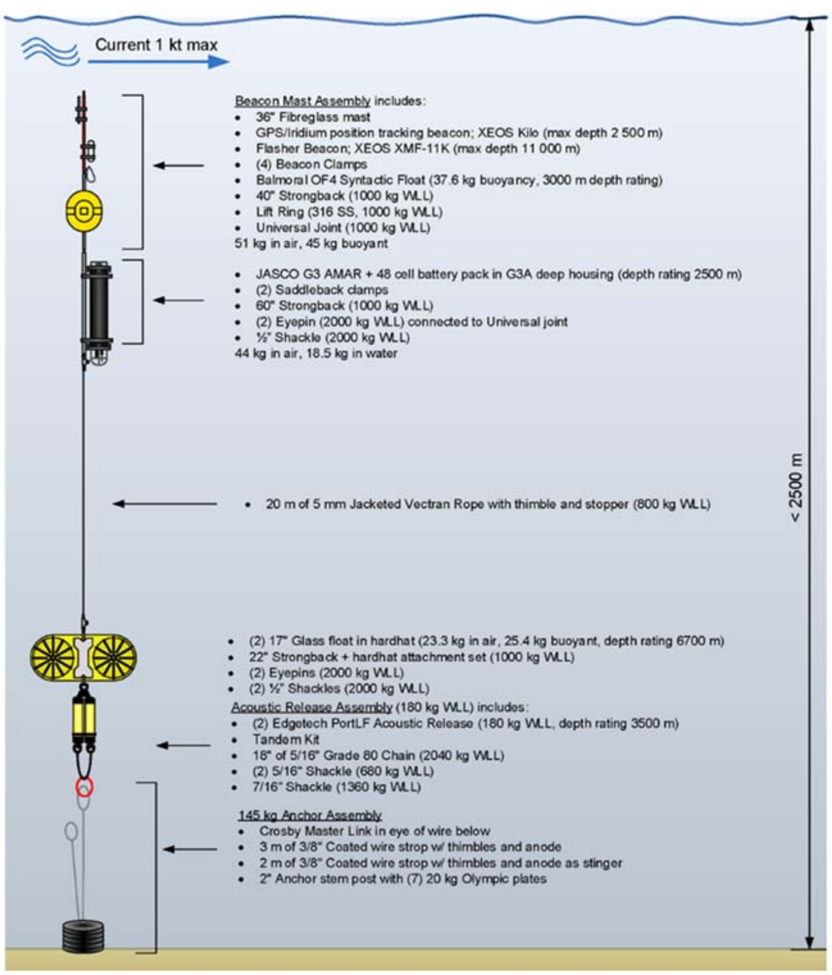

Figure 4. Mooring design: Kilo beacon on mast, OF4 float assembly, AMAR-G3, and tandem PortLF.

2.1.2. Deployment Locations

The AMARs were deployed at two locations (Figure 1; Table 3) using the BIM Research Vessel and retrieved with the icebreaker *MSV Botnica* (Figure 5). AMAR-MI and AMAR-BH were deployed on 1 Aug 2023 and retrieved on 9 Oct 2023. Both AMARs were retrieved using acoustic releases and recorded as planned from deployment until retrieval, for a recording duration of 69 days each.

Figure 5. (Left) BIM Research Vessel and (Right) *MSV Botnica*, used to deploy and retrieve the acoustic recorders, respectively.

Table 3. Operation period and location of the Autonomous Multichannel Acoustic Recorders (AMARs) deployed for the 2023 Acoustic Monitoring Program.

Station	Latitude	Longitude	Water depth (m)	Start date	Stop date	Recording duration (days)
AMAR-MI	72.03636° N	-80.5569° W	327	1 Aug 2023	9 Oct 2023	69
AMAR-BH	72.05939° N	-80.5515° W	368	1 Aug 2023	9 Oct 2023	69

2.2. Automated Data Analysis

The AMARs collected approximately 4 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 the frequency band of 10–64 000 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 (specifically, shipping).

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 64,000 frequencies (representing the frequency range 1 Hz to 64 kHz) in the power spectral density data to a manageable set of bands that approximate the critical bandwidths of mammal hearing. 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 6 shows wind data obtained from Pond Inlet (https://climate.weather.gc.ca) which is the nearest weather station to the recording locations.

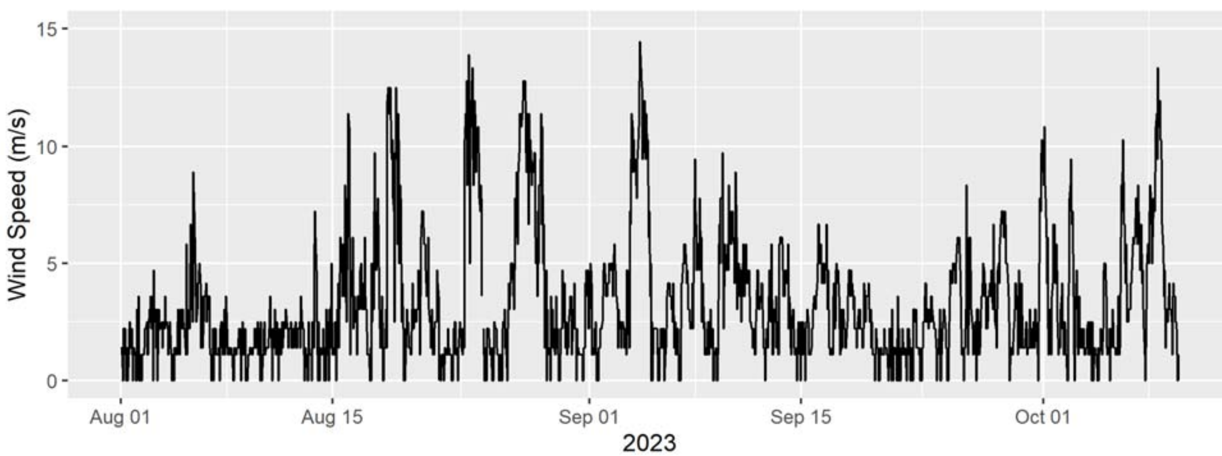

Figure 6. Wind speeds at Pond Inlet in August–October 2023.

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 64,000 Hz) and the levels in the decade bands of approximately 10–100, 100–1000, 1000–10,000, and 10,000–64,000 Hz. 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 (not a Baffinland activity). 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 (not a Baffinland activity in 2023). 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, 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). Note that while here we have accumulated the total sound every received over a 24 h period, strictly this summation should be only over the times when vessel noise is present. This analysis thus presents a highly conservative measure of the potential for possible hearing impacts over a full day, given that vessel noise is only present for approximately 20 % of the recording period.

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).

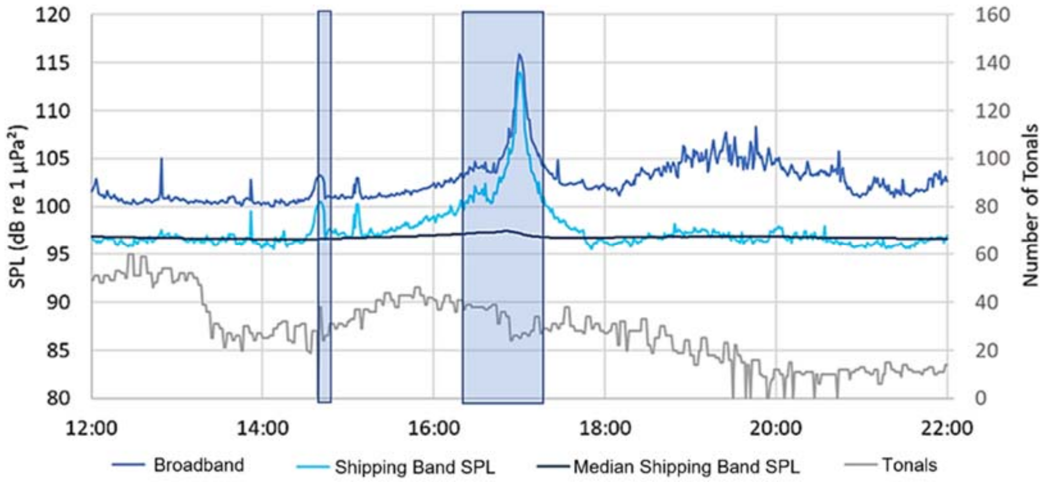

Figure 7. Generic example (not recorded during this project) of broadband and 40–315 Hz band sound pressure level (SPL), and the number of tonals detected per minute as a vessel approached a recorder, stopped, and then departed. The shaded area is the period of shipping detection. Fewer tonals are detected 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 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) for the 2023 dataset.

Band center frequency (kHz)	Decidecade band baseline ambient level (dB re 1 µPa)		Hearing threshold for mid-frequency cetaceans* (dB re 1 µPa)
	AMAR-MI	AMAR-BH	
1	84.5	83.7	96.7
5	81.2	81.3	74.1
25	75.1	74.5	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. 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, Delarue et al. 2022). Therefore, automated detector results must always be supplemented by some level of manual review to evaluate automated detector performance (Kowarski and Moors-Murphy 2020). 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 (10 min files sampled at 128 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 compared to narwhal, signals were preferentially assigned to narwhal. Narwhal vocalizations were categorized as high-frequency buzz, low-frequency buzz, knocks, whistles, and echolocation clicks following the definitions 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). In addition to these call types, narwhal are known to produce contact calls, which largely overlap in characteristics with low-frequency 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 whales 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. Clicks can also allow for differentiation between narwhal and beluga (Zahn et al. 2021, Jones et al. 2022), but the sampling rate of the present data set (maximum recorded frequency of 64 kHz) did not allow for such detailed click analysis as beluga clicks span above 80 kHz.

3. Results

3.1. Ambient Sound by Station

Results of ambient sound measurements and associated discussions are presented here for the two recorder stations (AMAR-MI and AMAR-BH) in the study area. The spectrogram and band-level plots (left panels of Figures 8 and 9) provide an overview of the sound variability in time and frequency, presenting an overview of presence and level of contribution from different sources. Short-term events appear as vertical stripes on the spectrograms and spikes on the band level plots. Long-term events affect (increasing or decreasing accordingly) the band level over the event period and appear in the spectrograms as horizontal bands of colour. The percentile figures (right panels of Figures 8 and 9) show boxplots by decidecade band (top of the right panels) and power spectral density by percentile (bottom of the right panels). 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 Figure 10.

The 2023 recording period of the two AMARs (1 Aug to 9 Oct 2023) began when Milne Inlet was ice-free, but there was still extensive ice cover in Eclipse Sound and Baffinland's shipping season was not yet underway. In 2023, the first inbound transit by a Project vessel in Milne Inlet occurred on 10 Aug 2023. The dominant anthropogenic contribution to the ambient soundscape at the acoustic recorder locations was from Project-related vessel noise. As shown in Figure 3, vessel noise was recorded at both recording sites with the majority of this representing Project vessel traffic. There were also natural contributions to the ambient soundscape, including weather and sounds from marine mammals. As the AMARs were deployed during open-water conditions in August 2023, ice movement was not a contributing sound source during the recording period.

Wind conditions were shown to be a contributing, but not dominant sound source at either recording station, with only a slight increase in broadband levels observed in the recording during periods of elevated wind speeds. It is noted that the weather data was collected from a location outside the acoustic monitoring recorder locations so no direct correlations between local wind speeds and underwater sound levels were possible. Sound levels were shown to increase on windy days, with this being more evident at AMAR-BH than AMAR-MI. This is likely a result of AMAR-BH being located further from the main shipping route and closer to the coast (where wave action is increased). Some examples of wind-driven noise were on 5 Aug, 16–19 Aug, 27 Aug, and 4 Sep 2023 and are reflected as broadband and lowest decade band increases.

Narwhal clicks were evident in the long-term data at both stations at the highest decade band, beginning in mid-August. The high frequency contribution by narwhals decreased as the animals departed the area, as shown in Section 3.5.3.

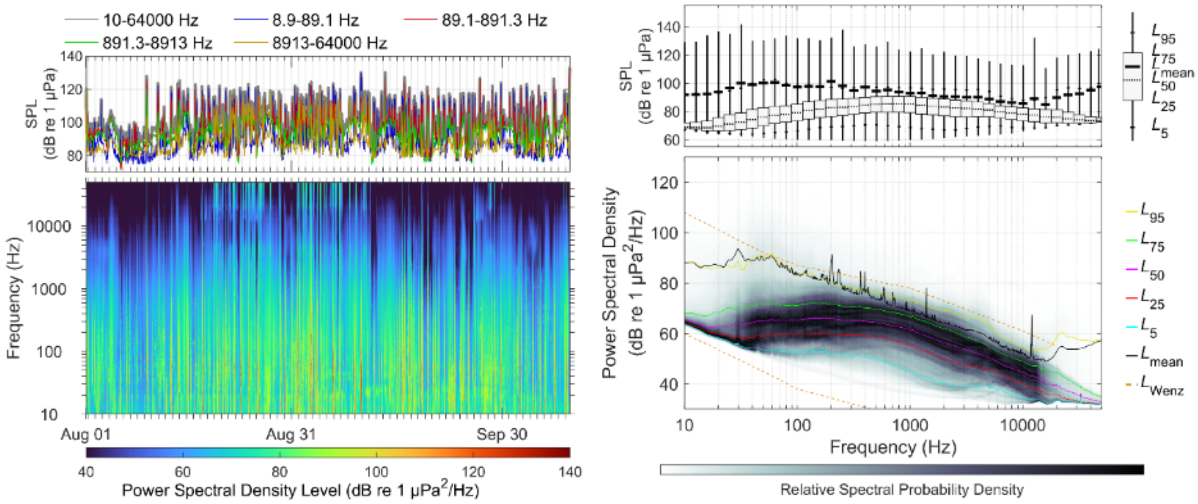

Figure 8. AMAR-MI: (Left) In-band sound pressure level (SPL) and spectrogram of underwater sound. (Right) Exceedance percentiles and mean of decidecade-band SPL and exceedance percentiles and probability density (grayscale) of 1-min power spectral density (PSD) levels compared to the typical range of sound levels(Wenz 1962).

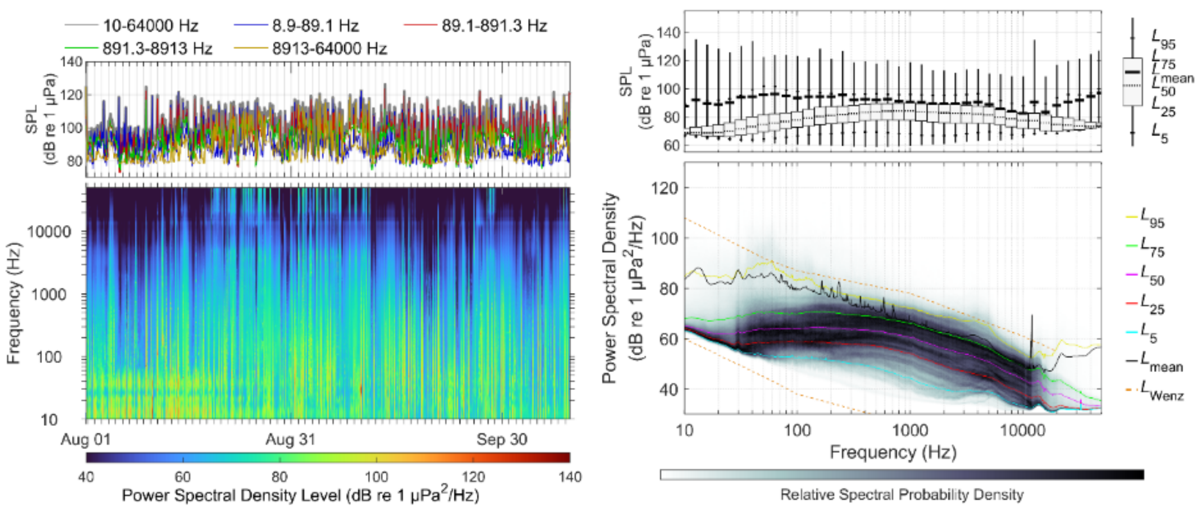

Figure 9. AMAR-BH: (Left) In-band sound pressure level (SPL) and spectrogram of underwater sound. (Right) Exceedance percentiles and mean of decidecade-band SPL and exceedance percentiles and probability density (grayscale) of 1-min power spectral density (PSD) levels compared to the typical range of 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-MI	81.9	143	111.5	97.9
AMAR-BH	81.6	139.3	108.1	97.2

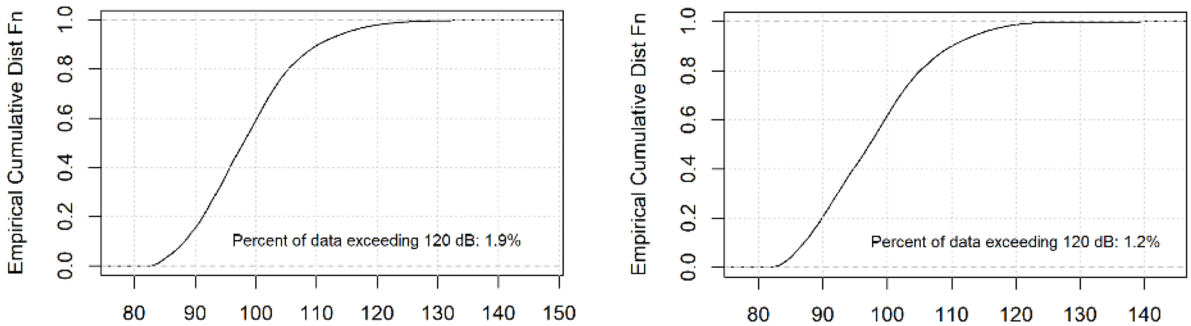

Figure 10. 2023: Empirical cumulative distribution functions for broadband sound pressure level (SPL) recorded at (left) AMAR-MI and (right) AMAR-BH.

3.2. Vessel Detections

Vessels were detected using the automated detection algorithm described in Section 2.2.2. Plotted vessel detections denote the closest points of approach (CPA) to a recorder by hour. Both AMAR-MI and AMAR-BH recorded nearly daily vessel presence beginning in early August. Vessel detections by hour are shown in Figure 11. The vessel noise detected on 1 and 8 Aug was associated with Baffinland's Research Vessel that deployed the recorders on 1 Aug and passed near the AMARs on 8 Aug while on route to conduct sampling for Baffinland's Marine Environmental Effects Monitoring Program in Koluktoo Bay and near Tugaat River. In 2023, Baffinland's first inbound transit by a Project shipping vessel in Milne Inlet occurred on 10 Aug, involving a convoy of two tugs and a resupply vessel. An example spectrogram of a Panamax class ore carrier passing AMAR-MI on 2 Sep is shown in Figure 12, and Figure 13 is an example of a Capesize class ore carrier passing AMAR-MI on 5 Sep.

The sound levels in vessel frequency bands were slightly higher at AMAR-MI than at AMAR-BH, since AMAR-MI is located directly on the shipping route and AMAR-BH is located closer to shore. Due to the proximity of the AMARs to each other, the two AMARs tend to detect the same large vessels (in red), but there is some variability in detection of smaller, quieter boats (black).

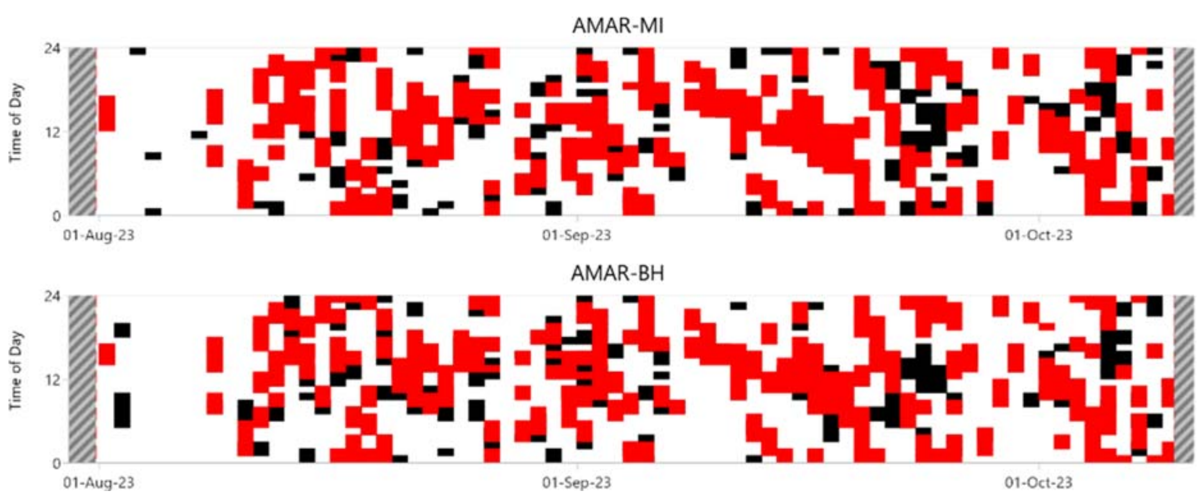

Figure 11. Vessel detections at AMAR-MI and AMAR-BH in 2023. Large vessels are in red and smaller boats in black. Grey stripes indicated time prior to and after recorder deployment.

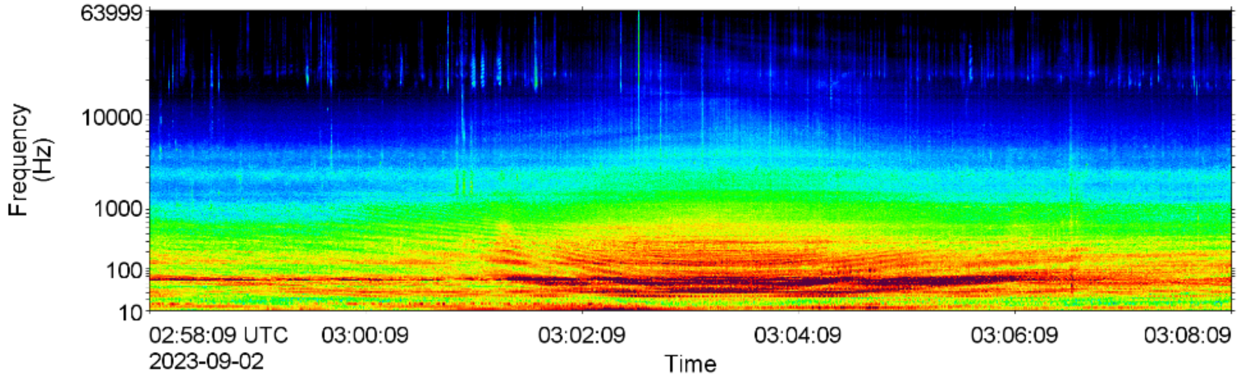

Figure 12. Example of the 225 m-long (Panamax) ore carrier *Golden Ruby* passing AMAR-MI while transiting outbound from Milne Port on 2 Sep 2023. The vessel's closest point of approach to the recorder was 263 m at 03:03 UTC.

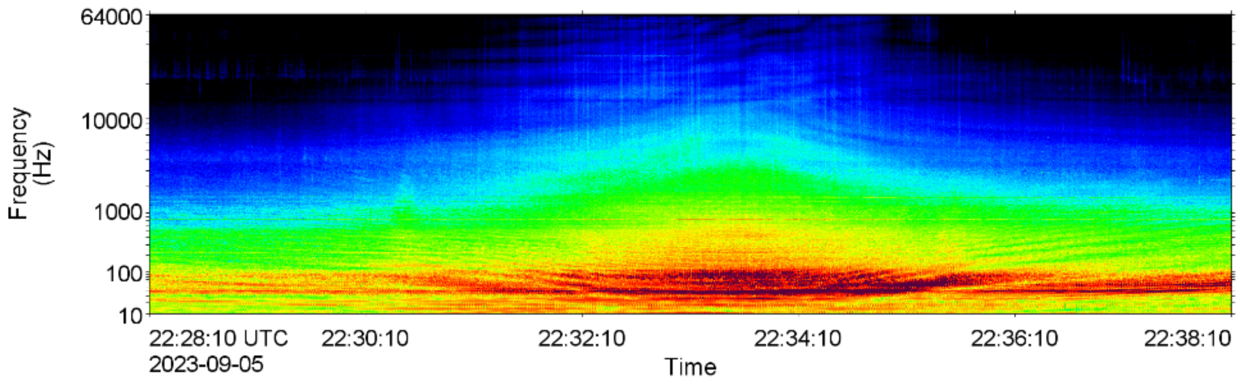

Figure 13. Example of the 300 m-long (Capesize) ore carrier *Heide Oldendorff* passing AMAR-MI while transiting inbound to Milne Port on 5 Sep 2023. The vessel's closest point of approach to the recorder was 239 m at 22:33 UTC.

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. Figure 14 shows 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 relevant functional hearing group with potential to occur in the RSA (Southall et al. 2019). The sound level increases occurring during the onset of vessel traffic are also reflected in these figures.

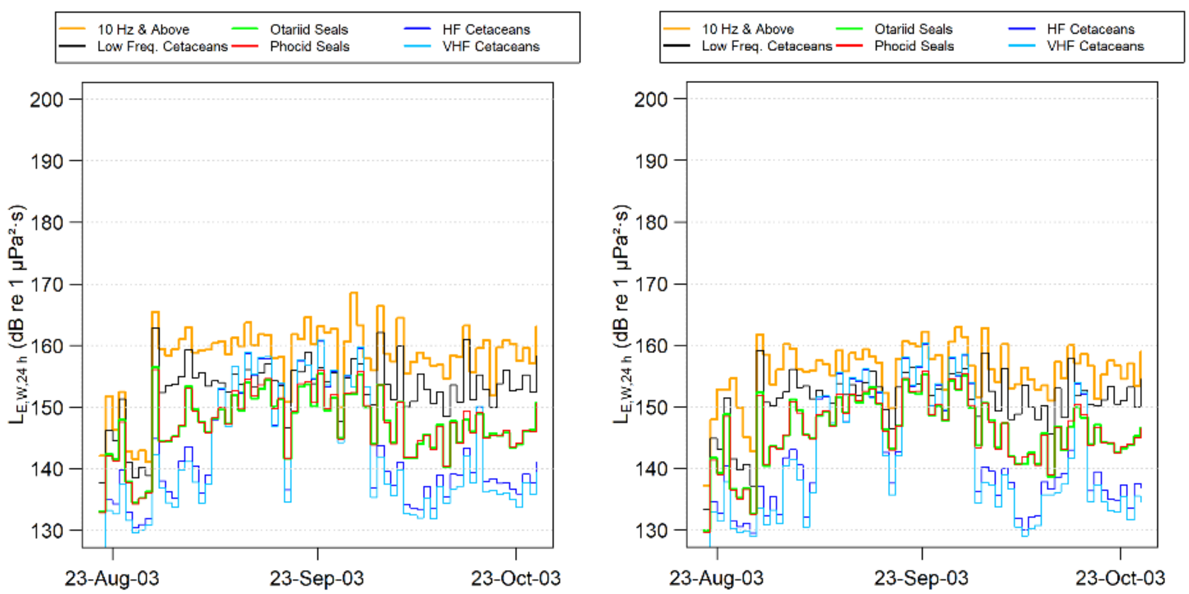

Figure 14. Daily sound exposure level (SEL) at (left) AMAR-MI and (right) AMAR-BH.

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 both recorder locations and for all narwhal vocalization types (clicks, high-frequency buzzes, whistles, knocks, and burst pulse or low-frequency buzzes). Figure 15 presents LRR results for recordings during the 2023 recording period, 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. Figure 16 shows 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 tugs and a cargo vessel transited past the recorder (10 Aug 2023, Figure 17). Figure 18 shows % LRR at AMAR-MI for a day in which no vessels transited through Milne Inlet, and ambient noise resulted in some LRR at 5 and 25 kHz. On this day, a Capesize ore carrier was loading at Milne Port for the full day, therefore, no vessels left or arrived at Milne Port. Figure 19 shows the % LRR on 1 Oct when the Capesize ore carrier left Milne Port (passing the recorder at 15:57 UTC), and an icebreaker and a Panamax ore carrier transited in to Port, passing the recorder at 02:44 and 19:07, respectively. There were some periods of elevated ambient sound levels on this day as well.

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
AMAR-MI	Ambient noise data	0.3	0	22.1	2.4	22	8.9
	Data with vessels detected	4.4	0.8	23.4	3.1	20.4	7.5
AMAR-BH	Ambient noise data	0.2	0	27.7	3.4	24.6	9.7
	Data with vessels detected	2.6	0.1	28	3.1	20.5	6.6

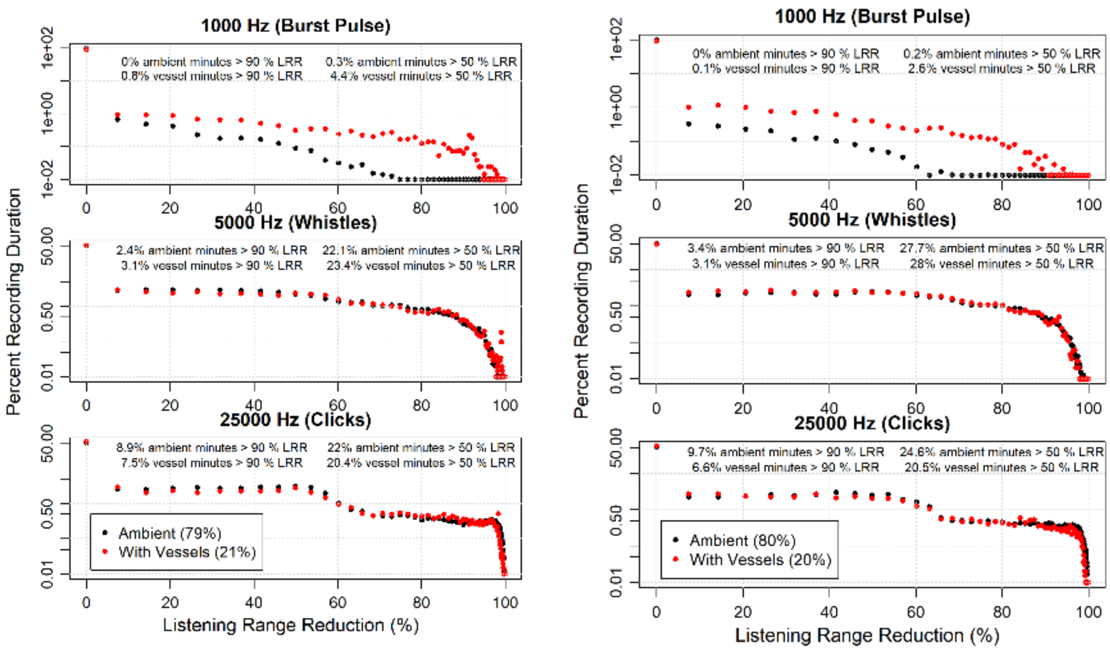

Figure 15. 2023: Listening range reduction (LRR) for the three considered frequencies at (left) AMAR-MI and (right) AMAR-BH. For each station, the top figure shows LRR for the 1 kHz decidecade band, which is representative of burst pulses, the middle figure shows LRR for the 5 kHz decidecade band, which 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.

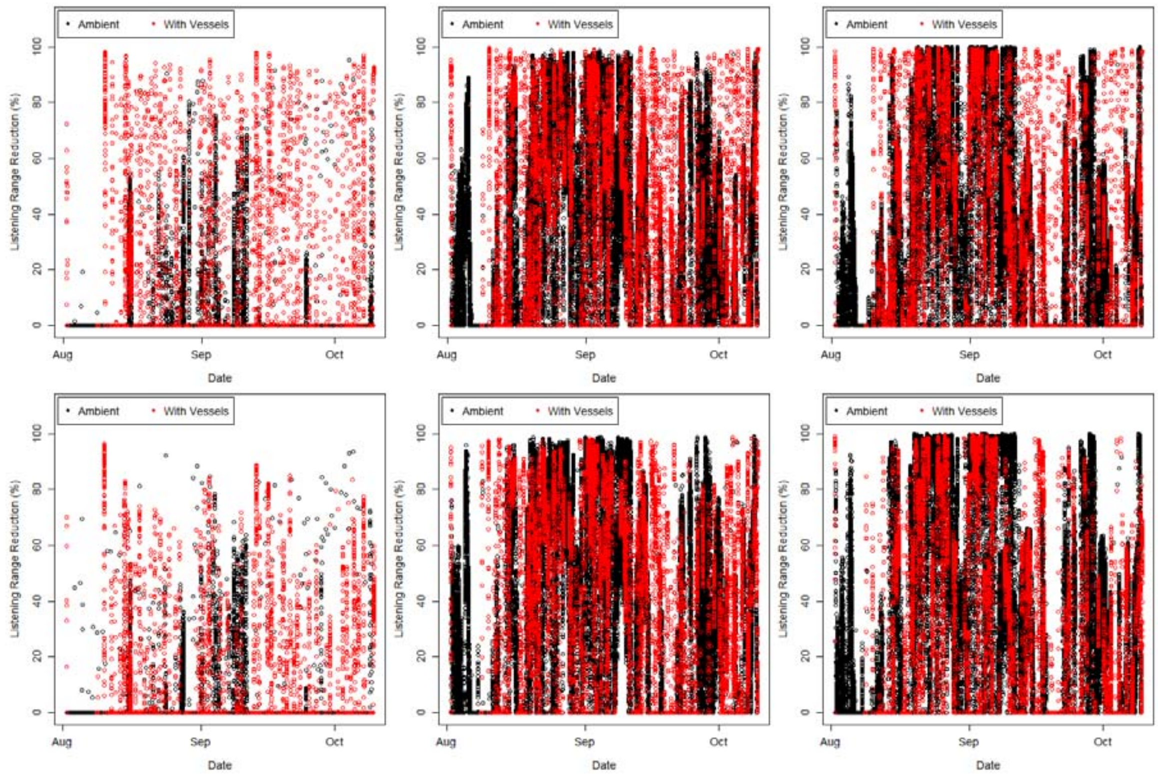

Figure 16. 2023: Listening Range Reduction over time for the three considered frequencies at (top row) AMAR-MI and (bottom row) AMAR-BH. For each station, the left figure shows LRR for the 1 kHz decidecade band, which is representative of burst pulses, the middle figure shows LRR for the 5 kHz decidecade 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).

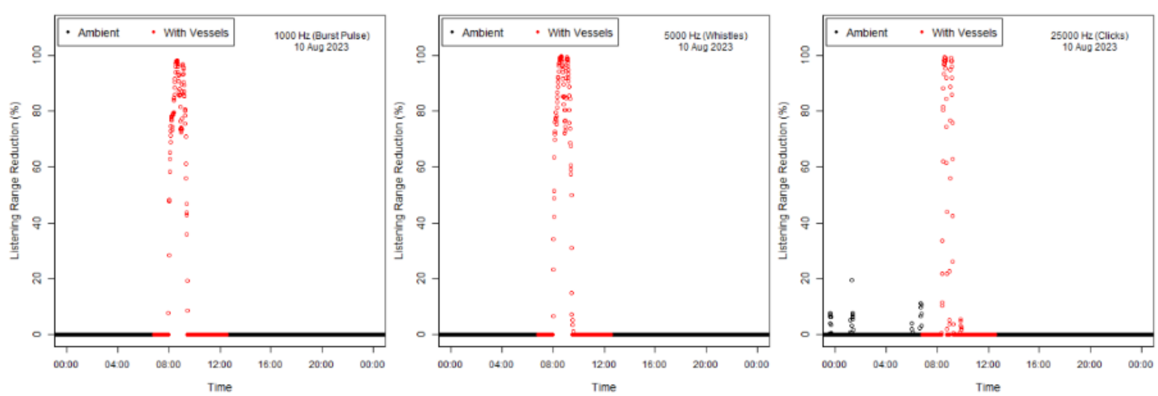

Figure 17. 10 Aug 2023: Listening Range Reduction over time for the three considered frequencies at AMAR-MI on a day with low ambient noise when a convoy of two tugs (*Ocean Taiga* and *Ocean Tundra*) and cargo vessel *Claude A. Desgagnes* transited in convoy inbound past the recorder, closest point of approach to the recorder at 08:30 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).

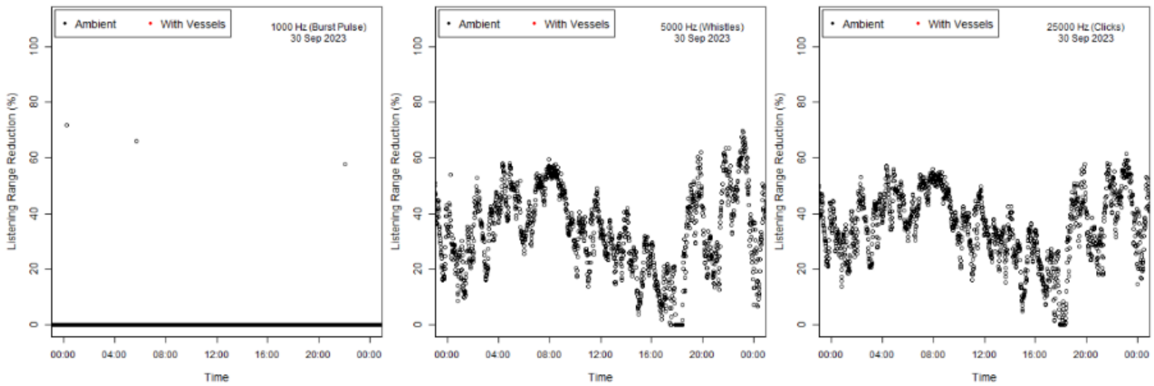

Figure 18. 30 Sep 2023: Listening Range Reduction over time for the three considered frequencies at AMAR-MI on a day with elevated ambient noise levels, when no Project vessels transited past the recorder. The left figure shows LRR for the 1 kHz decidecade band, which is representative of burst pulses, 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). There were no times with vessels detected, hence no red dots to show the distribution of LRR for recordings with vessels detected (vessels + ambient noise).

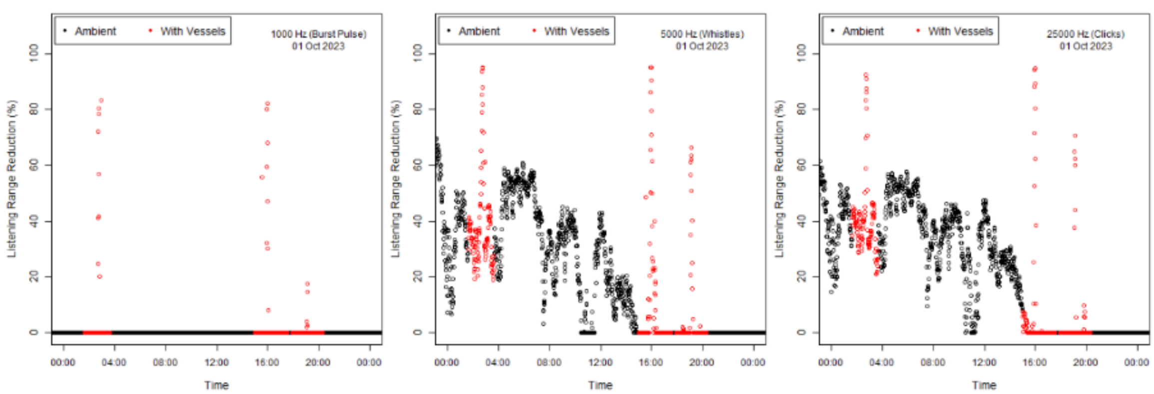

Figure 19. 1 Oct 2023: Listening Range Reduction over time for the three considered frequencies at AMAR-MI on a day when a Capesize vessel (*Hauke Oldendorff*) transited outbound past the recorder, with the closest point of approach to the recorder occurring at 15:57. Also on this day, the icebreaker MSV *Fennica* transited into Milne Port passing the recorder at 02:44 UTC and the Panamax vessel *Patricia V* passed the recorder at 19:07 UTC while also transiting inbound. 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 2.4), which represented 399 sound files, or 66.5 h of data (10-min sound files sampled at 128 kHz). The acoustic signals of bowhead whale, narwhal, and ringed seal were identified during analysis. In addition to these species, signals potentially produced by beluga were detected. Grunts possibly produced by fish were identified during manual analysis (e.g., Figure 20), however, this identification is not confirmed, as these sounds could have been produced by marine mammals. For each marine mammal 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.

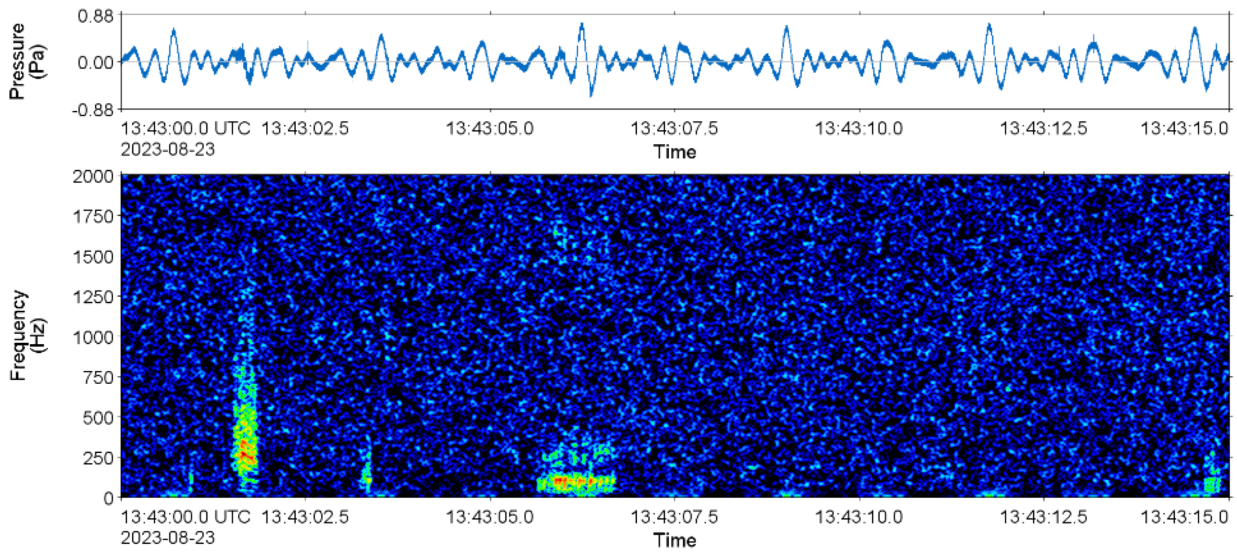

Figure 20. (Top) Waveform and (bottom) spectrogram depicting grunts, suspected of being produced by an unknown fish species. Data were recorded on 23 Aug 2023 at AMAR-MI (1 Hz discrete Fourier Transform (DFT) frequency step, 0.1 s DFT temporal observation window (TOW), 0.005 s DFT time advance, and Hanning window resulting in a 95 % overlap and DFT size (N_{DFT}) of 131072, normalized across time, 15 s of data).

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 never confirmed, but were noted on occasion as possibly present alongside narwhal whistles (see Section 3.5.3.5). The most convincing instance of beluga presence was on 2 Sep at AMAR-BH, when tonal whistles were very common along with buzzes and clicks (Figure 21). No beluga were recorded during visual surveys conducted at Bruce Head between 27 Jul and 22 Aug 2023, supporting the acoustic evidence that beluga were rare to absent in the area.

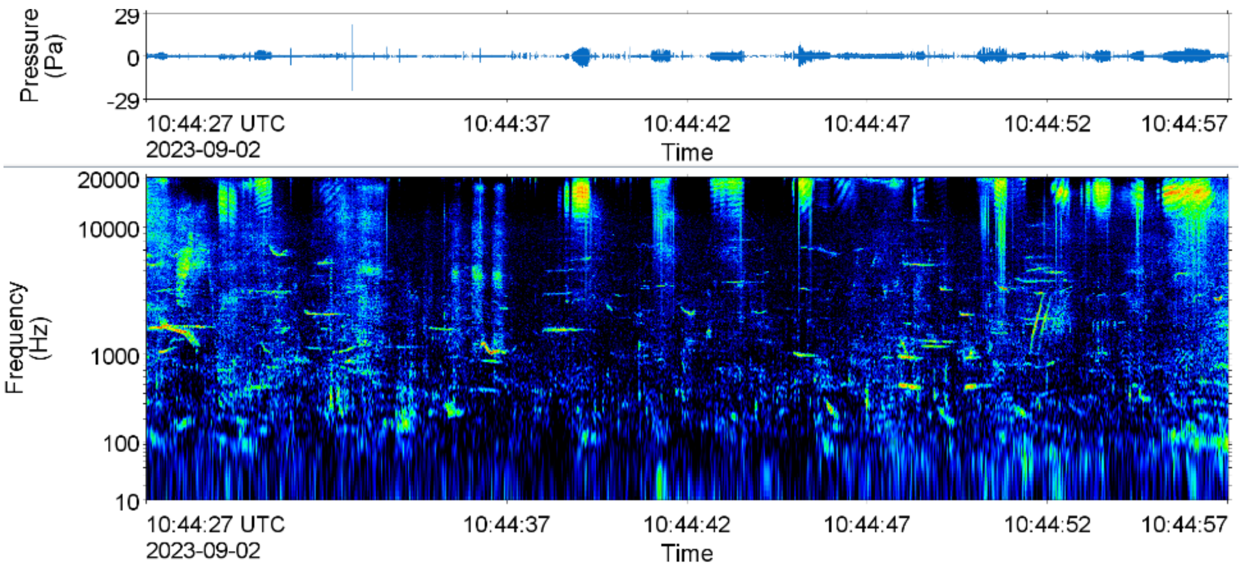

Figure 21. (Top) Waveform and (bottom) spectrogram depicting tonal whistles that occurred so frequently that beluga whales were possibly present. Buzzes and clicks are also present. Data were recorded on 2 Sep 2023 at AMAR-BH (4 Hz discrete Fourier Transform (DFT) frequency step, 0.05 s DFT temporal observation window (TOW), 0.01 s DFT time advance, and Hanning window resulting in an 80 % overlap and DFT size (N_{DFT}) of 32768, normalized across time, 30 s of data).

3.5.2. Bowhead Whales

Bowhead whale moans (Figure 22) were occasionally manually suspected in the acoustic data beginning in mid-Aug at both AMAR-BH and AMAR-MI (Figure 23). Detections reflected signals of non-song moans that were often brief and under 500 Hz. The uncertainty in detections reflects instances where low frequency moans were present in acoustic files, but the files were also so inundated with sounds of narwhal and potentially seals that analysts were uncertain whether the moans were from bowhead whales or another species. Indeed, masking from prolific narwhal signals may results in the acoustic presence of other species being under-estimated, especially if the other species are less common or further from the acoustic recorder.

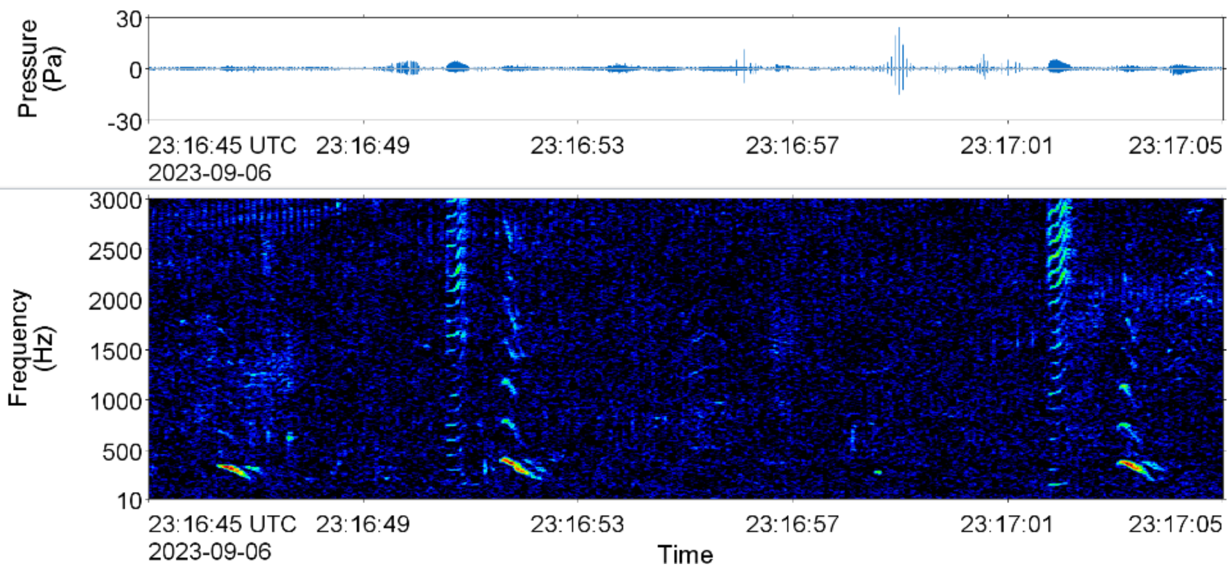

Figure 22. (Top) Waveform and (bottom) spectrogram of bowhead whale moans recorded on 6 Sep 2023 at AMAR-MI (2 Hz discrete Fourier Transform (DFT) frequency step, 0.125 s DFT temporal observation window (TOW), 0.03125s DFT time advance, and Hanning window resulting in a 75 % overlap and DFT size (N_{DFT}) of 65536, normalized across time, 20 s of data).

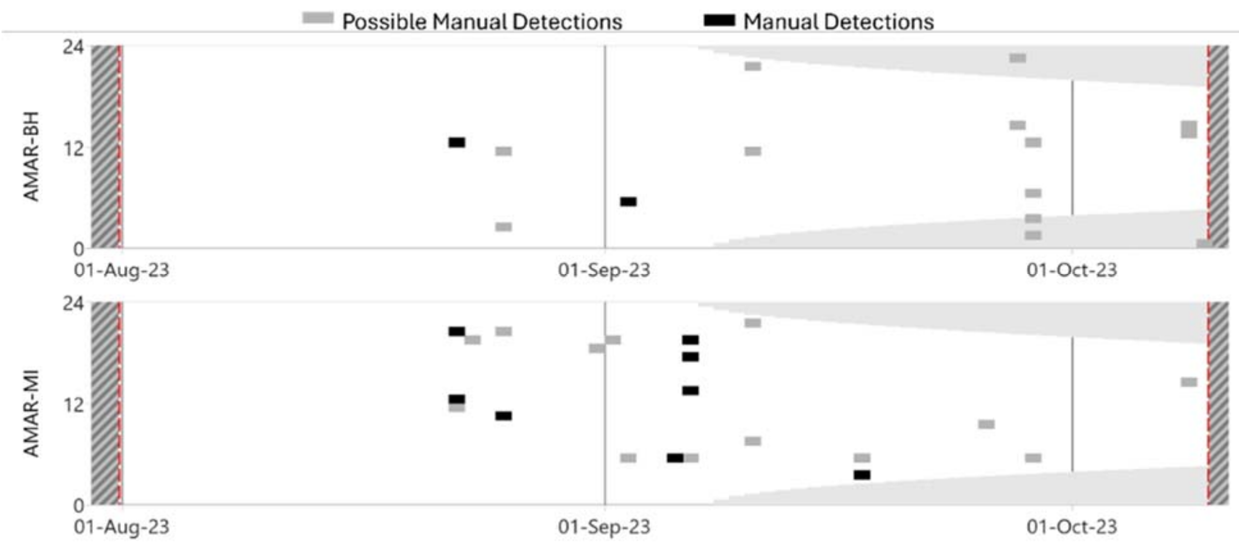

Figure 23. Hours per day with bowhead whale moan detections at each station through the recording period from 1 Aug to 9 Oct 2023. The light grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data.

3.5.3. Narwhal

Five call types were detected for narwhal as defined in Section 2.4.4: echolocation click (Section 3.5.3.1; Figure 24), high-frequency buzz (Section 3.5.3.2; Figure 24), low-frequency buzz (Section 3.5.3.3; Figure 25), knock (Section 3.5.3.4; Figure 27), and whistle (Section 3.5.3.5; Figure 24). Occasionally, low-frequency buzzes were identified as potentially being narwhal contact calls. For example, Figure 26 depicts signals similar to contact call type “T” (Ames et al. 2021). Potential contact call occurrence is captured, along with the low-frequency buzzes in Figure 30. Future work is needed to systematically differentiate these similar signals.

Narwhal acoustic occurrence was generally the same across call types and stations (Figures 28–32). The species was detected from 12 Aug to the end of the recording period, with a notable increase in detections from mid Aug to mid Sep at both stations. Indeed, narwhal clicks were particularly evident during this period even in the long-term spectrograms (Figures 8 and 9). Narwhal visual sightings off Bruce Head began on 5 Aug, earlier than acoustic detections. The animals may have been too far from the recorder for acoustic detection prior to 12 Aug, or they may not have been vocally active. Narwhal acoustic detections began after shipping began in the region (Figures 28 to 32).

When interpretting these results, we consider that beluga can produce many of these call types. Given the known predominance of narwhal in the region and lack of beluga sightings throughout much of the recording period, the detections are assumed to be narwhal.

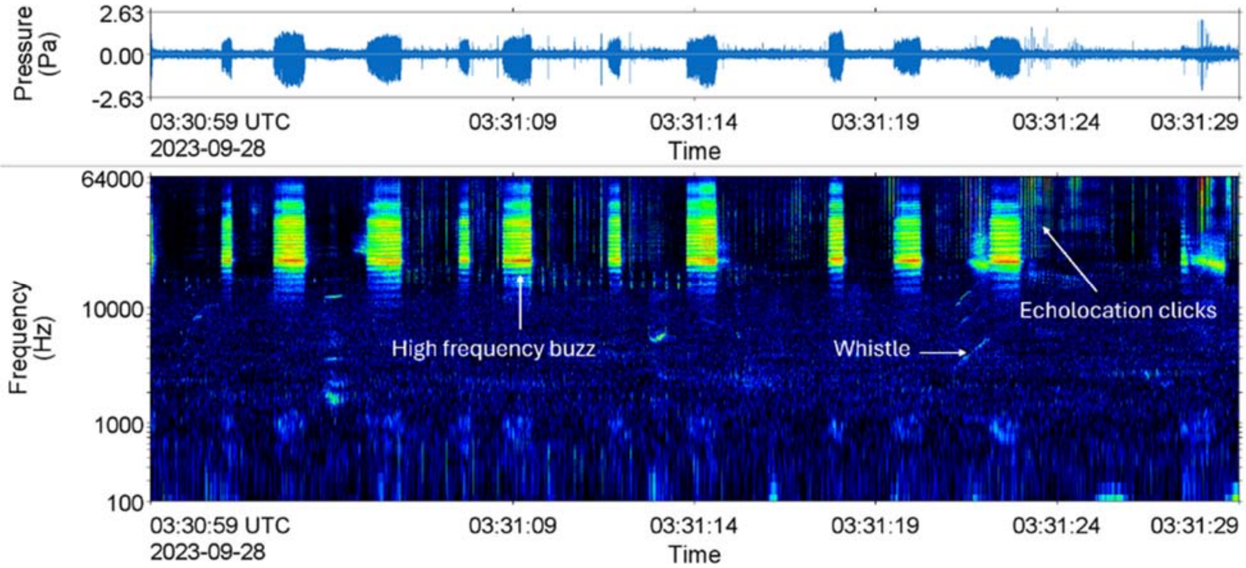

Figure 24. (Top) Waveform and (bottom) spectrogram of narwhal high-frequency buzzes, echolocation clicks, and whistles recorded on 28 Sep 2023 at AMAR-MI (64 Hz discrete Fourier Transform (DFT) frequency step, 0.01 s DFT temporal observation window (TOW), 0.005 s DFT time advance, and Hanning window resulting in a 50 % overlap and DFT size (N_{DFT}) of 2048, normalized across time, 30 s of data).

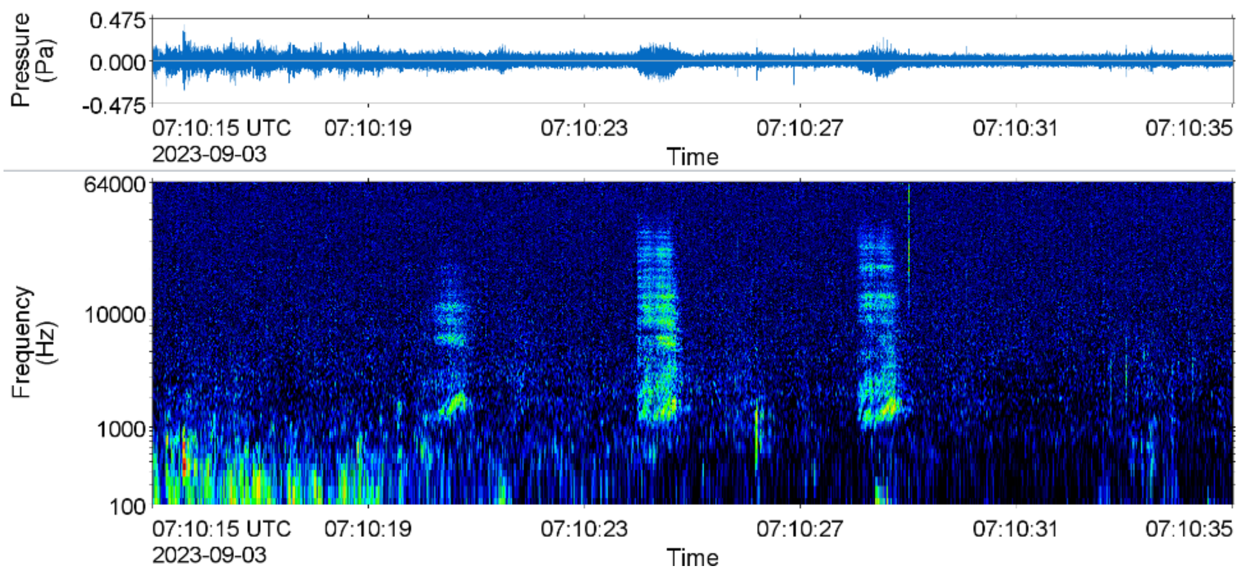

Figure 25. (Top) Waveform and (bottom) spectrogram of a narwhal low-frequency buzzes recorded on 3 Sep 2023 at AMAR-MI (64 Hz discrete Fourier Transform (DFT) frequency step, 0.01 s DFT temporal observation window (TOW), 0.005 s DFT time advance, and Hanning window resulting in a 50 % overlap and DFT size (N_{DFT}) of 2048, normalized across time, 20 s of data).

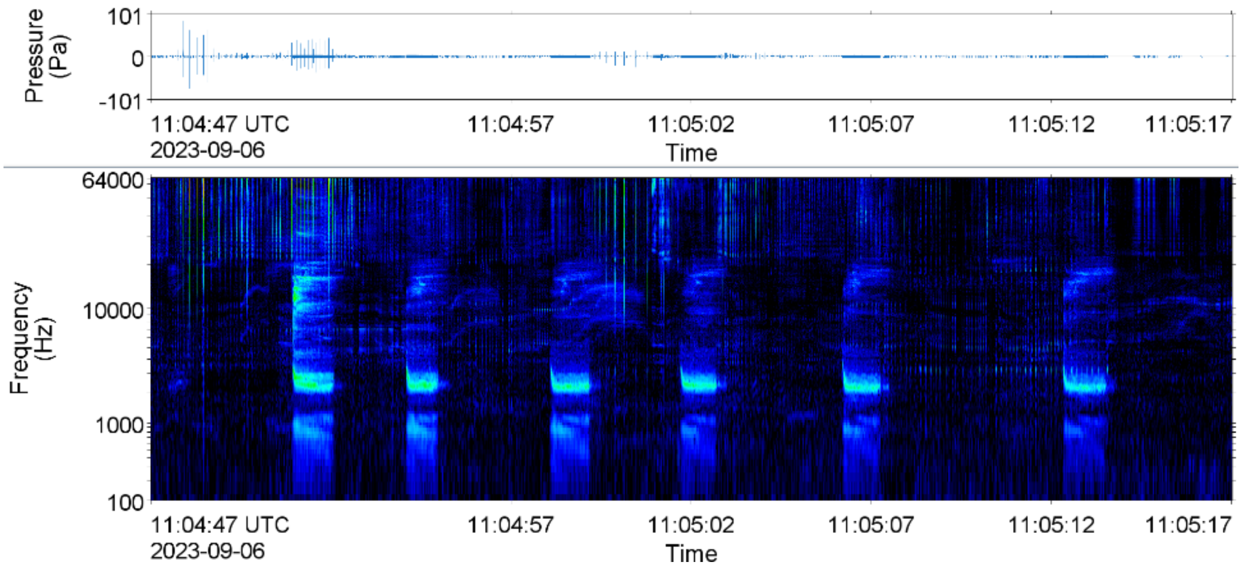

Figure 26. (Top) Waveform and (bottom) spectrogram of suspected narwhal contact calls recorded on 6 Sep 2023 at AMAR-MI (64 Hz discrete Fourier Transform (DFT) frequency step, 0.01 s DFT temporal observation window (TOW), 0.005 s DFT time advance, and Hanning window resulting in a 50 % overlap and DFT size (N_{DFT}) of 2048, normalized across time, 30 s of data).

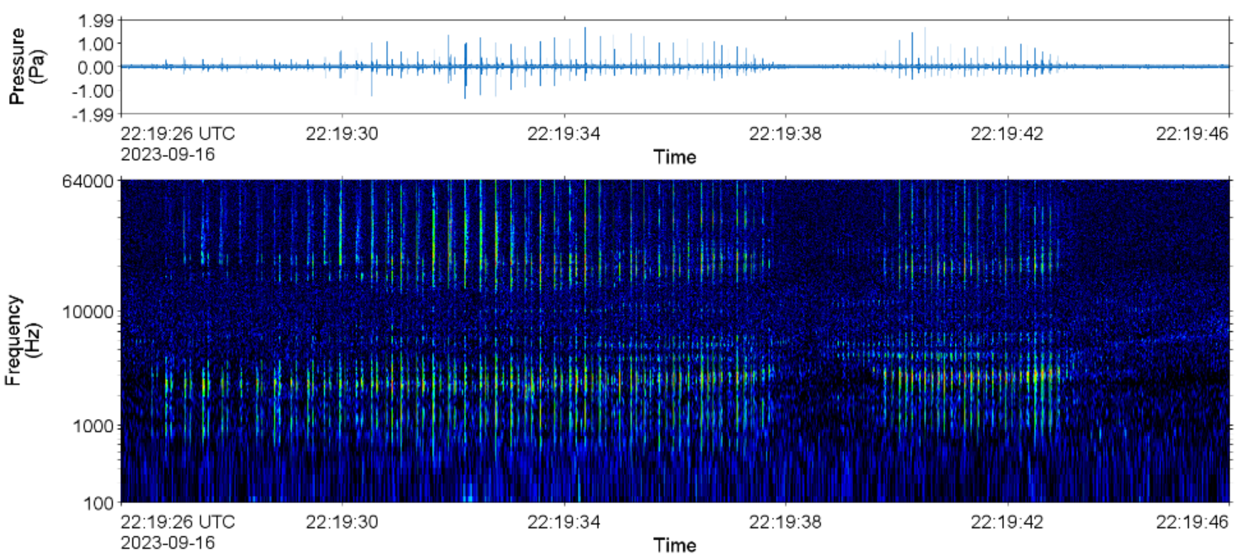

Figure 27. (Top) Waveform and (bottom) spectrogram of narwhal knocks recorded on 16 Sep 2023 at AMAR-BH (64 Hz discrete Fourier Transform (DFT) frequency step, 0.01 s DFT temporal observation window (TOW), 0.005 s DFT time advance, and Hanning window resulting in a 50 % overlap and DFT size (N_{DFT}) of 2048, normalized across time, 20 s of data).

3.5.3.1. Echolocation Clicks

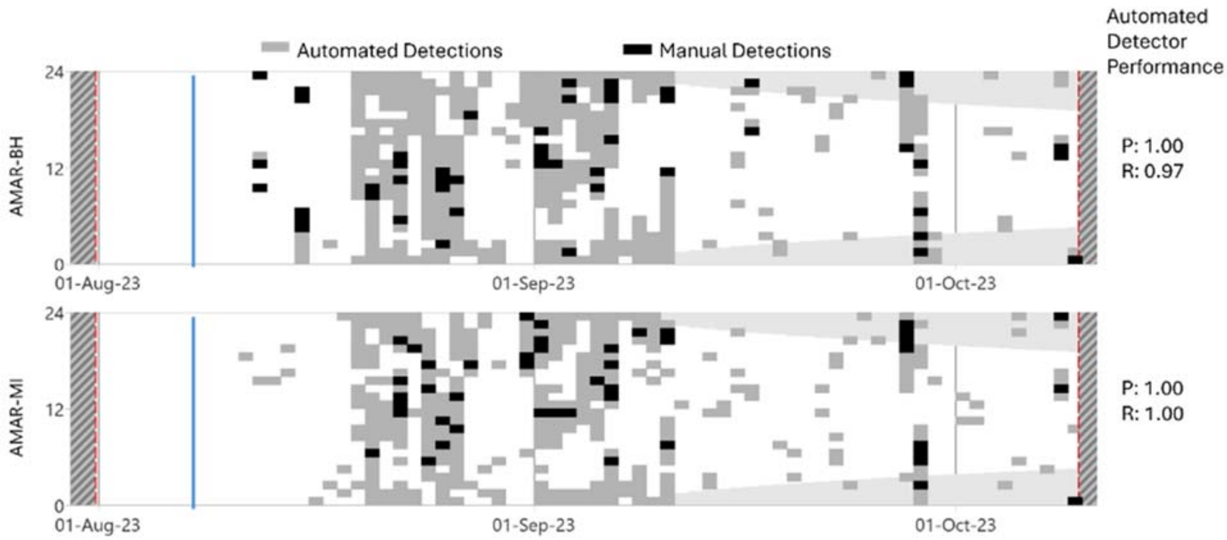

Figure 28. Hours per day with narwhal echolocation click detections at each station through the recording period from 1 Aug to 9 Oct 2023. Automated detector performance metrics are included on the right side. The blue line indicates the start of shipping in the region on 9 Aug 2023. The light grey areas 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 ClickTrain detector.

3.5.3.2. High-frequency Buzzes

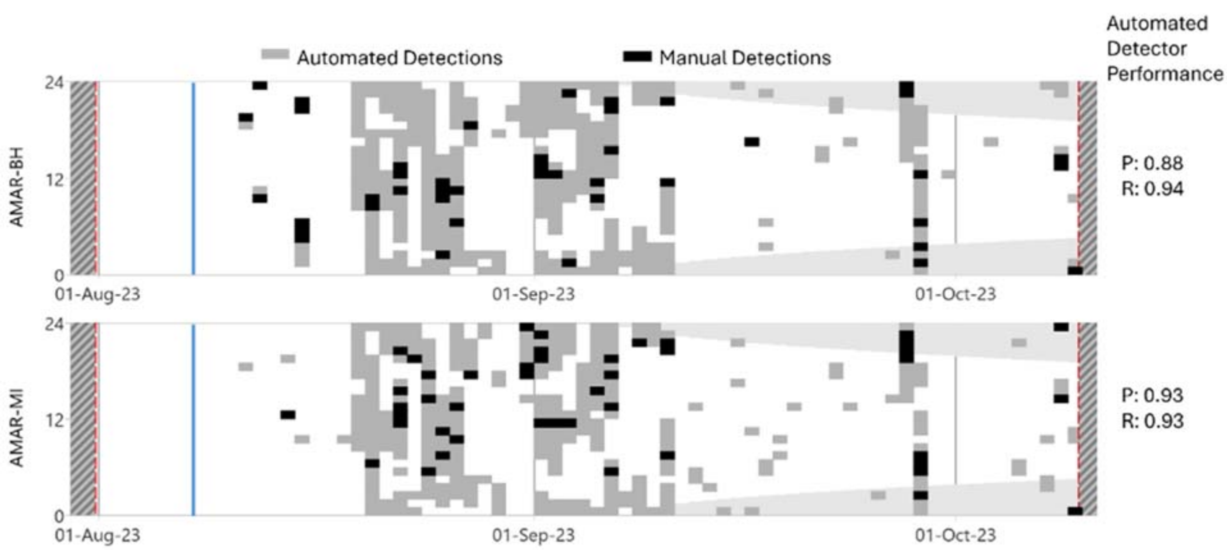

Figure 29. Hours per day with narwhal high-frequency buzz detections at each station through the recording period from 1 Aug to 9 Oct 2023. Automated detector performance metrics are included on the right side. The blue line indicates the start of shipping in the region on 9 Aug 2023. The light grey 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.

3.5.3.3. Low-frequency Buzzes

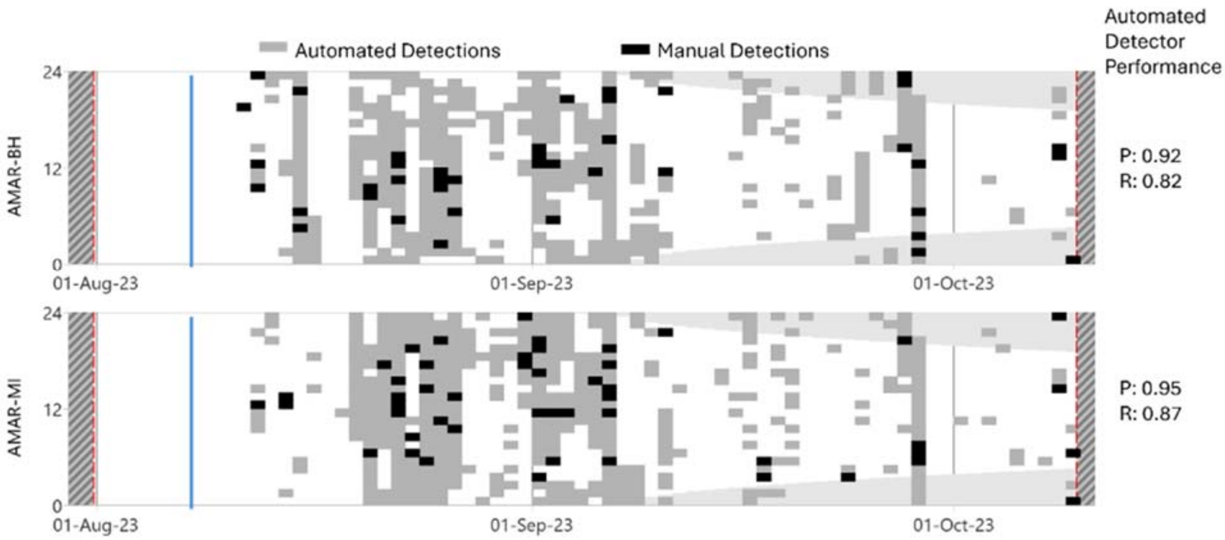

Figure 30. Hours per day with narwhal low-frequency buzz detections at each station through the recording period from 1 Aug to 9 Oct 2023. Automated detector performance metrics are included on the right side. The blue line indicates the start of shipping in the region on 9 Aug 2023. The light grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data.

3.5.3.4. Knocks

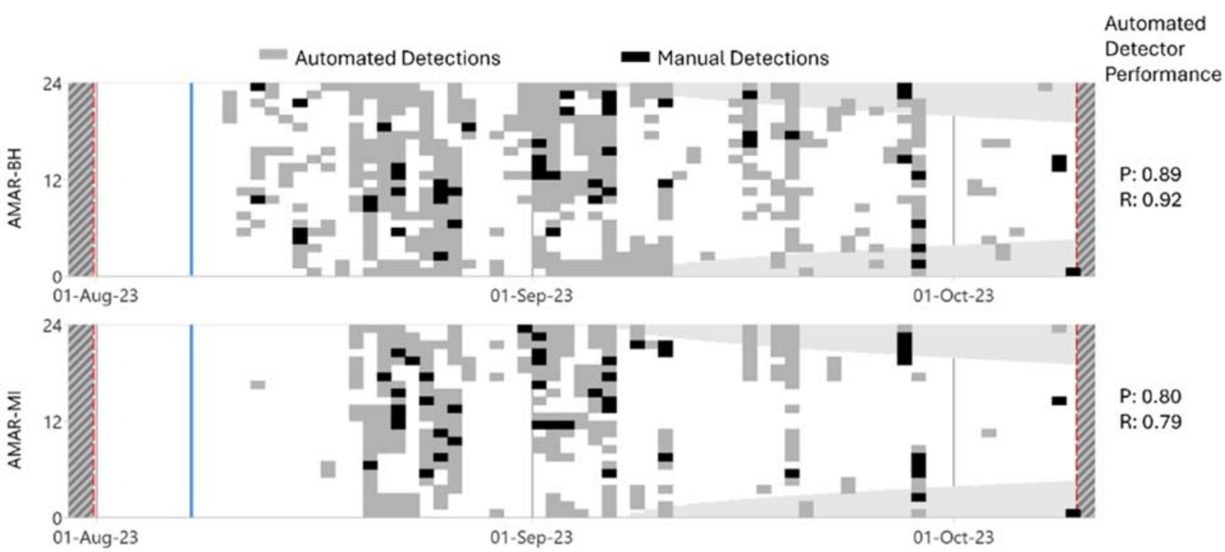

Figure 31. Hours per day with narwhal knock detections at each station through the recording period from 1 Aug to 9 Oct 2023. Automated detector performance metrics are included on the right side. The blue line indicates the start of shipping in the region on 9 Aug 2023. The light grey areas indicate 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.

3.5.3.5. Whistles

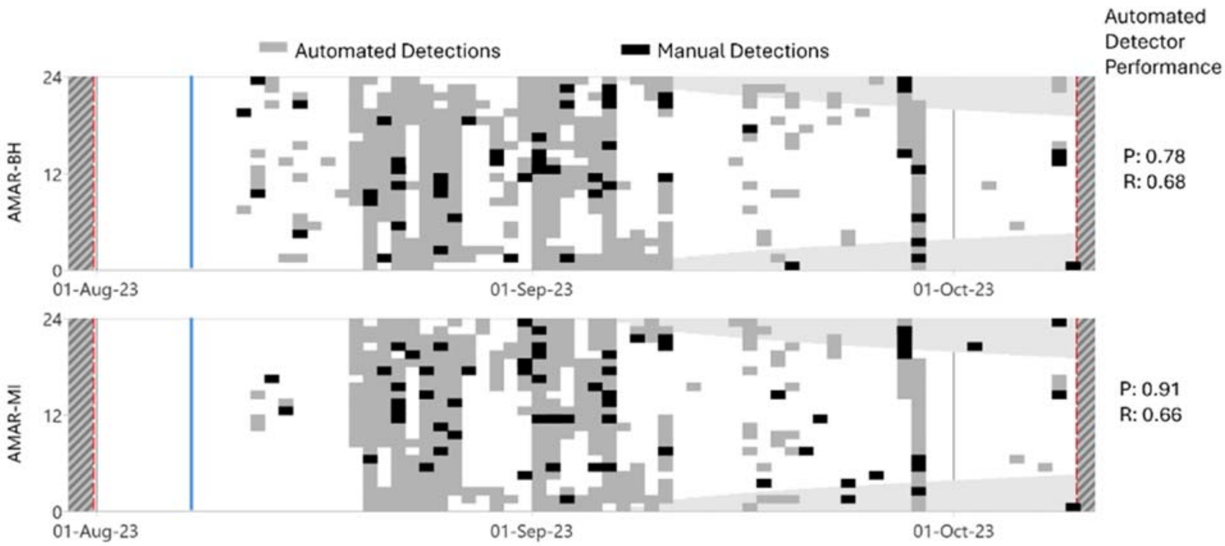

Figure 32. Hours per day with narwhal whistle detections at each station through the recording period from 1 Aug to 9 Oct 2023. Automated detector performance metrics are included on the right side. The blue line indicates the start of shipping in the region on 9 Aug 2023. The light grey areas indicate 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.

3.5.4. Pinnipeds

3.5.4.1. Ringed Seal

Sounds similar to the bark/yelp/grunts produced by ringed seals were identified during manual analysis (Figure 33) throughout the recording period at both stations (Figure 34). Acoustic files were often so inundated with narwhal signals that it was challenging to detect ringed seal sounds with certainty during manual analysis. However, brief bark and grunt-like sounds were common in the data as reflected by the possible manual detections in Figure 34.

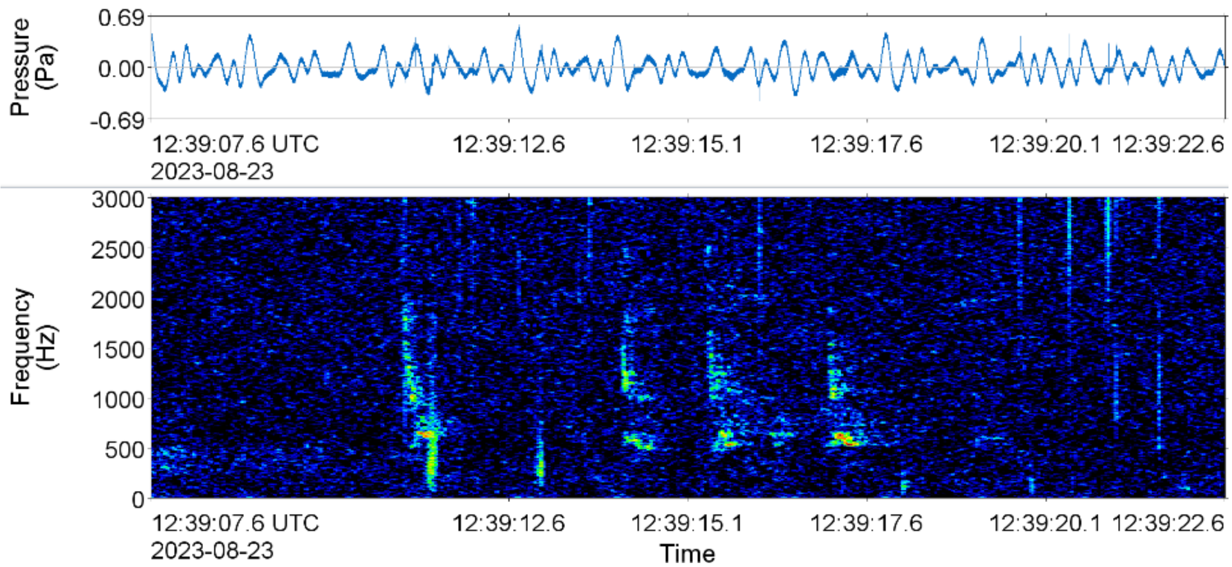

Figure 33. (Top) Waveform and (bottom) spectrogram of potential ringed seal bark-yelps recorded on 23 Aug 2023 at AMAR-MI (2 Hz discrete Fourier Transform (DFT) frequency step, 0.125 s DFT temporal observation window (TOW), 0.03125 s DFT time advance, and Hanning window resulting in a 75 % overlap and DFT size (N_{DFT}) of 65536, normalized across time, 15 s of data).

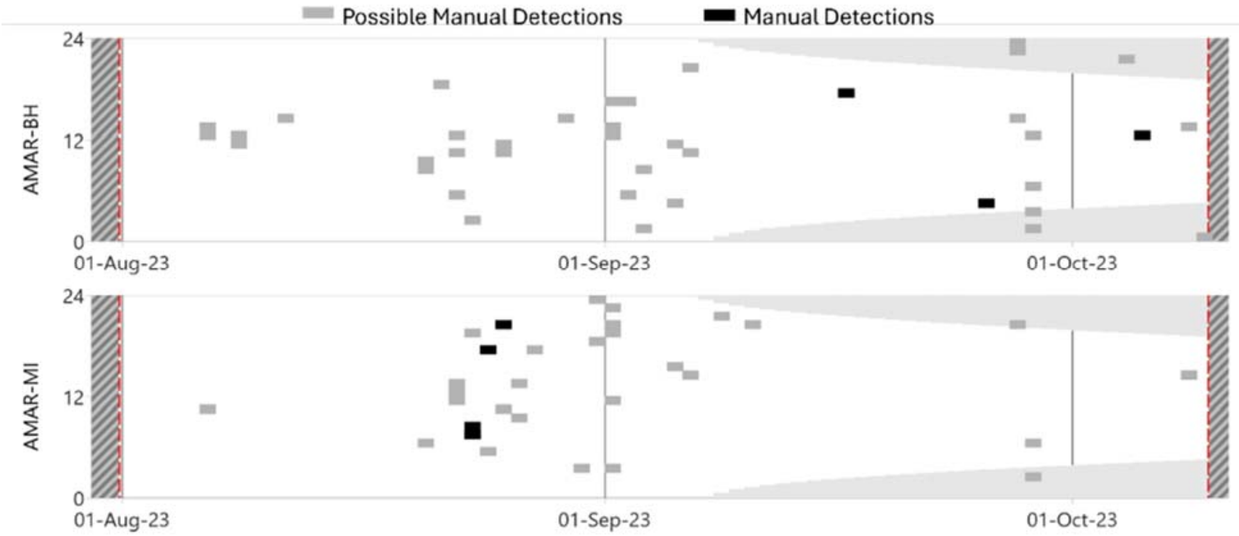

Figure 34. Hours per day with ringed seal detections at each station through the recording period from 1 Aug to 9 Oct 2023. The light grey areas indicate hours of darkness from sunset to sunrise (Ocean Time Series Group 2009). Hashed areas indicate when there was no acoustic data.

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 cue, such as a prey item 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 LRR 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, and 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.

Similar LRR results have been presented in Baffinland's acoustic monitoring reports since 2019 (Frouin-Mouy et al. 2020, Austin et al. 2022a, Austin et al. 2022b, Austin et al. 2023) and data has been collected consistently at a recording location near Bruce Head in each of these years. Although the exact location of this recorder 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 2023. The results for the decidecade band centered at 1 kHz are consistent across years, with vessel noise resulting in >50 % LRR in between 0.9 % (2023) and 1.9 % (2019) of the total recording periods and ambient noise not resulting in appreciable 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 (4.7 % in 2023). 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 2023.

Band center frequency (kHz)	>50 % LRR for data with vessels detected					>50 % LRR for ambient data				
	2019 [1]	2020 [2]	2021 [3]	2022 [4]	2023	2019 [1]	2020 [2]	2021 [3]	2022 [4]	2023
1 (burst pulse)	1.9	1.2	1.5	1.2	0.9	0.0	0.1	0.0	0.0	0.2
5 (whistles)	7.8	7.0	6.7	3.6	4.9	7.6	17.8	15.1	16.6	17.5
25 (clicks)	8.7	8.3	4.4	4.8	4.7	29.2	26.0	10.0	22.9	17.4

[1] Frouin-Mouy et al. (2020)
[2] Austin et al. (2022b)
[3] Austin et al. (2022a)
[4] Austin et al. (2023)

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	2023	
1	87.5	83.8	84.6	87.0	84.5	96.7
5	86.0	82.0	83.2	85.1	81.2	74.1
25	79.8	75.4	77.6	78.1	75.1	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)
[4] Austin et al. (2023)

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 [4]	2023
23	28	30	20	21

[1] Frouin-Mouy et al. (2020)
[2] Austin et al. (2022b)
[3] Austin et al. (2022a)
[4] Austin et al. (2023)

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 with potential to occur in the RSA. Nevertheless, vessel noise has the potential to result in disturbance or acoustic masking effects on marine mammals. Potential acoustic disturbance was investigated using the U.S. National Marine Fisheries Service (NMFS) disturbance criterion for continuous noise sources (such as vessel noise). This threshold is based on sound levels observed to produce deflections of migrating bowhead whales near industrial activities in the arctic (Richardson et al. 1985). This criterion, defined as when broadband SPL exceeds 120 dB re 1 µPa, is the current disturbance threshold used by NMFS for assessing disturbance to marine mammals by continuous-type sounds such as vessel noise (NMFS 2013). 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 1.9 and 1.2 % of the 69 day recording durations at AMAR-MI and AMAR-BH, respectively. On average, received sound levels at the AMAR locations exceeded the disturbance threshold of 120 dB re 1 µPa for less than 21 minutes per day (averaged over acoustic recording days within the shipping season). Table 11 also shows the maximum number of minutes in a day during which the SPL exceeded the 120 dB re 1 µPa threshold: 65 min (1.1 h) at AMAR-MI and 70 min (1.2 h) at AMAR-BH.

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-MI	21	65
	AMAR-BH	10	70

Figures 35 and 36 are plots of the hours in each day of the recording period when received sound levels at AMAR-MI exceeded 120 dB re 1 µPa, for times when vessels were detected in the acoustic recording and times when no vessels were detected, respectively. During times when no vessel acoustic signals were detected, the mean exposure duration was 7 minutes, and the maximum exposure duration was 63 minutes. During times when vessels were detected in the acoustic data, the mean exposure duration was 21 minutes, and the maximum exposure duration was 65 minutes.

Source levels for Capesize ore carriers were analyzed relative to those for smaller ore carriers and presented in a separate report (Austin et al. 2024). Capesize ore carriers were noted to be as much as 4 dB louder than smaller ore carrier vessels. Nevertheless, the total daily 120 dB exposure durations were not notably increased on days with Capesize ore carrier transits. On the days that Capesize ore carriers transited past the acoustic recorder while heading inbound to Milne Port (25 Aug, 5 Sep, and 25 Sep), the exposure durations were 23, 24, and 19 minutes, respectively (bars with green shading in Figure 35).

When transiting outbound on 31 Aug, 8 Sep, and 1 Oct, the exposure durations were 62, 12, and 21 minutes, respectively (bars with red shading in Figure 35). Note that the 62 min exposure duration on 31 Aug also included the inbound transit of two Panamax ore carriers in addition to the Capesize carrier. The 120 dB exposure duration on days when only Capesize vessels transited past the acoustic recorder did not exceed the mean 120 dB exposure duration. The daily 120 dB exposure durations on days with Capesize vessel transits do not stand out when compared to days when only Post Panamax or smaller class vessels transited near the recorders, and do not constitute days with the maximum exposure duration. The 120 dB exposure durations are also comparable to those that can occur occasionally as a result of background noise (Figure 36).

On 30 Aug, 7 Sep, and 30 Sep, the Capesize ore carriers were being loaded at Milne Port; the exposure durations from vessel noise were zero on each of those days. This is because no Project vessels arrived to, or departed from, Milne Port on the days when the Capesize carriers were being loaded. There were no other days in the recording period (after shipping through Milne Inlet began on 10 Aug) when exposure durations from vessel noise were zero, due to the otherwise daily transits of the smaller ore carriers into and out of Milne Port. Although there was not a measurable increase in the daily exposure duration on days involving Capesize ore carrier transits compared to days with smaller ore carrier transits, there was a measurable increase in the amount of time absent of vessel noise on days when Capesize vessels were being loaded at Port. Specifically, the use of Capesize ore carriers resulted in entire days without vessel noise in Milne Inlet in the 2023 shipping period that would otherwise not have existed.

In 2023, three days of the acoustic monitoring period included the transit of vessel convoys past AMAR-MI (10 Aug, 11 Aug, and 8 Sep). The 120 dB exposure durations on those days were 59, 17, and 12 minutes. While there can be 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 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.

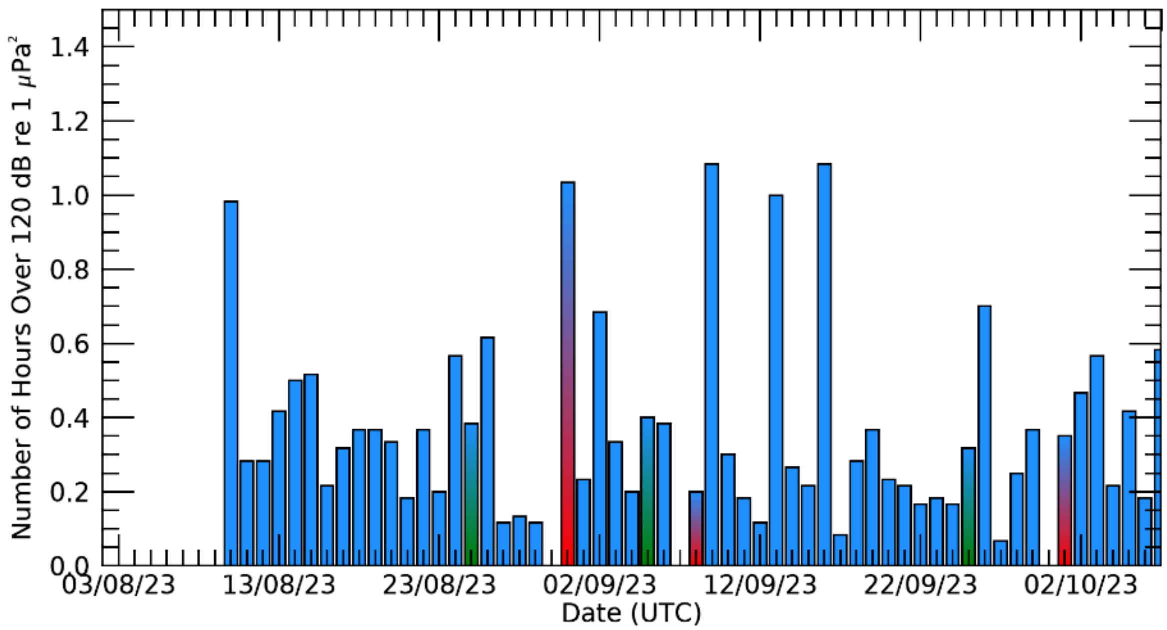

Figure 35. Hours per day with received levels exceeding 120 dB re 1 µPa when vessels were detected in the data, at an underwater acoustic recorder on the shipping lane in Milne Inlet in 2023. Bars with green shading indicate days when Capesize ore carriers transited inbound to Milne Port, bars with red shading indicate days when Capesize ore carriers transited outbound from Milne Port.

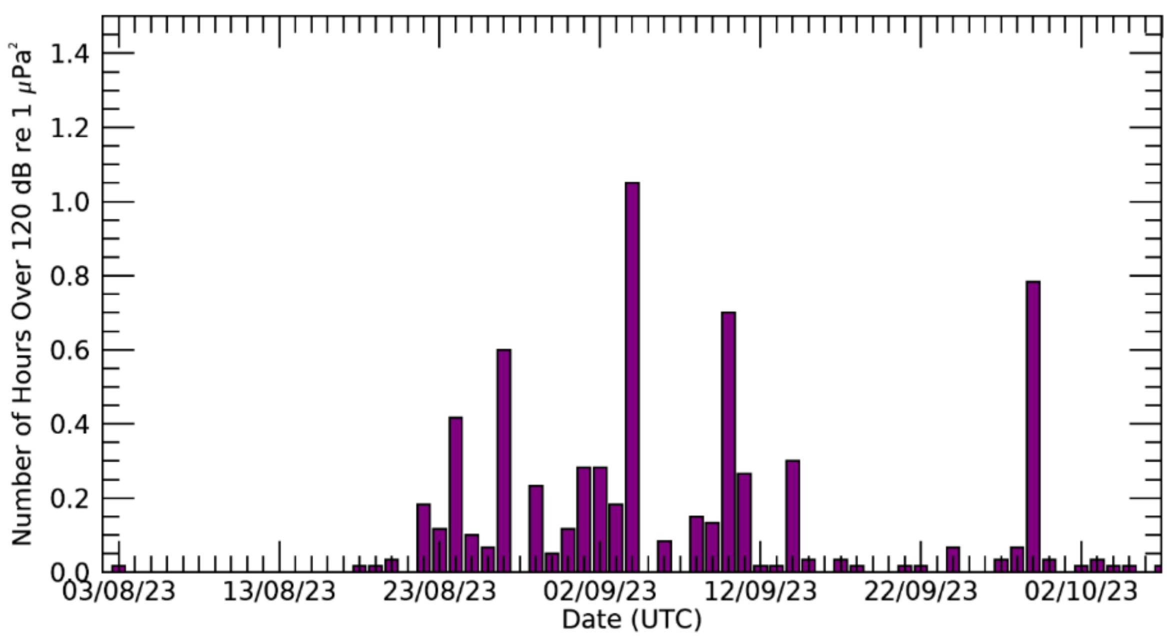

Figure 36. Hours per day with received levels exceeding 120 dB re 1 µPa when there were no vessels detected in the data (i.e., for background noise), at an underwater acoustic recorder on the shipping lane in Milne Inlet in 2023.

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. Their habitat preference varies by season and sex (Barber et al. 2001, Hauser et al. 2017). In summer, beluga whales centre in estuaries to forage, moult, and likely evade predation, but they can also occur offshore (Smith et al. 2017, COSEWIC 2020). 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. These analysis techniques indicate that beluga may have been occasionally present in the monitoring region among or near narwhal.

4.3.2. Bowhead Whales

Bowhead whales are endemic to the Canadian Arctic (COSEWIC 2009). Within Arctic waters, the Eastern Canada-West Greenland (EC-WG) bowhead whale population (COSEWIC 2009) follows seasonal migration patterns. The EC-WG 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). In summer, aggregation areas include waters around Baffin Island, Foxe Basin, and northern Hudson Bay (Ferguson et al. 2021, Hamilton et al. 2022b). Lancaster Sound has been identified an important spring migration corridor for bowhead between May and August (Davis and Koski 1980, Finley 2001) and also in early fall (NWMB 2000). Eclipse Sound and Baffin Bay also support bowhead whale habitat during spring (Koski and Davis 1979, Reeves et al. 1983, NWMB 2000, Finley 2001, Heide-Jørgensen et al. 2006). The acoustic occurrence of bowhead whales in the data is therefore expected (Heide-Jørgensen et al. 2008, Wiig et al. 2010) with evidence that some animals were within detection range of the acoustic recorders from mid-August to October 2023.

4.3.3. Narwhal

The acoustic occurrence of narwhal in the data was expected, as this Arctic species is commonly 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 (Hobbs et al. 2019, Hamilton et al. 2022a). In fall, narwhals from the Eclipse Sound and adjacent summer stocks migrate to their wintering grounds in Baffin Bay and Davis Strait where they aggregate in dense pack ice (COSEWIC 2004b).

Though narwhal were occasionally detected throughout the recording period, the animals were most prevalent near the recorders from mid-August to mid-September when the species was present almost hourly. This pulse in detections likely reflects the seasonal movements of narwhal. The first narwhal detections in 2023 occurred later than in previous acoustic monitoring programs , presumably related to the heavy ice conditions in Eclipse Sound that persisted through early August, delaying narwhal migration into Milne Inlet in 2023. The identification of potential contact calls in the data is noteworthy. These signals are of biological significance as they could indicate communications between individuals, such as mother-calf pairs. However, currently not enough is known about the distinguishing features of contact calls versus low-frequency buzzes to allow systematic identification and characterization of these signals.

4.3.4. Ringed seal

Ringed seals occur in the recording area and were acoustically confirmed. With few descriptions of the vocal repertoire of ringed seals available (Stirling et al. 1987, Jones et al. 2014), their acoustic signals are challenging to confidently detect and differentiate from other species, which may result in an underestimate of the species' acoustic presence. Indeed, 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 seal distribution is strongly related to pack ice and shore-fast ice, and to areas covered at least seasonally by ice (McLaren 1958). Summer high-use areas include Baffin Bay, the Labrador coast, Melville Bay, Lancaster Sound, and the Amundsen Gulf (Hamilton et al. 2022b).

5. Summary

In 2023, marine mammal vocalizations were detected throughout the recordings from bowhead whales and narwhal, as well as likely detections of bearded seal and ringed seal and of sounds that were likely from beluga 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 first detected a few days after Baffinland Project vessels first passed through Milne Inlet and continued throughout the recording, with a peak from mid-August to mid-September.

In 2023, vessel detections on both recorders included noise from both large vessels and small boats. Vessel noise was detectable in ~20 % of the acoustic recordings and was demonstrated to be temporary in nature (i.e., occurring for short portions of the day) and below sound levels that are thought to result in acoustic injury (NMFS 2018). Assessed relative to the established acoustic disturbance for marine mammals (broadband SPL of 120 dB re 1 µPa; (NMFS 2013)), sound exposure durations averaged less than half an hour per day.

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 increased 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 fairly consistent over the years of reporting (since 2019).

In 2023, underwater noise emissions from Capesize vessels were measured for the first time since the start of Project operations . Capesize carrier transits did not result in protracted periods when sound levels exceeded 120 dB re 1 µPa relative to other days of the shipping season. In fact, on days when Capesize carriers were being loaded at Port, there were no other Project vessels transiting through Milne Inlet and therefore no associated Project vessel noise generated in the RSA. On the days associated with no Project vessel movements, several periods occurred when background sound levels (in the absence of vessel noise) exceeded 120 dB re 1 µPa and resulted in LRR of 60–70 %. Characterization of the source levels for Capesize ore carriers, along with all other measured Project vessels, is available in a separate report (Austin et al. 2024). In that report, Capesize ore carriers were noted to be as much as 4 dB louder than smaller ore carriers

Overall, the results of the 2023 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, in that acoustic impacts are understood to be localized and temporary and that there are substantial periods in each day when marine mammals are not disturbed by Project vessel noise.

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Glossary 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

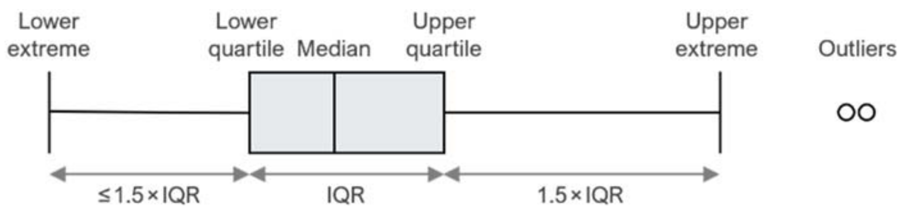
Combination of ambient sound, acoustic self-noise, and sonar reverberation. Ambient sound detected, measured, or recorded with a signal is part of the background noise.

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

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

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

peak-to-peak pressure

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

percentile level

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

permanent threshold shift (PTS)

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

phocid

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

phocid pinnipeds in water (PPW)

See hearing group.

pinniped

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

pressure, acoustic

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

pressure, hydrostatic

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

received level

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

reference values

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

Quantity	Reference value
Sound pressure	1 μPa
Sound exposure	1 μPa^2 s
Sound particle displacement	1 pm
Sound particle velocity	1 nm/s
Sound particle acceleration	1 $\mu m/s^2$

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 μPa² s.

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

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 ($L_{p,\text{rms}}$) of the time-mean-square sound pressure (p_{rms}^2). Unit: decibel (dB). Reference value (p_0^2) for sound in water: 1 μPa².

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

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 μPa²m².

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.

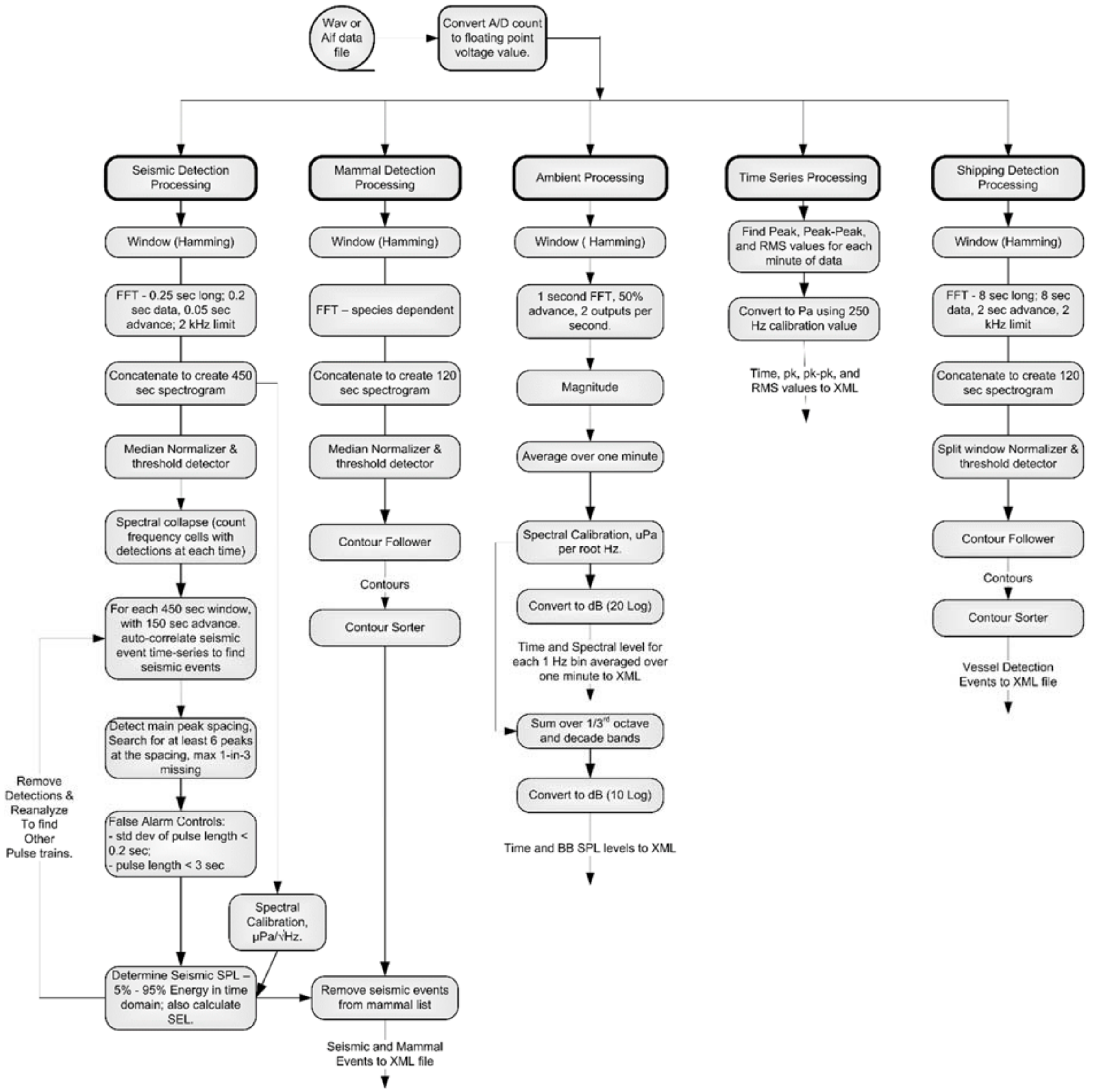

Figure B-1. Major stages of the automated acoustic analysis process performed with JASCO's PAMlab software suite.

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 $L_{\rm pk}$; 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, $p(t)$:

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

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):

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

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 ($L_{p,\rm fast}$) 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 $L_{p,\rm boxcar\ 125ms}$.

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):

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

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:

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

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:

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

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

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

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:

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

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).

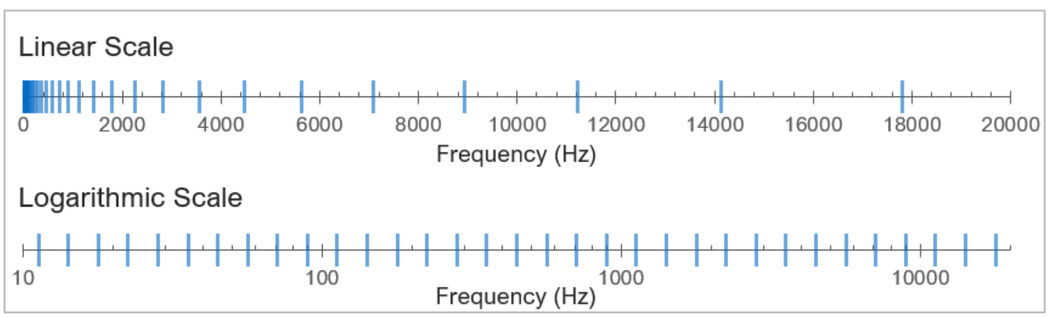

Figure B-2. Decidecade frequency bands (vertical lines) shown on (top) a linear frequency scale and (bottom) a logarithmic scale. On the logarithmic scale, the bands are equally spaced.

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.

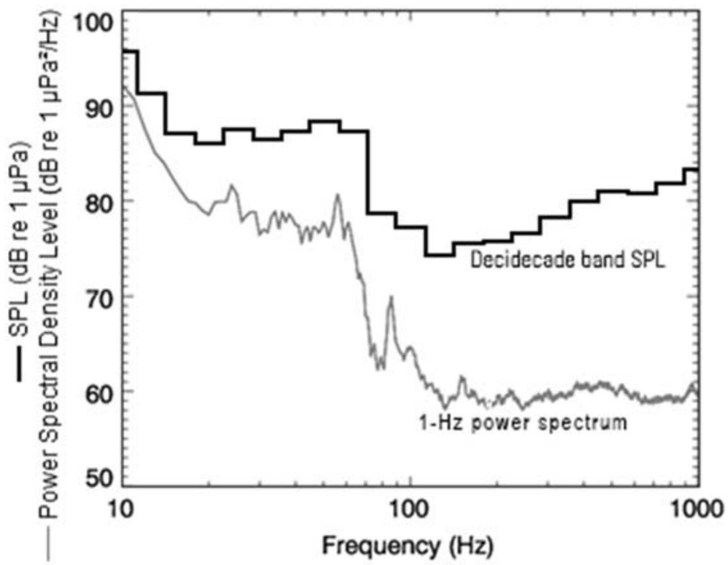

Figure B-3. Sound pressure spectral density levels and the corresponding decidecade band sound pressure levels (SPL) of example ambient sound shown on a logarithmic frequency scale. Because the decidecade bands are wider with increasing frequency, the decidecade band SPL is higher than the power spectrum, 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	Band	Lower frequency	Nominal centre frequency	Upper frequency
10	8.9	10.0	11.2	26	355	398	447
11	11.2	12.6	14.1	27	447	501	562
12	14.1	15.8	17.8	28	562	631	708
13	17.8	20.0	22.4	29	708	794	891
14	22.4	25.1	28.2	30	891	1000	1122
15	28.2	31.6	35.5	31	1122	1259	1413
16	35.5	39.8	44.7	32	1413	1585	1778
17	44.7	50.1	56.2	33	1778	1995	2239
18	56.2	63.1	70.8	34	2239	2512	2818
19	70.8	79.4	89.1	35	2818	3162	3548
20	89.1	100.0	112.2	36	3548	3981	4467
21	112	126	141	37	4467	5012	5623
22	141	158	178	38	5623	6310	7079
23	178	200	224	39	7079	7943	8913
24	224	251	282	40	8913	10000	11220
25	282	316	355	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).

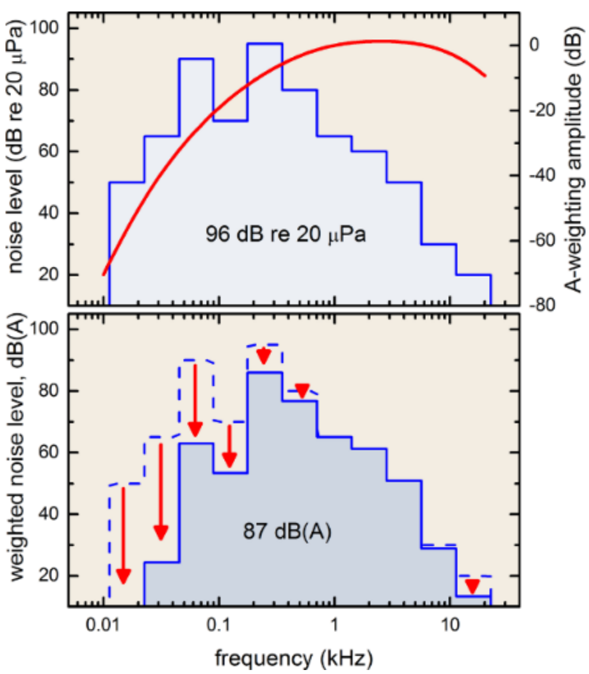

Figure C-1. Application of an auditory weighting function. Blue line shows a hypothetical, octave-band sound pressure spectrum in air, with a total sound pressure level (integrated over all octave-bands) of 96 dB re 20 µPa (This example uses in air-noise levels; therefore, a different reference pressure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

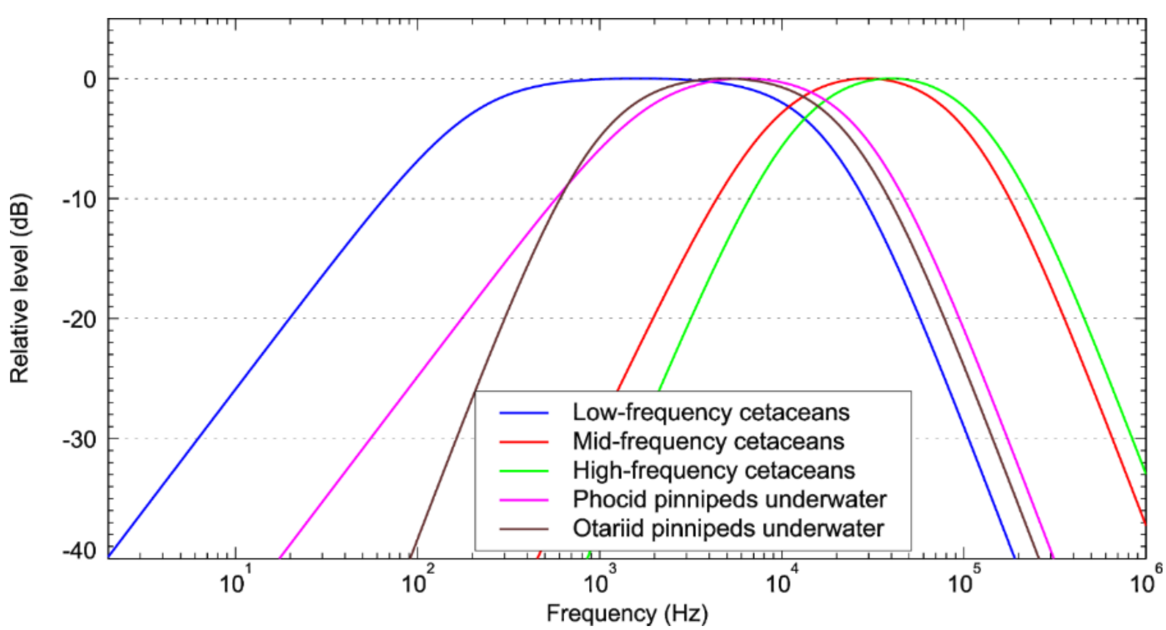

Figure C-2. Auditory weighting functions for functional marine mammal hearing groups as recommended by NMFS (2018).

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.

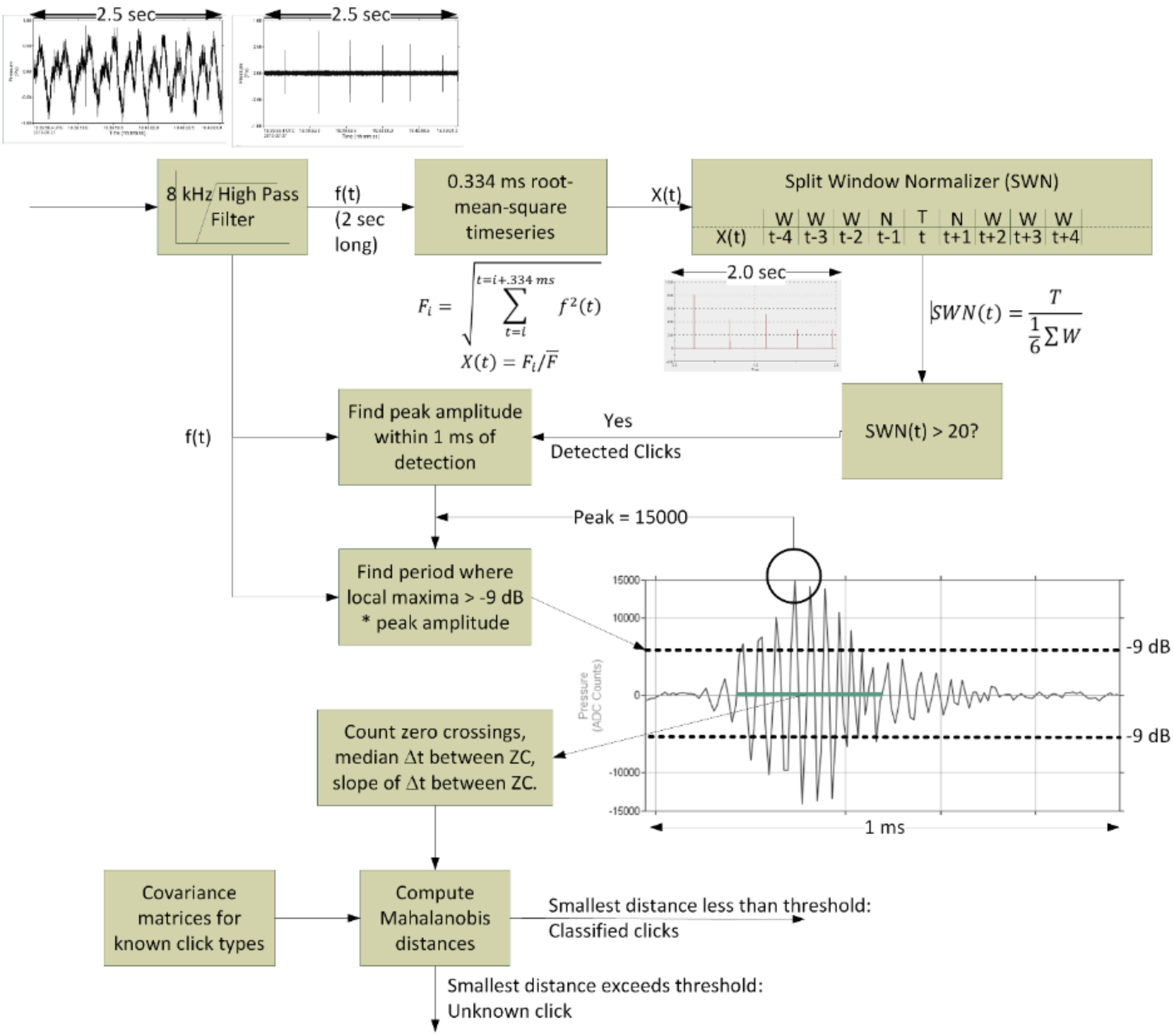

Figure D-1. Flowchart of the automated click detector/classifier process.

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 automated click train detector 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 80 % 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 2.5 times 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 (using a ‘time series’ with a bin duration of 0.5 ms).

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. 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.
8. Output a species click train detection if the click features, total clicks, and mean ICI match the species.

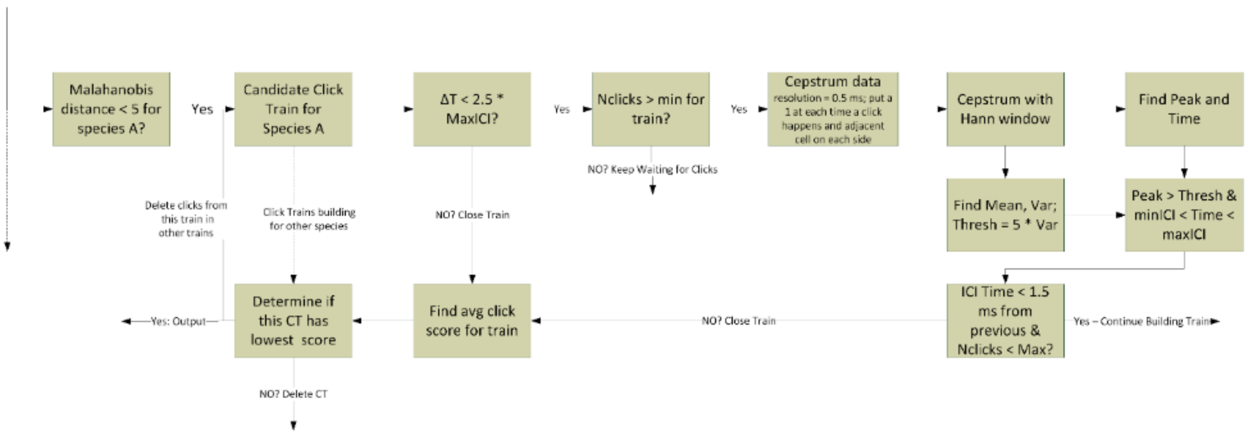

Figure D-2. Flowchart of the click train automated detector/classifier process.

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).

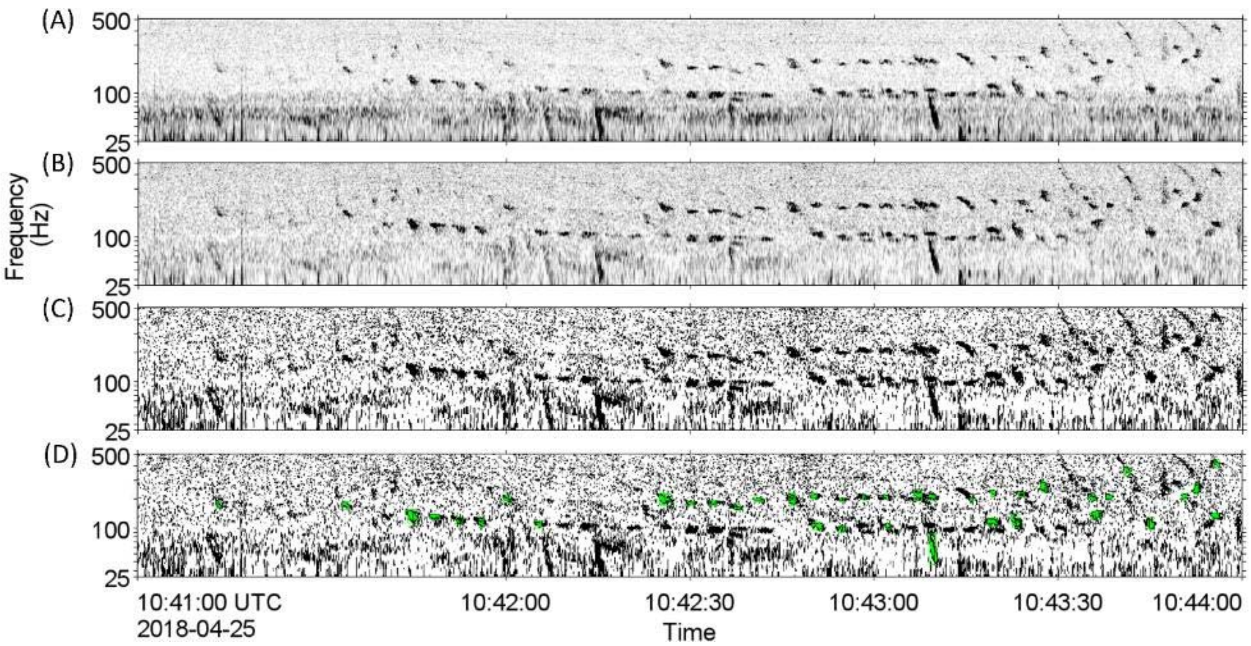

Figure D-3. Illustration of the contour detection process. (A) A spectrogram is generated at the frequency and time resolutions appropriate for the tonal calls of interest. (B) A median normalizer is applied at each frequency. (C) The data is turned into a binary representation by setting all normalized 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.

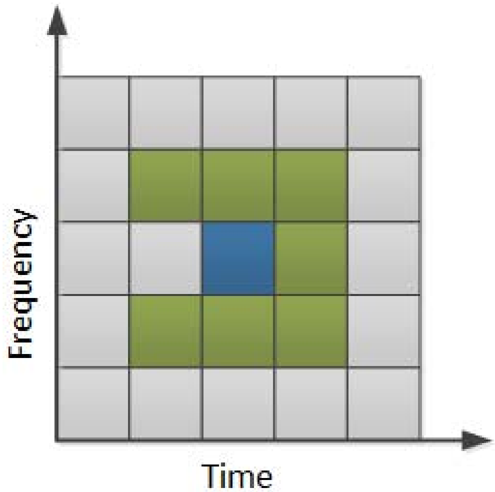

Figure D-4. Illustration of the search area used to connect spectrogram bins. The blue square represents a bin of the binary spectrogram equalling 1 and the green squares represent the potential bins it could be connected to. The algorithm advances from left to right, so grey cells left of the test cell 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. Discrete Fourier Transform (DFT) and detection window settings for a selection of 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	DFT			Detection window (s)	Detection threshold
	Frequency step (Hz)	Temporal observation window (s)	Time advance (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
Ribbonseal_downsweep	4	0.1	0.05	5	3
Walrus_knock	32	0.03125	0.016	5	4

Table D-2. A sample of vocalization sorter definitions for the tonal vocalizations of cetacean species expected in the area. Automated detectors are capable of triggering on species and signals beyond those targeted.

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	<50 Hz f_{min}
Narwhal_HFbuzz	Narwhal	14,000–100,000	0.1–10	>3000	NA
Narwhal_LFbuzz	Narwhal	1000–10,000	0.5–5	>1000	<5000 Hz f_{min}
Narwhal_Whistle	Narwhal	1000–20,000	0.5–5	20–1000	<9000 Hz f_{min}
Beardedseal_downsweep	Bearded seal	200–1500	1–10	>100	SR: −30 to −500 Hz/s
Beardedseal_upsweep	Bearded seal	150–2000	1–6	>100	SR: 100–1000 Hz/s
Beardedseal_fulltrill	Bearded seal	125–8200	10–90	>500	SR: −5 to −150 Hz/s
VLFMoan	Baleen whale, pinniped	10–100	0.30–10.00	>10	<40 Hz f_{min}
LFMoan	Bowhead whale	40–250	0.50–10.00	>15	MIB: <50 Hz
ShortLow	Baleen whale, pinniped	30–400	0.08–0.60	>25	NA
MFMoanLow	Bowhead whale	100–700	0.50–5.00	>50	<450 Hz f_{min}; MIB: <200
MFMoanLowHighThreshold	Bowhead whale	100–700	0.5–5.0	>50	<450 Hz f_{min}; MIB: <200
MFMoanHigh	Bowhead whale	500–2500	0.50–5.00	>150	<1500 Hz f_{min}; MIB: <300
MFMoanHighHighThreshold	Bowhead whale	500–2500	0.5–5.0	>150	<1500 Hz f_{min}; MIB: <300
LowWhistleSupp	Narwhal, beluga, and killer whale	1000–10000	0.8–5.0	>300	<5000 Hz f_{min}; MIB: <1000; 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	4000–20000	0.3–5.0	>700	MIB: <2000; suppress detections for high SPL (>125 dB) between 50–1000 Hz
LowWhistleLoud	Narwhal, beluga, and killer whale	1000–0000	0.8–5.0	>300	<5000 Hz f_{min}; MIB: <1000; 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; 1 multi component; 50 min. component bandwidth; 0.4 min. component duration
HighWhistleLoud	Narwhal, beluga, and killer whale	4000–20000	0.3–5.0	>700	MIB: <2000
HighWhistleQuiet	Narwhal, beluga, and killer whale	4000–20000	0.3–5.0	>700	MIB: <2000 MIB
Ribbonseal_downsweep	Ribbon seal	20-2000	0.6-2.5	>400	NA
Walrus_knock	Walrus	20-8000	0.03-0.3	>1200	<750 Hz f_{min}

f = frequency, MIB = median instantaneous bandwidth, SR = sweep rate, TC = time component, NA = not applicable.

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.

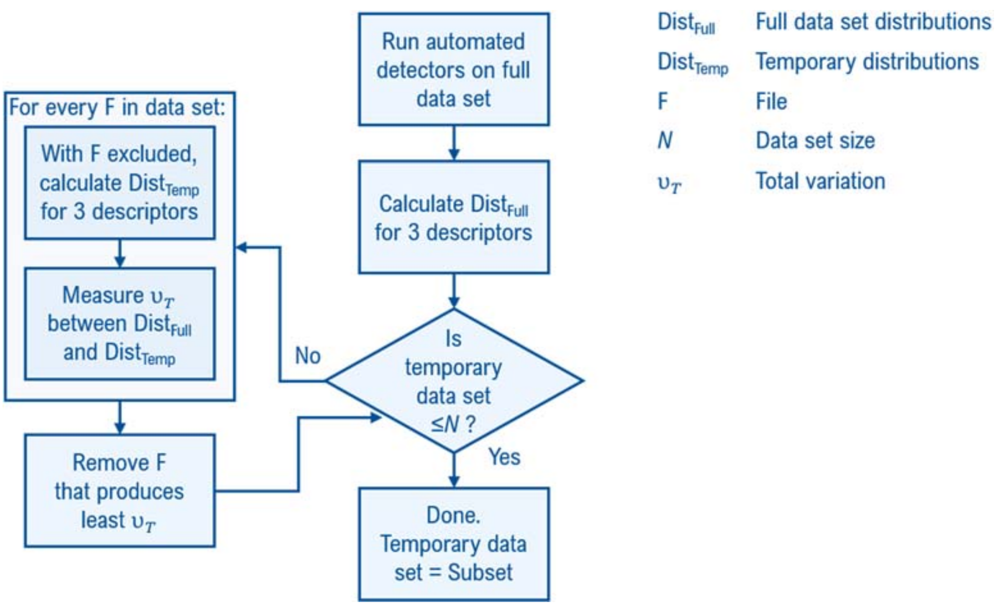

Figure D-5. Automated Data Selection for Validation (ADSV) process based on Figure 1 from Kowarski et al. (2021).

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. Here, Figure D-6 provides support that a sufficient amount of data were manually reviewed.

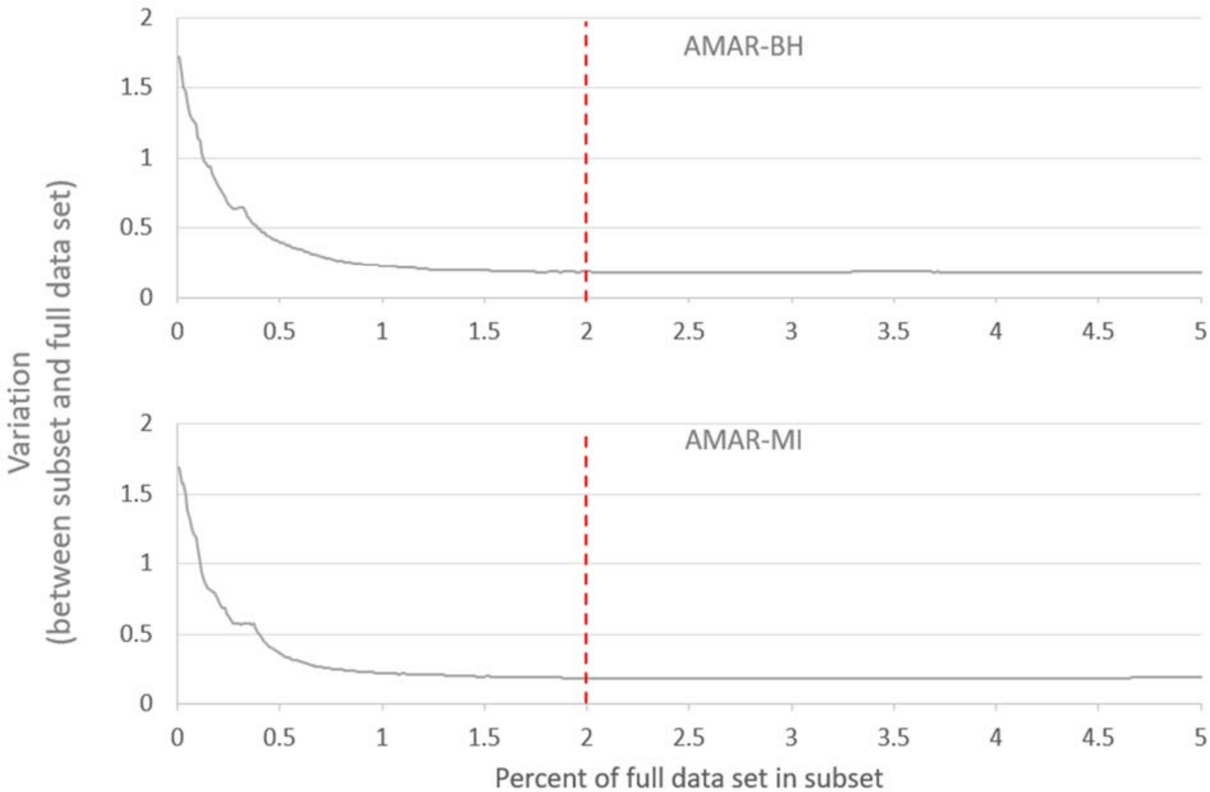

Figure D-6. The total variation between the subset selected by Automated Data Selection for Validation (ADSV) for manual analysis and the full data set. ADSV subsets were created for each recording period and station. The dashed line indicates the size of the subset selected by ADSV for the present analysis. Total variation combines the three automated detector result descriptors used in ADSV: Counts, Diversity, and Temporal Distribution. The aim of ADSV is to achieve a subset with as little variation from the full data set as possible. Here at 2 % of the full data set, the variation has plateaued to its minimum, and analyzing a subset greater than 2 % would not reduce the variation much farther. This provides evidence that sufficient data were analyzed to assess marine mammal occurrence.

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 narwhal and bowhead whale vocalizations confirmed to occur in the data during manual analysis. While the acoustic signals of ringed seals were also confirmed in the data, there were too few validations to assess automated detector performance. Similarly, bowhead whales were confirmed so rarely and amongst so many overlapping signals of narwhal, no automated detector performed well. The performance metrics of the narwhal detectors in Table E-1 were generally high but varied across vocalization types and stations. Automated detector results deemed reliable (P > 0.75) and refined to incorporate the classification threshold are presented in Section 3.5.

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	Temporal restriction	Threshold	P	R	MCC	TP	FP	FN	TN
Narwhal click train (Narwhal ClickTrain)	AMAR-BH	1-10 Aug	2	1.00	0.97	0.98	64	0	2	129
	AMAR-MI	1-10 Aug	12	1.00	1.00	1.00	63	0	0	134
Narwhal click (Narwhal Click)	AMAR-BH	1-10 Aug	47	1.00	0.95	0.96	63	0	3	77
	AMAR-MI	1-10 Aug	246	1.00	1.00	1.00	63	0	0	99
Narwhal low-frequency buzz (Narwhal_LFbuzz)	AMAR-BH	1-10 Aug	2	0.92	0.82	0.80	55	5	12	121
	AMAR-MI	1-10 Aug	1	0.95	0.87	0.87	61	3	9	127
Narwhal high-frequency buzz (Narwhal_HFbuzz)	AMAR-BH	1-10 Aug	7	0.88	0.94	0.87	50	7	3	128
	AMAR-MI	1-10 Aug	7	0.93	0.93	0.90	57	4	4	128
Narwhal knocks (NarwhalKnockTrain)	AMAR-BH	1-10 Aug	1	0.89	0.92	0.86	59	7	5	128
	AMAR-MI	1-10 Aug	4	0.80	0.79	0.71	44	11	12	125
Narwhal tonal calls (Narwhal_Whistle)	AMAR-BH	1-10 Aug	1	0.78	0.68	0.61	45	13	21	120
	AMAR-MI	1-10 Aug	1	0.91	0.66	0.67	53	5	27	115
Bowhead whale moan (MFMoanLow)	AMAR-BH	None	12	0.50	0.33	0.40	1	1	2	122
	AMAR-MI	None	1	0.10	0.56	0.14	5	47	4	129